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Mimi Zumwalt
Maria Fernandez-del-Valle
Editors

The Active Female

Health Issues throughout the Lifespan

Third Edition

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I am dedicating this book to my husband, Robert Parks McComb, who is always there to support me, no matter what the cost.

Jacalyn J. Robert-McComb, PhD, FACSM

I would like to dedicate this book to all the significant females in my life: my grandmother who helped to raise me but now has passed, my mother who fought to bring me here from Vietnam, and especially my daughter who provides me with more joy than words can express. I dearly love and appreciate them all!

Mimi Zumwalt, MD

I would like to dedicate this book to my beloved family—my dear dad, mom, and sister—who helped me in all things great and small. This is for all of you.

Maria Fernandez-del-Valle, PhD

Preface

It is well known in the sports world that many times, young female athletes do not take in enough calories to meet their energy demands [1, 2]. This deficiency is not always associated with an eating disorder [3]. This is not only true for athletes, but is also true for female recreational players, given society's role in subsidizing body image distortions in the broad realm of social media [4]. An imbalance between caloric intake and energy demand for exercise or sports performance may cause bodily impairments or impaired physiological function that continue to evolve undetected, unless professionals, educators, and family members are trained to recognize the risk factors that contribute to energy deficiency [4–6]. It is not well known why some girls and young women are more vulnerable to this pathology than others. Yet there are some commonalities that can be elucidated or demystified for early detection. Contributing variables to energy restriction or imbalances between energy intake and energy expenditure can be grouped into two broad categories: high training volume and inadequate energy intake [5].

Yet what are the hypothesized factors that contribute to these broad categories? High volume of training may result from: high training demand, poor training program, and/or exercise dependence/addiction [3, 7, 8]. Inadequate energy intake can be impacted by body image dissatisfaction and disordered eating and eating disorders [5, 9, 10].

Also sports in which a lower body weight enhances sports performance or is aesthetically desirable may cause girls and young women to intentionally restrict caloric intake without an underlying pathology such as an eating disorder [8, 11, 12]. Additionally, some athletes, particularly college athletes, significantly underestimate their energy requirements for their sport [13, 14]. Sports which have a high energy demand, such as swimming and ultradistance sports may require athletes to consciously increase food consumption throughout the day even when they are not particularly hungry [15–18].

Slightly outside the arena of sports performance is another possible contributing construct to energy deficiency which is behavioral in nature and that is exercise addiction [19, 20]. These individuals feel constantly pressured to exercise. While not always the intent, this condition is associated with negative energy balance and weight loss. Another behavioral pattern that is not so well known in the sports arena that may contribute to energy deficiency is orthorexia nervosa. Orthorexia is a pathological fixation on healthy eating. This may lead to restrictive eating and malnourishment [21].

It is for these reasons and many others that this book was written, namely, to help alleviate the suffering of girls and women who may be walking down a pathological walkway that has long-term adverse health outcomes without even knowing it. It is up to the professionals and educators who touch the lives of these young girls and women to be knowledgeable about the signs and symptoms suggesting impaired physiological function.

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About the Editors

Jacalyn J. Robert-McComb, PhD, FACSM is a Professor of Exercise Physiology in the Department of Kinesiology at Texas Tech University (TTU). She is a Fellow of the American College of Sports Medicine (ACSM) and is certified by ACSM as a Program Director (PD) in the Rehabilitative Sciences. She is also certified by ACSM as a Clinical Exercise Physiologist (CEP) and Exercise Test Technologist (ETT). As an exercise physiologist, she believes that "Exercise is Medicine." Additionally, she maintains certifications from the American Council of Exercise (ACE) and the Biofeedback Certification International Alliance (BCIA). In order to maintain these certifications, professionals must meet education and training standards progressively to recertify. She is continually studying and learning.

Her area of research for the past 30 years has been examining how psychological stress affects physiological functions. She has been interested in two primary axes: the Gonadotropin-Releasing Hormone (GnRH) axis and the Cortisol-Releasing Hormone (CRH) axis. The GnRH axis affects the female menstrual system through the production of Follicle-Stimulating Hormone (FSH) and Luteinizing Hormone (LH) by the Anterior Pituitary. These two axes are intricately connected. In times of war, or extremely stressful situations, we may see women's menstrual cycles abrupted through the disruption of GnRH by CRH at the level of the hypothalamus. However, in a laboratory setting, it is almost impossible to stimulate a severe enough stress response to elicit menstrual dysfunction in women.

Because of the difficulty in eliciting a strong enough stimulus to disrupt the GnRH axis in a laboratory setting, her studies have evolved into examining exercise programs that alter the stress response positively. The coping programs or behaviors that she examined in her studies include walking, yoga, heart rate variability (HRV) breathing training using biofeedback and meditation. These types of programs help women cope with the daily stressors in their life.

Her future career plans are to begin a web-based consulting program for women and children who suffer from anxiety and disordered eating using exercise and meditation as a coping tool. Exercise changes your physiology and meditation opens your mind to the many gifts that are available in your life. Her plans are to retire to Tucson AZ where she will use her gifts to help others.

Mimi Zumwalt, MD is a native of Vietnam who was evacuated to America in 1973 at 11 years of age. Ever since childhood, she has always wanted to be a doctor. Shortly afterwards, her late foster father got her started in playing sports. Thus, beginning from her teenage years, she has been extensively involved with athletics even before entering high school, which continued into college where she earned an athletic scholarship to compete in tennis. She enrolled in pre-medical studies and traveled to numerous competitions. Then a repeated ankle injury led her to see the Team Physician for treatment, who sparked her interest and eventual specialization in Sports Medicine (fortunate turn of events).

After her collegiate tennis coach introduced the tennis team to weightlifting to augment physical training/conditioning, Dr. Z sought out various ways to improve her knowledge on fitness/wellness. To be more credible, she went on to obtain her American College of Sports Medicine (ACSM) certification as an Exercise Leader, then became certified as a Strength Trainer as well through another fitness organization, both of which helped fuel her passion to learn more about the human body and staying active. Additionally, stemming from her deep love for athletics, she competed in bodybuilding/powerlifting/fitness/extreme sports for a few decades. As a result of these competitions, injuries sustained along with rehabilitation programs she underwent made her more cognizant of the importance of training for and maintaining physical fitness.

Upon obtaining her Biology/Chemistry bachelor's degrees in 1985, Dr. Z wanted to continue her pursuit in the medical field. She completed her postgraduate studies in 1989 via an Army scholarship to earn her M.D. degree (Doctor of Medicine), served and trained in the military, Orthopaedic Residency from 1992 to 1996, then practiced Orthopaedic Surgery as an Army Surgeon for a few years up to 1999, until attending her civilian Sports Medicine Fellowship in 2000. Shortly afterwards she joined the Texas Tech School of Medicine Faculty as an academic clinician-physician/surgeon, teaching and practicing Orthopaedic Sports Medicine ever since.

As a sports specialist/surgeon by trade, Dr. Z trained in performing definitive procedures to address musculoskeletal injuries/conditions. However, being of Asian descent, she approaches medical treatment in a more holistic/preventative fashion. Treating various athletes and realizing that females (especially teenagers) tend to injure certain body parts more so than males while engaged in sporting activity, she sought out ways to help them train/condition in order to prevent injury. She began researching about sex/gender differences in anatomy/biomechanics, in addition to age/hormone-related changes in the musculoskeletal system/neuromuscular control, amongst other factors specific to different sports which could affect overall injury risk.

Dr. Z's involvement with academics/athletics makes it natural for her to enjoy sharing knowledge, distributing pertinent information, and teaching others how to stay active throughout the years without getting hurt. Being in the sixth decade of life herself and experiencing "aches and pains," she wants to let it be known that modifying how one goes about the daily activities and staying "in shape" will serve everyone well in terms of quality of living.

Besides the lectures/presentations given and articles previously published, she hopes her written chapters in this book will give the reader a useful reference source upon which they can build.

Newton's Law states "an object at rest remains at rest, and an object in **motion** remains in **motion**," so it is incumbent upon an individual to start moving and keep on moving. One may have to modify the manner of which to stay active but the key is not to stop; otherwise, the joints will be stiff and stuck!

Maria Fernandez-del-Valle, PhD is a Researcher in the Department of Functional Biology, School of Medicine at the University of Oviedo (Spain). After obtaining her Licentiate in Physical Activity and Sport Sciences, she earned her PhD and completed her training in Clinical Exercise Physiology at the *Hospital Universitario Infantil Niño Jesús* in Madrid. She is certified as a Level 3 Anthropometrist (since 2010) by the International Society for the Advancement of Kinanthropometry (ISAK) and as a Level 3 National Coach by the Spanish Volleyball Association (since 2012).

Dr. Fernandez joined Dr. Jacalyn J. Robert-McComb's lab as a predoctoral researcher in 2011. In 2012, after earning her doctorate degree, she moved to the United States. While in the United States, she received seed funding at Texas Tech University (2012–2016) and Southern Illinois University Edwardsville (2016–2021) which allowed her to run several randomized control trials involving resistance exercise. These studies, along with other research collaborations, have illuminated the need for a multidisciplinary approach in which resistance training could be a key modulator of specific markers and mechanisms of action involved in disease prognosis.

Because of these studies, Dr. Fernandez was able to secure funds from the National Institutes of Health (NIH) and the American Heart Association (AHA) in collaboration with Jon D. Klingensmith (Associate Professor and Chair at the Department of Electrical and Computing Engineering in Southern Illinois University Edwardsville). In 2021, she returned to Spain and has been awarded two grants in Spain: one funded by "La Caixa" Foundation and Caja Burgos Foundation program at Universidad Isabel I and the Margarita Salas Junior Fellowship program at Universidad de Oviedo. These funds support an emerging line of research focused on understanding biological mechanisms underlying anorexia nervosa and the effects of exercise.

Dr. Fernandez's goal as a scientist is to contribute to disease prevention and treatment through exercise with the purpose of growing a healthier society. Decreasing physical inactivity could prevent ~5 million deaths and save approximately INT$68 billion per year worldwide (excluding mental health and musculoskeletal related costs), which aligns with 2030 World Health Organization's objective of reducing inactivity by 15%. Providing more scientific evidence on the benefits of exercise "dose" adjusted to each condition–given its epigenetic benefits–could ultimately lead to the integration of exercise prescription into healthcare systems and policies.

Role and Scope Statement

The times certainly are changing as present-day society demands more equality in gender and race. This third edition of our Active Female textbook serves as a second update of information originally written in 2008, with the first revision published in 2014. We have retained the majority of previous authors and added others (including international authors), increased the number of chapters/expanded topics to include more current literature, and exchanged one of the three editors. We hope that by sharing our combined fund of knowledge backed up by collecting research studies/evidence, the reader can utilize specific scientific findings to educate themselves or to teach and/or share with others. Recognizing that our book is not completely inclusive, depending on the level of curiosity, we encourage further individual searching or exploring referenced articles for more details on the desired topic(s) of choice.

As editors, we have tried to preserve uniformity/similarity in structure/form of our new book. However, each author possesses his/her own unique writing style, thus certain differences may exist. We also aimed to address most health aspects of being an active female, stages of life she experiences, beginning from childhood then progressing through adulthood and beyond. We concentrated on sex/gender/age-related differences along with some variations due to ethnicity. We strived to address several important systems within the human body, starting with basic structure/anatomy, then continuing on to physiology/psychology. Within and in addition to these general domains, we also included musculoskeletal, physiological, neurological, nutritional, cardiovascular, endocrine (hormonal), and immunological related issues along with more specific entities.

Additionally, we outlined recommended guidelines in terms of injury prevention, alternative modalities for pain management, dietary/other supplements, postural considerations; also, how to exercise safely (resistance training/cardiovascular) from both a musculoskeletal and physiological standpoint. Furthermore, we delved into ways to help keep the body energy balanced for pregnant and obese females, concentrating on safety for these special female populations while being/staying physically active.

Although not entirely encompassing, what we have produced is a composite of over 30 chapters to distribute detailed information/impart pertinent knowledge on how to keep the female active and healthy, no matter at what age/stage of life she may be. Our charge is to make meaningful improvements upon previous editions, both online and in printed formats. Realizing that our book is indeed not a novel (primarily factual), we are hopeful that the reading experience is still interesting enough to leave longer than just a mere brief impression. Questions are also provided at the end of each chapter in hopes that those who read it will test themselves upon completion by evaluating their own level of material retention. This book, although quite extensive, is not meant to solely be "THE Bible" for the Active Female. Rather, it should be utilized as a source of reference for all individuals who are interested in female health and wellness. Everyone has family, friends, colleagues, relatives, and possibly knows numerous others who could potentially benefit from learning how to do things to take care of their own bodies, both physically and psychologically for enhancing the quality, if not the quantity of life.

Many thanks for the time and effort toward reading our book. Again, hopefully more insight and confidence about approaching the active female have been gained in doing so. We welcome any feedback or comments the reader may have regarding this published material.

Audience

Appropriate audiences for this book are teachers in health and fitness at all levels of education from junior high or high school to the college and university level since adolescence and young adulthood is a particularly momentous time for bone remodeling and reproductive health issues that may be impacted by energy deficiency.

This book would also be a useful textbook for a women's health issues class in a Women's Studies Program at the university level.

Fitness and wellness coaches, and students who are interested in advancing women's health issues in the field of sports medicine would find this book very insightful and useful in the field of preventative medicine. Others include:

- sports medicine specialists
- family practitioners
- gynecologists
- team physicians
- residents doing fellowships in sports medicine
- athletic trainers
- nurses
- physician assistants
- physical therapists
- sport psychologists
- licensed and certified professionals in the field of sports medicine

Lastly, the educated lay person or woman who may be experiencing these gender-specific problems or have daughters who may be experiencing this triad of disorders would find this book interesting and informative.

This book is by no means all-encompassing in terms of female fitness but provides a foundation upon which more information can be added, and innovative ideas built upon. It serves as a guide for any reader who is seeking further knowledge of girls and women who choose to stay physically active or want to become physically active from birth till death.

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First of all, I would like to thank Springer Nature for inviting us to publish the third edition of our book. Particularly, Kristopher Spring and Stephanie Frost, who are senior editors at Springer Nature. I would also like to thank my co-editors without whom I could have never completed the demanding task of writing and editing a book. Finally, the published book would not be possible without all of the chapter authors for the third edition.

Jacalyn J. Robert-McComb PhD, FACSM

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Mimi Zumwalt, MD

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Maria Fernandez-del-Valle, PhD

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Part I

Unique Gender and Sex Related Physical, Psychological and Physiological Characteristics of Females

Considerations of Sex Differences in Musculoskeletal Anatomy Between Males and Females

1

Kyla A. Petrie, Kimberly Burbank, Phillip S. Sizer, C. Roger James, and Mimi Zumwalt

Learning Objectives
After completing this chapter, you should understand

- sexual dimorphism and how it applies to humans
- sex differences in general morphology
- sex differences in skeletal geometry
- sex differences in collagenous, cartilage, and bone tissue
- sex differences in the upper extremity anatomy and mechanics
- sex differences in the lower extremity anatomy and mechanics
- sex differences in the spine anatomy and mechanics

1.1 Introduction

The musculoskeletal anatomy of women and men is grossly similar yet individually distinctive. Structural differences exist between the sexes, and these differences are due to both environmental and genetic factors. Sex differences in musculoskeletal anatomy can be described in terms of sexual dimorphism, which refers to physical differences in secondary sexual characteristics, such as size or color, between male and female individuals of the same species [1, 2]. Sexual dimorphism is present in many species of birds, spiders, insects, reptiles, fish, and mammals. For example, male pheasants are larger and more brightly colored than female pheasants, female spiders are usually larger than their male counterparts, male deer grow antlers, and males are larger than females in most species of mammals [2]. However, with a few well-recognized exceptions, such as body hair, muscle mass, and breast differentiation, sexual dimorphism in humans is more subtle compared to other species [2]. Yet, most people recognize that men and women exhibit different physical characteristics, including differences in body height, weight, shape, size, constituents, and alignment of the extremities (e.g., pelvic width, body mass distribution, and ligament/tendon laxity) [2–4]. Some of these differences in body structure are widely recognized and ingrained in cultural beliefs and stereotypes. For example, an artist's rendition of a typical man and woman was used to depict the sexes of the human species on the plaque of the Pioneer 10 spacecraft (Fig. 1.1) where the differences in gross structure are evident.

The typical differences in physical characteristics of the sexes are further exemplified by population data. Data from standard growth charts [6] demonstrate typical sexual dimorphic differences, but the division between men and women is usually less than one standard deviation and is age dependent [7]. For example, according to the clinical growth charts provided by the Centers for Disease Control (CDC), girls and boys at the 50th percentile are approximately the same height (usually within 1–2 cm) until puberty. However, beginning at about 14 years, the heights of girls and boys diverge at an increasing rate until the late teen years when growth slows down in both sexes. At 20 years, men are an average of approximately 14 cm taller than women. Similar relationships are documented for body weight, with a relatively small sex difference observed before the age of 14 years and an approximately 12.5 kg difference (men greater than women) at the age of 20 years (Fig. 1.2) [6].

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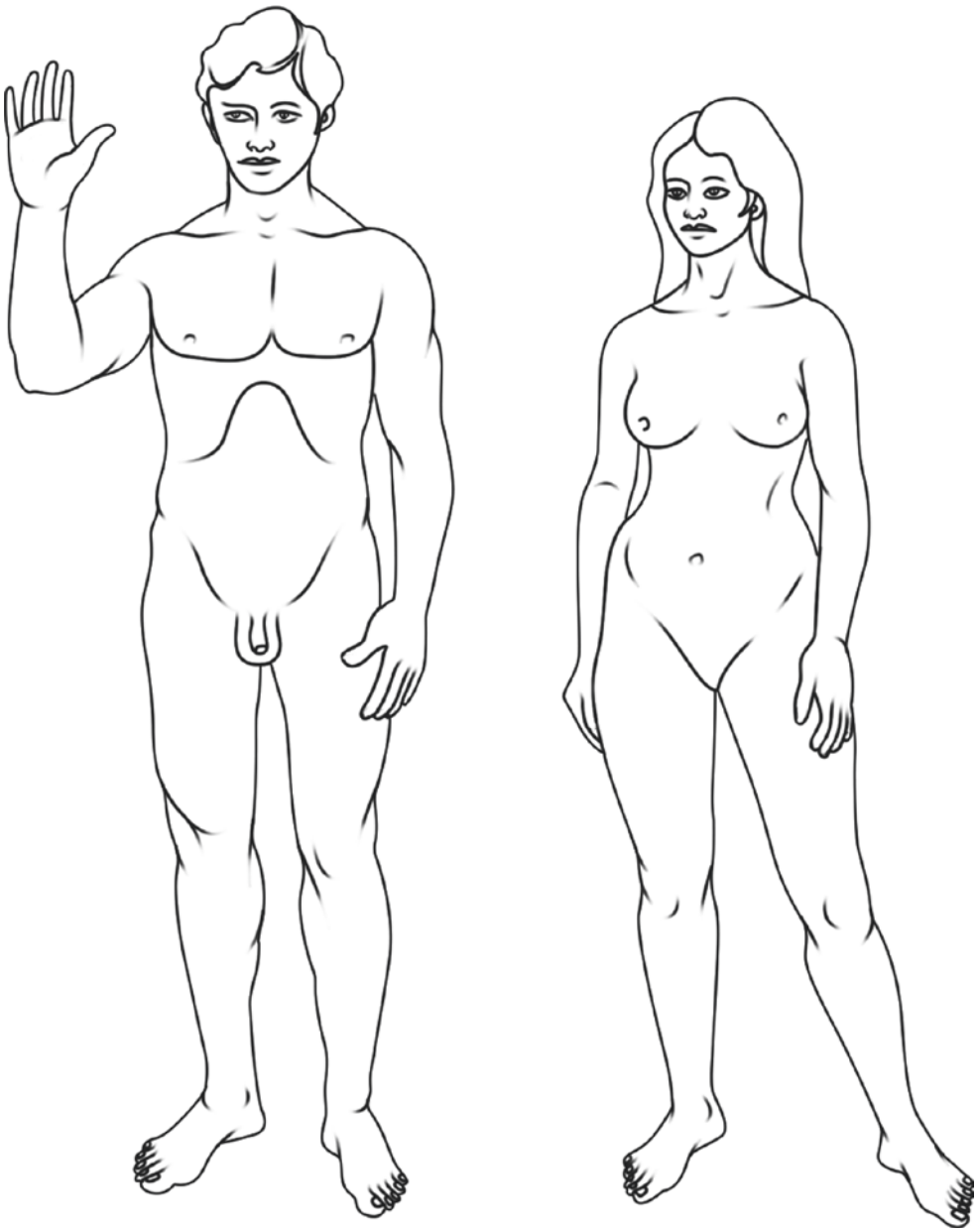

Fig. 1.1 Symbolic representation of men and women as depicted on the plaque of the Pioneer 10 spacecraft in 1972. Source: NASA (https://www.nasa.gov/centers/ames/images/content/72419main_plaquem.jpg) [5]

While sexual dimorphism is apparent in general body characteristics, other sexual dimorphic traits are less obvious. Reports of sex differences in skeletal and soft-tissue components are prevalent in the literature, which not only explain the differences in general appearance but also may influence movement patterns, injury risk, plus the development, and progression of musculoskeletal pathology. Consideration of the sex differences in musculoskeletal anatomy is important for both the general public and health care professionals in order to provide a basis for understanding of normal versus abnormal conditions that may exist. Moreover, a thorough appreciation that men and women have differences in musculoskeletal anatomy may indicate that they have distinctive health care needs. Therefore, the purposes of this chapter are to (1) examine sex differences in the anatomy of selected musculoskeletal components and (2) explore selected regional considerations in female functional pathoanatomy that are pertinent to women's health issues.

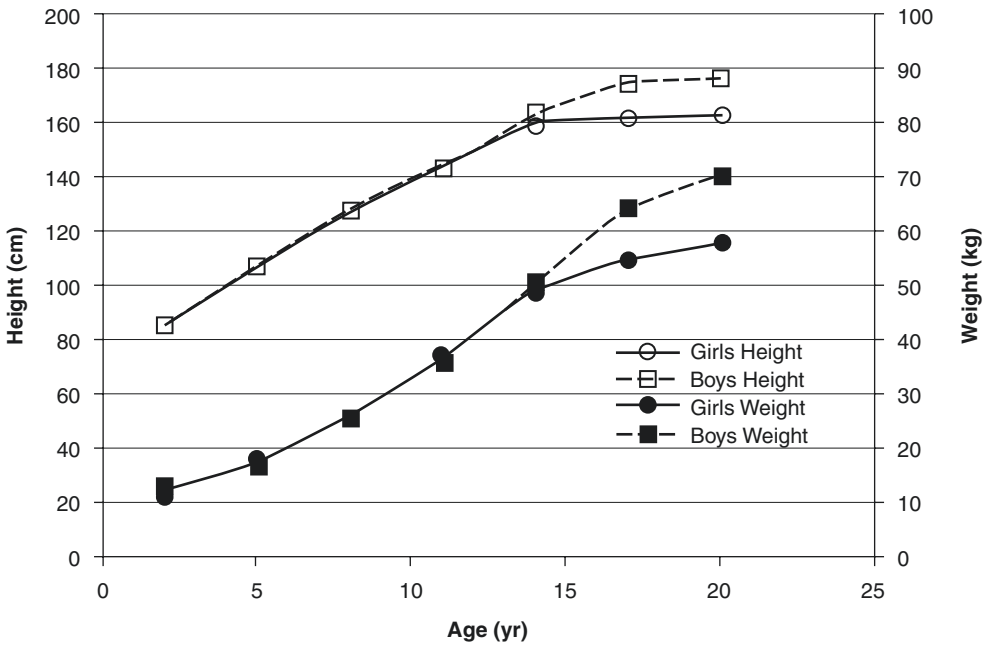

Fig. 1.2 50th-percentile height and weight of girls and boys from 2 to 20 years. Sexual dimorphic differences in height and weight begin to emerge at about the age of 14 years. Values are rounded to the nearest 0.5 cm and 0.5 kg. Adapted from Centers for Disease Control and Prevention, National Center for Health Statistics. CDC growth charts: United States. http://www.cdc.gov/growthcharts/. May 30, 2000 [6]

1.2 Research Findings

1.2.1 Sex Differences in the Anatomy of Selected Musculoskeletal Components

1.2.1.1 Sex Differences in Skeletal Geometry

There are several differences in skeletal geometry between men and women. In sports medicine literature, sex differences in musculoskeletal anatomy, including skeletal geometry, have been reported in context of common injuries that occur in active women and have mostly focused on lower extremity characteristics. For example, differences in size, shape, structure, or alignment of the pelvis, femur, tibia, tarsals, and toes all have been reported [3, 8–12]. Sex differences in the pelvis include a larger inlet and outlet [3], greater interacetabular distance [9], and a greater hip width normalized to femur length [4, 8] in women compared to men. Sex differences in the femur include increased femoral anteversion [4], and some researchers have reported a narrower femoral intercondylar notch width [10, 13] in women. However, other authors have reported no differences in notch width between the sexes [14, 15]. Greater genu recurvatum [3, 12], more lateral patellar alignment [3], increased internal tibial torsion [12], greater slopes of the medial and lateral tibial plateaus [16], plus more bunions and deformities of the lesser toes [3] in women have been reported, as well. Because of the mechanical linkage and interaction among structures of the lower extremity, skeletal differences in one or more interacting structures may result in differences in overall lower extremity alignment. For example, quadriceps angle (Q-angle) is the angle formed by the intersection of a line connecting the anterior–superior iliac spine and the midpoint of the patella with a line connecting the midpoint of the patella and the tibial tuberosity. In the literature, the Q-angle is generally reported to be greater in women than in men [8, 11] and is a function of the structural and alignment characteristics of the involved bones (e.g., pelvic width, patella position, and tibial torsion). Additionally, large deviations in Q-angle have been suggested to contribute to selected knee and foot pathologies [3, 17], although reports are equivocal.

Further evidence supporting the existence of sex differences in skeletal geometry comes from the areas of forensic anthropology and archeology. Scientists from these areas have used knowledge of skeletal sexual dimorphism to determine the sex of deceased individuals from their skeletal remains. A large amount of literature exists, which discusses the skeletal geometric characteristics commonly used and the ability of these characteristics to predict sex. The humerus [18], pelvis [19, 20], femur [18, 21–26], tibia [27–29], talus [30], and calcaneus [30–32] all have been used for this purpose. The ability to discriminate sex based on one or more skeletal geometric characteristics varies somewhat by which bone, as indicated by the percentage of individuals accurately categorized as male or female in the respective studies cited: tibia (96%) [28], femur (95%) [22], calcaneus (92%) [31], pelvis (88%) [20], and talus (81%) [30]. Furthermore, different parameters from the same bone appear to be better discriminators than other parameters [19, 20, 22, 25–27, 32]. For example, some scientists reported that a differing percentage of individuals could be grouped correctly using a discriminant analysis when evaluating different characteris-

tics of the femur. In this study, the femoral head transverse diameter (89.6% of cases correctly categorized) was the best discriminator, followed by the head circumference (87.7%), vertical head diameter (86.8%), condylar width (81.4%), maximum midshaft diameter (72.4%), and maximum length (67.7%). Using a combination of variables (midshaft diameter and head circumference), 91.7% of the cases were classified correctly [25].

The presence and magnitude of sex differences in skeletal geometry appear to be dependent on a number of factors including skeletal maturity [19, 33], environmental stresses (i.e., loading) [18, 22, 24, 29], and genetics (i.e., race) [20–24, 26, 34]. Consideration of these factors is important in establishing sexually dimorphic traits in skeletal geometry. Nevertheless, ample evidence exists to support the presence of sex differences in skeletal geometry.

1.2.1.2 Sex Differences in Musculoskeletal Tissues

In addition to sex differences in skeletal geometry, there are several reported sex differences in musculoskeletal constituents, including collagenous components (e.g., tendon, ligament, skin), cartilage, and bone tissues [35–38]. Collagen is a primary protein of connective tissues in mammals and constitutes more than 30% of the protein in the human body [39]. It provides much of the strength of tendon, ligament, skin, and cartilage [39, 40]. Additionally, it is the main protein component of bone [39, 40].

In collagenous tissues, the collagen molecules align based on stress patterns and provide strength against tensile loads [39, 40]. Some of the reported sex differences in collagen include differences in thickness [35], orientation [35], content [41], diameter [36], volume [37], and metabolism [38] for the specific tissues examined. Some of these sex differences are associated with fiber strength. Moreover, sex differences in collagen degradation have been observed in subjects as young as 2 years of age [38], while other sex differences may not appear until after several decades of life [37]. Many disorders of collagenous tissues (e.g., lupus erythematosus, scleroderma, rheumatoid arthritis, dermatomyositis, and Sjögren's syndrome) have been associated with sex differences. Etiological factors associated with collagenous tissue diseases are thought to exist at many levels (e.g., genetic, cellular, organ, age, behavioral, environmental), but sex hormones are thought to influence the onset and course of these disorders [42].

Sex differences in articular cartilage are reported in the literature [43–46] and have been associated with differences between men and women upon the onset of osteoarthritis [44, 46, 47]. Epidemiological evidence suggests that women are more likely (1.5–4 times at greater risk) to develop osteoarthritis than men [44]. Sex differences in articular cartilage morphology have been reported in children (age 9–18 years), which persist throughout adulthood, and increase during the postmenopausal years [43–45, 48]. Reported sex differences in articular cartilage morphology include greater cartilage volume, thickness, and surface area in male compared to female subjects [43–46]. These differences appear to be partially related to other characteristics such as age, body mass index, bone region, physical activity, and the specific articulation involved [44, 48]. However, research suggests that sex differences remain at some cartilage sites even after adjustment has been made for these other factors [43, 44]. Furthermore, the sex differences in cartilage morphology have been associated with faster cartilage tissue accrual rate in boys compared to girls (i.e., more cartilage tissue early in life) [44] and greater cartilage tissue degradation in older women compared to older men (i.e., greater loss of cartilage later in life) [49].

The presence of sex hormone receptors in cartilage tissue is thought to be an indicator that sex hormones influence these accrual and degradation processes [46, 47, 49, 50]. Evidence for the role of sex hormones in cartilage morphology/metabolism has been demonstrated in both animal [46, 50] and human [49] models. In mice, sex hormones have been shown to influence the inflammatory induction of cartilage degradation via modulation of cytokine production and release in granulomatous tissue [50]. Additionally, male rats have demonstrated higher levels of proteoglycan and collagen, less glycosaminoglycan loss, and greater proteoglycan synthesis than female rats in vitro. Furthermore, cartilage from female rats was shown to have greater susceptibility to degradation when implanted into female rats compared to male cartilage implanted in female rats or both male and female cartilage implanted into male rats [46]. In humans, urinary markers of cartilage degradation have provided evidence that cartilage loss is greater in women than in men. Additionally, cartilage degradation was shown to be greater in postmenopausal women compared to age-matched premenopausal women and less in postmenopausal women undergoing hormone replacement therapy compared to postmenopausal women not undergoing hormonal supplementation [49]. Therefore, sex differences in cartilage morphology/metabolism that exist early in life appear to increase with advancing age and may be explained by the difference in sex hormones.

Sex differences in bone tissue are also reported in the literature [51–54] and have been associated with disparities between men and women in terms of fracture risk [55–57]. Sex differences in bone tissue vary by skeletal site [33, 58] but are reflected by variation in both morphological [33, 52, 55, 57–61] and remodeling [51, 53, 54, 58, 61, 62] characteristics, particularly in osteoporotic individuals [40, 58, 63, 64]. Sex differences in bone tissue are present at an early age [33, 51, 52, 59], persist throughout adulthood [40, 53–55, 61, 62], and diverge even more in older age groups [40, 53, 54,

56–58, 60, 62]. Bone mass accrues during childhood through adolescence then peaks at about the age of 30 years in both men and women [40]. A lower amount of peak bone mass has been associated with a greater risk for osteoporosis in later life; [51] therefore, sex differences in the development of bone tissue during youth may partially explain some of the bone tissue differences between adult men and women. Several factors influence bone mass accrual, including nutrition (e.g., calcium, vitamin D), physical activity, lifestyle behaviors (e.g., smoking), genetic factors (race, sex), and hormonal factors (e.g., estrogen) [63, 65].

In children, serum markers of bone turnover have been reported to change significantly with pubescence in both boys and girls. In girls, these markers were shown to peak at mid-puberty and decrease thereafter; in boys, the markers continued to increase through late puberty. Moreover, the serum markers of bone turnover were overall higher in boys than girls even after adjustment for age, body weight, and pubertal stage [51]. These sex differences in bone turnover more than likely influence differences in peak bone mass [51], volumetric bone mineral density [52], selected measures of bone area [33], cortical thickness [33], plus ultimately compressive [52] and bending [59] strength. However, some authors have suggested that sex differences in some of these characteristics can be explained by differences in anthropometric dimensions (e.g., height and total lean body mass) [59].

In adults, there are several reported sex variations in bone tissue. Differences between men and women have been reported in bone mineral density (men greater than women) [60], peak bone mass (men greater than women) [40], cortical thickness (men greater than women) [55], age-dependent hormonal responsiveness of osteoblasts (less responsiveness in older cells from women when compared to older cells from men) [53], bone turnover (men greater than women) [61], and bone strength (men greater than women) [40, 55]. In older adults, sex differences in bone mineral density [56, 58], cross-sectional area [56], cortical thickness [56], bone width [56] and strength [40, 56, 60] remain considerable, with some variance (i.e., bone mineral density and strength) further diverging as compared to younger adult values [40, 56]. Furthermore, many of these sex differences do not disappear after adjusting for anthropometric factors such as height and weight [56].

The role of sex hormones in the loss of bone mass in older women has been explored widely in the literature. It is well known that a decrease in estrogen production following menopause is a primary contributing factor to the accelerated loss of bone mass in older women when compared to older men [63, 64]. However, older men also lose bone mass and are at greater risk for hip and vertebral fractures compared to younger men [54]. Even though men do not experience a physiological event comparable to menopause and, therefore, do not undergo a substantial decline in total serum testosterone or estrogen, some evidence suggests that a reduction in the bioavailable estrogen (non-sex hormone-binding globulin bound) might explain the loss of bone mass in both women and men [54].

1.2.2 Selected Regional Considerations in Female Functional Pathoanatomy

1.2.2.1 Upper Extremity

Shoulder

Sex-based anatomical differences of the shoulder complex are tissue and pathology specific. For example, a group of researchers [66] observed significant differences between men and women in the distribution of the articular branch of the axillary artery, which may influence decisions made during shoulder surgery. Differences have been associated with the incidence of external impingement of the shoulder. While women appear to have less prominent coracoid processes [67], no sex-based differences have been found in the role of the coracoid process in subscapularis impingement [68]. However, differences in the role of the acromion with external impingement have been observed. Historically, Bigliani [69] classified the acromial shape into three types. Type I processes are flat, Type II are curved, and Type III are hooked. This orthopaedic surgeon suggested that these differences could lend to the incidence of impingement and any subsequent rotator cuff tearing. Later, he and his coinvestigators [70] reported that 78% of all full-thickness rotator cuff tears were associated with a Type III acromion. More recent investigations have reported an increased incidence of full-thickness rotator cuff tears in women versus men [71]. Selected investigators have suggested that acromial differences are acquired, resulting from altered tension loads imposed by the coracoacromial ligament and deltoid insertions [72]. Another group of researchers [73] observed that Type III acromion was more common in female patients and discovered that Type II acromion was related to adaptive shortening of the glenohumeral joint posterior capsule.

Although external impingement has been associated with sex and age, the relationship between age, sex, and incidence of acromial type is controversial [73–75]. More recently, investigators have suggested that while the changes of the inferior surface of the acromion increased with age, they were not different between sexes [76]. However, investigators have observed limited sex-based differences in the acromiohumeral distance with the shoulder at rest, where women exhibited a narrowed space compared to men [77]. The influence of gender-based differences in scapular position at rest on impingement pathology needs further exploration, where

women appear to demonstrate less scapular protraction versus their male counterparts [78].

Although men appear to experience more frequent anterior dislocations of the glenohumeral joint [79], women seem to be more predisposed to glenohumeral instability [80]. This disparity appears to be related to the notion that not all joint instability results in dislocation, where grade I and II instabilities represent increased motion and possible humeral head perching on the anterior labrum, versus frank dislocation of the head from the glenoid cavity in grade III [81]. While glenoid fossa inclination appears to influence instability incidence [82], few sex differences in this architectural feature have been noted [83]. Recently, investigators found that women differ from men because the shape of their glenoid fossa is more oval, more inclined, and exhibits deeper anterior glenoid notches [84]. Although the woman's predisposition appears to be more related to increased anterior capsular laxity and resultant hypermobility along with decreased joint stiffness [80], further research is merited for studying the relationship between these architectural findings and the onset and persistence of glenohumeral pathology.

Finally, women between the ages of 40 and 60 years are more predisposed to developing idiopathic capsulitis [85]. This condition is associated with increased thickening of the anterior–superior joint capsule at the coracohumeral ligament [86], along with a noninflammatory synovial reaction in the proximity of the subscapularis tendon [87]. These changes demonstrate active fibroblastic proliferation accompanied by tissue transformation into a smooth muscle-like contractile tissue phenotype that is similar to Dupuytren's disease [88].

Elbow

Women appear to be at greater risk for developing tennis elbow due to tendinosis that emerges from mesenchymal changes in the collagenous constituents of tendons [89]. Tennis elbow tendinosis is a degenerative condition, typically lasting greater than 12 months in duration, is more likely noninflammatory in nature [90], and affects one of four possible different regions of the tendinous insertions into the lateral elbow. The tendons at risk are specifically located about the lateral epicondyle of the distal humerus. The extensor carpi radialis longus (ECRL) originates on the distal 1/3 of anterior supracondylar ridge, possesses almost no tendon at the origin, and demonstrates an immediate transition into muscle. The extensor carpi radialis brevis (ECRB) starts from a 5 mm by 5 mm square area on the superior surface of the lateral epicondyle (10% of origin) along with collagen/fascial layers of intra-compartmental septa that share fascia with the extensor digitorum communis (EDC) coursing distally to the second and third metacarpals, especially fascia associated with third metacarpal. Thus, resistive wrist plus resisted extension of the second and third metacarpophalangeal joints may be suggestive of tendinopathy at either the EDC or ECRB. The ECRB tendon is juxtaposed between the muscle bellies of ECRL and EDC. This common physical finding merits palpatory discrimination between the two regions for a differential diagnosis. The ECRB can exhibit tendinopathy at its origin, along the tendon between ECRL and EDC, or at its musculotendinous junction more distally. Finally, the EDC can be found at the anterior surface of the lateral epicondyle. If involved in lateral tendinopathy, resistive extension of the second through fifth metacarpophalangeal joints (MCPJ 4 and 5 differentiates this lesion from pathology involving the ECRB. This condition seldom occurs in isolation but is typically discovered in combination with affliction to the ECRB [91].

The woman's predisposition for lateral elbow tendinosis is increased when her estrogen level decreases, especially after premature hysterectomy (at less than 35 years of age) and/or reduced estrogen levels from other causes [89]. While inflammatory tendinitis involves a chemically mediated inflammation due to tendon injury [89], the tendinosis to which women are more predisposed produces a non-chemically mediated degenerative change associated with long-term repetitive tendon stress [92], resulting in a condition that could persist longer than 12–14 months. This process produces tissue necrosis that manifests as a "moth-eaten" appearance within the tendon [93]. As a consequence, the tendon becomes friable, along with possible associated bony exostosis at the lateral epicondyle [89]. This elbow tendinosis, a chronic condition, can be accompanied by an imbalance between vasodilatory or vasoconstrictive variations [93], substance P, and CGRP proliferation in the vicinity of the affected tendon [93], accompanied by a high concentration of glutamate in the surrounding tissues [94].

Women also appear to be more predisposed to ulnar nerve lesions at the medial elbow as well. The medial elbow anatomy affords three different predilection sites for ulnar nerve entrapment. The nerve first courses under the arcade of Struthers just dorsal to the medial intermuscular septum. Distally, the nerve courses through the cubital tunnel, whose boundaries are the medial collateral ligament complex (ceiling), medial epicondyle (medial wall), olecranon process (lateral wall), and cubital tunnel retinaculum (floor). In selected individuals, the retinaculum is dorsally bordered by the anconeus epitrochlearis muscle that is innervated by the radial nerve and is activated simultaneous with the triceps, lending to possible entrapment symptoms during resisted elbow extension. The retinaculum that courses from the medial epicondyle to the olecranon tightens with passive elbow flexion, which can create nerve entrapment symptoms at end-range passive flexion. Finally, the ulnar nerve must course under the retinaculum between the two heads of the flexor carpi ulnaris. As a consequence, entrapment symp-

toms may increase during resistive wrist flexion–ulnar deviation as well [95].

Wrist and Hand

Only a few afflictions of the wrist and hand appear to differ between men and women. Tendon pathologies, including tenosynovitis and tendinosis, seem to be more frequent in women [96], but data related to the pathoanatomical and physiological influences on these differences have not been explored. Similarly, carpal tunnel syndrome (CTS) is more common [97, 98] and prolonged [99] in women. However, multiple factors have been elucidated, which may contribute to this difference. The etiology of carpal tunnel syndrome is multifactorial, resulting from anatomical, biomechanical, pathophysiological, neuropathological, and psychosocial influences. Anatomical factors, such as tunnel architecture and volume [100], lumbrical anatomy [101], and the shape of the hamate hook [102], have been associated with CTS. Specific anatomical and anthropometric factors appear to influence a woman's greater predisposition to CTS [103, 104]. Although carpal bone size and scaling do not appear to differ between men and women [105], hand–length ratios, space indices at the wrist, and digital features appear to differ between the sexes [103]. Along with these variations, differences in body mass index seem to predispose women to CTS because increased fatty tissue within the carpal canal leads to increased hydrostatic pressure upon the median nerve [103].

The onset and progression of CTS appear to be related to an increase in intra-tunnel pressure [106]. Different factors tend to raise this pressure, including tunnel space narrowing associated with wrist movements [107, 108], carpal instability [109], increased muscle force production [110], and trauma that produces perineural edema and fibrosis [111]. Women may be more susceptible to these influences versus men, due to reduced available space for the median nerve within the tunnel. The median nerve seems to increase in cross-sectional diameter with sustained repetitive hand movement in women as compared to men [104], thus, compromising the relative tunnel size and potentially increasing pressure within the tunnel in context with the previously discussed factors.

The individual suffering from CTS may experience sensory and/or motor changes, including paresthesias or true numbness that reflects deficits in neurological function. Women have demonstrated greater neurological dysfunction involving the median nerve when compared to men [112, 113]. However, controversy exists over the value of neurophysiological testing for the diagnosis of CTS [114]. Orthodromic median sensory latency is typically prolonged with CTS patients [115], and median nerve motor amplitudes are decreased in patients with CTS [113]. Yet, a researcher [116] discovered a poor relationship between electrodiagnostic test outcomes and final symptom constellations. Another investigator [117] found that the difference between the median and ulnar motor latencies was greater in patients experiencing CTS versus controls. The differences appear to be important for the diagnosis of CTS [112].

The presence of autonomic disturbances appears to be associated with a woman's predisposition to CTS [118]. Disturbances in neural function could be related to local sympathetic fiber stimulation and/or brachial plexus irritation associated with the double crush phenomenon, which has been observed in as many as 40% of all patients suffering from CTS [119]. As result, a vasoconstrictive event could lead to decreased perineural microvascular flow along with increased protein leakage from the vascular supply that produces epineural and perineural edema [111], as well as increased endoneural pressure plus ischemia [120], contributing to the symptoms of CTS.

1.2.2.2 Lower Extremity

Hip Joint

Women are at greater risk for both microtraumatic stress fracture [121] and macrotraumatic frank fracture at the hip [122] especially involving the femoral neck [121]. This predilection appears to be influenced by differences in bony architecture about the hip and pelvis [123]. Acetabular depth and femoral head width appear to be less in women versus men [124]. The coxadiaphyseal angle has been reported to be wider in men versus women in selected races, thus, potentially predisposing women to a higher incidence of stress reactions [125]. Women appear to have decreased femoral neck strength versus men, as evidenced by decreased femoral neck cross-sectional moment of inertia (CSMI) [126, 127]. Compressive stress (Cstress), defined as the stress in the femoral neck at its weakest cross section arising from a fall, is higher in women [127]. These features interact with women's altered estrogen level associated with menstrual irregularities [128] and menopause [122], thus, enhancing their fracture risk predisposition. Over the past decade or so, postmenopausal women have relied upon the long-acting, bone density-maintaining effects of bisphosphonate administration for reducing the rate of fragility fractures in this population [129]. However, this benefit has been accompanied by an increase in atypical subtrochanteric fractures at a younger age in response to chronic drug intake [129], especially in Asian females [130, 131]. The risk associated with bisphosphonate use continues to be controversial [132]; thus, comorbidities and management strategies should be assessed when its usage is considered [129].

The outer margin of the hip joint socket or acetabulum is completely lined with the cartilaginous labrum that serves to enlarge the articular surface [133, 134]. The labrum enhances the articular seal, fluid pressurization, load support, and joint lubrication of the hip joint [135] while also possessing a vari-

ety of sensory endings important for proprioception and nociception [136]. The labrum is vascularized in a fashion similar to the meniscus in the knee, where the outer periphery receives good vascularization, and the inner margin is lacking in blood vessels [137]. The labrum is at risk for traumatic vertical, as well as horizontal, degenerative type tears [134, 138]. The propensity for tears is increased by the deficiencies in the mechanical properties of the labral tissue, especially in women. Labral tissue obtained from male patients is stronger against tensile stress than those from female patients [139]. Moreover, labral degenerative changes may influence those same mechanical properties, adding to the risk of tearing [140, 141].

Labral tears appear to occur more frequently in the superior region of the acetabular structure, due to decreased mechanical properties accompanied by increased demand/load [140, 142]. The superior region of the labrum appears to be less well vascularized, lending to the susceptibility of that area to traumatic and degenerative tears [140, 142]. One significant mechanical contribution to this loading demand is the impact of the femoral neck against this region during full flexion of the hip [141]. Femoral neck architecture also appears to differ between men and women, where increased thickening and decreased coxadiaphyseal angulation of the neck and deformation/fullness of the neck diameter in older women predispose them to anterior acetabular labral trauma, especially when the hip is positioned in full flexion [143]. However, severity of such deformations and changes observed with imaging do not appear to correlate with the incidence of femoral–acetabular impingement and subsequent labral lesions [144], making the clinical examination paramount to diagnosis.

Knee Complex

Little evidence is available to describe sex-based differences in the patellofemoral complex of the knee. One might explain differences in terms of cartilage volume, where the female sex exhibits 33–42% of the variation with women having reduced knee cartilage area versus men [43]. However, T2 MRI examination of young, healthy volunteers did not reveal any sex-based differences in the magnitude or spatial aspect of knee cartilage [145].

Investigators have attempted to describe sex-based differences in terms of patellofemoral contact areas at various positions of knee flexion. In males, some researchers [146] reported larger contact areas of posterior patellar surfaces with the knee flexed to 30°. In addition, they observed a greater change in the female's patellar contact pressures in response to varying vastus medialis activity with the knee positioned at 0°, 30°, and 60° flexion. Although no differences were seen by another group of scientists [147] with the knee in full extension, they did observe larger contact areas in male patellofemoral joints with the knee flexed to 30° and 60°. However, the contact areas were not different when the data were normalized by patellar dimensions of height and width. Subsequently, investigators have turned their attention to the role of hip control deficits while landing in contributing to the development of anterior knee pain syndrome (AKPS), where decreases in eccentric control from the hip external rotators and abductors were shown to be associated with increased AKPS [148]. However, another set of researchers [149] found no relationship between hip control deficits and gender in subjects suffering from AKPS.

More striking is the relationship between sex and knee ligament injury. Injury to the anterior cruciate ligament (ACL) can be a devastating event, and a woman's increased risk for this injury over male counterparts is well documented [150, 151]. It has been reported that 70% of all ACL injuries result from a non-contact mechanism [150, 152], where older girls and women appear to tear their ACL two to eight times more frequently than men [153].

Since the reason for this increased ACL injury risk is unclear, investigators have explored many possible causes including anatomical, hormonal, and mechanical/neuromuscular differences. One of the classic anatomical factors attributed to sex-based differences in ACL injury is the width of the femoral intercondylar or Grant's notch. The intercondylar notch is found in the roof of the space between the femoral condyles, lending a point where the ACL could crimp up, stretch, or tear during forced rotational non-contact loading [151]. The female knee was once thought to possess a smaller notch versus men, lending them to greater vulnerability for traumatic tears [13, 15]. However, other investigators have suggested that increased female risk was based on differences in the ratio between the notch width and width of the femoral condyles (notch width index) [154].

The role of the notch width still remains controversial. Certain scientists [155] have suggested that the narrower notch width in the female knee simply reflects the smaller diameter ACL within the notch, which still must constrain the same relative loads and stresses as the male ACL. The difference in ACL diameter, along with an increase in creep deformation under sustained loading [156], subsequently renders this ligament susceptible to greater injury potential in female athletes. Some researchers [157] found no differences in notch width characteristics between the sexes, and other clinicians [14] suggested that any individual with a smaller notch width is at higher risk for injury, regardless of sex. More recently investigators have suggested that different regions of the notch may vary in width, where women appear to demonstrate greater narrowing at the base and middle of the notch versus their male counterparts. To delve into this issue further, these scientists turned to MRI three-dimensional (3D) notch volume analysis to better describe differences. They subsequently found that males exhibited a larger 3D notch volume versus females, furthering the dis-

agreement regarding the role of femoral notch size/shape affecting female ACL injury risk [158].

Other morphological characteristics have been examined in terms of their contribution to increased ACL injury risk in females. Investigators have noted that the disparity between the intercondylar axis and joint motion axis of the femur at the knee to be greater in women and compounded in those females with a history of ACL injury, suggesting its role in ACL tear risk [159]. These researchers discovered that the strain on the anterior–medial bundle of the ACL was increased in females versus males and that this relative strain pattern was positively correlated with ACL cross-sectional area and lateral tibial slope [160]. Finally, another group of scientists [161] discovered that ACL-injured females demonstrate a significantly greater posterior tibial plateau slope versus an uninjured control group.

Static knee postural and alignment characteristics have been considered to be factors that could contribute to the woman's greater risk for ACL injury [162]. The Q-angle is a clinical measure used to determine the position of the knee in the frontal plane [162]. A couple of investigators [163] compared Q-angles between male and female lower extremities and found no significant sex or right-to-left lower limb differences. Conversely, another group of researchers [17] reported that women exceeded men in quadriceps angle (Q-angle) and thigh–foot angle (TF angle) [164]. However, the TF angle, which is a measurement of tibia external rotation (toeing out), is not clearly linked to ACL injury [165].

Biomechanical features have been linked to sex-based ACL injury predisposition [165]. Kinematically, differences in knee flexion angle at contact (<30°), tibial rotation in the coronal plane, and frontal plane motion have all been implicated [166]. Investigators have linked reduced contact and less peak knee and hip flexion during selected load-bearing functional activities with female ACL injury [167, 168]. Similarly, investigators have observed decreased peak hip abduction in women when cutting during sports [167, 169].

Female athletes have been found to exhibit increased valgus motion in the frontal plane during landing or cutting maneuvers, which may serve as a factor in female ACL injury predisposition [170]. Numerous investigators have observed this behavior [167, 168, 171], along with an increased variability in the valgus motion during the landing and/or cutting sequence [167]. A group of scientists [172] reported that these excessive lower limb motions could be reduced through appropriate jump/land training. Yet, sex-based sagittal [171] and frontal [173] plane movement differences have been disputed, where expected differences did not emerge, and the authors suggest that other factors are at play in producing the increased injury risk for the female ACL. Additionally, other investigators have reported increased coronal plane excursion for the hip and knee in women versus men during drop-landing tasks [174], producing increased internal rotation of the lower extremity during those activities. Finally, another set of researchers [175] examined the timing of kinematic occurrences during a landing sequence in men and women. They found that maximal hip adduction, knee valgus, and ankle eversion occurred significantly earlier in women versus men. Moreover, maximal hip adduction and knee valgus occurred before maximal knee flexion in women versus after in men. Maximal ankle eversion occurred earlier in women than in men and women produced a significantly higher angular velocity of knee valgus versus men. The authors concluded that these differences predisposed women to increased ACL injury.

Increased joint laxity and anterior tibial translation are associated with non-contact ACL injury [165, 176]. Some researchers [165] reported that sex and excessive subtalar joint pronation are the only predictors of knee joint laxity. Women exhibit increased anterior knee joint surface translation during extension [177]. This is accompanied by reduced protective hamstring activity during that translational movement [153, 177] that renders the female ACL less protected when exposed to anterior shear forces [178]. In a similar fashion, the female's ACL injury predisposition may be related to excessive subtalar joint pronation in the ankle [165, 167, 179], which appears to promote the previously discussed increase in tibial internal rotation [179] and anterior tibial translation [165]. This behavior does not appear to relate to genu recurvatum and the tibiofemoral angle [165]. In contrast, other authors have not observed the sex-based differences in subtalar pronation [17].

Differences in kinetic behaviors when cutting or landing have been attributed to increasing the female ACL injury risk [180]. Female athletes have been found to exhibit reduced peak knee flexor moments [181] and increased peak knee valgus moments [168, 181, 182] during cutting tasks. Similarly, other investigators have [168] found women to have increased greater peak vertical and posterior force than men during landing. These altered kinetic behaviors are accompanied by reduced leg stiffness during rapid load bearing [183], which could translate into a reduced ability to diffuse stress from the ACL [184].

Load management appears to be related to appropriate co-contractive behavior between the quadriceps and hamstrings during cutting and/or landing. Thus, differences in muscle activation, timing, coordination, and force production may serve as a contributing factor to female ACL injury predisposition [185, 186]. Women's differences in muscle activity may begin early, as girls developmentally increase the quadriceps strength disproportionately more than their hamstring strength [187]. While some investigators [188] questioned the role of sex in co-contractive disturbances, several authors have suggested that female athletes exhibit greater quadriceps versus hamstring activity during landing and/or cutting [189–191]. Similarly, women appear to demonstrate pro-

longed quadriceps recruitment and reduced hamstring activation during the post-contact phase of cutting versus male counterparts [192]. Increased soleus [189] and gastrocnemius [190] activity may contribute to women's muscular recruitment differences, while decreased hamstring activity may reduce their ability to decelerate/control tibial translation, internal rotation, and anterior shearing [177, 193]. These differences may be exaggerated by prolonged exercise causing muscular fatigue. Researchers have [194] found that after exercise, females exhibited significantly less quadriceps motor-evoked potential EMG amplitude compared to males, which may contribute to females' increased risk for ACL injury in response to changes in central nervous system drive capacity.

As a consequence of the woman's differences in kinematic, kinetic, and neuromuscular control strategies, the ACL potentially sustains greater loads with athletic activity. Unfortunately, the sex-specific ACL demonstrates different mechanical behaviors amidst these altered strategies. During passive cyclic loading, the female ACL appears to exhibit greater creep versus the male ligament [156]. The difference in ligament creep could compound the previously discussed deleterious mechanical effects, as quadriceps electromyographic activity may increase after ACL creep, while hamstring co-activation is not likely to change [195].

Another factor that appears to interact with the anatomical and biomechanical influences contributing to female ACL injury predisposition revolves around changes in sex-specific hormones. Ovarian sex hormone fluctuations have been related to increased non-contact ACL injury [178, 196]. Estrogen and progesterone receptors have been identified within the substance of the ACL [197], likely responsible for the relationship between peaks in estrogen levels and increased laxity [198]. Exposure to estrogen appears to increase metallomatrix protease activity and decrease fibroblastic activity within the ligament, lending to increased tissue laxity [198]. More recent findings suggest that increased estrogen levels negatively correlate with hamstring rate of force production, suggesting a reduced protective response from that important muscle group during upswings of estrogen levels [199]. However, correlation between injury risk and specific menstrual phases is controversial at best, since other authors have reported increased ACL injury during the follicular [178, 200] and luteal [200] phases.

Ankle and Foot

Women appear to be more predisposed to ankle and foot injuries than men in selected populations. Research has [201] found that women in military physical training were at greater risk for developing Achilles tendinopathy and ankle sprains than their male counterparts. Moreover, another study [202] reported that symptomatic females suffering Achilles tendinopathy do not benefit as much as symptomatic males from 12 weeks of eccentric training in terms of pain reduction or improvement in functional scores. Structural differences have been noted in the female foot, which demonstrate smaller width and length, as well as specific shape [203]. However, sex differences are not observed in terms of medial longitudinal arch measurements [204] or overall arch height [205].

Women appear to be at greater risk for ankle inversion trauma. Some scientists have [206] found that female athletes are at greater risk for grade I inversion trauma, where there is disruption of the anterior talofibular ligament. The same authors found no sex-based differences in grade II (anterior talofibular and calcaneofibular ligament involvement) or grade III (the same ligaments plus the posterior talofibular ligament). This predisposition is related not only to the sports in which female athletes participate [207] but also by selected structural differences in the lower extremity. Female athletes' risk of ankle inversion trauma is increased by increased tibia varum and rearfoot eversion with weight bearing [207]. Neuromuscular responses may contribute to the female's predisposition toward ankle inversion trauma. Other investigators reported that while males demonstrate decreased peroneus longus reflex amplitude following neuromuscular fatigue, the same reflex in females is actually increased, suggesting the female's reduced protective response to a sudden inversion perturbation [208].

Other structural differences have been noted, which add to the female's predisposition to ankle and foot affliction. Women demonstrate decreased cartilage thickness over the talar dome, which is at risk for developing osteochondritis and necrotic changes [209]. Women also appear to demonstrate increased obliquity of the first metatarsal base, resulting in increased metatarsus primus varus and potential increased incidence of clinical hallux valgus [210]. Additionally, women demonstrate increased incidence of hallux rigidus in the first metatarsophalangeal joint, with the vast majority of the subjects demonstrating a flat articular surface configuration.

Achilles tendinopathy has been attributed to numerous factors, including histochemical, pathomechanical, and neurophysiological influences. In addition, the female sex has been touted as a factor lending to the development of Achilles tendinopathy, possibly interacting with other contributors. Marked deficiencies have been noted for tissue histochemical responsiveness in female rabbit tendons [211]. Sex-based factors may contribute to differences in tendon pathology and response. For example, a female's tendon may experience increased load in response to footwear with hard soles and insufficient rearfoot control or high heels [212], all of which have been associated with increased incidence of tendinopathy. However, this sex-based predilection for Achilles tendinopathy is controversial, where more recent studies have questioned differential

female predisposition [213]. Sex-based differences in Achilles tendon properties and pathology may be related to muscle and tendon strength differences, rather than other sex-specific tissue characteristics [214].

1.2.2.3 Spine

Cervical

Sex-related anatomical differences in the cervical spine have been observed in vertebral structures [215, 216], lending to clinically relevant differences of bony processes and the joints they form, as well as the foraminal spaces through which important neurovascular components course. For example, investigators have observed sex differences in dimensions of lower cervical vertebral laminae and pedicles. This group has [215] found that women demonstrated smaller pedicular widths, lengths, and transverse angles at C3 through C7 when compared to men. Similarly, other researchers [216] have observed smaller laminar height, width, thickness, and angulation in women at levels C2 through C5. The role of sex-based cervical vertebral structure differences is not well elucidated [217]. Yet, men appear to have a larger vertebral canal-to-body anterior–posterior diameter ratio versus women, potentially predisposing them to a wider canal in proportion to their overall axial skeletal morphology and decreased incidence of cervical myelopathy [218]. Conversely, women appear to demonstrate greater spinal canal narrowing after soft-tissue neck injury versus their male counterparts [219], possibly contributing to their increased incidence of whiplash-related disorders [220], as well as the latent clinical sequelae and delayed recovery status post-whiplash trauma [221, 222].

Female cervical zygapophyseal (facet) joints may be at greater risk for injury during a whiplash trauma versus their male counterparts. Excessive segmental translation has been shown to be a potential cause of injury. Simulated rear-impact vehicular accidents using human volunteer subjects showed greater degrees of cervical retraction in women who were unaware at time of rear-end impact [223].

One researcher [224] found that the facet articular surfaces in female cadavers were less adequately covered by cartilage than similar specimens in men. In addition, these joints exhibited a greater distance from the dorsal-most region of the facet joint to the location where the cartilage began to appear (cartilage gap), potentially lending these joints to greater translation during unanticipated loads. Another group of investigators [225] found that female cadaveric specimens exhibited increased compression in the dorsal region of the facet joint during the early phase of whiplash. These biomechanical behaviors could predispose female facets to injury in the subchondral bone during normal physiological or traumatic loads, especially when accompanied by endplate perforations and older age.

Female cervical disks may be at greater risk for failure when exposed to unexpected abnormal loads. Some scientists [226] examined the geometric characteristics and loading response of the cartilaginous endplates in cadaveric cervical disks. They found that the female sex was associated with significantly lower endplate fracture loads when exposed to compression.

Thoracic

The primary sex-based differences that have been observed in the thoracic spine appear to center around differences in postural alignment. Fundamental sex-specific differences have been found in children and adolescents regarding the extent of the thoracic kyphosis in the sagittal plane. The presence and severity of kyphosis are especially more marked in females [227]. Thoracic kyphosis degree changes as children age, where the rate of change is greater in women versus men [228]. The change in the kyphotic curve seems to progress in a fashion similar to the lumbar spine lordotic curve during childhood. However, the relationship between the change in kyphosis and lordosis decreases in girls by the age of 15, but not in boys [229].

Of greater interest are the sex-based differences in the development and progression of adolescent idiopathic scoliosis (AIS), where the individual develops a rotatory 3D deformation in the thoracolumbar spine, especially in the frontal plane. A single thoracic curve is most common in selected populations, followed by other configurations of single and double curves in the thoracolumbar spine [230]. Investigators have reported increased incidence of AIS in adolescent girls [230–232], where female prevalence appears to be genetically coded [233]. Young girls appear to be at greater risk for developmental curve progression versus boys, especially in the age prior to the onset of menses [232]. Similarly, girls with scoliosis generally grow faster than similar age girls without the same spinal condition [234]. Yet while an age greater than 15 years, skeletal maturity, postmenarchal status, and a history of spine injury are all associated with the prevalence of back pain in people with AIS, sex, family history of scoliosis, leg length discrepancy, curve magnitude, and spinal alignment are not [235].

Investigators have looked at not only the interactions of physical changes with sex in scoliotic patients but also the role of sex-affecting psychosocial factors associated with the condition. Girls with scoliosis seem to be at greater risk for psychosocial stresses, including feelings about poor body development, troubled peer interactions, and health-compromising behaviors [231]. Yet, while investigators have evaluated the impact of scoliosis on health-related quality of life (HRQoL), the role of sex in that evaluation is controversial. While an investigative group [236] discovered that male adolescents scored higher on validated self-report instruments that measured HRQoL, other researchers [237] found

no effect of sex, curve type, and curve size on a similar battery of measures. Additionally, adolescents undergoing brace-based management did not appear to score on HRQoL instruments differently from age-adjusted norms.

Lumbar

Premenopausal women demonstrate decreased bone density in the lumbar vertebrae versus men [238]. A study has [239] shown that adult women demonstrate lower vertebral bone mass than age-matched men. Additionally, women exhibited decreased compressive load tolerances, accompanied by increased mechanical stress [239, 240]. However, bony differences may not be limited only to adults. Other researchers [241] found similar bone mass differences in preadolescent and adolescent girls, who exhibited lower vertebral bone mass than age-matched boys. However, these investigators reported that this variation was likely related to differences in bone size versus bone density [240, 241]. Another set of scientists [242] went further to report that volumetric bone density of the third lumbar vertebra did not differ between the sexes, whereas observed differences in areal bone density were likely related to variations in bone size.

An account of sex-based differences in low back pain (LBP) is controversial. However, a group of researchers [243] has reported a higher incidence of LBP and dorsal pain (DP) in female youth, especially with those girls involved in sports. However, the structural etiology of sex-based differences in back symptoms has not been fully elucidated. Evidence of variations in intervertebral disk structure or function is scarce. Some scientists have [244] found that the female sex was a contribution to the cellular proliferation potential within the annulus fibrosis surrounding the disc nucleus pulposus, along with a contribution from increased age, degree of degeneration, and surgical modification. Other investigators have shown differences in lumbar zygapophyseal facet size, pedicle facet angle, and facet shape [245, 246]. These variations appear to be related to a greater incidence of degenerative anterolisthesis at L4 in women versus their male counterparts [245].

Sex differences are observable in the posture and postural control of the lumbar spine. Certain researchers have [247] found a greater lumbar spine lordotic curve in women versus men. Others [248] have examined the impact of unstable versus stable sitting surfaces on recruitment and control of the superficial lumbar multifidus, transverse fibers of the internal obliques, and iliocostalis lumborum pars thoracis. While these investigators reported no sex-based electromyographic (EMG) differences, they did observe that women exhibited greater medial–lateral postural sway versus men on an unstable surface. While the role of posture and postural control in the development of LBP is inconclusive, future studies could examine the role of these neuromuscular factors on the development of lumbar pathology.

Other investigators have observed sex-based differences in lumbar muscles cross-sectional area and muscle geometry [249]. These variations, coupled with differences in trunk motor control strategies, could have an influence on biomechanical behaviors of the lumbar spine. Women exhibit decreased type II fiber diameter versus men, lending to decreased strength and increased endurance of the lumbar muscle groups [250]. Moreover, females appear to experience greater compressive and anterior–posterior shear loading at the lower lumbar spine [251]. These loading differences seem to be related to altered co-activation of the muscles surrounding the lumbar segments, where women produce greater flexor antagonistic co-activation than men [252]. It is likely that these altered behaviors result in distorted strategies for controlling dynamic spinal loading conditions. For example, another group of researchers [253] studied the effect of sustained flexion postures on protective paraspinal muscle reflexes. These investigators not only observed a detrimental alteration in the reflexive activity after sustained trunk flexion but also found that women demonstrated greater detriments in the protective reflexive response. Moreover, they appear to have decreased stiffness and increased segmental motion in the lumbar spine versus men [254]. These factors added together could lend the female lumbar segments to the development of clinical lumbar instability [255].

Sacroiliac Joint and Pelvis

Women appear to suffer from pain associated with the sacroiliac joint (SIJ) more frequently than men, most likely associated with anatomical differences and hormonal fluctuations. The incidence of clinical hypermobility in the SIJ is greatest between the ages of 18–35 years. However, this prevalence appears to be sex specific, where the SIJ mobility begins to decline at 35 years old in men and 45 years old in women. Thus, SIJ-related pain that is associated with clinical instability could persist in women after 45 years, especially when the individual is on estrogen replacement.

Anatomical changes are seen in the SIJ throughout the course of life, and those changes appear to be different between men and women [256–258]. By the second decade, differences between the sexes are observable [259]. While the male synovial capsule thickens and the joint architecture visibly adapts, the female SIJ soft tissues become more pliable as hormones fluctuate with the onset of menses.

Although the sacral vertebrae start ossifying in the third decade, the mobility of the female SIJ continues to increase, producing a ratio of mobility of approximately 5:1 compared to men. Pregnancy can also contribute to the sacroiliac joint being more mobile 2.5 times, increasing the dynamic movement disparity between women and men [259]. Movement persists in the female SIJ through the fourth and fifth decades, whereas the male SIJ demonstrates further decline of motion

in the same time frame [260, 261]. While complementary ridges and depressions form on the iliac and sacral cartilages plus the synovial membranes thicken in both men and women, men appear to be more prone to the development of periarticular osteophytes and sacroiliac bridging, further lending the male SIJ to decreased mobility [259, 262–264].

The external contours of the SI joint articular surfaces are generally a C shape in men and an L shape in women, lending the female articulation to greater translation during select situations such as pregnancy and delivery. The joint surfaces at the S1 level are the largest compared to the smaller surfaces at S2 and S3. Each SIJ surface is approximately 17.5 cm [3] in surface area, well suited for absorption and transfer of large forces [265]. The sacroiliac joint itself is found deep within the sacrum and ilium. The iliac cartilage is thin (0.5 mm), bluish, dull, and rough, compared to the sacral cartilage which is thick (3 mm), white, shiny, and smooth [262]. The iliac cartilage has the same relative thickness in both sexes, in contrast to the sacral cartilage which is thicker in women [266].

Women present with SIJ-related pain in the last trimester of pregnancy [267, 268], in response to an increase in relaxin that changes the stiffness of the elaborate ligament system and produces a hypermobile state in the joint itself [269, 270]. The ligamentous system of the SIJ enhances stability by increasing the friction in the SI joint and contributes to a self-locking mechanism [271–273]. In addition, the entire system offers proprioceptive feedback in response to activity due to a rich plexus of articular receptors.

The SIJ ligament system can be divided into four different layers, the most superficial layer being the thoracolumbar fascia to which numerous muscles attach and impose dynamic control, including the latissimus dorsi, gluteus maximus, transverse abdominis, and serratus posterior inferior [273]. The next layer associated with the SIJ includes the sacrospinous and the sacrotuberous ligaments that constrain sacral nutation (or anterior sacral rotation about its internal transverse axis of rotation at S2) and control movement of the pubic symphysis on the anterior aspect of the pelvic ring [274, 275].

The long dorsal SI ligament (also known as the longissimus ligament) courses from the posterior superior iliac spine to the inferior lateral sacrum outside the coccyx. This ligament is approximately 2 cm wide and 6 cm long. It is the only ligament that maximally tightens during counternutation, lending it to strain and other clinical symptoms during a woman's third trimester of pregnancy after the fetus descends [276]. The iliolumbar ligament constrains both SIJ movements and motion of the lower lumbar segments with respect to the sacrum [277, 278]. Along with the dorsal SIJ ligaments that are less developed in females [279], the self-locking mechanism is further enhanced through the constraints imposed by the deep interosseus ligaments, especially during nutation [271–273]. These ligaments are found to be thicker in females [279], and their stiffness decreases under the influence of hormonal changes in the final stages of pregnancy so that the birthing process can be enabled. Moreover, the SIJ tends to counter-nutate during these stages, where the sacral base tips posterior and opens the pelvic inlet for fetal decent. Counter-nutation reduces ligament constraint and promotes joint hypermobility that can contribute to postpartum pelvic pain [269, 280, 281], which can persist several years after birth [282].

1.3 Contemporary Understanding of the Issues

Sexual dimorphism in the human musculoskeletal system is apparent but more subtle than sex differences often observed in other species. Some musculoskeletal sex differences in humans are present at an early age, while others tend to appear later in life, especially at puberty and menopause. Sex variations in gross skeletal geometry and specific tissue characteristics are common. For example, women are generally shorter, have less body mass, and have a different general morphological appearance than men. Women tend to have different characteristics of specific bones and skeletal features than men, which have been explained by both genetic and environmental factors. In the pelvis, women tend to have a larger inlet and outlet, greater interacetabular distance, and greater hip width normalized to femur length. In the femur, women tend to have greater femoral anteversion and narrower intercondylar notch features. Additionally, there are several differences in specific characteristics of the femur, such as head diameter and circumference that are relatively strong predictors of sex. In the knee, tibia, and foot, women tend to exhibit greater genu recurvatum, greater quadriceps angle, more lateral patellar alignment, increased tibial torsion, greater tibial slope angles, and more bunions and deformities of lesser toes. Moreover, women and men appear to have several differences in collagenous components, cartilage, and bone tissues, which may predispose females to certain pathologies such as osteoarthritis and osteoporosis later in life. In other collagenous tissues, there are sex differences in collagen thickness, orientation, content, diameter, volume, and metabolism. In cartilage, women tend to have less volume, thickness, and surface area at specific sites. Additionally, prepubescent girls tend to have slower cartilage accrual rate, and postmenopausal women tend to have greater cartilage degradation than their male counterparts at either age, respectively. In bone tissue, women tend to have a slower accrual rate in youth, less peak bone mass, and slower bone turnover in adulthood as compared to men. Additionally, women tend to have decreased volumetric bone mineral density, smaller bone area, reduced cortical thickness, plus less

compressive and bending strength at some bony sites compared to men, even after correction for anthropometric differences such as height and weight.

Sexual dimorphism can manifest itself by specific differences in each joint system throughout the body, possibly resulting in variations of clinical pathology and symptomology. While differences in subacromial space have been attributed to sex-based variations of clinical impingement at the shoulder, the role of those differences remains controversial. More trustworthy are the female glenohumeral capsular responses that appear to contribute to sex-based differences in the incidence of joint laxity and/or idiopathic capsulitis. Hormonal variations appear to affect tissue changes related to the woman's higher incidence of tendinosis in the lateral elbow tendon structures, while the female predisposition for increased incidence of carpal tunnel syndrome seems to relate to differences in architectural shapes in the wrist and hand especially found around this tunnel. Similarly, architectural differences are at the root of female predilection for fracture responses at the hip joint, while tissue biomechanical variations accompany architectural distinctions in contributing to the female incidence of acetabular labral tears.

The woman's increased risk for anterior cruciate ligament injury has received special attention in the literature, which has suggested that several factors are responsible for this elevated incidence. Anatomical, hormonal/physiological, mechanical, and neuromuscular differences have all been examined, along with multiple mechanisms which have been proposed. While the femoral intercondylar notch size/shape has been suggested, its contribution remains controversial. Similarly, the role of static measures including Q-angle and thigh–foot angle has remained questionable, while differences in joint movement at both the knee and hip during cutting and landing have been deemed partially responsible for sex-based differences in ACL injury. Joint laxity and anterior tibial translation behaviors appear to contribute to this disparity, along with altered joint motion responses in the subtalar articulation. Moreover, locomotor control strategy differences are exhibited by female athletes, lending to their heightened predisposition toward ACL tears. Finally, the female's hormonal fluctuations affect not only changes in ACL architecture but also the biomechanical response of the ligamentous tissue to stress, along with neuromuscular control of the lower extremities.

Selected sex-based differences have been observed in the structural and mechanical features of the ankle and foot. These differences appear to contribute to the woman's increased risk for both ankle sprains and Achilles tendinopathy, especially in those who are athletically inclined. On the other hand, the role of cervical spinal architectural differences in female musculoskeletal health is unclear. However, the woman's cervical spine structures that include facets and intervertebral discs appear to respond more poorly to macrotrauma, such as neck "whiplash." Furthermore, the preadolescent female is more susceptible to developing thoracolumbar postural changes that include excessive kyphosis, lordosis, and/or scoliosis. These differences not only are influenced by physical differences in the vertebrae, articular structures, intervertebral discs, and/or attached musculature but are apparently influenced by psychomotor control and psychobehavioral variations as well. Finally, sacroiliac joint differences between men and women are influenced not only by architectural disparities but additionally by the influence that hormones have on integrity of the complex capsuloligamentous structures surrounding the articulation itself.

1.4 Future Directions

Sex differences in musculoskeletal anatomy are evident in gross body structure, regionally and at the tissue level. Much is known about sex-based variations in musculoskeletal anatomy and how these differences are manifested in functional and/or health-related disparities. However, a great deal of information still remains unknown. Future research should continue to investigate the relationships among structure, function, and health, especially in relation to sex-based differences. Specifically, the ways in which these variations influence the care that health professionals provide to each sex. A few specific recommendations for future directions include the need to better understand

- the influence of sex-based differences on scapular position at rest and during elevation with external impingement of the shoulder;
- the influence of sex variations on the relationship among glenohumeral structure, hypermobility, and pathology;
- the influence of pathoanatomical and pathophysiological mechanisms on sex-based differences in tendon pathologies such as tenosynovitis or tendinosis;
- the comorbid fracture risks associated with chronic bisphosphonate administration used for treating osteoporosis;
- the role and influence of sex-based differences in the development of hip neuromuscular control deficits in the development of knee disorders such as anterior knee pain syndrome and ACL injury; and
- the influence of sex-based differences on posture plus postural control in the development of low back pain and lumbar pathology.

1.5 Conclusion

There exists an abundance of literature that documents sex differences in general body characteristics, skeletal geometry, musculoskeletal tissue characteristics, and joint-specific functional anatomy and pathomechanics between males and females. While the musculoskeletal anatomy of men and women is grossly similar, important differences do exist that may influence the way in which the general public views and health care professionals respond to women's musculoskeletal health issues.

Review Questions

1. What may predispose women to OA earlier than men?
   (a) Differences in BMI
   (b) Differences in collagen
   (c) Differences in articular cartilage morphology
   (d) Differences in skeletal geometry
2. A decrease in what hormone leads to an increase in a woman's predisposition for lateral elbow tendinosis?
   (a) Progesterone
   (b) Estrogen
   (c) Testosterone
   (d) Relaxin
3. What are some factors that predispose women to fractures of the femoral neck (hip fracture)?
   (a) Less acetabular depth/femoral head width
   (b) Smaller coxadiaphyseal angle
   (c) Decreased femoral neck strength (lower cross-sectional area)
   (d) All of the above
4. An increased valgus motion in the frontal plane during a landing or cutting maneuver may predispose female athletes to what injury?
   (a) ACL tear
   (b) MCL tear
   (c) Patellofemoral subluxation
   (d) Knee dislocation
5. What are thought to be reasons for increased mobility in the sacroiliac joint of females?
   (a) Hormonal fluctuations with the onset of menses/pregnancy
   (b) Structural/anatomical changes with aging
   (c) Both a & b
   (d) No associated instability with the peri-menopausal period

Answers

1. c
2. b
3. d
4. a
5. c

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Body Image Throughout the Lifespan

2

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Learning Objectives

After completing this chapter, readers should be able to do the following:

- Define body image.
- Compare and contrast positive body image with body dissatisfaction and other body image concerns.
- Discuss risk factors that contribute to body dissatisfaction in females across the lifespan.
- Compare and contrast how body image concerns affect females throughout the lifespan.
- Examine theoretical foundations that can be applied to body image and eating disorder prevention interventions.
- Discuss various strategies that can be used in body image and eating disorder prevention interventions across the lifespan.
- Examine different assessment tools for the evaluation of body image with females across the lifespan.
- Discuss future directions for body image and eating disorder prevention research and practice.

2.1 Introduction

Body image is a dynamic, multidimensional, and highly complex construct [1–3] that can be defined in general terms as "the subjective evaluation of one's appearance" ([4] p. 4). Body image can include "experiences related to one's physical functional competencies and biological integrity (e.g., health, fitness, athletic skills, and coordination)" ([2] p. 34). In a broader sense, body image encompasses cognitive, perceptual, affective, and behavioral dimensions [2, 5]. Body image can also be considered both positive and negative, and a deficiency in one does not necessarily connote the presence of the other [6]. As Tylka ([6] p. 57) clarified: "Deconstructing negative body image, then, will not automatically construct positive body image. Accordingly, positive body image should not be characterized simply as the opposite pole of a 'single body image dimension' anchored at the other end by negative body image." Although positive and negative body images have historically been viewed as opposing concepts, more recent studies have revealed that there are different body image continuums (positive and negative) that concurrently exist [7–11]. Cultural influences, interpersonal relationships, physical characteristics and changes, and personality characteristics all interact in a dynamic way to contribute to body image development [2, 12].

Positive body image is conceptualized as multifaceted and holistic [9] and is integral to healthy development and wellness throughout the lifespan. Positive body image encompasses positive body esteem, mindful connection with the body's needs, and self-appreciation for body functionality and diverse appearances [9, 13–15] and may be considered a protective factor against body dissatisfaction. Body appreciation and positive embodiment are related concepts and considered key aspects of health and quality of life [16, 17]. Both body appreciation and positive embodiment focus on body integration through appreciating, feeling connected to, and caring for the body [17, 18]. Self-compassion is another associated concept that is expressed through self-kindness rather than self-criticism and accepting imperfection as part of being human [19]. A systematic review of 28 studies revealed that self-compassion was linked to lower levels of eating pathology and appeared to be protective against poor body image and eating pathology [20].

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In contrast, negative body image is conceptualized as poor body esteem, body dissatisfaction, and feelings of body shame, anxiety, and self-consciousness [21, 22]. Various terms have been used to depict body image concerns, including negative body image, body dissatisfaction, body dysphoria, body image distortion, and body image disturbance. Due to the complexity of the body image construct, researchers have typically focused on examining disturbances within the cognitive–affective (evaluative) and perceptual components of body image. A disruption within the evaluative component is usually represented as body dissatisfaction [23], which refers to a person's negative self-evaluation of his or her body weight, size, and shape that can lead to cognitive, psychological, affective, and behavioral disturbances [24, 25]. Body dissatisfaction can also be defined by the difference between one's perceived body size and ideal body size. In contrast, a disturbance within the perceptual component is usually referred to as body image distortion, which involves a person's inability to accurately perceive body size and shape [26] and is a symptom of eating disorders such as anorexia nervosa and bulimia nervosa [27].

It is widely recognized that body dissatisfaction is ubiquitous among girls and women, particularly with regard to the desire to be thin. In fact, body dissatisfaction has become so commonplace that it has been described as "normative discontent" [28]. Body dissatisfaction is a predictor of depression [29–32] and considered one of the most robust risk and maintenance factors for disordered eating and clinical eating disorders [27, 29, 33–39]. Body image and eating disturbances have also been linked to other psychological problems, including depressive mood and low self-esteem [29, 31, 37, 40, 41] as well as anxiety [40], body dysmorphic disorder [42], self-harm and childhood sexual abuse [43], and social phobia [40, 44]. Negative body image is also linked to physical disability [10, 45] and low levels of functionality and wellness [46, 47]. Overall, body image and eating problems hinder healthy development and adversely impact health, wellness, and quality of life.

Due to the persistent rise of eating disorders and obesity, researchers continue to investigate body image and body image difficulties among diverse females with various social identities, including those from different ethnic and cultural groups, older women, females living with chronic illness or disability, and females representing other special populations who may be at risk [8, 10, 21, 30, 48–62]. In sum, negative body image and body image disturbances know no boundaries; they impact females across age groups, ethnicities, cultures, and backgrounds. It is essential for health education specialists and health care clinicians to understand body image across the lifespan, including the etiology and development of body image problems. It is also important for health professionals to be familiar with body image assessment techniques as well as evidence-based prevention strategies and interventions that promote positive body image. Furthermore, health professionals can reflect about their own perceptions of body image and eating concerns and how these perceptions may influence their own attitudes and behaviors as well as their interpersonal interactions with clients and patients.

2.2 Research Findings

2.2.1 Risk Factors for the Development of Body Dissatisfaction

A wide range of risk factors contribute to the development of body dissatisfaction, including biological and physical factors, individual characteristics, and sociocultural influences [2, 63, 64]. For example, females with a higher body mass index (BMI) that is not in line with societal expectations of a thin-ideal body type—the thin ideal—can experience body dissatisfaction [30, 65–69]. Other ideal body types can also influence how females view their bodies, including the athletic and curvy ideals [70–72]. Individual characteristics such as low self-esteem, negative emotionality, and perfectionism are additional influencing factors [2, 68]. Furthermore, sociocultural factors such as ubiquitous media influences exert a powerful influence on body image by promoting the thin-ideal. Propensity to internalize the thin ideal and engage in high levels of appearance comparisons (or social comparisons) often leads to harmful effects such as body dissatisfaction, self-objectification, and disordered eating [56, 67, 73–79]. Media-internalization is critical to the development of body dissatisfaction, both directly and indirectly [74, 75, 80]. For example, research has shown that "media-internalization precedes and predicts social appearance comparison, which in turn predicts body dissatisfaction" ([75] p. 710).

In addition, females from multiple ethnic and cultural groups can experience an internal tug-of-war regarding their body image and sense of self-worth, particularly when they are acculturated or exposed to Western or Western-influenced cultures that promote the thin ideal [56, 60, 81–83]. Some studies have indicated that there are often more similarities than differences between White females and ethnic minorities regarding body dissatisfaction [60, 84]. Cheng et al. [60] found that African Americans are at similar risk for eating disorders as Whites. The same study also suggested that ethnic minority identity and culture may protect Hispanic females from thin-ideal internalization, body dissatisfaction, and disordered eating behaviors. Still, the relationships among ethnicity, acculturation, and body satisfaction are not clear [60, 85–88]. While Cheng et al. [60] found that Asian American females experience greater thin-ideal internalization than White and African American females, Chen and

Jackson [67] suggested that body dissatisfaction may be less prominent among Chinese adolescent females compared to their U.S. counterparts. In another study involving a large, population-based sample of adolescents [84], body dissatisfaction and self-esteem were strongly related in both boys and girls across almost every weight status, racial/ethnic, and socioeconomic status (SES) group. Nevertheless, there were some differences across race/ethnicity and SES. For example, Black girls had higher self-esteem and lower body dissatisfaction than many other groups. In addition, Asian girls had a weaker relationship between body satisfaction and self-esteem compared to White girls; however, they experienced lower self-esteem and higher body dissatisfaction than many other racial/ethnic groups.

2.2.1.1 Theoretical Perspectives

In viewing body dissatisfaction from a theoretical perspective, the tripartite influence model of body image and eating disturbance [5, 40, 75, 89–93] and the dual pathway model of eating pathology [34, 37, 94–96] have received solid empirical support. The tripartite influence model [92] (see Fig. 2.1) posits that three major sociocultural influences—peers, parents, and media—play a role in the development of body dissatisfaction, eating disorders, and negative affect. The model also proposes that internalization of the thin ideal and appearance comparison mediate the relationships between these influences and body image and eating concerns [91, 92]. The dual pathway model of eating pathology [95] (see Fig. 2.2) posits that thin-ideal internalization and social pressure to be thin (from family, peers, and media) both contribute to body dissatisfaction leading to dieting and negative affect, thereby increasing the risk for eating disorders [34, 37, 94–96]. Both models have been used with diverse cultural samples and appear to be viable models for studying risk factors leading to body dissatisfaction and eating disorders [34, 37, 40, 75, 91–96].

2.2.2 Body Image Concerns Across Age Groups

2.2.2.1 Preadolescent and Adolescent Females

Body image difficulties often begin at an early age as body dissatisfaction has been shown to affect approximately 40% of children aged 6 to 11 [97]. Approximately 50% of preadolescent girls experience body dissatisfaction with a majority of these girls wanting to be thinner [98, 99]. Psychological processes related to body dissatisfaction are already established by the age of 8 [100, 101], and the "normative discontent" with body shape and size that is so common among adolescent females and young adult women is applicable to young girls as well [102–104]. For example, studies have shown that girls as young as 5–8 years old can experience a greater awareness and internalization of the thin ideal in ways that negatively impact their body image development and self-esteem [36, 105]. Research involving girls aged 7–11 years (N = 127) also revealed that thin-ideal internalization predicted disordered eating attitudes [74]. Additionally, a longitudinal population-based study revealed that 63.2% of girls expressed concern about gaining weight by age 13 [106]. In another study involving 1515 preadolescent children (51.2% girls), a majority of the girls wanted a thinner body shape [98]. Other research revealed that a sizable percentage of preadolescents experienced body dissatisfaction [104], and body dissatisfaction in young adolescents developed concurrently with eating disorder symptoms rather than preceding them [107].

Research also suggests that parental communication and modeling can influence body image and eating concerns in young girls. One study showed that girls whose parents encouraged them to diet prior to age of 11 were eight times more likely to report early dieting than girls whose parents did not promote dieting [108]. In another study, Rodgers et al. [109] found that mothers' comments about their child's

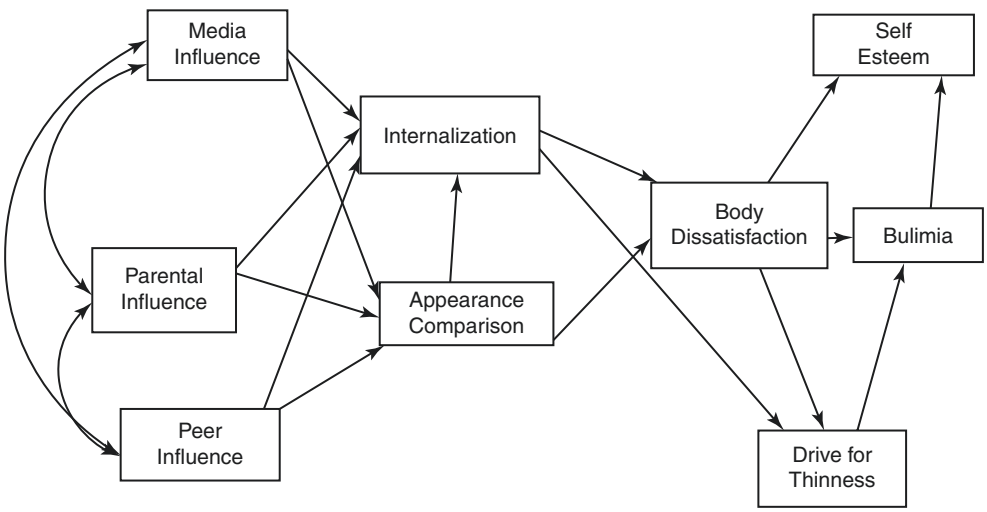

Fig. 2.1 The theoretical tripartite model [92]. Reprinted from Body Image, Vol. 8/Issue 3, Rodgers R, Chabrol H, Paxton SJ. An exploration of the tripartite influence model of body dissatisfaction and disordered eating among Australian and French college women, pages 208–215, 2011, with permission from Elsevier

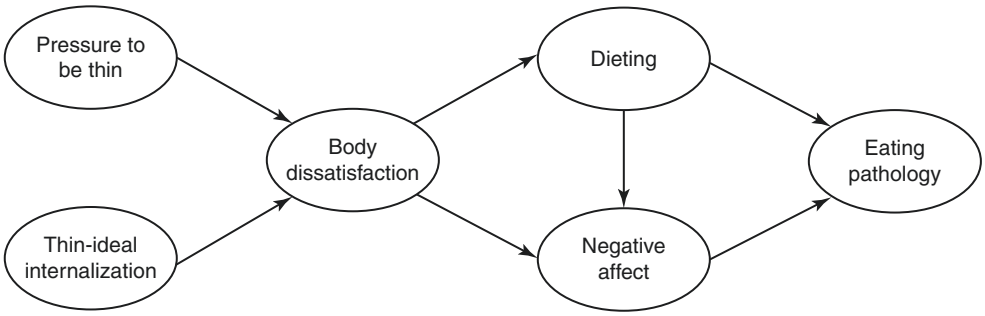

Fig. 2.2 Theoretical components of the dual-pathway model of eating pathology [96]. Reprinted with permission from Stice E, Rohde P, Shaw H. The body project: A dissonance-based eating disorder prevention intervention. 2013; New York: Oxford University Press. p. 16

weight, shape, and eating were associated with body image concerns and disordered eating in girls and boys as young as 7 and 8 years old. Maternal body dissatisfaction also predicted lower body esteem in both girls and boys, which is consistent with studies involving adolescents [110, 111].

Adolescence is another critical transitional period of significant growth and development [112] that is marked by the key developmental task of identity establishment [113]. Body image is a central focus of self-concept during the teen years [114], and adolescent females are particularly vulnerable to body dissatisfaction and eating difficulties [115]. Negative body image spikes during early adolescence and is often maintained throughout adolescence and emerging adulthood [21]. Findings from a study by Wojtowicz and von Ranson [68] suggested that self-esteem and BMI are pertinent factors to help identify middle-adolescent girls who may be at risk for experiencing increased body dissatisfaction. In addition, negative body image that persists over time can also lead to depressed mood in both adolescent girls and boys [41, 116]. In attempting to cope with negative affect, adolescents are at risk of engaging in unhealthy behaviors such as restrictive dieting, over-exercise, substance use, and excessive tanning [114]. In turn, these factors can initiate a vicious cycle of health-risk behaviors that can negatively impact body image.

Sociocultural factors are predominant influences during preadolescence and adolescence, and the peer group is a key sociocultural influence in the development of body image concerns [117, 118]. Young females are constantly exposed to sociocultural messages promoting the thin ideal; and these age groups are particularly vulnerable to experiencing body dissatisfaction in response to internalization of the thin ideal promoted through a variety of media channels, including social media platforms [105, 117–120].

According to a recent Pew Research Center Report [121], 95% of teens have a smartphone or access to one; and 45% of teens report they are online most of the time. The majority of this online activity revolves around social media networks; and the most prolific social media networks among teens are Snapchat and Instagram [121], with TikTok rising in popularity. With nearly constant access to mobile devices along with concomitant images and messages, preadolescent and adolescent females are highly susceptible to engaging in appearance comparisons. Body talk or appearance-focused conversation has been defined as "interpersonal interactions that focus attention on bodies and physical appearance, reinforce the value and importance of appearance, and promote the construction of appearance ideals" ([122] p. 2). Appearance comparisons are linked with body dissatisfaction, and body talk on social network sites has shown to be positively associated with body surveillance and body shame [122]. Studies have also shown that more time on social network sites is positively related to higher thin-ideal internalization, body surveillance, and drive for thinness [105, 114, 123]. In one study, adolescents with frequent (>2 h per day) engagement with highly visual social media (e.g., Instagram and Snapchat) reported high levels of body image concerns and internalizing symptoms such as depression and anxiety. In the same study, body image concerns mediated the positive relationship between highly visual social media use and internalizing symptoms [114]. In addition, vulnerability to media influence is mediated/moderated by individual factors such as self-esteem, personality traits, and investment in body image and social comparisons [84, 123–127]. These findings support an array of research indicating that frequent social media use may negatively impact body image and mental health [53, 119, 120, 123, 128–130].

In sum, body dissatisfaction that begins at a young age often extends through puberty into adolescence and young adulthood [21, 115, 131]. Although levels of body dissatisfaction vary among girls, various factors help predict these trajectories, including individual characteristics of BMI, self-esteem, and perfectionism as well as environmental influences such as parental communication and modeling, peer dieting, appearance comparisons, and weight teasing. Overall, it appears that body dissatisfaction takes root in early adolescence, indicating that childhood and early adolescence may be crucial periods for shaping body image [21, 53, 109, 115]. Therefore, focusing on body dissatisfaction during childhood or early adolescence may reduce the development of eating disorder behaviors in adolescence and into emerging adulthood [21, 74, 104, 107, 115, 132, 133]. According to Wang et al. ([115] p. 1411), strategies and interventions "aimed at enhancing self-esteem, decreasing

depression, increasing parent/child connectedness, and reducing and responding effectively to weight-based teasing and peer dieting may be particularly influential in altering body dissatisfaction over time."

2.2.2.2 Young Adult Women

Body image, body weight, and eating concerns are prevalent among college-aged females as well. According to the American College Health Association National College Health Assessment (ACHA-NCHA II) [134], 59% of college women are trying to lose weight, 57% are exercising to lose weight, and 44% are dieting to lose weight. Other studies have also demonstrated that college-aged females struggle with body dissatisfaction as well as disordered eating [94, 96, 135, 136]. Multiple factors influence body image and eating concerns in young women, including sociocultural pressures surrounding the thin ideal, copious social media usage, and negative self-talk.

There is support for the sociocultural model as it relates to body image and eating disorders among college-aged women [92]. Sociocultural pressures aimed at the thin ideal exert the most negative impact on young women when they are internalized [137]. To explicate how internalization of the thin ideal may lead to body dissatisfaction, Fitzsimmons-Craft et al. ([137] p. 48) found that social comparison and body surveillance mediated the relationship between thin-ideal internalization and body dissatisfaction among college-aged females. Yet, "only body surveillance emerged as a significant specific mediator of this relation—that is, neither general social comparison tendencies nor appearance-related social comparison tendencies emerged as specific mediators." In a different study [40], the combination of media influence and social phobia emerged as a significant predictor of body dissatisfaction in college-aged females.

Approximately 84% of young adults (aged 18–29) actively use social media [138], and studies demonstrating a relationship between social media and body image concerns are vast. Social media use has a demonstrated effect on appearance concerns. Researchers found that participants who took and uploaded a selfie on social media without the options of editing, applying a filter, or taking multiple photos felt more anxious, less confident, and less physically attractive afterward; and these differences were significantly greater than the control condition (i.e., reading a neutral news article online) [139]. In addition, engagement with appearance-based social media has been determined to increase body dissatisfaction, negative mood, and social comparison among young women [72, 78, 140–143]. Hogue and Mills [143] argued that young women's increasing struggle with appearance satisfaction can be explained by upward social comparisons that result from engaging with appearance-based social media. Their study showed that women are more likely to compare themselves to peers and celebrities they consider superiorly attractive, which increases negative body image. Social media has also propelled an exercise culture driven by a desire for an ideal fit appearance rather than a desire to be healthy [72]. Even though fitness posts are often promoting strong bodies instead of thin ones, these photos are idealized and often unrealistic, causing young women to "invest in their body as a self-worth index and place importance on their appearance" ([123] p. 11). Therefore, it is no surprise that studies have validated an existing relationship between appearance-motivated exercise and negative body image, further illustrating that young women's body satisfaction suffers when they internalize sociocultural pressures surrounding the thin ideal [144].

Furthermore, a related aspect of body image centers on "fat talk," which is a term for how females talk with each other about the size and shape of their bodies, generally in disparaging terms [145]. Although females of all ages engage in fat talk, research indicates that these conversations occur most frequently during late adolescence and young adulthood [146]. Young women have indicated that engaging in fat talk acts as a type of coping mechanism because it helps them express distress about "feeling" fat as opposed to "being" fat ([147] p. 27). However, engaging in fat talk may actually be maladaptive because this type of talk is linked with thin-ideal internalization, body dissatisfaction, negative affect, depression, anxiety, body image disturbance, and eating pathology [147, 148]. In addition, research has demonstrated that body dissatisfaction significantly mediates relationships between weight discrepancy, upward appearance comparison, body surveillance, and fat talk [149]. As fat talk is a frequently occurring sociocultural phenomenon among females, more studies are needed to examine strategies that females can implement to successfully navigate through these conversations. For example, one proposed strategy is to help females interrupt the fat talk cycle by using socially acceptable, positive body talk [150].

Female athletes represent a subgroup of young women who are at particular risk for experiencing body image and eating concerns. Collegiate and elite athletes, particularly those participating in "weight-sensitive sports," such as gymnastics, dance, swimming and diving, track/cross-country, are at risk for thin-ideal idealization, body dissatisfaction, and disordered eating that are distinctive from non-athletes [151–154]. Females athletes who struggle with issues related to body dissatisfaction and disordered eating are also faced with concomitant pressure to remain competitive in their sport, which can exacerbate physical and emotional stress [151, 152. 155, 156]. In 2005, the International Olympic Committee (IOC) [157] addressed these concerns by recognizing the Female Athlete Triad (Triad) as the interaction among disordered eating and irregular menstrual cycles that leads to a reduction in estrogen and other key hormones,

resulting in low bone mineral density. Based on this work, the American College of Sports Medicine [158] clarified the Triad as the interrelationships among energy availability, menstrual function, and bone health that can exhibit clinical consequences via eating disorders, amenorrhea, and osteoporosis. Then in 2014, the IOC released a consensus statement redefining the Triad. Now recognized as Relative Energy Deficiency in Sport (RED-S), the IOC ([155] p. 1) defined the syndrome as "...impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, [and] cardiovascular health caused by relative energy deficiency." In a 2018 updated report, the IOC RED-S Consensus Statement authors highlighted multiple scientific developments that shed further light on the negative health and performance outcomes associated with low energy availability in both female and male athletes [156].

Female athletes who participate in sports that emphasize leanness and/or weight appear to be most at-risk for developing RED-S, which can consequently jeopardize their performance abilities and health. Furthermore, interpersonal relationships with teammates, athletic trainers, and coaches can exert influence on female athletes' body image. For example, research has shown that coaches and teammates can positively or negatively affect athletes' body image and health behaviors, including those related to eating and body weight [153, 154, 159]. Notwithstanding, knowledge and awareness of the prevention of RED-S appear to be lacking among athletes and their support staff, including coaches, athletic trainers, and physicians [156]. Therefore, there is a clear need to examine the roles of coaches, teammates, athletic trainers, and sports medicine clinicians in preventing body dissatisfaction and RED-S among female athletes. This line of research can also investigate relationships between coach communication and self-esteem, body image, and thin-ideal internalization, and whether coach communication is mediated by these and other factors [153, 154].

2.2.2.3 Older Women

Similar to younger females, body image in older women is multifaceted and varies among women [160, 161]. However, there are distinct differences. Although more attention has been devoted to studying body image in middle-aged and older women in recent years, findings are mixed regarding the relationship between aging and body image [160–162]. In a scoping review of literature Pearce, Thogerson-Ntoumani, and Duda [163] found that women often simultaneously experience positive and negative body image; and the relationship between aging and body image is complex. Body satisfaction can increase even when women's body dissatisfaction remains stable [9].

Many correlates and risk factors associated with body dissatisfaction and disordered eating that are found in younger females have also been found in older women, such as BMI, sociocultural influences, and internalization of the thin ideal. In a systematic review, Bouzas et al. [164] found that low physical activity, high caloric intake, or a significant reduction in caloric intake are associated with body dissatisfaction in women aged 55 and older. Other factors can also present unique body image challenges to older women, including menopause and anxiety related to the aging process [23, 161]. Women in midlife and beyond may face similar eating- and weight-related obstacles as younger girls and women, including body dissatisfaction and body image distortions; and these issues are often intensified by the aging process. For example, life events that often take place in midlife, such as career changes, marital problems, divorce, "empty-nest" syndrome, and chronic illness, can create significantly more distress for women who are already struggling with body image and eating difficulties [163].

There also has been a 42% increase in the number of women over the age of 35 seeking eating disorder treatment within the past 10 years, indicating an increase of body image and disordered eating struggles in this population [165]. In a large Internet survey study of women aged 50 and older, 13% of the sample reported current eating disorder symptomatology. In addition, over 70% of the participants reported experiencing body dissatisfaction, with a large percentage (83.9%) expressing dissatisfaction with the stomach. Researchers also found that higher BMI was associated with higher rates of diet pill/diuretic use, both of which are considered maladaptive weight management behaviors and have been reported in other studies [166]. However, regardless of BMI, excessive concern with body shape and weight and body dissatisfaction can negatively impact women's self-esteem and overall quality of life, and even lead to full-blown clinical eating disorders [166].

In spite of these challenges and risk factors, Liechty's ([160] p. 84) qualitative study of older women revealed "complex cognitive and behavioral means by which older women were able to feel satisfaction with their bodies despite desire for physical change." Participants conveyed that health and functionality were more important to their body image than their physical appearance. Those with positive body image focused on controllable elements of their physical appearance (e.g., clothing) and had developed at least some degree of acceptance of their physical imperfections. Conversely, participants who highly valued youthfulness and conforming to society's thin ideal experienced increasing body dissatisfaction as they aged. According to McLean et al. [167], appearance acceptance and placing less emphasis on the appearance aspect of self-concept may serve as protective factors that buffer aging women from the negative impact of body dissatisfaction. In addition, Liechty and Yarnal ([162] p. 1213, 1215) found that women's body image exhibited both stable and fluctuating patterns throughout the

lifespan. The participants' thoughts about body image went beyond "level of satisfaction" and "included evaluations of health and ability, beliefs about the importance of appearance, and feelings about their overall lives."

2.2.3 Body Image Assessment

Due to the multidimensionality of the body image construct and the wide availability of various instruments, it is particularly important to carefully consider the selection of body image assessment tools as there is no particular instrument or battery of tests that is appropriate for use in all situations [168, 169]. Thompson [169] outlined ten tips for enhancing body image assessment in clinical and research settings, including the importance of selecting instruments with established reliability and validity and using selected instruments with appropriate target populations. In addition, Banasiak et al. [170] pointed out that many instruments used to assess body image concerns in adolescents have been validated using adult samples. Nevertheless, many of these measures can still be used with adolescent females when care is taken to ensure that girls understand the terms used in the particular instrument. For example, the Physical Appearance State and Trait Anxiety Scale [171] was validated with an adult sample yet exhibited excellent internal reliability (0.93) in measuring weight-related body dissatisfaction in adolescent girls aged 14–16 [172]. In the same study [172], researchers measured appearance dissatisfaction with an adapted version of the Body Image State Scale, a six-item scale that has good construct validity [173] and demonstrated high internal reliability with an adolescent sample in a previous study [174]. As illustrated in these examples, researchers must establish new reliability and validity scores whenever they use an instrument with a target population that differs from the standardized sample [169]. In addition, researchers have acknowledged the need to develop valid and reliable instrumentation for studying body image in diverse female populations, including younger girls [175], older women [48, 160], and females from diverse ethnic and cultural backgrounds [59, 86, 92, 160, 176].

2.2.3.1 Body Image Assessment Scales and Questionnaires

There are a number of well-validated instruments that have been developed to assess body image and eating concerns in children, adolescents, and adults; many of these measures are discussed in more detail elsewhere [5, 168, 176–180]. Table 2.1 lists a few of the body image measures that have been reported in the research literature with an internal consistency rating and test–retest reliability rating of at least 0.70 [171, 173, 181–190].

Table 2.1 Instruments for assessing body image with high internal consistency and/or test–retest coefficients (>0.70)

Author	Test name	Description of test	Reliability IC: Internal consistency TR: Test–retest	Standardization sample
Cash and Fleming [181]	Body Image Quality of Life Inventory	A 19-item instrument designed to quantify the impact of body image on aspects of one's life Participants rate the impact of their own body image on each of the 19 areas using a 7-point bipolar scale from −3 to +3	IC: 0. 95 TR: 0.79	116 college-aged women (M = 21.3 ± 5.1)
Cash et al. [173]	Body Image States Scale	A multi-item measure of momentary evaluative/affective experiences of one's physical appearance	IC: 0.77 (women) IC: 0.72 (men) TR-state: 0.69 (women)[a] TR-state: 0.68 (men)[a]	174 college students—116 women, 58 men (median age = 20)
Cash and Szymanski [182]	Body-Image Ideals Questionnaire	A measurement of self-perceived discrepancies from and importance of internalized ideals for multiple physical characteristics	IC: BIQ discrepancy: 0.75 IC-BIQ importance: 0.82 IC-weighted discrepancy: 0.77 TR: none given	284 college undergraduate women at a mid-Atlantic urban university

(continued)

Table 2.1 (continued)

Author	Test name	Description of test	Reliability IC: Internal consistency TR: Test–retest	Standardization sample
Garner [183]; Garner and Olmstead [184]	Eating Disorder Inventory (EDI and EDI-2). Body Dissatisfaction Scale	9-item subscale assesses feelings about satisfaction with body size; items are 6-point, forced choice; reading level is fifth grade	IC: Adolescents (11–18): Females = 0.91 Males = 0.86 Children (8–10): Females = 0.84 TR: None given	610 males and females ages 11–18 (Shore and Porter, 1990) [185] 109 males and females ages 8–10 (Wood et al., 1996) [186]
Littleton et al. [187]	Body Image Concern Inventory	A *brief* instrument for assessing dysmorphic concern; only takes a few minutes to answer. Despite its brevity, the BICI provides an assessment of body dissatisfaction, checking and camouflaging behavior, and interference due to symptoms—such as discomfort with and avoidance of social activities (see Appendix 2)	IC: 0.93 TR: None given	184 undergraduates at a medium-sized Southeastern University; approximately 89% were women
Reed et al. [171]	Physical Appearance State and Trait Anxiety Scale	Participants rate the anxiety associated with 16 body sites (8 weight relevant, 8 non-relevant); trait and state versions available	IC: Trait: 0.88–0.82 State: 0.82–0.92 TR: 2 weeks, 0.87	205 female undergraduate students
Shisslack et al. [188]	McKnight Risk Factor Survey III (MFRS-III)	Participants use 5-item subscale that assesses concern with body weight and shape	IC: Elementary = 0.82 Middle school = 0.86 High school = 0.87 TR: Elementary = 0.79 Middle school = 0.84 High school = 0.90	103 females, 4–fifth grade; 420 females, 6–eighth grade; 66 females, 9–12th grade
Wooley and Roll [189]	Color-A-Person Body Dissatisfaction Test	Participants use five colors to indicate level of satisfaction with body sites by masking on a schematic figure	IC: 0.74–0.85 TR: 2 weeks (0.72–0.84) 4 weeks (0.75–0.89)	102 male and female college students, 103 bulimic individuals
Mutale et al. [190]	Body Dissatisfaction Scale	A pictorial scale used to measure body dissatisfaction. Includes 9-female and 9-male images that are computer generated to construct bodies of varying sizes. Participants place body types in descending order based on size, select the most desirable body size (ideal), and choose their perceived size (actual). The discrepancy between one's ideal and actual body size indicates their body dissatisfaction score	IC: TR: 5 weeks, 0.88–0.97	190 male and female undergraduate students

[a] Acceptable for a *state* assessment

In addition, examples of body image questionnaires that have been validated for college-aged women and have internal consistency and test–retest reliability scores above 0.70 are located in Appendices 2.1–2.3: Body Image Quality of Life Inventory [181], Body Image Concern Inventory [187], and Physical Appearance State and Trait Anxiety Scale [171]. In addition, Cash and Grasso [191] reported the normative data and acceptable internal reliability measures of four body image instruments—Body Image Disturbance Questionnaire [192], Appearance Schemas Inventory-Revised [193], Body Image Coping Strategies Inventory [194], and Body Image Quality of Life Inventory [181, 195]. These instruments measure various facets of the body image construct and were used across seven studies with female and male college students. Other valid and reliable scales that can be used in body image research include Body Image Assessment Scale-Body Dimensions [196]; Body Shape Questionnaire [197], which has a shortened version [198] and is available in different languages [199]; Eating Disorder Inventory-3 [200], which contains the Drive for Thinness and the Body Dissatisfaction subscales; the Sociocultural Attitudes Towards Appearance Scale-3 for measuring

multiple societal influences on body image and eating disturbances [201]; and Children's Body Image Scale [97, 202–203]. Researchers have also explored using realistic 3-dimensional body-scan images for body image research and found that the scanned images are a viable alternative to contour line drawings [204]. Innovative tools for investigating changes in adolescent body perception have also been developed, such as the Adolescent Body-Shape Database and Adolescent Body Morphing Tool [205].

2.3 Contemporary Understanding of the Issues

2.3.1 Theoretical Foundations

Body image and eating disorder prevention programs focus on preventing or delaying the onset of subclinical and full-blown clinical eating disorders by reducing risk factors and increasing protective factors that promote resilience and overall health and well-being [206–209]. Health education and health behavior theories and models can guide the development and evaluation of health promotion and education programs and interventions [210–211]. For example, the ecological model can be effective for prevention programs aimed at promoting positive body image and decreasing eating disorder risk [212, 213]. The underlying premise of the ecological model is that there are multiple levels of influences on health attitudes and behaviors, including intrapersonal (biological, psychological), interpersonal (social, cultural), institutional and organizational, community, physical environmental, and public policy. The ecological model forms a type of meta-model in which other health behavior theories and models are integrated into a broader, coherent whole. As a meta-model, "ecological models are a useful [comprehensive] framework for conceptualizing multiple levels of determinants of health behaviors, and they are used widely as guides for the design of comprehensive multilevel interventions" ([213] p. 47). For example, healthy body image can be promoted through targeting individual attitudes, knowledge, beliefs, and behaviors (intrapersonal); involving family, peers, and other supportive individuals (e.g., teachers and coaches) in reinforcing positive body image in concert with healthy and balanced nutrition and physical activity (interpersonal, environmental); integrating healthy body image, nutrition, physical activity, and mind–body wellness interventions into school and worksite health programs (organizational, environmental); advocating for health education/promotion and health communication campaigns with messages that promote healthy body image (community); and enacting legislation to support body image and eating disorder prevention programs and research (policy).

Additional theoretical frameworks that can be used to guide body image interventions include social cognitive theory (SCT) [214] and social marketing [215, 216]. The hallmark of SCT is reciprocal determinism, which is the dynamic interaction of individuals and groups, their behavior, and the environment. Other SCT concepts relevant to the promotion of positive body image include outcome expectations (beliefs about the likelihood and value of the consequences associated with behavioral choices), self-efficacy (beliefs about one's ability to successfully engage in positive behavior change), observational learning (learning to perform new behaviors by observing others, e.g., via peer modeling), facilitation (providing tools and resources or modifying the environment to facilitate behavior change), and self-regulation (controlling oneself through self-monitoring, goal setting, self-reward, and social support) [217]. School- and community-based body image interventions can reinforce key SCT concepts by emphasizing personal and group goal setting, teaching media-literacy skills, encouraging healthy peer group interaction, providing regular opportunities to practice decision-making and problem-solving skills linked to real-life body image issues, and incorporating meaningful family involvement activities.

Healthy body image can also be fostered through social marketing, which is designed to influence voluntary behavior change that can positively impact health and quality of life at the intrapersonal, interpersonal, organizational, community, and public policy levels, thereby contributing to an ecological approach to promote positive body image and mitigate eating problems. Social marketing includes communication that focuses on the four "Ps" of the marketing mix: product, price, place, and promotion [216]. Effective social marketing campaigns should promote a "superior offer" ([218], slide 10) and consider appropriate segmentation of their target audience (e.g., using demographic, psychological, and behavioral variables) [219]. For example, with positive body image as the *product*, health professionals can develop messages and slogans in conjunction with the use of diverse body images to promote positive body image and emphasize the benefits of healthy body image while identifying the negative costs associated with body dissatisfaction. These messages can influence females' perceptions of the cost–benefit ratio associated with adopting and maintaining attitudes and behaviors reflecting positive body image, sound nutrition, and healthy physical activity (*price*). Health professionals can also increase access to quality information about body image through various *places*, such as schools and other education centers, medical offices, health clinics, community centers, churches and other places of worship, hair and nail salons, Internet ads, and social media outlets. *Promotion* of healthy body image can occur by making incentives accessible to the target audience,

including popular items such as T-shirts and water bottles, sling bags, posters, social media contests, and games.

With a consumer focus in mind, targeting social norms and normative beliefs has proven to be another successful social marketing strategy. A person's normative beliefs include "whether important referent individuals approve or disapprove of performing the behavior, weighted by the person's motivation to comply with those referents" ([220] p. 97). Therefore, because perception is paramount, social marketing can be used to target social norms and promote shifts in normative beliefs. Social marketing campaigns can promote shifts in normative beliefs by informing females about the actual frequency of certain attitudes and behaviors linked with body image dissatisfaction (e.g., dieting among peers, unrealistic expectations for body type, internalizing the thin ideal, use of "fat talk"), with the intent to create social pressure for change. Additionally, as "positive body image is more than... the mere absence of body dissatisfaction" ([53] p. 624), health professionals can also implement programs to promote a new social norm [221] emphasizing attitudes and behaviors that support a healthy body image. Campaign messages can be geared towards encouraging females to "appreciate the unique beauty of their body and the functions that it performs for them; accept and even admire their body, including those aspects that are inconsistent with idealized images; feel beautiful, comfortable, confident, and happy with their body … [and] emphasize their body's assets rather than dwell on their imperfections" ([15] p. 22). These messages should be followed by positive reinforcement at different levels of influence within the ecological framework (e.g., social support from family and peers, "body image friendly" messages and environments that facilitate the development of positive body image). For additional discussions involving theoretical approaches and prevention programs aimed at promoting healthy body image and preventing disordered eating, see Bauer et al. [222], Levine and Smolak [211], Massey-Stokes et al. [208], and Sinton and Taylor [207].

2.3.2 Body Image Intervention Strategies

2.3.2.1 Socioecological Framework

In line with the socioecological framework and environmental factors within SCT, it is beneficial for health professionals to implement body image and eating disorder prevention strategies to address multiple levels of influence [208, 223], including the individual, family and peers, institutions (e.g., schools, universities, and worksites), the broader community (e.g., multimedia messaging and advocacy), and policy. Tailoring interventions to meet the interests and needs of the priority audience increases the relevance for program participants and has the potential to promote sustainable changes in mindsets and behaviors. At the intrapersonal level, it is crucial to help females of all ages and backgrounds cultivate positive body image, which includes an integrated sense of self [39] and appreciation for one's authentic and functional self [224–226]. Autonomous motivation and a sense of competence help comprise an integrated sense of self and can lead to healthy behaviors [39]. In addition, high, general self-determination (a strong sense of self that is "integrated, unified, and non-contingent") can buffer females from having an adverse response to the thin ideal portrayed through the media ([227] p. 490). Furthermore, autonomous motivation, self-determination, positive sense of self, and perceived self-competence are related to the concept of presence, which Cuddy ([228], p. 24) portrayed as "the state of being attuned to and able to comfortably express our true thoughts, feelings, values, and potential." When females are present, they are able to access their authentic best selves [228], which can lead to greater self-acceptance and resilience in the face of challenges. Resilience development is a related approach that allows girls and women to acknowledge their areas of challenge and vulnerability while embracing their strengths and areas of competence [229]. Resilience can be fostered by helping females develop healthy self-esteem, self-determination, self-efficacy, and an array of essential life skills, including interpersonal, communication, critical-thinking, and adaptive coping skills. Adaptive coping includes skill development for recognizing and effectively managing sociocultural pressures espousing the thin ideal. All of these intrapersonal strengths can help buffer females against body dissatisfaction and promote body image.

Due to the longitudinal "reciprocal relationships" that exists among the mediational variables of media-internalization, appearance comparison, and body dissatisfaction, it is important to address all three of these concerns through well-designed strategies and programs aimed to enhance body image at multiple levels of influence [75, 79, 90–94]. For example, Happy Being Me [64] is a theory- and school-based body image intervention for young adolescent girls that targets internalization of the thin ideal, body comparison, appearance conversations, appearance teasing, body image, and self-esteem. The brief, interactive program also aims to teach girls how to effectively contend with sociocultural factors that can threaten self-esteem and body image. Evaluation results demonstrated that the intervention group reported significantly more positive outcomes than the control group concerning program content knowledge, risk factors for body dissatisfaction, body image, and dietary restraint and self-esteem. The positive results were sustained at 3-month follow-up, and qualitative results indicated that the majority of program participants agreed or strongly agreed that they enjoyed the program [64]. In another study, Bird et al. [230] examined the effects of Happy Being Me among a population of UK preadolescents. Results for the

girls showed significant improvements in body satisfaction, appearance-related conversations, appearance comparisons, eating behaviors, and content knowledge. There was also a significant decrease in thin-ideal internalization from baseline to follow-up. However, body satisfaction was the only improvement sustained at follow-up [230].

Promoting body functionality is an additional approach for combating the adverse effects of thin-ideal media images on body image [231]. Research has shown that educating females to concentrate on and appreciate the *functionality* of their bodies, rather than mere aesthetics, increases body satisfaction following exposure to thin-ideal imagery. Moreover, addressing these concerns in childhood and early adolescence may also help mitigate negative outcomes in later adolescence and emerging adulthood [21, 75, 135]. Although programs promoting positive body image in children and adolescents have demonstrated a degree of efficacy, a systematic review by Guest et al. revealed that there are a small number of studies with "good evidence of efficacy of increasing body appreciation and body-esteem in adolescent girls using cognitive dissonance, peer support, and psychoeducation" ([232] p. 624). The researchers also identified a lack of evidence for effective interventions aimed at children aged 11 years and younger. Thus, more research is needed, particularly involving more rigorous evaluation across different components of body image in children and adolescents, such as body functionality and self-care [232].

Health education specialists, clinicians, and other health professionals working at the interpersonal, institutional, and community levels can integrate the aforementioned strategies within interactive programs designed to increase knowledge and skills to foster positive body image and reduce internalization of appearance ideals and social comparisons. These programs can emphasize self-awareness and self-care, self-compassion, self-esteem, and self-efficacy [59, 64, 100, 223, 232–235]; body appreciation and body functionality [232, 236–239]; multimedia literacy [64, 78, 79, 97, 239]; physical activity and healthy weight management [239–245]; peer relationships [118, 231], as well as healthy emotions and positive coping [209]. Research has also highlighted the importance of parental connection and support [118, 246, 247] when promoting positive body image among preadolescent and adolescent girls. Parents need to learn how to communicate about body image and eating that focuses on wellness as opposed to attaining a particular body weight or shape. In conjunction with these efforts, health professionals can call parents' attention to their own body image and eating behaviors and how they can serve as positive role models for girls and young women [109, 246–249]. Parental attitudes and behaviors related to physical activity and media messaging can also be addressed.

The policy level of the socioecological framework is also important to consider. For example, body image friendly policies within the school environment can support the development of positive body image among students. Examples include refraining from weighing students in school, providing the opportunity to engage in non-weight-loss-focused physical activity, and training teachers to use body friendly language with their students [250]. At a broader level, public policy has the potential to create changes in attitudes and behaviors among a wide audience. Although lack of government willingness or ability to create and enact public policies aimed at improving body image and reducing the prevalence of eating disorders continues to be a challenge [251], governments around the world are beginning to take action to address body image and eating disorders. Bills, laws, and government actions targeted to address body image issues have been termed Body Image Law [252]. Some countries have implemented voluntary and self-regulated codes and charters (e.g., Australia and Canada) with the intent of encouraging the media, fashion, and advertising industries to take action to promote positive body image messages [250, 253]. Other countries have successfully passed laws targeting eating disorder prevention. For example, France passed a law in 2016 requiring retouched images of models to be labeled [254]. Israel also regulates the use of Photoshop and image editing in media and advertising [255]. The use of underweight models has also been banned in some countries such as Spain, France, and Italy [256].

Currently, there are few public policy approaches to improving body image and decreasing eating disorders in the United States [256]. Multiple federal- and state-level policies have been proposed, but many were not passed (e.g., Federal Response to Eliminate Eating Disorders Act, LIVE Well Act) [256, 257]. The Anna Westin Act was passed in 2016 and is the first legislation passed by Congress that specifically aims to help individuals affected by eating disorders [258]. Overall, it is unclear if policy-level strategies have been effective in promoting positive body image and reducing the risk of developing an eating disorder [253, 256]. For example, a systematic review of 15 experimental studies on the effects of media disclaimers on young women's body image revealed that disclaimers did not reduce women's body dissatisfaction and in some cases increased it [259]. These findings indicate that negative effects of exposure to thin-ideal images are not mitigated by informing girls and women that the images are Photoshopped. Exposure to diverse body images such as content used in body-positive social media posts may be a more effective approach for improving female's body image [260]. For additional discussions involving public policy approaches aimed at promoting positive body image and preventing disordered eating, see Puhl and Himmelstein [256] and Paxton [253].

2.3.2.2 Dissonance-Based Prevention

Studies have also supported the use of dissonance intervention to increase females' resistance to internalizing the thin ideal that often resonates from peer appearance conversa-

tions and other appearance-related messages that are so prevalent in the lives of adolescent females [9, 94–96, 238, 242]. Cognitive dissonance-based prevention programs address body dissatisfaction risk factors by teaching participants how to effectively counter unrealistic body image messages through verbal, written, and behavioral exercises [9, 95, 96]. For example, the Body Project is an effective dissonance-based eating disorder prevention program designed for young adolescents and women who experience body dissatisfaction [95, 96, 261]. This program is based on the dual pathway model of eating pathology [95] (Fig. 2.2) that highlights the negative effects of thin-ideal internalization on body image, which, in turn, can lead to dieting, negative affect, and disordered eating behaviors [95, 96]. There is strong empirical evidence supporting the efficacy of the Body Project in reducing thin-ideal internalization, body dissatisfaction, and disordered eating behaviors [238, 261, 262]. Moreover, the Body Project has been replicated in a variety of settings, including multiple global settings through strategies such as peer-led programs, train-the-trainer models, and collaborating with partners such as National Eating Disorder Association, Dove, World Association of Girl Guides and Girl Scouts, and Eating Recovery Foundation [261].

2.3.2.3 Physical Activity

There is additional empirical support regarding the positive relationship between body image and physical activity [244, 245, 263–267]. Research has also shown that physical activity, body image, self-esteem, and eating attitudes are interrelated [59, 267]. As health-related attitudes and behaviors often become established at a young age, interventions aimed at decreasing body dissatisfaction and increasing physical activity among young girls are particularly important. These interventions can promote positive body image through physical activity, nutrition education, multimedia literacy, self-efficacy, self-compassion and self-esteem, social support, and leadership. One example is Go Girls!, a 10-week interactive intervention targeting diverse groups of preadolescent and adolescent girls (aged 10–16). Topics include body image and self-esteem, goal setting, personal safety and assertiveness, healthy eating and physical activity, trust and confidence, and peer connections. Evaluation results showed that preadolescent and adolescent participants experienced a significant increase ($p < 0.05$) in self-esteem and self-efficacy (mental and physical health self-efficacy), while adolescent females also demonstrated decreased dieting. Furthermore, these improvements were sustained at 6-month follow-up [59]. In addition, research has demonstrated that training young women to serve as positive role models and mentors for younger girls has the potential to increase physical activity as well as decrease body dissatisfaction and drive for thinness among younger girls [241].

Other studies have shown that adolescent females can benefit from physical activity as higher levels of physical activity appear to mitigate body dissatisfaction and increase self-esteem [245, 267, 268]. Body image interventions with a physical activity component can foster positive embodiment, healthy behaviors, and social support among adolescent females. For example, New Moves [243] is a school-based intervention designed to prevent weight-related concerns among adolescent girls by incorporating physical activity, healthy eating, social support, individualized coaching, and parent involvement. Study results showed improvements in girls' body satisfaction and self-image, physical activity, dietary behaviors, and unhealthy weight control practices. Girls and parents also reported strong support for the program [243, 244]. Another example is the Healthy Body Image (HBI) intervention, a multi-component health promotion intervention focusing on positive embodiment and health-related quality of life among Norwegian high school students [17, 269]. HBI includes three main domains related to body image, media literacy, and healthy lifestyle (e.g., nutrition and physical activity). Results of a cluster-randomized controlled study in 30 schools demonstrated that the HBI intervention caused an immediate change in positive embodiment and health-related quality of life in girls, which was sustained at 3- and 12-month follow-ups [17].

Overall, physical activity can foster body awareness and functionality as well as elicit enjoyment related to health, movement, fitness, and quality of life [17, 224, 225]. Females of all ages can participate in a range of physical activities in a variety of settings, including homes, schools (EC-12), colleges and universities, worksites, health care facilities, community centers, and online. In addition, it can be beneficial to examine the relationship between positive body image and physical activities such as martial arts, hiking, rock climbing, horseback riding, swimming, scuba diving [7], pilates, and weight training. Yoga is of particular interest as it appears to be a promising medium for promoting mindfulness, embodiment, and positive body image with diverse females. Studies have shown that practicing yoga can foster mind–body awareness, body appreciation, and positive changes in body satisfaction [225, 226, 270]. There may be even more pronounced improvements among those beginning with lower levels of body satisfaction; and it also appears that body satisfaction improves as frequency of yoga practice increases [226]. There is also evidence to support yoga as an intervention strategy to prevent and treat eating disorders [226, 271].

2.3.2.4 Female Athletes

Body image and eating disorder programs aimed at female athletes are also warranted. A review by Bar et al. [152] identified several elements that are shared by successful eating

disorder prevention programs tailored for athletes. For example, effective interventions target coaches and sports administrators in addition to the athletes. In addition, programming is interactive and employs several methods of instruction, including lecture, skills-based assignments, and activities involving teamwork. The IOC Consensus Statement authors [155] recommended multiple strategies for preventing RED-S among female athletes, including:

- education concerning RED-S, healthy eating, energy availability, the risks of dieting and energy deficiency, and how these factors affect health and performance;
- emphasis on nutrition and health with less focus on weight;
- incorporation of credible sources of information;
- development of realistic goals related to weight and body composition;
- restrain from critical comments concerning an athlete's body weight or shape; and
- awareness that quality performance does not necessarily infer the athlete is healthy.

To address further gaps, recommendations from the updated IOC Consensus Statement report included the need to address:

- evidence-based identification of athletes at risk for RED-S;
- enhanced awareness of RED-S through required prevention education for athletes, coaches, support staff, and sport organizations;
- further awareness and education concerning the health and performance risks associated with RED-S; and
- guidelines for treatment and safe return to play for athletes with RED-S [156].

2.3.2.5 Health and Wellness Coaching

Health and wellness coaching is another arm of prevention and wellness that can bring about healthy attitudes and behaviors. A health and wellness coach focuses on the whole person, fosters a relationship of mutual trust, and helps a person achieve transformational change [272–274]. Moore et al. ([273] p. 1) aptly described coaching as "a growth-promoting relationships that elicits autonomous motivation, increases the capacity to change, and facilitates a change process through visioning, goal setting, and accountability, which at its best leads to sustainable change for the good." At its core, coaching is a conversation. As Kinsey-House et al. ([274] p. 1) illustrated: "…this is no ordinary, everyday conversation. An effective coaching conversation gets to the heart of what matters. It is a focused, concentrated conversation designed to support the client in clarifying choices and making changes." In the realm of body image, a health and wellness coach can help females: (1) explore expectations about health, wellness, and body image; (2) develop a personal wellness vision; (3) discern possible discrepancies between values and current behaviors; and (4) set goals to develop positive body image. Action-oriented strategies can generate forward movement in areas the client has indicated readiness to change. For example, writing about aspects they value and respect about their body (and life) in a daily journal can help promote a surplus mindset. Additional experiential strategies include practicing mindfulness to connect with their body's needs, critiquing media messages promoting the thin ideal, expressing appreciation for their body's functionality, and focusing on their body's assets versus dwelling on imperfections [15].

2.3.2.6 Health Communication Strategies

Health communication can be employed to promote positive body image among females, and the dynamics of health communication influencers in social networks will continue to gain in importance over the next few years [275]. Schiavo ([276] p. 9) comprehensively defined health communication as:

> a multifaceted and multidisciplinary field of research, theory, and practice. It is concerned with reaching different populations and groups to exchange health-related information, ideas, and methods in order to influence, engage, empower, and support individuals, communities, health care professionals, patients, policymakers, organizations, special groups and the public, so that they will champion, introduce, adopt, or sustain a health or social behavior, practice, or policy that will ultimately improve individual, community, and public health outcomes.

Although health communication is multidimensional and complex, it plays an essential role within an overall prevention initiative and is an effective adjunct to other body image programming. Health communication campaigns are more likely to effect change when they are tailored to specific target audience characteristics [275, 276]. In addition, online health communication strategies and interventions are of increasing relevance [276, 277] as they can foster eHealth literacy and provide space for the development of online social networks, which can foster trust and strengthen healthy behavioral norms [278, 279].

Mobile Apps

Widespread health communication to a large audience may strengthen the effect of positive body image interventions as it can help with supporting and reinforcing changes in attitudes, values, and language associated with body image. Considering the prolific use of mobile devices, mobile-based interventions show promise as a strategy for reaching a wider audience. For example, Appreciate a Mate was implemented during 2013–2014 as a positive messaging social marketing campaign employing an online tool (website) and a mobile

application (app) to promote positive body image, self-esteem, and enhance respect for self and others. Through this campaign, participants were able to "create and share crafted and customizable messages that emphasized physical and character traits as strengths" ([15] p. 31). The messages were customizable using different fonts, colors, and images and were intended to be shared across social media sites such as Instagram and Facebook. Examples of some of the messages include "You Rock," "Do What Makes You Happy," and "100% Swag" ([15] p. 31). Study results indicated that Appreciate a Mate provided young people an opportunity to create inspirational online content that helped them feel self-confident and empowered to promote positivity in others. Through their involvement in the campaign, young people engaged in positive behaviors (e.g., supporting and complimenting friends) and reported improved self-esteem and social connectedness [280]. A key to this campaign was its participatory design, which allows for the ideas and experiences of members of the target audience to be combined with expert perspectives, thereby leading to an intervention that is authentic and user-centered. The young people actively involved in the development of Appreciate a Mate highlighted the importance of interactivity, personalization, and shareability, which were then integrated into the campaign [15].

BodiMojo is another mobile-based intervention (app) that promotes positive body image. BodiMojo promotes positive body image via three elements: intervention messages, mood tracking and emotional regulation, and gratitude journaling [281]. The content of the intervention messages centers around self-compassion (mindfulness, self-kindness, and common humanity), body image (media literacy, fat talk, appearance comparison, and teasing), and health behaviors (healthy eating, physical activity, and sleep). The messages vary in format, including affirmations, behavioral tips, and psychoeducation. Additionally, quizzes and audio meditations are used to support learning and engagement. A randomized controlled evaluation of BodiMojo found that appearance esteem and self-compassion increased in the intervention in comparison to the control group [281]. These findings show promise for the effectiveness of an app-based intervention to promote positive body image.

Diverse Ad Campaigns

Extensive research has revealed there is a clear relationship between media exposure and body dissatisfaction [275]. This link is pronounced, indicating that "the mass media play an outsized role in the communication of cultural stereotypes about the aesthetics of body image" ([275] p. 363). Although the thin ideal continues to be prevalent in media, increasingly more retailers are beginning to use models with diverse bodies in their media campaigns along with meaningful hashtags (#), which are used to categorize social media content around a particular topic, theme, or conversation [282]. For example, Lane Bryant has #ImNoAngel (a response to Victoria Secret's campaign using thin-ideal models) and Plus Is Equal; and Aerie has the #AerieReal campaign [283]. Other retailers such as ModCloth, Target, and JCPenney also use body-positive strategies in their ad campaigns such as using affirming messages (e.g., "I am enough"), including their employees as their campaign models, and featuring plus-size male models [284]. Although few studies have examined the effect of these types of campaigns on body dissatisfaction in women, initial findings are encouraging. Studies by Convertino et al. [285] and Rodgers et al. [286] found that the Aerie Real campaign images were less harmful to female's body image than typical advertisements using models representing the thin ideal, and most of the participants reported that the Aerie Real images helped them feel more confident and accepting of their own bodies. Another study by Clayton et al. [283] examined the impact of viewing fashion models of varying body types on women and found that females experienced less social comparison and better body satisfaction when viewing plus size models. Rodgers et al. [286] also found that women want to see more diverse bodies in the media and view companies who use diverse bodies in their campaigns positively. Continued depictions of diverse and realistic bodies in advertisements and campaigns can be instrumental in promoting positive body image across the lifespan.

Shifting the focus to body function may be another promising health communication strategy for improving body image. Two functionality-focused media campaigns, This Girl Can and #jointhemovement, were evaluated for impact on body image and intention to exercise. Both campaigns consisted of a video less than 2 min in length. This Girl Can campaign was conducted in England and portrays females of varying ages, abilities, and body types in various active settings such as running or dancing. Motivational messaging was used along with the active images such as "Sweating like a pig, feeling like a fox" [287]. The #jointhemovement campaign was conducted in Australia and promoted an active lifestyle by using realistic depictions of the female body being physically active. Diverse models were used in the campaign representing different ethnicities, ages, and body types. Results revealed that both campaigns produced improved appearance satisfaction and intention to exercise [287]. However, these effects were not present when the models in the campaigns represented idealized images. Although the focus of the campaigns was on the body's capabilities, the "mere exposure to a functionality-based campaign may not be enough to change deeply ingrained sociocultural views regarding body image" ([287] p. 33). Multiple studies have found that models representing the thin ideal still elicit negative effects on women's body image even when presented in a physically active context (vs. traditional poses) [287].

Social Media Campaigns

It is also important to consider the role of social media in health communication strategies aimed at promoting positive body image. As "social media and contemporary digital technologies are the playing field of today's youth" ([275] p. 11), health promotion interventions and campaigns should be directed to reach the target audience. Social media can be used to effectively counter thin-ideal images and messages and foster positive body image to promote body appreciation and prevent body dissatisfaction among females [261, 275]. As such, body-positive social media campaigns may be a promising avenue for promoting positive body image. These campaigns can counter thin-ideal messaging through multiple strategies, including posting diverse body images and inspirational messages supporting positive body image; facilitating positive peer interactions as a strategy to model behavior that encourages body appreciation; using body friendly language that emphasize the body's assets; and integrating uplifting interpersonal communication such as peer affirmations. In addition, research has suggested that body-positive captions on attractive social media posts may have a protective effect on female body esteem and viewing self-compassion messages on Instagram can increase body appreciation and satisfaction, self-compassion and decrease negative mood [235, 288].

The perceived credibility of spokespeople for social media campaigns should also be considered. For example, a female who has overcome an eating disorder may be viewed as more credible than a health expert when disseminating messages about combating negative body image and eating disorders [275]. Public health professionals should seek to strengthen their social media skills to provide girls and women with evidence-based information supporting positive body image. By developing a trusted online presence, health professionals can establish social networks to influence social norms, behaviors, and attitudes related to body image and eating disorders [279]. As with any health intervention, it is important to pilot health communication messages and campaigns to ensure that the intended audience will both understand the materials and act on their message [276, 289]. This is particularly relevant when targeting individuals who may experience communication and health literacy barriers, such as those who speak English as a second language and those who experience hearing loss. To obtain more information about health communication campaigns, Pilgrim and Bohnet-Joschko [279] addressed techniques that can be used to guide the development of targeted, group-oriented campaigns. For a more comprehensive discussion of health communication and related strategies, see Schiavo [276].

2.4 Future Directions

Theory, research, and practice can be viewed as a continuum of dynamic interchange, and there is a need for insightful health professionals to move along this continuum "with ease" [210]. According to Glanz, Rimer, and Viswanath, "among the most important challenges facing us is to understand health behavior and to transform knowledge about behavior into effective strategies for health enhancement" ([210] p. 24). It is important for researchers to continue developing and refining theories and models to guide research and practice in the areas of body image and eating disorder prevention. In sync with this focus, practitioners need to be diligent in staying abreast of the literature so they can implement programs and health communication campaigns supported by empirical evidence. Regardless of the particular type of body image intervention that is implemented, it is important for researchers and practitioners to conduct formative and summative evaluations, including follow-up procedures and assessments to determine whether changes in knowledge, attitudes, and behaviors are significant and sustainable over time.

2.4.1 Emotional Intelligence and Mindfulness

Researchers have called attention to the need for a meta-theoretical model to clearly convey the pathways through which dimensions of emotional intelligence may protect against body image and eating difficulties [20, 290]. According to Goleman [291], there are five key elements to emotional intelligence: self-awareness, self-regulation, motivation, empathy, and social skills. Emotional intelligence encompasses the ability to perceive and effectively respond to one's emotions and as well as the emotions of others. Furthermore, deficiencies in emotional intelligence can inhibit healthy growth and development and lead to problems such as depression, eating disorders, and substance abuse [291]. Therefore, strengthening all five dimensions of emotional intelligence can serve as a preventive buffer against body image and eating concerns.

Mindfulness is a related concept that requires further investigation. Understanding the relationship between self-compassion and protective factors such as mindful and intuitive eating can inform theory-based interventions to prevent body image and eating concerns [20]. Mindfulness can serve as a foundation for creative body image intervention strategies that focus on a pathway toward self-awareness, self-compassion, and flourishing. Niemiec ([292], p. 6) described mindfulness as:

> shifting in the way we relate to ourselves. It's about seeing and experiencing ourselves in a different way.…Mindfulness helps us not to change our thoughts but to relate to thoughts (and ourselves) in a different way—a way that is balanced and nonjudgmental, curious, and accepting.

All of these elements can synergistically assist females of all ages to be in tune with their bodies, experience self-compassion and body appreciation, and withstand media messages that often diminish self-esteem and body satisfaction.

2.4.2 Developmental Stages and Life Transitions

There are multiple developmental trajectories of positive body image throughout the lifespan [8], indicating the need to explore various approaches for promoting positive body image during key developmental stages and life transitions. Halliwell [7] recommended studies across different developmental stages, social interactions, and cognitive processes. For example, there is a need to examine the initial development of positive body image in children, preadolescents, and adolescents [8] to inform the development, implementation, and evaluation of body image and eating disorder prevention interventions at salient life stages. Body image and eating disorder prevention interventions for preadolescents that incorporate mentoring by older teens or young adult women have the potential to deliver reciprocal benefits and should be further examined. Furthermore, Hatch's [293] "life course perspective" concerning body image can help researchers design more robust studies, such as how the body image construct might change as women age. Studies such as these can guide health practitioners' awareness about appropriate screening measures for body image disturbances among older women [161, 164, 167, 294]. Future studies can also investigate whether certain methods can enhance the sustained effects of positive body image and healthy weight interventions, such as online interventions, booster sessions, and support groups; increasing the number and duration of program sessions; and adding an intervention component involving parents [111, 242, 243, 248, 249, 295] and other supportive individuals from salient social networks. The efficacy of these methods with females at different life stages also needs to be assessed.

Due to the range of risk factors that contribute to the development of body dissatisfaction and eating disturbances across the lifespan, it is important to continue to study how the impact of acculturation, sociocultural factors, and socioeconomic factors on body image and eating may vary across different ages, ethnicities, and cultures [56, 60–62, 85, 92, 93, 296–300]. These differences can be studied between as well as within groups to provide a richer knowledge base to inform body image assessment and development of culturally relevant prevention programs that reflect distinctive ethnic and cultural factors [93, 85, 298]. Researchers have also recommended including acculturation measures when examining ethnic differences in eating disorders risk factors and prevalence [61, 62].

2.4.3 Spectrum of Body Image and Eating Concerns

Eating disorders and obesity have traditionally been considered as polar opposites; however, there is considerable overlap between the conditions [243, 301–304]. Shared risk and protective factors can be addressed through interventions targeting a spectrum of problems revolving around body image, eating, and weight [244, 301, 302]. Although the prevalence of obesity is a public health concern, obesity-prevention campaigns should consider the psychological impact of increasing focus on body weight, shape, and size. When developing campaigns and interventions aimed at obesity prevention, public health professionals should consider the potential for propagating fat stigma and shame and increasing eating disorder risk factors (e.g., body dissatisfaction, preoccupation with weight, or restrictive eating) and choose the content and messaging carefully [303, 305, 306]. Treating and preventing obesity and eating disorders should include weight-neutral interventions focusing on health and well-being that foster healthy relationships with food and bodies [303]. Evidence suggests that obesity prevention and treatment do not predispose females to eating disorders if designed and implemented appropriately (i.e., emphasizing health and wellness as opposed to body weight and shape) [307].

2.4.4 Mental Health Literacy and eHealth Literacy

Other areas to address in moving forward include mental health literacy and eHealth literacy. It is concerning that the general public's awareness about body image difficulties, eating concerns, and clinical eating disorders is lacking [308, 309]. Furthermore, many health care providers are ill-equipped to effectively respond to body image difficulties and eating disorders, particularly in the acute treatment setting [310]. Therefore, there is a need to foster awareness, knowledge, and skills related to body image and eating disorder prevention and treatment among public health professionals. These activities can be categorized within the broader lens of mental health literacy, which has been defined as:

understanding how to obtain and maintain positive mental health; understanding mental disorders and their treatments; decreasing stigma related to mental disorders; and, enhancing help-seeking efficacy (knowing when and where to seek help and developing competencies designed to improve one's mental health care and self-management capabilities) [311].

All females (as well as the general public) need to be better informed regarding risk factors and symptoms associated with body image difficulties and eating disorders. This knowledge can enable females and individuals within their social networks to identify a potential problem and seek help as well as provide support to others struggling with negative body image and eating concerns. For example, adolescents with eating disorders rarely seek help for body image in the early stages; therefore, promoting early, appropriate help-seeking among young females may be particularly crucial [312].

A related concept is eHealth literacy, which is defined as the ability to locate, comprehend, and evaluate online health information and apply that understanding to address a health concern [313]. eHealth literacy encompasses six forms of literacy that can be categorized into two main types: analytic (traditional, information, media) and context-specific (computer, health, scientific) [313]. Due to the vast amount of information cascading across the Internet and the prolific online presence of individuals across the globe [314], eHealth literacy is a fundamental asset to effectively navigate through health issues that can accompany life transitions. For example, research has shown that college students may understand how to search for relevant online health information; however, they lack the self-efficacy to evaluate and use online health resources [315]. This disconnect is problematic and can hinder young adults and others from making informed decisions as health consumers. Because eHealth literacy is a dynamic "process-oriented skill," it is important for health professionals to stay abreast of a constantly changing sociocultural environment that can impact body image and eating behaviors in females of all ages. As influencers, public health professionals and other stakeholders also need to enhance their digital skills to provide females appropriate and timely information [275] regarding these important public health issues. Overall, future research and practice can be directed toward promoting mental health and eHealth literacy to address these gaps.

2.4.5 Assessment

To enhance eating disorder prevention practice, Levine ([316] p. 7) recommended additional studies focusing on "program efficacy, effectiveness, and dissemination." In addition, more robust assessment for body image is requisite for accurately detecting body image difficulties and disturbances in diverse female populations. There is also a need to examine protective factors that mitigate body image concerns and foster positive body image. Incorporating positive image assessment in prevention programs can advance understanding of mediators of change as well as protective factors [16].

The assessment process includes the development of age-appropriate measurement instruments for preadolescents and adolescents [8]. Instruments that are valid and reliable to use with a certain group of females must be reevaluated when used with other groups. For example, many body image instruments that have been validated with adolescent or young adult females may not be appropriate or relevant to use with older females. Cultural differences may also impact an individual's response to a particular instrument or assessment method [176] (e.g., self-report questionnaire, semi-structured interview, or focus group interview). Furthermore, there continues to be an increased use of online body image measures, which will require researchers to validate these assessment tools among diverse female populations across the lifespan. Overall, health professionals should be knowledgeable about body image assessment, including how to access evidence-based assessments and effectively use them in multiple practice settings. In addition, allied health mediums that focus on body awareness and functionality such as adapted physical activity, athletic training, cardiac rehabilitation, physical therapy, and occupational therapy should be encompassed.

2.5 Concluding Remarks

Body image is not fixed but rather dynamic and fluctuating [3]. Each individual constructs body image differently based on her "unique constellation of social identities" ([9] p. 127). The complexities inherent in body image are well documented, and body image concerns can range from a desire to be physically fit and look attractive to body dissatisfaction and a pathological concern with thinness or perfection. There are numerous risk factors associated with negative body image and eating concerns, including biological and physical factors, individual characteristics, and sociocultural influences. Body image difficulties impact females of all ages across different ethnic, cultural, and socioeconomic groups; therefore, it is important to examine and address body image from various angles and at different levels of influence within a socioecological spectrum. As a result of these efforts, health professionals as influencers will be in better position to foster positive body image that can lead to enhanced wellness and quality of life among females across the lifespan.

Appendices

Appendix 1: Body Image Quality of Life Inventory

Different people have different feelings about their physical appearances. These feelings are called "body image." Some people are generally satisfied with their looks, whereas others are dissatisfied. At the same time, people differ in terms of how their body image experiences affect other aspects of their lives. Body image may have positive effects, negative effects, or no effects at all. Listed below are various ways that your own body image may or may not influence your life. For each item, circle how and how much our feelings about you experience affect that aspect of your life. Before answering each item, think carefully about the answer that is most accurate about how your body image usually affects you.

BIQLI items	−3	−2	−1	0	+1	+2	+3
	Very negative effect	Moderate negative effect	Slight negative effect	No effect	Slight positive effect	Moderate positive effect	Very positive effect
1. My basic feelings about myself—feelings of personal adequacy and self-worth							
2. My feelings about my adequacy as a man or women—feelings of masculinity or femininity							
3. My interactions with people of my own sex							
4. My interactions with people of the other sex							
5. My experiences when I meet new people							
6. My experiences at work or at school							
7. My relationships with friends							
8. My relationships with family members							
9. My day-to-day emotions							
10. My satisfaction with my life in general							
11. My feelings of acceptability as a sexual partner							
12. My enjoyment of my sex life							
13. My ability to control what and how much I eat							
14. My ability to control my weight							
15. My activities for physical exercise							
16. My willingness to do things that might call attention to my appearance							
17. My daily "grooming" activities (i.e., getting dressed and physically ready for the day)							
18. How confident I feel in my everyday life							
19. How happy I feel in my everyday life							

Appendix 2: Body Image Concern Inventory

Please rate how often you have had the described feeling or performed the described behavior on a Likert scale anchored by 1 = "never" and 5 = "always"

		1	2	3	4	5
		Never	Seldom	Sometimes	Often	Always
1.	I am dissatisfied with some aspect of my appearance					
2.	I spend a significant amount of time checking my appearance in the mirror					
3.	I feel others are speaking negatively of my appearance					
4.	I am reluctant to engage in social activities when my appearance does not meet my satisfaction					
5.	I feel there are certain aspects of my appearance that are extremely unattractive					
6.	I buy cosmetic products to try to improve my appearance					
7.	I seek reassurance from others about my appearance					
8.	I feel there are certain aspects of my appearance that I would like to change					
9.	I am ashamed of some part of my body					
10.	I compare my appearance to that of fashion models or others					
11.	I try to camouflage certain flaws in my appearance					
12.	I examine flaws in my appearance					
13.	I have bought clothing to hide a certain aspect of my appearance					
14.	I feel others are more physically attractive than me					
15.	I have considered consulting/consulted some sort of medical expert regarding flaws in my appearance					
16.	I have missed social activities because of my appearance					
17.	I have been embarrassed to leave the house because of my appearance					
18.	I fear that others will discover my flaws in appearance					
19.	I have avoided looking at my appearance in the mirror					

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Appendix 3: Physical Appearance State and Trait Anxiety Scale: Trait

The statements listed below are to be used to describe how anxious, tense, or nervous you feel in general (i.e., usually) about your body or specific parts of your body.

Please read each statement and circle the number that best indicates the extent to which each statement holds true in general. Remember, there are no right or wrong answers.

Never	Seldom	Sometimes	Often	Always
1	2	3	4	5

In general I feel *anxious*, *tense*, or *nervous* about

1. The extent to which I look overweight	1	2	3	4	5
2. My thighs	1	2	3	4	5
3. My buttocks		2	3	4	5
4. My hips	1	2	3	4	5
5. My stomach	1	2	3	4	5
6. My legs	1	2	3	4	5
7. My waist	1	2	3	4	5
8. My muscle tone	1	2	3	4	5
9. My ears	1	2	3	4	5
10. My lips	1	2	3	4	5
11. My wrists	1	2	3	4	5
12. My hands	1	2	3	4	5
13. My forehead	1	2	3	4	5
14. My neck	1	2	3	4	5
15. My chin	1	2	3	4	5
16. My feet	1	2	3	4	5

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Chapter Review Questions

1. All of the following concepts are associated with positive body image **except**:
   (a) body appreciation.
   (b) body functionality.
   (c) sociocultural model.
   (d) self-determination.
2. According to the Tripartite Influence Model, which of the following mediate(s) the relationships between sociocultural influences, body image, and eating concerns?
   (a) Appearance comparison
   (b) Internalization of the thin ideal
   (c) Self-esteem
   (d) Both a and b
3. All of the following are elements within the social marketing mix **except**:
   (a) place
   (b) price
   (c) product
   (d) program
4. Which of the following is <u>not</u> a level of influence within the ecological model?
   (a) Interpersonal
   (b) Institutional
   (c) Community
   (d) Normative
5. Integrating positive body image interventions into school health programs is an example of a prevention strategy at what level of influence within the ecological model?
   (a) Intrapersonal
   (b) Interpersonal
   (c) Organizational
   (d) Policy
6. The interaction of females, dieting behaviors, and sociocultural influences promoting the thin ideal refer to the theoretical concept of:
   (a) observational learning
   (b) outcome expectations
   (c) reciprocal determinism
   (d) self-regulation
7. Which of the following are important factors to consider when selecting the correct body image assessment tool?
   (a) Reliability
   (b) Validity
   (c) Previous use with target population
   (d) All of the above
8. Which researcher (s) outlined tips for enhancing body image assessment in clinical and research settings?
   (a) Cash and Colleagues
   (b) Gardner and Colleagues
   (c) Neumark-Sztainer
   (d) Thompson
9. At what age can females experience body dissatisfaction?
   (a) College age
   (b) Preadolescence
   (c) Middle age
   (d) All of the above
10. Impaired physiological function associated with RED-S includes all of the following **except**:
    (a) lipid profile
    (b) menstrual function
    (c) bone health
    (d) cardiovascular health

Answers

1. c
2. d
3. d
4. d

5. c
6. c
7. d
8. d
9. d
10. a

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The Psychology of Female Sport Performance from a Gender Perspective

3

Claire-Marie Roberts and Danika A. Quesnel

Learning Objectives
After reading this chapter, you should have an understanding of the following:

- How gender impacts on the experiences of high-performance sport
- Gender differences in self-confidence in sport
- Gender differences in the management of competitive state anxiety
- Gender differences in motivation and competitiveness in sport
- Gender nuances of the cohesion–performance relationship in all-female teams
- Gender differences in the experiences of sport-specific stressors and associated coping (including self-compassion)
- Gender differences in the female-specific risk of weight pressures, body dissatisfaction, and disordered eating in sport
- Gender preferences in coaching behaviors
- Gender-specific microaggressions displayed towards female athletes and their impact on sport performance

3.1 Introduction

Gender, as it is used in this chapter, refers to the *non-physiological* aspects of being male or female. That is to say, the expectation that our culture and our society has for us depending on whether we are a man or a woman. Gender is a useful topic of consideration in sport because it helps us understand how and why any differences in behavior or experiences between male and female athletes are not born from it of biological differences. Indeed, gender differences in sport performance are predicated on cultural development and formative socio-cultural influences [1, 2]. These differences relate to the manner in which girls and boys are typically encouraged to develop throughout childhood. Undeniably, gender socialization starts early in childhood with adolescence being a critical period for determining gender attitudes, particularly because the onset of puberty brings new and intensified expectations related to gender [3]. Specifically, in the sport and exercise domain, the way in which girls and boys engage in, and are allowed access to certain types of recreational exercise and competitive sports varies according to social convention and expectation [1]. In fact, these environments are centered on persistent gender stereotypes in sport influence perceptions, behaviors, and achievements in sport. These gender differences, which are ultimately socially driven generate a number of nuanced behaviors which ultimately impact on resultant sport performance. For example, empirical research indicates that there are differences in confidence, competitive anxiety responses, the motivation for engagement in sport, competitiveness and risk-taking, group dynamics, the cohesion–performance relationship, conflict, stressors and coping reactions, and self-compassion in the female athlete. Additionally, society views the female athlete in a different way than male athletes which may lead to specific societal and sport-related physique ideals that drive weight pressures, body dissatisfaction, and associated eating disorders [4]. Of additional significance is the impact that coaches have on the athletes they work with. Certainly, this is one of the most formative relationships in competitive sport [5]. Through this relationship, there is reciprocity of motivation, assurance, satisfaction, an enhancement of the optimal sport experience, and wellbeing [6, 7]. Gender is a key influence here. Additionally, there are differences in preferred coaching behaviors dependent on gender [8]. Finally, through a pervasive assumption of inferiority, objectification, and restrictive gender roles [9], female

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athletes are still subjected to subtle biases (or microaggressions) that dismiss their abilities, focus primarily on their appearance, and shine a light on those who do not fit into the "traditional feminine" image society has for females. Indeed, gender differences have been reported as being larger in sport than in other domains [10]. This chapter will use empirical research to explore the gender-specific nuances of sport performance, present contemporary understanding of how these impact on sport performance, and examine the harmful consequences that society's blueprint still has on female athletes in the twenty-first century. Before we continue, it is important at this juncture to acknowledge that when we refer to 'female athletes' throughout this chapter, we refer to heterosexual women, women who identify with a non-heterosexual sexual orientation (e.g., gay, lesbian, bisexual, pansexual, asexual) and individuals who identify as a female. When we refer to the generalizations in the way in which girls and boys are socialized, we refer to society's construction of their gender and the norms that are imposed by parents, peers, and society.

3.2 Research Findings and Contemporary Understanding of the Issues

3.2.1 Confidence

Confidence is a fundamentally important construct required for successful sport performance. There are a number of discrete "versions" self-confidence in sport, as defined by the literature. For example, self-confidence is thought of as a global construct although there is a general lack of agreement on how to conceptualize and operationalize it [11]. Bandura [12] describes self-confidence as the belief as an individual that you possess the internal resources to achieve success, whereas *self-efficacy* is a fluctuating state of judgment of one's ability to organize and execute specific actions needed to produce a certain level of performance. Sport-confidence on the other hand is sport-specific belief in one's ability to succeed in sport more generally [13]. There are measured gender differences in levels and sources of confidence in a sporting context. Above all, males tend to display higher levels of self-confidence than females [14]. In addition, there are gender differences in the antecedents and temporal patterning of self-confidence pre-competition [15]. For example, personal goals and standards predict confidence in females, whereas males tend to derive theirs from interpersonal comparison and winning [16]. In addition, research has concluded that females may derive confidence from their coach's encouragement, positive feedback/reinforcement, and compliments, akin to the 'social support' source of sport confidence identified by Vealey [17]. When considering sport-confidence, findings from research in the last decade suggest that elite female athletes attribute sources of sport-confidence to; mastering personal skills, reinforcement from significant others, perceptions of their body image, coach's leadership, and feeling comfortable in the competition environment to a greater degree than the male athletes [18]. As confidence is such a strong predictor of sport performance, it is of fundamental importance the coaches and other support staff working with female athletes have an understanding of the influence they may have over it. Certainly, to have a greater and more accurate insight into the psychology of the female athlete should lead to more tailored communication designed to enhance confidence in these athletes.

3.2.2 Competitive Anxiety

One of the most prevalent issues requiring sport psychology intervention in athletes is the debilitating presence of competitive state anxiety [1]. Competitive state anxiety is a complex, multidimensional construct consisting of both cognitive and somatic anxiety that unfolds over time. It is generally accepted that competitive state anxiety is effectively mediated by a high degree of self-confidence (see above). Although commonplace in (and almost characteristic of) sport competition, the presence of competitive state anxiety has the potential to have a catastrophic impact on sport performance. Although it is considered that male and female high-performance athletes share more similarities than differences in their psychological approach to competition, research has uncovered gender differences in the susceptibility to cognitive anxiety [19] and of the temporal patterning of anxiety more generally [20–23]. A study by Jones and Cale found that females reported a gradual increase in cognitive anxiety alongside a concurrent increase in the intensity of somatic symptoms and a decline in self-confidence pre-competition [20]. However, a more recent examination of gender differences in the reporting of competitive state anxiety experiences concluded that female athletes *did not* report higher intensities in cognitive anxiety symptoms as compared to their elite male counterparts [24]. In fact, in this 2017 study, male athletes experienced a greater intensity of both cognitive and somatic anxiety symptoms than the corresponding female group regardless of skill level. These findings support those of Woodman and Hardy in their meta-analysis of studies up to and including January 2002. They controversially suggested that 'pre-competitive cognitive anxiety and self-confidence have a greater impact on the performance of men than that of women' (p. 452). Attempts to investigate gender differences in the effects of competitive anxiety on sport performance have further yielded contradictory views [25]. For example, Hagan and associates found that elite females were less cognitively anxious, interpreted somatic symptoms as more facilitative, and were more stable

7 d before competitive fixtures compared to their male counterparts [24]. In a follow-up study addressing a similar research question in elite table tennis players, Hagan, Pollmann, and Schack concluded that their findings contradicted the commonly held belief that gender differentiates multidimensional anxiety experiences, when they found no differences at all. They went on to explain any differences as being attributable to culture, team dynamics, and/or competitive level. In each of the studies with what could be described as counter-intuitive findings, it is interesting to note that they do not support the research hypotheses. In each of the discussions, critiques of the research search for reasons why the predicted relationship was not observed. However, none of these studies investigated (or suggested further investigation of) whether female athletes possess more superior coping skills for dealing with competitive anxiety than their male counterparts. Clearly, further investigation is needed to replicate these findings and to build up a more comprehensive picture of the gender influence in competitive state anxiety experiences [26]. Either way, as a practitioner working in high-performance sport, understanding the athletes you work with on an individual and holistic level will help dispel any associated stereotyped predictions about how effectively they may or may not be coping with the pressures of high-performance sport competition.

3.2.3 Gender Differences in the Motivation for Sport Participation and Competitiveness

It is well-documented that, in general, men engage in sport at least two times more frequently and for longer than women [27, 28]. This trend occurs across adults and children internationally and is attributed to a lesser desire among the female population to participate and excel in sport [29]. In addition, non-sport-related research has reported on gender differences in motivation, specifically, competitiveness, responses to competition, and risk-taking, a correlate of competitiveness [30, 31]. In order to further understand the gender differences in motivation, it is useful to utilize the framework of one of the most prominent theories of a person's achievement behavior—the Achievement Goal Theory [32]. The Achievement Goal Theory draws on a social-cognitive approach to motivation. It proposes that achievement goals (the competence-based aim used to guide behavior) and motivational climate (perception of social environment) can determine the quality of the individuals' affective, cognitive, and behavioral experience [32]. The propositions of the Achievement Goal Theory are of great significance in sport as we are able to understand the key influence of the motivational climate for athletes [33]. To elaborate, the motivational climate is the environment created around the team or the athlete by the structure of the sport, by coaches, peers, officials, etc., that influence their perception of the criteria needed for achievement. Task-involving motivational climates are environments that encourage athletes to improve relative to their own performances, to celebrate the role of personal effort in success and when goals are not met, they are viewed as learning experiences and opportunities to try different strategies. Ego-involving climates on the other hand, are characterized by benchmarking the athletes' performance against others, to attribute success to ability and to view setbacks as failure. There is a great deal of research support for the creation and maintenance of task-involving climates in sport, which help to maintain motivation and effort under periods of challenge. What is particularly interesting about motivational climate is the gender differences in preferences for these environments [34]. Stereotypically, perhaps, male athletes tend to engage in sport for the competition, and report gaining competence and satisfaction from beating others in a move that demonstrates higher ability compared to others. This is a preference for what is called an ego-orientated environment [32]. Female athletes, on the other hand, have been shown to have a preference for task-orientated sporting environments where competence and satisfaction is derived from learning new skills, improving their own performance and doing their best [35]. Notably, this distinct difference in preference is most likely influenced by a combination of upbringing, peer, and socio-cultural influences. Regardless of the antecedents for this gender difference, it is advantageous as a sporting organization, coach, or parent to understand how a creation of the right environmental conditions can help get the best out of the female athlete in order to maximize their experiences of sport.

3.2.4 Group Dynamics, the Cohesion–Performance Relationship and Conflict

Cohesion is a significant variable that contributes to *team* sport success. It represents 'a dynamic process that is reflected in the tendency for a group to stick together and remain united in the pursuit of its instrumental objectives and/or for the satisfaction of member affective needs' [36]. This definition encompasses the unity experienced in teams from two perspectives: (1) individual members' attractions to their task (i.e., performance-related) and (2) their attraction to the social (i.e., relation-orientated) aspects of the group. Interestingly, while the absolute amount of cohesiveness measured by the Group Environment Questionnaire [36] is similar in teams of males and females [37], teams of female athletes perceive their level of cohesion to be higher [38]. On further investigation, studies have found that teams of female athletes tend to be more socially orientated, with a

particular emphasis placed on the relationships within the team. Once again, a product of society's expectations and their resultant upbringing means that many females place great importance on the creation and maintenance of close relationships with others and the need for belongingness [39]. Using this understanding as a baseline, gender has been previously identified as a strong moderator variable in the cohesion–performance relationship [40].

On the surface, the significance of the level of social orientation typified in all-female teams coupled with a greater perception of cohesion would lead people to think that these teams have a distinct competitive advantage. However, some teams' strengths may also serve as their weaknesses, as a high degree of social orientation in teams may actually have a detrimental impact on team performance as it may lead to group polarization, group think, and the pressure to conform [41]. Indeed, the loss of this predominately social cohesion 'might be expected to be more detrimental to team success in female teams' [40]. Likewise, in Eys and colleagues' recent study exploring perceptions of the cohesion–performance relationship by coaches who have led teams of both genders, one participant noted: 'Group cohesion is harder to achieve in female teams because women handle things more on a personal level' (p. 103). Another participant explained: 'My observations are that for the females, the need for harmony within the training group was stronger than for men' (p. 103) [42]. Further observations were made about the ease of formation of subgroups or cliques and the difficulty of handling of personal conflict in female teams, as resentment is often harbored for longer [1]. It is important to emphasize, however, that the existence of psychological differences does not attribute greater significance to one gender's norms over the other. It merely reinforces the need to ensure that coaches and athlete-support personnel fully understand the gender-specific approach to team sport, such that teams can be coached and supported competently to help them achieve optimal performance.

3.2.5 Stressors and Coping

The stressors or demands presented by sport can be considered distinctive for female athletes. Predictably, the standard sources of performance pressure and competitive anxiety driven by high expectations and a fear of scrutiny and evaluation hold true (see above). Yet, research shows female athletes are likely to face additional stressors resulting from the perception of unequal or unfair treatment based on sex, the often-poor organization of women's sport, machismo, and the patronizing attitudes of male administrators, coaches, and referees [1]. Additionally, to add further gender-specific sources of competitive stress, the existence of unhelpful gender stereotypes, microaggressions (see below), and substandard treatment of female athletes in some elite sports may contribute to a more negative competitive performance in these athletes [43].

The way in which we appraise and cope with these stressors is often a very individualized and complex process [44]. However, there are some common themes that arise when we look at the resources used by female athletes to cope with these challenges [45]. For example, female athletes are more likely to use more emotion-focused coping and support-seeking to manage stressors when compared to their male counterparts [46]. 'Emotion-focused' coping functions to regulate (tolerate, reduce, or eliminate) the physiological, emotional, cognitive, and behavioral reactions that accompany the experience of stressful encounters by minimizing the emotional distress that results from stressors. On the other hand, 'support-seeking' refers to behaviors that involve engaging in social contact and using the resources that come from this contact to achieve a desired outcome [47]. Although these approaches to coping often characterize the female athlete's approach to the challenges and stressors outlined above, it is critical that the individual has the self-awareness and the ability to self-reflect to evaluate—and, if necessary, redirect—their coping efforts, as well as establish external support in addressing deficiencies in coping [1]. Family, friends, significant others, coaches, training partners, psychologists, exercise leaders, and others who have gone through something similar have all been identified as sources of such support [48]. Having an awareness of the nuances of female-specific stressors in sport is key to the effectiveness of coaches and support staff. In addition, in understanding female athletes' preferred modes of facilitative coping as a coach or member of support staff, one can help bring about the swift enactment of those coping behaviors by signposting and providing encouragement when needed.

3.2.6 Self-Compassion

Most athletes encountering the hardship, difficulty, or challenge outlined above have a tendency to be harshly critical and overly evaluative of themselves [45]. Thus, helping an athlete to manage stressors in a facilitative manner is important as it is related to improved sport performance and overall wellbeing, particularly for those at elite levels [49]. With a view to this, self-compassion has garnered much attention in the sporting arena as a way to help manage stress and cope with the challenges of sport [50]. Neff (2003) describes self-compassion as a way of relating to the self in a manner that is positive, accepting, and understanding. Self-compassion holds its roots in Eastern philosophy, and the underlying concepts of self-compassion entail being non-judgmental, kind, and understanding when one encounters feelings of suffer-

ing, failure, inadequacy, or pain [51]. Self-compassion encompasses three core concepts: (1) mindfulness, (2) self-kindness, and (3) common humanity [51]. Mindfulness is described as the capacity to acknowledge and accept difficult thoughts as they pass through the mind without internalizing or suppressing them. Self-kindness involves extending the kindness typically demonstrated to others to one's self, while diminishing critical thoughts. Lastly, the core concept of common humanity is the understanding that one is not alone in their struggles, and that often, others are struggling in the same manner.

In general, literature on self-compassion has demonstrated its ability to improve perseverance, satisfaction with life, mastery, and bolster-adaptive responses to the situation [51, 52]. In fact, athletes who are highly critical, and fear settling for "good enough" instead of embracing self-compassion are more likely to encounter detrimental impacts on their wellbeing [53]. Self-compassion has been identified as a coping mechanism which can protect against emotional turmoil and negative judgement experienced by female athletes [45, 52, 54, 55]. Specifically, in sport, self-compassion facilitates an athlete's ability to cope better with the stressors previously defined in this chapter by emphasizing and teaching beneficial cognitive emotional and behavioral response to stress.

To date, interventions have investigated the potential of self-compassion in athletes at both the individual and group levels. One study conducted a self-compassion intervention in athletes who were identified as self-critical. The intervention consisted of psychoeducation sessions and a writing component over a 7-day period. When compared to the control group, the intervention group had significantly improved their abilities to manage self-criticism, ruminations, and concerns over their mistakes [56]. Additionally, other research has demonstrated that higher self-compassion is related to improved sport performance [57].

Despite the idea that self-compassion is an inborn trait or capacity, research has demonstrated that it can quite effectively be learned [50, 56]. A key factor to the success of self-compassion in sport is athlete "buy in" [48, 58]. It is crucially important that teams as a whole adopt self-compassion initiatives and that role models in the athlete's lives consistently demonstrate such behavior. Thus, adapting the training environment to exemplify self-compassion by coaches, parents, and teammates may be highly beneficial in the process of self-compassion becoming second nature [48, 58]. In fact, one study assessing how athletes were able to move from a self-critical to self-compassionate mindset highlighted the role of the coach, the influence of other athletes, and the impact of significant others as some of the most important factors (along with developing balanced self-awareness and lastly, maintaining an accepting mindset) in developing self-compassion among the athletes [50].

Introducing self-compassion as a concept to a team may not necessarily be met with open arms. Acknowledging an athlete's reluctance and challenges in adopting a self-compassionate mindset along with identifying instances for relevant, individually tailored integration is important to successful long-term incorporation of self-compassion. Thus, introducing self-compassion in a way that athletes are able to understand, identify with, process, and effectively utilize in a simple manner within the context of their own sport may further help engrain this practice into their practice. Lastly, it is valuable to be mindful of an athlete's unique training and competition contexts. Researchers have suggested that encouraging an athlete to reflect on their past coping skills and processes while discussing how they could proceed forward with a self-compassionate mind set is a necessary step in fostering this skill. A tool that may aid athletes in their journey to becoming self-compassionate is weekly reflective journaling. Adopting self-compassion may be difficult for athletes, however, opportunities to practice it successfully will increase their skill and self-efficacy in this area. Ultimately, self-compassion is a useful tool that may serve to help our female athletes reach their goals, while teaching valuable transferable skills for use outside the sporting context [50].

3.2.7 Weight Pressures, Body Dissatisfaction, and Associated Eating Disorders

Elite sport promotes and encourages a culture that is synonymous with the promotion of body consciousness [59]. Due to the inextricable link between sport and the body, the body becomes a tool for performance which is openly displayed and evaluated [60]. As a result of this relationship, it is not surprising to learn that athletes, the majority of which are females, experience performance-related weight pressures [4]. More alarming is the relationship between performance-related weight pressures and the open critique of the athlete's body shape and size by coaches [61]. This is otherwise known as "body surveillance," the practice of which can render athletes, especially females at risk of body image disturbance and its associated consequences [62], including social physique anxiety [63], low self-esteem [64], and disordered eating [65].

This relationship is more prevalent in high-performance sport [66], and in lean (e.g., distance running), weight-contingent (e.g., lightweight rowing) and esthetic (e.g., gymnastics) sports where there is a distinct competitive advantage of low body weight [67]. Layer onto this are the cultural expectations such as celebrated thinness in the Westernized feminine ideal [68], increased media attention of successful female athletes [69], and the requirement of some sports for their female athletes to wear revealing clothing (e.g., beach

volleyball), it is clear why females in these sports categories are at a high risk. In an extension of this complex and multidimensional realm of weight pressures, body dissatisfaction and eating disorders is a concept termed the 'female athlete paradox.' This paradox relates to the juxtaposition of the requirement of the Westernized feminine 'ideal' body shape (thin and lean) *plus* the requirement to be athletic, powerful, strong, and physically competent simultaneously [70]. It is proposed that the female athlete paradox can lead to "dual and dueling identities" [70] where female athletes experience body satisfaction within their sporting environments but body dissatisfaction in social situations [71]. Body image and body satisfaction is a continuing concern for female athletes throughout their lifespan, as even in retirement, perhaps as a result of decreased muscle tone and increased body fat percentage, the majority report dissatisfaction and the desire to lose weight, even if weight per se has not increased since leaving sport. The changes in body composition after retirement from sport leave female athletes feeling "neither athletic nor feminine," which places them at risk of prolonged body dissatisfaction [66]. In order to effectively counsel retired female athletes through this potentially complex period, encouragement of the use of effective social support, broadening and pursuing new identities (to decrease the salience of their athletic identity), and helping bring about a change in eating and exercise behaviors to focus to health rather than weight control are likely to be the most successful approaches. Clearly, if the athlete (retired or current) exhibits symptoms commensurate with an eating disorder, support from clinical psychologists specializing in eating disorders is fundamental to the likely recovery of the individual. All things considered, the aforementioned tactics are designed to be delivered reactively, and at an individual level. There is, however, additional merit in a proactive stance that addresses the body monitoring and weight management cultures of many high-performance sports [59]. In these cultures, key people such as sport administrators, coaches, and teammates may be aiding and abetting these body ideals and destructive weight management practices to the point where they become norms [66]. One of the most significant influences in an athletes' life is the interpersonal relationships they forge in sport through their access to support and guidance. One of the most important of these relationships is that of the athlete and coach. This relationship is often all-encompassing and can have stark influences on the athletes' motivation [72], confidence [73], perceptions of competence [74], and self-perception [75]. In addition, the coach may see their influence extending to weight management and diet which for female athletes specifically, may influence positive or negative perceptions of body image [61, 76]. With that, the manner in which coaches initiate and conduct discussions about weight management can be precarious. For example, research has shown that an ill-informed and insensitive conversation about the athletes' body composition, public weighing practices, linking weight management to selection etc.…can lead some athletes into disordered eating and even full-blown eating disorders [77]. In order to circumvent this potentially intricate situation, coaches should be supported by psychologists and nutritionists to help them understand (1) the complexities of the female athlete paradox in today's (Westernized) society, (2) and the likely impact of their communication about weight management and body composition on female athletes' body image and eating practices, (3) whether there is a particular setting in which these discussions are best held and who is best suited to initiate discussions, and (4) that any weight management discussions are anchored in the health context rather than a sport performance context. In summary, the topic of weight management for female athletes is a potentially delicate and sensitive one given the pressures inflicted on them by society. Any discussions should be approached carefully, and after consultation with psychologists and nutritionists.

3.2.8 Coaching and Coach Behaviors

Extending the discussions about the significance of the coach–female athlete relationship, there is a small body of research that has begun to examine an athlete's preferences in coaching and coach and leadership behavior which has started to uncover specific preferences of female athletes. When examining this topic, the Multidimensional Model of Leadership (MML) is used as a theoretical anchor [78]. Chelladurai states that an athlete's preferred coaching behavior is one component of the MML, and that these preferences depend upon personal characteristics such as age and gender of the coach, alongside situational characteristics such as the sport being coached and the level at which the athlete competes at. However, research has uncovered the importance of the reciprocal nature of the coach–athlete relationship through the use of social exchange theories [79], motivation [80], and interpersonal as well interdependency theories [81, 82]. Through this important work, we have come to understand that athletes require autonomy, communication, commitment, empowerment, trust, and respect from their coaches in order to sustain an effective and productive relationship [80, 83–85]. However, a separate line of enquiry has identified gender differences in preferred coaching behaviors. Researchers report that female athletes tend to prefer training and instruction from their coaches with communications tailored based on the maturity and skill level of the athlete [86]. Additionally, research has concluded that female athletes have a preference for democratic behaviors in their coaches [87], getting involved in the process of making decisions [88], and team happenings [89] as well as for their coaches to be aware of the interpersonal dynamics in team sports, fos-

tering team spirit and enabling the formation of friendships [90]. When considering what female athletes did not appreciate, Vargas and Short demonstrated that within elite football (soccer) teams, female athletes disliked coaching communication that was critical and negatively focused without instructional cues. Despite some clear-cut coaching style preferences, the task of successful leadership is not as simple as it may seem. The context of the situation seems to impact the style of coaching females would like their coaches to engage in [91].

However, a degree of caution should be noted regarding the studies previously undertaken in this domain. It has been previously noted that the social and cultural context of coaching is largely absent from the literature, with any quantitative measures of coaching behaviors being limited to just describing instructional styles [92]. Additionally, what is universally understood by "the coaching process" is likely to be received differently due to the manner in which males and females develop psychosocially [93]. In answer to this Norman interviewed 27 high-performance female athletes who suggested that they would like their coaches to support them as an athlete and a person (e.g., to have an in-depth understanding of them, and treating them as individuals…rather than just athletes). Her participants also expressed a preference that coaching was a joint endeavor, rather than the coach playing the role of an authority figure and that communication should be regular, and positive (where warranted). Additionally, these athletes highlighted the importance of gender in the coach–athlete relationship. That is to say that the coach should understand that men and women may approach their training and competition differently, and that the gender of the coach is likely to affect the athlete's perception of them. For example, the athletes reported a deep emotional connection to their training and performances which they felt it was important for their coach to understand [8]. To conclude, it is critically important that coaches tailor their communications to the athletes they are coaching, to ensure gender in the coach–athlete dyad is not ignored and to generate a coaching partnership with their female athletes to ensure that they get the best out of this significant relationship.

Of additional interest in the coach–athlete relationship is the impact that gender has on leader behavior and follower outcomes, especially in sport teams [94]. Korabik and Ayman suggest that the behavior of a coach (for example) and the resultant athlete's behavior are influenced heavily by gender role orientation, expectations of role behaviors, and the gender make-up of the group [94]. To add to this, recent research has uncovered a gender difference in the preference or perceived benefit from authentic leadership; interestingly, authentic leadership practices were central to team functioning in male teams only [95]. As a result, there is call for further research to understand the role of gender dynamics in sport coaching in order that we are able to understand the most effective approach to leading female sport teams.

3.2.9 Microaggressions Towards Female Athletes

The final area worthy of discussion in this chapter is the impact of microaggressions that female athletes are regularly subjected to by virtue of their gender. Microaggressions are described as brief and commonplace daily verbal or behavioral injustices, whether intentional or unintentional, (subtle, unconscious discrimination) that communicate hostile, derogatory, or negative messages and insults toward marginalized/minority populations [96]. Microaggressions are associated with unconscious bias and prejudice and as such, female athletes are a distinct group of people that are subjected to them [97, 98]. According to Sue and colleagues, there are a total of nine different categories of microaggressions which are directed towards women. These include sexist humor/jokes, sexual objectification, use of sexist language, assumption of inferiority, denial of the reality of sexism, denial of individual sexism, restrictive gender roles, invisibility, and second-class citizenship. Much of these themes center around females being less capable, less strong, judged by their femininity and sexual objectification, and gender roles [96]. These themes carry into the sporting area as described by Kaskan & Ho, and we will discuss a variety of them as they apply to female athleticism [99].

The first is assumptions of inferiority which proposes that women are less stable and capable physically and mentally then men [9]. In the sporting arena, research has suggested that women's successes are often attributed to their opponent's weakness, rather than the winner's strengths [100]. Secondly, this theme is suggested to be present in the lack of female sporting coverage by the media. We see this play out in the continued lack of coverage of female events in comparison to males, despite the increase in female sporting engagement [101]. In fact, females are 40% of the participants in sport but only have 4% of the coverage in the media [101]. Despite television networks' argument that they are "giving people what they want" and do not have budgets for female coverage, this phenomenon can leave females to feel as though they will never amount to the importance of males in sports [99]. In addition, the way that female athletes are referred to in the media (e.g., as "girls," rather than "women") perpetuates this assumption of inferiority, specifically as men are rarely if ever referred to as "boys" [102].

The second is the sexual objectification of women in sport [103]. Sexual objectification is the phenomenon described as "the experience of being treated as a body (or collection of body parts) valued predominantly for its use to (or consumption by) others" [104]. In sport, many female athletes have been extremely sexualized unnecessarily, from the impractical bikinis worn during beach volleyball to featuring on the cover of sports magazines. Researchers showed teams and individual athletes a range of images depicting female ath-

letes demonstrating on-court competence, to off-court soft pornography. They then asked the athletes what message those images where portraying, in comparison to how they wished to be represented. Most female athletes wished to be depicted by images such as on court competence which they felt "represented for self/sport" they relayed that these images would "increase respect" towards them as an athlete. However, 47% of the athletes felt that in reality they were represented by "soft porn" which would result in "increased interest" for audiences. The authors concluded by stating that when it comes to women's sports, sex sells, particularly for male audiences [105]. Worse yet, female athletes who are sexualized, are shown to be taken less seriously by males [106]. Unfortunately, this form of microaggression may not be decreasing in prevalence as readily as one might hope. In 2012, the Badminton World Federation attempted to force females to play in skirts [99]. Fortunately, this initiative was not successful.

The third form of microaggression experienced by female athletes is restrictive gender roles. By that, it means an overemphasis on femininity that is primarily related to sports perceived to be "feminine" such as ballet or figure skating. In these contexts, females who participate in more male-dominant sports, such as basketball, experience a downplaying of their masculine traits, and encounter efforts for feminine portrayal. For example, in the Women's National Basketball Association, they are offered wardrobe sessions—to ensure that the athletes' makeup and uniforms look "right" [99]. Although it may seem harmless, perhaps even useful for some athletes, for others these types of actions enforce traditional gender roles and alienate women who may have more masculine traits, builds or tendencies. Thus, strict adherence to gender roles may act as microaggressions and perpetuate sexism and negative reaction to female athletes in their given sport [103].

The last microaggressions found in female sport are those based on shape and weight. For ages, fans and media have been obsessed with the shape and weight of athletes, males and females alike. However, for females often their shape and weight are discussed in the context of beauty culture and female beauty ideals, and often not in how their physique relates to their sport performance. It must be noted that these types of aggression are not uniquely perpetrated by Caucasian males, on the contrary, there are several records of reporters of color also discussing female athletes in such a manner [103].

Together, microaggressions of any kind have a detrimental impact on female athletes. This impact has been broken down by Kaskan and Ho into four categories [99]: (1) biological, (2) cognitive, (3) emotional, and (4) behavioral [107]. Biological consequences, although a novel construct in the field of microaggressions, are said to impact the endocrinological, immunological, and cardiovascular health of female athletes. The stress of encountering, ruminating, and entertaining other internal dialogues related to microaggressions is explained to result in heightened acute and chronic stress hormone—cortisol [108]. This increase in cortisol subsequently results in poorer health due to increased risk of infection and may make athletes more vulnerable to heart disease and hypertension. It has been proposed that the outlined outcomes could be particularly detrimental to athletes, as their performance, livelihood, wellbeing, and general health often depend on their ability to engage effectively in their sport [99].

Cognitive consequences have been proposed by Sue to be resulting from the time spent ruminating about if an assault has or has not happened. Evidence has suggested that the time spent engaging in these cognitive processes is disruptive. For athletes having their "head in the game" is crucially important to their success [9]. Two theories are suggested as potential mechanisms underlying the cognitive disruptions impacting female athletes. First, stereotype threat underlies the idea that microaggressions may facilitate the negative stereotypes about women in sport and ultimately be detrimental to their performance [109]. The second proposed is the objectification theory [104]. It suggests that the objectification of women can influence how a female performs in sport. Worrying about appearing in an "appealing" way to the fans, media, cameras can take away from the athlete's ability to focus and concentrate on her game [99]. Emotionally, research suggests that microaggressions can be related to body image concerns, eating disorders, and can create gender role conflicts. At times female athletes have struggled to balance the physical needs of their sport with the Westernized feminine 'ideal' (see the female athlete paradox above). The balance between sport performance and femininity can be a heightened by notion that athletes may want to want to limit themselves physically, in order to remain feminine [99, 110]. For example, some women do not want to lift heavy weights, for risk of being bulky. Ultimately, their performance could be sacrificed but along with it these concerns may put in question the athlete's self-concept and self-esteem [111]. Lastly, the behavioral consequences of microaggressions are proposed by Sue and colleagues who suggest that forced compliance or the tendency to surrender natural behavior to meet the "expectations" of society is key to the behavioral outcomes of microaggressions [9]. Kaskan and Ho suggest that as a result of the male dominant themes that overarches in sports, female athletes engaging in feminine-like behavior on and off the court to compensate for the potential of them seeming masculine for engaging in sport [99]. If our female athletes are too worried about being feminine, they may miss out on opportunities to benefit from a feature that might be considered masculine (for example larger muscles) [110]. In turn, if there was not an underlying male dominance in sport, females with more masculine traits may view their body and capacities in higher regard, leading

them not to overcompensate by feeling as though they need to behave in a more feminine manner.

Sadly, research analyzing the press coverage of women's sports suggests that it assists in creating a "dismissive, hostile and sexualized environment" for female athletes at all levels. They conclude that identifying the characteristic of the athlete, then, is not her strength, dedication, or performance; it is her gender. In fact, in sport, microaggressions towards female athletes are endemic, with a great deal of work needed in order to educate a wide section of society to change their behavior [99].

3.3 Future Directions and Concluding Remarks

The construct of gender is borne out of societal expectations of what males and females should be, and how they should act. As individuals, this shapes our relationship with sport from an early age. Our formative socio-cultural influences impact and inform us on how females engage with sport, and as a consequence how society views them when they do. This chapter has examined the extant research informing our understanding of key topics that characterize female athletes' experiences of sport performance. The research presented has uncovered gender differences in the sources and timing of self-confidence—a construct that is fundamental to success in training and competition. Female athletes, for example, are likely to take confidence from striving for personal goals, achieving self-imposed standards and receiving positive reinforcement from significant others. In order to build a greater understanding of the effective coaching of female athletes, we suggest investigating the impact of a knowledge of gender-specific sources of confidence in sport may help facilitate the athletic development of this population.

Interestingly, self-confidence in sport is a mediating factor in the anxiety–performance relationship. Although competitive state anxiety is a construct experienced regularly by most athletes, the research we presented in this chapter has revealed gender differences in its manifestation and management. In recent studies, the competitive state anxiety experienced by female athletes has defied prediction. It was found that female athletes are often less cognitively anxious than men, and that they are more likely to interpret their somatic anxiety as facilitative to their performance. What is of particular significance here is that despite observing results that rejected the hypotheses of the researchers, no suggestion has been made to investigate the manner in which female athletes cope with the demands of competitive state anxiety. It may be that female athletes have superior coping skills compared to their male counterparts in times of intense stress. Certainly, this is a valid suggestion for future investigation.

It is disappointing to note that the odds are stacked against females in sport from an early age. The research we have presented shows that males are likely to engage in sport twice as frequently and for longer than females. This trend crosses international boundaries and cultures and is linked to the motivational climate in sport. The motivational climate is the environment created by others that influences the perception of what is needed to be successful. Research informs us that female athletes prefer a task-orientated climate in sport—one where successful performance is self-referenced, and the importance of effort is emphasized over winning. We hypothesized that this preference is accountable to upbringing, peer and socio-cultural influences on the female throughout her lifespan. It would be useful, however, to understand more fully the impact of the application of this knowledge into practice. By creating more task-orientated sporting environments at every level, surely, we can reverse the inequality in engagement with sport in the future.

When female athletes form part of a high-functioning sport team of the same gender it tends to be characterized by a high degree of social cohesion, which results from a key focus on relationships within the team. Under certain circumstances, this can have a positive impact on the team's performance, but it can also lead to negative connotations such as group polarization, group think, and the pressure to conform. Currently, there is a dearth of research that seeks to examine the impact of high social cohesion in all-female teams and the interventions needed to support the cohesion–performance relationship in such teams. This is certainly a viable avenue for future research.

The pressures and demands of a career in high-performance sport are undeniable. Yet, for female athletes, there is an added dimension that is often overlooked. The stressful impact of unfair treatment based on gender, the poor organization of some women sports, the patronizing attitudes of some individuals in the sporting domain, stereotyping, microaggressions, and generally being on the receiving end of a second-class style of treatment can contribute to the likelihood of negative sport performance. However, research shows that female athletes are often adept at coping with these and other stressors. Specifically, the use of emotion-focused coping and social support strategies tend to serve them well under these circumstances. However, a wider awareness of some of the gender-specific challenges female athletes face would serve coaches and support staff well in their support of their athletes. This warrants future research attention.

One particular method of coping that serves female athletes well is the application of self-compassion. This refers to the adoption of a more positive, accepting and understanding approach to the self. Self-compassion can protect against emotional turmoil and enhance wellbeing—this may be especially useful for the female athlete who often attracts

media, public evaluation, and is subject to microaggressions. Understanding how to effectively introduce and maintain self-compassion in a team setting, involving coaches and support staff would be a useful focus of attention for future research.

Body surveillance is actively promoted by the elite sport environment and is of higher significance for female athletes. If enacted by coaches and support staff, body surveillance if handled incorrectly can put female athletes at a high risk of body image disturbances, low self-esteem, social physique anxiety, and disordered eating. This is due to a phenomenon known as the female athlete paradox where the competing interests of the Westernized 'ideal' female body, which is thin and slender, alongside the physical requirements of the individual's sport for power and strength create an often-untenable situation. For female athletes this paradox extends beyond retirement. The manner in which coaches and support staff talk to female athletes about their weight can have a profound effect on their self-perception. Much more work is needed to educate coaches and support staff on this complex and highly sensitive issue. Indeed, more research-informed guidance is needed for these populations. Special significance is placed on those working in lean, weight-contingent, and aesthetic sports, as these place female athletes at higher risk.

The relationship between the female athlete and the coach is a significant and influential one. Research in this area has uncovered athlete gender specificity in the preferences for coaching behaviors. Specifically, female athletes have been shown to prefer democratic coaches that involve their athletes in the decision-making process. In addition, female athletes place a high degree of importance on coaches helping to facilitate the interpersonal dynamics within a team and helping to foster team spirit. Research shows that gender is an important variable in the coach–female athlete relationship which should not be ignored when the coach is male. Certainly, there is a need for future research to uncover the nature of gender dynamics in coaching female athletes in order that we might help to advance the effectiveness of coaching this population.

The final issue addressed by this chapter was a subtle, yet significant topic that impacts the lives of female athletes on a regular basis. Microaggressions are regular verbal or behavioral injustices that communicate hostile, derogatory, or negative messages based on gender discrimination. Unfortunately, sport provides a breeding ground for microaggressions towards female athletes as society and the media impose their assumptions of inferiority, sexual objectification, restrictive gender roles, and an obsession with the size and shape of the individual's body on the female athlete. Indeed, press coverage is often outwardly hostile towards female athletes and work is needed to investigate how to start to disrupt this concerning trend. It is our collective hope that female athletes' efforts can ultimately be celebrated and revered in the same way as male athletes'.

Chapter Review Questions

1. Research suggests that female athletes gain self-confidence from
   (a) feeling like they are superior to their competitors
   (b) winning
   (c) encouragement from coaches and meeting their personal goals and standards
   (d) having a large following on Instagram
2. Stressors that are *specific* to the female athlete in a high-performance sport environment include
   (a) the expectations of family members
   (b) unhelpful gender stereotypes, microaggressions, and substandard treatment
   (c) combining an athletic career with other hobbies, interests, and work
   (d) sponsorship and funding
3. The 'female athlete paradox' means
   (a) the requirement for female athletes to be thin to meet society's ideals, and strong and powerful for success in their sport
   (b) female athletes should never expect to be treated in the same manner as male athletes
4. The style of leadership female athletes generally prefer their coaches to exhibit is
   (a) Laissez-Faire
   (b) Autocratic
   (c) Transactional
   (d) Democratic
5. Microaggressions can be unintentional. True or False?
   (a) True
   (b) False

Answers

1. c
2. b
3. a
4. d
5. a

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4 Reproductive Changes from Puberty to Menopause and the Effects of the Menstrual Cycle on Bone Formation and Bone Loss

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Learning Objectives

After completing this chapter, you should have an understanding of the following:

- The major physiological transitions during a woman's life
- The pertinent female reproductive anatomy and physiology of a normal menstrual cycle, including the different phases and roles of various hormones
- How reproductive hormones change throughout the lifespan of a woman
- The interaction between different ovarian hormones and various bone components
- The importance of achieving peak bone mass and the impact of the menstrual cycle on attainment of peak bone mass
- The impact of menopause on health measures

4.1 Introduction

Puberty and menopause distinguish the beginning and ending of the reproductive competence in females, marking two major transitions in a woman's life. Before puberty, the reproductive system remains dormant and secondary sexual characteristics are absent. The initiation of puberty in late childhood stems from a rapid change in endocrine function resulting in growth, sexual maturation, and reproductive capability. Puberty can be broken down into two phases: adrenarche—activation of the development of secondary sexual characteristics and gonadarche—activation of the hypothalamic–pituitary–gonadal axis. Menarche, or the initiation of the menstrual cycle, occurs at the end of puberty and is an important sign of this transition into sexual maturity [1]. During this second stage of sexual maturity, which in the United States lasts from about 13–51 years of age, menstrual cycles occur cyclically except when interrupted by factors such as pregnancy, hormone replacement, or lack of available energy. Menstrual cycles can be suppressed by stressful life events or by lack of nutritional resources, the latter sometimes spurred by extreme dieting and/or excessive exercise. Most women enter menopause and stop having menstrual cycles in their late forties or early fifties, entering the postmenopausal stage [2]. Length of time spent in the postmenopausal state has increased, due to the average lifespan extending over 80 years of age [3]. The transitions between these two stages, puberty and menopause, are accompanied by drastic changes in levels of the most important female hormones, estrogen and progesterone which has caused concurrent increases in the health concerns of postmenopausal women.

The systemic hormonal milieu of the menstrual cycle plays a very important role in bone formation, especially during puberty. Studies have found that 40–50% of adult peak bone mass is accumulated during puberty [4] and peak bone mass is achieved around ages 25–35 years [5]. Sex hormones help to maintain peak bone density until menopause. During menopause, the quiescence of sex hormone production, primarily estrogen, leads to rapid bone loss. Age-related bone loss is correlated to an increased risk in bone fracture. This chapter will focus primarily on the female menstrual cycle and its influence on peak bone mass achieved during and after adolescence.

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4.2 Research Findings and Contemporary Understanding of the Issues

4.2.1 Puberty

Puberty is not a single event but classified as a series of events that culminate in the development of reproductive capability. These events start in utero and as an infant, sometimes known as 'pre-puberty,' with a brief activation of the hypothalamus–pituitary–gonadal (HPG) axis [6–8] and then becomes quiescent until the beginning of puberty [9].

In females, puberty starts with the re-activation of the HPG axis, resulting in the secretion of gonadotropin-releasing hormone (GnRH), which stimulates the pituitary to release luteinizing hormone (LH) and follicle stimulating hormone (FSH). GnRH pulse control is under both excitatory and inhibitory regulation, so as a female starts puberty the excitatory control increases, while the inhibitory control decreases [10]. Both GnRH and FSH hormones stimulate the ovaries to enlarge and begin the production of estrogen, this phase is also known as gonadarche [11]. The development of secondary sexual characteristics, primarily thelarche (onset of secondary breast development, also known as breast budding) comes next [12]. This begins around 8–13 years of age and is followed by the development of pubic hair and increased growth velocity, and ends with menarche, or start of the menstrual cycle [13, 14]. Menarche is one of the final phases of puberty and represents the completion, or near completion, of sexual maturation.

The onset of puberty is determined by a combination of genetic, endocrine, and environmental factors and can be altered by disease, energy availability, exercise, and environmental chemicals [15, 16]. Genetic studies have identified nearly 400 genetic variants that contribute to the age of menarche with an estimated variability of 57–82% [17–20]. The onset of puberty in females is highly sensitive to nutritional status and energy balance which is detected by GnRH neurons [21, 22]. Increasing rates of obesity, especially in developed countries, have been linked to earlier onsets of menarche [23, 24]. A higher body fat composition in females leads to earlier puberty onset; likewise, earlier onset is associated with increased risk of obesity later in life [25]. The age of menarche in industrialized nations has been declining in recent decades, most likely due to increased improvements in nutrition and public health [1, 26–28]. In the United States, the decrease in the age of menarche over the last 30 years has shown a strong relationship between the dramatic rise in body mass index (BMI) [25, 29].

Athletes, especially in sports like swimming, running, and gymnastics, reach menarche later in life than non-athletes. Gymnasts and ballet dancers present with delayed menarche of 2 to 3 years often accompanied by oligomenorrhea (irregular menstruation) or secondary amenorrhea (absence of menstruation) [30–32]. In a recent meta-analysis comparing athletes to non-athletes, menarche occurred 1.13 years later in athletes [33]. In gymnasts, the mean difference range was 1.79 years later and 0.49 years later in athletes compared to non-athletes [33]. In rhythmic gymnastics, menarche was significantly delayed compared to the menarche age of their mothers and sedentary sisters [34]. However, athletes training 15 h or less per week do not display menstruation abnormalities or delayed maturation [35].

Abnormal puberty, either early or late, is classified as 2.5 standard deviations from the mean [9]. Agreement for the classification of early puberty, also known as precocious puberty (PP), has not been firmly established. Historically, it has been defined as the development of secondary sex characteristics before the age of 8 years [9]. Due to the myriad of factors contributing to secondary sex characteristics and earlier breast development, the age has been changed to 7 years old [36]. There remains little agreement on the classification of PP. Pubertal delay is classified as the absence of thelarche, or breast development, by the age of 13 years [9]. Delay of menarche (primary amenorrhea) is characterized by the absense of first menstruation by age 16 and may be due to genetics, insufficient intake of appropriate nutrition, polycystic ovary syndrome, environmental factors, among other factors [9, 37].

4.2.2 Menstrual Cycle

The menstrual cycle functions in a highly coordinated fashion with the contribution from multiple systems comprised of the hypothalamus, pituitary gland, ovaries, uterus, and vagina. At the center of the reproductive system are the ovaries, a paired organ which has both a reproductive and an endocrine function. The ovaries store and release the ovum, as well as produce female sex hormones. Three levels of hormones are secreted in a feedback loop termed the hypothalamic–pituitary–ovarian (HPO) axis: (1) by the hypothalamus—gonadotropin-releasing hormone (GnRH); (2) by the anterior pituitary—follicle-stimulating hormone (FSH) and luteinizing hormone (LH) in response to GnRH; and (3) by the ovaries—two gonadal steroids, estrogen and progesterone, in response to FSH and LH (Fig. 4.1). Regulation of the menstrual cycle is controlled by both LH and FSH from the anterior pituitary gland in response to GnRH from the hypothalamus. These hormones are secreted in a pulsatile fashion with varying amounts during various phases of the menstrual cycle.

The 'textbook' menstrual cycle characterized by the cyclical growth and decline of the endometrium in young, healthy women lasts 28 days (from the first day of menses to the beginning of the next menses) [39]. However, in real life,

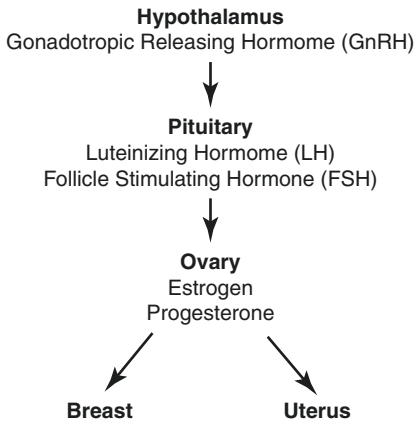

Fig. 4.1 This figure shows the primary components of the female reproductive system and the hormones that communicate between the various organs. The hormones produced by each gland are shown in parenthesis (*GnRH* gonadotropin-releasing hormone; *LH* luteinizing hormone; and *FSH* follicle stimulating hormone). Figure adapted by Amber McCord, Texas Tech University, from Norman, R. (2014). Reproductive changes in the female lifespan. In J. Robert-McComb, R. Norman, & M. Zumwalt (Eds.). The active female: Health issues throughout the lifespan (pp. 25–31). New York, NY: Springer Science + Business Media [38]

the cycle is highly variable and ranges from 25 to 34 days, with menstrual flow lasting from 3 to 7 days [40, 41] and remains variable from the start of menses to menopause. Typically, two phases encompass the menstrual cycle: (1) follicular or proliferative phase (growth of the endometrium stimulated by estrogen) and (2) luteal or secretory phase (transformation of the endometrium from a proliferating into secreting-type tissue under progesterone influence). The 'textbook' duration of the follicular and luteal phase is 14 days each; however, the majority of the variability in menstrual cycle occurs in the follicular phase [42] and luteal defects are common in athletic females [43].

The first day of menses and the follicular phase is marked with the initial sign of vaginal bleeding due to the shedding of the endometrium (uterine lining). During menses both estrogen and progesterone levels are low (Fig. 4.2). The pituitary gland releases FSH which stimulates the ovaries to start the growth of several follicles (usually 8 to 10), then levels begin to decline until the late follicular phase. After a few days, one of the follicles becomes the dominant follicle and in turn starts to produce estrogen. As the follicle grows it produces greater concentrations of estrogen, with levels

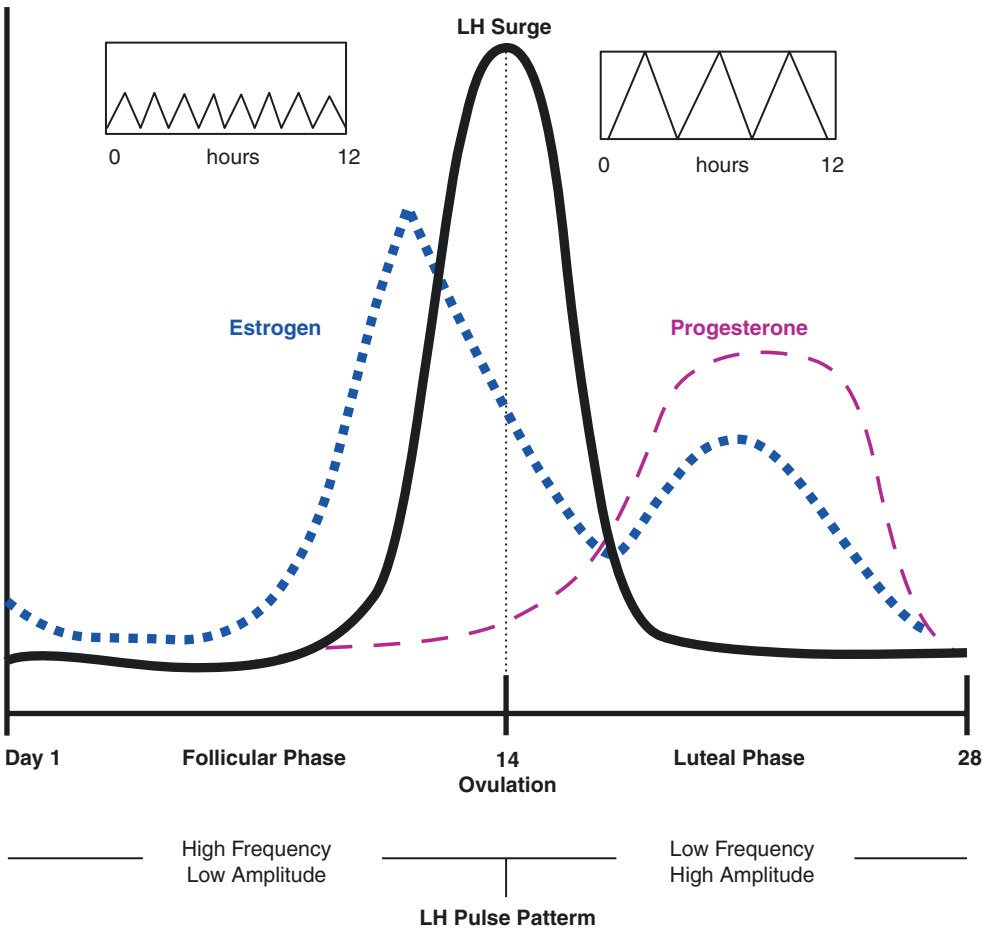

Fig. 4.2 Changing levels of pituitary (LH, FSH) and ovarian hormones (E, P) throughout the menstrual cycle plotted in reference to the day of the ovulatory LH peak. *E* estradiol, *P* progesterone, *LH* luteinizing hormone, and *FSH* follicle-stimulating hormone. Figure adapted by Amber McCord, Texas Tech University, from Zumwalt M, Dowling B. Effects of the Menstrual Cycle on the Acquisition of Peak Bone Massin J. Robert-McComb, R. Norman, & M. Zumwalt (Eds.). The active female: Health issues throughout the lifespan (pp. 81–90). New York, NY: Springer Science + Business Media [47]

peaking just before ovulation [44]. The estrogen produced from the follicles triggers the uterus to rebuild the lining that was shed from the previous menses, causing it to thicken. This thickening of the endometrium occurs in order to create the proper environment for a potential fertilized egg to implant and grow [45]. LH concentration slowly increases towards the end of the follicular phase until peaking at mid-cycle, generally occurring on the same day of the estrogen surge. This peak in LH and FSH concentrations causes ovulation (release of the follicle from an ovary). The luteal phase then takes over during the second half of the cycle under the continuing influence of LH. Next, the released follicle transforms into the corpus luteum and produces progesterone and estrogen [45, 46]. Progesterone secretions surpass estrogen levels, though the latter concentration remains fairly high. If there is no fertilization, the corpus luteum degenerates, causing both hormonal levels to simultaneously fall. The rapid drop in estrogen and progesterone causes the monthly cycle to repeat itself by shedding of the endometrium, manifested by menstrual flow and the start of the follicular phase.

4.2.3 Disruption of the Menstrual Cycle

When a woman becomes pregnant, her menstrual cycle stops because of elevated levels of estrogen and progesterone, which suppress the secretion of pituitary LH and FSH. Initial levels of estrogen and progesterone are supported by a hormone from the embryo called human chorionic gonadotropin, HCG. This is the hormone that is detected in pregnancy tests. After the woman gives birth and begins to nurse her baby, the hormone prolactin elevates, due to the suckling stimulus, and inhibits GnRH secretion, resulting in suppressed menstruation. This event is termed lactation amenorrhea and has been directly correlated with suckling 'intensity' [48, 49]. Studies have shown that at least 6 bouts per day and 80 min of suckling in a 24-h period is enough to induce lactation amenorrhea [50]. The length of lactation amenorrhea, and subsequent return of menses, is highly dependent on the duration and bouts of breast feeding, mother's age, and introduction of foods to the infant, among others [51].

Abnormal menses can be classified into two different categories: primary and secondary. Primary amenorrhea is defined as the absence of menstruation by age 15 [9]. Secondary amenorrhea is termed as the absence of three or more consecutive menses following menarche [52]. Potential consequences of amenorrhea are infertility, failure to reach peak bone mass, premature bone loss, and increased musculoskeletal injury risk. Disordered menstrual cycles occur in 24% of adolescent females and 3–66% of adult females [53, 54]. A higher prevalence of irregularity is reported in the female athletic population compared to sedentary women [55, 56]; it is estimated that one in five female athletes have some form of menses abnormality [57]. Many factors have been attributed to the disruption of the menstrual cycle (e.g., low body weight, poor nutrition, excessive exercise, stress, endocrine disorders), thus identifying a single determinant can be difficult.

The variability of reported menstrual irregularity has been related to participation in particular sports, primarily running, gymnastics, and swimming. For instance, the prevalence of amenorrhea was found to increase from 3% to 60% in long-distance runners as the weekly distance increased from less than 8 miles to over 70 miles [58]. Intense training causes an increase in secretion of cortisol, endogenous opioids, and prolactin—all which suppress the secretion of GnRH and LH [59]. Reduced GnRH and LH secretions in turn reduce estrogen levels, which can result in a disruption of the menstrual cycle. Excessive exercise has also been shown to increase testosterone production which may also play a role in the disruption of a normal cycle.

Diet also plays an important role in the normal menstrual cycle. Endocrine function is highly dependent on the amount of available energy. Energy availability (EA) is the quantity of energy remaining after physiological energy is utilized (i.e., energy for everyday movement and activity). More specifically, 'energy availability' is defined as dietary energy intake (DEI) minus exercise energy expenditure (EEE). In effect, EA is the amount of dietary energy remaining after exercise training for all of the body's other important functions. An EA of about 45 kcal/kg of fat-free mass (FFM) per day maintains a healthy adult in energy balance. EA declines when DEI is reduced and/or EEE is increased. When EA falls below 30 kcal/kgFFM/day, reproductive and skeletal health is often impaired [60]. Although a threshold of 30 kcal/kg FFM/day has been suggested for the maintenance of menstrual function, there will be some women who consume less than this amount without menstrual dysfunction and others who consume more but present with dysfunction. This threshold has recently been debated and it has been suggested that a sliding scale is more applicable [61]. A dose response is clearly evident [62], but the threshold of 30 kcal/kg FFM/day should be used with caution as it does not apply to every athlete.

As long as energy availability is maintained, the endocrine system will function optimally with normal hormone serum levels. Disruption of non-essential functions, like reproduction, because of low EA allows for the redirection of energy to be used for vital processes such as thermoregulation, locomotion, and health maintenance. Insufficient energy will adversely affect the pulsatile secretion of LH [63]; adolescent females are more sensitive to LH disruption than females who are older [64]. Even a temporary restriction (5 days) of EA has shown to decrease the pulsatile release of LH [65], which causes a decrease in hormones such as estrogen, testosterone, GH, and insulin-like growth factor 1 (IGF-1). On the other end of the spectrum, an extreme excess of available energy, as seen

in obesity, has been shown to cause a massive alteration of multiple hormones as well [66]. Specifically, obesity affects the function of the HPG axis resulting in increased LH secretion, which also disturbs the cyclical function of the menstrual cycle [67].

In female athletes, amenorrhea is often part of a multipart syndrome termed Female Athlete Triad. This term was officially described in 1993 to describe female athletes who exhibited disordered eating, loss of bone, and amenorrhea [68]. Women who are at greatest risk are those training in sports where low body weight is desired, but the triad could occur in any sport [60, 69], and has been found to be present in men as well. The International Olympic Committee suggested the use of a broader, more comprehensive term, relative energy deficiency in sport (RED-S). The classification of RED-S consists of disordered eating (low EA), amenorrhea, and decreased bone mineral density. Identification and early intervention of RED-S is highly stressed. Coaches, trainers, and clinicians should be educated about the Triad or RED-S in order to identify and recognize key traits before they reach pathological levels.

A more in-depth discussion of the female athlete triad is described in Chap. 5 A Modern Understanding of the Models of Energy Deficits in Athletes of this book.

4.2.4 Cessation of the Menstrual Cycle

Females typically begin the transition from a reproductive to a non-reproductive state during the end of their fourth decade, and remain in this transition period for 4–5 years before reaching menopause [70, 71]. Menopause is defined as 12 consecutive months of amenorrhea without any pathological or physiological causes and typically occurs around 51 years of age in the United States [72]. The Stages of Reproductive Aging Workshop (STRAW) developed a system to classify ovarian aging, starting with normal menses to menopause, all centered around the final menses. There is a total of seven stages, five before the final menses and two after: late reproductive stage (Stage −3), early menopause transition (Stage −2), late menopause transition (Stage −1), early postmenopause (Stage +1a, +1b, +1c), and late postmenopause (Stage +2). All stages are classified by critical changes in the HPG axis and ovarian function [72]. Stage −3, late reproductive, marks the time when fertility begins its decline and menstrual cycles start to become irregular. Early follicular FSH levels increase causing the phase to become more variable. The early menopause transition (Stage −2) has increased menstrual variability, especially increased in length, accompanied with an increase in FSH levels. Late menopause transition (Stage −1) is marked by amenorrhea of 60 days or longer with 25 IU/L of FSH [73]. This stage is estimated to last 1–3 years with menopausal symptoms most likely occurring at this stage. Early postmenopause (+1a, +1b, +1c) is associated with a continued rise in FSH serum concentrations and decreased estradiol until approximately 2 years after final menses, at which time hormone levels stabilize. Stage +1a and + 1b last on average 2 years, whereas Stage +1c lasts 3–6 years. The entire early postmenopause stage, therefore, lasts 5–8 years in length. Finally, Stage 2+, late menopause, results in further aging of the reproductive endocrine cycle with symptoms of vaginal drying and urogenital atrophy.

Because the life expectancy for women is now approaching 80 years and menopause occurs at about 50 years of age, the average female will live approximately 30 years after her ovaries have ceased to produce estrogen. This has serious physical and mental health implications in the aging female population. The physical health implications of menopause, likely due to the associated loss of estrogen, include an increase in cardiovascular disease risk factors [74, 75], unfavorable changes in body fat distribution [76], and an increased risk of osteoporosis [77]. Typical physical, social, and psychological symptoms that occur during the menopause transition and beyond include hot flashes, sleep disturbances, vaginal dryness, decreased libido, headaches, joint pain, fatigue, depression, anxiety, and memory loss [78]. Of these menopausal-related health consequences, increased fracture incidence as a result of osteoporosis, is a major public health concern [79, 80]. Osteoporosis is considered in more depth in the chapter on exercise and osteoporosis in this book; however, the interaction of reproductive hormones on bone formation and bone loss will be considered here.

Hormone replacement therapy (HRT) relieves some of the uncomfortable aspects of menopause and may protect against osteoporosis. The use of HRT, however, has fallen out of favor since 2003 due to concerns, primarily from the Women's Health Initiative [81], over increased risk of breast cancer [82] and cardiovascular disease [83]. Additional research is needed to unravel the complex actions of hormone replacement formulations so that women can have a healthier life after menopause, although risk seems to be dependent on existing contraindications, age since menopause and dose and method of delivery [84].

4.2.5 Bone Composition and Physiology

Bone is living mineralized, connective tissue, comprised of specialized cells, along with non-cellular substances, organic matrix (35% by weight), and inorganic mineral (65%). Two key types of bone cells are osteoblasts, which are involved in bone formation, and osteoclasts, which are involved in bone resorption. Bone growth occurs when the osteoblasts secrete collagen, thus trapping some osteoblasts in the matrix caus-

ing them to turn into osteocytes (mature bone cells). Bone is extremely dynamic and undergoes constant modeling and remodeling during a woman's lifespan. Bone modeling occurs when the bones change shape due to a physiological response or mechanical stress. Mechanical loading of bone exerts a positive effect on bone formation at points of stress, in a process defined by Wolff's Law. During this process of bone modeling, bone formation and absorption are not tightly coupled and is less frequent in adults [85]. With bone remodeling, osteoclast and osteoblast action is tightly coupled. Remodeling consists of consistent breakdown of mature bone and mineralization of new bone. Bone balance is the difference between the breakdown of mature bone and the new bone being formed. The equilibrium between breakdown and building is critical in the maintenance of healthy bone. Increased breakdown of bone with no increase in building can lead to bone disease, such as osteoporosis, leading to decreased bone density and increased risk of fracture [86]. This bone remodeling process is further covered in the chapter on exercise and osteoporosis in this book.

Bones serve multiple functions, primarily providing a structural support for other organs and allows for normal movement and exercise. Bone also serves as a mineral bank, sequestering 98–99% of the body's total calcium. Maintenance of the narrow range of serum calcium levels is controlled by the endocrine system. Total calcium concentration is regulated between 8.5 and 10.5 mg/dL [87]. If this level deviates even slightly, the calcium receptor of the parathyroid gland signals secretion of parathyroid hormone. Increase in parathyroid hormone concentration in turn stimulates the kidneys to produce calcitriol, the hormonal form of Vitamin D, and activates bone resorption, causing calcium levels to rise. Calcitriol acts on bone, kidneys, and the intestines to raise serum calcium levels which in turn switches off the calcium receptors and disrupts the secretion of PTH. Adolescents (during puberty) are highly efficient in absorbing calcium from their diet; however, as they age the efficiency decreases and the elderly must resort to utilizing calcium from other stores. During pregnancy, calcium absorption doubles [88, 89]. Aging and menopause are associated with a 0.21%/year decline in calcium absorption after the age of 40 years [90, 91].

4.2.6 Effects of Female Sex Hormones on Bone

The female reproductive system plays a major role in the maintenance of skeletal bone integrity from menarche to menopause. The skeleton is a primary target for estrogen, and to a lesser extent, progesterone. Estrogen and progesterone receptors are found on bone cells, and when activated positively, stimulate bone formation and inhibit bone resorption. Estrogen inhibits bone resorption directly via estrogen receptors (ERα), which exist on both osteoclasts and osteoblasts, but also has indirect effects on bone turnover. A key component in the indirect signaling pathway of bone turnover in response to estrogen is through the family of tumor necrosis factor (TNF) cells, receptor activator of necrosis factor-kappa B (RANK), RANK-ligand (RANK-L), and osteoprotegerin (OPG). The binding of RANK-L to RANK promotes fusion, differentiation, and maturation of osteoclasts, resulting in increased bone breakdown. Osteoprotegerin works as a decoy receptor for RANK-L by blocking the binding of RANK-L to RANK, therefore, playing a role in both preventing and regulating bone resorption. Bone resorption ends when the osteoclast dies by apoptosis. Both osteoblasts and osteocytes express RANK-L and OPG, while RANK is expressed on the surface of osteoclast precursors; hence, all three cells, as well as osteoclast precursors, are involved in bone resorption [92]. With optimal levels of estrogen, RANK-L expression is attenuated and the binding of RANK-L to RANK is blocked by OPG. However, when estrogen levels are low, RANK-L expression is increased, and OPG, which also decreases, is overwhelmed and unable to block its binding to RANK, resulting in increased osteoclastic activity and accelerated bone resorption [93, 94]. A summary of the proposed mechanisms involving estrogen and its effect on both bone formation and bone resorption is given in Fig. 4.3 [95]. The specific mechanism by which estrogen modulates bone turnover is still open to debate, but it is clear that an absence or withdrawal of estrogen, based on markers of bone turnover [96], leads to an increase in osteoclastic activity resulting in excessive bone resorption. This increased bone resorption is not fully compensated by an increase in bone formation, which leads to net bone loss.

Estrogen has other influences on bone remodeling. Estrogen controls the production of several cytokines, which leads to increased bone resorption. Notable bone-resorbing cytokines include interleukin (IL)-1, IL-6, tumor necrosis factor-α (TNF-α), macrophage-colony stimulating factor (M-CSF), and prostaglandins [97]. These cytokines increase in response to suboptimal levels of estrogen, and cause the inhibition of OPG expression and increase RANKL expression [98]. Estrogen also exerts its influence on bone formation; for instance, low levels of estrogen cause a reduction in osteoblast migration, recruitment, differentiation, and an increase in osteoblast apoptosis [99]. Low levels of estrogen are also associated with an increase in oxidative stress, evidenced by increases in pro-inflammatory cytokines [100], which decrease the lifespan of the osteoblast.

Other key hormones are involved in the bone remodeling process, which have relevance for bone maintenance in a female, include calcitonin, parathyroid hormone (PTH), follicle-stimulating hormone (FSH), and testosterone. Calcitonin and PTH work together to maintain the homeostatic balance of calcium in the blood. When calcium is low, PTH increases, stimulating RANK-L expression [93]. Calcitonin opposes the effects of PTH, inhibiting osteoclast activation and causing increased calcium uptake. Bone loss has been associated with an increase in FSH. High levels of

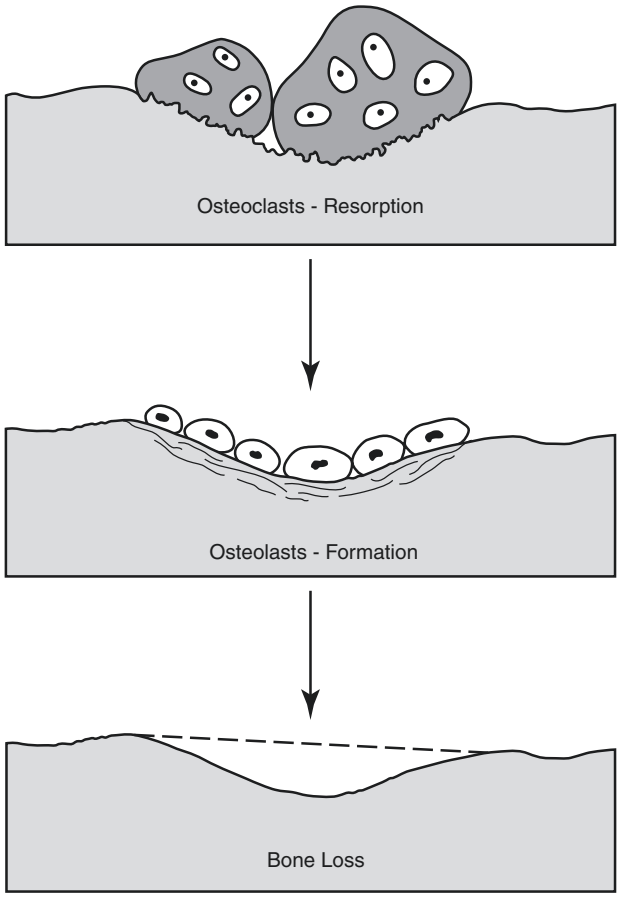

Fig. 4.3 The equilibrium between bone breakdown and building is critical in the maintenance of bone. Increased breakdown of bone without increased bone building leads to bone loss

FSH occur in the perimenopausal period, often before a significant reduction of estrogen is observed [101], as well as during other times of low estrogen, such as with subclinical menstrual dysfunction. Receptors for FSH on osteoclasts stimulate osteoclastogenesis and FSH increases the expression of RANKL [101]. Androgens, which include testosterone, can increase bone health by decreasing osteoclastogenesis, inhibiting osteoblast apoptosis, and improving calcium absorption [102]. Androgens bind directly with androgen receptors or indirectly through binding to estrogen receptors following aromatization in adipose tissue [103]. There is a close relationship between estrogen and circulating levels of growth hormone (GH) and IGF-1; these two hormones stimulate longitudinal bone growth, skeletal maturation, and bone mass acquisition [104, 105]. Insulin growth-like factor receptors (IGF-1R) are also located in the kidneys, where they are associated with the production of the hormonal form of vitamin D [106, 107]. With increased vitamin D in serum, IGF-1 indirectly stimulates the absorption of calcium and inorganic phosphorus in the intestines [108].

Sex hormone receptors have been found in growth plate chondrocytes (cartilage cells) during puberty. At the early stages of puberty, sex hormones stimulate longitudinal bone lengthening of the diaphyses (shafts of long bones) resulting in the "pubertal growth spurt" [109]. However, at the late stages of puberty the sex-specific hormones, primarily estrogen, play a large role in the closure of growth plates [110–112], thus, highly influencing the final height achieved in females (Fig. 4.4).

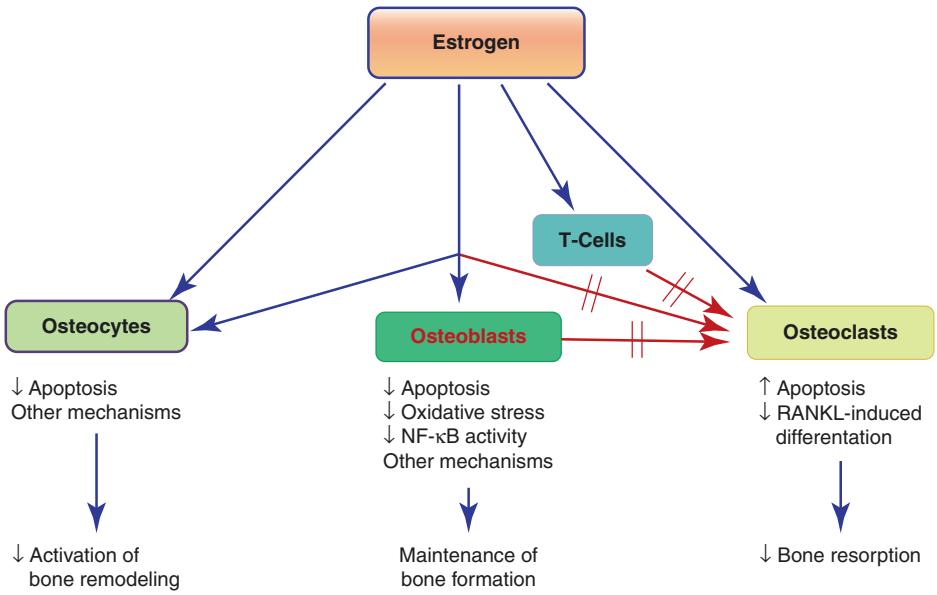

Fig. 4.4 Working model for estrogen regulation of bone turnover via effects on osteocytes, osteoblasts, osteoclasts, and T-cells. Reprinted from Trends in Endocrinology & Metabolism; Vol. 23/Number 11; Khosla S, Oursler MJ, Monroe DG; Estrogen and the skeleton; pgs. 576–581; © 2012, with permission from Elsevier [112]
The main effect of estrogen is to inhibit bone remodeling, likely via the osteocyte. Estrogen also inhibits bone resorption, principally by directs effects on osteoclasts, although effects of estrogen on osteoblast/osteocyte and T-cell regulation of osteoclasts likely also play a role. Estrogen deficiency is associated with a gap between bone resorption and bone formation, likely due to the loss of the effects of estrogen on decreasing osteoblast apoptosis, oxidative stress, osteoblastic NF-κB activity, and perhaps other, as yet undefined, mechanisms.

4.2.7 Peak Bone Mass

Bone mass, a measure of bone size and volumetric density, contributes to ultimate bone strength. Peak bone mass (PBM) designates the maximal quantity of bone gained primarily during the adolescent years (the critical window being between 9 and 20 years) while the skeleton is undergoing an accelerated growth in both size and density. By age 7, females have reached 80% of their adult height but only 40% of their PBM [113]. Before puberty, there is no substantial difference in bone mass in lumbar and appendicular spine when adjusted for age and physical activity [114]. Gender dimorphism occurs during puberty; this "adolescent growth spurt" occurs 1–2 years preceding the rapid deposition of bone into the skeleton. Adult bone structure is largely determined during the first two decades of life. In females, up to 92% of PBM is accumulated by 18 years of age [115]. After this, bone still continues to develop in terms of strength and density, up until about age 25–35 years, at which time true PBM is reached [113, 116, 117]. After attainment of PBM, measures to maintain bone density are vital because physiologic bone loss inevitably occurs over time [113, 117, 118]. Individuals with greater PBM as young adults are less likely to develop osteoporosis. Prior to reaching menopause in their fourth or fifth decade, females lose about 0.3% of their entire skeleton each year after the final acquisition of peak bone mass [113]. In postmenopausal women, researchers have predicted that increasing PBM by 10% could reduce risk of fracture by 50% [119] (Fig. 4.5).

Dual-energy x-ray absorptiometry (DXA) is the "gold standard" for the measurement of bone mineral density (BMD) to assess bone quantity. This technique uses emission of x-rays at two separate energy levels to distinguish bone from the surrounding soft tissue with very low radiation exposure. Results from DXA between 1.0 and 2.5 standard deviations (SD) below the mean for young adults, classify bone as being osteopenic. Even at this level, there exists a 2–2.5 times higher risk of spine or hip fractures due to increased fragility of the skeleton. Bone is deemed osteoporotic if the BMD is equal to or greater than 2.5 SD from the mean.

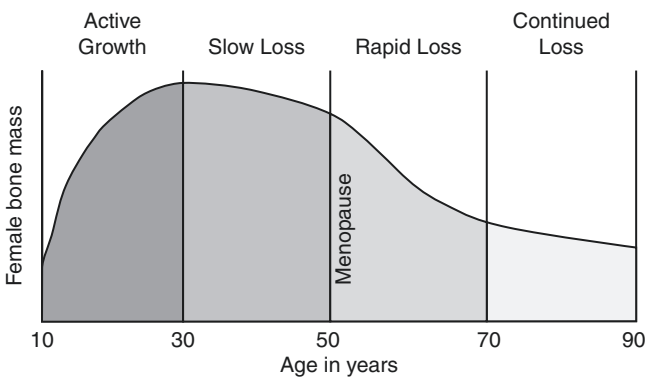

Fig. 4.5 Rate of bone loss through a women's lifetime

The quantity of bone deposited in the skeleton is influenced by both genetics (uncontrollable) and environmental (controllable) factors [120]. Physical activity is considered to be beneficial for skeletal growth and maintenance [121, 122]. The magnitude of the peak loading force acting on bone is a major factor on bone modeling and remodeling [123]. The load placed on the skeletal system varies with the type of physical activity. Activities involving the development of ground reaction forces are classified as impact sports which include gymnastics and running versus activities that do not contain ground reaction forces, like swimming, are called active loading sports [124]. Athletes involved in impact sports have greater BMD than athletes participating in active loading sports [124–126]. Vigorous physical activity has been shown to produce greater bone mass accrual in active children than sedentary children [127]. Studies have shown that estrogen increases skeletal sensitivity to mechanical loading, suggesting that early and mid-puberty are optimal times for skeletal benefit in terms of bony deposition [128]. Female athletes, particularly in sports such as running, gymnastics, and swimming, reach menarche later than non-athletes, which may potentially affect their bone mass negatively [129].

Appropriate and adequate nutrition (i.e., sufficient consumption of key bone-building nutrients such as calcium, magnesium, zinc, and vitamins K and D), and normal, regular menses all contribute to optimal bone health. Peak bone mass is also associated with calcium intake during puberty and early adulthood. In fact, adolescents and young women who consume low levels of calcium-rich foods have lower bone mass compared to age-matched individuals who consume adequate amounts of calcium [130]. Smoking is considered a risk factor for bone loss and increased risk for osteoporotic fractures [131, 132]. Comparing smokers to non-smokers, the former had decreased bone mineral density at the femoral neck [131]. Specifically, smoking is associated with increased FSH and LH serum levels, which cause a decrease in estrogen levels resulting in bone degradation [133]. The effects of alcohol on bone density are less conclusive; however, it has been suggested that moderate alcohol consumption is inversely related to hip fracture risk, while heavy alcohol use was associated with an increased risk [134].

4.2.8 Results of an Abnormal Menstrual Cycle on Peak Bone Mass

A delay in menarche, dysmenorrhea, oligomenorrhea (insufficient number of cycles per year), or secondary amenorrhea all interfere with the final attainment of PBM [135, 136].

Bone mass density has been shown to steadily decline, particularly in non-weight-bearing limbs, as the number of missed menses increased, and it was reported this loss of BMD may not be completely reversible [117]. Specifically, women with menstrual disorders will lose as much as 2% of their skeleton per year, almost tenfold more than the usual, natural rate. While bone is highly sensitive to exercise, exercising excessively can negatively affect both the reproductive and the skeletal systems, altering the body's normal hormonal milieu and causing a reduction in bone mass [137].

Endocrine function is highly dependent on the amount of EA. As long as energy availability is maintained, the endocrine system will function optimally with normal hormone serum levels. As discussed in "Disruption of Menstrual cycle" section of this chapter, insufficient EA can cause altered endocrine function, especially the functionality of the HPG axis, resulting in abnormal hormone levels, which can disrupt the menstrual cycle. This causes a decrease in hormones such as estrogen, testosterone, GH, and IGF-1. Concepts associated with EA are explored more thoroughly above and in Chaps. 5 and 19.

Bone mass density further declines as the number of missed menses increases [138]. Stress fractures are more common in female athletes with amenorrhea, with a relative risk of fracture four to five times greater than in eumenorrheic athletes [139]. Additionally, menstrual disturbance in adolescent athletes has been associated with increased risk of musculoskeletal injury. In high school athletes, females who reported to have menstrual abnormalities sustained a greater amount of musculoskeletal injuries compared to their peers with normal menstrual cycles [140, 141]. However, there is a positive effect of certain types of exercise on bone density. Scientists have studied a group of retired female gymnasts and reported higher BMD compared to women who did not exercise or participate in sports [142]. Even though involvement in a regular program of exercise, especially under high loads such as gymnastics, may partially offset the osteopenic bone caused by being amenorrheic, this is still far from being sufficient if there is inadequate available energy. Research has shown that bone mass in females who were sedentary, ate well, and had normal monthly cycles was actually higher than those athletes who exercised to the point of losing their menses [143].

Correction of any offending factor contributing to the rapid bone loss is key to the prevention of early onset of osteopenia/osteoporosis in an adolescent female. First steps should focus on energy status and modification of diet and exercise training, resulting in increased EA [60, 144]. The targets of treatment should be varied and athlete dependent but should include one of the following: reversal of recent weight loss, obtain body weight associated with normal menses, and energy intake should be set at a minimum of 2000 kcal/day (possibly more depending on exercise energy expenditure) [145]. Proper nutrient intake can greatly aid in the prevention of bone loss. Calcium [146] and vitamin D [147, 148] supplementation have been shown to be more beneficial before the onset of puberty. A study conducted on 8-year-old prepubertal girls found that by increasing the daily calcium dose from 700 to 1400 mg raised the BMD by 58% compared to the placebo group after 1 year of supplementation [149]. Regulation of menses can be obtained by hormonal replacement therapy (HRT)—the oral contraceptive pill is a popular form of this type of pharmacological treatment. However, the ultimate effectiveness of HRT for increasing BMD has not been shown to be effective [150–152]. Oral estrogen leads to suppression of GH and IGF-1 concentrations and these two hormones are vital in bone development [153, 154]. Specific lifestyle changes are recommended instead: avoidance of inactivity, refraining from cigarette smoking [131, 132, 155], and minimizing drinking alcohol [156–158]. Avoiding caffeinated beverages and drinks such as soda is recommended because both of these substances contribute to calcium wasting and, thus, could secondarily affect bone formation. Finally, appropriate exercise is recommended, especially dynamic, weight-bearing and high-impact loading exercise. Resistance training induces more effective changes in BMD than aerobic conditioning in postmenopausal women as well [159].

4.2.9 Menopause and Bone Mineral Density

With the beginning of menopause and during the menopause transition there is an associated decline of bone mineral density [160–163] and this decline is accelerated in the last phase of this transition [164–166]. In fact, the most important risk factor for bone loss in women at midlife is menopause. Declining levels of estrogen and increasing FSH levels are likely contributors to this decline in bone mass [162–165, 167–169]. For every doubling in FSH serum level there is an additional 0.3% decline per year in both femoral neck and lumbar spine BMD [167]. In 130 non-Hispanic Caucasian women (aged 31–50 years), women who lost BMD at a faster rate had significantly higher FSH, LH, and lower bone estradiol compared to those who lost bone at a slower rate [170]. Lumbar and femoral neck density losses are greatest in the year prior to, and up to 2 years after, the final menses [167, 171, 172]. During this 3-year transition period, white women display 2.5% and 1.8% per year rate of decline in the lumbar spine and femoral neck, respectively. Accounting for BMI, black women have the smallest rate of decline for both bone sites (2.2%/year in the spine and 1.4% per year in the femoral neck) and Japanese and Chinese women have greater losses at the femoral neck (2.1% and 2.2% per year, respectively) [171]. When dividing menopause into stages based around final menses, some scientists reported decline of spi-

nal BMD was highest in stage 3 and 4, and the BMD at stage 4 was 6.4% and 5% lower at the spine and femoral neck, respectively, compared to those at stage 1 [163]. Although bone loss accelerates after menses stop completely, the rate of bone loss varies based on location, ethnicity, and weight.

Markers of bone degradation also increase over the menopausal transition. A marker for type 1 collagen fiber breakdown, urinary N-terminal telopeptide of type 1 collagen (U-NTX), starts increasing 2 years prior to the final menstrual period and peaks 1.5 years afterwards [173]. The decline of estrogen and surge of FSH occur around the same time. Postmenopausal Japanese women have the highest levels of U-NTX and black women have the lowest [173], corroborating with the greatest decline in bone seen in Japanese women and the smallest decline seen in black women [171]. Measuring U-NTX during MT may help predict the total amount of bone loss. Longitudinal data show measuring U-NTX levels in late perimenopause and early postmenopause strongly predicts rate of bone loss in both the femoral neck and spine [174].

Attempts to mitigate rapid bone loss are vital in the aging female. Mechanical stress, as provided by dynamic, high-impact, muscle strengthening or weight-bearing exercises, is very important for maintaining bone integrity and has been identified as a key preventative and treatment option for osteoporosis [175]. Hormone replacement therapy has been shown to reduce vertebral fractures by 33% [176]. Women who initiated HRT during the menopause transition had 0.4% less BMD degradation per year [177]. Studies have shown bone mass and strength are improved with HRT [178], as well as increased muscle mass and composition [179]. However, the use of HRT effect on risk of fractures remains unclear; while estrogen is beneficial for the skeleton, oral contraceptives come with a negative side-effect. Long-term HRT use is associated with decreased tendon cross-sectional area, especially in an athletic population [180]. This could cause stronger and bigger muscles pulling on brittle tendon tissue attached to a stronger bone, with a potential increased risk of musculoskeletal injury. Specific drugs for osteoporosis have significant adverse effects which increase with increased duration of use [181]. Ingestion of calcium and vitamin D decreases bone absorption and mineralizes the osteoid. Administration of at least 800 IU/day of vitamin D combined with 1200 mg of calcium has been shown to be effective in the reduction of osteoporotic fracture risk [182, 183].

4.3 Future Directions and Concluding Remarks

During the lifespan of women, there are dramatic and life-changing transitions associated with the beginning and cessation of reproductive functions. These transitions, puberty and menopause, result in dramatic changes in the anatomy and physiology of females and are caused by fluctuating levels of estrogen and progesterone. The organs involved with controlling the menses are the hypothalamus, anterior pituitary and, of course, the ovaries. Each organ secretes different hormones, which interact in a complex, loop-type feedback mechanism to regulate the monthly female menstrual cycle. A regular, well-functioning monthly cycle is of paramount importance in bone deposition during the adolescent growth spurt and then in the prevention of bone loss after peak bone mass is achieved in the second decade of life. Irregular or absent cycles may indicate some underlying pathology. If menarche is delayed or if menstrual dysfunction occurs or menses disappears entirely, then the protective mechanism of estrogen on bone is lost. Relevant for female athletes in general, and especially adolescent female athletes, are the long-term consequences of insufficient energy availability that results in menstrual cycle disturbances and low bone mineral density. If this menstrual disturbance is not corrected promptly, it will eventually result in osteopenia or osteoporosis, ultimately increasing these females' susceptibility to fractures.

Osteoporosis prevention should start in adolescence, at the initial onset of menarche. Other factors, such as lifestyle habits (nutrition, training, etc.), play a very essential part in contributing to bone building or bone loss. As such, measures taken to ensure that the monthly female menstrual cycle is functioning correctly and optimally are of utmost importance to positively influence the final attainment of peak bone mass. The standard curriculum for high school and college coaches of female athletes should include the health consequences of exercise-induced menstrual dysfunction and specific methods of prevention and treatment.

As women enter their menopausal years, HRT has primarily been used to treat the menopausal symptoms that cause the most discomfort: hot flashes, vaginal dryness, and disturbed sleep. However, evidence from large clinical trials has revealed that our knowledge of the constellation of effects of HRT on cardiovascular health, cognition, and reproductive organs is very limited. Additional studies examining both basic and clinical aspects of the effects of HRT on hormonally responsive systems are needed before rational replacement therapies can be effectively used to improve health outcomes in postmenopausal women.

Chapter Review Questions

1. The hormone from the hypothalamus that stimulates pituitary LH release is
   (a) Estrogen
   (b) ACTH
   (c) Progesterone

(d) GnRH

2. The hormones primarily responsible for breast development at puberty in girls are
   (a) Estrogen and progesterone
   (b) LH and FSH
   (c) Cortisol and thyroxine
   (d) GnRH and TRH
3. The phase of the cycle when the lining of the uterus is growing is
   (a) Menstrual
   (b) Luteal
   (c) Follicular
   (d) Secretory
4. The hormone that causes ovulation is
   (a) FSH
   (b) LH
   (c) Prolactin
   (d) GnRH
5. What hormone prepares the lining of the uterus for implantation of the early embryo?
   (a) LH
   (b) FSH
   (c) GnRH
   (d) Progesterone
6. How many follicles normally mature and ovulate in the human?
   (a) One
   (b) Two
   (c) Ten
   (d) Many
7. Primary amenorrhea is when a young woman
   (a) Has her first menstrual period
   (b) Has not had her first menstrual period by age 15
   (c) Is infertile
   (d) Has had her first menstrual period by age 12
8. Menstrual cycles can be disturbed by many internal and external factors. The factor thought to be the primary influence on cycles in female athletes is
   (a) Too much exercise
   (b) Low energy availability
   (c) Birth control pills
   (d) Pituitary tumors
9. Amenorrhea in women who exercise excessively is most likely due to
   (a) Exercise
   (b) Psychological stress
   (c) Low energy availability
   (d) Genetics
10. Which hormones play a role in bone development?
    (a) Estrogen
    (b) GH and IGF-1
    (c) Vitamin D
    (d) All of the above
11. Which hormone is primarily responsible for closing the growth plates?
    (a) GnRH
    (b) Progesterone
    (c) Estrogen
    (d) FSH
12. True or False: Bone mineral density is shown to decline as the number of missed periods increases.
    (a) True
    (b) False
13. During menopause there is a decline in estrogen and increase in levels of which hormone, both of which are likely contributors to the decline in bone density?
    (a) Progesterone
    (b) GH
    (c) FSH
    (d) LH
14. One of the primary benefits of estrogen replacement therapy after menopause is
    (a) Continued menstruation
    (b) Protection against bone loss
    (c) Protection against stroke
    (d) Continued breast development

Answers

1. d
2. a
3. c
4. b
5. d
6. a
7. b
8. b
9. c
10. d
11. c
12. a
13. c
14. b

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A Modern Understanding of the Models of Energy Deficits in Athletes

5

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Learning Objectives

After completing this chapter, the reader should have an understanding of the following:

- The concept of energy availability
- The history and modern understanding of the female athlete triad
- Overview and development of the relative energy deficiency in sport (RED-S)
- Physiological relationship between energy availability, amenorrhea, and bone mineral density
- Performance consequences of low-energy availability
- Athletes at the highest risk for developing signs and symptoms associated with this syndrome

5.1 Introduction into Energy Availability

The concept of energy deficiency is central to the Female Athlete Triad and a new conceptualization, the Relative Energy Deficiency in Sport. Before we describe the models above, first, we must understand the concept of energy availability (EA). Loucks et al. (1998) [1] described EA as dietary energy intake (DEI) minus exercise energy expenditure (EEE). Perhaps, it could be paraphrased by stating that EA is the amount of dietary energy remaining after exercise training for other functions of the body such as cellular maintenance, thermoregulation, growth, and reproduction.

Daily Energy Intake (DEI) − Exercise Energy Expenditure (EEE) = Energy Availability (EA)

The threshold where normal physiological functions begin to be disrupted or impair health seems to be 30 kcal/kg lean body mass (LBM) or fat-free mass (FFM)·day, yet the threshold is not the same for all women [2]. It should be noted that **energy availability** (DEI − EEE) is not the same as **energy balance**. Energy balance is defined as DEI minus total energy expenditure (heat from all cellular functions, including exercise), not just EEE. Energy availability is much simpler to estimate and requires less expensive equipment, and so the term is more practical in real-life settings.

Daily Energy Intake − Total Energy Expenditure = Energy Balance

Low EA may occur with or without eating disorders and excessive energy expenditure during exercise without compensation through dietary means. When EA is too low, physiological mechanisms reduce the amount of energy used for cellular maintenance, growth, thermoregulation, and reproduction. This compensation tends to maintain energy balance (by slowing down metabolism and not providing energy for non-critical functions such as reproduction) and promote survival but impairs general health [2].

Today, around 42% of young women consider themselves athletes [3]. On average, the physical activity rates of these athletes have been reported as two to three times greater (13.2 h of training per week) than the rates of the physically active population (5 h per week) [4]. However, not all sports are equal in their risk for low-energy availability. On the contrary, athlete's most susceptible to decreased energy availability and are (a) athletes who participate in

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sports in which thinness confers a competitive advantage; (b) athletes who reduce their EI unintentionally and unknowingly due to appetite suppression resulting from exercise training; and (c) athletes with signs and/or symptoms of eating disorders [5]. Endurance athletes may inadvertently become low on energy availability without purposeful dietary restriction in the absence of an eating disorder or even disordered eating [6].

5.1.1 The Female Athlete Triad (FAT)

In 1992, the term Female Athlete Triad was used to diagnose when an athlete had an eating disorder, amenorrhea, and osteoporosis [7]. The triad was considered cyclical, one disorder drove another disorder, and all disorders were intermingled. According to The American College of Sports Medicine's (ACSM) 2007 Position Stand, the updated definition of the triad now describes the FAT as a spectrum of interrelationships among energy availability, menstrual function, and bone mineral density that may transcend towards the following clinical manifestations; eating disorders, functional hypothalamic amenorrhea, and osteoporosis [8] (see Fig. 5.1).

Despite a low estimated prevalence of the triad (0–1.2%), the prevalence of any two or any one of the triad events can range from 2.7 to 27.0% and 16.0 to 60.0%, respectively [3]. Although any athlete may suffer from the disorders associated with the female athlete triad, girls, and women who participate in sports that place a premium on appearance and thinness are especially susceptible [9]. According to the International Olympic Committee's Position Stand on the FAT, high-risk sports include not only ones that emphasize a thin body size or shape (distance running, cycling, cross-country skiing) but also in sports that categorize weight classes (rowing, martial arts, wrestling, weightlifting), use revealing attire (swimming, volleyball, diving, cross-country skiing, track and field, cheerleading), are judged (diving, figure skating, gymnastics) or have an appearance aspect (rhythmic gymnastics) [10]. Literature has included mostly Caucasian females in energy availability studies; therefore, current literature is lacking with inclusion of African–American, Hispanic, and Asian athletes [11].

5.1.2 Relative Energy Deficiency in Sport (RED-S)

The International Olympic Committee has argued that a more holistic approach, then the FAT is required since physiological impairments due to low energy are not limited to metabolic rate, menstrual function, and bone health, nor are they unique to men. Instead, the impact of low energy is more complex and impacts many interrelated physiological changes [12]. Low-energy impacts, psychological factors, immunology, endocrine, metabolic, gastrointestinal (GI), cardiovascular and growth and development, immunity, protein synthesis, cardiovascular health, psychological health, and endocrine function, which all interplay (see Fig. 5.2). As a result, the International Olympic Committee developed the Relative Energy Deficiency in Sport (RED-S) model, which captures physiological disturbances associated with athletes who are energy deficient.

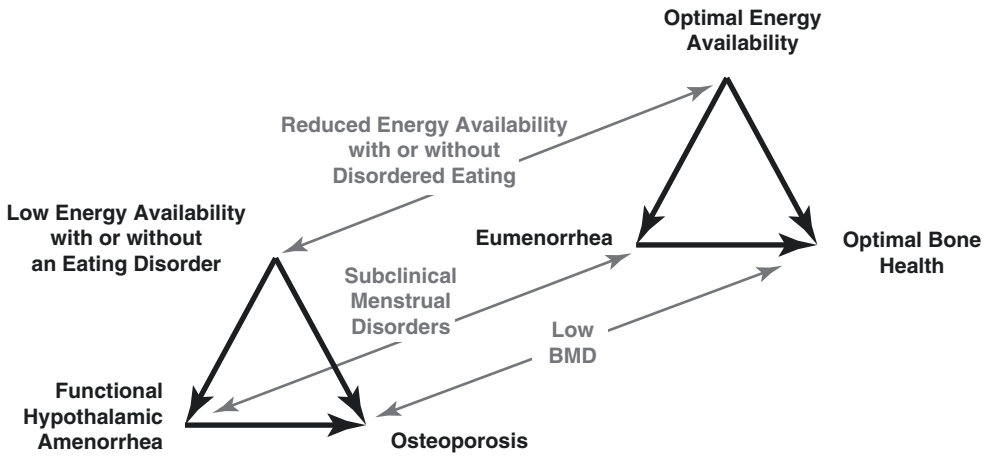

Fig. 5.1 The Female athlete triad. The spectrums of energy availability, menstrual function, and bone mineral density along which female athletes are distributed (narrow arrows). An athlete's condition moves along each spectrum at a different rate, in one direction or the other, according to her diet and exercise habits. Energy availability, defined as dietary energy intake minus exercise energy expenditure, affects bone mineral density both directly via metabolic hormones and indirectly via effects on menstrual function and thereby estrogen (thick arrows). Reprinted from Nattiv A, Loucks AB, Manore MM, et al. American college of sports medicine position stand. The female athlete triad. Medicine & Science in Sports & Exercise. 2007;39(10):1867–82, https://journals.lww.com/acsm-msse/Fulltext/2007/10000/The_Female_Athlete_Triad.26.aspx, with permission from Wolters Kluwer Health, Inc. [8]

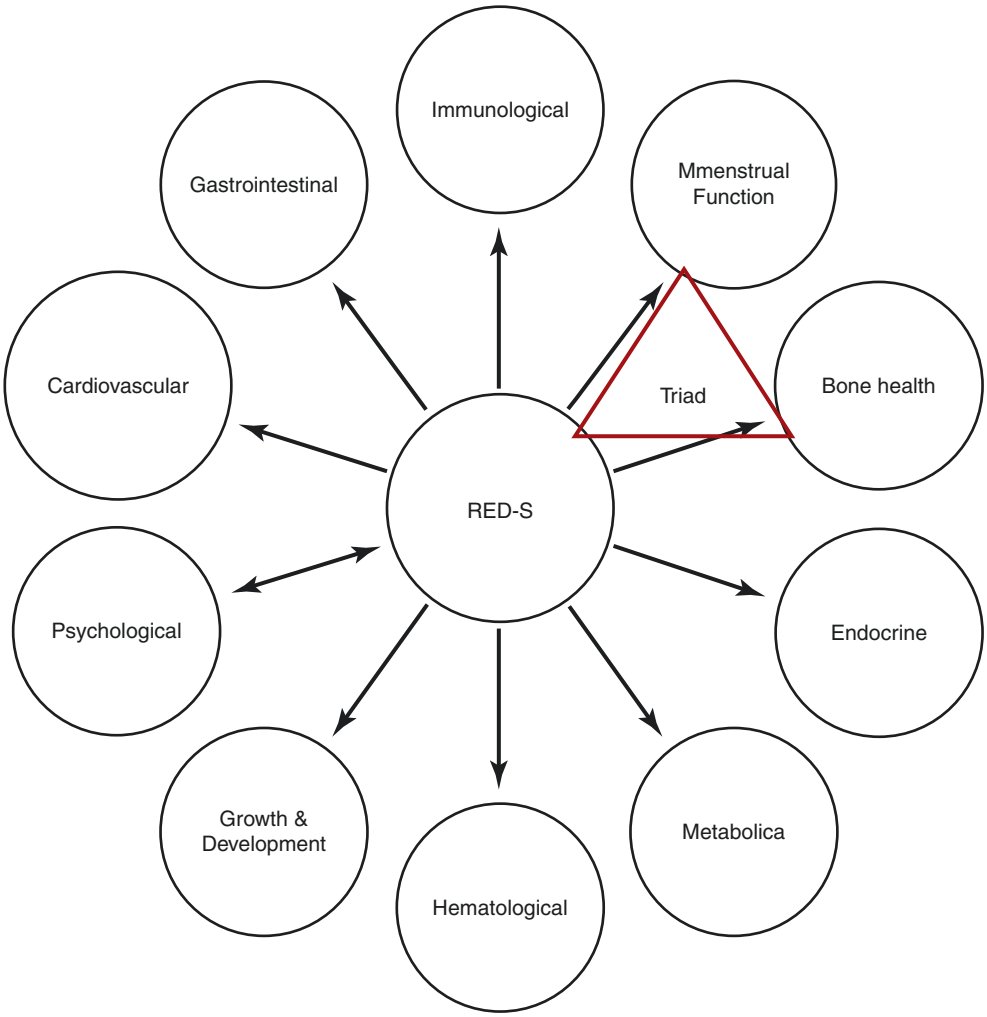

Fig. 5.2 A wide array of physiological health consequences of Relative Energy Deficiency in Sport showing an expanded concept of the Female Athlete Triad. Reproduced from The IOC consensus statement: beyond the female athlete triad-relative energy deficiency in sport (RED-S); British Journal of Sports Medicine; Mountjoy M, Sundgot-Borgon J, Burke L, et al.; Vol. 48; pages 491–497; © 2014; with permission from BMJ Publishing Group Ltd.

However, due to broad physiological descriptions captured with the RED-S, lack of evidence supporting the physiological, health, and performance outcomes of this syndrome has garnered criticism [13]. Williams et al. (2019) argue that the RED-S should be viewed as a biomedical syndrome as the model does not depict continua from a healthy state to a pathological state [13]. More so, it is unknown if relative energy deficiency on GI function, cardiovascular function, immune function, growth, and development, and hematological function are reversible.

5.2 Research Findings and Contemporary Understanding of Health Consequences of Low-Energy Availability

5.2.1 Eating Disorders

As aforementioned, low EA can occur without having an eating disorder or disordered eating. However, a broad spectrum of abnormal eating behaviors such as excessive caloric restriction, binge eating, and purging or the use of diet pills, laxatives, diuretics, and enemas has been documented to reduce EA [2, 7, 8]. Also, if an athlete is unable to stabilize their energy expenditure or energy intake, they may be suffering from disordered eating (i.e., extreme dieting, restriction, etc.), or an eating disorder. The DSM V outlines several different EDs; however, in the context of sport Anorexia Nervosa, Bulimia Nervosa, and Other Specified Feeding and Eating Disorder, Binge Eating Disorder (for definitions, see Table 5.1) is relevant [14]. Eating disorders are of specific concern as they are associated with considerable morbidity leading to one of the highest mortality rates among mental illness. Also, they are more prevalent in athletes than the general population. Indeed, EDs are present in 2–25% of athletes, dependent on sport type [15]. Similarly to low-energy availability risk factors, the rates of EDs are higher for women in individual sports competing in weight-class sports (boxing) and sports emphasizing leanness (gymnastics, ballet). For example, in sports outlined as high risk for EDs, 46.7% had clinically relevant ED symptoms compared to 19.8% in other sports and 21.4% in non-athletic control group [4].

Table 5.1 Summary of eating disorder definitions. Adapted from American Psychiatric Association. Diagnostic and statistical manual of mental disorders (DSM-5®). American Psychiatric Pub; 2013 May 22 [14]

Eating disorder	General characteristics
Anorexia Nervosa	• Restriction of energy intake leading to a weight less then minimally normal for the individual • Intense fear of gaining weight • Disturbance in one's view on their weight and body
Bulimia Nervosa	• Recurrent episodes of binge eating • Recurrent inappropriate compensatory behavior during binge episode (laxative use, dysfunctional exercise, purging) • Above behaviors occurring once a week for 3 months • Self-evaluation by body shape or weight
Binge Eating Disorder	• Recurrent episodes of binge eating • Episodes of binge eating associated with at least 3 of the following: feeling uncomfortably full, eating when not hungry, secretive eating, disgust and guilt following the episodes • Distress regarding binging episodes • Binging occurring once a week for 3 months • Binge eating is not associated with compensatory behaviors
Other Specified Feeding or Eating Disorder	• This category applies to eating disorder presentations in which symptoms cause clinically significant distress or impairment in social, occupational, or other areas of functioning but does not meet the full criteria for any of the disorders

Note. The table above does not include all eating disorders, nor each specific criteria outlined in the DSM-V

5.2.2 Menstrual Dysfunction

The spectrum of menstrual function ranges from eumenorrhea (regular menstrual cycles) to amenorrhea, with the latter having negative physiological consequences. Primary amenorrhea is defined as the absence of menarche by the age of 15 after secondary sexual characteristics [8]. In contrast, oligomenorrhea is defined as menstrual cycles occurring at intervals longer than 35 days, but anovulation and luteal deficiency have no apparent symptoms [8].

In the female athlete triad, low EA may cause functional hypothalamic amenorrhea leading to persistent anovulation and secondary amenorrhea. Chronic anovulation is often associated with stress, weight loss, excessive exercise, or a combination thereof [16, 17]. In a healthy-cycling female, GnRH causes the release of gonadotropins—Luteinizing Hormone (LH) and Follicle Stimulating Hormone (FSH)—from the pituitary gland [17]. These hormones, LH and FSH, in turn, cause the release of progesterone and estrogen from the ovaries. These end hormones in the hypothalamus–pituitary–ovarian (HPO) axis are key to regular, ovulatory menstrual cycles [17–20]. Disturbance to the GnRH pulsatility at the hypothalamus leads to the abnormal pituitary secretion of FSH and LH, thereby leading to a reduction in progesterone and estradiol, inadequate folliculogenesis, and anovulation [12]. Without normal LH and FSH pulsatility, the follicles do not develop in the ovary, estrogen, and progesterone production decrease due to lack of ovarian stimulation, and menses either occurs irregularly or not at all (see Figs. 5.3 and 5.4) [21, 22].

A dose–response relationship exists between relative energy deficit (percentage decrease in EA from baseline) and the frequency of menstrual disturbances. Current literature suggests that there is no correlation between the severity of menstrual disturbances and the magnitude of energy deficiency. Despite this, there is an increasing probability of developing menstrual dysfunction if more than 50% of absolute energy availability drops below 30 kcal/kg^{-1} FFM/day [23]. In other words, if half of the days of the week an athlete only consumes 30 kcal/kg FFM/day, they will be at risk of menstrual dysfunction. Specifically, LH pulsality disrupts when EA reduces below approximately 30 kcal/kgFFM/day. Loucks and Thuma (2003) measured LH pulsatility after manipulating the energy availability of 29 regularly menstruating, habitually sedentary females for 5 days during the early follicular phase. Subjects consumed clinical dietary product at 10, 20, 30, or 45 kcal/kg lean body mass (LBM) per day along with supervised aerobic activity expending 15 kcal/kg of LBM in two randomized trials separated by 2 months. LH pulse frequency decreased below 30 kcal/kg LBM per day, suggesting the physiological disruption caused by reduced energy availability [24].

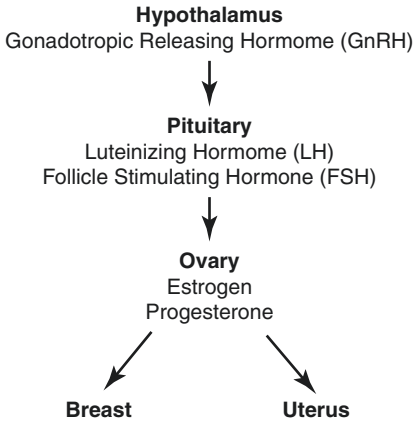

Fig. 5.3 This figure shows the primary components of the female reproductive system and the hormones that communicate between various organs. The hormones produced by each gland are shown in parentheses. Figure adapted by Amber McCord, Texas Tech University, from Norman, R. (2014). Reproductive changes in the female lifespan. In J. Robert-McComb, R. Norman, & M. Zumwalt (Eds.). *The active female: Health issues throughout the lifespan* (pp. 25–31). New York, NY: Springer Science + Business Media [21]

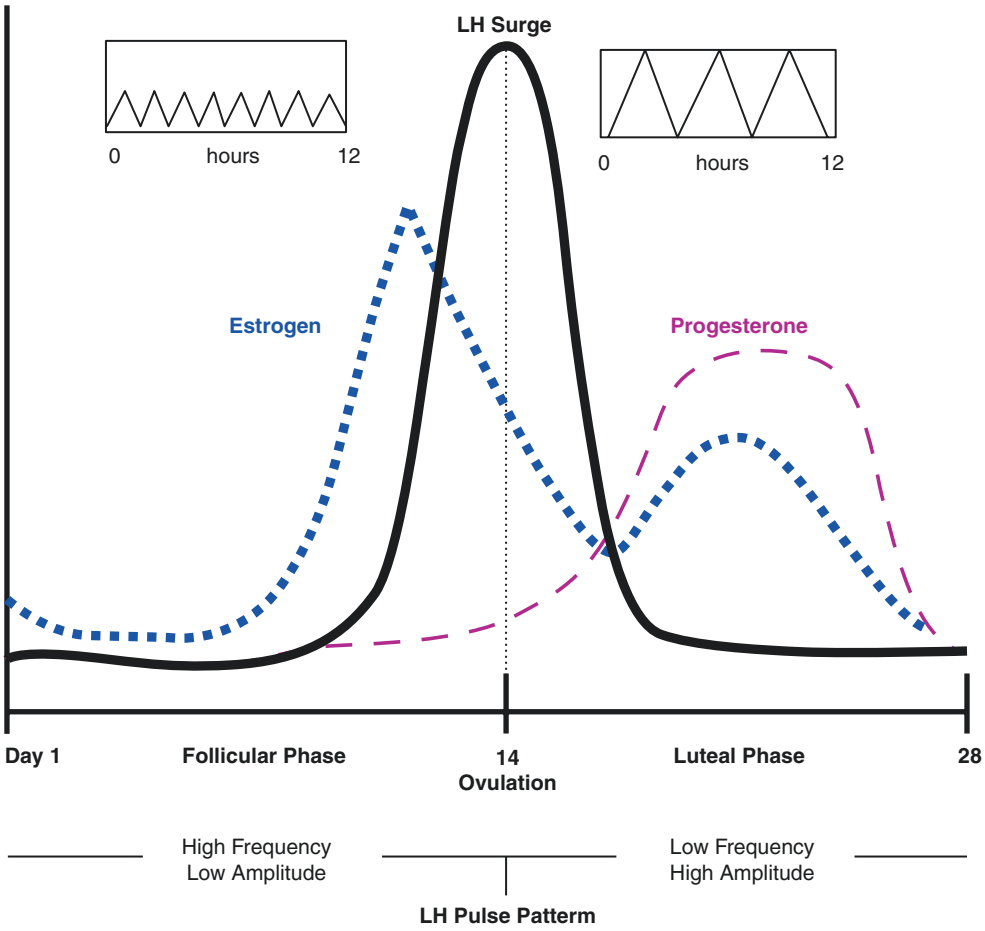

Fig. 5.4 An LH surgery at the time of ovulation and marks the division between the follicular phase (days 1–14) and the luteal phase (days 15–28). LH pulse pattern also changes across the menstrual cycle; pules frequency decreases from the follicular phase (−65 to 80-min intervals) to the luteal phase (−185 to 200-min intervals), whereas pulse amplitude increases from the follicular phase (−5 miU/mL) to the luteal phase (−12 miU/ml). Figure adapted by Amber McCord, Texas Tech University, from Norman, R. (2014). The human menstrual cycle. In J. Robert-McComb, R. Norman, & M. Zumwalt (Eds.). *The active female: Health issues throughout the lifespan* (pp. 61–66). New York, NY: Springer Science + Business Media [22]

5.2.3 Bone Health

Osteoporosis is a disease characterized by compromised bone strength leading to an increased risk of bone fracture. Adolescence and young adulthood are crucial for bone acquisition to obtain peak bone mass and may have implications for bone health and fracture incidence [25]. Low EA and menstrual dysfunction may predispose premenopausal osteoporosis in active young women due to decreases in ovarian hormone production and hypoestrogenemia [26]. Specifically, hormonal changes in females with amenorrhea demonstrate hypothalamic–pituitary–gonadal axis suppression, decreased insulin, leptin, and insulin-like growth factor 1 (IGF-1) with concomitant increase in Peptide YY (PYY) and cortisol thereby negatively impacting bone mineral density (BMD), bone microarchitecture, and bone turnover markers [27].

A z-score of less than −1.0 is regarded as low BMD [28]. Low BMD is prevalent in a range of 0–15.4% of female athletes with a z-score below −2.0 and increases to 39.8% when low BMD is considered a z-score of −1.0 [29]. Typically, endurance athletes and athletes who play sport in which leanness is emphasized are subject to high risk of low BMD [30]. The process of bone resorption and renewal requires three elements: (a) the regular supply of protein, calcium, and vitamins; (b) the regular use of the bones (exercise); and (c) hormones which control breakdown and removal of old bone and the creation of new bone [28]. When EA reaches below 30 kcal/kg FFM/day, a suppressive effect exerts on bone formation; meanwhile, estrogenic deficiency affects the upregulation of bone reabsorption [31].

Papageorgiou et al. (2018) investigated the acute effects of low-energy availability through exercise or diet on bone turnover markers in active, eumenorrheic women. Ten eumenorrheic women were included in a randomized group with varied dietary conditions (45 kcal/kg per day vs. 15 kcal/kg per day) along with increasing energy expenditure consisting of supervised running sessions. Blood samples were collected during the 3-day trial analyzing bone turnover markers, markers of calcium (Ca) metabolism, albumin-adjusted Ca, and various hormones, including IGF-1, insulin, and leptin [32]. A 17% reduction ($p < 0.001$) in procollagen 1 intact n-terminal propeptide (P1NP) concentrations related to bone formation was seen with the restricted dietary conditions, but no change was induced with bone resorption.

Low BMD occurs over time, as such a dietary (vitamin D and calcium and protein) along with an exercise intervention

will serve to stimulate bone mineralization sufficiently to maintain BMD throughout low EA. In 2007, the ACSM suggested that an **EA of 45 kcal/kg FFM/day** and higher may be needed to replenish low bone mass [8]. Specifically, high impact activity and weight-bearing activity are recommended [28, 30]. Due to the increased risks for athletes to suffer from stress fracture, continued low bone mass density, and other long-term effects such as osteopenia and osteoporosis, it is vital to implement nutritional and activity interventions in this population, particularly in youth athletes [30].

5.2.4 Energy Availability, Bone Health, and Menstrual Dysfunction Interaction

Achieving an appropriate EA level by consuming enough calories for the amount of exercise performed seems to be critical for maintaining ovulatory cycles, and therefore, the protective effect of estrogen on bone [33]. On the contrary, the lack of EA causes demineralization or premature osteoporosis, leading to an increased risk of stress fractures, and other more severe conditions. Rectifying a low EA is critically important, as even with resumption of regular menses, some of the changes in bone health are irreversible [29]. Despite the genetic variations in BMD, maximizing peak bone mass begins early in life and requires adequate nutrition and exercise [34]. Two years before menarche, 25% of adult bone is laid [5]. During adolescence, when 60–80% of skeletal bone density is laid down and consolidated, nutritional deprivation and poor nutrition will result in estrogen deficiency and may lead to a low-peak bone mass, deficits of calcium, iron, and other essential nutrients. If the EA does not increase, it can lead to an inability to increase BMD further and establish an adequate peak for protection against stress fracture and early onset osteoporosis [5].

Nose-Ogura et al. (2019) found that female teenage athletes had a higher incidence of stress fractures compared to athletes in their 20s. In these teenage athletes, secondary amenorrhea, low BMD, and a low ratio of actual body weight to ideal body weight increased stress fracture risk by 12.9 times, 4.5 times, and 1.1 times, respectively [35]. Fracture risk is associated with abnormal bone microarchitecture despite normal bone mineral density assessed by dual-energy x-ray absorptiometry (DEXA), implying that microarchitecture is more sensitive at measuring fracture risk as this study utilized a high-resolution peripheral quantitative computed tomography [36]. Especially young athletes with amenorrhea compared to non-athletic controls with eumonorrhea displayed negative alterations in bone microarchitecture. Despite the positive effects of weight-bearing sport and exercise, amenorrhea in adolescent athletes still displays attenuating bone anabolic property effects leading to stress fractures [36].

The EA hypothesis conceptual framework is summarized as such, if the brain's energy requirements are not met, an alteration in brain function occurs, which disrupts the GnRH pulse generator [24]. Deficiency in GnRH pulsatile secretion may ultimately lead to FHA. Furthermore, the suppression of reproduction subsequently alters metabolic hormones, the use of substrates, and stress (total tri-iodothryronine [T3], leptin, insulin, growth hormone (GH), IGF-1, IGF-binding protein-1[IGFBP-1], and cortisol). A study by Loucks (2006) compared the effect of the stress of exercise and low energy availability (LEA) alone on LH. In the exercising women, LEA reduced LH pulsality by 10%, and amplitude by 36% while the stress of exercise did not have any effect on LH pulsality or amplitude [37]. Thereby, emphasizing the importance of sufficient energy availability through dietary means to prevent physiological disturbances.

5.2.5 Performance Consequences of Low-Energy Availability

Adequate fueling is not only crucial for everyday function, evidently, it impacts sport performance. Mountjoy and colleagues (2018) have summarized these impacts by stating that low LEA impairs performance by influencing the body's glycogen stores, protein synthesis, or increasing risk for injury or diseases [4].

First, the body's glycogen stores are essentially the body's fuel for physical work. To meet the demands of sport, the body produces energy to facilitate muscular contraction, and this energy is called adenosine triphosphate, or ATP. Without adequate energy, the body is unable to produce ATP at its highest efficiency resulting in overall bodily fatigue. Fatigue impacts the body's ability to sustain physical activity, and it is of particular importance during sport which requires higher power outputs, sprinting and finishing in the later part of a race [38].

Second, protein synthesis, or the production of protein for a variety of bodily functions including muscle building, is impaired by low EA. To produce muscle, the body requires adequate hormones, stimulation (muscular work), and protein. If the athlete has low EA, the body may not have the available protein to synthesize muscle, and it may also lack the hormones needed to create muscle fibers. As a result, muscle will not grow and strengthen to meet performance demands. Relatedly, the suppression of estradiol and progesterone, low metabolic hormones (T3 and IGF-1), are related to decreases in performance [39]. In terms of bone health, the increased risk of stress fracture related to low EA puts athletes at a greater risk for stress fracture, and if a fracture does occur, the athlete will have to spend time away from training and playing.

Low-energy availability indirectly effects mechanisms for declines in performance including impairing recovery which

can lead to not only physical avenues (decreased muscle mass and function) but also by impacting the athletes phycological functioning. There are a variety of mental risks resulting for low EA, such as impaired judgment, irritability, depression, and decreased concentration [4]. As much as having the physical capacity to engage in the sport is important, complimenting those skills with mental fortitude, thus, the saying "having your head in the game," has never rung more true.

5.3 Future Directions and Concluding Remarks

5.3.1 Importance of Early Intervention and Prevention

The Female Athlete Triad Coalition Consensus statement and ACSM continue to emphasize prevention and early intervention to avoid progressive physiological disturbances of the triad [40]. Treatment targets for low EA include reversal of recent weight loss, return to a bodyweight associated with regular menses, achieve weight gain BMI of above 18.5 kg/m^2 or above 90% of predicted weight, and set energy intake at a minimum of 2000 kcal/day or more [40]. A recommended treatment to prevent further physiological disturbances is a reversal of energy deficits by gradually adding 200–400 kcal on top of the usual dietary intake [13]. Nutritional changes must be individualized and periodized according to athletic sport demands and exercise goals. Reduction or cessation of exercise may also be necessary depending on the severity of energy deficit, symptoms, and compliance level [4]. Vitamin D and calcium supplementation may also be recommended to maintain serum 25-hydroxyvitamin D levels between 32 and 50 ng/mL to prevent stress fractures [3]. However, pharmacologic strategies such as estrogen-containing oral contraceptives are not useful for increasing BMD or regaining menses and not recommended [4]. Evidence also shows no effect with transdermal estrogen, testosterone, or bisphosphonates pharmacology for the affected female athlete as increasing caloric uptake and reducing associated ED factors being the most effective to target [3].

Stewart et al. (2019) evaluated 481 female collegiate athletes to study the efficacy of the Female Athlete project (FAB) in reducing ED symptoms and risk factors [41]. The FAB included one peer-led 1.3-h session per week over 3 weeks touching on positive body image ideals, Triad education, nutrition, the importance of balancing caloric input and output, sleep, and self-identifying health and unhealthy behaviors. The three groups included the FAB intervention, a behavioral ED risk-factor reduction program, or a waitlist control condition. 18-month outcomes revealed lowered ED pathology and risk factors, lower thin-ideal internalization, and increased BMI within the FAB group demonstrated favorable outcomes with brief education intervention. Utilizing a 10-min educational video on the Triad based on the Social Cognitive Theory can also increase awareness of triad components and consequences by approximately 89% in an intervention group involving 46 female high-school students, thereby implying positive effects with shorter duration sessions for female athletes [42].

Mountjoy and colleagues [11] recommends increased awareness with not only athletes, but with physicians, coaches, physical therapists, and athletic trainers regarding identifying triad components not limited to low-energy availability with or without an ED, menstrual dysfunction and low BDM. A 2015 survey study demonstrated that only one third of 931 physicians have only heard of the triad, and approximately one half of physicians were comfortable treating/referring a patient with the Triad [43]. Effective eating disorder prevention programs should be multimodal, interactive, and target athletes, along with coaching staff and allied health professionals.

5.3.2 Conclusion

The ultimate goal for the active female athlete should be to improve sport performance with favorable energy availability. Low EA, with or without disordered eating, disrupts physiological function of the female athlete body and notably leads to functional amenorrhea. Identification and prevention guidelines for athletes at risk for energy deficits in sport are crucial despite clear scientifically, validated prevention interventions [4]. Additionally, long-term health and sport performance consequences are unclear in not only in women, but in males, para-athletes, and athletes of various races. Young girls and athletes with the FAT have significant health risks despite being cleared to participate in sport. Even after medical illness or injury, athletes with the Triad will return to sport with inappropriate treatment, intervention, or follow-up [40]. Further research is needed to analyze the effectiveness of sound treatment and "return to play" guidelines to ensure proper return to sport as well.

A multimodal approach is required with the female athlete, coaches, providers, and allied health professionals to promote optimal health. Education and non-pharmacologic interventions are the first choice in treating the Triad components [4]. As we work to help athletes recover with the Female Athlete Triad, we must also be cognizant and respectful of the athlete's feelings and perceptions of her situation when considering recovery process planning. A deeper understanding of the Triad plus providing athlete-centered care is critical to achieve a resumption of a healthy lifestyle, successful sports participation, and maximizing performance.

Chapter Review Questions

1. What is the energy availability (EA) formula?
   (a) Daily energy intake − exercise expenditure = EA
   (b) Daily energy intake + exercise expenditure = EA
   (c) Daily energy intake + body mass index = EA
   (d) Daily energy intake × exercise expenditure = EA
2. The female athlete triad is a term which describes
   (a) Muscular endurance, cardiovascular endurance, and muscular strength
   (b) Amenorrhea, oligomenorrhea, and eumenorrhea
   (c) Speed, agility, and power
   (d) Disordered eating, amenorrhea, and osteoporosis
3. The relative energy deficiency in sport is a term which describes
   (a) Limited to disordered eating, amenorrhea, and osteoporosis
   (b) Inclusion of more interrelated physiological and psychological changes
   (c) Only psychological, cardiovascular health, and metabolic features
   (d) Related to sports performance to maximize function
4. Athletes at greatest risk for developing signs and symptoms associated with the Triad are
   (a) Female power lifters training for strength
   (b) Female basketball players under tremendous pressure to perform
   (c) Athletes competing in sports that emphasize leanness or low body weight
   (d) Female soccer goalie during the peak of their season
5. In this particular eating disorder, even though the weight and shape concerns persist, the individual's body weight is typically normal throughout the disorder:
   (a) Bulimia Nervosa
   (b) Anorexia Nervosa
   (c) Binge eating disorder
   (d) Compulsive overeating
6. Luteinizing hormone (LH) pulsatility is likely to be disrupted when energy availability is reduced below:
   (a) 30 kilocalories (kcal) per kilogram (kg) of body weight (BW) per day (kcal/kgBW/day)
   (b) 45 kilocalories (kcal) per kilogram (kg) of body weight (BW) per day (kcal/kgBW/day)
   (c) 45 kilocalories (kcal) per kilogram (kg) of fat-free mass (FFM) per day (kcal/kgFFM/day)
   (d) 30 kilocalories (kcal) per kilogram (kg) of fat-free mass (FFM) per day (kcal/kgFFM/day)
7. In regard to bone health, hormonal changes in females with amenorrhea lead to
   (a) Reduced bone mineral density, improved bone microarchitecture, reduced bone turnover markers
   (b) Significant increased risk in lumbar spine fractures
   (c) Reduced bone mineral density, reduced bone microarchitecture, reduced bone turnover markers
   (d) Negative effects only in the cardiovascular system
8. Which describes the best first-line treatment for a female athlete with the Triad:
   (a) Immediate pharmacology intervention
   (b) 10-min educational video on the Triad and psychological counseling
   (c) Education, reversal of weight loss, and increasing dietary intake
   (d) Pharmacology intervention, education, and increasing dietary intake
9. Effective eating disorder prevention programs should be:
   (a) Multimodal
   (b) Interactive
   (c) Target athletes, along with coaching staff and allied health professionals
   (d) All of the above
10. Luteinizing hormone (LH) pulsatility has a rhythm that would be characterized as having _____ pulses during the follicular stage of the menstrual cycle.
   (a) High frequency, low amplitude
   (b) High frequency, high amplitude
   (c) Low frequency, low amplitude
   (d) Low frequency, high amplitude

Answers

1. a
2. d
3. b
4. c
5. a
6. d
7. c
8. c
9. d
10. a

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The Physiology of Anorexia Nervosa and Bulimia Nervosa

6

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Learning Objectives

After completing this chapter, you should understand

- the significance of an eating disorder,
- the varying types of eating disorders (ED),
- differentiating and similar signs and symptoms of each disorder,
- the physiological changes that occur in anorexia nervosa and bulimia nervosa, specifically,
- the potential long-term physiological consequences of anorexia nervosa and bulimia nervosa,
- the importance of genetics, neurotransmitters, and key hormones in ED.

6.1 Introduction

Feeding and eating disorders (FEDs) are defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) as disorders characterized by a persistent disturbance of eating or eating-related behavior that results in the altered consumption or absorption of food and that significantly impairs physical health or psychosocial functioning. FEDs include a number of disorders; however, this chapter will focus on avoidant/restrictive food intake disorder, binge-eating disorder (BED), and primarily on anorexia nervosa (AN) and bulimia nervosa (BN) [1]. The World Health Organization's International Classification of Diseases (ICD-10) is another commonly used classification system for FEDs and went into effect January 1, 2022 [2].

While diagnostic criteria for FEDs are mutually exclusive, there are common psychological and behavioral characteristics, disorder-specific subtypes, as well as disorder crossover. For example, there are two subtypes associated with AN: anorexia nervosa, restricting type [3]; anorexia nervosa, binge/purge type (AN-BP); bulimia nervosa, purging type (BN-P); and bulimia nervosa, non-purging type (BN-N). Additionally, other specified feeding or eating disorder (OSFED), formerly known as eating disorder not otherwise specified (EDNOS), is included for *symptoms characteristic of a feeding and eating disorder that cause clinically significant distress or impairment in social, occupational, or other important areas of functioning predominate but do not meet the full criteria for any of the disorders in the feeding and eating disorders diagnostic class*. Presentation of OSFED can be specified as (1) atypical anorexia nervosa, (2) bulimia nervosa (of low frequency and/or limited duration), (3) binge-eating disorder (of low frequency and or limited duration), (4) purging disorder, and (5) night eating syndrome [1].

FED health outcomes are impacted by several characteristics including (1) demographic characteristics; (2) experiences in adolescence; (3) low self-esteem and negative ideations; (4) medical and psychological comorbidity; and (5) issues with weight, shape, and the stereotype of beauty [4]. Factors such as swiftness of weight loss, current weight, and chronicity of the FED are related to the intensity of the comorbid illness [5]. Furthermore, the majority of FED patients experience other psychological or personality disorders as well. A 2007 study reported that 56.2% of individuals with AN, 94.5% with BN, 78.9% with BED, and 63.3% with subthreshold BED met the criteria for another mental disorder, most often mood disorders, anxiety disorders, impulse control disorders, or substance use disorders [6].

Even with considerable underreporting, the incidence of FEDs has increased over the past 50 years [5, 7]. Increase in the prevalence of FEDs might be due to improved under-

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standing of the symptomatology and risk factors, as well as changes in diagnostic criteria, referral practices, and accessibility to help [7]. Incidence of FEDs in women ranges from 0.5 to 3% [8, 9], and while this may seem low, it is of significant concern due to FEDs association with mental illness [10, 11] and other adverse acute and chronic health consequences [1, 5, 12], decreased psychosocial functioning, and compromised interpersonal interactions [5, 13–15].

Frequently, the onset age for AN and BN is between 15 and 19 [8, 10, 14, 16]. Although body dissatisfaction is common for young women, FEDs can occur in older women. In a randomly selected nonclinical sample of 1000 women aged 60–70 years, more than 80% used strategies to control their weights, over 60% reported body dissatisfaction and 3.8% met the criteria for an eating disorder [17]. FED occurrence in older women may be due to their independence, accessibility to privacy, and co-occurrence with life transitions, such as losing a spouse [18]. As one ages, there is also a slight change in the expression of EDs. Adolescents and young women are more likely to show signs and symptoms related to AN and BN, whereas older adults may exhibit signs and symptoms more closely aligned to BED [11, 16]. These differences may exist because young people are more likely than older people to internalize cognitive distortions about body image and pressure from society to be thin [7].

FEDs often last several years and tend to have high relapse rates [10, 13, 18]. Specifically, the average duration of BN is 8.3 years, and the average duration of BED and subthreshold levels of BED is 8.1 and 7.2 years, respectively [6]. By the fifth year of the FED, the symptoms, pathology, and the clinical track of the FED likely stabilize [19]. Early identification of an FED is associated with shorter duration and fewer medical complications [20]. Unfortunately, recent estimates show that only about 33% of AN patients and 6% of BN patients are receiving proper treatment for their illnesses [7]. Comorbidity plays an important role in the treatment of FEDs, as people are more likely to seek treatment for their non-FED mental health problems than for the FED itself [8]. In clinical settings, women and girls are ten times more likely than men and boys to receive treatment [5, 10, 18], but this ratio might not accurately represent the number of men and boys compared to women and girls who actually have ED [18]. Thus, increased understanding of FEDs is imperative so that treatment for people with FEDs is more accessible and more effective.

6.1.1 Diagnostic Criteria for Anorexia Nervosa

Although AN has its own diagnostic criteria, it overlaps with Avoidant/Restrictive Food Intake Disorder, defined by the DSM-5, in part, *as an eating or feeding disturbance (e.g., apparent lack of interest in eating or food; avoidance based on the sensory characteristics of food; concern about aversive consequences of eating) as manifested by persistent failure to meet appropriate nutritional and/or energy needs* [1]. One characteristic of AN is a drastic reduction in eating which results in very low body weight [21]. Although patients with AN consume food, they eat with extreme limitations. Strict calorie and food restriction, as well as obsessive exercise, can produce an unhealthy level of weight loss in AN patients [5, 21].

Weight concerns, fear of fatness, social influence, distorted body shape, eating concerns, yearning for thinness, and body dissatisfaction are consistently found to be predictors of EDs and lie at the core of AN. Accordingly, the DSM-5 includes the following general characteristics for AN: (1) restriction of energy intake leading to a weight less than minimally normal for the individual; (2) intense fear of gaining weight; and (3) disturbance in one's view of their weight and body [1]. Often, the AN patient is totally preoccupied by thoughts of shape and weight, including obsession about weight gain and the perceived largeness of her body, and she often sees herself as being overweight regardless of how much weight she loses [5, 14, 16, 22]. An excess of physical activity has been recognized as hyperactivity in AN patients and is present in roughly 80% of those with AN [23].

Initially, the individual must be at a weight that is 85% or less of her expected weight, based on her height and her age, which is equivalent to a body mass index (BMI) of less than 18 (A BMI that falls between 18.5 and 24.9 is considered to be in the healthy range). According to the DSM-5, BMI defines the level of AN severity, as follows: *Mild* = BMI $\geq$ 17 kg/m^2; *Moderate* = BMI ranging from 16–16.99 kg/m^2; *Severe* = BMI ranging from 15–15.99 kg/m^2; *Extreme* = BMI < 15 kg/m^2 [1]. The ICD-10 specifies that patients with AN have a BMI equal to or below 17.5, which is well below the healthy range (18.5–24.9) [24]. Other ICD-10 criteria for AN include amenorrhea, weight loss that is self-induced and purposeful, a fear of fatness, and a perception of being fat. Unlike the *DSM-5* classification, the ICD-10 specifies that binge eating is an exclusionary criteria for AN. The ICD-10 criteria are based on behavioral symptoms and methods of weight loss, in contrast to the *DSM-IV-TR* that emphasizes psychological distortions and disturbances [14, 24]. Table 6.1 presents a comparison of the DSM-*5* and ICD-10 diagnostic criteria for AN.

AN patients can be further subdivided into two subtypes: restricting subtype [3] and binge/purge subtype (AN-BP). The AN-R subtype describes those individuals who severely restrict their food intake and do not use compensatory behaviors, like self-induced vomiting, to compensate for calories consumed. The AN-BP subtype is diagnosed when periods of restriction are accompanied by periods of overeating and extreme compensatory purging behaviors, like self-induced

Table 6.1 Comparison of DSM-5 and ICD-10 diagnostic criteria for anorexia nervosa [1, 14, 24]. Adapted and republished with permission of John Wiley & Sons, Inc., The International Journal of Eating Disorders, Anorexia Nervosa: Definition, Epidemiology and Cycle of Risk, Academy for Eating Disorders, Vol. 37 Supp/Issue 51, © 1980 [1]

	DSM-5	ICD-10
Code	307.1	F50.0
Weight	Body weight is significantly low: BMI < 17.0 kg/m^2 for adults or a BMI < 18.5 kg/m^2 for adults with clinical history or other physiological support for diagnosis; BMI for age below the fifth percentile or failure to maintain expected growth trajectory for children and adolescents	Body weight is maintained at least 15% below that expected (either lost or never achieved) Quetelet's body mass index is 17.5 kg/m^2 or less or Prepubertal patients may show failure to make the expected weight gain during the period of growth
Phobia/ associated behaviors	Intense fear of gaining weight or becoming fat, even though underweight DSM-5 behaviorally differentiates between types: Restricting = not engaging in binge-eating or purging behavior Binge eating/purging = regularly engaging in binging or purging behavior	Weight loss self-induced by avoidance of "fattening foods" and one or more of the following: self-induced vomiting, self-induced purging, excessive exercise, use of appetite suppressants and/or diuretics
Body perception	Disturbance in the way in which one's body weight and shape are experienced Undue influence of body weight or shape on self-evaluation or Denial of the seriousness of the current low body weight	Body-image distortion in the form of a specific psychopathology whereby a dread of fatness persists as an intrusive, overvalued idea, and patient imposes a low-weight threshold on himself or herself
Amenorrhea/ hormonal fluctuations	Not specified	In women, amenorrhea, and in men, loss of sexual interest and potency (an apparent exception is the persistence of vaginal bleeds in anorexic women who are receiving replacement hormonal therapy, most commonly taken as a contraceptive pill) There may also be elevated levels of growth hormone, raised levels of cortisol, changes in the peripheral metabolism of the thyroid hormone, and abnormalities of insulin secretion
Pubertal development	Not specified	With prepubertal onset, the sequence of pubertal events is delayed or even arrested (growth ceases; in girls, the breasts do not develop and there is a primary amenorrhea; in boys, the genitals remain juvenile). With recovery, puberty is often completed normally, but the menarche is late.

Note: DSM-5 Diagnostic and statistical manual of mental disorders, *ICD-10* International classification of diseases

vomiting. AN, particularly the restricting type [3], is the most rare form of eating disorder [1].

Notably, there is some debate regarding the inclusion of fear of weight gain in the diagnosis of AN. Although some argue that fear of weight gain is a classic feature of AN, this fear may not be present in all individuals with AN. Furthermore, the subtypes associated with AN have been questioned. The AN-R and AN-BP subtypes were originally differentiated because women in these two subgroups were thought to be different in terms of comorbidity and recovery cycles, but recent evidence suggests that the current separation might not be needed [25]. Still, others have pushed to eliminate the AN-BP subtype all together and limit AN to only those individuals who severely restrict their food intake and to include AN-BP with BN and include a low-weight specifier [26].

There are different theories that attempt to explain the onset and continuation of AN. However, it is thought that a combination of genetics, environmental factors, and specific personality traits likely contributes to the development and maintenance of AN [27]. For example, anxiety and mood disorders affect about 25% of people with AN, and comorbid conditions like depression, anxiety, phobias, and personality disorders might contribute to worse outcomes for AN patients [28]. Moreover, some research suggests that AN patients have lower levels of novelty seeking and higher levels of harm avoidance, and both factors can prevent a person from developing binge-eating and purging behaviors [29, 30]. However, AN-BP patients do develop binge-eating and purging behaviors, and these behaviors are intermingled with periods of fasting, excessive exercise, and other compensatory behaviors [5].

6.1.2 Diagnostic Criteria for Bulimia Nervosa

Prevalence rates of BN range from 1.1 to 4.6%, making BN approximately three times more common than AN [31]; however, prevalence varies by age and sex with much less known in regards to disorder prevalence in males [1]. BN is a complex disorder characterized by recurrent binge-eating, compensatory behaviors to avoid weight gain, and self-evaluation excessively focused on body weight and shape. The diagnostic criteria for BN include several criteria that

reflect the physical manifestation of the disorder. Specifically, the current *DSM-5* criteria indicate that all with BN have recurrent episodes of binge eating [1].

According to the *DSM-5*, BN is characterized by compulsive, extreme binge eating, or the consumption of excessive amounts of food in a limited time period, usually less than 2 h. Such occurrences may take place in more than one setting and are typically accompanied by a sense of lack of control or a feeling that one cannot stop eating or control what or how much is being consumed. For most, foods consumed during bingeing periods do not meet particular cravings but do consist of foods typically avoided. To compensate for the large amount of food that has been consumed during the eating binge, the individual with BN engages in behaviors to prevent weight gain, such as (1) self-induced vomiting; (2) misuse of laxatives, diuretics, enemas, or other medications; (3) fasting; or (4) excessive exercise. Diagnostic criteria state that this type of cyclic behavior must occur for at least 3 months, and binge-eating and purging episodes are to occur at least once per week. Additionally, this type of disturbance must occur impudently of episodes of AN [1].

As with AN, there is also ICD-10 criteria for BN diagnosis, which are similar to the *DSM-5* criteria. The ICD-10 criteria for BN include having an adverse relationship or preoccupation with food, engaging in binge-eating and purging behaviors, and attempting to keep body weight below a level that would optimize health [32]. Table 6.2 provides a comparison of the DSM-5 and ICD-10 diagnostic criteria for BN.

Table 6.2 Comparison of DSM-5 and ICD-10 diagnostic criteria for bulimia nervosa [1, 14, 24]

	DSM-5	ICD-10
Code	307.51	F50.2
Relationship with food	Binge/purge cycle must occur for at least 3 months, at a rate of once per week, on average	Continued obsession with food Strong cravings Fear of weight gain
Binge eating	Eating, in 2 h or less, a portion of food that is substantially larger than most others would eat; loss of control when consuming this food	Period of overeating when are a great deal of food is eaten quickly
Purging/purge behaviors tendencies	Recurrent methods of compensation (vomiting, diuretics, other medications, fasting, or exercise)	Methods to compensate for the binge include vomiting, restriction of food intake, and drug use may include appetite suppressants, thyroid treatments, or diuretics
Beauty ideal	Weight and shape are a major influence in defining the identity of a BN patient	Strives to achieve a weight that is well-standard weight or weight expected for a particular person

Note: DSM-5 Diagnostic and statistical manual of mental disorders, *ICD-10* International classification of diseases

Individuals who engage in binge eating also commonly engage in the excessive use of weight-loss supplements. According to Reba-Harrelson et al., women with BN are more likely to use diet pills if they have a higher BMI, higher novelty seeking, anxiety disorders, alcohol abuse, or borderline personality disorder. Many of these characteristics are commonly found to co-occur with BN [33].

6.1.3 Eating Disorder Crossover and Identification

Although AN and BN are separate disorders, there are several traits commonly found in both AN and BN patients, including high neuroticism, perfectionism, obsessiveness, and low self-directedness. These shared traits may increase the chance of crossover from AN to BN [19]. Commonalities between AN and BN patients may be attributed to the symptom overlap between the two disorders or may help account for the high crossover rate from AN to BN [14, 19]. Other traits associated with the crossover from AN to BN include prior anxiety, childhood sexual abuse, negative affect, and improvement in the AN condition [19, 27].

Also, ED classification can be difficult as crossover from one form of ED to another is fairly common. It has been estimated that between 8 and 62% of patients with AN eventually crossover to BN [14, 19]. The highest percentage of crossover occurs when restricting AN patients crossover to the binge/purge subtype of AN (AN-BP) or to BN [5, 19]. Additionally, BN can crossover to BED [11, 34]. The symptoms associated with AN-BP and BN overlap, making diagnosis difficult. A person's weight distinguishes those with BN from those with AN-BP. People with BN typically have a weight that is in the normal range, and some are overweight [35]. Moreover, it is difficult for researchers to design well-controlled studies for EDs, particularly studies that will distinguish the causes and early signs of EDs. There are multiple reasons for this difficulty. For instance, it is often difficult to accumulate a large enough sample of people with EDs, and AN and BN often consist of similar or overlapping characteristics [8, 11, 27].

Crossover from one ED to another typically occurs during the first 5 years of the illness; after 10 years, the rate of crossover is substantially reduced [5, 14]. Furthermore, certain personality traits in AN patients, such as novelty seeking and low self-directedness, have been associated with higher crossover probability compared to other AN patients without these traits [36]. There are theories attempting to explain why the crossover from AN to EDs with binging behavior occurs frequently. Several animal and historical studies have shown that restricted eating will result in binge eating later; therefore, many believe that the restricting behavior directly causes a person to begin binge eating [21]. Conversely,

crossover from BN to AN occurs in only few cases (10–15%) and reversion to BN is common [1].

6.2 Research Findings

Most recently, FEDs, including anorexia nervosa (AN) and bulimia nervosa (BN), are understood as psychiatric disorders with complex pathophysiology involving alterations related to genetics, epigenetics, nutrigenomics, and gut microbiota [1]. Numerous short-term and long-term physiological signs and symptoms are associated with AN and BN, and many of these physical symptoms are life threatening. Unfortunately, severe starvation has been linked to depressed mood, decreased concentration and attention, and poor problem-solving skills and memory. These problems may contribute to poor judgment about the severity of the FED and, therefore, hamper the individual's recognition of the need for treatment [37]. Short-term and long-term adverse effects of AN and BN are described below.

6.2.1 Adverse Health Effects of Anorexia Nervosa

A summary of some of the physical consequences of AN is provided in Table 6.3. Although numerous physical abnormalities may be found in people with AN, research findings indicate that laboratory results may be normal even in the presence of profound malnutrition [38].

Table 6.3 Physical consequences of anorexia nervosa [23, 27, 30, 39–43]

Cardiovascular	*Gastrointestinal*
Bradycardia	Abdominal discomfort
Tachycardia	Bloating/feeling of fullness
Arrhythmias	Constipation
Hypotension	Delayed gastric emptying
Fainting	Decreased gastric and intestinal motility
Dizziness	Pancreatitis
Endocrine	*Integumentary*
Amenorrhea	Dry, flaky/scaly, yellowish orange skin
Cold sensitivity	Decreased body fat
Oligomenorrhea	Lanugo (fine facial and body hair)
Anovulation	Thinning hair
	Brittle nails
Hematologic	*Central nervous system*
Anemia	Poor problem-solving skills and memory
Hypercortisolism	Decreased concentration and attention
Leukopenia	Depressed mood
Pancytopenia	Peripheral neuropathy
Thrombocytopenia	Seizures
Skeletal	*Fluids and electrolytes*
Osteopenia	Electrolyte imbalance
Osteoporosis	Dehydration
Bone fractures	Rebound peripheral edema
Stunted growth	Renal failure
	Metabolic acidosis

The body weight of the individual with AN generally reflects the degree of calorie restriction, the severity of purging behaviors (if present), and the amount of exercise engaged in by the individual. Adults who are diagnosed with AN generally show extreme weight loss and may be described as thin or emaciated. Children and adolescents may not lose an extreme amount of weight, because weight loss goes against the body's natural tendency to grow larger. Rather, children and adolescents might lose smaller amounts of weight (e.g., 5–10 lb.) or might not grow to a weight that would be expected for them based on their height, age, and developmental level [44].

6.2.1.1 Gastrointestinal Abnormalities

Individuals with AN frequently describe mealtime as an uncomfortable experience associated with symptoms of anxiety, such as sweating and increased pulse and respiratory rates [37]. When a person eats little food, a series of adverse consequences affect normal digestion. Food is held for longer periods in the stomach and intestines, which can cause bloating and a feeling of being full, in addition to stomachache and constipation [44]. Additionally, laxative abuse in AN may contribute to the impairment of gastric emptying. Food normally passes through the stomach in about an hour, but when the consumption of food is restricted, food may stay in the stomach for 4 or 5 h [44]. For example, after eating a normal amount of food for lunch, she may still feel full when it is time for supper. Thus, it may be difficult for a young woman with AN to resume a normal pattern of eating. Moreover, the alteration of bowel habits is a common complaint among patients with AN, once again due to abuse of laxatives which leads to colonic dilation and loss of contractility or inflammation [45].

Due to malnutrition [46] and repeated episodes of binge eating [47], pancreatitis is a common occurrence in patients with ED. Patients with pancreatitis may complain of steady and intense upper abdominal pain that may diffuse to the back, chest, or lower abdomen. Numerous mechanisms have the potential to cause pancreatitis, including a sudden increase in calorie intake after malnutrition or the ingestion of various medications including laxatives and diuretics used in purging [48]. Purging type AN may increase an individual's risk of developing Barrett's esophagus which is damage to the esophagus due to acid reflux [45].

6.2.1.2 Fluid and Electrolyte Abnormalities

Individuals with AN can develop imbalances in body fluid and electrolyte levels due to prolonged malnutrition and dehydration. These imbalances can reduce fluid and mineral levels and result in *electrolyte imbalance.* Fluid and electrolyte imbalances can become more serious when an individ-

ual also engages in purging behaviors, such as vomiting and laxative abuse. Dehydration may result from inadequate fluid intake or excessive fluid loss during purging or exercise. Dehydration leads to increased blood levels of urea, urate, and creatinine and may result in decreased urine volume and renal failure. A *rebound peripheral edema* (i.e., swelling of body tissue due to excessive fluid retention) may also occur and can contribute to a dramatic increase in body weight (approximately 10–45 lb.) [49].

Metabolic acidosis, a condition when the body produces too much acid or the kidneys do not remove enough acid, may result from vomiting and loss of stomach acid and sodium bicarbonate. If the individual also engages in laxative abuse, the loss of alkaline bowel fluids may result in metabolic acidosis [50]. Individuals who abuse laxatives are four times more likely to suffer serious medical complications than non-laxative abusers [51]. Reduced blood flow, and lower blood pressure have all been linked to electrolyte imbalance. Electrolytes, such as calcium and potassium, are critical for maintaining the electric currents necessary for a normal heartbeat. These imbalances can be very serious and can even be life threatening unless fluids and minerals are replaced. Hyponatremia is common among patients with AN and occurs when the concentration of sodium in the blood is abnormally low. It can be caused by a number of things, such as impaired renal sodium reabsorption, excessive water consumption, electrolyte disturbances, and the use of psychotropic medications [52].

6.2.1.3 Integumentary Abnormalities

Malnutrition, loss of body fat, and dehydration can also cause changes in skin and tissues. Frequently, the skin is dry, scaly, and covered with *lanugo*, a fine, downy hair resembling that of newborn babies. Fingernails and hair are often brittle, and hair loss may occur in patches or uniformly over the scalp and other body areas [53]. A yellowish or orangish discoloration of the skin occurs in approximately 80% of patients with AN [38]. This unusual skin color, which is most noticeable on the palms of the hands, soles of the feet, and creases inside the elbows, is due to faulty metabolism of β-carotene in the liver leading to an excessive level of β-carotene circulating in the blood, some of which is deposited under the skin [44]. Xerosis is a skin condition found in patients diagnosed with severe AN, which results in painful, dry, and cracked skin [54]. In some extreme cases, lanugo hair growth develops on the sides of the face and along the spine as a response from the body to attempt to conserve heat [54].

6.2.1.4 Hematologic Abnormalities

Hematologic abnormalities are often found in patients with AN. Poor nutrition with severe weight loss often results in dramatic decreases in red blood cells, white blood cells, and blood platelets. Specific to alterations in red blood cells, anemia is a common result of AN, particularly pernicious anemia, which can be caused by low levels of vitamin B_{12}. Normochromic anemia (RBCs with normal red color), normocytic anemia (RBCs of normal size), and thrombocytopenia, or low blood platelet count, have been found in approximately one third of patients with AN [55]. Additionally, over 60% of patients with AN have leukopenia (a reduction in the number of leukocytes, or white blood cells, in the blood), and this abnormality may be related to bone marrow hypoplasia and decreased neutrophil (a granular leukocyte having a nucleus of three to five lobes) lifespan [38]. Leukopenia accompanied by a relative lymphocytosis has also been reported [49]. In some severe cases of AN, the bone marrow dramatically reduces its production of blood cells, a life-threatening condition called *pancytopenia.*

6.2.1.5 Skeletal Problems

Dietary deficiency, low circulating estrogen levels, hypercortisolism, laxative misuse, and disturbed acid–base balance, high levels of stress hormones (which impair bone growth), low levels of calcium and certain growth factors, and reduced dehydroepiandrosterone (DHEA) contribute to adverse physical consequences contributing to bone loss [56]. Bone loss and decreased bone density are common problems for people with AN and are particularly prevalent in individuals with AN who have been severely emaciated for a prolonged period [57–59]. In a long-term study of 103 patients with AN, osteoporosis with multiple fractures accounted for the most severe disabilities experienced by the patients [60].

Since puberty is a critical time for skeletal development, developing AN during this period can interfere with the development of peak bone mass and, therefore, produce permanent long-term skeletal effects [37]. When a young child is severely underweight, there is a danger that the child's growth will be limited. However, if AN starts after puberty begins and ends before the growth plates in her bones have closed, then a young woman's growth in height will not be stunted [61].

Approximately 90% of women with anorexia experience osteopenia—a decrease in bone mass—and some have osteoporosis—brittle and fragile bones [62]. In a study assessing decreased bone density and bone loss in women with AN, nearly half of the women had osteopenia at the hip, and 16% had osteoporosis at the hip. More than half had osteopenia at the spine, and almost 25% had osteoporosis at the spine. Over 90% of women had abnormally low bone density at one or more sites in the skeleton. Additionally, weight was the factor most related to bone loss. The less a woman weighed, the more likely it was that she would have substantial bone loss [62]. Fractures of the long bones, vertebrae, and sternum have also been reported in individuals with AN who have had amenorrhea for as short a period as 1 year [49].

Skeletal problems can be minimized or prevented by early recognition and intervention, but long-term complications can be expected to occur and progress as long as an individual continues to exercise without proper nutritional intake [63]. Unfortunately, weight gain does not completely restore bone loss, but achieving regular menstruation as soon as possible can protect against permanent bone loss. The longer the eating disorder persists, the more likely the bone loss will be permanent.

6.2.1.6 Central Nervous System Abnormalities

Disruptions in neuroendocrine and neurotransmitter systems are prevalent in people with AN and affect the brain and other parts of the body. Seizures, disordered thinking, and *peripheral neuropathy* (i.e., numbness or odd nerve sensations in the hands or feet) have all been reported. Structural changes in the brain include widening of the sulcal spaces and cerebroventricular enlargement [55] and reductions in the size of the pituitary [64]. People with AN also demonstrate increased metabolism in the cortex and caudate nucleus [65].

6.2.1.7 Effects on Pregnancy

Most pregnant women with a history of EDs have healthy pregnancies [66]: however, some research suggests that women who have had EDs may face higher risks for a number of complications, including cesarean sections, postpartum depression, miscarriages, complicated deliveries, and premature birth [44, 67]. Some women with diagnosed ED have been known to deal with ovulatory infertility more than women without an eating disorder. This also puts women with AN at increased risk of miscarriage [68].

In one of the few studies that investigated pregnancy outcomes for women who had a previous diagnosis of AN, a large sample of women who were discharged from the hospital with a diagnosis of AN from 1973 to 1996 and who gave birth from 1983 to 2002 were compared with a large sample of healthy women who gave birth during the same years. The researchers collected information about preeclampsia (i.e., pregnancy-induced hypertension), instrumental delivery, prematurity, small for gestational age, birth weight, Apgar score, and perinatal mortality. Results showed that the main birth outcome measures in women with a history of AN were very similar to those without a history of AN. The only observed difference was a slightly lower mean birth weight for babies whose mothers had a history of AN [66]. This research suggests that women who have a history of AN and who have been treated for the disorder are often able to become pregnant and have healthy pregnancies.

Pregnant women suffering from malnutrition may put their child at risk of preterm birth, low birth weight, and restricted fetal growth. In some extreme cases of malnutrition due to famine during pregnancy, there is an increased risk of neonatal mortality [69] (see Chap. 21).

6.2.2 Comorbidities and Mortality Rates for Anorexia Nervosa

6.2.2.1 Cardiovascular Abnormalities

Some of the most serious and life-threatening complications of AN result from impairment of the cardiovascular system. For example, people with AN might complain of heart palpitations, dizziness, fainting, shortness of breath, and chest discomfort. If these cardiovascular abnormalities are not recognized and treated, they could result in death.

Heart disease is the most common medical cause of death in people with AN, and a primary danger to the heart is from abnormalities in the balance of minerals, such as potassium, calcium, magnesium, and phosphate. Prolonged starvation leads to decreased sympathetic tone in the heart and blood vessels. The heart's ability to pump and the vessels' ability to transport blood may be altered, which could result in *bradycardia* (i.e., heart beats too slowly), *tachycardia* (i.e., heart beats too quickly), or extremely low blood pressure [55]. Bradycardia may occur due to a starvation-induced metabolic decrease controlled by circulating *catecholamines* (i.e., "fight or flight" hormones released in response to stress) and a change in thyroid hormone levels. Tachycardia can occur when the circulating fluid volume decreases because of dehydration, and the heart is forced to pump faster to compensate for the decrease [70]. The reduction in blood pressure may lead to light-headedness or dizziness, and the individual with anorexia may experience orthostatic hypotension (light-headedness when standing up or getting out of bed) [44]. Episodes of fainting may occur because of abnormally low blood pressure. Studies have shown that 91% of individuals with AN have pulse rates less than 60 beats per minute [71], and up to 85% of patients with AN also have hypotension, with blood pressures below 90/60 [72]. Individuals with AN have been found to have higher incidences of mitral valve abnormalities and left ventricular dysfunction than individuals who do not have ED [73]. All these factors contribute to a significant risk of sudden death due to cardiovascular problems in this population [74, 75].

Cardiovascular abnormalities also contribute to the coldness that people with AN experience. Because the blood circulates more slowly, a person's hands and feet turn cold and appear blue because red blood cells have been depleted of oxygen. Additionally, another reason that individuals with anorexia feel cold is the loss of the insulation normally provided by a thin layer fat all over the body [44].

6.2.2.2 Endocrine Abnormalities

Hormonal problems are one of the most serious effects of AN due to disruptions in the endocrine system and alterations in neuroendocrine mechanisms. Changes in the hypothalamic–pituitary–adrenal axis (HPA axis) result in hypercortisolemia and increased cerebrospinal fluid (CSF)

levels of corticotropin-releasing hormones. Since the hypothalamus controls the pituitary gland, pituitary function is also inhibited, resulting in alterations in the normal circulating levels of gonadotropins, cortisol, growth hormone, and thyroid hormones. As a result, prepubertal patients may have altered sexual maturation and arrested physical development and growth patterns [76].

Starvation and weight loss are known to create hypothalamic abnormalities that profoundly affect other organs within the endocrine system. A chain of interrelated events begins when the hypothalamus fails to signal the release of gonadotropin-releasing hormones from the pituitary. The absence of this signal causes a decrease in luteinizing hormone (LH) and follicular-stimulating hormone (FSH) levels and inhibits the positive feedback mechanism to the ovaries. Consequently, the ovaries do not release estrogen or progesterone in normal amounts, which further inhibits the pituitary gland. Ovarian volume and uterine volume are decreased, and the vaginal mucosa becomes atrophic [55].

Adults with AN have decreased levels of reproductive hormones, including estrogen and DHEA. Estrogen is important for heart health and bone health. DHEA, a weak male hormone, is also important for bone health. For women, these hormonal abnormalities may result in menstrual cycle disruptions, including anovulation (lack of regular ovulation), oligomenorrhea, and amenorrhea [77, 78], and these abnormalities can occur even *before* a person has lost a significant amount of weight. Oligomenorrhea is infrequent (or very light) menstruation. More strictly, it is menstrual periods occur at intervals of greater than 35 days, with only 4–9 periods in a year. Amenorrhea is the absence of a menstrual period in a woman of reproductive age.

For those girls who have not reached menarche, they will typically fail to begin menstruating at the expected time, an occurrence known as primary amenorrhea, or the failure of menses to occur by age 16 years, in the presence of normal growth and secondary sexual characteristics. Additionally, secondary or functional hypothalamic amenorrhea may occur in those who have reached menarche. Secondary amenorrhea is defined as the cessation of menses for 6 or more months sometime after menarche has occurred. Functional hypothalamic amenorrhea is a reversible form of gonadotropin-releasing hormone deficiency commonly triggered by stressors, such as excessive exercise, nutritional deficits, or psychological distress.

Eventually, bone loss, osteopenia, and associated stress fractures (discussed in the next section) may also contribute to endocrine disturbances that alter normal hormonal mechanisms and lead to oligomenorrhea and amenorrhea [56]. After a person has been treated and her weight has increased, estrogen levels are usually restored and menses usually resume. However, in some cases, menstruation may never return, resulting in infertility.

Normal functioning of the thyroid gland is also disrupted in individuals who have ED. Individuals with AN frequently demonstrate thyroid abnormalities because of decreased calorie intake and starvation. Free thyroxine (free T4) decreases to low normal levels, whereas triiodothyronine (T3) levels decrease to abnormally low levels in proportion to the degree of weight loss [55], but thyroid-stimulating hormone levels are usually within normal range [79]. Thyroid function tests reveal low T3 levels in proportion to weight loss, low normal T4 levels, and decreased metabolic rates [55].

6.2.2.3 Mortality Rates

Causes of death in women with FEDs include starvation, suicide, and electrolyte imbalance [4]. In young females, AN is recognized as having the highest mortality rate of any psychiatric condition [10, 11, 80–83]. Estimates of premature deaths in AN patients range from 5 to 6% [5] and occur between the age of 25 and 34 years [84]. The most frequent causes of death among patients diagnosed with AN are circulatory collapse, cachexia, and organ failure [85]. AN is also associated with elevated levels of suicide ideation and high rates of suicide [80, 86, 87], which is the most common non-natural cause of death among two thirds of AN patients [84].

Several factors may be predictors of mortality, including having a body weight that is less than 77 lbs., repeated inpatient admissions, and severe alcohol and substance use disorders [4, 88]. Multiple studies have shown that patients with AN are at a higher risk for developing other psychiatric disorders, even after recovery from AN. Two thirds of patients with a persistent eating disorder and one third of those who stopped meeting eating disorder criteria had at least one other psychiatric disorder [89].

6.2.3 Adverse Health Effects of Bulimia Nervosa

Behaviors associated with BN may have few adverse consequences for individuals who briefly engage in self-induced vomiting, purging, or fasting [90]. However, when those behaviors are recurrent and persistent enough to lead to a diagnosis for BN, individuals are likely to have these physiological consequences: (1) erosion of the teeth, (2) enlargement of the parotid salivary glands, and (3) acidic stomachs leading to regurgitation of acidic stomach and heartburn [90, 91]. Additional common symptoms include xerosis (dry skin), nail fragility, pruritis (itchy skin), and cheilosis (inflammation/cracking of the corners of the mouth) [92]. If purging is present, there is a possibility of skin abrasions on the hand that could result in callous formations also known as Russell's sign [92]. Signs and symptoms related to BN are

Table 6.4 Signs and symptoms of bulimia nervosa [45, 48, 50, 51, 90, 91, 93–95]

Anovulation	Hypotension
Calluses on back of hand and fingers	Integumentary
Cardiomyopathy	System
Cheilosis	Disorders
Constipation	Metabolic
Dental abscesses	Acidosis
Dental caries	Alkalosis
Diarrhea	Mitral valve prolapse
Dry, flaky skin	Muscle cramps
Dyspepsia	Musculoskeletal weakness
Endocrine disorders	Palpitations
Esophagitis	Pancreatitis
Heart failure	Pruitis
Hematemesis	Sore throat
	TetanY

listed in Table 6.4. This table is not all inclusive but lists some of the more common pathologies in BN.

Excessive vomiting causes erosion on the enamel and dentin of teeth, increasing the susceptibility to cavities and gum disease [90, 91]. Acid arising from the stomach is very destructive to the tooth substance, and those individuals that report purging have a 5.5 times higher risk of dental erosion than those without purging behavior [96]. Periodontal disease, tooth hypersensitivity, dental caries, and xerostomia (dry mouth) are common occurrences in patients with self-induced vomiting [92].

Vomiting can also cause acid from the stomach to rise up to the esophagus, which may lead to esophageal bleeding, ulcers, and Barrett's esophagus, which is a condition where there is a change in the mucosal lining type due to chronic acid exposure [92]. Additional consequences of excessive vomiting include infections, gastro-esophageal reflux disease (GERD), and may eventually cause a ruptured esophagus [91].

Other short-term complications resulting from BN include impaired satiety, decreased resting metabolic rate, and abnormal neuroendocrine responses. These symptoms increase in severity with continued disordered eating [97]. These complications should be thought of as occurring on a continuum, and in some cases, the symptoms are reversible.

6.2.3.1 Gastrointestinal Abnormalities

Gastrointestinal function, motility, and hormone release are disrupted with BN and contribute to symptoms such as nausea, postprandial fullness, and bleeding as a result of tears in the esophagus, which is also known as Mallory–Weiss Syndrome [98]. Laxative abuse in BN is the primary cause of electrolyte disturbance due to main electrolytes such as chloride, calcium, and potassium lost through chronic diarrhea [92]. Hypokalemia, or low potassium, may also lead to slowing of intestinal motility as well as rhabdomyolysis, or the breakdown of muscle tissue [92, 99].

Due to its effects on appetite perception and energy intake, excessive vomiting may also contribute to gastrointestinal issues. Rectal prolapse is a common occurrence in BN patients due to the process of vomiting. Retching causes a strong contraction of the diaphragm and abdominal muscles to expel the contents of the stomach. This abdominal pressure along with constipation, pelvic floor weakness, and over-exercise all contribute to the co-occurrence of BN and rectal prolapse [98].

6.2.3.2 Gynecological Problems and Hormones

Gynecological problems are one of the most frequent long-term complications of FEDs [93, 94]. The unsatisfactory nutrition in BN results in hormonal dysfunction, menstrual disturbances, and infertility [100]. These symptoms may be reversible with early treatment of the FED [93, 95]. Menstrual irregularities as a result of BN may be caused by weight fluctuations, nutritional deficiency, and prolonged stress [101]. This same menstrual irregularity or oligomenorrhea can lead to polycystic ovary syndrome in individuals who are bulimic, especially if they are also obese [101, 102]. Approximately 7–40% of patients with BN report amenorrhea and 36–64% report oligomenorrhea [103]. 75% of patients with BN had polycystic ovaries and ~33% of women with polycystic ovary syndrome (PCOS) report bulimic eating patterns [103]. Studies have also shown that women with a history of BN have an increased rate of lifetime miscarriages than the general population [104].

Gonadal steroids are among the many factors that influence food intake and body weight in mammals [105]. A key role of estradiol is related to food intake and energy balance. The actions of estradiol may have a gender-specific effect on the regulations of eating, which could explain why BN is more common in women than men [106]. During the estrogen-releasing cycle, the amount of food being consumed fluctuates in response to ovarian rhythms in bulimic women [105, 107]. Late menstruation and cycle disorder can occur due to insufficient energy stores, which causes hypothalamic dysfunction and, therefore, results in suppression of ovarian hormones by the hypothalamus [104].

Disturbances in hormonal regulation in BN can also lead to severe mood changes and aggressive behavior patterns. Researchers have found that individuals with BN have a decrease in plasma levels of prolactin and estradiol, and an increase in cortisol and testosterone [108, 109]. There is a positive correlation between testosterone plasma levels [110] and aggressiveness in individuals with BN that is not seen in other individuals [108, 109]. Individuals with BN tend to have a higher score when rating depressive symptoms and aggressiveness on eating-related psychopathology assessments, which suggests that BN plays a role in the modulation of aggressiveness [108].

6.2.3.3 Cardiovascular Abnormalities

Hypercholesteremia—the presence of high levels of cholesterol in the blood—is a cardiovascular risk factor associated with BN. Hypercholesterolemia is not a disease, but an abnormal metabolic state that can be secondary to many diseases and can be also contributed to many forms of disease, most notably cardiovascular disease [111]. Pauporte and Walsh [112] found that the mean serum cholesterol levels of patients with BN were significantly higher than the cholesterol levels of individuals in a comparison group (patients: 194 ± 36 mg/dL; comparison group: 176 ± 34 mg/dL; $t = 2.77$; df = 159; $p = 0.006$). Additionally, individuals who binge or overeat, or who are obese, are also at high risk for developing hypertension, which is another pathway to long-term cardiovascular disease [112].

Mira et al. [113] found that individuals with BN and other EDs not only had higher levels of cholesterol, but they also had lower levels of electrolytes, such as potassium, chloride, and phosphate in the plasma. The misuse of laxatives and weight-loss supplements over time can cause these electrolyte imbalances and gastrointestinal abnormalities [113]. Ipecac is commonly utilized among BN patients to induce vomiting. Abusing ipecac has been related to cardiac complications such as damage to the heart muscles, congestive heart failure, tachycardia, and hypotension [99].

Cardiac autonomic regulation and stress reactivity may also be altered in BN patients due to energy restriction. Altered eating patterns in BN can result in metabolic and cardiovascular abnormalities [114]. Messerli-Bürgy et al. [115] found that heart rate stress reactivity was highest in BN patients when looking at biological stress responses. During the stress recovery stage of the laboratory stressor, heart rate variability (HRV) decreased in the participants with BN compared to a group of other women [115]. A decrease in HRV is associated with coronary artery disease and congestive heart failure [116–120]. A similar study investigated cardiac autonomic regulation and stress reactivity in relation to biochemical markers of dietary restriction in women diagnosed with BN. These investigators found that women with BN who were fasting (compared to women who had BN but were not fasting or women who did not have BN) showed increased vagal dominance and decreased sympathetic modulation during both resting and recovery periods. These results support the notion of cardiac sympathetic inhibition and vagal dominance during dietary restriction and suggest the specificity of starvation related to biochemical changes for cardiac autonomic control [121]. Vögele et al. [114] also found that individuals with BN have higher resting cardiac vagal tone than controls [114]. Based on the findings from their studies, Murialdo et al. [122] hypothesized that BN patients have sympathetic failure, prevalent vagal activity, and impaired sympathetic activation. These findings indicate a relationship between energy restriction and vagal dominance [122].

Elevated homocysteine levels (an amino acid in the blood) are associated with cognitive decline in dementia and healthy elderly people and are also associated with a high risk of cardiovascular diseases, stroke, and peripheral vascular disease [123, 124]. While elevated homocysteine levels are more common in AN than BN patients, BN patients also exhibit signs of elevated homocysteine levels [124]. This condition can be caused by several conditions, such as malnutrition, starvation, alcohol abuse, or genetic predisposition [125]. Deficiencies of three vitamins—folic acid (B_9), pyridoxine (B_6), or cyanocobalamin (B_{12})—can also lead to high homocysteine levels. Wilhem et al. [126] found a small decrease in levels of homocysteine following a 12-week treatment period for individuals with ED; however, the change was small and statistically nonsignificant. Nonetheless, their conclusion was that during effective treatment that concomitantly increased BMI, hyperhomocysteinemia was partially reversible. Considering the findings from Frieling et al. [124], decreasing homocysteine levels may not improve memory in an FED population. Interestingly, in a mixed group of patients (14 with AN and 12 with BN), elevated homocysteine levels were associated with normal short- and long-term verbal memory, and normal plasma homocysteine levels were associated with poorer memory performance. These results indicate that, under the special circumstances of FED, elevated homocysteine levels improve memory signaling, possibly by facilitating long-term potentiation.

6.2.3.4 Immunologic Abnormalities

Individuals with BN may also have a compromised immune system. Several studies have reported changes in immune cells and natural killer cells important for immunity in patients with AN and BN [127]. With a decrease in lymphocyte number, individuals with BN are more vulnerable to disease—one study reported that approximately 38.5% of BN patients also had an autoimmune/autoinflammatory disease present [128].

6.2.4 Comorbidities and Mortality Rates for Bulimia Nervosa

BN is a long-term disorder with a waxing and waning course. Comorbid medical and psychiatric conditions associated with BN include (1) irritable bowel syndrome; (2) fibromyalgia; (3) mood disorders, such as major depression; (4) anxiety disorders, such as generalized anxiety disorder, panic disorder, and phobias; (5) alcoholism and substance abuse, (6) personality disorders, and (7) aggressive behavior and poor impulse control [129]. These comorbid conditions are similar for BN and AN [129]. Ninety-five percent of patients with BN have had at least one comorbid disorder and 64% had three or more comorbid disorders [130].

Recent data suggest that mortality rates for BN are around 3.9% [131]. Mortality rates are slightly higher (5.2%) for (OSFED), formerly known as eating disorder not otherwise specified (EDNOS), a disorder in which an individual's behavior may meet some but not all the diagnostic criteria for BN [131]. Suicide attempts are common with BN and are estimated to occur in 17% of patients [130].

6.3 Contemporary Understanding of the Issues

6.3.1 Genetic Variables and Eating Disorders

Genetics is known to play an important part in the development of FEDs, but few specific genetic risk factors have been conclusively identified and much is still unknown. Research related to core behavioral, neurobiological, and temperamental variables of both anorexic and bulimic phenotypes is ongoing, and there are an increasing number of studies related to environment and other risk factors that may play a role in the development of one disorder over another.

There are numerous published candidate gene studies, but few have provided definitive conclusions. Regardless of the type of FED, most candidate gene studies have focused on those related to factors influencing the control of eating, satiety, and reward systems. The main pathways explored in FED candidate gene studies of FED include homeostatic pathways (leptin melanocortin pathway genes) and reward-related pathways including central neurotransmission of serotonin, (5-Hydroxytryptamine [5-HT]) norepinephrine, opioid, and the cannabinoid endogenous system. Studies of these genes are important since a balance in homeostatic and reward processes is essential for maintenance of healthy eating behavior. The dysregulation of these processes is observed in all types of FEDs, but research has not demonstrated a conclusive link between a single nucleotide polymorphism (SNP). In addition, the relationship between body mass index (BMI) and any common variant has been conflicting [132].

FEDs are believed to be moderate to highly heritable. Even if great progress in genetics and epigenetics has unveiled the pathophysiological architecture of many complex human diseases, most of the genes predisposing people to develop EDs still remain undiscovered [132]. Based on information about relatives and siblings of people with EDs, the role of genetics in the etiology of EDs has long been postulated to be a risk factor based. Studies have shown that individuals are more susceptible to developing an ED if a close relative also has an ED [133]. First-degree relatives of AN persons are six times more likely to develop AN [134]. Twins have a tendency to share specific patterns of ED symptoms, such as obesity, AN, or BN [135]. The compilation of several twin studies has indicated a 48–76% heritability in AN and 50–83% heritability for BN [11]. However, there is little statistically relevant evidence linking AN and heritability in twin studies [134]. The importance of genetic predisposition in BN is shown by the difference in concordance rates for monozygotic and dizygotic twins. The concordance rate for BN is 23% for monozygotic twins and 9% for dizygotic twins [129, 135]. In other words, when one member of a twin pair has BN, the other twin is more likely to also have BN if the twins are identical genetically than if their genetic similarity is that of any other pair of siblings. The fact that the concordance rates for BN found in twin studies are nowhere near 100% demonstrates clearly that many factors other than genetic predisposition contribute to BN.

The role of common and symptom-specific genetic and environmental influences on eating disorder symptoms across the lifespan remains unclear. Preliminary research data support the influence of newly emerging and stable genetic influences on the co-occurrence of body dissatisfaction, bulimia, and drive from adolescence to young adulthood. Conversely, environmental influences were less stable and contributed to change in symptoms over time [136]. Environment is believed to be very important to the development of an ED; therefore, the role of shared environmental influences must be considered in studies of siblings and twins. Evidence supports a strong association between genetically determined factors, such as (5-HT) (5-Hydroxytryptamine [5-HT] and dopamine (DOP) levels, and environmental risk factors. This suggests that environmental risk factors play a large role in the expression of behaviors that are also genetically determined [137, 138]. Epigenetics, changes in gene expression, is believed to bridge the gap between genetics and environmental factors. Epigenetic modifications, including the methylation of deoxyribonucleic acid (DNA), can be influenced by various environmental factors, including stress and eating behavior. Methylation of the dopaminergic genes dopamine receptor D2 (DRD2) and dopamine active transporter 1 gene (DAT1) have been demonstrated in patients with AN [134, 139, 140]. However, other investigators have noted only a small overlap between genetically determined and environmental risk factors. Evidence suggests that ED also create alterations of methylation in genes involved in mental status, metabolism, anthropometric features, and immunity. Furthermore, some research in individuals with anorexia nervosa suggests the presence of reversible, malnutrition-induced epigenetic alterations that 'reset' as patients recover [141]. The behavior components of BN, such as self-induced vomiting, have also been found to be inheritable [142]. Some have suggested that overeating or behaviors consistent with BN are related to genetically determined, dysfunctional neurotransmitter systems [143, 144]. Some have suggested that overeating or behaviors consistent with BN are related to genetically determined, dysfunctional neurotransmitter systems [132].

Genetics makes a significant contribution to the etiology and development of BN; however, specific genetic contributions to AN remain unknown [132]. This presents challenges to our understanding of heritability and EDs, because no specific genes have been linked to eating disorder phenotypes [145].

6.3.2 Neurotransmitters and Neuropeptides

6.3.2.1 Serotonin and Tryptophan

The role of the monoamine neurotransmitter, Serotonin or 5-hydroxytryptamine (5-HT) is to regulate appetite, sleep patterns, and mood. Studies on patients with AN have reported serotonergic system dysfunction, but findings have not found a clear association between AN or BN variables [146]. The ingestion of food produces chemical changes in the brain that cause a variety of neurochemical responses throughout the body. Specific hormones are released to create instructional pathways for neural communication. Tryptophan, an essential amino acid found in many common foods, such as nuts, meats, and dairy products, is a precursor for 5-HT. Low levels of tryptophan and 5-HT are commonly seen in individuals with psychological disorders, such as depression, AN, and BN [146–149]. The drop of serotonin levels during the acute phase of the AN due to shortage of tryptophan may explain the serious body image disturbances that are typical in AN [150]. Although the exact neurophysiological mechanism that causes such disturbances is not known. A decrease in 5-HT can contribute to the abnormal eating patterns seen in individuals with BN by interfering with the homeostatic regulation of eating by the hypothalamus [151, 152].

As stated previously, 5-HT is biochemically derived from tryptophan and is primarily found in the gastrointestinal tract, platelets, and central nervous system of humans and animals. Regulation of serotonin is important in the pathophysiology of an ED [153, 154]. Serotonin is responsible for regulation or involvement in some of the main functions of the central nervous system, such as control of mood, appetite, sleep, muscle contraction, pain sensitivity, blood pressure, and some cognitive functions including memory and learning [155, 156]. Serotonin transports, especially the serotonin transport protein 5-HTT (or SERT), are considered good markers for gene studies focused on ED [146, 157]. Serotonin is involved in the etiology of AN by altering physiological and behavioral functions that affect mood, impulse regulation, and appetite [157]. Serotonin also influences the hyperactivity associated with AN [147]. Serotonin is likely involved in the etiology of BN by modulating physiological and behavioral functions including anxiety, perception, and appetite [158, 159].

6.3.2.2 Neural Signaling Response to Food Consumption

The neural signaling that occurs in response to food consumption is a link in the feedback mechanisms that normally keep carbohydrate and protein intake more or less constant [160]. Carbohydrate consumption causes insulin secretion which also increases 5-HT release, whereas the consumption of protein lacks this effect on insulin. The consumption of carbohydrates causes the secretion of insulin from the pancreas into the blood, reducing plasma levels of glucose and allowing the uptake of tryptophan in the brain. Tryptophan enhances 5-HT release and also increases the saturation of tryptophan hydroxylase [154, 160, 161]. Hydroxylase is the enzyme responsible for 5-HT synthesis. When BN patients are given a pharmacological stimulus for the production of 5-HT (serotonin-stimulated prolactin secretion), the number of their eating binges decreases [151].

Other investigators have suggested that protein should be added to the diet of BN patients in order to reduce binge eating [162]. Wurtman and Wurtman [154] reported that individuals whose eating binges consist of primarily protein have fewer eating binges than those whose eating binges consist primarily of carbohydrates [154]. In that study, individuals with BN reported less hunger and greater fullness, and consumed less food at test meals, after protein intake than after carbohydrate intake (673 kcal vs. 856 kcal). This discrepancy between protein and carbohydrate consumption during eating binges deserves attention in future research.

6.3.2.3 Receptor Subtypes for Serotonin

The pharmacology of 5-HT is extremely complex, with its actions being mediated by a large and diverse range of 5-HT receptors. At least seven different receptor subtypes (5-HT1–7) are known to exist, each located in different parts of the body and triggering different responses. Serotonin receptors include 5HT1Dβ, 5HT2A, 5HT2C, and 5-HT7 tryptophan hydroxylase 1. Associations between a functional variant in the 5-HT transporter gene have been found with other psychiatric symptoms such as depression, alcoholism, and suicidal behavior [163]. Alleles are different forms of the DNA sequence of a particular gene. By conferring the allele-specific transcriptional activity on the 5-HT transporter gene promoter in humans, it has been found that the 5-HT transporter gene-linked polymorphic region (5-HTTLPR-a serotonin-transporter-linked promoter region) influences a constellation of personality traits related to anxiety and increases the risk for neurodevelopmental, neurodegenerative, and psychiatric disorders [146, 164]. The S, G, and A alleles have been implicated in the transmission of an ED from mother to child [165]. It has been hypothesized that alterations in the S-allele contribute to the pathophysiology of AN and binge eating [157, 166]. Simply carrying the S-allele increases risk of AN and binge eating [157, 167].

Particularly the 5-HTTLPR (serotonin-transporter-linked promoter region) S-allele has been linked to AN, high anxiety, and low levels of impulsiveness in some studies [157]. A study by Akkermann et al. [167] investigated the association between the 5-HTTLPR and binge eating to determine if the 5-HTTLPR genotype influenced the severity of binge eating. Women prone to binge eating and carrying the S-allele showed significantly higher levels of BN scores. Among these women, those with s/s genotype also had higher levels of state anxiety and a tendency for higher impulsivity [167].

Not all researchers are in agreement about the relationship of the S-allele and the pathophysiology of BN. Lee [168] found that overall EDs were significantly associated with the S-allele and genotype, but a meta-analysis led to the conclusion that while AN was associated with the S-allele and the S carrier genotype, BN was not associated with this allele [168]. Racine et al. [169] found that the T-allele and the S-allele gene were associated with higher levels of impulsivity, but there were no main effects for the 5-HT genotypes on any binge-eating measure, and interaction between genotypes, impulsivity, and dietary restraint were nonsignificant [169].

6.3.2.4 Dopamine

Among the many candidate genes analyzed in patients with FED, those involved in dopaminergic functions may be of special relevance, as dopamine is known to play a significant role in feeding behavior, the distortion of body image, hyperactivity, and reward and reinforcement processes [139]. Dopamine is classified as a catecholamine (a class of molecules that serve as neurotransmitters and hormones). Dopamine is a precursor (forerunner) of adrenaline and another closely related molecule, noradrenaline. Central DOP mechanisms are involved in the reward and motivational aspects of eating and food choices, and they play a role in the compulsive feeding patterns observed in BN and purging disorders [170]. Foods high in fats and sugars are likely to promote DOP stimulation [171]. It has been hypothesized that deficiencies in DOP may promote reward-seeking behaviors that result in instant gratification such as carbohydrate eating binges [172–174]. Reduced food intake engages mesolimbic dopamine neurons, thereby increasing the risk of anorexia nervosa by rewarding dieting behavior. Recent fMRI studies have confirmed the activation of dopamine neurons in patients with anorexia nervosa, but it is not clear whether this response is due to the disorder or to its resulting nutritional deficit.

When the body senses the shortage of nutrients, it rapidly shifts behavior toward the normal physiological food foraging response and the mesolimbic dopamine neurons may be involved in that process. On the other hand, the altered dopamine status of anorexics has been suggested to result from a brain abnormality that underlies their complex emotional disorder. Also, DOP can contribute to the hyperactive characteristic in AN patients via increased concentrations of DOP in the hypothalamus [139, 175, 176].

Genetic variants in dopamine pathways affect personality dimensions displayed by patients with ED. However, the complexity of the body's systems and number of different pathways and receptors make targeting the role/concentration of DOP in the pathophysiology of both AN and BN difficult [177]. Food restriction in AN not only decreases overstimulation but also sensitizes the dopamine system. That coupled with an extreme fear of weight gain creates a situation where dangerous weight loss occurs due to the failure of normal eating stimulating mechanisms. In patients with BN, the need for control paired with hyposensitive dopamine circuits can lead to periods of food restriction and episodes of binge eating and purging [178].

6.3.2.5 Catechol-O-methyltransferase

In spite of not being classified as a neurotransmitter, catechol-*O*-methyltransferase (COMT) is an important protein in the degradation of DOP and other catecholamines in the brain, so it deserves attention in the discussion of ED. It is one of several enzymes that degrade catecholamines such as DOP, epinephrine, and norepinephrine. Dysregulation of DOP has been implicated in many genetic studies related to BN [170, 171].

Patients with BN and BED presented higher S-COMT activity in erythrocytes, which is in agreement with previous studies on the literature addressing the high-activity COMT allele, Val158, as risk factor for ED [179]. The COMT gene lies in a chromosomal region that is of interest in investigations of psychosis and mood disorders [165]. In particular, regions on chromosome 10 have been linked to BN and obesity [180]. However, despite a considerable research effort, a clear relationship between the genetic variation in specific chromosomes and the psychiatric phenotype has not been substantiated [144, 181].

6.3.3 Peptides and Proteins

Individuals with a FED are less sensitive to the satiating effects of food [169, 182, 183]. For example, after eating BN patients report lower subjective ratings of fullness than other individuals [183]. Ample evidence supports the notion that individuals with BN have a disturbance in satiation, which helps explain the consumption of very large amounts of food that is recorded during binge meals in laboratory settings [183–187].

There are several specific physiological mechanisms that help explain the deficit in the normal development of satiation when individuals with a FED consume food. Peptide

signals from surrounding tissues communicate with the hypothalamus to control hunger and eating behavior [134]. Abnormal levels of leptin, ghrelin (the satiety peptide), cholecystokinin (CCK), and androgens have all been implicated as playing a role in food intake, satiety signaling and binge-eating behavior [188].

6.3.3.1 Leptin

Leptin is an adipose-derived hormone that plays a key role in regulating energy intake and energy expenditure, including appetite and metabolism [189]. Leptin level alterations in FEDs have been hypothesized as maintenance factors for pathological reward-related FED behaviors, given leptin's role in the dopaminergic reward systems [152]. Certain levels of leptin must exist in order to support menstruation; consequently, low leptin levels have been linked with amenorrhea.

Low leptin levels have also been associated with AN [190, 191]; however, the relationship with BN is more controversial. Some studies have found that individuals with BN have low levels of serum leptin [121, 122, 192, 193] while others have reported that leptin concentrations were significantly higher in patients with BN than in a comparison group [194]. There is also no consensus among researchers examining ED patients about whether plasma levels of leptin are significantly related with patients' body weight or BMI [195–200]. In one study of 62 patients with FEDs and 41 healthy controls, in the presence of high levels of FED psychopathology, leptin levels were negatively associated with dietary restraint and compensatory exercise, and positively associated with both emotional and binge eating. Leptin also showed an indirect effect on the association between BMI and all reward-related behaviors. These results suggest that a variation of BMI maintains pathological FED behaviors created when there is a variation in leptin levels. Considering the role of leptin in reward mechanisms, results of this study seem to confirm an aberrant food-related reward mechanism in FED patients [201].

6.3.3.2 Ghrelin

Ghrelin is a hormone that stimulates hunger. It is considered the counterpart to the hormone leptin, produced by adipose tissue, which induces satiation when present at higher levels. Ghrelin is produced mainly by P/D1 cells lining the fundus of the human stomach and by the epsilon cells of the pancreas. Ghrelin levels increase before meals and decrease after meals. Both acute and chronic fasting increase ghrelin levels [134, 202, 203]. Weight loss brought about by dieting causes ghrelin levels to rise as body weight and body fat decline. Ghrelin may blunt the appetite-reducing effect of leptin [204]. Because ghrelin levels increase before meals, it would be expected that ghrelin levels are higher in individuals in the acute stage of AN. Schalla & Stengel [203] compared patients with AN to healthy lean subjects and found that AN patients had double the levels of fasting and 24-h ghrelin levels. The effects of ghrelin are unclear in those who chronically suffer from AN. However, research has shown that ghrelin levels drop in individuals with AN who are receiving treatment. This information could explain why AN patients are even more resistant to food during treatment, making the recovery process very difficult [23, 144].

It has been suggested that individuals with BN have high ghrelin levels [205]. Supporting the hypothesis that individuals with BN have high ghrelin levels, Kojima et al. [205] found that patients with BN exhibit elevated ghrelin levels before meals and reduced ghrelin suppression after eating. Postprandial ghrelin suppression is significantly attenuated in patients with BN compared to individuals who do not have BN [205, 206]. Monteleone et al. [204] also found that the ghrelin levels of individuals with BN did not decrease as much as would be expected after a meal. In healthy women, circulating ghrelin showed a drastic decrease after food intake, whereas this response was significantly blunted for individuals with BN. The blunted ghrelin response to food ingestion for individuals with BN may explain the impaired suppression of the drive to eat following a meal, which can lead to binge eating [204]. Elevated ghrelin levels have all been found to decrease significantly after treatment, despite similar BMI, percent body fat, and leptin levels [121, 206]. When ghrelin levels return to normal for an individual with a FED, abnormal eating behavior, and depressive symptoms both improve [121].

6.3.3.3 Cholecystokinin

Cholecystokinin (CCK) is a peptide hormone of the gastrointestinal system responsible for stimulating the digestion of fat and protein. It also acts as a hunger suppressant and contributes to the feeling of satiation [207]. Individuals with BN have a reduced level of postprandial CCK compared to individuals who do not have FEDs [184, 208–212].

The development of CCK and satiety has been greatly explored in BN, including gastric capacity, gastric emptying, gastric relaxation reflex, and the postprandial release of CCK [43, 45]. A significant enlarged gastric capacity has been found in women with BN compared to non-BN women [213]. This suggests that a larger amount of food must be consumed before the development of gastric signals. Along with this gastrointestinal abnormality, gastric emptying has found to be delayed in women with BN [45, 208, 214–216]. As a result of this irregularity, there may be a delay in the development of satiety cues that result from the presence of food in the intestine. Finally, another gastrointestinal problem that arises with BN is that there is a reduced gastric relaxation occurring following food ingestion [217].

6.3.3.4 Brain-Derived Neurotrophic Factor

Lastly, certain proteins, such as brain-derived neurotrophic factor (BDNF), have been implicated in the etiology of an ED. This protein may influence an individual's vulnerability to AN and BN [180] via regulation of apatite control [134, 149]. Specifically, the genetic contribution of the BDNF-specific receptor neurotrophic tyrosine kinase receptor type 2 (NTRK2), is implicated in the susceptibility of developing a FED [218]. In most candidate gene association studies (CGASs), decreased levels of BDNF are typically present in those with AN [134, 219]. It is important to note the difficulty in linking protein levels to genetic traits associated with an eating disorder. If protein levels return to normal with restored weight and proper nutrition, the disturbed protein levels may be related to improper nutrition rather than the traits associated with the eating disorder [134].

6.4 Future Directions

6.4.1 Anorexia Nervosa

Individuals with AN frequently lack insight into their problems and often deny the existence of problems related to eating. They are often reluctant to seek help from friends, family members, or health professionals, because the eating disorder becomes a lifestyle, and they fear changing their habits and gaining weight. When they do seek help on their own, it may be due to severe distress over physical or psychological problems that occur because of the eating disorder or in conjunction with the eating disorder. In an attempt to conceal their disorder from health professionals, individuals with AN may try to hide signs of this disorder or might provide inaccurate information to the clinician [44]. For example, an individual with AN might drink a lot of water prior to being weighed by a professional or might hide weights in her clothing to increase the number on the scale.

Treatment must be specific to each individual because of the different levels of severity and because of the unique characteristics each individual with AN develops [44, 220]. Effective treatment of individuals with AN should include weight restoration and restoring healthy eating habits. However, successful treatment of AN requires more than a focus on eating and weight gain. Focus on emotional issues that are related to the disorder and family conflicts that contribute to the disorder are also needed [44].

Successful treatment depends on the individual with AN gaining weight and maintaining a normal weight and adequate nutrition. Initially in treatment, the focus is on supporting the individual with AN and building a cooperative relationship with her while she gains weight. Because of the cognitive impairments resulting from semi-starvation, it will be difficult to deal with emotional and interpersonal problems until the individual's weight returns to the normal range [44]. Sometimes, however, the focus on weight gain may be too narrow, so that the person gains weight during treatment, but has not accepted that weight gain or changed her attitudes and perceptions related to weight and eating. Many patients with anorexia gain weight in treatment but then lose it soon after leaving treatment. Also, some treatment programs focus on rapid weight gain, which will be difficult for the individual with anorexia both psychologically and physically, and may expose the individual to some serious health risks, such as heart failure [44].

Weight restoration must be done gradually and patiently. Additionally, returning the individual with AN to a normal pattern of eating can be either easily accomplished or extremely difficult, depending on how long the disorder has persisted. She may rebel against a 2000–3000-cal diet because she will feel as though she is being overfed and may, therefore, also stop cooperating with other aspects of treatment. Therefore, enlisting the help of a dietitian can assist in educating the person about her nutritional needs. However, including too many professionals into the treatment might pose problems for the person being treated for AN, so an ideal approach might be for the therapist to work closely with the nutritionist [44]. There are also physical reasons that she will be unable to resume a normal diet immediately. Attempting rapid weight gain in a person who has been starving may lead to excessive fluid retention with a risk of heart failure. In addition, any nourishment may be difficult for her because of her empty and shrunken stomach. So, eating may trigger nausea and vomiting, and these physical responses must be carefully distinguished from common psychological variables, such as revulsion at food and self-induced vomiting [44]. Without early, aggressive intervention, AN will most likely last for several years, and it may persist or reoccur throughout the individual's life [44]. Long-term follow-up studies reveal a mortality rate as high as 18%, with the majority of deaths related to medical complications of the disorder [28].

Current research is focusing on the use of ghrelin agonists/antagonists and the treatment of ED; however, most studies are animal-based studies and only few studies have used human subjects with AN. For example, ghrelin antagonists have been found to reduce the hyperactivity associated with AN but may cause appetite depression. Therefore, treatment with ghrelin antagonists is controversial. Ghrelin agonists are a possible treatment option for AN-R due to the resultant increase in food intake seen in human subjects. Yet, larger studies using human subjects are needed to clearly understand the relationship between ghrelin and AN-R and more studies need to focus on ghrelin and the AN-BP subtype [23]. Serotonin is also being considered for the use of AN treatment [147]. Additional treatments under investigation include ketamine, an n-methyl-D-aspartate (NMDA) receptor antagonist, which may be useful in the treatment of various psychiatric disorders, including depression, anxiety, and substance

abuse disorders. While ketamine may be useful, particularly in combination with other therapies, future studies are needed to determine the efficacy and safety in patients with AN [221].

6.4.2 Bulimia Nervosa

There are many effective treatment options for individuals with BN, such as pharmacology (most commonly antidepressant medications) [222], psychological treatment, therapeutic exercise such as yoga, and behavioral modification. Cognitive behavior therapy is effective in reducing the symptoms of BN and BED [223]. However, even though improvement over a short-term period is commonly found in the research literature, treatment may have a more limited effect over the longer term [224]. Vigilance is needed in helping girls and women to have healthy eating patterns and to avoid BN and other EDs in a culture that places so much emphasis on physical appearance and has such unrealistic ideals regarding the weight and shape of the human body.

It would be great if FEDs could be prevented from occurring (primary prevention) but that goal seems unattainable based on the research on past prevention programs. Efforts to prevent FEDs shave produced temporary results, a change in knowledge but no change in attitudes or behavior, or an increase in symptoms of ED [225–227]. Unfortunately, prevention efforts can lead girls and young women to focus even more than they had before on their bodies and on dieting, and may promote unhealthy behaviors among especially vulnerable girls [44]. Another reason that primary prevention is so difficult is that any prevention programs are unlikely to have as much of an effect on girls and young women as the influence of their peers and of media messages. Therefore, the best type of prevention for a FED may be secondary prevention—identifying the early signs of trouble and starting treatment as soon as possible.

6.4.3 Secondary Prevention and Education

Health professionals must be educated about the dangers and warning signs of FEDs to promote early recognition, evaluation, and treatment. Parents, teachers, and coaches who recognize common signs of an eating disorder in girls or young women should express their concerns to these individuals and their parents and should also encourage them to seek further evaluation. Because individuals often develop an eating disorder in the aftermath of a diet, overweight individuals should be encouraged to lose weight through nutritionally balanced meals and exercise rather than by strict dieting that can trigger binge eating and purging cycles [46]. Health professionals must develop realistic attitudes about body weight and shape in order to communicate information effectively and to promote appropriate preventive efforts.

Early diagnosis of a FED is related to a better prognosis because the patient is more receptive to treatment. Earlier diagnosis is an important first step for many patients and allows for intervention before the adverse eating patterns are ingrained due to repetition [228]. Vigilant friends and family can notice signs and symptoms of the FED and attempt to seek proper help. If a FED is suspected, one of the most practical screening tools to use in the primary care setting is the SCOFF questionnaire [229]. Because of its 12.5% false-positive rate, this test is not sufficiently accurate for diagnosing ED, but it is an appropriate screening tool that physicians can use as a first step in identifying and treating the FED. Although a substantial amount of progress has been made in the field of eating disorder research and treatment, there are still many questions without answers. By reading this book, you will see where we are on the journey toward better understanding and treating ED.

6.5 Concluding Remarks

The key feature of AN is the refusal of the girl or woman to eat an adequate amount of food [44]. BN is an eating disorder that involves binge eating and the use of inappropriate methods to avoid weight gain [230]. There are also shared qualities, as more than half of patients diagnosed with AN-R crossover to AN-BP and approximately one-third crossover to BN during the first 5 years of being diagnosed with an eating disorder [231].

All of the physiological changes that occur in AN are caused by malnutrition or "semi-starvation" [44]. Those changes are the adaptive responses of the body to survive despite inadequate intake of food: conservation of energy, shifts in electrolyte balances, attempts to use fat and spare the body's glucose and protein, and changes in the functioning of the hypothalamus and the pituitary gland.

With fluctuating eating patterns, individuals with BN are at risk for developing cardiovascular health problems [114] such as coronary artery disease, hypertension, and congestive heart failure [116–120]. Many other adverse health conditions are also associated with the disorder such as alcoholism, panic disorder, generalized anxiety disorder, phobia, and major depression [129]. Two of the most prevalent co-occurring conditions for individuals with BN are anxiety and depression [232].

Both genetics and environmental factors (culture and family) play large roles in the behavioral, neurobiological, and temperamental variables that represent the core features of FED development. The family environment is especially important in the development of a FED, since adolescence is a particularly vulnerable age for females [230].

The psychological and physiological aspects of BN are often tightly linked [233]. Biomarkers associated with BN include but are not limited to the dysregulation of hor-

mones that contribute to irregular dieting behaviors, possibly through serotonergic mechanisms [43]. Alterations in 5-HT and DOP can result in the dysregulation of mood, satiety, appetite, sleep, muscle contraction, and some cognitive functions including memory and learning [155, 156]. Research does not indicate a direct relationship between pathophysiological markers and the diagnosis of AN [94].

The initial evaluation of an individual with an eating disorder must include a comprehensive physical exam and health history to rule out existing physiological pathology. Several lab tests, including a complete blood count (i.e., full blood chemistry, electrolyte profile, liver and function tests, and urinalysis) should also be performed. An EKG is essential to evaluate the cardiovascular system and to rule out potentially life-threatening arrhythmias, and a chest X-ray may be performed to evaluate heart size and placement [234].

A number of long-term complications may result from the prolonged and severe malnutrition that often accompanies ED. Medical complications can be expected to progress as long as the individual continues to exercise without proper nutritional intake [63]. Inadequate nutritional intake and poor absorption of nutrients result in physical consequences, including extreme weight loss, electrolyte imbalances, cardiac abnormalities, hormonal changes, central nervous system abnormalities, bone loss, and muscle wasting. Unfortunately, these physical consequences can result in death; therefore, adequate nutritional intake and weight restoration are vital in the treatment of a FED [28].

Chapter Review Questions

1. Incidence of Feeding and Eating Disorders is of significant concern due to Feeding and Eating Disorders association with
   (a) Mental illness
   (b) Substance use
   (c) Low Socioeconomic status
   (d) Adverse acute and chronic health consequences
2. Known predictors at the core of Anorexia Nervosa include all except
   (a) Concerns about weight
   (b) Fear of being fat
   (c) A desire to please others
   (d) An extreme desire to be thin
3. Factors associated with the rate of crossover from Anorexia Nervosa to Bulimia Nervosa include
   (a) Common traits such as obsessiveness and high self-directedness
   (b) A history of anxiety and/or childhood sexual abuse
   (c) A tendency to strive for perfectionism
   (d) Symptom overlap between the two disorders
4. Which is not a characteristic that impacts Feeding and Eating Disorder health outcomes?
   (a) Low self-esteem
   (b) Experiences in adolescence
   (c) Medical and psychological comorbidity
   (d) Occupation
5. Which Feeding and Eating Disorder is more common?
   (a) Anorexia Nervosa
   (b) Bulimia Nervosa
   (c) Anorexia type 2
   (d) Anorexia-exercise type c
6. Which is a subtype of Anorexia Nervosa?
   (a) Restricting subtype
   (b) Exercise subtype
   (c) Anorexia type 2
   (d) Nervosa subtype
7. _____ is the most common medical cause of death in people with Anorexia Nervosa.
   (a) neuropathy
   (b) Bradycardia
   (c) Heart Disease
   (d) Osteoporosis
8. Often times, individuals with Anorexia Nervosa feel bloated and full because food can stay in the stomach for _____ hours) as opposed to the normal passage time of _____ hour(s).
   (a) 4–5, 1
   (b) 6–7, 4–5
   (c) 2–3, 3–4
   (d) 1, 4–5
9. Which of the following is known to stimulate hunger?
   (a) Leptin
   (b) Cholecystokinin
   (c) Ghrelin
   (d) Peptide Y-Y
10. _____ is synthesized extensively in the human gastrointestinal tract, and helps regulate appetite, sleep patterns, and mood.
    (a) Leptin
    (b) Serotonin
    (c) Dopamine
    (d) Catechol-O-methyltransferase

Answers

1. b
2. c
3. a
4. d
5. b
6. a
7. c
8. a
9. c
10. b

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Exercise Metabolism and Menstrual Cycle

7

Maria Fernandez-del-Valle

Learning Objectives
Upon completion of reading this chapter, the reader will be able to the following:

- Become aware of the importance of sex hormone fluctuations for females
- Learn the different terminology utilized related to menstrual cycle phases
- Understand estrogen and progesterone differences across menstrual cycle phases
- Become aware of the limitations of the existent research
- Understand the effects of estrogen on substrate metabolism at rest and during exercise
- Understand the effects of progesterone on substrate metabolism at rest and during exercise
- Understand the interactions between estrogen and progesterone with other hormones and regulatory proteins

7.1 Introduction

Although research in sex differences and exercise is extensive, current exercise recommendations have been developed based on scientific research studies carried out mainly in men (~70% of the studies in exercise science) [1]. The main reason for exclusion of women has been the complexity of their hormonal make-up and fluctuations during the menstrual cycle (MC) throughout the lifespan. In fertile years, sex hormone fluctuations impact functions beyond reproduction (i.e., substrate metabolism, risk of injury, or fatigability). All of these have an effect in the responses and adaptations to exercise and performance.

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In general, research in the physiological impact of sex hormones has shown a link between hormone concentrations and fat deposition or bone and muscular health [2]. But, research in the influence of sex hormones on substrate metabolism has shown to be controversial. Methodological limitations, sample size, oversimplification in the classification of MC phases and the complexity of designing studies that analyze more than two MC time-points have led to contradictory results in effects of exercise on substrate utilization [3–6]. These circumstances have made difficult to interpret results, so they must be analyzed carefully.

Normal reproductive years of women are characterized by monthly changes in sex hormonal concentrations in phases during the MC. Normal MC (28 ± 7 days) starts with menstruation (day 1). In order to contextualize research findings, we are going to define MC phases based on estrogen and progesterone (P_g) fluctuations. MC have two distinct phases, the follicular phase (FP) and the luteal phase (LP), which are separated by ovulation, sometimes referred to as the mid-cycle (around day 14). Based on the varying level of 17β-estradiol (E_2)—the most common form of estrogen—and P_g, both FP and LP could be subdivided in early and late stages (see Fig. 7.1): Early-FP (days 1–7) is characterized by low E_2 and P_g levels with E_2 level being higher than P_g. Late-FP (days 8–13) is characterized by the increasing level of E_2 (E_2 peaks in this phase) while P_g level remains low. Early-LP (days 14–21) is characterized by increasing P_g level (P_g peaks at the end of this phase) and elevated E_2 concentration that remains lower than P_g. Lastly, Late-LP (day 21–28) is characterized by decreasing levels of P_g and E_2 levels, which remains lower than P_g. The changes in concentrations of E_2 and P_g are shown in Figs. 7.1 and 7.2. In this context, we are going to review the research findings in substrate metabolism and MD.

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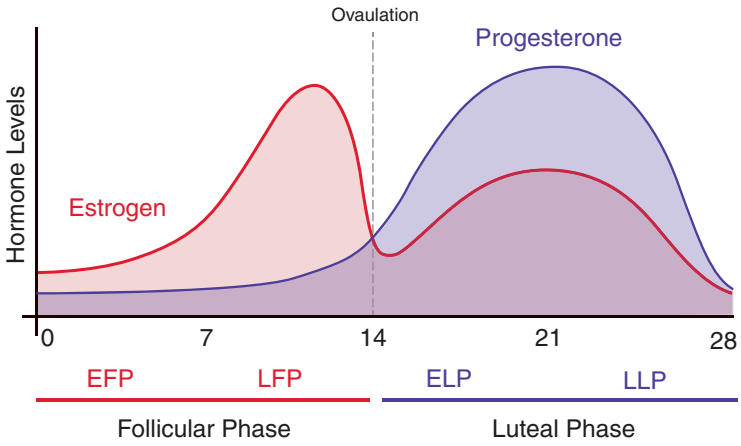

Fig. 7.1 Representation of different phases of a 28-day menstrual cycle and corresponding blood level of estrogen and progesterone. Figure courtesy of Eloi Badia-Rovira, BSc, University of Lleida, Spain. *EFP* early follicular phase (day 1–7); *LFP* late follicular phase (day 8–13); *ELP* early luteal phase (days 14–21); *LLP* late luteal phase (days 22–28)

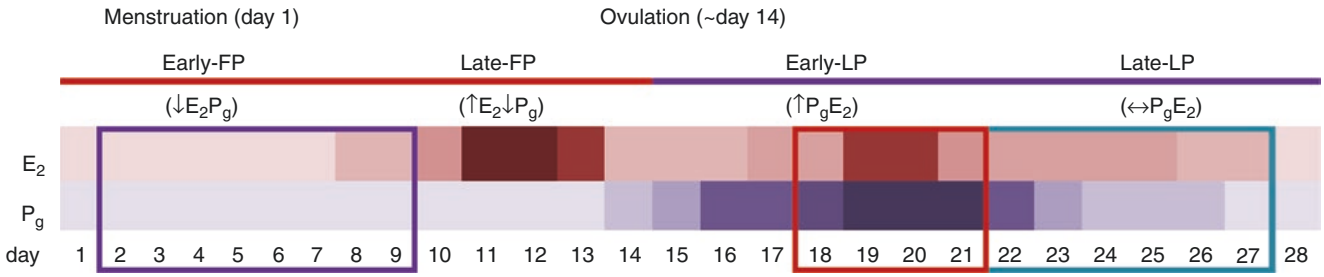

Fig. 7.2 Color-coded representation of estrogen and progesterone fluctuations throughout a 28-day menstrual cycle and main days selected for research in substrate metabolism. E_2 estradiol, P_g progesterone; $\downarrow E_2P_g$ low estradiol and progesterone concentrations, with estradiol above progesterone; $\uparrow E_2 \downarrow P_g$ high estradiol concentrations; $\uparrow P_gE_2$ significantly elevated progesterone concentrations, higher than elevated estrogen concentrations; $\leftrightarrow P_gE_2$ moderately elevated concentrations of progesterone that remain higher than estradiol; *Early-FP* early follicular phase; *Late-FP* late follicular phase; *Early-LP* early luteal phase; *Late-LP* late luteal phase. Color code: light- and dark-colored cells correspond to low and high hormone concentrations, respectively: Pink—represents P_g hormone concentrations, and Purple—represents E_2 hormone concentrations. Borders: *purple*—main days selected to assess FP (early- and mid-point FP); *red*—main days selected to study LP (second half of early-LP and mid-point LP); *blue*—main days selected to study Late-LP (only a few studies)

7.2 Research Findings and Contemporary Understanding of the Issues in Substrate Metabolism

7.2.1 Methodological Limitations and Recommendations

Research in substrate metabolism has focused predominantly on the study of aerobic exercise (AE) [5–15] with very little research in RT [16–18]. The main days studied are days 2–9 of the MC [5, 7–11, 13–15] which correspond to early-FP and mid-FP, and days 18–27 of the MC [5, 8, 10, 14] which correspond to mid-LP (see Fig. 7.2). Therefore, researchers have mainly compared $\downarrow E_2P_4$ levels with $\uparrow P_4E_2$. The oversimplification of terminology and lack to study MC time-points (phases) that include peak E_2 have generated some confusion. For example, when analyzing FP none of the time-points selected matched peak E_2 levels (occurring ~2 days before ovulation) [19], hence, missing to examine the effects of high concentrations E_2 alone (with very low P_g). Figure 7.2. shows the days selected on studies comparing two MC phases: early-FP (purple border) *versus* early- to mid-LP (red border), and one study selecting late-LP (blue border). Also, it is worth to mention that most studies referred to mid-point LP as a phase of elevated E_2 concentration rather than $\uparrow P_gE_2$ (peak concentration of P_g followed by increased levels of E_2). Overall, only one study in substrate metabolism included three MC phases: early-FP (days 2–6), and late-FP and mid-LP in which the selected days were not provided [9]. Lastly, the available literature in RT have focused mainly on muscular fitness (muscle mass and muscular strength) with only three studies analyzing substrate utilization [16–18]. Thus, further study of the effects of AE and RT on substrate metabolism during different phases of MC addressing all these limitations could help to optimize RT exercise prescription for women.

In a review published in 2019, de Jonge et al. analyzed the research in exercise and MC published between 2008 and 2018 [20] with the purpose of outlining "Methodological recommendations for MC research in sports and exercise." They reported that, despite that sex hormones are likely to influence responses to exercise in different ways, only about 40% of the studies included quantification of E_2 and P_g. Additionally, sample sizes were found to be rather small

(i.e., most samples ≤10 and only a few between 15 and 20). Based on their findings they propose the following recommendations to improve MC research:

1. A combination of three methods to verify menstrual cycle phase: "the calendar-based counting method combined with urinary luteinizing hormone surge testing and the measurement of serum estrogen and progesterone concentrations at the time of testing." The verification limit for P_g should be >16 nmol L to detect a non-luteal phase-deficient cycle (low progesterone levels) or normal ovulatory cycle.
2. The inclusion of the late follicular estrogen peak.
3. Sample size should be enough to detect significant changes. So, inclusion of effect sizes, power, and/or sample size calculations should be considered when designing studies and reporting results.

These methodological recommendations will help clarifying some of the contradictory findings on the effects of the MC on exercise performance in general, and more specifically on the effects of MC in substrate metabolism.

7.2.2 Substrate Metabolism at Rest

Metabolism is the term used to describe all the biological activity occurring in the body to maintain homeostasis. When comparing sexes, E_2 enhances whole-body metabolic rate in women about one-third as testosterone does in men [21]. While estrogen and P_g are considered primarily reproductive hormones, they also have an impact in resting fat and CHO metabolism [22] by acting either directly on liver, muscle, and adipose tissue [23]. Figure 7.3. summarizes the effect of E_2 and P_g concentrations on fat and carbohydrate metabolism in women with normal MC.

7.2.2.1 Estrogen Receptors and Estrogen Action

Estrogen receptors (ERs) are proteins found in multiple tissues (i.e., liver, muscle, adipose tissue, brain, etc.).

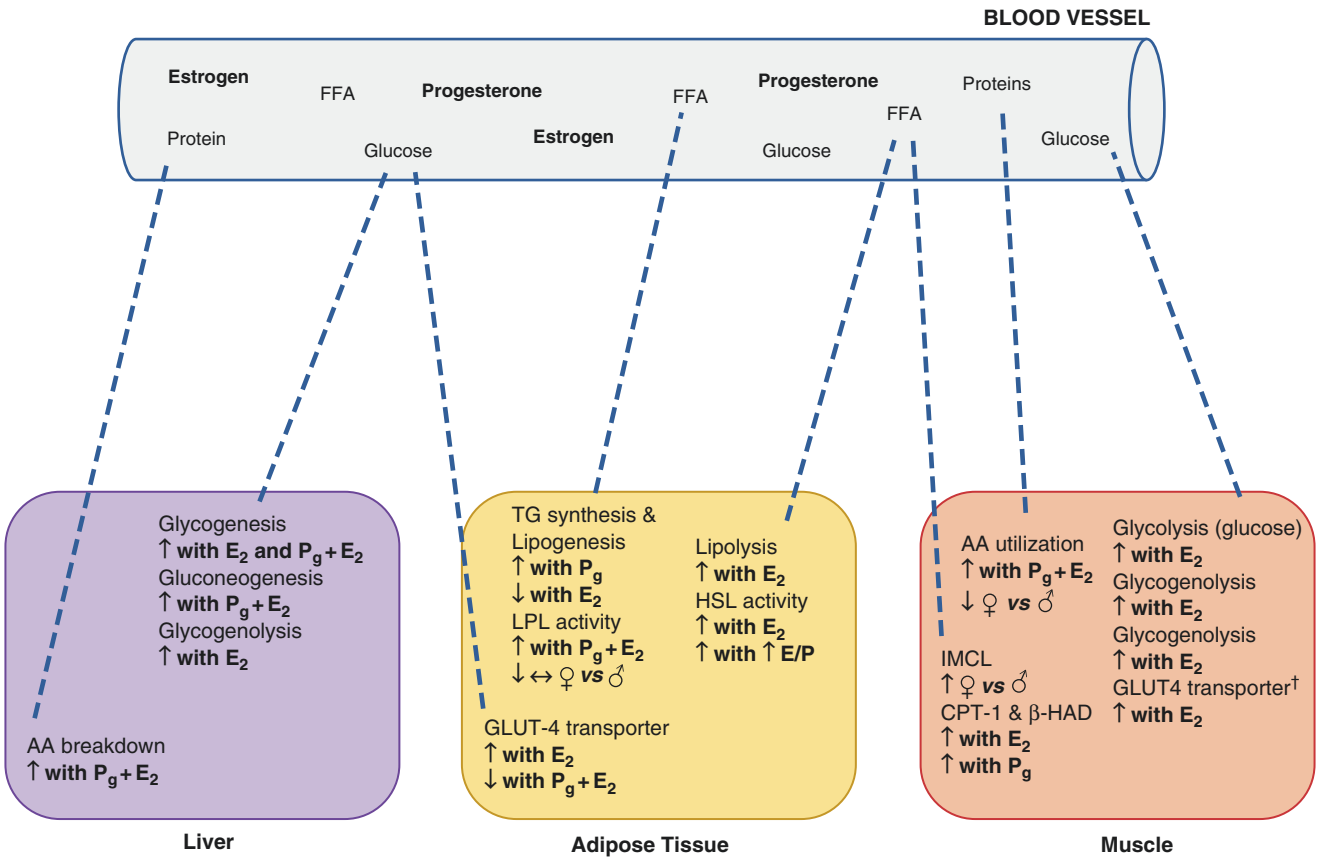

Fig. 7.3 Summary of the effects of estradiol and progesterone concentrations on fat and carbohydrate metabolism in women with normal menstrual cycle. *FFA* free fatty acids; E_2 estradiol; P_g progesterone; *TG* triglycerides; *AA* amino acids; *LPL* lipoprotein lipase; *HSL* hormone-sensitive lipase; *CPT-1 carnitine palmitoyltransferase-1*; *3β-HAD* β-*3-hydroxyacyl-CoA dehydrogenase*; *Gluc*. glucose; ↑ increased the flux in pathway; ↓ decreased the flux in pathway; ↔ no change in flux; ↑E/P higher estrogen-to-progesterone ratio (lower concentration of P_g relative to E_2); ♀ vs ♂ women compared to men and not between menstrual cycle phases; † glucose uptake concomitant to activation of glycogen synthase

Intracellular ERs can be found at the nucleus, membrane, cytoplasm, endoplasmic reticulum, and mitochondria (capable of modulating gene transcription and activate signaling processes mainly through second messengers). The two major types of ERs include alpha (ERα) and beta (ERβ) and they have similar affinity for E_2. Their distribution differs substantially by tissue, and the proportion is higher during women's fertile years compared with the menopause. Adipose tissue, liver, and skeletal have higher expression of ERα compared to ERβ [19]. More specifically, ERα is largely expressed in Type I muscle fibers. This is of great importance, because (1) research in sex differences and fiber-type composition have concluded that Type I fibers are more prevalent in women [24]; and (2) stimulation of ERα is normally associated with increased lipolysis, fat oxidation, and glucose tolerance. The stimulation of ERβ is associated with lipogenesis and insulin resistance [19]. Hence, it shows a greater potential in women to utilize fat metabolism compared to men.

7.2.2.2 Effects of Estrogen and Progesterone on Carbohydrate and Fat Metabolism

In order to understand how research examined substrate metabolism, we show the most common measurement techniques for quantification of both carbohydrate (CHO) and fat metabolism (see Table 7.1.).

Table 7.1 Measurement techniques and location for quantification of substrate metabolism in human research. Adapted with permission from Ruby BC. Gender differences in carbohydrate metabolism: Rest, exercise and post-exercise. Gender Differences in Metabolism: Practical and Nutritional Implications. 1999:121–54 [25]

	Assessment method	Location
Invasive	Blood glucose, fatty acids, or glycerol	Whole-body oxidation
	Muscle biopsy	Muscle glycogen and IMCL Muscle tissue mRNA expression
	Adipose Tissue biopsy	TG, LPL, or HSL content Adipose Tissue mRNA expression
	Isotope Tracer methodology	Hepatic glucose production (Ra) Glucose uptake by the tissues (Rd) Rate of lipolysis (glycerol Ra)
Non-invasive	Respiratory Exchange Ratio (RER)	Whole-body oxidation
	Magnetic Resonance Spectroscopy (MRS)	Variable: single or multiple sites

RER respiratory exchange ratio; *MRS* magnetic resonance spectroscopy; *PET* positron emission tomography, *mRNA* messenger RNA; *IMCL* intramyocellular lipids; *TG* triglycerides; *LPL* lipoprotein lipase; *HSL* hormone-sensitive lipase; *Ra* rate of appearance; *Rd* rate of disappearance

Most data available indicate that women use relatively more fat than men at rest and at any given submaximal intensity [6, 26, 27]. Increased E_2 and P_g concentrations alter metabolic pathways and regulate glucose homeostasis with the purpose of conserving CHO and utilize fats [28]. Some initial studies showed no differences in substrate metabolism when comparing women with normal (N) and abnormal (ABN) MC ($N \leq 32$ and ABN > 32 days) [29–31]. The study by Ruby et al. [29] measured CHO metabolism through glucose rates of appearance (Ra) and disappearance (Rd) in blood. Ra is determined by endogenous release and the production of glucose to plasma (liver glycogenolysis and gluconeogenesis, respectively) and Rd. is determined by insulin-mediated and contraction-mediated glucose transport. The group of women with abnormal MC supplemented with E_2 showed a decrease in CHO utilization at rest [29]. In the same study, the authors assessed the *Respiratory Exchange Ratio* (RER). RER is a quotient between CO_2 production (VCO_2) and O_2 utilization (VO_2), where 1 represents 100% use of CHO and 0.7 represents 100% use of fats. The study did not find correlation between RER and glucose Ra or Rd., suggesting that glucose utilized during exercise could have been from muscle stores (muscle glycogen) rather than blood plasma. Another study using muscle biopsies at rest showed that women in late-LP had significant lower glycogen stores at the quadriceps. Also, resting biceps glycogen stores were lower than the quadriceps in women, but similar to men and between phases. Liver glycogen at rest was similar between sexes and between MC phases [16].

At a molecular level, E_2 supplementation in animals was found to aid in restoring the activity of *carnitine palmitoyltransferase-1* (CPT-1) and *β-3-hydroxyacyl-CoA dehydrogenase* (*β-HAD*) [32–34]. These are key elements in the transport and oxidation of fats in the mitochondria. In this sense, elevated E_2 concentrations have been found to increase fatty acid transport (*CPT-1)* and oxidation (*β-HAD*) in women with normal MC [14, 34], which results in more fats being "burned." In a study by Campbell et al. [32], E_2 stimulatory effect on *CPT-1* was reversed with P_g supplementation, presenting P_g as a contributor to reduce fatty acid transport to the mitochondria.

Glucose tolerance is also influenced by hormonal fluctuations in women during the MC. Insulin resistance increases with both E_2 [35, 36] and P_g [36]. A longitudinal study with 257 premenopausal women concluded that insulin resistance begins to increase at the end of late-FP (close to ovulation) and reaches the maximum levels during LP (including both early- and late-LP). Another study investigating insulin sensitivity in a group of young women supplemented with E_2 and P_g with premature ovarian failure—a condition characterized by low levels of estrogen—showed a significant decrease in insulin sensitivity during LP [37]. This fact highlights the important dual effect of E_2 on both fat transport and

oxidation, and inhibition of glucose transport. At the same time, muscle glycogen seems to be affected by hormonal fluctuations during the MC. Even in resting conditions, muscle glycogen levels are higher during mid-LP compared to early-FP [38–40]. In this sense, animal research has shown increased *glycogen synthase* activity when E_2 concentrations are elevated [41]. However, research including women is necessary to determine if this happens through the different phases of the human MC.

Results in the effects of P_g in substrate utilization have been contradictory as both antagonistic and synergistic relationships with E_2 have been described [32, 42–44]. Human research suggests that P_g stimulates the *Glucose transporter type 4* (*GLUT4*) synthesis [14] and *GLUT4* translocation to the sarcolemma [14, 45], favoring glucose uptake as opposed to E_2 [36]. In this sense, Yeung et al. [36] reported an increased glucose control during early-LP and mid-LP compared to early-FP that was associated to high P_g levels. So, the potential for increased fat oxidation and glucose sparing effects of E_2 could be blunted during early- and mid-point LP by elevated P_g concentrations above E_2. It is important to note that research in the effects of P_g or E_2 alone is scarce, and, consequently, the effects of both E_2 and P_g should be examined carefully and taking into account the relative concentrations.

In 2010, a review published by Oosthuyse and Bosch [34] described estrogen to progesterone ratio (E/P) as an important factor to consider when studying substrate metabolism. In their summary, they showed that studies including women with a higher E/P ratio (lower concentration of P_g relative to E_2) during mid-point LP displayed a significantly increased fat oxidation and overall exercise performance when compared to early-FP [34]. But, women with a low E/P (higher concentration of P_g relative to E_2) did not raise significant differences between early-FP and mid-point LP. Missing to analyze the E/P could have impacted the results in prior studies, and therefore contribute to the contradictory results regarding substrate metabolism throughout the MC at rest and during exercise.

7.2.2.3 Effects of Sex Hormone-Binding Globulin in Estrogen Action

Sex hormone-binding globulin (SHBG) is a protein responsible for mainly the transport of estrogen (only ~1% SHBG binds to P_g) in the blood. Approximately 98% of E_2 is bound to SHBG, with only ~2% E_2 being free. When E_2 is unbound the hormone is biologically active. Total E_2 includes both SHGB-bound and unbound E_2, and to calculate the free E_2 the following equation is used: Free E_2 = Total E_2/SHBG. SHBG synthesis is controlled by different factors. For example, increased free E_2 concentrations can stimulate the synthesis of SHBG, while increased levels of insulin, obesity, or androgens (i.e., anabolic steroids) can inhibit SHBG synthesis. Therefore, all these variables must be considered if we want to understand the relationship between substrate metabolism and hormonal bioavailability. Despite the link between insulin and E_2 bioavailability, some research has reported no associations between insulin sensitivity and sex hormones at different time points of the MC [46, 47]. Little to no research in substrate metabolism at rest or during exercise has included the assessment of SHBG or free E_2. This might have contributed to the conflicting results by missing to detect differences between subjects (i.e., baseline comparisons) and within subjects (i.e., intervention comparisons).

7.2.3 Substrate Metabolism During Exercise

7.2.3.1 Substrate Metabolism During Aerobic Exercise (AE)

Sex-based differences in substrate metabolism in response to submaximal-intensity AE exercise have been well established [5, 48, 49]. Numerous studies including athlete and non-athlete women, different duration (25–120 min), intensities (50–75% VO_2max), and type of activity (i.e., treadmill and cycling) have examined both sex and MC differences in substrate metabolism in response to AE exercise [5–7, 9–15, 29, 32, 50, 51]. Substrate metabolism has been measured through RER (RER = CO_2 production/O_2 utilization), which is assessed using indirect calorimetry. Also, authors have utilized glucose and glycerol Ra and Rd to determine the fuel source (i.e., liver *versus* muscle CHO or fats), and whether the source of fuel was coming from the liver (i.e., gluconeogenesis and glycogenolysis) adipose tissue (i.e., lipolysis) or the muscle (i.e., glycogenolysis or lipolysis). Lastly, some studies utilized biopsies to determine muscle glycogen and intramyocellular lipid (IMCL) stores and utilization.

Overall during AE exercise, women have shown lower values in RER [5, 49, 52], and higher fat and lower CHO oxidation compared to men at all intensities up to approximately 75% VO_2max [13, 51]. Women also seem to rely less in liver glycogen as shown by ↓glucose Ra and Rd, and ↑glycerol Ra [5]. However, whether muscle glycogen stores are utilized or not, or which is the source of increased glycerol in plasma during AE (i.e., plasma fatty acid and/or IMCL) remains controversial. One stream of studies did not find sex differences on muscle glycogen utilization [5, 53–55] and RER [38, 50, 56–58] when exercising at submaximal intensities <65% VO_2max. Other stream of research found that women utilized 25–50% less muscle glycogen than men when exercising at greater intensities (i.e., Wingate test, running 15 km at 65% VO_2max) [49, 59]. Also, CHO oxidation has been found to be significantly higher for men at all intensities (55, 65 and 75% VO_2max) and type of activity (i.e., cycling and running) compared to women [51]. So, it seems

that there is a link between sex, intensity of exercise, and the differences found in utilization of CHO and fats, and more specifically muscle glycogen.

When examining research comparing MC phases, there are only two studies that evaluated three MC phases (only one targeting peak E_2 concentrations alone) [9, 60]. Authors of these studies reported a higher RER (greater CHO utilization) during early-FP (low E_2 and P_g) compared to late-FP and mid-point LP (peak P_g) in untrained and trained females during incremental exercise, suggesting a link between fat metabolism, and peak concentrations of E_2, an effect that might be blunted by high concentrations of P_g. In the first study, Hackney et al. [60] observed a significantly lower RER at ovulation or late-FP compared to early-FP (low E_2 and P_g), but not mid-point of the LP (Ovulation RER = 0.86 ± 0.02, early-FP RER = 0.94 ± 0.02, and mid-point LP RER = 0.89 ± 0.01) in a group of 15 women [60]. The second study including three MC phases (i.e., early-FP, late-FP, and mid-point LP), compared the effects of a 40 min run at 75% VO_2max on substrate utilization [9]. Results revealed a higher RER (greater CHO utilization) during early-FP (lowest E_2 and P_g concentrations) compared to late-FP and mid-point LP [9]. This suggests that more fat is metabolized at peak E_2 concentrations during ovulation, followed by mid-point LP. Therefore, there seems to be a link between E_2 and increased fat utilization and glucose sparing at submaximal intensity AE exercise [60]. Supporting this evidence, a study with women supplemented with E_2 and P_g exercising at submaximal intensity (~60% VO_2max) showed a decrease in glucose utilization and increased fat utilization (decreased RER) compared to normal MC [5]. When considering intensity, fat utilization has been shown to increase [48, 61] or remain the same at workloads up to 65% of the VO_2max, as shown by Devries et al. who reported a gradual decline in fat utilization rate when exercising for 90 min at 65% VO_2max [5]. At the same time, mid-point LP showed reductions in glucose Ra and Rd., and muscle glycogen utilization compared to early-FP without significant differences in RER [5]. However, mobilization and oxidation rates of CHO and lipids were not significantly different between MC phases when exercising at higher intensities (~75% VO_2max) [61]. Other authors comparing only two MC phases (early-FP *versus* late-LP) on women exercising ~25 min at 90% of the lactate threshold ≈ 55% VO_2max, reported a −13% CHO oxidation, +23% fat oxidation, −14% glucose Ra, and −15% glucose Rd in late-LP [7]. In general, authors reported a higher reliance in CHO during early-FP and a higher reliance in fats during mid-point LP [7, 26, 28, 32, 62, 63]. More research including late-FP or peak concentrations of E_2, sufficient sample size and the exhaustive assessment of E_2 and P_g is needed in order to bring light to inconsistent findings.

7.2.3.2 Substrate Metabolism During Resistance Training (RT)

Despite the numerous studies focused on the influence of the MC on body composition and overall muscular performance, there is very little research in the effects of RT on substrate metabolism. Since RT helps with long-term total fat and visceral fat loss (internal fat at the abdominal area) and increases metabolic rate, further analysis of the effects of RT on substrate metabolism could help optimize exercise prescription for women.

In 2017, Price et al. [16] examined the sex differences and MC effects of prolonged lift and carry exercise (muscular endurance) in muscle and liver glycogen utilization. A total of 10 women and 15 men participated in this study. They were asked to squat and lift a 30 kg load three times/minute for ~3 h or until exhaustion. The participants stopped every 15 min to assess glycogen content at the muscle and the liver (i.e., magnetic resonance spectroscopy). Overall biceps muscle glycogen depletion rates were different between men and women, but similar between MC phases. Also, liver glycogen showed less decline during the late-LP compared to men but not early-FP [16]. This study suggests that women and men work their lower body (quadriceps) similarly, but women store more quadriceps glycogen during early-FP. However, future research should consider including loads relative to the body size, muscle mass, or body weight of the individual.

A second study by Farinatti et al. [64] studied oxygen consumption and substrate metabolism during RT exercises performed with different muscle mass. This study included only men and compared substrate metabolism between leg press and chest fly exercises (5 sets of 10 repetitions with 15 RM workloads and 1 min rest between sets). Leg press exercise yielded a higher RER compared to chest fly at sets 1, 3, and 5 and with respect to baseline. CHO utilization increased from set 1 to 4 in both exercises, with higher increases in leg press, but no significant differences were found for fat utilization [64]. Although no females were included in this study, it shows that upper and lower RT exercises might affect substrate metabolism differently. Therefore, future studies in the effects of substrate metabolism and RT should consider not only intensity and volume but also target muscle groups when designing exercise protocols.

The effects of MC on substrate metabolism at rest and during exercise is a complex topic. More research addressing methodological issues is needed to bring light to some contradictory findings reported in the literature. Education of those involved with female athletes or active women, will help in developing sex-specific exercise programs based on the potential for greater performance linked to the MC. In all, women show a greater potential for fat oxidation than men, and some research shows that fat oxidation and glucose

sparing increased during late-FP (peak E_2), but more consistent scientific evidence is required to establish that those differences can be extrapolated to all women with normal MC.

7.3 Future Directions

Future research should include a combination of three methods to verify menstrual cycle phase (i.e., the calendar-based counting method, urinary luteinizing hormone surge testing, and serum estrogen and progesterone concentrations) with a verification limit for P_g > 16 nmol L; MC phases should include Late-FP estrogen peak; and sample size of studies should be enough to detect significant changes (i.e., ≥20 depending on the design and number of groups). In terms of exercise professionals, the knowledge of those working with active women—competitive or not—should include an understanding of substrate utilization and exercise type, duration and intensity, and how E_2 and P_g potentially affect substrate metabolism and performance.

7.4 Concluding Remarks

Women's sex hormones—E_2 and P_g—have been recognized to influence metabolism, muscular fitness, and body composition. Existing research in sex hormone variation during MC and substrate metabolism has focused predominantly on the study of aerobic exercise. Research in women's differences in substrate metabolism during the MC phase must be analyzed carefully, as there have been some methodological limitations that have led to contradictory findings. In all, the results can be grouped in two streams of thought. One that did not find differences between MC phases, and the other that supports that glucose sparing and fat oxidation are increased when estrogen and P_g are elevated at rest and during exercise. However, these effects seem to disappear when exercising at intensities >75% VO_2max. In all, women exhibit an increased potential for higher performance in AE moderate-to-high intensity exercise that might vary with hormonal fluctuations. The effects of RT on substrate metabolism need further examination. But, given the potential for glycogen storage and utilization at specific MC phases, E_2 and P_g could impact performance in power/velocity-related events. Still methodological limitations have led to findings that—contradictory or not—must be analyzed carefully.

Chapter Review Questions

1. Which of the following methodologies are recommended to improve research in menstrual cycle and substrate utilization?
   (a) Sample size big enough (~20 participants or more)
   (b) Exclusion of late follicular estrogen peak
   (c) Use only one method to verify menstrual cycle phase
   (d) None of the above
2. Estrogen receptor alpha (ERα) is largely expressed in _____ (which are the types of fibers more predominant in women) and it is associated to _____.
   (a) Type 1 muscle fibers, decreased fat oxidation
   (b) Type 2a muscle fibers, decreased glucose tolerance
   (c) Type 1 muscle fibers, increased lipolysis
   (d) Type 2a muscle fibers, decreased lipolysis
3. _____ is determined by endogenous release and production of plasma glucose.
   (a) Ra
   (b) Rd
   (c) Glycerol
   (d) Leucine
4. Which of the following is a key element in the transport of fats that increase with E_2 concentrations in women with normal menstrual cycle?
   (a) β-3-hydroxyacyl-CoA dehydrogenase (β-HAD)
   (b) Glycogen synthase
   (c) Carnitine palmitoyltransferase-1 (CPT-1)
   (d) Lactate Dehydrogenase
5. In premenopausal women, insulin resistance begins to increase at the end of _____.
   (a) Early follicular phase
   (b) Late follicular phase
   (c) Early luteal phase
   (d) Late luteal phase
6. Estrogen-to-progesterone ratio (E/P) is an important factor to consider when studying substrate metabolism given
   (a) Women with a higher E/P (lower concentration of P_g relative to E_2) during early follicular phase have an increased fat oxidation and exercise performance
   (b) Women with a lower E/P (higher concentration of P_g relative to E_2) during early follicular phase have an increased fat oxidation and exercise performance
   (c) Women with a higher E/P (lower concentration of P_g relative to E_2) during mid-point luteal phase have an increased fat oxidation and exercise performance
   (d) Women with a lower E/P (higher concentration of P_g relative to E_2) during mid-point luteal phase have an increased fat oxidation and exercise performance
7. When exercising at high intensity (i.e., Wingate test) women utilize _____ muscle glycogen than men.
   (a) 10–25% more
   (b) 10–25% less
   (c) 25–50% more
   (d) 25–50% less

8. Mobilization and oxidation rates of carbohydrates and lipids are not significantly different between MC phases when exercising at
   (a) intensities ~25% VO_2max
   (b) intensities ~55% VO_2max
   (c) intensities ~75% VO_2max
   (d) none of the above
9. Liver glycogen is utilized to _____ extent during _____ when performing muscular endurance exercise.
   (a) less, late luteal phase
   (b) more, late luteal phase
   (c) less, early follicular phase
   (d) none of the above
10. Which is the verification limit for progesterone to detect minimum luteal phase progesterone level that indicates an ovulatory cycle or non-luteal phase-deficient cycle?
   (a) $P_g > 1$ nmol L
   (b) $P_g > 5$ nmol L
   (c) $P_g > 16$ nmol L
   (d) $P_g > 26$ nmol L

Answers

1. a
2. c
3. a
4. c
5. b
6. c
7. d
8. c
9. a
10. c

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Part II

Inequities in Women's Health Care and Alternative Management Strategies for Women's Health

8 Racism, Health Disparities, Health Inequities, and Black Women's Health and Healthy Activity

Aretha F. Marbley, Stella L. Smith, Sharhonda Knott Dawson, Jasmine D. Parker, and R. Patrice Dunn

The heart of a woman goes forth with dawn
As a lovebird, soft winging, so restlessly on,
Afar o'er life's turrets and vales does it roam
In the wake of those echoes the heart calls home.
The heart of a woman falls back with the night
And enters some alien cage in plight,
And tries to forget it has dreamed of the stars
While it breaks, breaks, breaks, on the sheltering bars.
Georgia Douglass Johnson

Learning Objectives

- Addressing the link between health disparities and health inequities in the African-American community and the impact of racism on Black Women's health.
- Adding to the academic discourse on the impact of perceived racism, racial stressors, and racial discrimination on Black Women's health and health activity of the active Black woman.
- Understanding the difference between disparities in health and health care and between health disparities and health inequities.
- Exploring findings from past studies on the negative impact of racial discrimination and related factors on Black Women's health.

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8.1 Introduction

It is also well documented that African-American women have had racist and inequitable experiences in the healthcare system [1–4]. Black American women, regardless of their backgrounds, have catastrophic health experience. Recently, the musician Beyoncé and the athlete Serena Williams, two of the most famous African-American women alive today, experienced life-threatening complications during their pregnancies. One of them also nearly died after giving birth, experiencing firsthand that education and socioeconomic status (SES) do not protect Black women. Yet health professionals and the health profession have been slow to acknowledge the role that racism plays in poor outcomes. In order to eliminate inequities and barriers to good health care for Black Women, public health professionals, policy makers, and the women themselves must address barriers that impede equitable healthcare delivery in the African-American community.

For nearly two decades, interest in the potential role of discrimination (both racial and gender based) on Black wom-

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en's health has been developing among African-American female scholars. Earlier studies have examined personal and health risk factors affecting Black women including medical conditions, sexual activity, biosocial stressors, drug and alcohol use, physical activity and nutrition, healthcare accessibility, psychosocial and family health histories, and psychological and emotional stress. But very few have examined the specific effect of racism and racial discrimination on the mental and physical health of people of color.

In order to address the impact of racial bias, racism, and health disparities that leads to Black-American women's health, this chapter begins by tracing inequities and disparities within the African-American community. To focus on African-American women, in particular, perceptions of racism, sexism, and the combination of both affecting their lives and livelihood, the authors discuss findings from Marbley's study [5] on the effects of racial and gender discrimination among Black women and Marbley's study [6] on health disparities in the African-American community. The findings from the study on the effect of racism and sexism suggest that Black women's experience of racism is common and pervasive and the study on health disparities in the African-American community points to racial discrimination. The findings from both studies are foundational in helping to provide a connection of the impact of racism on the health of African-American women [5, 6].

The authors highlight from the media of stories in which powerful Black women such as Beyoncé and Serena Williams nearly lost their lives as present-day and powerful examples related to racism and the health of physically fit Black women. These stories together with the authors' personal reflections link Black women's experiences of racial discrimination and racism to risk factors that affect Black women's health and threaten their lives regardless of cultural, economic, and professional backgrounds.

8.2 Internal Racism and an Absence of Female Consciousness Frameworks

To take a closer look at racism and, perhaps, unpack the power of racism and racial discrimination on the health of African-American Women, the authors use as a combination of internal racism and feminist consciousness as a theoretical lens. This theoretical framework is subsumed under Bivens's [7] four areas of unequal distribution of systemic power for people with White-skin privilege and Stone's [8] five factors contributing to the absence of feminist consciousness for African-American women. Combining Bivens [7] framework on *internal racism* and Stone's [8] model for the *absence of feminist consciousness* provide a solid theoretical framework for understanding African-American women's health experiences.

8.2.1 Internal Racism

In her work at the Women's Theological Center, Bivens [7] defines racism and the internalization of racism as "the primary assaults on [Black people's] love for ourselves and each other," noting that racism is "a system of oppression based on race that in [the United States] is perpetrated by White people against people of color." Although Bivens further labeled racism as an unequal distribution of systemic power for people with White-skin privilege, for Black women and their health, racism translates into inequality in outcomes, access, and voice.

According to Bivens's framework, racism involves limiting Black people's access to (a) the power to make and enforce decisions; (b) resources, broadly defined; (c) the ability to set and determine standards for what is considered appropriate behavior; and (d) the ability to define reality. The resulting inequities in power, outcomes, access, and voice result from our history of colonialism, genocide, and oppression in which material, intellectual, spiritual, and emotional resources of Black women are exploited in service of others through force, deception, and disrespect for Black women's cultural and gendered identities. For Black women, racism is both internalized and an act of violence.

8.2.2 An Absence of Female Consciousness

Stone [8] attributes African-American women's absence of feminist consciousness during the 1960s and 1970s to five factors. These factors were their view that sexism was racially divisive [9–11]; White women's racism [11–15]; the importance of African-American men's liberation [16–18]; the myth of Black matriarchy [19, 20]; and the Black church [21].

African-American women, to this day, rarely see the benefits of a strictly feminist agenda to their lives, and as result, have been slow to embrace feminist advocacy. Although they were strong advocates of Black feminism during the second wave of feminism, *feminism* was not at the center Black feminism. Therefore, there has been little support and participation from Black women or the Black community in White feminist agendas [22]. Perhaps, this lack of visible participation of women of color in first-, second-, and third-wave feminism, and now fourth-wave feminism can be attributed, to a large extent, to racism, sexism, and classism, and dynamics of the interplay of these oppressions with politics [23, 24] surrounding the Black movement and the feminist movements from all three eras. Or just maybe, Black feminist absence from these three feminist movements can be attributed to White racist media that decides that Gloria Steinem is more important to feminism than bell hooks, Alice Walker, or Audre Lorde, which creates visibility.

Perhaps because of racism's oppressive, brutal, and violent nature stemming from slavery and residuals of four centuries of survival of the African-American family and community, many African-Americans, both male and female, viewed sexism as a factor of minimal importance [8]. Meaning, Black American women have perceived and reported that racism negatively affected their lives and health more than sexism. Research on how discrimination affects African-American women's psychological and physical problems that focuses on stress reactions to perceived racial and gender discrimination has found that attributes of ethnic and ethgender discrimination were associated with increased stress [25].

King [25] identifies ethgender discrimination as the type of discrimination African-American women experience due to their "position at the intersection of African-American ethnicity and female gender" (p. 204). However, research does not suggest that gender discrimination was associated with stress for Black women, which suggests that racially motivated discrimination may play a primary role in negative outcomes [25].

8.3 Racism, Racial Discrimination, Health, and Health Care

Structural racism impacts health and health care, and consequently, the health disparities and inequalities that are prevalent in the African-American community and other communities of color and ultimately, the health of active Black women. Research shows that racism affects many aspects of Black women's healthcare experience, even before they make clinical contact, specifically factors that contribute to those outcomes [26, 29]. The impact of racism ranges from lower access to quality health care to lower quality of care. It also includes the effect of racism on Black women giving birth experiences and the doggedness of racism in perinatal care for women of color, regardless of wealth or fame. Fundamentally, systematic and pervasive racism and stereotypic threats are connected to both physical and mental health challenges, which include emotional stress, premature aging, and increases in allostatic load [27, 28, 30–32].

Simply put, Black women are significantly more likely than White women to give birth prematurely, die in childbirth, lose their babies, and have life-threatening complications during pregnancy. Granted, factors such as poverty, low SES, and poor education are major risk factors for Black women having pregnancy complications, but there is clear evidence that wealthy Black women also face a disadvantage.

Twentieth-century historian and journalist Theodore White [33] believed that "Three issues have dominated American history: those of bread and butter, war and peace, and Black and White relationships" (p.19). White's conversations and commentaries, like all three issues, were grounded in what can be deemed as *American interests*. On the one hand, the legacy of slavery has dominated the United States for at least four centuries and has kept White people in power. On the other hand, sexism, a legacy of patriarchy, has dominated our world for more than forty centuries of recorded history and has kept men in power and women marginalized. On account of both slavery and patriarchy, African-American women have been historically and systemically marginalized by both structural sexism and racism.

This means that for centuries, pervasive sexism has kept women marginalized and men in power, and the status of Black and White race relations has kept Blacks marginalized and White people in power. Both gender and racial relationships have kept Black women marginalized and vulnerable to gender and race-based stressors that have affected their health.

Our nation is structured and stratified along race, gender, and class lines such that African-American women have ended up on the bottom rung of the ladder. All in all, history has shown that the United States' political vigilance and relentless pursuit for US interests documented in our history books, has not served the *interests* of Black folks in the Unites States, nor those of women, and by default, those of African-American women. Essentially this means that the vigil of *American interests* perpetuated by White supremacy served to elevate White people while keeping Black folks from prospering. Factually, in the United States, *bread and butter, war and peace*, and *Black and White relationships* are intertwined and inseparable and together have sustained many forms of disparities and inequities, including a history of health-related disparities for Black women, Black people, people of color, and other marginalized people.

Javaid [1] stated, "Historically African-Americans have not always received equity in health care, access to health care and equality in treatment, which has led to poorer overall health status than Caucasians" (p. 19). Therefore, given the pervasiveness of historical racism and the insidious nature of racism and racial discrimination, it should not be surprising that literature and life show racism as a chronic and acute stressor harmful to Black people and Black women's health. Racism affects Black Americans from all backgrounds and impacts health status, health behaviors, health outcomes, and access to health care. Ultimately, racism has adverse effects on the mental and biopsychosocial, and acute effects on the physical health of Black folks generally and Black women in particular.

African-Americans have higher incidence of health *disparities* and health *inequalities* between them and the Whites group than between African-Americans and other groups of color [1, 34–36]. For example, across most health indicators,

African-American women fare worse than other women of color do. Researchers report that African-Americans have a higher probability than Caucasians of having two or more chronic diseases such as diabetes, cardiovascular disease, arthritis, HIV and AIDs, asthma, sickle cell disease, lupus, renal disease, and obesity. Moreover, among those diagnosed with many chronic diseases, Black Americans have worse experiences than non-Hispanic Whites of similar SES [37].

Based on her study of the experiences of Black middle-class women in the healthcare system, Sacks [27] stated that, "Black women cannot afford to be sick and tired even though the doctor's office is ostensibly the place one should be able to let one's guard down and fully explain one's condition to the provider" (p. 17). Moreover, Booker et al. [37] found that when Black women do fully disclose their medical challenges, they are likely to feel that their healthcare providers "lack cultural sensitivity and do not take the time to address their health complaints and other issues" (p. 106).

Black Americans also face barriers to access; a long-standing problem that has recently increased [37]. Such barriers may manifest in the form of difficulty accessing a healthcare provider, attaining prescription medications, obtaining transportation to medical appointments, and paying for medical services.

Some disparities begin in adolescence and continue throughout adulthood, affecting Black women's quality of life and wellbeing as well as their work and family life [38]. Barr concludes that some factors, such as poverty, increase the size of the disparities [39], across neither age, sexual orientation, SES, nor geographic region explains the health disparities affecting African-American women.

One in four African-American women over the age of 55 have diabetes, which is 1.8 times more than Caucasian women. In terms of childbirth, African-American women have the highest incidence of preterm delivery and low birth weight than any ethnic group in the United States. African-American women are also more likely to die from breast and cervical cancer as well as cardiovascular disease than White women are. Further, African-American women are disproportionally impacted by HIV-AIDS, 22 times more than other minorities to die from complications related to the disease [38]. African-American women have a greater prevalence of Lupus than White women do, and Black women who have the disease have higher levels of chronic inflammation and tissue damage and renal and cardiovascular complications. They are also more likely to be diagnosed late and after diagnosis, die more quickly than White women with the same disease [40]. Social stressors affect the progression of Systemic Lupus Erythematosus (SLE), and along with unfair treatment based on race, are associated with greater disease progression for African-American women [40].

Compared to White women, African-American women also have the highest-level prevalence of obesity of any ethnic group, at 80% [38], and 14% of African-American women are extremely obese [41]. Evidence implicates racism directly in the prevalence of this condition, which is a risk factor for numerous other chronic conditions. A longevity study shows that self-reported perceptions of both everyday racism and racism experienced over the lifespan have a positive correlation with both weight gain and increase in waist circumference, an association that was robust across geography, level of body mass index (BMI), and educational attainment.

In addition, because in these study, racism causes weight gain, weight gain is a measure of how well respondents coped with racism and becomes a measure of NOT coping with racism [41]. Research also ties the prevalence of hypertension among African-American women, which is **much higher** than that of White women, to racism [1].

For example, a study that used a sample of Black college students found that racist stimuli increased blood pressure while stimuli featuring anger provoking but non-racist stimuli did not [42]. Another study looked at the relationship between blood pressure and the reported experiences of racial discrimination on young African-American and Caucasian adults.

They found that listening or responding to a racist outburst raised blood pressure (BP) as well as self-reports of anxiety, resentment, and cynicism more than listening to or responding to a non-racist outburst. This raised BP reading persisted at least 10 min, a sustained elevation that can lead to vascular damage [43]. The same study found that social support may buffer the effects of stress by decreasing hypertensive responses to the incidents and that systolic blood pressure in working-class Black adults was higher among those who had experienced unfair treatment and racial discrimination. Moreover, for professional African-American adults, blood pressure was lower if they challenged unfair treatment but did not experience racial discrimination. Researchers [28] theorize that challenging the unfair treatment avoided the internalization of experiences of discrimination.

Researchers [26] have also studied the association of experiencing racist events with negative health consequences for African-American women. They found that women reporting experiences with racism have "higher levels of psychological distress, negative health behaviors and physical health problems" (p. 456). These problems include higher distress, colds that are more frequent, more chronic illnesses, and increased instances of drinking alcohol and smoking. Some researchers attributed a 5% variation in health outcomes to lifetime racist experiences.

Health Inequities and Disparities: In recent years, more studies have focused on the impact of racial discrimination on the health inequities and disparities of African-American women in the United States. Despite often being used interchangeably, health disparities and health inequities have

slightly different meanings. As defined by the Institute of Medicine report on unequal treatment, a health inequity is related to access to proper health care, clinical needs, preferences, and necessary interventions [1]. By contrast, a health disparity is a difference in health outcomes within a population. These differences can be determined by social, demographic, environmental, and geographic attributes [1, 44]. Each of these aspects of health is discussed throughout this study as it relates to African-Americans, specifically Black American and African-American women.

Black feminist scholars including Patricia Hill Collins and Melissa Harris Perry have examined stereotype threat and racism through an intersectional lens of race and gender. They argue that societal stereotyping for African-American women is devastating that it creates what Collins calls "controlling images" that are pervasive and normalized [45]. Examples of these images include "the Jezebel the hypersexual, predatory black women, the Mammy, the heavy set asexual domestic worker who happily serves her White charges at the expense of her own family, and the Sapphire, the angry, emasculating, wise-cracking 'sista'" [27, 46]. Healthcare workers are not immune to these controlling images. Gilens [47] as cited by Sacks [27] argues that the "welfare-queen, the black woman that does not control her fertility, has children with multiple partners, and subsequently relies on the state to support them" (p.30) is the most prominent in healthcare interactions.

Sacks [27] research indicates that Black women, regardless of SES exhibit specific characteristics to try to mitigate the effects of stereotype threat and discrimination in their health care. She found that they pay particular attention to their physical presentation in healthcare settings, work hard to connect personally with doctors, and use knowledge to demonstrate legitimacy [27]. However, as Gilmore [48] indicates, no individual behavior can mitigate the effects of historical and structural racism.

In the vein of structural racism, notwithstanding war and peace, centuries of exposure to both racism and sexism, lack of economic resources, coupled with a stress laden matrifocal role Black women have played and continue to play in Black life, it is not surprising that discrimination has a monumental impact on both Black women's physical and mental health. For African-Americans, the *Bread and Butter* socioeconomic factors that determine health are education, employment, and income, which are a source of racial health disparities and as such are innately racist and have consistently landed Black women on the bottom socioeconomic rung of society. Thus, given the compounded impact of racism, sexism, socioeconomics (bread and butter), and the systemic oppressions, the multiplicity of health issues facing Black women should not be surprising.

Precisely, this means that during war and peace, there are disparities and inequities within our social structures that deny Black women access to quality health care. Further, as a country, we are committed to the elimination of racial injustices toward Black folks and the persistent patterns and practices of sexism against females. Compared to White women, the status of Black women's health is dismal. Up till now, African-American and other Black women in the twenty-first century, regardless of SES, continue to narrate and share anecdotal reports of their experiences of discrimination.

In the psychosocial context of African-American Women's health, studies point to a negative relationship between SES and the treatment of allergies, PID, and pregnancy-related illness. In addition, these findings expand our understanding of the stressors low SES patients might experience including not only lack of income but also due to tax liabilities and unstable employment. Based on these findings [49], "It is important for health care providers to address discrimination in the lives of Black women and provide opportunities to explore race-based inequality, which may influence [Black women's] visits to healthcare facilities as well as their physical and psychological symptoms" (p. 287).

In short, aside from disparities in health and heath care, Black women are dying at faster rates than White women and other women. Therefore, we deemed it appropriate to address the impact of racism and racial discrimination on women health, specifically, the health of the active Black woman.

Health Inequities and Black American Women: One factor that identified as a barrier to access and quality healthcare for African-Americans is the patient–doctor relationship. Trust in the healthcare provider is critical for patients to trust the information being shared about health diagnosis and to have confidence in treatment [37]. Researchers [38] have found that the mistrust that African-Americans feel toward doctors "further marginalizes a group disproportionally affected by negative health outcomes" (p. 725).

Researchers [50] investigating the experiences that cause barriers in patient–doctor relationships including perceived discrimination, medical mistrust, and poor communication found that the genesis these feelings can be connected to the entire experience in the healthcare system and not just their interaction with their physician. From the experience at the reception desk checking in, treatment in the waiting room, and ultimately seeing the physician, each of these interactions could lead to patient mistrust. The research also found that as long as the physician demonstrated competence, racial discordance did not occur.

Also, many African-Americans do not have health insurance, are underinsured or have gaps in insurance due to unstable employment that disrupt continuous and quality health care. Researchers [1] found that "people who have health insurance receive more preventative care, regular check-ups and screenings; consequently, they die less pre-

maturely than those individuals who are uninsured or underinsured" (p.24) However, even for those African-American women with health insurance, paying for medical expenses can be a challenge [37].

Health Disparities and Black-American Women: Across most health factors, African-American women fare worse than other ethnic minority women. Researchers [26] have also studied the association of experiencing racist events with negative health consequences for African-American women. They found that women reporting experiences with racism have "higher levels of psychological distress, negative health behaviors and physical health problems" (p. 456). Specific negative results include higher distress, more common colds, more chronic illnesses, and increased instances of drinking alcohol and smoking. They found that lifetime racist experiences accounted for a *variance of 5 percent* in health outcomes for participants.

Racism in Health and Health Care—White Spaces: Sacks [27] purports that in spite of the "persistence of racial discrimination as a determinant of healing, many public health and health service researchers seem to focus almost exclusively on ethno-racial minorities who are poor, thereby ignoring the durability of racism against class" (p.18). This limited view dismisses the effects of racial discrimination regardless of class and the impact of these anticipatory effects and stereotype threats against African-Americans in American society.

Anderson [51] speaks of the distinct difference between Black and White social environments and argues that Black professionals often find themselves in work settings or social settings in which they are the only Black person, in an environment that is typically a "*White space*" [27, 51, 52]. Sacks [27] expands on this concept to argue that "healthcare services may be characterized as a White space that Black middle-class women have to navigate" (p. 21).

Further support for the labeling of healthcare spaces as "*White spaces*" can be found when looking at the demographics for the healthcare profession. Just 4% of doctors are African-Americans [53]. However, having the opportunity to have an African-American physician is not the remedy to racist treatment. Sacks [27] found that even when the physician was Black, Black people still experience discriminatory treatment because the culture of healthcare is built on a racist and discriminatory system.

One such type of discrimination is stereotype threat, a term coined by Claude Steele [54]. Health-related stereotype threat posits that when interacting with healthcare environments, patients recognize the threat of being stereotyped and, thus, alter their behavior to try to avoid being discriminated against [27, 55]. Examples of health-related stereotype threat [28] include "being a waste of a provider's time, unintelligent, unworthy of quality care, unable to adhere to medical protocols, or generally unpleasant" (p. 23). The consequences of stereotype threat, both emotional and physical, can have lasting affects even if the medical provider provides good and respectful care as the stereotype threat is not caused by the patient–provider interaction, but rather by the anticipation of interacting with the healthcare system as a whole [27, 56].

8.4 Bridging the Gaps Study: Health Disparities and Inequities in the African–American Community

For African-Americans, major and life-threatening barriers to health and disparities in health care are in the areas of access to health care and in their general health and wellbeing. Barriers include lack of health insurance, types of insurance (e.g., Medicaid), income, availability of and proximity to healthcare providers, and cultural barriers; whereas marked health disparities include differences in survival and rehabilitation following medical conditions such as cancer and strokes and differences in the incidence of medical conditions such as hypertension and diabetes. In short, African-Americans have higher incidents of health disparities and health inequalities than other racial groups [57].

Moreover, health disparities have manifest differences in not only a lack of medical insurance, access to primary healthcare services, early detection of diseases, and the quality of health care, but also the incidence, prevalence, mortality, and disproportionate burden of diseases that exist between the majority group and among marginalized populations, specifically groups of color. Birth and infant health outcomes are the poorest for African-Americans.

Rates of HIV/AIDS are at an epidemic high for African-Americans and AIDS is now the leading cause of death for Black women ages 25–44. As of 2017, according to the Center for Disease Control [58], African-American women are more likely to die of the disease than the women of other races. African-Americans make up 59% of all AIDS cases reported in the United States (Hispanic/Latina 16%; White 20% and Other 4%) reaching near epidemic levels. Furthermore, African-Americans in contrast to other racial groups who have AIDS die younger.

Noticeable inequities exist among groups of color and by geographic region. Improved access to primary healthcare services promotes good health, reduces morbidity, and decreases complications from chronic disease. National Statistics reported 8.8%, or 28.1 million, in 2017 have no insurance. For non-Hispanic Whites, 6.3%; for African-

Americans, 10.6%; for Asian 7.3%; and for Hispanics, 16.1% [59].

According to the Texas Medical Association (TMA), in 2019, 15% of all Texans have no insurance; for non-Hispanic Whites, 23%; for African-Americans, 11%; and for Hispanics, 62% [60]. In 2017 and 2015, almost 36% of rural residents in Texas have low incomes compared with 29% for urban dwellers and 65% in border counties; 35 counties in Texas have no primary care physicians, 138 counties have no pediatricians, and 147 counties have no obstetricians/gynecologists [59, 61].

The above data suggest major inequities in early diagnosis, treatment, and too often, access to medical care. African-Americans have much higher incidence rates of diseases such as cancer than other groups, particularly for colorectal, prostate, and cervical cancers for which early detection preventive screenings exist, which could save their lives.

Moreover, African-Americans are also plagued with the highest mortality rates of heart disease, stroke, and diabetes than any other groups. In terms of gender and ethnicity, African-American males have higher rates of lung cancer than both European-American and Hispanic groups. Similarly, African–American females who experience a lower incidence of breast cancer than other ethnic groups have a higher mortality from this disease [62].

Bridging the Gaps: A Patient-Centered Curriculum: As part of the Bridging the Gaps Patient-Centered Curriculum for Cultural Competence evaluation plan, the study examined African-Americans' experiences of health care and their perceptions of the health care inequities in an urban community. These qualitative data were collected via focus groups developed by the project evaluation team. In this context, the purpose of conducting focus groups was to investigate African-Americans' perceptions of and experiences with health care in an urban region of West Texas.

Focus groups were primarily used to explore the range of ideas, understand differences in perspective, capture meaningful language, and understand factors of influence [63].

In effect, these African-American focus groups were designed to permit the Project Team to address the primary goal of the Project, namely, training students and physicians to provide culturally competent patient care. Accordingly, results from these data are just another effort to integrate community-based cultural competence training into this new curriculum that aligns a School of Medicine's Patient-Centered Curriculum for Cultural Competence with the needs of the African-American community in this community in Texas. Improved access to primary health care services encourages good health, saves lives, and decreases complications from chronic disease. Therefore, it was of critical importance to hear the voices and the personal stories of African-Americans and integrate them into the cultural competence training.

8.4.1 Procedures

The focus group data were collected from 16 African-Americans participants in two focus groups. The Medical Professionals group members responded as both patients and as medical professionals. The lead author, Marbley and an African-American psychiatrist and internist facilitated two African-American focus groups, one consisted of laypersons (mostly residents of East Lubbock-–the African–American community) and the other group consisted of medical professionals. The same two facilitators co-led each group and the same questions and topics were discussed in each group.

The Medical Professionals Group and the Laypersons Group were identical in size and gender: 2 co-facilitators and 6 members (5 females and 1 male). The first group (Medical Professionals) consisted of 3 nurses, 2 physicians, and 1 dentist ranging in age from 37 to 59 years with a mean age of 47.7. Members of the second group (Laypersons) consisted of a mental health specialist, attorney, hospital administrator, academic advisor, pastor, and secretary ranging in age from 30 to 53 years with a mean age of 40.0. In terms of levels of education, all members of the professional group had masters' or professional degrees. In contrast, only half (three) of the Laypersons Group members had masters' and professional degrees and the other three had high school diplomas or GEDs with some college.

Audio-taped interviews of the participants in both groups yielded 36 pages of transcript. Transcript data were indexed in order to make the analysis process more manageable for interpretation. The data are aggregated and discussed to answer guided questions. According to Coffey and Atkinson [64], indexing allows components of data to be aggregated in ways that are relevant to a specific theme, topic, or hypothesis. Index codes were assigned to various paragraphs and sections of the data that proved relevant. Through the process of analytic induction, several themes were uncovered. The process of analytic induction is a "means to derive explanatory hypotheses which apply to all the data available of a particular phenomenon or problem [65]".

8.5 Research Findings

Based on participants' lived experiences, several factors related to *access*, *quality,* and *cultural dimensions* were identified across interview data with the medical professionals as being the most important for African-Americans and the African-American community.

Themes from both groups were collapsed into three categories.

Thus, for the study reported herein, these themes from both African-American focus groups are (a) *Access* which includes *political bureaucracy and affordability; (b) Quality* which includes *touching the patient, being a good servant,* and *having bedside manners*; and (c) *Cultural Dimensions* which includes *community knowledge*, *poor, elderly*, and *medical professionals of color*. Thus, the major themes that emerged from the data and the analytic induction process included: (a) *Access*, (b) *Quality*, and (c) *Cultural Dimensions*.

Discussion Questions: Although the discussion in the groups varied somewhat, there was a standard open-ended interview guide of consistent questions that was asked of both groups. Following are five of the key or guiding questions included in the interview protocol (these questions were asked in the order below) will be used as the organizing centers to facilitate the discussion: *What experiences have you had regarding health care in your city and surrounding areas?*; *what do you do when you need to go to the doctor or get medical help?*; *what are some positive experiences that you have had regarding health care?*; *what are some negative experiences that you have had regarding health care?*; *what are some things that you would like for your health provider to know about you, your people, and your culture*?; and w*hat experiences have you had regarding health care in your city and its surrounding areas?*

Participants in both focus groups responded at random. Although an attempt was made to stimulate as much discussion as possible, attempts were also made to assure all participants responded. These open-ended questions allowed the participants to set the tone of the conversation with very little prompting from the facilitators. There was a mix bag of responses to the question that were person specific, time specific, and incident specific. For example, some respondents absolutely loved the medical services they received (mostly those who were part of the medical system). Others told of incidents where they needed specific procedures or expertise that were not available, while others share times where they received great services and other times the service was not only awful, but almost fatal.

When asked, *"What are some positive experiences that you have had regarding health care in your home city?"* In the professional focus group, it was very difficult to get the participants to be specific on the impact of the cultural (race, ethnicity, color, or gender) aspect of medical care, it was clearly *the elephant in the room*. Even after several probing questions, the conversation continued to revert to what they considered to be the more germane issues of medical care such as money and insurance and Medicare and Medicaid. It was only when an open-ended question of African-Americans' utilization of medical services was asked that the group responses were more specific to issues in the African-American community and the racial undertones of racism and racialism.

> *"I found that as far as the Black community, I would have more patients that didn't have pre-natal care. There was a higher percentage as far as our population they just wouldn't come in."*
>
> *"I'm talking about the Black community, because that's where I'm from. I'm very concerned about the youth and the kids who are not in good health as far as nutrition-wise. And of course, a lot of us don't have the health care."*

The participants were asked, "*What do you do when you need to go to the doctor or get medical help?"* One African-American medical doctor answered immediately with, "Pull strings, cause I can." The medical professionals knew that they were privileged in that they were a part of a network that guaranteed them not only access to medical services, professionals, and advice upon demand, but also, they received special treatment and good health care. That is, according to them, "The group sitting at this table, we are outliers, we are sitting outside the Bell Curve, because we are in and have access to the health care system. We are highly educated and sophisticated. We know what to ask, who to ask, and pick up the phone and know who to call."

In response to the question, *"What are some negative experiences that you have had regarding health care in your city and county," the p*articipants address this question, before it was asked. As medical professionals, they felt that negative experiences were minimal and attributed the negativity to several things relating to having an inside perspective and an inside advantage such as having medical expertise, medical colleagues, good insurance, money, being educated, and knowing how to advocate for themselves and how to navigate the medical terrain.

An example from on the participant who said "We paid out of pocket for one year, because at the time when we needed the services, my insurance didn't have a spot available for him to be able to get those services, like ASAP like he needed them, and we weren't willing to wait three to four months to get him in. So, we paid."

In contrast, one Medicaid recipient from the Laypersons Group said that she could not find a dental specialist for her child that would take her Medicaid card and she could not afford to pay out of pocket to get her son the medical care he needed. She was still waiting to find an oral surgeon who would take her medical card or to find one in a neighboring city. *"My son needs dental work; they were talking about us having to go to cities that were a 2-hour drive away. There are so many things that we don't have here. We need to find a way to get those professionals and those services here and doctors that will take certain types of Medicaid insurances. You just have to go through the same routine and call them and ask."*

In their collective experiences, these African-Americans participants reported experiencing what seemed to be a *per-*

vasive invisibility from White medical professionals. For example, one of the African-American professionals recanted an elderly African-American woman's devastating experience with the death of her husband. *"One elderly lady in particular whose husband died told me the thing that caused her the most grief when her husband died was that no one talked to her…as if she didn't exist."*

At the end of the interview, this sentiment is recaptured in the participants' imaginary dialog with doctors and medical professionals. "Somebody may be really concerned about me;" "I don't want you to treat me as if I'm nobody, as well as, you care. Treat me like I'm somebody worthy of respect, and my time is valuable;" "One customer at a time;" "Not just swing one through and let's go to the next one;" and "Do not make assumptions!"

In addition to the planned questions listed above, many clarifying questions were asked of each group depending on their response to the planned questions. The medical professionals were asked to respond to the questions from their personal and professional experiences. These questions were used to gain specific information regarding comments and to verify interpretation of their comments.

At length, the purpose of this study was to communicate the understanding that we have developed regarding African-American patients' experiences of success or lack of success with medical services. Phenomenology, which lends itself to the investigation of the unique and cultural heritage of ethnic groups, is an appropriate framework for uncovering the unique and shared experiences of these minority patients. Patton [66] states that consequently, this "essence or essences of shared experiences," resulting from the phenomenological approach, is a brilliant vehicle for understanding how people's of color experience and interpret the world (p. 70).

8.6 A Quantitative Study of the Impact of Sexism and Racism of Black Women

African-American women's health status has remained virtually overlooked and missing from empirical research, in part, because of her status of being a Black female has made her a victim in a racist, sexist society; overlooked and unimportant. As previously mentioned, few studies have been conducted uniquely about the Black woman's health diagnosis resulting from exposure to deep-rooted sexism and racism. Therefore, Marbley's study investigating the individual and aggregate impact of sexism and racism on Black women found that Black women's reports of their experience of racism and the combination of racism and sexism are experiencing discrimination much more than White women.

8.6.1 Method

A total of 55 females completed the survey. Of those 55, 29 were black and 26 were white. The women ranged in age from under 18 to 66 and up with the majority falling in 26–35 age category. Forty-six percent of the White women compared to 14% of the Black women had a family size of one. The Black women's income ranged from less than $10,000 to 39,999, whereas, the White women's income ranged from under $10,000 to 50,000 and above. In terms of marital status, 75% of the Black women indicated that they were single compared to 50% of White women; 7% of Black females specified being married compared to 19% of the White women.

In order to show that Black females (being both Black and female) are experiencing discrimination much more than White females, a survey administered to test this theory. The results of the pilot study were used to develop an extensive list of areas where women felt discrimination. The administered questionnaire was a three-part series of questions. The first section consisted of three questions that serve as screeners or qualifiers for completing the questionnaire.

Findings: The study found that the sample group collectively and all three areas of discrimination were found to be statistically non-significant: (a) the effects of racism on Black women and the effects of racism on White women; (b) the effects of sexism on Black women and effects of sexism on White women; and (c) the combined effects of racism and sexism on Black women and the combined effects of racism and sexism on White women. Furthermore, when the Black and White women's responses were separated for discrimination because of gender, statistically there was no difference found.

However, there was a statistically significant difference found between Black women and White women in their responses in the perceptions of experiencing discrimination because of race and discrimination because of the combination of gender and race. Statistical significance was found in the following five areas: (a) denied a promotion and because of gender, race, or the combination of both; (b) denied access to a prestigious college or university, because of gender, race, or the combination of both; (c) denied access to a prestigious college or university because of race; (d); denied housing because of race; (e) denied the right to play sport because of race; and (e) denied the right to play a position in your sport because of race.

Racism Discrimination linking to Black American Women's Health: In studies on racial and ethnic discrimination, one study [34] found that "Subjective experience of racial bias may be neglected determinant of health and a contributor to racial disparities in health" (p. 535). Another study [30] of the physiological impact of racism revealed that ultimately racial encounters do have some effect on health dis-

parities. "External stressors can permanently alter physiological functioning. Racism increases the volume of stress one experiences and may contribute directly to the physiological arousal that is a marker of stress related disease" (p. 247).

Yet another study [67] investigating the effect of racism on the sexual and reproductive health of African-American women researchers argue that "racism, in both historical and contemporary contexts, is one condition that warrants more attention in models seeking to understand the sexual and reproductive health outcome of African-American women" (p. 664). Finding from the study concludes that there are implications of racism throughout the lived experiences of African-American women including individual, interpersonal, community, and societal levels. To combat this racism, the suggest strategies with more broad impact will be most "efficient and effective" (p. 668).

Some researchers [38] describe social detriments including social and environmental factors as leading to minority stress, which can result from institutional, structural, and interpersonal discrimination. For example, one study found that minorities (i.e., racial/ethnic, gender, and sexual) have increase vulnerability to disease and adverse health outcomes resulting in this unique stress.

Moreover, in their study [68] investigating racial discrimination, coping, life satisfaction, and self-esteem of African-Americans, the researchers describe racial discrimination as a multidimensional. They classify racism with a tripartite topology—individual racism, institutional racism, and cultural racism. They found that there are gender differences of reactions to racial discrimination, with African-American women seeking social support-coping strategies more than African-American men. Further, when encountering individual racism situations, African-American women use avoidance coping strategies more than problem-solving or social support-coping strategies.

Synergistic research [69] sought to support the hypothesis that "racism is a unique source of stress for African-Americans." Research focused on three types of stress including daily stress, racism, and greater perceived impact. Data suggest that discrimination is a unique stressor in African-American lives as compared to Caucasians. However, the experience of racism was similar for African-Americans as it was for other minority groups indicating that racism might be experienced in different ways by minority groups.

Researchers [29] have also studied the relationship of racist experiences and health outcomes. They found that perceived racist expressions and racial stress were associated with poorer health outcomes and hypertension. Unique to this study was the investigation of spirituality as a coping mechanism and buffer to these poor health outcomes. Researchers stated that "spirituality is emerging as a viable facet in Western science for improving the health status, life style and mental well-being of individuals. Spirituality has always played a central role in the Black Community" (p. 33).

Researcher [70] have hypothesized that stereotype threat is a social detriment of health-related decisions and behaviors for African-American women. Finding from this research indicates that stereotype threat was strongly identified as Black women reporting significant anxiety in the study's healthcare setting.

In a synthesis of research [71] examining both intergroup and intragroup racism for African-Americans and the biopsychological effects found that indeed the perception of racism resulted in physiological and psychological stress responses. African-Americans employ coping strategies to mitigate these effects, which are associated with physiological reactivity and health status. Unique to this study is a finding that suggests that non-Africa-Americans also perceive racism and are also adversely affected.

Findings have been mixed regarding the association of discrimination and health outcomes with some studies finding no significant association and others reporting inverse correlations. Researchers [40] posit that these inconsistencies could be because there is not a consistent definition operationalized for discrimination.

8.7 Future Directions and Concluding Remarks

8.7.1 Health Inequities and Disparities in Black Communities

Cultural Stories: According to Rubin and Rubin (1995) [72], relativism is learning that other people's worldview is as legitimate to them as yours is to you, and until you recognize the worth or legitimacy of someone else's views, you will have a hard time communicating across cultural boundaries. To recognize the legitimacy of ethnic and racial patients, the medical literature for the last few years is becoming less culturally encapsulated and more inclusive of differences in cultural values and worldviews. Along with the inclusion of groups of color is an emergence of conceptually grounded frameworks that includes an understanding of the sociopolitical, economic, historical, and societal ramifications, as well as multiple oppressions that form the cultural context for minority clients' presenting problems.

According to Eisner (1991) [73], a metaphor can be a powerful tool to aid the researcher in examining actions with a renewed sense of curiosity. The cultural story, which as of late has been used in family therapy, is the metaphor used in this study to refer to the process of the participants being allowed to tell their personal story in such a way that it

encompasses social constructions of ethnicity, the life cycle, class, and race as well as being within the context of society's stories [74].

Like grounded theory, cultural stories in the medical field assume that patients bring to the medical care services, not only a story but society's stories about their gender, ethnicity, class, and race. Therefore, the metaphor *cultural story* it is appropriate for uncovering African-American patients' unique and shared experiences and a useful way to refer to the individual and shared cultural stories of these African-American participants.

The findings from the study on heath disparities and health inequities in the African-American community [5] corroborate the well-documented health disparities and health inequities in voice, access, and outcomes between African-Americans and European-Americans in the United States. The findings from this study also suggest that Black American women's health is adversely affected by factors which play key roles in their experiences of seeking quality health care such as political bureaucracy and affordability; those that impact quality such as touching the patient, being a good servant, and having bedside manners; and emic or cultural specific factors such as community knowledge and the individuals most impacted by other marginalized statuses such as living in poverty and aging. Further, the study found that not only did political bureaucracy and affordability play key roles in African-Americans and African-American women's access to quality health care, but also both bureaucracy and affordability are intertwined with racism, and arguably, to a lesser extent sexism.

From their cultural stories, the African-American participants shared horror stories about people who were elderly, poor, and without good health insurance, those most negatively impacted by the politics and bureaucracy in supplemental and government funded health care such as Medicaid. Multiple stories were woven around in the art of practicing medicine with multiple examples of medical professionals who were with and without bedside manners and a sense of servitude and those who were or were not genuine and empathic. Further, stories were heard of the need to be seen through both human and cultural lens and the need to acknowledge their differences that separate them from other cultural, racial, and ethnic groups. Thus, in order to be successful with African-Americans patient care, their stories tell us that treatment must be tailored to this specific population based on better knowledge of African-Americans in multiple domains.

Finally, there were painful stories told of White medical professional's indifference contrasted with heartwarming stories of medical professionals of color whose real and human approach was more caring and concerned and showed more respect for elders. Thus, the call to the profession is to get more medical professionals of color.

8.7.2 Black Women's Experiences of Racial Discrimination

The study on the effects of racial and sexual discrimination highlights the importance for more empirical research on the impact of racism on Black women and other people of color [6]. Also, it indicates a need for researchers, counselors, educators, medical professionals, and practitioners in parallel fields to be more aware of and sensitive to the gender and racial/ethnic differences among women in terms of the impact of sexism and racism, specifically, Black women with multiple marginalized identities.

Finally, this study calls for further research could be done to determine the impact of exposure to stressful and chronic racism and/or sexism on Black women's lives (coping, self-esteem, intimate relationships), with major implications to associations to major health concerns, disproportionately risk of ill health, negative health behaviors, health problems, and overall lifestyle.

Investigated scholarship on racial and gender discrimination connects in theory, to both types of discrimination that exists within the Black community and as does Black American women's experience of discrimination in health and in health care. This means that is evidence that racism intersects with the health of Black women under certain conditions and any analysis of women's health that ignores race will be incomplete and simply describe patterns for White women.

Perspectives from scholars' research rooted in Black women's experiences of racial discrimination, events, variations, provocation, and stressors and the relationship of racism to Black women's health and health outcomes are slowing working their way into the academic discourse. In this manner, focusing on the intersection of race and gender, specifically racism, leads to research that enriches our understanding of health disparities and inequality and provides the most accurate conceptualization of health systems and processes.

Overall, as the authors of this book chapter, we remain hopeful that the feedback from our studies and those in the literature on the consequences of racism on the health and wellbeing of the active Black women will prove helpful. Although disparate outcomes can occur even if Black women love themselves and each other—the racism of White people has discrete harms independent of Black people's experience. The participants in these studies seek quality, affordable non-racist medical services to be made available for Black and African-American patients, the African-American community, and others who are marginalized, for instance, those from impoverish backgrounds, people of color, other marginalized communities, and the elderly—those who are not only negatively impacted by the healthcare system, but are dying because of racist health system and racism that limits access to quality health care.

Chapter Review Questions

1. Health disparities for African-American women exist across _____.
   (a) Age
   (b) Socioeconomic status
   (c) Geographic region
   (d) All the Above
2. _____ discrimination is a unique typed of discrimination experienced by African-American women at the intersection of African-American ethnicity and female gender.
   (a) Ethgender
   (b) Racists
   (c) Sexist
   (d) None of the Above
3. A health _____ is related to access to healthcare, whereas a health _____ is related to difference in health outcomes within a population.
   (a) Disparity, Inequity
   (b) Inequity, Disparity
   (c) Inequity, Access
   (d) Access, Difference
4. _____ percentage of doctors are African-American.
   (a) Ten
   (b) Five
   (c) One
   (d) Four
5. According to Theodore White, twentieth century, which issues have dominated American history?
   (a) War and Peace
   (b) Racism and Sexism
   (c) Black and White relationships
   (d) Both a & c
6. Which of the following has research NOT found true regarding Black women reporting experiences with racism?
   (a) Negative Health Behaviors
   (b) Lower Levels of Psychological Distress
   (c) Physical Health Problems
   (d) Increased Blood Pressure
7. Black feminist scholars have studied stereotype threat and racism through the following intersectional lens:
   (a) Sexuality and Levels of Education
   (b) Age and Socioeconomics
   (c) Race and Gender
   (d) Religion and Gender
8. Which of the following can corrode the patient–doctor relationships?
   (a) perceived discrimination
   (b) medical mistrust
   (c) medical diagnosis
   (d) Both A & B
9. Which of the following are true?
   (a) Disparities in *Health* and *Health Care* Are Related, But Not The Same
   (b) Disparities in *Health* and *Health Care* Are Not Related
   (c) Disparities in *Health* and *Health Care* Are Synonymous
   (d) All the Above
10. Studies on racism and sexism have found that:
   (a) Racism, not Sexism Affects Black Women's Health
   (b) Sexism Affects White Women's Health More Than Black Women's Health
   (c) Racism Impacts Black Women's Health More Than White Women's Health
   (d) Racism Adversely Affects Black Women's Health

Answers

1. d
2. a
3. b
4. d
5. d
6. b
7. c
8. d
9. a
10. d

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The Pandemic Within Systemic Injustice: Intersectional Cultural Dimensions of Women's Aging, Health, and Case Stories of COVID-19

9

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Learning Objectives

- Expose the racism, sexism, and systemic injustice within COVID-19
- Link COVID-19 and other pandemics to increases in health disparities, health inequities, and health gaps
- Recognize the devastation of COVID-19 on women's health and healthcare
- Share the stories of women of different ages and cultural backgrounds who died of or survived COVID-19
- Understand the importance of communications and networks for aging women during COVID-19 and pandemics

The Roaring Twenties of the twentieth century *roared* in with bursting economic growth, the rapid growth of consumer goods, and booming prosperity, creating a definite cultural advantage for those who were wealthy and White with privilege in major cities such as Berlin, Chicago, London, Los Angeles, New York City, Paris, Sydney, and Tokyo. Yet the world had not yet recovered from the devastation of World War I when the Spanish Flu arrived, inflicting nearly a third of the global population. There was prosperity and justice for some, but not everyone. And yet the Roaring Twenties of the twenty-first century caught our world by surprise. Instead of growth, prosperity, and strength, it roared in with massive devastation of economies, economic slowdown, poorly performing or suffering indicators of consumer confidence, and lagging prosperity, all due to the advent of the coronavirus.

Much as they did in 1920, dominant groups in major cities experienced cultural advantages in 2020. Arguably the list of cities in which they lived was longer: Berlin, Boston, Chicago, Dallas, Florence, Hong Kong, London, Los Angeles, New York City, Paris, Sydney, and Tokyo. And much like 1920, 2020 is steeped in social injustices and disparities and the stench of racism, sexism, and violence (against women and people of color). We are not recovering from a war, but rather, effervescently, teasingly teetering on the brink of a Third World War. Globally, there are countries and regions in active wartime, those who appear to target the weaker and more vulnerable neighbors to bully, while others have yet to recover from civil unrest. There is nothing new about this pandemic except that COVID-19 is the first pandemic in the era of social media.

For example, in this era, social media plays a major role in amplifying the voices of oppressed people during this COVID-19 pandemic by shedding light on the system injustice in healthcare. Just as social media has played a major role in making it more difficult to hide horrific acts of elitism and racism, likewise, social media has also contributed to viral acts of elitism and racism. In that regard, social media has spotlighted acts of elitism and racism in healthcare

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against people of color diagnosed with COVID-19. Even So, social media is a structural entity and a social microcosm, and as such, in some ways, it is also another platform that is infused with societal systemic injustice and continues the status quo.

Nonetheless, it is within that spirit of wealth and prosperity and unrest, widespread hunger and poverty that a world of nations (developed and undeveloped) face the COVID-19 pandemic. By August 2020, over 18.35 million people worldwide had been infected with COVID-19, including almost ten million in the Americas and almost five million in the United States alone. It had killed over 696,000 people, predominantly those marginalized by socioeconomic status (SES), age, race, and ethnicity [1–3]. Women have suffered more from the economic impact, and have suffered less from the impact of the disease.

As of this writing, COVID-19 is still aggressively ravishing economies, dismantling and destabilizing social institutions, taking lives, and destroying our feeling of safety and way of life. It has led to the shutdown of countries, caused economic instability, and crippled health care systems, fueling blame, fears, exacerbating inequality gaps, and extant social injustices. Like the Spanish Flu, COVID-19 has increased the racial divide and the divide between the haves and the have-nots. A century later, the onset of 2020, like 1920, *roared in* with violent collisions between prosperity and justice. Justice for some, but not everyone.

This chapter aims to examine how pandemics, specifically the arrival of COVID-19, exposed inequities and amplified current health disparities for minoritized women. It also discusses how the pandemic has impacted discourse, ideologies, and narratives on health disparities and the effect of COVID-19 on women aging within a privileged context. Further, in our exploration of health disparities, we question how gender reflects and intersects with health determinants of oppressed identities to produce disparate health outcomes, affecting the activity of women as they age.

Last, this chapter explores those platforms (e.g., paternalism, racism, classism, heterosexism, and ageism) dominated by privilege and the politics of pandemics that ultimately affect women's health outcomes and their ability to stay active and healthy as they age. It concludes with real case stories of victims of COVID-19 that capture the devastation of the virus, health and healthcare disparities, and the injustices wreaked on women's health, mental health, and healthy activity in the rhetoric of a post-racial United States of America.

9.1 COVID-19

The COVID-19 pandemic has taken a huge toll on the world, especially in the United States. It is taking a major toll on the healthcare workers who risked their lives for others on the front line battling the widespread virus as the United States surpassed all others in numbers of cases and casualties during this crisis. Many continue to grieve the loss of life, jobs, and daily activities that facilitated human-to-human connection as we rely on technology to remain connected in this unprecedented event. When we take a closer look at the outcome of COVID-19, age, race, gender, sexuality, and SES status, for some women at the intersection, this pandemic delivers a quadruple blow and has an enormous impact on families. In short, COVID-19 has caused sweeping changes in who can receive lifesaving healthcare and how they access healthcare —literally determining who will live and who will die.

Even well after the implementation of the Patient Protection and Affordable Care Act (a.k.a. Obamacare), and after many measures that have in at least some respects maintained it, health disparities still weaken the health and well-being of culturally diverse populations. Many people of color in the United States, especially those with limited English proficiency, the elderly, and women face barriers to accessing health care, quality health care, and appropriate treatment. Such barriers mean that people who live at the intersections (gender, sexual orientation, age, ethnic background, and SES) face health disparities that are mostly unexplored.

For example, the LGBT Foundation in the United Kingdom points toward evidence that COVID-19 may be disproportionately affecting LGBT communities because they may have less access to healthcare, are more likely to be living with HIV, are more likely to be insecurely housed, and are more likely to smoke or have other less healthy behaviors [4, 5]. Other organizations point out that decreased interaction with positive social groups and increased interaction with negative social interaction (especially for people still in the closet) significantly affected the mental health of LGBTQI folks during the pandemic [6].

Not surprising, the Institute of Health reports that people of color tend to receive lower quality of health care than the White population, even controlling for patients' insurance status and income [7]. The study found evidence that stereotyping, biases, and uncertainty on the part of health care providers all contribute to unequal treatment. Yet, people of color's propensity toward developing chronic and terminal diseases are rarely viewed through the lens of systemic injustices and structural inequities. Access, communication, screening, diagnosis, and treatment lead to discrepancies in mortality and disability rates among different cultural groups. The report calls for cross-cultural training for providers.

9.2 Cultural Competency

Historically, health differences between White people and people of color result from unequal economic and social conditions. In public health emergencies and pandemics,

people who are socioeconomically marginalized are often unable to access the necessary and basic resources they need to prepare for and respond in order to survive. Nothing has made this gap in healthcare for the elderly and those marginalized broader and more obvious than the advent of COVID-19 in 2020 [8].

From the very onset, strong evidence of rapid spread and high morbidity and mortality among socially disadvantaged groups, low-income populations, and older adults emerged [9–11]. Thus, the need to revamp and restructure the healthcare system such that these groups receive culturally sensitive care is clear; preliminary evidence of the impact on the LGBTQI community reflects the same, urgent need [12].

Recent research connects the practice of culturally competent healthcare to increases in access, utilization, outcomes, and safety for patients. According to the American Hospital Association, "A culturally competent health care system is one that acknowledges the importance of culture, incorporates the assessment of cross-cultural relations, recognizes the potential impact of cultural differences, expands cultural knowledge, and adapts services to meet culturally unique needs" [13]. Ultimately, cultural competency is an essential means of reducing racial and ethnic disparities in health care. This means that the impact of cultural competency can produce more successful patient education and improve patients' healthcare-seeking behavior.

The most important aspect of culturally competent healthcare is that it extends to cover patient safety. Culturally competent medical professionals understand and administer appropriate testing and screening, resulting in fewer diagnostic errors and drug complications [14]. For minoritized patients, exposure to quality and culturally sensitive and appropriate curriculum and healthcare systems expand their choices and access to high-quality clinicians and achieve greater adherence to medical advice, ultimately saving their lives.

In a similar manner, enhancing cultural relevance and measuring the cultural competence of healthcare providers remain critical for spanning the healthcare divide's fault lines. Healthcare disparities affect groups according to ethnicity, gender, age, acculturation, SES, and insurance class. The healthcare fault line also crisscrosses health belief systems and practices, language, communication styles, and stereotyping, self-esteem, empowerment and provider skills. Cultural competency is a key tool with which to level the playing field. Healthcare professionals need to be culturally competent in order to effectively navigate structural injustices in health, healthcare, and healthcare systems on behalf of oppressed people.

Nonetheless, public health policy and research are becoming more aggressive in tackling the substantial health inequities and recognizing disparities for those existing on the intersection. Further, there are major healthcare inequities among seniors living in poverty, immigrants, people of color, people with disabilities, the LGBTQI community, and women.

Like all medical professionals serving marginalized communities, mental health professionals must be culturally sensitive and culturally competent to do so. Otherwise, they are complicit in maleficence of social inequity, trauma, health disparities, safety, and suffering for already vulnerable populations. For this reason, cultural competency in mental health is a necessary and critical intervention for attaining a more optimistic life condition and saving lives.

9.3 The Disproportionate Impact of COVID-19

People of color are overrepresented as essential workers (75%), have disproportionately low SES, and experience considerable detrimental bias when assessed and evaluated by others. The high mortality rates among African-Americans, specifically the elderly, are one more indication of the long-standing need to address disparaging treatment and inequities that exist in this country [12, 15–17].

Essential-Worker Designee, Frontline Women, and COVID-19: Women outnumber men as teachers, registered nurses, childcare workers, housekeepers, home health aides, first-line supervisors and managers of retail sales, and mental health practitioners. Although many of these are not officially designated as providing COVID-19 essential services, they may nonetheless be going to work in the pandemic. Many of these jobs are also disproportionately staffed by women of color. They are also unpaid, underpaid, and disproportionally shoulder the burden of labor. Given their professions and traditional roles as caretakers for the family, these essential workers during COVID-19 became the caretakers for the government, social institutions, and communities. Female frontline workers within the healthcare systems are worried that women's safety, symptoms, treatments, and vulnerabilities to COVID-19 are not a priority.

Historically, national and global health institutions such as the World Health Organization (WHO) and the U.S. Centers for Disease Control (CDC) have failed to share data and data analysis to address the gender impacts of pandemic diseases. Although there are tons of anecdotes indicating the impact of COVID-19, gender analysis data of the COVID-19 are not available. A first step to understanding healthcare barriers that those who are marginalized within culturally different enclaves face and to save lives is to understand how and recognize the degree to which pandemics affect genders and ethnic groups differently.

Women's voices, expertise, and knowledge are muted in the global health security surveillance, detection, and prevention mechanisms. Bringing the voices of culturally

diverse women to the table requires digging deeper and focusing on structural causes of differences in treatment and outcomes. Although race is a major predictor in death from COVID-19 and the other pandemics, interventions to end discrimination and disparities for women fail when they focus primarily on race. Therefore, interventions must extend into the intersections where most women and their voices become invisible. In fact, addressing women on the intersection's experiences of disparities, inequalities, biases, and discrimination in healthcare, specifically with the coronavirus pandemic need be realized and framed within the broader context of structural racism and sexism.

9.3.1 Structural Racism, Structural Sexism, and Intersectionality

The authors introduce structural racism, structural sexism, and intersectionality as frameworks to shed light on how healthcare interacts with employment, education, welfare, politics, religion, and other structures and social institutions to produce racialized and patriarchal outcomes. Similarly, structural sexism advantages males, maintains patriarchal social structures, and reinforces prescribed gender roles that produce adverse outcomes for females. Structural racism and sexism are systems of hierarchy and inequity primarily characterized by White supremacy and patriarchy.

Structural Racism: According to Lawrence and Keleher, structural racism in the US is "the normalization and legitimization of an array of dynamics—historical, cultural, institutional and interpersonal—that routinely advantage White people while producing cumulative and chronic adverse outcomes for people of color" [18]. Bonilla-Silva argued that the study of racism had historically been inadequate as a result of the use of theories that were too simplistic, thus, he put forth a structural theory of racism that was based on the framework of racialized social systems. Bonilla-Silva also stated that the theory of structural racism, like structural sexism, is conceptually distinct as it can be maintained without the awareness of the individual perpetuating the discrimination, and it is grounded in systemic inequality [19].

Theories of structural racism utilize system-based reasoning designed to identify underlying and often hidden causes of problems experienced by marginalized people of color across social systems [20]. Building on Bonilla-Silva's theory, Powell later defined structural racism as the set of systems and social processes that intersect to initiate and maintain inequities that exist for racial and ethnic groups [21]. Bonilla-Silva's original work initiated a change in how we think about structuralism. That is, it clarified that the only way to successfully intervene in structuralism, like structural racism, within society and its social systems is by extricating its systemic roots. Bluntly put, these structural acts are preferential treatment, privilege, and power for men and White people at the expense of women, people of color, and other gendered and racially oppressed people [19].

According to Lawrence and Keleher, *structural racism* encompasses the entire system of White supremacy, diffused, and infused in all aspects of society, including our history, culture, politics, economics, and our entire social fabric [18]. Structural racism is the most profound and pervasive form of racism—all other forms of racism (e.g., institutional, interpersonal, and internalized) emerge from structural racism. In short, structural racism is not only historical, interactive, and pervasive across multiple structures, and systems, it is the overarching catalyst for all other forms of racism.

Structural Sexism: The evolving theory of structural sexism has experienced a paradigm shift from the traditional Eurocentric, western focus on the individual and interpersonal domains of gender discrimination to a more open-minded structural framework that examines how systematic gender inequality in power and resources such as structural sexism impacts women's health. Using a structuralist perspective, Homan believes that gender starts with the social construct of gender as a social system of difference and inequality as opposed to an individualistic attribute system of difference and inequality [22].

Furthermore, she refers to structural sexism as the systematic gender inequality in power and resources that varies across social contexts. Like structural racism, structural sexism exists not only in social institutions but also in relationships and in individuals' belief systems. Homan argued that structural sexism can be observed at each level of the gender system, including macro-levels, meso-levels, and micro-levels. The macro-levels are institutional in nature, while the meso-levels are interactional, and the micro-levels reference the individual domain. In that manner, Homan has proposed a multilevel approach to structural sexism research and theory. As she argues, this approach is most important because gender theory and research are designed to focus on interactional processes [22].

Intersectionality: Feminist theory originated when feminists began to argue that psychology had neglected the study of women and gender [23]. Likewise, the grassroots women's movement of the 1960s played a role. The racism of White women in the first and second wave movements tended to marginalize the agendas of women of color [24, 25]. The experiences and struggles of the women of color got little attention [26].

Although the origins of the theory of intersectionality can be traced back to the movements of multiculturalism and feminism, Kimberle Crenshaw coined the term as a way to pinpoint the marginalization of Black women within antidiscrimination employment law in the US and within feminist and antiracist theory and politics. Intersectionality is based on the idea that oppressive situations, such as racism and sexism,

are interrelated and influenced by one another [26]. It was a space on the intersection where power collides, interlocking and intersecting patterns of racism and sexism and oppressive structures related to issues of gender, race, class, age, ability, and sexuality. In short, it is at those intersections where Black women and others become invisible [26].

Many scholars regard intersectionality as the cutting edge of contemporary feminist theory [27]. It has been heralded as the most important contribution to women's studies in this century [28]. Intersectionality supports the belief that research, theory, and practice must embrace a range of oppressed identities if we are to address women's issues and women's needs for empowerment.

Hence, to understand health disparities, specifically the impact of COVID-19, we will structure racism's structural nature. Structural racism, in and of itself, is most visible. Thus, we will examine racial disparities in healthcare through the lens of inequalities in power, opportunities, treatment, access, and policy impact and outcomes in past and present. It will create new and recycle old forms of racism and its strain of resistance to reform and change.

9.4 The Essential Intersection of Social Networks and Active Lifestyles as Women Age

Over the past few decades, health communication researchers increasingly acknowledge that interpersonal communications and networks play a central role in the health decisions of individuals in all stages of life. Communications and networks are especially important for aging adults who may not have the means or knowledge to access online or other technology-based health information resources [29, 30]. Specifically, the term *health information mavens* has emerged to describe individuals who share health information through their interpersonal networks, and who become sought out sources of health information within their communities [31, 32]. Health information mavens tend to be well informed about a range of health issues, to feel confident sharing their information, and to know how to point people to fresh resources [31].

Several studies have indicated that women more often take on the role of health information mavens than do men, potentially suggesting women depend more than men on their social networks to maintain a healthy lifestyle as they age [31, 32]. At the same time, studies show that populations of color and low SES populations depend on personal networks for health information more than their counterparts. These findings suggest that health information campaigns that target mavens may be more successful than other types of health information campaigns and that more attention to the role of health information mavens should be given to address health disparities in aging women of color or lower socioeconomic status [30, 33, 34].

Similarly as well, several recent studies have acknowledged the central role that social interaction plays in staying healthy, and specifically how being active with others fosters a stronger sense of self [35–37]. This concept has also gained traction in recent mainstream discourse, as publications such as Lydia Denworth's book, *Friendship: The Evolution, Biology, and Extraordinary Power of Life's Fundamental Bond* and a recent article on Upworthy that discussed the findings of a study that found women with a strong circle of female friends get paid more, and are ultimately happier and healthier [38, 39] reflect.

Thus, when looking at how women can stay healthy through active lifestyles, it becomes crucial to factor in the social networks of aging women and how they intersect with their active lifestyle. Aging can bring a whole cadre of emotional and psychological fears, and evidence suggests physical activity can alleviate some of those fears by allowing individuals to take control over their aging process and resist societal devaluation of aging bodies [40]. Since strong social networks also have been shown to improve longevity and overall health status of aging adults (and especially women), it makes sense that combining physical activity and social connections can have a direct positive effect on active aging [30, 41, 42]. Studies looking at the intersectionality of active lifestyles and social interaction have emerged in the last decade, suggesting the importance of the intersection of social networks and active lifestyles [35, 43].

The importance of social networks in women's lives as they age became especially salient as COVID-19 began sweeping the world. Self-isolation, social distancing, and eschewing social activities became necessary to avoid infection in many cities and countries around the globe. However, despite the extenuating circumstances in which the coronavirus normalized isolation—or maybe because of them—anecdotal evidence is emerging that new types of networks are emerging among women's groups, utilizing geographic closeness (i.e., neighbors talking window to window) or technology (i.e., happy hour on Zoom) to maintain social ties while maintaining physical distance.

For example, some community centers are now offering virtual versions of their networking groups and organizations already dedicated to serving marginalized populations are taking many of their services online and increasing community members' options to meet virtually [44]. A few states have implemented online resources specifically for aging marginalized populations [4].

9.5 The Importance of Social Networks for the LGBTQI Community

As with other marginalized groups, the importance of social support groups seems especially salient among people in LGBTQI groups, especially in terms of being connected to groups where positive identity affirmation was present [45–47]. Additionally, influential social support groups, external to family, are linked to better long-term health outcomes in sexual minority groups [46]. Many LGBTQI rights groups are pointing to the compounded adverse effects that COVID-19 may have on sexually diverse people, people who are not cisgender. The following case stories of female victims and survivors of COVID-19 are real stories of women, much like us, professional, educated, and minoritized women. The stories walk the reader through the devastation and loss of lives and impact on families and communities of the pandemic.

9.6 Case Stories of COVID-19

9.6.1 Knock, Knock, It Is Déjà Vu: Marbley

Thursday, June 11, 2020. I sat typing at my desk. Then I paused for a moment of silence in honor of the anniversary of Mama's death, 51 years ago. Black female ancestors, who survived pandemics and the stories of those (male and female) afflicted by COVID-19 sat at my desk with me. Stored in an iCloud photo gallery are images of Black females stricken by COVID-19. Uncensored images of friends, students, and loved ones diagnosed with the coronavirus, those who died and those who survived, struck the backspace button on my keyboard. Lurking in the computer camera were images of my niece who survived COVID-19 and next to Mama who survived the Spanish Flu (and World Wars, Jim Crow, two major floods) and her sister Minnie who did not survive the Spanish Flu—active without mobility, invisible but hopeful.

In a frayed notebook nestled in the corner of my desktop are exciting secondhand stories of 10-year-old Minnie who died in 1919 without legal records of her life or her death. A real-life example of Kimberlé Crenshaw's idea of intersectionality, intersections where Black women are invisible, immobile, powerless, and silenced. Captured in that notebook are Mama's memories of Minnie and other loved ones, small glimpses of their lives, eternal love, and the pain and grief of death.

The sour smell of death, COVID-19, and the Spanish Flu began fighting for space in the document I am writing. I flipped through the pages anyway, feeling honored as I reread for the 100th time these stories passed down through generations to me and now to my daughters and granddaughters. At 7 and 11, they are the exact same age as Mama when the Spanish Flu ended in 1920 and as old as Minnie would have been that year if she had lived.

Like the Spanish Flu, the photo of Minnie's story recedes to the background as the faces of Black women and girls with COVID-19 rose to the forefront. Women of color on the intersections emerge dressed in the dark fabrics of pandemics, painted with the deaths of other women, and began tapping around in my headache.

With each stroke and brush of my fingers on the keyboard, incidents of blatant racist, sexist inequities become viral and hold my PC hostage. The residuals of slavery and Jim Crow knotted up inside Black women's souls and deaths and knotted up in these viruses and relentless knocking. Piles of documents of Black people bearing the burden of disproportionality, specifically Black women, are dispiritingly distracting. As I took command of my breathing, slowing it down so that I could enter these places and spaces, suddenly, Black women in the books and articles that I am reading, stand straight up on my desktop.

Each woman is swinging an enormous stick, using it as a weapon to bring harmony to the chaos, standing up and fighting for justice and for the women of today and century pasts. They pause, allowing for a moment of silent prayer for the lives lost to COVID-19, the Spanish Flu, pandemics throughout history, and to racism and sexism diseases. I felt blessed to witness these beautiful Black women stand and join hands in solidarity, and selflessly combine their collective strength, and then, share it with the world. They also stood up for coronavirus victims—White and of color, male and female, and women of all ages, connecting their stories and forcing me to see and feel them. By standing tall, they restored resilience in the lives of my daughters and granddaughters and all the daughters and granddaughters of the twenty-first century, restoring warmth, life, and safety for all the Minnies who lived and needlessly died of diseases throughout the globe, trapped at the intersections without records of their births or their deaths, remembered only on the tattered pages of family lore.

I pressed the *Caps Lock key*, and the words *RACISM IS UPPERCASE* appeared on the screen, and I was freed to write my manuscript. I wrote about how disparities, pandemics, and diseases such as COVID-19, ageism, classism, racism, and sexism viciously kill my people, and the women standing up. As I type, these Black women begin painstakingly wiping away our tears, using my manuscript to clean up our unhealed wounds and lingering trauma from pandemics and centuries of oppression. As they stood together at the intersection, hope battled through my grief and fear, wiped angrily at the tears in my eyes, silently knocking on our cynical hearts, and finishing my manuscript. Knock, Knock! We

ask, "Who is there?" Though (like you), I already knew who. It is Déjà vu.

Thursday, August 6, 2020, on Johnnie's 111th birthday, I finished writing my manuscript.

9.6.2 Friends Indeed: Starkey

"Lori has the virus." The sound of my mom's voice saying those words caused my heart to drop into my stomach, churning there with a deep fear. My mom had gone and dropped off a painting on her porch last week, had rang the doorbell…had she picked it up? What would I do? She was 600 miles away from me. But my fearful obsessing was interrupted by her jarringly cheerful follow-up to the sobering news, "But she's in pretty good spirits. The gang [as their core group of about eight women and two gay men refers to themselves] did a Zoom call with her the other day to cheer her up. She feels okay right now, but her doctor says she will likely decline again in a week or so. We have arranged for one of us to provide one meal a day for her. Her roommate is self-quarantining with her, so she can get the meals from the porch and then take them into her room."

As I listened to my mom ramble on about what she was planning on preparing (something about pineapple chicken with turmeric, because pineapple has cough expectorant properties, as does turmeric…) my mind drifted to imagining my mom and her group of friends, the youngest of whom was turning 65 this summer, navigating Zoom. Many of them were artists or other tradeswomen, variously versed in technology. They were prone to fits of hysterical laughter about any endeavor when they would get together in person, often over the ridiculously strong margaritas at the taqueria down the street from my mom's house, so I could only imagine what it looked like as they coaxed and supported each other through the learning curve of navigating the virtual meeting space.

"…and then I showed them how to do the fake background thingy in Zoom, so we spent about an hour all playing around with that…" I realized that as my mind had drifted, her monologue had shifted to talking about how the gang was navigating this new social space. "Shirley doesn't have a laptop, so we are trying to figure out if we can get it on her phone. Did you know you can also do Zoom on phones?" I said I was and reminded her to tell Shirley about the app store or Google play, depending on the type of her device. We chatted for a few more minutes and then hung up.

Our next phone conversation was almost a week later when the state where she lived was considering ending the lockdown. She confirmed that Lori was not getting worse but was still sick. She had been bedridden for so long now that she got winded from walking to the bathroom and her bedroom door to get the meals her roommate left her, before knocking and scurrying away to avoid catching the virus. According to my mom, Lori's only social interactions were with the gang, and she was feeling pretty down. Her sister and brother had only called a few times, despite living down the street. The gang was now concocting some sort of group performance over Zoom to try and cheer Lori up, and had been musing whether or not it would be safe to meet up and go for a hike in one of the state parks or go out and drink beer at the city reservoir, two of their pre-pandemic favorite summertime activities.

"We've also been doing 'garden tours' using the Facebook messenger thingy…you know, the video call thing I use with the kids," my mom continued to share her technological adventures. "Everyone just *loves* my poppies," she said with pride, "and the camera on my new phone captures the colors so vibrantly! We've all been sending Lori pictures too, and yesterday Sam and Sharon went over and cleaned up her garden and sent her pictures, and even did a Zoom call while they were outside her house so she could show them where she wanted some seedlings placed.

"I'm going to have so many paintings to keep me busy this winter from all these amazing flower pictures," she said. "But speaking of painting, I've been thinking about how to take my art classes online. Can you offer any ideas with that?" For a few minutes I told her about camera angles, video uploading, YouTube channels, and engaging viewers.

After we hang up, I sit quietly for a few minutes, staring at my phone, hot from being pressed up against my ear, and marvel at how my mom and her gang—a group of aging people, determined to maintain their social network and stay active and healthy, even in the face of a global pandemic, have grown more and more comfortable with technology.

9.6.3 Unsung Shero: Murphy

May 15th, 2020, I received a panic call from my client with her earth-shattering news that she had tested positive for COVID-19 and had to quarantine in her home. Alice, a 58-year-old African-American female veteran nurse practitioner, was referred to me in April with depression. She was distraught after her husband's suicide. He had been her best friend, a veteran, suffering from PTSD and drug addiction. In our first session, I could see that she was clearly distressed and fatigued. Her face wore a heavy, dark overcast and shadow of despair with dark circles around her eyes. Her nursing wrinkle-free scrubs were really wrinkled, with coffee stains all over the top. As Alice spoke, the tears in her eyes and cracking in her voice expressed a deep concern for her daughter, and about her health as she had been putting in overtime at the hospital where she works.

I was totally unprepared, despite my many years of training and experience as clinical mental health therapist, for the

impact knowing Alice's diagnosis would have on me personally. Even after her diagnosis, she was more worried about others than herself. Then 7 weeks later, she died.

Alice was a beautiful, warm, and strong Black woman, a registered nurse with more than 30 years with a legit job with full benefits. When she got sick, she was flat broke, with no insurance. Her death left her only child a ward of the state. Alice had great insurance, but she was denied quality health care to live.

During my last session with her, Alice spoke about being caught in a crossfire to get medical help. She had been told that she could not have a coronavirus test, and then that she could not receive the lifesaving medical services she needed because her insurance carrier had been changed. I struggled to focus on her and her needs, but I could not prevent bursts of hurt and anger from entering our counseling services. I felt overwhelmingly vulnerable and helpless knowing that Alice's experience was a step-by-step parable of the differential, spotty, and shoddy treatment of many other Black and Brown women diagnosed with COVID-19 by the healthcare system, health profession, and doctors. With no inkling or forewarning that Alice's life also would spiral into despair, remarkably, I was able to resist this strong urge shout the injustice out loud. Instead, I sobbed silently inside and shifted my energy to her.

Even now, I can still hear her voice, shallow and broken, reaching out to me, coupling with the pain and despair that I now feel, churning and turning both my own hurt and desolation, and festering the angst. A sickening realization seemed to stick to me like tar. I realize Alice was me, educated and middle class. Her experience was the grim reality I live as a Black woman in the United States.

Alice would become for me the poster woman for Black and Brown women and her story would be indicative of the horrific and invisible experiences of the many women of color diagnosed with COVID-19, regardless of their money or professional backgrounds. Alice's fight to stay alive will not be televised or written about in the major newspapers, but deep in my heart, she is a real-life shero. Her story will forever be a living example of the disparities and expanded gaps in health care for women of color triggered by COVID-19.

As I sit in dark silence instinctively flipping through the pages of her life and flipping through the pages of my life, I know that I have to fight to stay professionally relevant, and emotionally and physically healthy, if I want to help my clients and if I want to keep fighting for Black women like Alice. It is July 15 and I sit with unshed tears for this valiant shero. I had somehow found a bit of solace, perhaps in meditation, deep friendships, or therapy. But then I received a frantic call a couple of days later from my client Naquita with the news that she too tested positive for COVID-19. The cycle started all over again.

9.6.4 A Chill Is in the Air: Abdullah

I walked briskly through the hospital corridors, past the ER doors, barely noticing the March chill in the air and my empty stomach. It was the middle of March in the windy city and we were during the global outbreak of COVID-19. As a Chicagoans, I knew that the wind was not only blowing from the Chicago Lakefront but also from the city's politicians. That same chill combined with the chill of the pandemic, death and despair blew and circled in and outside of the hospital and throughout its corridors. With little time or energy to spare for the weather or the politics, I quickly stopped my wayward thoughts and began my shift.

I soon found myself rapidly scanning the chart of a Black female patient sitting on bed 7 in the psych area. With little time to waste, I took a deep breath, put on my professionalism, and prayed for compassion before introducing myself. Teresa was a tall, elegant, expensively and well-dressed African-American female with shoulder-length hair pulled back loosely with a black rubber band. Yet she appears disheveled and extremely nervous. Her white blouse was wrinkled and slightly untucked from her dark blue trousers and her ponytailed hair was pulling out around the edges. She was anxiously twisting and rubbing her hands together as a gesture of distress.

Teresa is a 41-year parking meter aid, single, mother of young children, pursuing a degree in psychology. She had a history of depression and anxiety. According to her medical chart, her father had died of COVID-19 recently and she was experiencing an episode of depression. I noticed and noted in her chart her breathing with difficulty, panting heavily, and her dry and slightly greyish skin. While waiting for the doctor, Teresa began more distressed, anxiously twisting and rubbing her hands together. As the intake continued, rather than actively listening to her story, I could no longer remain impersonal, and the lines between patient and therapist blurred.

I realized that this woman not only could have been me; she was me. We were about the same age, social status, from similar neighborhoods, and had similar career paths and tastes in clothes. The reality of being this emotionally and physically close to her along with my vulnerability through working in a hospital emergency room with not only Teresa but six other patients who had been exposed to and suspected to have COVID-19 hit me with full force. What if she has COVID, I thought, and what if I get it from her?

Teresa talked about her two boys and her preexisting conditions that increased the likelihood she would have a long recovery or not recover at all, if she had the disease. She spoke about not sleeping or eating due to her depression. When she started to cry, I heard her from a distance, a place outside of my body and spirit. I tried to shift my body and heart toward a safe place, reducing the probability of infection and inflection. In the background, I could hear the fami-

lies of other patients who arrived at the ER screaming when they learned their family member was positive, while others sobbed quietly. Her phone rang, it was her son. "I'll call you back," she said and asked to use the hospital phone. But then the doctor entered. Teresa stood up. Her test had come back positive. I moved even further into the background of her story and my story.

More tears came as she plopped down on the bed, asking herself out loud what do next and whether she could take care of her children, and reminding herself that her dad was sick, and her mom already overly burdened. I listened and took copious notes until once again Theresa's life and future became a mirror image of my life. Fifteen years on this job and I asked myself yet again, "Is this the day I quit"? As I walked back to my office, I prayed for Teresa and her family and I grieved the massive number of my people who were afflicted and died from COVID-19 of all ages and genders, and Black women just like me.

Forlorn, solemn, cold, and still hungry, I left work. As I stepped out of the ER onto the streets of Chicago, the chill was in the air and the wind from Chicago lakefront was still blowing cold and hot air, and not surprisingly, so were the politicians.

9.7 Reflection

As coauthors of this chapter and coauthors of our lives, structural racism and structural sexism (and even heterosexism) are real, as our own stories suggest. All the women in the case stories are middle class, professional women living on the intersection. One of the case stories is that of White lesbian surviving COVID-19 on the intersection of sexuality and gender. The other three case stories capture Black women's experiences, some living in poverty, some middle class, facing gender and racial discrimination during past pandemics such as the Spanish Flu and COVID-19.

Johnnie and Minnie: In the first case story, Marbley recounts the devastation of historical structural racism and sexism starting with the Spanish Flu pandemic that wreaked havoc on the lives of the Black women in her family. Buried in her story are the residuals of slavery and Jim Crow that follow her family through other national and global pandemics such as the Floods of 1927 and 1937, the Great Depression, and two World Wars.

Her case study also captures the patterns of structural racism and sexism in the devastation of the COVID-19 and the Spanish flu pandemics wrought on Black women in her family in the twentieth and twenty-first centuries. Most importantly, the stories of Minnie and Johnnie and their female ancestors capture a century of women's spirit of resiliency and their visible invisibility as they stand at the intersections, standing up for justice, freedom, and equity for all women.

Alice: A 58-year-old African-American female veteran nurse practitioner in Dr. Murphy's case story, Alice was one of the frontline healthcare workers who has lost her life to COVID-19. Despite being at high risk of exposure to the coronavirus, she continued to go to work, often working multiple shifts, putting her life on the line every day. Due to structural racism and sexism in healthcare and health insurance, Alice, a first coronavirus responder, a dedicated and experienced nurse practitioner, and widower of a decorated veteran, died without health insurance.

A technicality in her employer's insurance plan forced Alice to delay critical treatments. As a result, and despite her education, medical background, and job, she died on the intersection (Black and female). Alice became another Black middle-class woman unable to navigate frontline gatekeepers, red tape, and obstacles in the social structures, including the healthcare system, created by structural racism and sexism in order to get the lifesaving medical care she needed.

Teresa: In the case story of Teresa, one of the authors talks about her vulnerability and constant exposure to COVID-19 as a frontline mental health worker. Like Alice, Teresa is a mother of young children diagnosed with COVID while battling depression, anxiety, and the loss of a loved one while worrying about the future of their children.

Like Alice and other essential workers, Teresa, a designated essential worker, did not have the rights and protections she needed and deserved. These rights and protections include a living wage, adequate safety gear, access to quality insurance, health care, paid family and medical leave, or the power to ensure fair treatment and compliance with existing COVID-19 guidelines. Like Alice, Johnnie/Minnie, and Teresa, as a Black woman living on the intersection, she did not have a strong voice to talk above the loud noise and rhetoric of pandemics.

Lori and Her Friends: Lori and her circle of friends, mostly gay, all above age 65 and thus at a higher risk of being very sick or dying from the coronavirus, found themselves leaning toward each other through technology to combat isolation created by COVID-19. As White women on the intersection of age, gender, by generation, and sexuality, they were isolated from each other by COVID-19-and had to navigate new ways to support each other. Like the African-American women, Teresa, Johnnie, and Minnie, Lori and her friends ended up turning to each other and their families (biological or otherwise), rather than assuming a reliance on the social support systems set in place by the power structures. At those intersections, the women in these case stories found each other, even as society left them unprotected, following the long tradition systemic injustices within the US and society that denied their freedom and human rights. In short, healthcare is a human rights issue.

Access to healthcare for the GLBTQI community is already crowded with barriers due to stigmatization, discrim-

ination, and hate attacks on their personhood, livelihood, and mental health. COVID-19 only adds more fuel to the flame. Therefore, Lori and her friends had learned early on how to rely on each other. As related in their case story, Lori survived COVID-19 and flourished because of her circle of friends who were willing to push through knowledge boundaries to support a friend in need. Much like the Lux (2019) study, they found that women do better in a strong circle of female friends and are ultimately happier and healthier with such support.

9.8 Conclusion

Health-based organizations dedicated to understanding and supporting the aging process can use the information within this chapter to develop culturally sensitive interventions that combine social activity and physical activity to increase health outcomes in older and diverse populations. Health professionals should be knowledgeable about cultural differences and the impact of structuralism (racial and gender based) and systemic injustices on patient's health, especially during the COVID-19 pandemic. Moreover, medical and mental health practitioners can take care to ask about their patients' social and support networks in addition to their level of activity and help find resources for patients that can combine social activity with physical and spiritual activity.

The implications for this intersection of social networks and active lifestyles in aging women have relevance for health communication, aging studies, cultural studies, medical practice, and many others. Within health communication, aging women, especially those culturally, sexually, and socioeconomically marginalized, rely on their interpersonal networks to receive health information. Consequently, understanding the role of interpersonal networks in staying active and healthy should be a central concern of all health professionals.

Furthermore, healthcare professionals should acknowledge and integrate into their practice of care the color line's problem, where Black and Brown people are ravaged by disparities in health and healthcare. Disparities in healthcare are a reality that has been present for centuries, and widely and extensively studied for decades. Likewise, sexism and heterosexism have historically proven to be undaunted, almost omnipotent and invincible. Women, members of the LGBTQI community, and people of color are still disproportionally impacted by diseases and pandemics regardless of their education, SES, or upward mobility. In nearly every healthcare area, people of color and women are more likely to get sick, die earlier, and pay more for the same healthcare coverage as their male counterparts.

During pandemics and prosperity, in good times and in bad times, the lives, health, and jobs of women from all intersections have been regarded as more expendable. The rhetoric surrounding the notion of female expendability that purports society can better cope with the loss of a woman than with the loss of a man (if not for their reproductive roles) has been circling the globe for millennia. In the United States, elderly and people of color, particularly Black people, are expendable too. This disregard has shown up in our society's response to COVID-19, in the disproportional number of essential workers and critical workers unsafely exposed to the virus and in the deaths of people of color from the coronavirus.

The expendability of women, elderly, and people of color, and those on the intersections is evident in not only the statistics, but also the case stories of Alice, Lori, Johnnie and Minnie, and Teresa. Their stories give meaning to our knowledge that in a pandemic, people of color, women, and the elderly are more likely to get sick, die earlier, and to be unable to buy the same health or healthcare. Indeed, COVID-19 roared in with a definite cultural advantage for those with privilege in urban cities such as Berlin, Chicago, London, Los Angeles, New York City, Paris, Sydney, and Tokyo. Prosperity and justice for some, but not everyone—another pandemic within systemic injustice.

9.9 Recommendations

1. Become culturally competent and aware of the multiple factors that play a major role in health disparities and health inequities for marginalized people.
2. Be sensitive to those women living on the intersections, such as an elderly, disabled African-American lesbian.
3. Encourage LGBTQI and other marginalized patients and clients to connect to personal networks to help in maintaining a healthy lifestyle during the pandemic and find an online social support group that will allow for positive identity affirmation and help with technology.
4. Be mindful of the lack of resources and special needs of essential workers living on the margins.
5. Healthcare professionals working with marginalize people should look internally at their own values and biases at the outset and throughout a clinical encounter with individuals whose culture and backgrounds are different.
6. For meaningful social change to occur within healthcare, it is vital to make sure the voices of those marginalized are in included, heard, and represented in decision making and policy changes.
7. Public health and research organizations must continue to advocate for better and more specific data regarding the impact of pandemics on marginalized populations.

8. Healthcare should be approached and understood as a human right.
9. Encourage others to use social media as a tool to provide a voice for marginalized people during this COVID-19 pandemic and to call attention to the system injustice in healthcare.

Chapter Review Questions

1. Social media has _____.
   (a) Made it difficult to hide acts of racism, sexism, and elitism
   (b) Contributed to acts of elitism and racism
   (c) Become an emerging vehicle for women to social network
   (d) All the above
2. The study of racism has historically been inadequate because _____.
   (a) It advantages White people
   (b) The theories were too simplistic
   (c) It is grounded in systemic inequality
   (d) It is pluralistic and inclusive
3. What does the term "health information mavenism" mean?
   (a) Individuals who are good at organizing and creating health information pamphlets
   (b) Individuals who share health information through their interpersonal networks, and who become sought out sources of health information within their communities
   (c) Individuals who seek out health information from friends
   (d) Individuals of an advanced age who enjoy reading health information
4. Strong social networks have been shown to _____.
   (a) Improve longevity
   (b) Increase overall health status
   (c) Decrease levels of anxiety and depression
   (d) All the above
5. During pandemics, historically, the gap in health disparities are widened by race and ethnicity, yet unrelated to:
   (a) Gender
   (b) Disability status
   (c) Sexual identity
   (d) Political affiliation
6. Addressing racism during pandemics has historically been inadequate because _____.
   (a) It advantages White people
   (b) The use of theories that were too simplistic
   (c) It is grounded in systemic inequality
   (d) All the above
7. People of color represent ____ of essential workers during COVID-19.
   (a) 20%
   (b) 90%
   (c) 75%
   (d) 33%
8. The normalization and legitimization of an array of dynamics—historical, cultural, institutional, and interpersonal—that routinely advantage White people while producing cumulative and chronic adverse outcomes for people of color is:
   (a) Structural racism
   (b) Individual racism
   (c) Community racism
   (d) Prejudices and bias
9. Ultimately, _____ is an essential tool for reducing racial and ethnic disparities in health care.
   (a) Structural racism
   (b) Cultural competency
   (c) Healthcare inequalities
   (d) None of the above
10. Key frameworks that are used to shed light on how healthcare interacts with employment, education, welfare, politics, religion, other structures and social institutions, health, and healthy activity to produce racialized and patriarchal outcomes include:
    (a) Structural racism
    (b) Structural sexism
    (c) Intersectionality
    (d) All the Above

Answers

1. a
2. b
3. b
4. d
5. d
6. b
7. c
8. a
9. b
10. d

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Evidence-Based Disordered Eating Prevention Programs for Active Females Including Mindfulness

10

Jacalyn J. Robert-McComb, A. M. Tacón, and Yi-Yuan Tang

Learning Objectives
After completing this chapter, you should have an understanding of:

- The importance of self-esteem in disordered eating
- The Transtheoretical Model in the process of health behavior change
- General treatment principles and medical criteria for hospitalization
- Program examples including mindfulness
- Eating disorder resources

10.1 Introduction

Low self-esteem, accompanied with perfectionism, is a well-recognized trait of those with disordered eating, and could also be a precipitating factor in the development of eating disorders. This characteristic likely increases females' vulnerability to disordered eating when combined with recently documented genetic and neurobiological findings: the heritability of eating disorder symptoms increases from zero risk before puberty to ≥50% during and after puberty; also, Functional Magnetic Resonance Imaging (fMRI) studies show decreased activity in brain areas involved in self-regulation and impulse control [1, 2]. Self-esteem, as a component of self-regulation, frequently triggers behavioral and cognitive strategies to maintain or enhance a sense of self-esteem [3]. The terms self-concept, self-worth, and self-image are used interchangeably with self-esteem and are all based on self-perception. Self-esteem can be defined as the extent to which a person feels positive about himself or herself [4]. Often, self-esteem is described as dichotomous, with a person possessing either high or low self-esteem. People with low self-esteem feel positive about themselves when they encounter affirmative experiences. Conversely, when they face negative experiences, they are disapproving of themselves. People with high self-esteem embrace and benefit from positive experiences and have developed strategies to mollify negative feedback. In short, they have learned how to *offset* negative experiences [5].

Effective prevention and intervention programs must recognize the importance of enhanced self-esteem and embrace the development of this concept in their programs. Education to prevent disordered eating can only be effective if the individual understands and accepts him or herself, even his or her limitations. Many times, physically active women have a heightened awareness of the body and its limitations [6]. These limitations may contribute to low self-esteem (losing a race, finishing last, etc.). Rosenberg [7] describes self-esteem as consisting of three major components: (a) social identities (how an individual defines him or herself in society); (b) personal dispositions (perceptions of traits, preferences, response tendencies); and (c) physical characteristics (height, weight, body fat distribution, attractiveness, etc.). While there are many models for self-concept, all models recognize that the development of positive self-esteem is multidimensional, and an individual's perception of self can be affected by the social, emotional, and physical involvement in sport and exercise.

10.2 Research Findings

10.2.1 The Transtheoretical Model in Health Behavior Change

Numerous theoretical frameworks have been proposed to explain and predict the process of health behavior change. One frequently used is the Transtheoretical Model (TTM) developed by Prochaska and DiClemente as a model of

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intentional behavior change [8]. The TTM assumes that individuals vary in motivation and readiness to change their behavior, and as well, realistically acknowledges that relapse is normal under situations that involve such significant behavior change. Four related concepts considered central to health behavior change are included within this model: stages of change, self-efficacy, decisional balance, and processes of change.

The five stages of change are: precontemplation (PC, no intention to change health behaviors within the next 6 months) contemplation (C, seriously considering behavioral change within the next 6 months); preparation (P, still lack commitment to change, but investigating the possibility of change within the next 30 days); action (A, actively modifying problematic behavior within the last 6 months); and maintenance (M, self-control of the behavior established more than 6 months ago).

In the PC stage, information needs to be provided about the behavioral and potential medical problems associated with the behavior. In the C stage, health professionals must help individuals assess the pros and cons of the behavior change so that they will make a commitment to change. Health professionals must encourage initial small steps to initiate change, no one can force someone to change, and individuals must begin to place greater significance on the benefits of behavior change in the P stage. The A stage occurs when benefits outweigh the costs. Initiating a new health behavior change is bound to be fraught with relapse; health professionals should act to reinforce an individual's self-confidence along with their decision to change. The M stage occurs when individuals are able to continue the new behavior. Conceptually, progression through these stages during attempts at behavioral change is expected to be linked to differences in self-efficacy, decisional balance, and the processes of change [9].

Self-efficacy and decisional balance represent beliefs about behavior that are common to many social cognition models. Specifically, self-efficacy refers to an individual's confidence in his or her ability to perform a specific behavior, which is expected to increase as an individual moves through the stages [10]. Indeed, self-efficacy for health behavior change reliably predicted stages of change; precontemplators and contemplators had the lowest efficacy, while those in the maintenance stage exhibited the highest efficacy [11].

Decisional balance relates to the pros (benefits) and cons (costs) of the behavior; for example, eating gives me more energy, yet it might make me fat. Individuals who change their behaviors have positive decisional balance because the positive beliefs about the behavior outweigh the negative ones. Additionally, the pros increase, while the cons decrease across the stages of change.

Lastly, the TTM also includes processes of change and specifically define a process of change as a "type of activity that is initiated or experienced by an individual in modifying affect, behavior, cognition or relationships" [8]. Health professionals can assist the process of change and the maintenance of the new behavior by providing follow-up support [12].

10.2.2 General Treatment Principles

Treating eating disorders is both a science and an art. Even though the treatment goals for anorexia nervosa (AN) and bulimia nervosa (BN) are well defined [13], the method of achieving these goals is less certain [14] (Table 10.1).

Treatment is less likely to occur without proper screening in terms of medical criteria used for hospitalization. Table 10.2 lists the general criteria for in-patient hospitalization for patients with AN and BN [15–19].

Achieving and maintaining a normal weight and nutritional status is essential for recovery for both anorexia nervosa (AN) and bulimia nervosa (BN). Perfectionist attitudes, low self-esteem, unrelenting pursuit of thinness, intolerance of mood fluctuations, and poor coping skills are problematic for both AN and BN. Recovery is unlikely without a fundamental change in these attitudes.

Research has shown that the therapist should function in the therapeutic encounter as a parent, teacher, guide, and coach and that the personality of the therapist is a major therapeutic element in the treatment of patients with AN [14]. The therapist must make every effort to engage the

Table 10.1 Treatment goals for anorexia nervosa (AN) and bulimia nervosa (BN) [13, 14]

Major goals for AN	Major goals for BN
• Restore weight and improve eating habits • Change dysfunctional attitudes especially eating behavior • Work with the family	• Identify the factors and processes that maintain the binge–purge–starve cycle • Cessation of the binge–purge cycle and compensatory behavior (vomiting, misuse of laxatives and diuretics)
• Reduction of associated psychopathology (body image disturbances) • Treat concomitant medical complications (disturbances in the gonadal axis, infertility, osteoporosis) • Pharmacotherapy to treat depression, moderate obsessive perfectionism, to target certain neurotransmitters, or to treat concomitant complications • Prevent relapse (most difficult task)	Note: Cognitive behavioral therapy (CBT) has been found to be most effective for both AN and BN. However, self-help (SH), using a written manual based on the principles of CBT, has gained wide appeal since the patient may use it with or without the guidance of a therapist

Table 10.2 Sample hospitalization criteria [15–19]

	Adults	Children and adolescents
Heart rate	<40 bpm or >110 bpm	<50 bpm daytime; <45 bpm nighttime arrhythmia
Blood pressure	<90/60 mmHg or orthostatic hypotension (pulse increase of >20 bpm or drop in BP of >10–20 mmHg/min from lying to standing)	<80/50 mmHg; orthostatic blood pressure changes (>20 bpm increase in heart rate or >10–20 mmHg drop in blood pressure)
Glucose	<60 mg/dL	<60 mg/dL
Electrolytes or metabolic function	Potassium <3 meq/L; electrolyte imbalance; dehydration; metabolic abnormalities	Hypo- or hypernatremia, hypophosphatemia, hypokalemia, hypomagnesemia; serum chloride concentration <88
Gastrointestinal	Hematemesis; esophageal tears; intractable vomiting	Hematemesis; esophageal tears; intractable vomiting
Temperature	<97.0 °F; inability to sustain body core temperature	<96.0 °F, dehydration
Hepatic, renal, or cardiovascular	Organ comprise requiring acute treatment	Organ compromise requiring acute treatment; arrhythmias
Weight and body fat	<75% of healthy body weight or acute weight decline with food refusal	Acute weight decline with food refusal even if not <75% of healthy body weight; body fat <10%
Motivation to recover	Very poor to poor; preoccupied with ego-syntonic thoughts	Very poor to poor; preoccupied with ego-syntonic thoughts; failure to respond to outpatient treatment
Comorbid psychiatric disorders	Any existing disorder that would require hospitalization such as suicidal risk and depression	Any existing disorder that would require hospitalization such as suicide risk and depression
Purging behavior (laxatives and diuretics)	Needs supervision during and after all meals and in bathrooms	Needs supervision during and after all meals and in bathrooms
Ability to care for self; ability to control exercise	Complete role impairment; structure required to keep patient from compulsive exercising	Complete role impairment; structure required to keep patient from compulsive exercising
Stress and support	Severe family conflict; lack of structured treatment in home; inadequate support	Severe family conflict; lack of structured treatment in home; inadequate support

family, especially if treating patients with AN under 18 years of age. Family therapy has shown to be very effective in younger patients with AN of shorter duration (less than 2 years) [20].

Although most patients with BN can be treated in an outpatient setting, the first issue a clinician must decide with AN is the treatment setting. Most clinicians will recommend inpatient treatment for a patient who weighs less than 75% of average weight, has severe metabolic disturbances, if feeling suicidal, or has failed to improve after a period of outpatient or partial program treatment [18, 21]. Again, refer to Table 10.2 as to the medical criteria for hospitalization.

Traditionally, inpatient treatment is continued until a patient reaches a reasonably healthy body weight. Discussing a target weight is one of the most important initial tasks of weight restoration. Currently, most clinicians use a body mass index of 18.5 kg/m^2 as the minimal healthy weight for a patient older than 16 [14].

The treatment of BN is usually conducted in an outpatient setting. Cognitive behavioral therapy (CBT) is the treatment of choice and is effective whether conducted individually [22] or in a group setting [23].The most widely used CBT is the version developed by Fairburn and is implemented over a period of 18 weeks [24]. In the first stage, behavioral techniques are used to replace binge eating with a stable pattern of regular eating. In the second stage, the goal is to eliminate dieting; the focus is on the thoughts, beliefs, and values that reinforce dieting. The third stage is focused on the maintenance of these new healthy behaviors and thought patterns.

Self-help (SH), using a written manual based on the principles of CBT, has been shown to be effective for BN patients and is more accessible than CBT [25]. The patient may use it without any guidance or with the help of a therapist. Under guidance, the program usually consists of 7 sessions and is conducted over a period of 12 weeks. The most widely used manual, by Fairburn, provides a step-by-step discussion of implementing the program [26].

In 2019, *Treatment of Anorexia-New Evidence-Based Guidelines* was published in Germany, these guidelines are referred to as the German S3 guideline for eating disorders revised and the key findings are presented in Table 10.3 [27]. Table 10.3 summarizes not only *the S-3 guidelines,* but also insights, and recommendations from various governing bodies *and/or* authorities on the treatment of ED [28–30].

Table 10.3 Insights and Recommendations (I&R) from leading agencies or governing bodies [27–30]

Selected German S3 I&R for patients with anorexia nervosa (AN) [27]
• Comorbid conditions should be systematically assessed and taken into considerations
• Severe family conflict, lack of structured treatment in home
• Inpatient treatment should take place in a setting with multidisciplinary teams
• Stabilization of weight for a certain period should be ensured before transferring to an outpatient setting
• The energy supply for the expected weight gain is highly variable and should be continually monitored
• Outpatient treatment of first choice should be evidence-based psychotherapy
• Family-based therapy (FBT) is recommended for younger patients
• Therapy should be tailored to the needs of the patient and the skill of the therapist: FPT; CBT-E, MANTRA, and SSCM are recommended
Selected I&R for all ages for the treatment of eating disorders by the Royal Australian and New Zealand College of Psychiatrists [28, 29]
• AN is the most lethal of the psychiatric conditions
• Recovery for AN is slow and arduous. Children and adolescents are more likely to fully recover compared to adult
• A new designation, Severe and Enduring Eating Disorder (SEED) has been established by the Royal Australian and New Zealand College of Psychiatrists
Selected I&R for children and adolescents from the American Academy of Pediatrics [30]
• Hospitalizations for children younger than 12 years have increased by 119% from 1999 to 2006 for eating disorders (ED)
• Children with ED in the United Sates are increasingly males, minority populations, and progressively younger children
• Clinicians should focus on healthy eating and building self-esteem

FBT family-based treatment; *FPT* focal psychodynamic therapy; *CBT-E* enhanced cognitive behavior therapy; *MANTRA* Maudsley model of anorexia nervosa treatment for adults; *SSCM* specialist supportive clinical management

Table 10.4 Core themes in exercise as a therapeutic tool in the treatment of anorexia nervosa (AN) and bulimia nervosa (BN). Reprinted from Cook BJ, Wonderlich SA, Mitchell JE, Thompson R, Sherman R, McCallum K. Exercise in eating disorders treatment: Systematic Review and Proposal of Guidelines. Med Sci Sports Exerc. 2016;48(7):1408–14 with permission from Wolters Kluwer Health [31]

Core theme	Manifestation of theme
• Team approach	A multidisciplinary team of experts in exercise, nutrition, mental health, medicine, and physical therapy should work collaboratively
• Medical concerns	Safety is the primary concern
• Screen for exercise-related psychotherapy	Identify pathological attitudes and behaviors such as exercise dependence, exercise addiction, and compulsive exercise that may indicate that unsupervised exercise would exacerbate ED pathology
• Create a written consent	The written consent should be agreed upon by all members or the team
• Include a psychoeducational component	This is a main component of Cognitive behavioral therapy
• Focus on positive reinforcement	Excessive exercise habits have been managed by using exercise as a reward for following treatment guidelines
• Create a graded exercise program	Incremental exercise is paramount in managing exercise used in therapy
• Start with mild intensity and slowly build to moderate	Initially limit ED individuals to short bouts of mild intensity that gradually condition the physiological systems
• Mode of exercise	For AN, resistance training can be used to increase weight; for BN patients, aerobic activity can be used for weight loss and other psychopathology associated with BN
• Nutrition	Exercise should not be implemented until there is progress in weight stabilization
• Debriefing	Sensations, emotions, and thought evoked by exercise should be discussed with the therapist

10.2.3 Exercise as Medicine in the Treatment of Eating Disorders Program

The concept of exercise as medicine has resulted in a published systematic review and proposal of guidelines for exercise in the treatment of ED. Table 10.4 lists the core themes in using exercise therapeutically for ED treatment [31].

10.2.4 Dissonance-Based Eating Disorder Prevention Program

Almost 10% of teenage girls and young women experience threshold or subthreshold anorexia nervosa, bulimia nervosa, or binge-eating disorders [32, 33]. A meta-analytic review [34] found that only five from dozens of randomized controlled efficacy trials investigating disordered eating prevention programs produced significant reductions in disordered eating symptoms among intervention participants compared to controls that extended at least 6-month post-intervention [35, 36]. One program, cognitive dissonance-based prevention or DBP, which utilizes the theory of cognitive dissonance, is accumulating data as to its empirical effectiveness with EDs [33]. Dissonance theory posits that having inconsistent cognitions creates psychological discomfort which motivates people to change their cognitions for the sake of consistency. Dissonance may be activated by having individuals act in ways that are not consistent with their beliefs; dissonance can then be reduced by altering the behavior or belief. Recent research indicates that DBP interventions can help athletes with disordered eating by reducing negative thoughts and feelings [37–41].

Smith and Petrie [42] tested the effectiveness of a cognitive dissonance-based intervention compared to a psychoeducational-based healthy weight and a wait-list control to determine their relative effectiveness in reducing body dissatisfaction, negative affect, dietary restriction, and internalization of the sociocultural ideal. The sample of 29 self-

identified disordered eating female athletes engaged in exercises that questioned the thin ideal body type so as to produce dissonance. Possibly due to low power, no treatment effects were found; however, exploratory post hoc analyses suggested that the cognitive dissonance intervention provided some positive effects, that is, decreases in sadness/depression, internalization of a physically fit body type, and increases in body satisfaction.

Another study focused on the issue of education in the female athlete triad. Specifically, Becker and colleagues evaluated whether two exploratory peer-led interventions could have a positive effect on athletes at risk for an ED [37]. Athletes were randomly assigned to either an athlete-modified dissonance prevention or a healthy weight intervention (AM-HWI); ED risk factors were assessed pre/post-treatment, at 6-week and 1-year follow-up. The results (N = 157) indicated that both interventions reduced dietary restraint, thin ideal internalization, bulimic pathology, shape/weight concern, and negative affect at 6 weeks. Bulimic pathology, shape concern, and negative affect were reduced at 1-year follow-up. Also, qualitative results suggested that AM-HWI may be the more preferred intervention by athletes.

10.2.5 Riding the [Third] Wave of Mindfulness

"Third-wave" behavior programs have become popular in treating a range of physical and psychological conditions. Acceptance-Commitment Therapy (ACT) and Mindfulness-based programs (MBIs) are examples of "third-wave," interventions [43]. While such programs have some "second-wave" or cognitive-behavioral aspects (CBT), third-wave therapies include new principles and techniques to improve psychological functioning. These interventions focus on awareness of cognitive and emotional processes via strategies that encourage: acceptance, mindfulness, metacognition, and psychological flexibility to reduce avoidance and thought suppression [43]. Thus, third-wave therapeutic approaches highlight emotional regulation and the changing of *cognitive processes—not content.*

Mindfulness is the disciplined practice of paying attention to the present moment with uncritical, nonjudging acceptance [44]. Kabat-Zinn describes mindfulness as the "awareness that emerges through paying attention in a particular way: on purpose, in the present moment and non-judgmentally to the unfolding of experience moment by moment." The mindfulness [meditation]-based stress reduction program (MBSR) of Kabat-Zinn's, which includes mindful breathing, eating, walking, hatha yoga, and group support, has flourished into a universal concept and program commonly found in hospitals, clinics, and universities. The MBSR has produced beneficial psychological effects for symptoms of anxiety, stress, and depression to improvement in physical conditions such as chronic pain and cancer-related symptoms [45, 46]. Such interventions have been applied to disordered eating populations in terms of modifying how one interacts with thoughts in relation to eating and weight.

10.2.5.1 Mindfulness-Based Eating Awareness Training (MB-EAT)

Mindfulness is a form of "…mental training to reduce cognitive vulnerability to reactive modes of mind," associated with emotional distress and psychopathology [47]. Kristeller, an early proponent of clinical benefits of mindfulness, developed a program for eating disorders, the MB-EAT or Mindfulness-Based Eating Awareness Training program, originally for binge-eating disorder (BED). The MB-EAT integrates the science of meditation with multiple factors: relationships to eating, nutrition, food, body and self-awareness, self-acceptance, and theories of self-regulation [48].

Over several decades of evolved practice and components, clinical trials have documented improvement as to how participants relate to eating; for example, significant improvements in self-regulation and depression have been found in those with BED and those with subclinical eating issues [49]. Kristeller is a founder and past president of *The Center for Mindful Eating* (TCME) which is a US-based 501(c)3 nonprofit organization with a web-based educational component [50]. TCME provides resources for educating professionals, institutions, as well as individuals in the principles and practices of mindful eating. The TCME website provides resources about the MB-EAT program and training for a variety of professionals. The program has expanded to serve new populations of disordered eating such as diabetes, obesity, etc. Mindfulness has become a central component in the treatment of diabetes and obesity as well as other forms of eating disorders. A session outline for the MB-EAT program [51] can be found in Table 10.5.

Table 10.5 Session outline for the MB-EAT. Reprinted from Kristeller J, Wolever R, Sheets V. Mindfulness-Based Eating Awareness Training (MB-EAT) for binge eating: A randomized clinical trial. Mindfulness. 2014;5(3):282–97, with permission from Springer Nature [51]

Session 1: Introduction to self-regulation model; raisin exercise; introduction to mindfulness meditation with practice in group
Session 2: Brief meditation (all sessions); mindful eating exercise; concept of mindful eating; body scan
Session 3: Binge triggers; binge trigger meditation; mindful eating exercise
Session 4: Hunger cues; physiological vs. emotional; hunger meditation; eating exercise: mindful food choices (cookies vs. chips); healing self-touch
Session 5: Taste satiety cues—type and level of cues; taste satiety meditation; seated yoga
Session 6: Fullness cues—type and level of cues; fullness meditation; potluck meal;
Session 7: Forgiveness; forgiveness meditation
Session 8: Inner wisdom; wisdom meditation; walking meditation
Session 9: Others noticed? where from here? maintaining change/relapse prevention; celebratory potluck meal

10.2.5.2 Mindfulness Disordered Eating Prevention Programs

Mindfulness-based strategies have emerged as a therapeutic approach to disordered eating prevention and treatment programs. Most eating disorder programs emphasize that the reduction of risk factors is important; yet research suggests that awareness and inclusion of protective factors are also needed for successful disordered eating prevention [52]. Data indicate that mindfulness may be associated with risk and protective factors in the pathology of disordered eating; for example, mindfulness strategies have been found to reduce negative affect and body image concerns [53]. Additionally, mindfulness has been positively correlated with body satisfaction, self-compassion, and psychological well-being, all of which are indicated to be protective against eating disorders in youth [54].

One meta-analysis of 24 studies (including 13 randomized controlled trials or RCTs) explored the potential of third-wave interventions for eating disorder prevention programs by examining effects on eating disorder risk factors and body image in samples without a disorder [55]. Each third-wave treatment, including Mindfulness-Based Interventions (MBIs), produced significant pre-post and follow-up improvements in risk factors and body image; also, combined third-wave intervention strategies produced even greater efficacy, further suggesting potential benefit from mindfulness-based disordered eating programs. A meta-analytic review on eating disorder prevention included mindfulness programs; however, the programs included were selective, comparing only no/minimal-treatment controls [56]. A structured review as to the role of mindfulness and mindful eating in changing eating behaviors concluded that mindfulness approaches appear most effective in addressing binge eating, emotional eating, and eating in response to external cues by increased awareness of internal cues, and this awareness may prevent weight gain [56]. In sum, mindful eating can potentially address problematic eating behaviors; thus, a mindful eating approach would seem to be a "positive message to be included in general weight management advice to the public" [57].

A recent systematic review and meta-analysis evaluated the effects of mindfulness-based eating disorder prevention programs on participants' risk and protective factors associated with developing an eating disorder; these effects also were compared to those of dissonance-based programs [58]. Specifically, 20 relevant articles [including 15 Random Controlled Trials RCTs] and five non-randomized studies were included. This review included universal and selective indicated mindfulness programs, comparing effects to both wait-list and active controls, and included subgroup analyses when possible. Results indicated that mindfulness programs were effective in reducing two risk factors and enhancing a protective factor (when compared to wait-list/assessment only controls); that is, body image concern, negative affect, and body appreciation, respectively. Such findings are of import, for body image concern and negative affect have consistently predicted eating disorder onset, and indeed, may be causal risk factors [59]. While heterogeneity was a limitation, MBIs also were found to improve self-esteem significantly more so than active/dissonance-based controls. Lastly, all pooled effects favored mindfulness-based programs over control [58]. The integration of mindfulness techniques with dissonance-based programs was suggested since both target unique and overlapping risk and protective factors for eating disorders. In sum, while more research is needed, these data indicate that mindfulness-based eating disorder prevention strategies have the potential to increase the effectiveness of established programs. It should be noted that although MBSR showed effects compared to waitlist control, recent studies have shown that MBSR did not outperform active control conditions such as same amount of health education class, suggesting the importance of RCTs with active controls in the future research of MBIs [7, 60–63].

10.2.5.3 Mindful Eating

Mindful eating practices have become a lifestyle option for the lay public, students and athletes. According to the Center for Mindful Eating, mindful eating helps one identify what, when, and why one eats as well as practice mindful awareness of the present moment as one is eating. Principles of mindful eating were developed originally by a team of 19 psychology and therapy professionals at the Center for Mindful Eating, which include such basic tenets such as: engage all senses when choosing foods to eat; pay attention to how they look, feel, smell and taste; create time to choose, prepare/cook meals with intent; pay attention to how your body responds to different foods; and, increase mindful awareness as to body cues that guide when to eat and when to stop eating. The most basic of mindful practices can have a significantly positive impact, for example, state and trait mindfulness predicts healthier eating in addition to previously discussed physical and psychological benefits [64–66]. Table 10.6 contains the basic tents of what has come to be known as "Mindful Eating" [50].

Mindfulness-based eating programs exist for different populations and contexts. In the case of athletes and competitive performers, training in mindful eating may enhance performance as well as help to counter unique body image and eating concerns found in many sport and performance environments [67]. Also, mindful eating programs and training have been developed by Dr. M. May, not only for health professionals working with certain populations, but also, for students and athletes under the Am I Hungry?® Mindful eating program [68]. Dr. May's organization provides professional development and continuing education credits (CEs, CECs, CPEs, CPEUs, CEUs) for psychologists, dieti-

Table 10.6 Principles of mindful eating. Reprinted with permission from The Center for Mindful Eating https://www.thecenterformindfuleating.org/ [50]

• Mindfulness is deliberately paying attention, non-judgmentally
• Mindfulness encompasses both internal processes and external environments
• Mindfulness is being aware of what is present in each present moment for you mentally/emotionally/physically
• Mindfulness practice cultivates the possibility of freeing yourself of reactive, habitual patterns of thinking, feeling and acting
• Mindfulness promotes balance, choice, wisdom, and acceptance of what is
Mindful Eating is:
• Allowing yourself to become aware of the positive and nurturing opportunities that are available through food preparation and consumption by respecting your own inner wisdom
• Choosing to eat food that is pleasing to you and nourishing to your body by using all your senses to explore, savor and taste
• Acknowledging responses to food (likes, neutral or dislikes) without judgment learning to be aware of physical hunger and satiety cues to guide decisions to begin eating and to stop eating

Table 10.7 Mindful Restaurant Eating Session. Reprinted from Timmerman GM, Brown A. The effect of a mindful restaurant eating intervention on weight management in women. Journal of Nutrition Education and Behavior. 2012;44(1):22–8 with permission from Elsevier Science and Technology Journals [67]

Session 1	Weight management principles and general strategies to prevent gaining weight; barriers to weight management when eating out; goal setting skills
Session 2	Portions; energy needs; general strategies to prevent weight gain in restaurant eating
Session 3	Strategies to improve satiety/satiation; strategies to prevent weight gain when eating fast food; salad skills; internet resources
Session 4	Strategies to prevent weight gain (SPWG)* when eating out at Italian, Chinese and Mexican restaurants
Session 5	SPWG* when eating out at seafood, steak and family-style restaurants
Session 6	SPWG* when eating out for breakfast, dessert and beverages; relapse prevention

tians, nurses, coaches, and other health and wellness professionals. Finally, we all are tempted when eating out; see the mindful eating restaurant intervention and session topics in Table 10.7 [66].

10.2.6 Pharmacological Treatment of Eating Disorders

Research suggests substantial influence of genetic factors on the development of eating disorders and neurotransmitters such as serotonin and dopamine. Both of these neurotransmitters have etiological importance [69]. Therefore, pharmacological treatment (see Table 10.8) for the treatment of eating disorders is many times necessary, since the cause of the disorder could be related to the deficiency of certain neurotransmitters or other biological agents. Pharmacological therapy may be coupled with psychotherapy, but there is no clear evidence to recommend the addition of pharmacotherapy to psychotherapy in the treatment of AN. The combination of psychotherapy and pharmacological therapy seems to have a ceiling effect in the treatment of BN. Because of the many and varied types of medicine or pharmaceutical drugs, only the very broad psychopharmacological agents for the treatment of ED and the mechanism of action for that classification are listed. For a more detailed examination of the use of pharmaceutical drugs or medicines used to treat ED, please refer to World Federation of Societies of Biological Psychiatry (WFSBP) Guidelines [13] as well as other published research on the neurobiology of ED [69, 70].

Table 10.8 Broad psychopharmacological agents for the treatment of eating disorders [13, 69, 70]

Antidepressants
Their main action is through the serotonergic and/or noradrenergic system. It is possible that the central serotonin system contributes to the dysregulation of appetite, mood, and impulse control. Other monoamine functions may also be disturbed in Anorexia Nervosa.
Antipsychotics
The main site of action is thought to be on the dopaminergic system with additional serotonergic involvement. The cortico-mesolimbic dopamine system may also be involved in addictive eating behavior.
Antiepileptics
The neuro-stabilizing effect of antiepileptics maybe of therapeutic benefit in eating disorders. These drugs have many possible sites of action (sodium, calcium, potassium channels); on gamma aminobutyric acid and glutamate receptors; as well as anhydrase inhibition.
Antihistamines
Histamine, a neurotransmitter that regulates appetite and energy metabolism. Neuronal histamine suppresses food intake via jistamine-1-receptors within the paraventricular nucleus and the ventromedial hypothalamus.

10.2.7 Eating Disorder Organizations and Resources

Education programs at exercise facilities and sporting events can help prevent the triad of disorders in girls and young women by making them aware of the issues. Information packets can educate parents and children. Furthermore, education materials can be displayed on bulletin boards, web pages, newsletters, etc. Social media can be used as a positive force in the education of both parents and children.

Workshops related to improving body image, healthy eating habits, and coping with stressors during puberty can be provided by after school programs, youth organizations, and fitness facilities. These workshops can be hosted as a community service and as advertising for the sponsoring organization or facility. Mental Health America (MHA)—founded in 1909—is the nation's leading community-based nonprofit

dedicated to addressing the needs of those living with mental illness and to promoting the overall mental health of all Americans. Mental Health America also has resources for eating disorders https://www.mhanational.org/conditions/eating-disorders [71]. There is a confidential and scientifically validated online eating disorder test that is free. The BodyWise Handbook: Eating Disorders Information for Middle School Personnel can be found on the United States Department of Agriculture (USDA) National Agricultural Library (NAL) website https://naldc.nal.usda.gov/catalog/1759348. This manual was developed by the United States Department of Health and Human Services (HSS) Office on Women's Health in 2005 [72].

The Female Athlete Triad Coalition, now known as The Female and Male Athlete Triad Coalition, is a nonprofit 501(c)(3) organization. This organization represents key medical, nursing, athletic, and sports medicine groups, as well as concerned individuals who come together to promote optimal health and well-being for athletes and active individuals. The Coalition developed from a collaborative effort to support cultures that promote healthy athletic environments as well as establishing public policy for both national and international governing bodies. The Female and Male Athlete Triad Coalition web page https://www.femaleandmaleathletetriad.org/about/ contains additional helpful information that exercise professionals can use as educational tools [73].

Resources exist for physicians in treating eating disorders. A wonderful online resource for physicians is Patient Care, https://www.patientcareonline.com/. There is a section on obesity on this site and if you type in eating disorders in the search box, you will find resources for both men and women with eating disorders [74]. Table 10.9 has specific online sites for eating disorders specifically that can be used to educate and treat patients and their families.

Table 10.9 Resources for the education and treatment of eating disorders for physicians, educators, family members and even patients themselves [21, 71, 75–80]

Mental Health America [71] 500 Montgomery Street Suite 820 Alexandria, VA 22314 Phone (703) 684-7722 Toll Free (800) 969-6642 FAX (703) 684 5968 Website: https://www.mhanational.org/conditions/eating-disorders
Academy for Eating Disorders (AED) [75] 11130 Sunrise Valley Drive Suite 350 Reston VA 20191 Phone: 1+703-234-4079 FAX: 1+703-832-4545 Website: https://www.aedweb.org/home E-mail: info@aedweb.org *About:* Founded in 1993, the Academy for Eating Disorders (AED) is a global professional association committed to leadership in eating disorders research, education, treatment, and prevention
American Psychiatric Association (APA) [21] 800 Maine Ave, SW in Washington, D.C Phone: 1-888-35-PSYCH (toll free) or 888-357-7924 or 202-559-3900 for callers from outside the U.S. and Canada Website: https://www.psychiatry.org/ E-mail: apa@psych.org *About*: The American Psychiatric Association is an organization of psychiatrists working together to ensure humane care and effective treatment for all persons with mental illness, including eating disorders
Internet Mental Health (IMH) [79] Vancouver, BC Canada, V5Z4C2 Website: http://www.mentalhealth.com *About:* Internet Mental Health is a free encyclopedia of mental health information created in 1995 by a Canadian psychiatrist, Dr. Phillip Long. Dr. Long received the Canadian Psychiatric Association's Special Recognition Award for the creation of this website. Dr. Long is retired, and the website is run out of his home. For security reasons, contact information is not on this website
National Association of Anorexia Nervosa and Associated Disorders (ANAD) [76] 220 N. Green St. Chicago, IL 60607 Office: 630-577-1333 Helpline: (630) 577-1330 Website: http://www.anad.org E-mail: hello@anad.org *About:* The National Association of Anorexia Nervosa and Associated Disorders (ANAD) is a nonprofit (501 c 3) organization working in the areas of support, awareness, advocacy, referral, education, and prevention of eating disorders. ANAD is the oldest organization aimed at fighting eating disorders in the United States
National Eating Disorders Association (NEDA) [77] 1500 Broadway Suite 1101 New York, NY 10036 Phone number: (212) 575-6200 or 1-800-931-2237 (toll-free) For 24/7 crisis support, text 'NEDA' to 741741 Fax: (212) 575-1650 Web: https://www.nationaleatingdisorders.org/ E-mail: info@NationalEatingDisorders.org *About:* The National Eating Disorders Association (NEDA) is the largest nonprofit organization dedicated to supporting individuals and families affected by eating disorders. NEDA supports individuals and families affected by eating disorders, and serves as a catalyst for prevention, cures, and access to quality care
Eating Disorder and Referral Information Center [80] Internet: http://www.EDreferral.com *About* Christine Hartline started EDReferral.com in 1999 to help others with eating disorders. Christine Hartline, the founder of EDReferral passed away in late March of 2012, she struggled with both anorexia and bulimia. This website is a resource for information and treatment options for all forms of eating disorders. It includes referrals to local treatment centers nationwide
The Cambridge Eating Disorder Center (CEDC) [78] 3 Bow Street, Cambridge, MA 02138 888.900.CEDC (2332) info@CEDCmail.com **617.547.0003 (FAX)** Internet: https://www.eatingdisordercenter.org/ *About*: CEDC's mission is to provide our patients with a comprehensive and quality continuum of care in a community setting. The CEDC conceptualizes ED as largely perpetuated by emotional intolerance and avoidance as well as relational disconnection from others

10.3 Contemporary Understanding of the Issues

Theoretical perspectives differ in the treatment of eating disorders, and the interplay among the many treatment variables is very complex and not well understood. Furthermore, many ED specialists in the sport world consider female athletes to represent a uniquely challenging population with which to work [37]. CBT and dissonance-based programs (DBP) are two intervention strategies aimed at providing further understanding of treatments for ED. The later (DBP) has been supported to the extent that it meets the American Psychological Association's (APA) criteria for an efficacious intervention (i.e., DBP outperformed no treatment control groups, an alternative intervention, and findings have been replicated by independent laboratories/researchers), which is rare for ED prevention programs [37]. Additionally, DPB effects appear to be long lasting with data showing reductions in ED risk factors continuing at 2- and 3-year follow-up periods [81]; DBP has been shown to reduce the onset of EDs by 60% *compared to an assessment only control* [37].

10.4 Future Directions

Practice guidelines for the treatment of patients with eating disorders have been developed by psychiatrists who are in active clinical practice and are available on the web at https://www.psychiatry.org/ [21]. These guidelines were approved by the American Psychiatric Association in 1999 and published in 2000. These guidelines are not intended to serve as a standard of medical care but rather provide recommendations for treating patients with eating disorders.

10.5 Concluding Remarks

Theoretical perspectives differ in the treatment of eating disorders, and the interplay among treatment variables is very complex. Despite the fact that treatment goals for AN and BN are well defined, a decisive therapeutic approach with which to achieve these goals remains unclear. Regardless of theoretical perspectives, however, the personality of the health professional and the therapeutic relationship developed between the health professional and patient are important elements in recovery [14].

Chapter Review Questions

1. The goals of treating anorexia nervosa include all below except:
   (a) Reduction of associated psychopathology (body image disturbances)
   (b) Treat concomitant medical complications
   (c) Identify the factors and processes that maintain the binge–purge–starve cycle
   (d) A & B
   (e) No exceptions—all included
2. A multidisciplinary team, medical safety concerns, identification of exercise-related pathological attitudes or behaviors, and positive reinforcement are core aspects of:
   (a) The Transtheoretical Model
   (b) Cognitive dissonance-based prevention
   (c) Mindfulness
   (d) Therapeutic exercise
   (e) None listed
3. The heritability of eating disorder symptoms has been shown to increase from zero risk before puberty to _____ during and after puberty:
   (a) ≤50%
   (b) 25%
   (c) ≤45%
   (d) ≥50%
   (e) None listed
4. _____ is a salient characteristic of individuals with disordered eating, and indeed, may be a precipitating factor in the development of eating disorders:
   (a) Low self-esteem
   (b) Disorganized identities
   (c) Personal and physical characteristics
   (d) A & C
   (e) All above
5. This intervention incorporates the practice and science of meditation in treating disordered eating:
   (a) Mindfulness-based eating awareness
   (b) Dissonance - based awareness
   (c) Self-esteem eating
   (d) A & B
   (e) None listed
6. Mindfulness refers to:
   (a) Attention to detail training
   (b) Non-judgmental awareness
   (c) Regulation of thoughts, emotions, or sensations
   (d) A & C
   (e) All of the above
7. Improving self-awareness helps:
   (a) Detection of subtle affective cues
   (b) Sleep quality
   (c) Decision-making
   (d) A & C
   (e) All of the above
8. Which of the following statements is correct:
   (a) Mindfulness improves attention
   (b) Mindfulness improves emotion regulation
   (c) Mindfulness improves self-awareness
   (d) Positive emotions help habit formation
   (e) All of the above statements are correct

9. Sample Hospitalization Criteria for children include:
   (a) Glucose <60 mg/dL
   (b) Potassium<3 meq/L
   (c) <90/60 mmHg or orthostatic hypotension
   (d) Heart rate <40 bpm or >110 bpm
   (e) All of the above
10. The main site of action for this drug is thought to be on the dopaminergic system with additional serotonergic involvement.
   (a) Antihistamines
   (b) Antiepileptics
   (c) Antipsychoticsc
   (d) Beta-blockers
   (e) Calcium channel blockers

Answers

1. c
2. d
3. d
4. d
5. a
6. b
7. a
8. e
9. a
10. c

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11 Alternative Treatment Modalities for the Active Female with Musculoskeletal Pain

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Learning Objectives

- Identify alternative treatment modalities to treat musculoskeletal pain in active females
- Understand how a female's musculoskeletal system is uniquely affected by pain and treatment
- Interpret current research and contemporary views of different musculoskeletal pain treatment modalities
- Delineate research methods that have the most potential to be clinically significant for the treatment of painful conditions
- Explain the complexity of researching alternative treatment modalities to treat musculoskeletal pain

11.1 Introduction

For the purposes of this chapter, we present an alternative treatment modality as any treatment that is not considered standard clinical management, i.e., surgical or pharmacological, but rather those methods that have gained popularity despite scientific controversy. The first tier of treatment modality includes heat, cold, exercise, exergames, neuroscience education, and supplements. The previously listed modalities are grouped together because these treatments have quality research supporting the fact that they can help to reduce certain types of musculoskeletal pain when appropriately applied. The second tier includes chiropractic manipulation and acupuncture. This group though has been heavily studied but still with highly controversial results due to the poor quality/quantity of data, yet some systematic reviews suggest that they can be beneficial in certain cases. Dynamic compressions, transcutaneous electrical nerve stimulation (TENS), Kinesio Taping, and cupping make up the third tier: these modalities either have a paucity of research or contain very low-quality supportive evidence. However, modalities in this tier tend to be commonly used by elite athletes, which has led to their popularity. Homeopathy makes up the final fourth tier, showing that it has no significant proof of being effective, in addition to having evidence of potentially being harmful to the body.

According to the American Academy of Orthopaedic Surgeons (AAOS), the key difference between the female and the male musculoskeletal system is that females on average have less muscle mass and different muscle fiber composition. Females also have vastly different levels of testosterone (lower) and estrogen (much higher). Testosterone (main male sex hormone) influences muscle mass development, while estrogen (female sex-specific hormone) affects bone size and growth. These inherent sex differences put women at a higher risk for osteoarthritis, anterior cruciate ligament (ACL) injuries, and other knee trauma. Additionally, females are more sensitive to painful stimuli which allow them to be more discriminative in differentiating pain patterns [1].

While there exist many alternative treatment modalities, there is an overall lack of quality data. Substantially less data are available for gender-specific outcomes of these treatments, which limit the specificity of this chapter. Another problem found while performing a literature search is that scientific evidence in this field is largely heterogeneous. Study heterogeneity among systematic reviews/meta-analyses occurs when the studies whose results are being combined are not organized in the same fashion. For example, in acupuncture studies, heterogeneity could occur as a result of the variability (or low formalization) of acupuncture points used on patients throughout different studies. This heterogeneity could also be caused by differences in the methods of the randomized controlled trials (RCTs) themselves, thus adding to the inconsistency in analyzing results.

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11.2 Research Findings and Contemporary Understanding of the Issues

11.2.1 Cold Therapy

The first line of management for many athletes with musculoskeletal injury/pain is typically a variation of RICE or PRICE (Protection, Rest, Ice, Compression, Elevation). Cold therapy, or cryotherapy, is loosely defined as any treatment that cools certain parts of the body below normal temperature. There are many methods of cold therapy such as ice bags, cold gel pads, wetted ice, and ice whirlpool baths. These different treatment methods have varying levels of effectiveness in cooling the superficial/deeper soft tissue layers. All of these methods are thought to be best applied within the first 48–72 h after injury. Cryotherapy is thought to help by decreasing the temperature of the skin and underlying muscles. This causes a decrease in blood flow and decreases metabolic activity in the applied areas. This in turn results in reduced inflammation, edema, and pain. Thus far, randomized controlled trials (RCTs) have not yielded strong enough evidence to support cold therapy as an effective treatment for musculoskeletal pain. It is suspected that the lack of substantial scientific support is due to several factors. First, that many of the studies which found cryotherapy to have a significant effect on musculoskeletal pain are considered low quality. Second, many of the RCTs conducted compared different cold therapy protocols and lacked a no ice control group. Additionally, it is difficult to blind patients to heat or cold therapy. Furthermore, there are several potential complications of cold therapy, especially if it is used/applied improperly, such as frostbite, allergic reactions, and neuropathy of superficial nerves. Despite the lack of strong scientific evidence supporting cold therapy, there exists no data negating any positive effect on musculoskeletal pain. It is expected to remain a common treatment for musculoskeletal painful issues. Hopefully, there will be quality RCTs testing the effectiveness of cold therapy in the near future [2].

11.2.2 Heat Therapy

Another widespread thermal treatment modality for musculoskeletal pain is heat therapy. There are a wide variety of methods used as therapeutic heat such as hot water bottles, heating pads, electric heat pads, heated wraps, infrared hot lamps, deep heat therapy, heated stones, hot baths, and heated towels. Deep heat therapy converts a different form of energy into heat such as ultrasound and shortwave/microwave diathermy. Spa therapy is "a nonpharmacological and widely used treatment, in which patients bathe in natural spring water with a temperature over 20°C with rich mineral contents for 20 to 30 minutes" [3]. Depending on the inclusion/exclusion criteria and other factors, systematic reviews have found the benefits of spa therapy on musculoskeletal pain to be inconclusive or mildly beneficial in relieving painful symptoms [3, 4]. Other RTCs have shown that moist heat is the most effective modality for reducing pain. Heat therapy increases the temperature of the skin and underlying muscles, which is thought to increase blood flow and metabolism of cells. This should ultimately promote healing, decrease pain, and increase tissue elasticity. There is strong evidence supporting heat treatment for decreasing the intensity of acute low back pain and increasing muscular pliability. This was demonstrated in a study that compared heat wrap therapy versus oral medication placebo. Another study showed sufficient evidence that heat therapy can be used to prevent the delayed onset of muscle soreness. There is a minor complication accompanying heat treatment such as temporary skin discoloration from vasodilation. It is recommended to use caution when applying heat therapy on patients who have a condition that can be worsened by heat or patients who are heat sensitive, so as not to cause skin burn [2].

11.2.3 Heat vs. Cold

After much review, cold therapy is most beneficial for soft tissue strain/sprains and acute joint pain, while heat therapy is best used for subacute or chronic lower back pain and muscle soreness. However, in the future, it would be ideal to have more conclusive research findings on the efficacy of heat and cold treatment, i.e., thermal therapy in order to ensure the most appropriate care is being provided for musculoskeletal injury [2] (Fig. 11.1).

11.2.4 Exercise

It may initially seem counterintuitive to some that exercise itself can help decrease chronic musculoskeletal pain (CMP); however, numerous RTCs are beginning to provide strong evidence that exercising (aerobic plus resistance training) can significantly reduce CMP. With CMP being a major cause of pain for many adults in the western world, it is no surprise that it is heavily researched. As public awareness grows about opioids that have been previously overprescribed, researchers are now looking for alternatives in pain management. Scientists/clinicians are starting to learn/realize that chronic musculoskeletal pain may have more of a psychological component in addition to a physical problem. It is not to say that all pain is only in an individual's mind, but rather chronic pain is a result of the brain trying to protect traumatized tissue that may no longer need protection.

Fig. 11.1 Thermal therapy: the man depicted is using a combination of heat and exercise therapy. "The Aquacisor by Thermospas" by Thermospas Inc is licensed under CC BY 2.0

This leads one to believe that for CMP, medical and other health providers need to look at treating the secondary pathological component rather than the primary issue [5].

It appears that one of the key factors for using exercise as a modality to be successful in treating CMP is that a "biopsychosocial treatment be used that acknowledges and addresses the physical, psychological and social factors underpinning pain and disability" [5]. For CMP to be most effective, the patient needs to be educated on the rationale for using exercise to treat his/her pain. Thus far, there is no evidence indicating that one form of exercise is superior to others, which then leads one to believe this may be due to the psychological and/or neurophysiological benefits which are the common denominator to all types of exercising, that this is the primary reason for pain to be relieved. It is also worth mentioning that knowing and managing the patient's expectations of the treatment goal are an important part of this process. If the patient's primary belief is for pain to be completely relieved, the patient may become disheartened when pain relief does not occur quickly. It is important for the patient to understand that the pain may never be completely gone, despite any mode of management. Engaging in a constructive dialogue with patients about their pain and realistic expectations is critical for the treatment to be effective. It is imperative that patients try to understand that pain does not always indicate that traumatized tissue is still damaged, but rather that the body is trying to prevent it from further injury, and sometimes the brain will try to protect the injured issue longer than required. Additionally, the patient should perceive/believe that the exercise method as safe and necessary to treat their musculoskeletal pain [5].

It is crucial to distinguish between musculoskeletal pain management with exercise modality versus treatment with painful exercise. In a meta-analysis of many studies on the effectiveness of painful exercise therapy versus pain free exercise, it was found that painful exercise had significantly greater reduction of pain, especially in the short term [6, 7]. A key to understanding these results may be establishing that pain does not necessarily mean harm. In other words, painful exercise actually is helpful to retrain the brain to reduce the perceived sensation of pain. Additionally, painful exercise may also decrease the sensitivity of the central nervous system in response to noxious stimuli. Furthermore, painful exercise could potentially release endogenous opioids into the body, in effect combating pain itself. While researchers are not certain of the specific mechanism behind this mode of treatment for pain at this time, there exists some moderately strong data supporting painful exercise as an effective treatment for CMP [7].

An important aspect of any treatment plan is the appropriate dosage. With exercise, this will vary depending on the type of exercise and the individual patient. There is the inherent danger that if the exercise is too strenuous it may cause injury to the patient. Engaging in an activity such as this would obviously be counterproductive, especially if the patient was encouraged to participate in specific painful exercising type. An aerobic exercise regimen, when performed for a duration between 20 and 60 min, at least twice a week for a minimum of 6 weeks was sufficient to reduce the level of perceived pain. This form of treatment is an excellent choice because it will also help treat several other medical comorbidities. On the other hand, resistance training may require allowing the patient more time/practice to become familiar with the different types of exercises before he/she will feel safe performing them. The benefit of having patients do resistance exercise is that it is easily quantifiable and can be progressively increased as tolerated. It has also been shown that resistance training for non-painful body parts can decrease pain in other areas. The third mode of exercise is aquatic, which can be beneficial as a starting point for patients, especially those who are fearful and avoidant of pain. However, the goal should be a progressive transition from water to land-based exercises. The intensity of any exercise depends on specific goals for the patient. The more demanding the work or activity to which the patient is trying to return, the more intense the rehabilitative exercise program should be. For example, athletes and manual labor workers will need a much

more intense regimen than an elderly woman, whose goal is perhaps to be able to walk around the park/stay active. In order to quantify the degree of exertion while performing exercises, it should be noted that higher intensity training, with heart rate greater than 70% of heart rate maximum, can be monitored during exercise sessions without adverse side effects for those previously physically fit [5].

11.2.5 Yoga

A study was conducted on dental hygiene students to determine if participating in yoga on a regular basis would reduce reported musculoskeletal pain. The 77 students were divided into the test group that would participate in a 60-min yoga session biweekly for 13 consecutive weeks. At the end of the 13 weeks, the test group reported significantly lower musculoskeletal pain than the control group. Even though this study was over a relatively small group of cohorts, it is worth mentioning that both groups were similar in profile, being mostly females around the same age of 23. The study also measured for changes in body composition, but no significant change was observed in either group. Another aspect where the study could have been improved if the investigators were to ask the test group if they experienced pain during the yoga sessions. By adding this question, it could have provided evidence for whether painful exercise is more beneficial than pain free exercise. Another study on yoga showed those who participated in a 90-min yoga session once a week for at least 9 weeks demonstrated a decrease in neck pain. These participants were able to reduce their pain medications after beginning the yoga regimen. Yoga may have many other potential health benefits such as reduced stress or depression, and an overall improvement in mental well-being. However, there is not much scientific data at this time to support these claims [8].

While many healthcare providers are beginning to use yoga in treating CMP, some have raised concerns that participation in yoga itself may result in musculoskeletal pain. The Bouvé College of Health Sciences conducted a study to determine if this theory had any validity. The study sample included 354 participants doing varying levels of yoga from two different yoga studios. Both studios had certified yoga instructors with more than 200 h of experience. All of those involved in the study had participated in yoga for at least 1 year prior to being surveyed. The study showed that 10.7% of participants had pain they attributed to yoga. A survey of yoga instructors revealed they believed injuries from yoga could mostly be attributed to excessive effort, poor technique, and inadequate instruction. The survey also reported that instructors believed some injury may be avoided by participants communicating about any pre-existing injuries to the instructor prior to beginning yoga exercise sessions [9].

With any form of exercise there is an inherent risk that injury could result, whether it be aerobic activity such as walking, yoga for stretching, or resistance/strength training. However, there are several precautions that can be taken to reduce the likeliness of unintended trauma. As mentioned above, participants should communicate with the instructor about any pre-existing conditions/injuries, only participate in exercise with certified instructors, recognize his/her physical limits and speak with their own physician prior to beginning a new exercise regimen. Despite the possibility of injury from exercising, it would appear that exercise remains a viable treatment option for CMP. With proper precautions, this type of exercise modality can be a great benefit to many who currently suffer from CMP [9].

11.2.6 Exergames

In the late 2000's, the world experienced a surge of popularity in a new form of games. Exergames were a new form of video games that required the player to actually move at least part of their body in order to play. Nintendo seemed to be leading the market with the Wii, claiming to help make exercise fun. So, naturally some might claim that the benefits of exercise would carry over to playing these new exergames. It is true that exergames require much more physical activity than traditional video games, but is it enough to have the same health benefits as exercise? A review of seven small studies revealed mixed results about the effect of exergames. Many of these reviews used some form of exercise or physical therapy as a control, which would make it more difficult for the exergames to have a significant reduction in pain over the control group. Despite this, four of the studies revealed results in favor of the exergames. However, these results were not deemed clinically significant by the reviewers. Currently, there is not enough research to support that exergames can significantly reduce musculoskeletal pain, but the current evidence does not suggest that it has no beneficial effect. This type of activity may be a good alternative to standard exercising because it may be more enjoyable to those who do not desire/tolerate traditional exercise. If patients are willing to do the exergames more often than they would traditional exercise, they may have better outcomes. Similar to many other treatment modalities, more research is needed before one can be sure they are effective in treating CMP [10].

11.2.7 Pain Neuroscience Education

A systematic review of RCTs researching the impact of pain neuroscience education (PNE) on reducing musculoskeletal pain, improving function and mobility, and decreasing disability was conducted by Louw, Zimney, Puentedura, and

Diener. After searching through 11 databases, these researchers were able to find 13 RCTs that fit the parameters of the review. The primary inclusion criteria were that the publication had to be in English within the last 20 years, and the participants were over 18 years of age. The purpose of this review was to focus on whether or not the treatment method for musculoskeletal pain included PNE regardless of what intervention was used. It is an interesting concept that the education may have more of an impact on perceived pain than the intervention itself. These investigators did not go as far to say that such a claim is supported, but it does cause the reader to raise the question [11].

Of the RCTs that focused on the relationship between PNE and pain, half of the RCTs showed significant pain reduction in the experimental groups over the control group of subjects. However, none of the RCTs showed a negative relationship between the PNE group and the control group, and in some of the RCTs, PNE may have been paired with an ineffective intervention such as dry needling. The other half of RCTs demonstrated that there was no significant difference between the experimental group and the control group [11]. As previously eluded to, it was shown that PNE can yield better results in reduction of pain when paired with an effective treatment modality such as exercise. The importance of PNE was indirectly mentioned in another study that focused on the importance of painful exercise. In that study, the authors indicated the importance of educating the patient that pain was not necessarily the body indicating that the tissue was damaged, but rather the body was trying to protect the tissue itself [6]. While no definitive scientific evidence exists thus far, it would appear that a pain inducing exercise regimen paired with PNE may have a significant reduction in the perceived pain. If this is true, then it may be a relatively cheap healthcare solution to the costly problem of CMP. Some of the RCTs reviewed in this study revealed that one PNE session was enough to significantly reduce the number of follow-up visits for pain. Overall, there is a strong indication to support further research on PNE alone or in combination with other interventions to treat CMP [11].

11.2.8 Supplements

Many supplements have been claimed to reduce musculoskeletal pain by various means. A systematic review of dietary ingredients for chronic musculoskeletal pain mitigation released in 2019 conditionally recommended some additional intake of "Avocado soybean unsaponifiables, capsaicin, curcuma, ginger (as a food source), glucosamine, melatonin, polyunsaturated fatty acids, and vitamin D" as dietary benefits outweigh inherent risks [12]. Nevertheless, there is still uncertainty about the trade-offs and supplementation is only beneficial up to a certain dose, which should not be exceeded. Furthermore, although glucosamine has the approval of the above review due to its low risk of harm, the extent to which glucosamine and other supplements are beneficial for varying painful symptoms is still controversial. For example, guidelines from The American Academy of Orthopedic Surgeons strongly recommends against the use of glucosamine and chondroitin for patients with osteoarthritis of the knee as there is little evidence of its benefits, even though it may have minimal harmful risk [13].

A new controversial and very politically charged treatment that has been receiving more attention is cannabidiol (CBD). Specifically, CBD is the non-psychoactive component of cannabis. This product continues to gain more widespread popularity since it has been recently legalized in several states with governmental bills allowing for the manufacture and sale of hemp products. There have been many claims about the health benefits of CBD since its legalization, such as its usage/ability to treat epileptic seizures, substance abuse, insomnia, extreme pain, inflammation, anxiety, PTSD, cancer and even reduction in muscle recovery duration. Most of these claims are largely unsubstantiated; however, there has been research lending support to some. Despite the recent rise in popularity of CBD for the possible reduction of musculoskeletal pain and inflammation, while this is promising for many people, the idea to use CBD to treat pain is nothing new [14].

In January of 2006, the FDA approved an application request to study Sativex for the treatment of patients with intractable cancer pain [14]. Recent RCTs have shown that Sativex significantly reduces pain in patients with multiple sclerosis. It should be noted that Sativex is a combination of tetrahydrocannabinol (THC), the psychoactive component of cannabis, and CBD in an approximately one-to-one ratio [15]. An animal study of CBD topical treatment showed that it significantly reduced joint swelling and apparent joint pain [16]. This study used a limb-posture scoring system as an indicator of pain in animals. Hammel et al. concluded that "topical CBD application has the therapeutic potential for relief of arthritis pain-related behaviors and inflammation without evident side-effects." However, in humans, another concern with CBD use is the unregulated over the counter (OTC) form that is available almost anywhere. The OTC CBD is considered a supplement, so its production and distribution are wide yet not regulated by the FDA. It is available in the form of vape products, oils, oral drops, gummies, and topical cream. The effectiveness of CBD may largely depend on the application route, because CBD is hydrophobic, it has poor oral bioavailability. While the potential of CBD looks promising, much more research needs to be done before investigators can determine/confirm that it can be used safely to effectively treat musculoskeletal pain. It is also advised that caution be exercised for anyone who chooses to

use a CBD supplement in any form, since impurities/harmful additives may be present in the chemical compound [16].

Another set of controversial supplements used for musculoskeletal pain and recovery are antioxidants. In the 1990s, new knowledge about the damage caused by free radicals in the body led to the quick publicizing of health-benefiting antioxidants such as Vitamins E, C, A, and beta-carotene. Before any clinical trials had been completed, the beneficial effects of supplementation of these vitamins were marketed by many companies. With premature promises of reduced cancer rates, decreased heart disease, and faster recovery time after exercise, these unconfirmed benefits led to much hype around this class of dietetic supplementation. So, the idea came about that if these supplements help the body at normal levels, they should benefit even more at increased quantities, correct? However, upon further detailed evaluation, the evidence does not substantiate the initial expectations [17].

While the mechanism of these antioxidants does work well inside the body, positive beneficial effects typically are most effective at normal levels—quantities common in those people who consume a balanced, healthy diet. However, in excess, these nutrients may not lead to any extra benefits, and in some cases, may actually cause some adverse effects [17]. While initial impressions indicated that supplemental antioxidants could increase recovery duration after exercising by reducing the amount of oxidative stress on the muscle, evidence now exists that high doses of some antioxidants, especially C and E, can actually impair bodily tissues recovering from exercise. Overall, the effects of antioxidants are very conflicting, and patients should be advised about the possible adverse risks associated with these vitamins at high doses [17, 18].

There are certain cases in which the effects of supplements are scientifically proven, especially when the mechanism of the supplement is well known. For example, it has long been understood that Vitamin B9 (Folic acid) supplementation is important for pregnant women to take in order to decrease the likelihood of fetal neural tube defects [19]. It is also well established that iron and Vitamin B12 (Cobalamin) supplements, when taken with the correct dosage/regimen, can be beneficial in treating iron-deficiency anemia and pernicious anemia, respectively [20, 21]. Further study is needed for determining the specific scenarios in which different supplements can be beneficial to treat musculoskeletal pain in active females. Despite active research in this area, it is important to keep in mind that no single supplement will help substantially more than sustaining a healthy, well-balanced diet [17, 18].

11.2.9 Chiropractic Therapy

Chiropractic spinal manipulation, also called manual therapy, has been suggested to help with many ailments and is commonly used by chiropractors to treat back, neck, headache, shoulder, and pain involving other body parts. The mechanism behind spinal manipulation is thought to be either biomechanical or biophysiological in nature. Biomechanically, it may relieve pain and increase function simply by reducing internal mechanical stress. Neurophysiologically, it theoretically could relieve pain by blocking sensory (afferent) neurons from paraspinal tissues. There are numerous studies on the effectiveness of spinal manipulation for a variety of conditions, most of which have remained inconclusive to date [22].

From 4184 reports found in the initial search, a 2019 systematic review on the benefits and risks of "any hands-on treatment of the spine, including both mobilization and manipulation" on chronic low back pain looked at 47 RCTs in quantitative analysis and 41 trials of meta-analysis. The primary outcome measures were pain intensity and back pain-specific functional status. The study concluded that these outcomes were similar in short, intermediate, and long-term basis compared to more standard interventions including exercise, nonsteroidal anti-inflammatory drugs, and analgesics. Furthermore, this review concluded that spinal manipulation resulted in better short-term function than other nontraditional interventions such as light soft tissue massage, electrotherapies, or no treatment at all. As for potential risks of spinal manipulation, the same study reports that data are too limited on the incidence of adverse events for any conclusions to be drawn about the involved harms. The data associated with this review appear promising for spinal manipulation, but it is important to note that even the authors admit that "[spinal manipulation therapy] is not currently recommended as a first line treatment for chronic low back pain and its effects are uncertain." This is largely due to the significant limitations of RCTs themselves, including conflicts of interest, statistical heterogeneity, and a limited number of studies containing low risk of bias. A more standardized method throughout all RCTs would be more beneficial in order to obtain a better picture of the outcomes of spinal manipulation for back/spine issues or other locations of musculoskeletal pain [22].

While the evidence for the benefits of spinal manipulation in back pain has improved in recent years, there remains many completely unfounded claims associated with chiropractic "medicine" and spinal manipulation. Among this similar hype is the claim that spinal manipula-

tion decreases symptoms of dysmenorrhea in women. In a study analyzing RCTs for the effectiveness and safety of this treatment, the authors concluded that there is no evidence for either beneficial or adverse effects relative to "sham" manipulations [23].

Another form of manual therapy that is not currently recommended is mechanical traction, a type of chiropractic manipulation in which a pulling/tensile force is applied to the spine or other joints via a mechanical system (ropes, pulleys, etc.) to purportedly relieve pressure and decrease musculoskeletal pain. This process uses/acts through continuous or intermittent traction mechanism. Continuous traction is applied for several hours at a time using smaller weights, while intermittent mechanical traction alternates between applying heavily weighted apparatus on then off-relaxation for a few minutes at a time. A systematic review revealed that there is inconclusive evidence for the benefits of either intermittent or continuous traction; however, the authors also concluded that intermittent traction is favored to continuous traction if one is to be used [24]. On the other hand, a more recent systematic review by Graham and colleagues showed findings remained inconclusive for the effectiveness of continuous or intermittent traction for "pain reduction, improved function or global perceived effect when compared to placebo traction, tablet or heat" in patients with chronic neck disorders [25].

Current guidelines from The American Academy of Orthopedic Surgeons show no indication for the usage of chiropractic therapy in clinical medicine. This governing body is unable to recommend for or against the use of manual manipulation due to the paucity/low quality available evidence. As mentioned previously, it is important that more standardized methods are used upon performing RCTs in order to better establish the utilization of chiropractic therapies [13].

11.2.10 Acupuncture/Trigger Point Dry Needling

Despite a long history of research on the efficacy/effectiveness of acupuncture to treat musculoskeletal pain, many systematic reviews of the effectiveness of this type of minimally invasive procedure have been inconclusive for a variety of reasons. This is mainly due to recurring methodological flaws inherent with RCTs, such as difficulty in identifying a proper or formal dosage or consistent acupuncture points for clinical practice—these factors are often locally passed down or determined by means of anecdotal clinical experience and therefore often lack uniformity throughout RCTs [26, 27]. Although systematic reviews have commonly led to inconclusive findings in this area, some researchers do report statistically significant results in specific forms of acupuncture [28] (Fig. 11.2).

Fig. 11.2 A patient being treated with acupuncture moxibustion in Nelson, New Zealand by Charlotte Stuart MAc RN by Wonderlane is licensed under CC BY 2.0. Photo by Jaap Buijs

For example, a systematic review/meta-analysis comprising 218 articles (narrowed down to 13 by selection criteria) showed that over a 12-week follow-up period, dry needling by physical therapists "may decrease pain and increase pain threshold" relative to a placebo control or no treatment. However, no significant effect was found at 6–12 months follow-up, and the study concluded that "evidence of long-term benefit of dry needling is currently lacking" [28].

Laser acupuncture is a more recently developed form of acupuncture, defined as "the stimulation of traditional acupuncture points with low-intensity, nonthermal laser irradiation." This newer relatively noninvasive method has shown more promise than other forms in available RCTs. This form of thermal acupuncture is less painful and does not require needles and has two main benefits. First, it is more friendly to those who have a fear of needles, and second, it allows for an easier (and likely more accurate) placebo treatment for RCTs. According to the 2015 Systematic Review with meta-analysis mentioned above, 31/49 of the RCTs reported proper dosage reporting and statistically significant results. These effects are important in long-term follow-up but not in the short term or time immediately after treatment. While these positive results are encouraging, the mechanism of action for pain relief is largely unknown, and this modality also differs from other forms of acupuncture [29].

Although some forms of acupuncture have shown potential toward pain relief to varying degrees, a majority of research on the effectiveness of acupuncture for the reduction of musculoskeletal symptoms or improvement of function has been inconclusive. Additionally, the data for this topic are limited similarly to chiropractic therapies—mainly by the lack of standardization and quality of RCTs. Current guidelines from The American Academy of Orthopedic Surgeons (AAOS) state that no indication exists for the use of acupuncture in clinical medicine; also, specifically has a strong recommendation against the use of acupuncture in patients with symptomatic osteoarthritis of the knee [13].

11.2.11 Dynamic Compression

Over the last decade, peristaltic pulse dynamic compression (PPDC), also known as sequential intermittent pneumatic compression (SIPC), is a recovery mechanism that has become popular among athletes. It is typically performed by putting on inflatable foot-to-hip stockings/boots that apply rhythmic "circumferential pressure to a limb in a peristaltic manner in a distal to proximal direction" for about 15 min [30]. Preliminary case studies have shown a possible short-term increase in flexibility and pressure-to-pain thresholds in elite athletes. However, these case studies have significant bias with poor blinding and small sample size [30, 31]. There is very limited literature on the effectiveness or safety of this technique, which is likely why it is not mentioned in guidelines from the American Academy of Orthopaedic Surgeons, American College of Sports Medicine, or American College of Physicians. Further studies need to be performed about this method of treatment, so in the meantime it is recommended that patients consult with their physician before trying out these devices [30, 31].

11.2.12 Transcutaneous Electrical Nerve Stimulation (TENS)

Treatment of musculoskeletal pain with Transcutaneous Electrical Nerve Stimulation (TENS) has become widespread as an accepted modality over time. This tissue stimulation modality is thought to work by delivering either high- or low-frequency electrical current to stimulate large AB fibers responsible for touch sensation. This will activate the analgesic response at the spinal cord level, thereby inhibiting ascending painful signals [32]. However, there is no scientific research proving that TENS can be used to significantly reduce musculoskeletal pain [32, 33]. It was noted that "TENS was no more effective for reducing pain than placebo in chronic back pain, neck pain, shoulder pain, knee and chronic musculoskeletal pain" [33]. A study that compared TENS and diadynamic (DD) showed that neither TENS nor DD was effective for reducing painful sensations. One small study did show that TENS could reduce exercise-induced pain [34]. In another journal review, more studies were cited showing improvement in managing primarily acute pain. These researchers found that there was more benefit shown in the short-term treatment of acute injuries over physical therapy alone. Size of the studies and lack of corroborating research raise questions about the validity of these results showing TENS as an effective treatment modality for pain. It would seem that any benefit that patients do experience from using TENS may be from the placebo effect; however, this has not yet been proven. Larger scientific studies are needed to determine whether or not the beneficial effect from TENS stems from more than just placebo [35].

11.2.13 Kinesio Taping

Kinesio taping has been around since the 1970s with increasing popularity in recent years. Kinesio tape is thinner and more elastic than normal tape, which should allow for more movement after application. Kinesio tape is applied to the target muscle in the stretched position creating tension along the epidermis. This tension then stretches the skin to reduce pressure on the mechanoreceptors below the dermis, causing a reduction in nociceptive stimuli. A review of 12 studies over Kinesio taping revealed that overall there is no significant benefit. Most studies showed that the test group did not experience any more beneficial effects than the control group, regardless of whether the control was no intervention or placebo taping [36]. The few studies that showed some improvement from Kinesio taping had a small test group and were considered low-quality research [37]. The authors of this review concluded that current evidence does not support the use of Kinesio taping for musculoskeletal pain; however, this is based on underpowered studies. The same researchers are now working on their own large randomized clinical trial to determine the effectiveness of Kinesio taping, if any, actually exists [36].

11.2.14 Cupping

Cupping is an old but recently trending practice that typically includes the skin being suctioned into a small, heated glass cup, resulting in a circular bruise due to breaking of underlying capillaries. This is typical of "dry cupping" or "fire cupping," but there are many other forms of this particular modality. For example, "wet cupping" includes the use of a scalpel to cut the skin so that blood is drawn during the suction. The appeal to cupping is largely due to its long history as a healing method used in Ancient Egypt, China, and Greece. Additionally, Michael Phelps and Alex Naddour aided in the recent popularity of dry cupping by showing up to the 2016 Rio Olympic Games with cupping bruises on their bodies. Proponents of cupping claim that it helps to stimulate blood flow, while skeptics of this mechanism argue that the breaking of capillaries and resulting bruising might decrease blood flow, as clotting cascades are a necessary part of the healing process. But what does the evidence say [27]? (Fig. 11.3).

Despite its long history, there is very little quality data on the benefits or safety of cupping. A 2017 systematic review of cupping and acupuncture showed some evidence of benefits of both methods, but none of the papers included in the

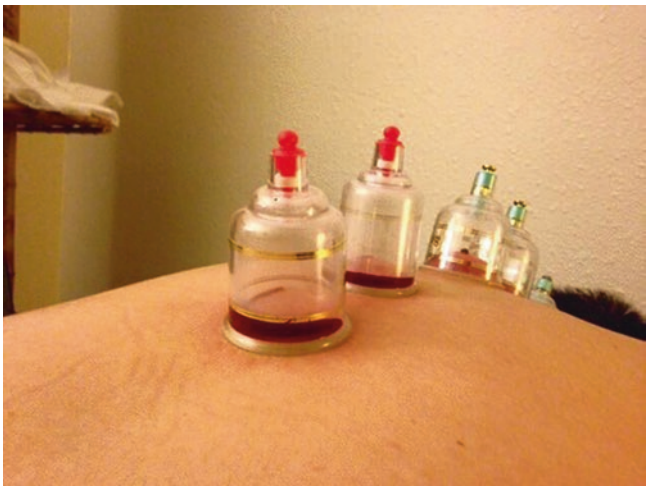

Fig. 11.3 Cupping: Pictured is a man receives cupping therapy to his back. "Acupuncture" by SupportPDX is licensed with CC BY 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/2.0/

review were considered RCTs, and all articles had significant bias [27]. A more scrutinizing 2019 systematic review of manual therapy techniques, dry cupping, and dry needling in reducing myofascial pain resulted in only 2 adequate RCTs for dry cupping. The small amount of evidence currently exists does not show that benefits of dry cupping being anything more than merely a placebo effect. On the other hand, it is important to remember that placebo effects can be strong and misleading especially among elite athletes, who often cling to superstitious or trendy practices hoping that it will give them an edge/psychological advantage against other competitors [38] (Fig. 11.4).

11.2.15 Homeopathy

Homeopathy is a form of alternative treatment claimed by some to stimulate the body's natural healing processes while using natural substances that have been highly diluted. Homeopathy was started in 1796 by Samuel Hahnemann and has continued per tradition rather than backed by any scientific evidence. Based on the idea "*similia similibus curentur*" ("like cures like"), homeopaths treat their patients with remedies made up of very diluted substances that, in a normal dose, would normally cause a healthy person to have the same symptoms. Very limited data exist on the benefits of homeopathy and the available studies have had significant bias, including lack of randomization or blinded controls. Furthermore, this form of treatment has the potential to cause harm since treating a poison or allergen with the same (although usually diluted) substance/chemical is likely to worsen such symptoms. A systematic review conducted in 2012, including 38 reports, provided evidence of 1159 people that had suffered adverse effects as a result of homeopathy, four of whom ended up dead! The most frequent negative side effect was an allergic reaction or intoxication, and the most commonly used remedy was Rhus Toxicodendron: a dilution of poison ivy. As such, it is strongly recommended to stay away from using homeopathy as a mode of treatment for musculoskeletal pain or other symptoms [39].

Fig. 11.4 Homeopathy: Natural ingredients are often ground in a mortar and pestle, as pictured, before dilution to be used for homeopathy treatments. "Grinding Lemon Myrtle" by jamieanne is licensed under CC BY-ND 2.0

11.3 Future Directions and Concluding Remarks

In summary, tier 1 modality has sufficient evidence to indicate that they can reduce musculoskeletal pain when used appropriately. Among the pain management modalities discussed in this chapter, these are the options that will likely lead to the best clinical outcomes when used as directed. However, further research would be useful in identifying proper doses and the components of the controversial and poorly understood specificities of certain treatment methods. Secondly, it is not recommended that health professionals encourage the usage of tier 2 modalities, since the studies of

these methods are heavily biased and inconclusive when held to the required scientific standard. Thirdly, without more evidence for the benefits of tier 3 modalities to treat musculoskeletal pain, these remain nonviable options as well. Lastly, careful consideration is encouraged before implementing homeopathic medicine based on its potential harms, poorly understood mechanism, and lack of evidence for reducing painful musculoskeletal conditions. It should be noted that all the treatment modalities discussed in this chapter were assessed specifically for their benefits in treating musculoskeletal pain and not for any other condition. Some of the treatments may be more beneficial for other health concerns that were not within the scope of this chapter. Due to the differences in gender-specific musculoskeletal systems, more gender-specific studies should be conducted in the future to further define indications/outcome of alternative treatments for musculoskeletal pain.

Chapter Review Questions

1. A 50-year-old female patient has had continued knee pain 6 months after a knee injury despite diagnostics and exams indicating that the injury has healed. She mentions that she is afraid to do much physical activity due to the pain. Based on the information in the chapter, what would be her best treatment options?
   (a) Prescribe the patient an opioid for the pain so she can resume her daily activities
   (b) Encourage her to try alternatives such as CBD and to start taking water aerobics
   (c) Discuss with her that pain may not always indicate the body is damaged then refer her to an exercise therapist
   (d) Inform the patient she should apply heat three times a day, start taking glucosamine and use KT tape before physical activity
2. What is a major obstacle for conducting quality randomized controlled trials for many alternative treatment modalities?
   (a) No one wants to participate in treatments that could possibly harm them
   (b) There is not enough funding to conduct the trials
   (c) It is difficult to blind patients to many of the treatments
   (d) There are no obstacles
3. On a return checkup to clinic, a 22-year-old female patient with chronic low back pain asks about homeopathy and chiropractic spinal manipulation. What do you tell her?
   (a) If the pain has not gone away with normal treatment, the patient might as well try homeopathy or chiropractic spinal manipulation because she has nothing to lose
   (b) Homeopathic medicine will not do any harm but chiropractic medicine has been known to cause dissected vertebral arteries so the patient should pursue homeopathic medicine
   (c) It would be foolish to try either of these treatments because neither has any evidence supporting its benefits
   (d) Some evidence has supported the use of spinal manipulation (but not homeopathy) for reducing back pain intensity, but both types of treatment have significant risk for adverse effects
4. Two college co-eds present to the emergency room after a collision during an intramural flag football game. The male is complaining of right knee pain, and the female has left knee pain, both rate the pain as a 7/10. Both test positive for anterior drawer and negative for posterior drawer and McMurray's. Without seeing X-rays or MRI results which patients would you suspect is more likely to have a torn ACL?
   (a) The male, due to their stronger muscles, males are more likely to rupture ligaments
   (b) The female, because of the biomechanics of their knee, females are more likely to tear their ACL
   (c) The male, because he probably had a previous knee injury in high school
   (d) The female, because females have inherently weaker tendons and ligaments
5. A high school athlete comes into your clinic with a sore shoulder and explains that she saw an Olympic runner training with Kinesio tape. The patient then asks you to treat her with Kinesio tape. How do you respond?
   (a) Kinesio taping has been shown to be effective for muscle aches, so do as the patient asks
   (b) Explain that although elite athletes can be great role models, they also tend to use treatments that are heavily based on placebo rather than evidence
   (c) Ask a nurse to wrap the patient using whatever tape is available because the effects are in the patient's head
   (d) Tell her that only fools believe Kinesio taping works better than placebo and she should never mention it again

Answers

1. c
2. c
3. d
4. b
5. b

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Part III

Screening, Prevention, and Management of Health-Related Issues/Injuries in Active Females

12 Screening for Eating Disorders, Dysfunctional Exercise, and Menstrual Dysfunction in Female Athletes

Maria Fernandez-del-Valle, Danika A. Quesnel, Jennifer J. Mitchell, and Jacalyn J. Robert-McComb

Learning Objectives

Upon completion of reading this chapter, the reader will be able to:

- Become aware of the estimated prevalence of disordered eating (DE) and eating disorders (ED) in female athletes
- Understand reasons for and methods of screening for disordered eating and eating disorders in the female athlete in both informal and formal settings
- Understand reasons for and methods of screening for disordered eating and eating disorders in the female athlete in both informal and formal settings
- Become aware of screening tools that are utilized for disordered eating and eating disorders, in general, and specifically, in athletes
- Become aware of the estimated prevalence of dysfunctional exercise (DysEx) in female athletes
- Understand the different components of DysEx: Quantitative and Qualitative
- Become aware of the limitations associated with the "diagnosis" and assessment of DysEx
- Understand the methods for DysEx screening in the female athlete
- Understand the importance of screening for menstrual dysfunction in the active female
- Be able to list groups of athletes in whom screening for menstrual dysfunction is essential
- Have a resource of potential screening questions for menstrual dysfunction
- Understand the relationship of functional hypothalamic amenorrhea (FHA) with menstrual dysfunction
- Understand the relationship of low energy availability (EA) and FHA causing menstrual dysfunction and the need to improve overall EA as the first step in management

12.1 Introduction

Throughout the lifetime of a female athlete, many health concerns may arise. A few pertinent ones include disordered eating, eating disorders, dysfunctional exercise, and menstrual dysfunction. There are a number of ways to screen for these conditions in order to review risks with athletes and develop management plans.

Disordered eating (DE) may occur as a sole entity or associated with eating disorder-type behavior. Some athletes are unaware of their disordered eating, which may occur in the form of inadequate fueling after exertion, creating low energy availability. Other forms of disordered eating) may include restrictive eating, skipping meals, overexercising, and laxative abuse [1].

Eating disorders (ED) are diagnosed as mental health illnesses, meeting defined criteria per DSM-V, characterized by pathologic eating behaviors which adversely impact health [2, 3]. ED impacts female athletes more regularly than males, but recent results indicate the window between the two is becoming smaller. With that, the risk of ED in the general population compared to athletes is also narrowing [4]. There is no clearly defined standard for the methods or

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timing of screening female athletes for DE or ED. Several screening tools are available, but no consensus exists yet, concerning the optimal tool with athletes. Various opportunities present themselves for screening athletes for (DE/ED), but no single time has proven most advantageous. Screening may be performed in various ways, but it is optimal to gather as many objective pieces of evidence as possible, since denial by the athlete is often a large component of DE/ED. Ultimately, ideal screening is specific to each athletic level and entity, whether recreational or competitive. This chapter covers various methods and timing options for the most effective screening of female athletes for DE/ED.

Relative to DE/ED, the phenomenon of dysfunctional exercise (DysEx) can be a paradox with regard to healthful activity engagement. Physical activity and exercise are considered by scientists as a critical tool to prevent chronic physiological and psychological pathologies [5–8]. Maintaining adequate physical activity levels has positive effects on physical and mental health [9]. However, exercise, as many other behaviors, can become dysfunctional. Thus, this chapter also covers ways to recognize, screen, and manage dysfunctional exercise in female athletes.

In light of the relationship between DE/ED and DysEx, menstrual dysfunction cannot be ignored and deserves attention. Menstrual dysfunction is a condition that can appear in the female athlete's lifetime as a result of energy imbalance (either intentional or unintentional) and/or decreased energy availability. However, screening for menstrual disorders in athletes is more complicated than it might seem. Historically, the simple question was, do you have normal menstrual cycles or periods? If yes, then that was the end of the screening questionnaire. If no, the athlete was referred to the physician. With improved understanding of the female athlete triad and the components involved, screening has become more complex. In addition to menstrual status, those responsible for the health of the female athlete must also evaluate the other two components of the triad; bone health and optimal energy availability, or whether indications of DE/ED exist. Evaluation of one component of the female athlete triad should not occur in isolation from the other two components.

12.2 Definitions

12.2.1 Eating Disorders

Eating disorders, and disordered eating are similar phenomenon, but distinctly different. In athletes, DE encompasses various abnormal eating behaviors that can be inadvertent, such as inadequate refueling or they may be intentional. An ED is a clinical mental disorder, meeting diagnostic criteria as defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-V); specifically, Anorexia nervosa, Bulimia nervosa, binge-eating disorder, and other specific feeding and eating Disorders. DE is defined as having disordered attitudes or behaviors toward food and eating (body dissatisfaction, shape and weight concerns, self-induced vomiting, dieting, and skipping meals). However, these behaviors do not amount to an ED diagnosis as per the DSM-V diagnostic criteria [10].

12.2.2 Dysfunctional Exercise

More than 30 terms have been adopted by researchers and clinicians to try to describe problematic or DysEx in mental health disorders [11]. Historically, the concept of addiction has been associated with the qualities and subsequent terminology related to DysEx [12–18]. However, most of the research has focused solely on populations having both DysEx and mental disorders. Therefore, insufficient research exists regarding DysEx in the general and physically active populations (recreational, amateur, or high-performance athletes). The most common terms found in the literature are exercise "addiction" [14], "dependence" [18], "abuse" [19], "obligatory" [20], "compulsive" [21], "morbid," and "driven" [22] exercise or excessive exercise [13]. As a result of the multitude of proposed terms, "dysfunctional exercise" will be used to encompass each term. This lack of consistency has limited our body understanding of negative versus positive exercise behavior and its role in the development of LEA (low energy availability), DE or ED, and poor bone health [23].

It was not until 2015, when Rizk et al. attempted to analyze the different components, quantitative and qualitative, of DysEx behaviors, that we gained a distinctive understanding of the concept [23]. The quantitative component involves factors such as time, duration, intensity, or volume and can be defined as the amount of programmed exercise performed beyond the physical healthy limits; previously known as "Excessive Exercise." The qualitative component of DysEx relates to mental health features such as compulsion, rigidity, and obsessiveness. Core features determining the quality of the exerciser's relationship with exercise can be to control weight or shape [23] or due to features of addiction. Ultimately, the quality of the relationship is negative, thus creating both mental and physical distress [24].

Coverley Veale et al. proposed a classification for DysEx depending on the role of the exercise [25]: primary and secondary DysEx. Primary DysEx is the exercise that is an end in itself (i.e., exercise is the objective); hence, practitioners are intrinsically motivated to exercise. Secondary DysEx co-occurs with an ED or other compulsive disorders, where individuals are extrinsically motivated to exercise according to their self-image [i.e., weight loss is the objective] (Table 12.1). According to this classification, it is important

Table 12.1 Primary and secondary dysfunctional exercise symptoms [25–27]

Primary dysfunctional exercise	Secondary dysfunctional exercise
Preoccupation with exercise routine	
Significant withdrawal symptoms if exercise ceases Relief of withdrawal symptoms if exercise is resumed	
Increased tolerance to exercise	
Significant distress or impairment in other areas of daily living resulting from engagement in exercise	
Exercise used to cope with emotions	
Secret or hidden exercise	
Exercise continues despite injuries or physical pain	
Preoccupation with exercise **cannot** be explained due to co-occurring with another mental disorder	Preoccupation with exercise **can** be explained due to co-occurring with another mental disorder
	Exercise as permission to eat

to determine whether DysEx is primarily affecting the practitioner's life or whether it emerges as a derived problem from another psychological disorder [25, 26].

12.2.3 Menstrual Dysfunction

Terms used when discussing menstrual screening include the following: primary amenorrhea, secondary amenorrhea, and functional hypothalamic amenorrhea (FHA). Although these terms have been described in previous chapters, a brief review provides a fuller understanding regarding screening and management recommendations. Amenorrhea is the absence of menstruation or a woman's monthly period.

- Primary amenorrhea occurs when a female has not yet started her monthly periods by age 15 but has gone through other normal changes that occur during puberty.
- Secondary amenorrhea occurs when a woman who has been having normal menstrual cycles stops having her periods for 6 or more months (some sources state 3 months, although 6 months is more common). Note, however, this does not apply to women who are pregnant, breastfeeding, or in menopause.
- Functional hypothalamic amenorrhea (FHA) is a reversible form of gonadotropin-releasing hormone (GnRH) deficiency, commonly triggered by stressors, such as excessive exercise, nutritional deficits, DE/ED, or psychological distress.

The Office on Women's Health, Department of Health and Human Services suggests the physical and behavioral/emotional characteristics to detect eating disorders should be examined during the routine screening of adolescent and preadolescent patients by their primary care provider for the detection of issues related to the female athlete triad.

There is not yet an agreed upon optimal timing or method of screening for female athlete triad disorders. An energy deficit in a female athlete may cause a spectrum of menstrual dysfunction, either subtle or obvious, which may then have an impact on bone health. This leads to the realization that a comprehensive menstrual history may be needed in all athletes.

12.3 Research Findings in Disordered Eating/Eating Disorders, Dysfunctional Exercise, and Menstrual Dysfunction

The American College of Sports Medicine Position Stand on the Female Athlete Triad describes the interrelationships among energy availability, menstrual function, and bone mineral density. As these three entities are interwoven, an alteration in one can impact the others. Energy availability is the amount of energy remaining once exercise energy expenditure (EEE) is subtracted from energy intake (EI): (EA = EI-EEE). DysEx is a component of EEE and thus can impact EA which then can impair menstrual function and ultimately bone density. These are complicated relationships, but each entity is distinctly different, and in athletes, abnormalities can present alone or in combination. The longer these disorders go untreated, the greater the long-term consequences [28]. Thus, prevention and early detection of female athlete triad disorders are of utmost importance for the health of young female athletes [29, 30]. The following section will review the prevalence, current research, and screening procedures for each DE/ED, DysEx, and menstrual dysfunction.

12.3.1 Prevalence

12.3.1.1 Prevalence of Disordered Eating/Eating Disorders in Active Females

It is difficult to know the exact prevalence of DE/ED in female athletes as the majority of studies have various methodological flaws including the use of nonstandard diagnostic procedures, small sample sizes, lack of or inadequate control group(s), inadequate statistics, and/or heterogeneous athlete population [31, 32].

There have only been two, well-controlled studies utilizing DSM-IV criteria for diagnosis of EDs. These were conducted with elite athletes and demonstrated 31% prevalence in athletes compared to 5.5% in the control population for the first study and 25 versus 9% in the second study. Other studies have shown secondary amenorrhea to be as high as 69% in dancers and 65% in long distance runners versus 2–5% in the general population [31].

The first study to look at the combined prevalence of DE, menstrual dysfunction, and low bone mineral density in college females demonstrated that the number of athletes suffering from all three disorders of the triad was small (1–3 athletes out of 112). However, a significant number suffer from the individual disorders of the female athlete triad [3].

A more recent systematic review of 65 studies evaluating the prevalence of the individual and combined components of the triad verified that initial study. It showed a relatively small percentage of athletes (0–15.9%) exhibited all three components of the triad. The prevalence of any two triad conditions ranged from 2.7 to 27%. The prevalence of any one condition was the highest, from 16 to 60%. The recommendation from that review is that additional research on the prevalence of the triad using objective and/or self-report/field measures is necessary to more accurately describe the extent of the problem [28].

12.3.1.2 Prevalence of Dysfunctional Exercise in Active Females

The prevalence of DysEx, more specifically the addiction feature, is variable and uncertain due to the lack of comparable methodology in research of clinical cases, i.e., heterogeneity of the instruments used to assess addiction (qualitative component), insufficient sample size, and heterogeneity of the population studied. The most recent observational data available suggest a prevalence of 0.3–0.5% of the general population and 1.9–3.2% of individuals who are regular exercisers [26]. In this sense, Lejoyeux and colleagues analyzed exercise behaviors on 300 practitioners from a fitness room [18 years and older]. A total of 125 (42%) presented risk factors of primary DysEx. These participants spent more hours (h) each day in the fitness center compared with participants who had no risk [2.1 h/day vs. 1.5 h/day], and they went more often each week [3.5 vs. 2.9 days/week]. Moreover, those that presented addictive features smoked less and were significantly more compulsive buyers (63% vs. 38%) [33].

Prevalence of secondary DysEx is much higher. Typically, although not exclusively, DysEx is secondary to an ED. DysEx in those with EDs ranges from about 26.8–80% of clients [21]. In one study of 366 participants, researchers found that DysEx rates were 45.5% among 165 inpatients and 26.8% in 355 outpatients. The large range in prevalence rates can be a result of the presence of exercise dependence within each type of ED, with anorexia nervosa restrictive or purging subtype presenting with DysEx most commonly and eating and disorders not otherwise specified the least common.

12.3.1.3 Prevalence of Menstrual Dysfunctional in Female Athletes

In athletes, amenorrhea is much more common than in non-exercising controls with prevalence reported from 3 to 69% compared to 2–5% in the general population [3, 30, 34]. Prevalence is typically an estimate as it is difficult to gain accuracy due to inconsistencies in studies, including various definitions of amenorrhea, selection bias, underreporting, lack of education on what is normal versus abnormal, various competition levels, sports disciplines with varied intensity, and frequency of training [30, 35]. Despite this, research has shown that in adolescents, the current prevalence of the female athlete triad is 0–1.2% of athletes. When two factors of the triad are present, the prevalence of the triad is between 2.7 and 27% [28, 36].

12.3.2 Current Research in Disorder Eating/Eating Disorders, Dysfunctional Exercise, and Menstrual Dysfunction: Screening Tools

When choosing an appropriate screening tool, things to consider include the specificity of the tool, the feasibility of using one tool or another, and strengths and weaknesses of the instruments for measuring each of the components (DE/ED, DysEx, and menstrual dysfunction). Further considerations for choosing an appropriate screening tool include the following:

- *Applicability*: It should be easy to apply and interpret.
- *Validity*: The instrument should be capable of measuring what it was created for. Those instruments that have not been validated might not be the best. Those whose validation analysis is inconclusive should be avoided.
- *Reliability*: If used for clinical practice, it is important that the instrument is reliable (precise) when measuring the same subject (intra-subject). In the case, if it is used for research, it is important to have both precision (intra-subject) and accuracy (inter-subject), so the changes detected are attributable to the intervention or the situation tested and not to the lack of reliability of the instrument.
- *Cost–benefits*: For example, the sample size could reduce or increase the chance of using one or another instrument.
- *Objectivity*: The most objective instrument has to be used. For example, if physical activity levels are assessed and both accelerometers and questionnaires are available, the most objective instrument will be the accelerometer.
- *Reactivity*: Be aware that participants tend to change behaviors when being evaluated. Some instruments may be more sensitive to reactivity than others.

12.3.2.1 Current Research in Disorder Eating/Eating Disorders

There are multiple risk factors, which predispose an athlete to DE or ED. This list includes four major groups of factors as shown in Table 12.2.

Table 12.2 Risk factors for disordered eating/eating disorders [37, 38]

I. Non-sport-related factors	II. Sport-specific factors
A. Biological factors	A. Sports that emphasize
1. Pubertal status	1. Appearance
2. Pubertal timing	2. Thin body build
3. Body mass index	3. Low body weight
B. Psychosocial factors	B. Sports that require weight classifications
1. Body image dissatisfaction	C. Early sport-specific training
2. Mood disorders	
3. Low self-esteem	
4. Perfectionism	
5. Family dysfunction	
C. Sociocultural factors	
1. Perceived pressure to conform to an unrealistic standard of thinness	

Further evaluation of the sport-specific factors seems warranted given conflicting data. A review from 2001 [32] and a 2004 study [39] indicate that EDs are more likely to occur in athletes in aesthetic or leanness sports such as gymnastics, cross-country, and figure skating compared with athletes in non-leanness sports and controls. This was again verified in 2008 by Torstveit, Rosenvinge, and Sundgot-Borgen in a study with 186 athletes compared to 145 controls. EDs were more common in athletes in leanness sports (46.7%) compared to non-leanness sports (19.8%) and controls (21.4%) [29].

However, Beals provides evidence to question the long-held belief that EDs are more common in athletes in leanness sports in the small study of 112 athletes. She specifically notes that the percentages of individuals with DE and bone mineral density disorders, individually or in combination, were similar between lean build and non-lean build sports. The implication from this is that all female athletes, regardless of sport, should be screened for components of the female athlete triad and intervention should begin early to prevent development of the full triad [40, 41]. In any event, avoiding external pressure on the athlete to lose weight is essential to avert preoccupation with dieting, as it is considered to be the number one trigger for EDs [30, 31].

Screening for Disordered Eating/Eating Disorders and Pre-Participation Examinations

Screening recommendations for the female athlete triad or its components are based mostly on consensus, usual practice, or opinion. The most common times recommended are during pre-participation physical examinations (PPEs), during routine health visits, or if an athlete presents with a component of the triad [1, 30, 31, 42].

Screening can not only occur at a common entry point to athletic participation such as during pre-participation physical examinations (PPEs), but should also be an ongoing process throughout the span of an athlete's participation. This ongoing process is particularly applicable to recreational athletes who participate in exercise clubs, individual activities, and "weekend warrior" activities. The screening process should be viewed as a two-step process [43, 44]. Once an athlete screens positively or if a concern exists, the athlete should be referred for further medical and psychological or psychiatric evaluation.

The main benefit of screening during PPEs is that medical personnel are able to quickly review the responses to the tool utilized, and potentially, they can immediately refer the athlete who screens positively. All new athletes are required to have a PPE, so all would at least be screened in this format. The disadvantage of screenings during PPEs is that they often occur in a station-centered setting, such as in an athletic training room. This provides minimal privacy and confidentiality in completion of questionnaires and in further discussions with the individual athlete. Although, in order to enhance confidentiality and improve efficiency, some universities are shifting to having athletes complete health histories either before arrival on campus or on web-based sites [40]. As technology and the patient-centered medical home (PCMH) advance, a web-based data center in an electronic health record may become the standard. The PCMH promotes organizing care around patients, working in teams, and coordinating and tracking care over time [45].

Another negative aspect of screening at PPEs is that there are typically multiple other forms to complete. The athlete may then rush through the DE/ED screening tool, not taking the time to answer accurately [34, 46]. Female athletes often feel uncomfortable discussing ED during PPEs and are more likely to withhold information [46]. This is another reason why screening females with a supplemental form within the first few weeks of arrival on campus may be a better method.

An additional concern arises in settings where PPEs are only required at entry and not yearly. In a study of the National Collegiate Athletic Association (NCAA) Division I universities, of the 257 (74%) schools that participated, only 32% require an annual PPE. In this case, if the athlete develops risk factors for DE/ED after her freshman year PPE, it may go undetected until a significant health event occurs, if at all [34].

When any of the informal signs and symptoms of DE/ED found at Table 12.3 are noticed among female athletes, areas of discussion that could be explored include: (1) eating behaviors such as binging, purging, eating in secret, recurrent dieting; (2) a history of or current mood disorder to include sadness, depression, or anger; and (3) the use of extreme weight control measure to manage weight or shape including starvation, diuretics, laxative, or saunas [30, 31, 47, 48].

Table 12.3 Informal signs and symptoms of disordered eating/eating disorders in athletes [30, 31, 47, 48])

Physical symptoms
Poor exercise tolerance including dehydration, cramping, pre-syncope, and bradycardia
Gastrointestinal upset, including bloating, diarrhea, or constipation, and abdominal discomfort
Hair, skin, or teeth changes including lanugo, alopecia, dry skin, callouses on hands and/or loss of tooth enamel from self-induced vomiting
Complaints of menstrual irregularities

Reasons to Screen for Disordered Eating or Eating Disorders and Screening Practices

Screening helps to identify athletes who may be having issues with eating pathology or low energy availability who require further assessment. Screening can be a complex and challenging task, but the sports medicine team must keep in mind the reasons why screening is important. These include [30, 31, 46]:

- Prevention of DE/ED; the most effective way to decrease the incidence of ED is to prevent them.
- Early intervention when DE/ED exists to minimize impacts on health and performance; the longer an ED is allowed to persist and progress without treatment, the greater the health and performance detriments.
- Athletes tend to deny or do not realize a problem exists.
- Athletes are unlikely to come forward on their own, so complications from low energy availability can go unrecognized until a major event such as a stress fracture occurs. There are several reasons why the athlete may not come forward including guilt, shame, fear of losing a scholarship, or fear of losing playing time [30].

With no clearly defined standard for screening athletes for DE/ED, practices fall across a wide spectrum that includes: no specific screening, a few general questions at the time of PPE, utilization of a self-report questionnaire screening tool (SRQST) at PPEs, or the use of a SRQST combined with an interview by a trained mental health provider.

A 2012 study evaluated PPE forms utilized at 257/347 NCAA Division I universities for efficacy in screening for the female athlete triad. It compared those forms to the 12 items recommended by the Female Athlete Triad Coalition for screening females for the triad [49]. Only 25 universities (9%) had nine or more of the 12 recommended items on their forms [34]. Another study has shown that only 60% of Division I schools, which responded to the study, screened for ED during PPEs. Of those that did screen, <6% used a standardized SRQST [3].

Because the goal of the PPE is to facilitate optimal performance for athletes while ensuring the best possible health for the athlete both today and in her future, it has been suggested to implement a separate supplemental health questionnaire specific to female athletes. It is felt that this method would allow health care providers to narrow in on female-specific issues. It might be implemented before, during, or shortly after PPEs on campus [50].

Table 12.4 Athletic personal and barriers to recognition

Personnel working with athletes	Potential barrier to recognition
Coaches	• Lack of knowledge, experience, or resources to address the problem • May not want to interfere with an athlete successfully training and performing, despite concerns about DE/ED • Fear of being accused of creating or contributing to the DE/ED behaviors
Teammates	• Fear of breaking the trust of a team member • May self-reflect upon her own DE, creating irrational fears that identifying a teammate's issue will expose her
Family/Parents	• Desire to see child succeed regardless of the consequences • Feel unsure how to approach disordered eating behaviors
Administrators	• May feel they lack knowledge, experience, or resources to address the problem • May fear feelings of inadequacy or challenges from others for not having been proactive in previously establishing resources or policies

Note: ED Eating disorder; DE Disordered eating; DE/ED Eating disorder/Disordered eating

An interesting innovation in screening female athletes for DE/ED is the physiologic screening test consisting of 18 items (4 measurements and 14 questions). It has been validated and has the potential to be combined with one of the athlete-specific questionnaires (see Table 12.4) to create a two-step screening process in an attempt to minimize false positives and false negatives prior to psychological referral [41].

Functionality of Screening Tools for Disordered Eating or Eating Disorders

What makes a screening tool useful is functionality as well as validity. SRQSTs seem more functional than interviewer applied tools. However, they are subject to report bias, as athletes tend to be not as forthright with these as in a one-on-one interview [3, 51]. The interview tools are more appropriate for an in-depth evaluation, in search of a specific diagnosis, but they are time intensive and require education on the part of the interviewer. They are most useful as the second step in evaluation, once an initial screening tool is positive or when there is reason to suspect DE/ED in an athlete [52].

In the athletic arena, time is frequently an issue. It is essential for a screening tool to be focused and time limited. Formal screening tools are ideally brief, self-report questionnaires with simple cut-off scores that indicate a level of dysfunction concerning for pathology in the athlete [51].

One must be assured that the tool utilized, when interpreted as positive, truly indicates an issue for which further evaluation and time requirements will be needed. Once a screening tool is positive, the athlete should then have a more formal evaluation to determine whether true pathology exists or risk factors for pathology are present. This includes a detailed medical, nutritional, and reproductive history and physical examination with lab evaluation by a physician and referral to a psychologist or psychiatrist [1, 47]. An ideal tool for further evaluation is a structured interview. Eating disorders exam (EDE) has been identified as the gold-standard tool for identification of ED in general [41, 51, 53]. During the one-on-one interview, the athlete must feel secure and not threatened [30].

In organized sports, the PPE is a common entry point for evaluation of athletes. Screening at that time is of utmost importance, but it is not the only opportunity to diagnose DE/ED. Screening female athletes for DE/ED needs to by a dynamic, ongoing process, throughout the span of recreational and competitive activity. It should not occur in a vacuum, only at the time of a PPE. Recreational athletes can also fall into low energy availability from DE/ED. A less formal approach to screening may be applicable in their case.

Screening Settings for Disordered Eating or Eating Disorders

Screening for or DE/ED in athletes generally) occurs in three settings: (1) informal settings, mostly by observation and interaction with athletic trainers and coaches; (2) formal settings, typically with a team physician or primary care provider or when referred to a psychologist or psychiatrist; and (3) clinical settings.

Informal Settings: The informal setting occurs in the athlete's day-to-day routine while interacting with athletic trainers, coaches, administrators, teammates, teachers, family, and friends. For recreational athletes, informal screening may occur with personal trainers, group exercise leaders, and gym personnel. The ideal is for all individuals interacting with athletes to be educated on recognizing concerning patterns of behavior and exercise (nutrition issues, overexercising, etc.). Once educated on what to look for, he/she can feel empowered to approach the athlete in an effort to assist her. Written policies on dealing with suspected ED are recommended and adequate resources to assist the athlete are ideal [54, 55]. Each individual interacting with the athlete has the opportunity to informally screen the athlete for DE/ED. Whether they actually do, often depends upon their level of education and whether they are alert to a potential issue with the athlete [30, 56]. Direct questioning can be utilized; however, the nature of ED tends to be secretive. It is likely that the individual will not readily disclose the embarrassing symptoms of an ED, such as vomiting or laxative use. The intensity of questioning has to be balanced between the relationship of the athlete with the person inquiring and the athlete's readiness to disclose her illness. Thus, the allied health professional sometimes must read between the lines and look for physical and behavioral characteristics that may signify an ED.

Formal Settings: The formal, structured setting occurs during pre-participation examinations and in the clinical setting. In the formal setting, SRQSTs are best utilized. A questionnaire tool is especially helpful as it can be difficult for the provider to remember the myriad of questions recommended for picking up on subtleties in order to discover DE or recognize an athlete attempting to hide an ED.

Clinical Settings: The other formal setting where the female athlete may be encountered is in the clinical setting when presenting for routine health care or for an acute illness or injury. The clinician then has the opportunity to screen for components of the female athlete triad, including those that set the athlete up for low energy availability (DE/ED). A full medical, reproductive, and skeletal health history should be taken as well as an appropriate physical examination looking for classic signs of ED [1, 47]. Questions to be asked during the history should also include nutrition questions incorporating weight and dieting history, current exercise regimen looking for any recent changes in intensity or amount, and mood-related questions. Physical complaints and findings such as amenorrhea, gastrointestinal disturbances, low body mass index, bradycardia, orthostatic hypotension, skin changes, and laboratory studies can help diagnose an ED [57]. However, during the early course of an ED, physical examination and laboratory findings may be normal. Again, there are time constraints in the clinical setting and the provider is likely to focus specifically on the illness, injury, or well woman examination at hand and not expand the history to include elements important in identifying ED/DE and female athlete triad disorders. Health providers (athletic trainers, team physicians, sports medicine fellows, physician assistants, and nurse practitioners) working with female athletes need to remember to focus on their medical roots to complete an entire history and physical examination looking for symptoms and signs of DE/ED and female athlete triad disorders.

Barriers to Recognition of Disordered Eating/Eating Disorders

Unfortunately, people close to the athlete can contribute barriers to recognition of the issue. This is often inadvertent but can also be intentional. These barriers are included in Table 12.4 [47].

In order to minimize barriers, it is critical to maintain an environment that promotes the clear expectation that DE/ED will be addressed with the intent to promote optimal health and performance for the entire team. This may minimize the concern for a "telltale" environment. It is a responsibility of

those who are close to the athlete to help recognize DE/ED and initiate further evaluation and assistance [46]. Once it is recognized that assistance is needed, screening becomes formalized in the clinical setting with the team physician or primary care provider.

Screening Tools for Disordered Eating/Eating Disorders

There are multiple screening tools for DE and ED in the literature (Appendix 1). Some are specific to athletes, while others are more general nutritional, DE/ED screening tools. Most of the general tools are validated, but few of the tools specific to athletes have been validated in female athletic populations [31, 58].

A screening tool may save time obtaining the athlete's history either before or as a part of a PPE or in the setting of a clinical visit with the physician. Questions may be incorporated into the PPE form or a supplemental screening tool. The American College of Sports Medicine Position Stand on the Female Athlete Triad and the National Athletic Trainers' Association Position Statement on Preventing, Detecting and Managing Disordered Eating in Athletes make the recommendation for screening during PPEs, but provides no guidance on any one particular tool [30, 31]. It is generally felt that a supplemental tool directed specifically at female athletes may ultimately be ideal.

The SRQST is utilized as a first step. These tools are not designed to diagnose an ED so athletes who screen positively, should then be further evaluated by a physician for medical evaluation and referred to a psychologist or psychiatrist. During that visit it is likely that one or more interview-based tools will be utilized to determine if the diagnosis of an ED is appropriate.

General Screening Tools for Disordered Eating/Eating Disorders and Diagnostic Screening Tools for Eating Disorders (Table 12.5)

The clinical interview is the assessment tool of choice when diagnosing ED as it allows for more detailed questioning. Disordered eating is not included here as it is not a clinical ED. Use of an interview-based tool is part of the second step in evaluation when a screening tool is positive (Table 12.6.) [51].

Table 12.5 General screening tools for disordered eating/eating disorders not athlete specific

Tool	Year	Key points	Validation
EAT-26 [51, 59]	1982	Most widely used standardized self-report measure of symptoms and concerns characteristic of EDs specifically Web-based; easily accessible; free	Score of 20 or more—interview by a qualified professional to evaluate for diagnostic criteria for ED; concurrent validity; good discriminate validity ChEAT-children's version
SCOFF [60, 61]	1999	5 questions; 1–2 min to complete	Two or more + responses, 100% sensitivity
EDE-Q [22, 61, 62]	1994	Self-completed, question form of EDE Widely used measure of eating disordered behavior 36 items; 15 min to complete Overestimates binge-eating frequency compared to EDE	Criterion validity
EDI-3 [52, 59, 63, 64]	2011	Developed from EDI (1983) and EDI-2 (1991) 91 questions; 12 subscales; 6 composite scores 20 min to complete Cost associated	Internal consistency satisfactory Discriminative Validity good
ESP [64]	2003	4 questions; 1–2 min to complete	As effective as SCOFF
BULIT-R [51, 65]	1991	Bulimia nervosa screening; 28 questions	Content construct criteria
NEDA screening program [65]	Yearly March	Evaluates resources of colleges and universities; online screen for students	No

Notes: EAT-26 Eating Attitude Test-26; *SCOFF* sick, control, one stone, fat, fear; *EDE-Q* eating disorder exam questionnaire; *EDI-3* eating disorder inventory 3; *ESP* eating disorder screen for primary care; *BULIT-R* bulimia test-revised; *NEDA* National Eating Disorder Association

Self-Report Questionnaire Screening Tools, Athlete Specific for Disordered Eating/Eating Disorders

There are a limited number of tools, which have been designed specifically for female athletes (Appendix 1). Some of the tools available screen both athletes and college students whether female or male. Another method of screening is through questions incorporated into a PPE form. In those, typically any nutrition questions will be directed at females and males. The following section of the form then has questions specific to females. Unless this is clearly delineated, this can be confusing for the athletes during completion of their history (Table 12.7).

Table 12.6 Interview-based tools—administered by qualified professional; second stage after screening

Tool	Year	Key points	Validation
EDE [51, 62, 66]	1987 revised 1993	Interview-based, semi-structured interview	Yes
		Gold standard of eating disorder assessment, specifically AN and BN	Good criterion validity
		28-d time frame, prior 4 weeks	Questionable construct validity
		62 items; 2 behavioral indices; 4 subscales	Not in athletic population
		30–60 min to administer	
IDED-IV [51, 52]	1990 revised 1998	Semi-structured interview	Not in athletic population
		Specifically, for diagnosing EDs, not DE; based on DSM-IV criteria	Good reliability and validity

Notes: EDE eating disorders exam; *IDED-IV* interview for diagnosis of an eating disorder; *AN* anorexia nervosa; *BN* bulimia nervosa; *ED* eating disorder; *DE* disordered eating

Table 12.7 Self-report questionnaire screening tools, female athlete specific

Tool	Year	Key points	Population
FAST [67]	2001	33 questions	F
		To identify disordered eating and atypical exercise and eating behaviors	
		Internal reliability; concurrent validity to EDI and BULIT-R	
HWDMHQ [58]	2002 updated 2006	First study to assess combined prevalence of all three components of female athlete triad	F
		Developed from:	
		EDI symptom checklist	
		EDE-Q	
PST [41]	2003	18 items:	F
		Four Physiologic measurements	
		14 Questions	
		15 min to complete	
		Validated; better than EDI-2 and BULIT-R	
Female Athlete Triad Coalition Screening Questionnaire [49]	2002	Internet accessible	F
		12 questions: nutrition, 8; menses, 3; bone health, 1	
		If positive, follow by in-depth evaluation with detailed	
		history of 19 questions and full medical evaluation	
AMDQ [59, 68]	2000	19 questions	F
		Designed to assess DE/ED	
		Compared to EDI-2 and BULIT-R, superior results on 7 of 9	
		Epidemiologic analyses	
		First instrument to operationalize the construct of DE	
		Not validated in a clinical population	
Athlete [69]	2005	Female athletes at three division I universities	F
		6 subscales from EDI, modified to athletes	
		Developed to assess psychological predictors of disordered eating in female athletes	
		Construct validity confirmed that the athlete questionnaire is a reliable and valid measure of the psychological factors associated with disordered eating in athletes	
LEAF [70]	2014	Females 25 questions across markers of energy availability Validated in the female population	F
BEDA-Q [71]	2014	The questionnaire has 9 items as answered in a "true or false" fashion or an on a 5-point Likert scale. Questions pertain to body satisfaction, drive for thinness, and perfectionism	F

Notes: FAST female athlete screening tool; *HWDMHQ* health, weight, dieting, and menstrual history questionnaire; *PST* physiologic screening test; *AMDQ* athletic milieu direct questionnaire; *EDI* eating disorder inventory; *BULIT-R* bulimia test-revised; *BEDA-Q* brief eating disorder in athletes questionnaire

Non-Gender-Specific Eating Disorder Tools (Table 12.8)

12.3.2.2 Current Research in Dysfunctional Exercise Etiology

Theories regarding the etiology of DysEx are diverse and multifactorial, based on physiological (endorphins hypothesis and sympathetic arousal hypothesis), psychological (general theory of addiction), or psychobiological (personality traits or the anorexia analogue hypothesis) issues.

Table 12.8 Self-report questionnaire screening tools, athlete specific

Tool	Year	Key points	Population
CHRIS [72]	2003	College student athletes	F, M
		Based on juvenile wellness and health survey (JWHS)	
		32 questions broken into four areas: mental health, 9; eating problems, 13; risk behaviors, 4; performance pressure, 6	
		Needs further validation	
SEDA [73]	1991	33 questions; self-reported eating pathology	F, M
		Athletic environment-related risk factors	
		Not validated in athletic population	
		Student athletes and students	
De Palma [38]	2001	ID pathologic eating in college students and athletes	
		16 questions; 8 from SEDA and 8 from DSED-diagnostic survey EDs	
PPE monograph [42]	2019	4 questions related to weight; 3 questions related to menses	F, M
International Olympics Committee Screening [74]		Athlete periodic health evaluation (PHE) form	F, M
		11 nutrition questions for both sexes	
		Female-specific questions: 6 menses, 2 bone health, 1 sexually transmittable infections	

Notes: CHRIS College Health-Related Information Survey; *SEDA* survey of eating disorders among athletes; *DSED* diagnostic survey for eating disorders; *PPE* pre-participation examination; *F* female; *M* male; *ED* eating disorder; *DE* disordered eating

Physiological Hypothesis

During the 1980s and 1990s, some authors had reported regarding the intense exercise effect in the endogenous opioid system, resulting in significant higher concentrations in bloodstream and spinal fluids: The Endorphins Hypothesis. β-endorphin and catecholamine form part of the brain reward system, and it was thought to be related to exercise addiction due to their capacity to regulate physiological responses to stress and intense exercise [24, 75].

Endorphins are endogenous opioids derived from pro-opiocortin polypeptides. Moreover, endorphins originate in the hypothalamus, and regulate pain perception, increasing pain threshold, and showing a greater effort perception in trained people. Exercise intensity (performed above 60% of the maximal oxygen uptake) and duration (sustained for at least 3 min) are related to increases in plasma β-endorphin concentrations. However, plasma endorphins cannot cross the blood–brain barrier (BBB), whereby there is no evidence that changes in plasma levels could lead to simultaneous brain changes. Notwithstanding, some authors believe that endogenous opiates in plasma also operate in central nervous system activity [26, 76]. In spite of the lack of sufficient direct evidence of an association between exercise addiction and the endogenous opioid system, and knowing that aerobic exercise stimulates the release of β-endorphin [77], an animal study with rats reported opioid tolerance and dependence in chronic exercisers [78]. Steinberg and colleagues established that chronic exercise practice [61]:

- provides an enjoyable effect that stimulates continuing practice;
- triggers an excessive and compulsive behavior;
- results in a reduced pain sensation dependent on the individual; and
- causes the emergence of a psychological and physiological withdrawal syndrome.

The Sympathetic Arousal Hypothesis was first proposed by Thompson and colleagues in 1987. This hypothesis is based on the idea that increased concentrations of catecholamine (adrenalin, noradrenalin, and dopamine) are induced by intense physiological or psychological stress (exercise or tasks). In addition, researchers have reported 1.5–20 times greater concentrations of catecholamine, depending on exercise type, duration, and intensity [79]. Catecholamine produces increases in heart rate, blood pressure, and a general reaction of the sympathetic nervous system known as "fight-or-flight response" [75, 79]. However, endorphin concentrations seem to be attenuated affecting the sympathetic nervous system regulation. On the one hand, habitual practitioners show a central effect of exercise that reduces the sensitivity to stress, producing lower concentrations of catecholamine and an increased efficiency of energy utilization [80]. On the other hand, research also has shown that greater physical fitness resulting in attenuated concentrations of these hormones and could promote negative feelings such as lethargy, fatigue, depression, and decreased arousal [53, 64]. These findings suggest a possible association between addiction and catecholamine behaviors, due to the fact that habitual exercisers are motivated to engage in increased levels of exercise in order to achieve the same arousal levels and suppress symptoms [75, 81].

Psychological Hypothesis

Szabo et al. proposed a general theory of addiction or Cognitive Appraisal Hypothesis to explain the etiology of exercise addiction. This theory means that habitual exercisers use exercise as a way to cope with stress, learning to need exercise for this purpose (coping mechanism). When the amounts are exaggerated, the exerciser explains and justifies the practice, and slowly takes a principal role instead of nor-

mal daily activities. Negative psychological feelings (irritability, guilt, anxiousness, etc.) appear when the person is required to reduce or stop exercising; feelings that are believed to represent the withdrawal symptoms. There is also a loss of the coping mechanism where the exerciser loses control over stressful situations and feels the need to exercise to manage the stress. Exercise is used as a way to manage their stress. However, as it begins to have a greater toll on the human body, it can ultimately amplify and increase vulnerability to stress. The dysfunctional exerciser is trapped in a vicious circle, exercising more to cope with daily stress that partly is caused by itself [76].

Psychobiological Hypothesis

Personality traits or Anorexia analogue hypothesis has been the most utilized to explain DysEx despite the limited research support. Individuals engaging in DysEx share common personality traits and behavioral dispositions with anorectic patients such as compulsiveness [82], neuroticism [83], low self-esteem [84], perfectionism [18, 81, 85, 86], high trait anxiety [87], high self-expectations, denial of potentially serious debility, and tendency toward depression [77]. These traits and dispositions seem to be more pathological in patients with anorexia nervosa than in dysfunctional exercisers [88]. The main effects of DysEx in female are concern about body image and appearance, development of anxiety and depression disorders, as well as the emergence of other behaviors as compulsive buying [33]. However, males often report having an uncertain identity, low self-esteem, and anxiety about physical ineffectiveness [85].

Dysfunctional Exercise in the Active Female

Gender incidence remains unclear, although some researchers reported equal prevalence in both males and females, while others have shown a higher prevalence of primary DysEx in males, compared with an increased secondary DysEx in females [89, 90].

Villella et al. reported DysEx behaviors in adolescents and young adults using the Exercise Addiction Inventory [91]. However, this inventory was validated for university students, not high school students [92, 93]. Participants with scores of 24 or more were identified as at risk for DysEx. From a total of 2, 853 high school students (1142 girls—40%) ranging between 13 and 20 years old, 8.5% were at risk of DysEx. Segregating the sample into adolescents and young adults, both groups showed similar percentages (8.7% and 8.3% respectively), and females' percentages were lower (6.3%) compared to males (10.1%) [91]. Exercise Addiction Inventory was used also by Griffiths et al. who identified 3% of the sample (n = 200) of adults between 18 and 40 years old at risk of DysEx scoring above 24, but no gender differences were reported [94].

Johnston et al. recruited 32 women (16–77 years old) from exercise facilities, weight-loss organizations, and school and university classes [13]. This study reported data of both quantitative and qualitative DysEx. Participants were engaged in a wide variety of activities (hockey, diving, exercise classes, running, weight training, etc.), where the weekly active time ranged from 1 to 16 h (mean of 5 h/week). A total of 18.75% scored above cut-off points of the Obligatory Exercise Questionnaire (OEQ), and half of them were defined as chronic dieters. They also showed that behavioral criteria such as frequency and amount of exercise (quantitative) are as important as psychological factors such as effort and enthusiasm (qualitative).

DysEx in adult runners has been previously reported showing that the more they exercise the greater their DysEx pathologies with no gender differences. In addition, these results were constantly significant in health club exercisers [90]. Edgar et al. recruited a total of 102 female athletes where 47 were dancers, 39 runners, and 16 hockey players. DysEx was lower in women who participated in collaborative sports (hockey, or soccer), followed by endurance practitioners (marathon or ultra-marathon), with higher rates in women practicing activities such as ballet or modern dance. The higher prevalence of qualitative DysEx behaviors in dancers and ballerinas could be explained by the different expectations related to technical demand, and aerobic and anaerobic fitness, intensity, body image, and weight control requirements [95, 96].

The prevalence of DysEx has been estimated in athletes; however, these studies are partly limited by confounding factors and small samples sizes, however, they can give provide an information on baseline prevalence. Despite this a most recent study of 234 Australian athletes of different sports and found a prevalence of 34% [92]. DysEx has been measured in varies levels of athletic competition finding higher levels of DysEx in high performance and professional athletes (64.3%) compared to amateur athletes (43.3%). One study demonstrated that 34% of athletes had an ED, and of those 34%, 50% of females, and 27% of males were dysfunctionally exercising. In female athletes specifically, the Obligatory Exercise Scale (OES) was used to assess DysEx in a group of 183 women age 26–71 year and found a mean prevalence of 3.3% across all ages [93]. Hence, we could expect DysEx prevalence to be the same across lifespan in active women. Hence, we could expect DysEx prevalence to be the same across lifespan in active women.

Dysfunctional Exercise Components

If the quantity of exercise is exclusively the defining feature of DysEx, this could be unnecessarily labeling athletes or others as pathologic. Many Olympic or high-level athletes are able to engage in high levels of activity without experi-

encing symptoms of DysEx such as reduced quality of life or depressive symptoms. Research has proposed that characteristics of DysEx go beyond the frequency or intensity of the exercise itself [97]. In a study of college females, the duration and frequency of self-reported activity were unrelated to DysEx. Rather motivations for exercise such as engaging in exercise to change weight and shape or experiencing negative affect like feeling guilt about missing a session was indicative of excessive exercise [37].

Qualitative Component

The above findings prompt us to consider a secondary component of one's relationship with exercise: the "quality." The quality of exercise can be conceptualized by contexts which may influence an individual to exercise in an unhealthy way. The contexts of exercise help us define the meaning, nature, and purpose of exercise engagement. Together, these contexts shape the quality of one's relationship with exercise. Calogero and Pedrotty suggest several contexts which can shape our relationship with exercise, including, but not limited to exercise history, physical condition, emotional experiences, belief systems, social relationships, ecological factors, and sociocultural pressures [97]. For example, Claire is an 18-year old living in Los Angeles, USA. She feels compelled to run around the block four times before she has a snack for fear of gaining weight. Claire would be an example of the sociocultural context defining the quality of her relationship with exercise. This is because her motivation for activity is based on controlling her shape or weight which depicts the sociocultural pressure, she feels to be thin. This example helps illustrate that it is not simply the quantity of activity that characterizes DysEx. It may have only taken Claire 20 min to run around the block. However, the activity she engaged in was dysfunctional in nature due to the motivation underlying it. Together, we can conclude that it is quality and not simply the quantity of exercise that underlies DysEx. As such, it has been proposed that the quality of exercise mediates the relationship between healthful exercise and DysEx [95].

Interestingly, the origins of attempting to characterize and measure DysEx lie in understanding its quality. In fact, the first conceptualizations of DysEx were based upon the criteria for behavioral addiction, such as gambling [83, 98]. Many similarities exist between the two characterizations. Based on these characterizations, a number of scales were developed to assess DysEx. These assessment tools have, however, progressed with the evolving understanding of DysEx.

Quantitative Component

Since "health" is considered a state of complete physical, mental, and social well-being and not merely the absence of disease, physical activity levels could determine the health status of the population [99]. The benefits of moderate to vigorous physical activity (MVPA) and exercise have been well documented [100–102]. However, DysEx refers to negative effects of engaging in "too much" exercise. While sedentary lifestyle has been deeply researched using accelerometers, excess of physical activity has been poorly studied. In fact, there is substantial research that supports improvements of cardiovascular risk and reduction of all-cause mortality linked increased dose of exercise [98]. This generates two questions: the first, is DysEx determined by its quantity? The second, "how much is too much exercise?" The studies focused on finding a threshold to determine the limit for healthy versus DysEx have some limitations. For example, they generally chose a very conservative threshold based on the Metabolic Equivalent for Tasks (METS). So, more than 6 METS/day or more than 42 METS/week were found to be most protective or beneficial [103]. A study in 2001 reported a direct relationship between greater increases in physical health parameters and the number of weekly hours spent exercising (from 2 to 7 weekly hours). Lower cardiovascular risk of mortality was reported in those who practiced between 4 and 7 weekly hours of regular physical activity. However, some cardiovascular risks reported when more than 7 weekly hours where performed, may be due to undiagnosed cardiac conditions. By contrast, lower risk of cancer, respiratory disease, or other diseases were addressed when the practice was more than 7 h/week of MVPA [101]. Other authors show that physical activity benefits depend on the intensity of the practice, where greater benefits and lower mortality rates were associated with vigorous activity, not light activity [104, 105]. Based on this research, the Center for Disease Control and Prevention and American College of Sport Medicine recommended 30 or more min of MVPA almost every day [105, 106]. Currently, this recommendation has been increased, especially in children, where at least 60 min of MVPA should be performed 5 days a week and ideally every day. Another important limitation regarding to the quantitative component is that the definition of "How much exercise is too much?" is far below what many athletes perform. For example, endurance runner athletes and triathletes perform ~20 METS/session or ~20 h/week of exercise [107]. An athlete's training level is unique to his/her discipline and each type of exercise is accompanied by unique physiological adaptations. Therefore, every discipline could have different cut-off points and health benefits.

In addition to the problematic thresholds, there is also an often-forgotten perceived positive psycho-physiological effect of exercise when it is part of the daily routine of an individual (i.e., habit). Habit is defined as a recurrent, often unconscious, pattern of behavior that is acquired through frequent repetition. Whether this is a positive elevated exercise practice or not, should be analyzed based on the characteris-

tics (quantitative and qualitative) of the behavior. Remember that regular practice of exercise has been found to improve psycho-physiological parameters such as self-esteem, physical fitness, and social behavior, all of which contributes to maintain exercise behavior or habit [108]. But "what happens when you eliminate a habit from equation?" Researchers have reported that 1–2 weeks of practice deprivation can result in depression symptoms, negative mood states, or even fatigue [104–106, 109]. "Do these effects reflect that reduction of exercise levels is a positive decision?"

Thresholds for Dysfunctional Exercise: What We Know

Exercise thresholds (i.e., duration and intensity) have been primarily studied, but not validated, in populations with DysEx (i.e., Eds). Some authors suggest that engaging in more than 6 h of exercise per week during at least four consecutive weeks is an indicator of DysEx [19]. This threshold was proposed initially by Davis et al. in patients with Eds as a compensatory behavior; therefore, relating more to secondary DysEx [110]. This threshold (>6 h/week for at least 4 weeks) was further defined by Bratland-Sanda et al. in 2010 as MVPA. Therefore, performing more than 52 min/day of MVPA can be considered the threshold for secondary DysEx only in the context of those with an ED and not for the general population [111].

Due to a wide range of different characteristics of populations, establishing thresholds for healthy *versus* DysEx between the general population, those with Eds, and athletic populations may be unrealistic. A healthy population will be expected to perform at least 60 min of moderate to vigorous exercise every day for children and adolescents, and a minimum of 150 min/week for adults [112]. In this sense, there is a lack of knowledge and understanding about how to appropriately establish a threshold for each population. Research could help us understand how much activity should be performed by each group and set relevant thresholds for each. Establishing thresholds for each population is important, both for general knowledge and understanding, as well as to determine the most effective way to help an individual experiencing DysEx.

Screening Tools for Dysfunctional Exercise

Screening tools should be used to assess both quantitative and qualitative components of DysEx (Appendix 1). Quantitative features of the exercise behavior should assess duration (i.e., min, h), frequency (i.e., days/week, sessions/day), intensity (i.e., light, moderate or vigorous), or total volume. Therefore, qualitative features should be assessed through psychological measures such as mood state, depression, anxiety, compulsion, addiction, or eating disturbances. To further the complicate DysEx assessment, screening tools can be subjective or objective instruments. Daily logs, questionnaires, inventories, and observations are the most used subjective instruments due to their easy application and low cost. Nevertheless, there are important limitations associated to their validity and reliability [113]. When these screening tools are compared with gold-standard methods (i.e., accelerometry or GPS tracking devices) [114, 115], it results in either over-estimation in healthy populations [116], or under-estimate real levels in ED patients [117, 118]. Additionally, when the variables assessed are physiologic, it results in greater over-estimations, because the inability to analyze all dimensions of physical activity [116]. Regarding objective instruments, pedometers and accelerometers are the most common devices used to assess spontaneous activity during prolonged periods of time. Of these, the accelerometer is a practical, precise, and inexpensive device [119].

Classification of the Screening Tools for the Assessment of Dysfunctional Exercise

Choosing one screening tool over the other could give the researchers different validity levels of data from the most objective to the most subjective measurements. When is a screening tool considered objective or subjective? A screening tool is considered to be highly objective when it measures what it intends to, and when it approaches the fact. Subjective screening tools approximate the data by delayed information where the perception of researchers or participants could alienate results. Using objective or subjective screening tools depend on which characteristics of the excessive exercise are aimed to be analyzed: min per day, week or month, intensity of exercise, mood state, or eating disturbances. Researchers are more likely to use objective tools when the assessment does not need from the participation of individuals, or subjective tools when the participation of one or both researcher and individual is needed. Therefore, screening tools like mechanical devices are shown as objective tools, and inventories, questioners, self-report diaries, and interviews are shown as subjective tools [31, 120]. Both subjective and objective screening tools can be classified as qualitative (subjective instruments) and quantitative—including both subjective instruments and objective mechanical devices as accelerometers or pedometers, or other technologies such as mobile apps or sport-*GPS* tracking devices.

Qualitative Screening Tools for Dysfunctional Exercise

Qualitative screening tools report information about the characteristics of exercise related to psychological and physiological issues. The main characteristics of these instruments (QEQ, EDS-R, and EAI), as well as principal sources, can be found in the following Table 12.9.

Table 12.9 Screening tools for dysfunctional exercise

Tool	Year	Key points	Population
OEQ [12, 20]	1988 1991	Originated from the obligatory running questionnaire but designed to measure obligatory exercise and problems of over exercising. It was updated in 1991, and now consists of 20 items related to exercise habits.	Adolescents Adults
EAI [121]	2004	The goal of the EAI was to develop a short dysfunctional exercise questionnaire. The EAI was operationalized using the components of behavioral addiction proposed by Griffiths. It has good validity and reliability good internal reliability, content validity, concurrent validity, and construct validity.	Adults
CET [122]	2011	The Compulsive Exercise Test was developed to assess the factors operating in the maintenance of excessive exercise. The subscales of the CET are consistent with a cognitive-behavioral maintenance model of excessive exercise and support the multidimensionality of the excessive exercise construct.	Females with ED Adolescents
EDQ [120]	1997	EDQ is made up of 29 items and eight factors: interference with social/family/work life, positive reward, withdrawal symptoms, exercise for weight control, insight into problem, exercise for social reasons, exercise for health reasons and stereotyped behavior. These factors were shown to have good internal reliability.	Adults
CES [123]	1993	The eight-item questionnaire is designed to assess an individual's psychological commitment to exercise. Primarily it assesses how individual's well-being is impacted by exercising and the degree to which adherence to exercise maintained by the individual.	Adults Females with ED
EBQ [124	1998	The EBQ is a 21-item self-report scale, measuring the beliefs people have about not exercising regularly. It assesses assumptions in exercise via four factors: (1) social desirability; (2) physical appearance; (3) mental and emotional functioning; and (4) vulnerability to disease and aging. The scale has acceptable-to-good psychometric properties.	Adults Athletes
BDS [125]	1998	Reviews three aspects of bodybuilding behavior: (1) social dependence; (2) training dependence; and (3) mastery dependence. It has been deemed a reliable and valid measure of bodybuilding dependency.	Adults
EDS [18]	1997	This scale adapted the DSM-IV criteria for substance dependence and applied it to exercise criteria	Adults
EDS-R [126]	2004	In 2004, this scale was revised and reduced the items to 21 (3 items for each of the 7 subscales). The total score and subscale scores can be calculated for the EDS. The higher the score, the higher the risk for exercise addiction. The EDS has good psychometric properties.	
EIS [127]	1994	This 9-item scale measures the salience of an individual's identification with exercise as an integral part of the self-concept	Adults
ESS [128, 129]	1990, 1994	The 40-item scale was validated in college aged students and items are scored on a 5-point Likert scale. It aims to measure exercise dependence qualifications including, engaging in strenuous exercise, anxious when cannot exercise, places exercise above social life, hold irrational expectations, continues exercising beyond injury, and ruminates about effect of decreasing exercise.	Adults
EEDQ [130]	2012	This tool was uniquely created to measure exercise in ED populations. It arose from clinical need to assess client's attitudes and thoughts surrounding compulsive exercise in individuals with EDs. It is based on the EDE-Q and reviews client's thoughts regarding exercise in the last 28 d. There is a 7-point scale (0–6), with higher scores indicative of greater pathology.	Male and females with ED
EDAS [92]	2012	This tool was developed to measure dysfunctional exercise in competitive athletes. It uses five domains specific to athletic populations to assess factors of dysfunctional exercise.	Competitive athletes
ART [131]	2018	The ART has 15 items scored on a 5-point Likert scale examining: (a) Affect-Driven Training; (b) Training Amount; (c) Training Against Medical Advice; (d) Body Dissatisfaction and aims to examine dysfunctional exercise in athletes.	Athletes

Notes: *OEQ* obligatory exercise questionnaire; *EAI* exercise addiction inventory; *CET* compulsive exercise test; *EDQ* exercise dependence questionnaire; *CES* commitment to exercise scale; *EBQ* exercise belief questionnaire; *BDS* bodybuilding dependence scale; *EDS* exercise dependence scale; *EDS-R* exercise dependence scale revised; *EIS* exercise identity scale; *ESS* the exercise salience scale; *EEDQ* exercise and eating disorder questionnaire; *EDAS* exercise dependence assessment scale: *ART* athletes' relationships with training scale; *ED* eating disorders

Quantitative Screening Tools

Researchers have been using multiple movement devices successfully, including accelerometry, *GPS*-tracking devices, and pedometers to provide information about objective quantification of physical activity. Accelerometers and pedometers are the most popular and have been used not only in healthy children, adolescents, adults, and elders of both genders, but also in different pathologies, owing to their low cost, storage capacity (more than 20 days), programming, data download, validity, and reliability [132].

Subjective quantification of physical activity levels is also possible through self-administered questionnaires and interviews. For example, the International Physical Activity Questionnaire (IPAQ) is a free and self-administered questionnaire that has been validated and is used worldwide with adults from 18 years and older [133]. There are other questionnaires specially validated for children and adolescents, such as the Physical Activity Questionnaire for Children and Adolescents (PAC-C or PAC-A) [134]. When incorporated into clinical practice, the most appropriate self-administered questionnaires should be selected based on age, sex, and validation within the intended population group. However, we must keep in mind the over- or under-estimations associated to the instrument and the population group.

12.3.2.3 Current Research in Menstrual Dysfunction Types of Menstrual Dysfunction

Aside from pregnancy and menopause, causes of secondary amenorrhea are most likely due to the following:

- Thyroid dysfunction
- Elevated prolactin
- Ovarian failure
- Polycystic ovarian syndrome (PCOS)
- Hypothalamic amenorrhea

Thyroid dysfunction and elevated prolactin are easily sorted out by blood testing for thyroid-stimulating hormone (TSH) and prolactin (PRL) levels. An athlete with ovarian failure will have elevated follicle-stimulating hormone (FSH) levels and very low or absent estrogen. PCOS and hypothalamic amenorrhea are typically differentiated based on clinical presentation, as they both may have normal FSH levels. The athlete with PCOS will usually be at or above a normal body as index (BMI) and will likely be hirsute and may show signs of insulin resistance [1, 35].

Functional Hypothalamic Amenorrhea

Loucks provides convincing evidence for the energy availability hypothesis related to menstrual dysfunction in athletes. Additionally, she provides evidence against the original theories concerning body composition and exercise stress. It is important to remember a series of events appears to be related to a deficit in energy availability causing menstrual dysfunction and subsequent issues with skeletal health. Exercise does not have an impact on LH pulsatility beyond the impact of its energy cost on energy availability [32, 47].

The energy availability hypothesis states if the brain energy requirements are not met, an alteration in brain function occurs which disrupts the GnRH pulse generator [50]. Regulation of puberty and reproductive function depends on interactions at specific levels of the hypothalamic-pituitary-ovarian (HPO) axis. The GnRH "pulse generator" neurons in the hypothalamus secrete GnRH every 60–90 min. This hormone causes release of gonadotropins (luteinizing hormone [LH] and follicle-stimulating hormone [FSH]) from the pituitary gland. These, in turn, cause release of progesterone and estrogen from the ovaries. These two end hormones are key to regular, ovulatory menstrual cycles [1, 53, 54]. Deficiency in GnRH pulsatile secretion leads to hypothalamic amenorrhea. Since hypothalamic amenorrhea in the athlete becomes a diagnosis of exclusion, it is often termed functional hypothalamic amenorrhea (FHA), because it is a functional suppression of reproduction [1]. Because FHA is the typical menstrual abnormality seen in athletes, it will be the focus of discussion concerning treatment of menstrual disorders for this chapter.

Who Should Be Screened for Menstrual Dysfunction?

The main populations to screen for menstrual dysfunction include the following groups [41, 135]:

- Adolescents involved in vigorous exercise with primary amenorrhea
- No menarche within 5 years after breast development that occurred less than 10 years old
- Failure of the thelarche (breast development) by 13 years old
- Athletes with previously regular cycles, at any age, with secondary amenorrhea or the lack of menses for 3 continuous cycles after beginning menses
- Athletes with oligomenorrhea, less than 9 cycles per year
- An intensively exercising, reproductively mature woman interested in conception

When to Screen for Menstrual Dysfunction

The answers concerning when to screen athletes for menstrual disorders are similar for screening of DysEx and ED. Evaluation of one component of the female athlete triad should not occur in isolation from the other two components. There is not yet an agreed upon optimal timing or method of screening for any component of female athlete triad disorders [3, 58]. Screening should be economical and

time-efficient and should create an environment that will not cause an athlete to minimize or deny certain medical conditions [58].

Timing of screening can include 1) during pre-participation examinations (PPEs) for competitive athletes, 2) during clinical presentation of the athlete for routine health care (i.e., well woman examination) or for illness or injury, and 3) incidental observation by an athletic trainer, parent, friend, coach, or administrator [3, 29]. Since menstrual dysfunction is often seen as related to sexuality, it can be a very sensitive topic and is not as likely to be incidentally discussed as energy availability might be. This leaves incidental observation the least likely scenario. Because of this, it is probably best to have a short screening tool utilized by those who interact on a routine basis with the athletes, such as athletic trainers, personal trainers or other gym personnel, and coaches who do not have availability of athletic trainers. The questionnaire tool could be distributed to all female athletes at specific times during the athletic year and would act as a first step to identify a possible disorder in menstruation. It ideally would also contain questions concerning nutrition and bone health. It would be easy to score and if the athlete screens positively with the tool, she would then be referred to a team physician or other designated intervention team for the second stage of screening, an in-depth evaluation.

Screening Questions for Menstrual Dysfunction

No validated tools to screen for menstrual dysfunction exist. Several pre-participation examination forms have from one to six questions included on the form [42, 55]. Tools used to screen for DE and ED may include a few questions about menstrual health. It is likely best to have a supplemental form, apart from the PPE form, in order to effectively screen for menstrual dysfunction. Screening should also include questions related to energy availability and skeletal health. Appendix 1.1 provides examples of tools used to screen female athletes for various components of the female athlete triad. The ideal will be to develop a standardized form to screen for the female athlete triad that is then validated. Any athlete who screens positively would need further evaluation by a physician [48].

Evaluation of Menstrual Dysfunction Beyond Screening

The in-depth evaluation with the physician or intervention team should include a routine health history, a comprehensive menstrual and obstetrical and gynecologic history, an appropriate examination, and an evaluation of bone mineral density. The physician could obtain the sexual history, in order to avoid an uncomfortable setting for the athlete and her athletic trainer and/or coaches [3, 29, 34, 44, 46, 58]. Some screening tools and PPE forms currently in existence already have a variety of questions concerning menstrual history. However, this varies from one question to several, to an entirely separate form [42, 55, 57, 77].

The question still remains concerning what makes up an adequate screening tool compared to an extensive obstetrical and gynecologic history. None of the existing forms have been validated for menstrual dysfunction screening. In a study done of NCAA Division 1 schools in 2003, 138 of 170 schools responded and 79% stated they did screen for menstrual disorders (MD). Only 24% of those used a comprehensive menstrual history questionnaire. A menstrual disorder treatment protocol was used by 33%. Of the responding schools, 60% screened for ED. However, less than 6% used a structured interview or a validated questionnaire. The conclusion from this study was there exists a pressing need for more standardized ED and MD screening, prevention, and treatment programs among NCAA Division 1 schools. A further conclusion was, at the very least NCAA member institutions should implement mandatory ED and MD education for all athletes and athletic personnel [28].

A study performed in 2012, involving menstrual irregularity in high school athletes, showed a high incidence of menstrual irregularity and an increased number of musculoskeletal injuries than in athletes reporting normal menses. More than half of the athletes reported a change in menses during training or competition. The recommendation from this study was for improved education of high school athletes to improve caloric intake to better balance their energy availability to prevent or correct menstrual irregularity [68].

Management of Functional Hypothalamic Amenorrhea

Once an athlete is identified as having a menstrual disorder, management becomes the next issue. In functional hypothalamic amenorrhea, there is insufficient energy availability. This then alters GnRH pulsatility in the hypothalamus and LH and FSH release. With limited pituitary secretion of LH and abnormal pulsatility, there is a lack of ovarian stimulation and thus an estrogen deficiency which impacts skeletal health from low sex hormones. There is also altered neuroendocrine function with low levels of insulin, glucose, leptin, triiodothyronine, and insulin-like growth factor-1 and elevated growth hormone and cortisol [53].

In adolescent girls, about 90% of total body mineral content is accrued by 15.5–18 years of age. Delayed puberty can compromise bone mass accumulation and low bone mineral density is a common finding in athletes with functional hypothalamic amenorrhea [53]. Twenty-five percent of bone mass accrual occurs in the 2 years surrounding menarche [34]. Due to this, the athlete becomes at risk for stress fractures, failure to achieve optimal peak bone mass density, and is thus at risk later in life for osteoporosis or delayed stress

fractures [46]. Other risks from hypoestrogenism may include cardiovascular disease, dementia, depression, delayed post-exercise recovery, decreased immune function, and other neurodegenerative and psychiatric disorders [29, 47, 54, 126].

12.4 Contemporary Understanding of the Issues

Screening female athletes for disordered eating, eating disorders, DysEx, and menstrual dysfunction is a complex issue. Those involved with active females need to encourage screening on multiple levels, both formally and informally, utilizing a combination of timing and methods (observation, standardized questionnaires, interviews, etc.). Screening needs to occur as an ongoing process, not only occurring as an isolated event during pre-participation examinations. Education of those involved with female athletes, on all levels, will help in ongoing informal recognition of signs and symptoms of DE/ED, DysEx, and menstrual dysfunction. This is essential because the longer low energy availability is allowed to exist, the greater the health and performance impairments that occur and the more difficult they are to treat.

Screening for DysEx or menstrual dysfunction should not occur in isolation and need to include evaluation of total energy availability and bone health to be thorough in evaluating for the female athlete triad. Currently, there is no universally agreed upon timing or method to screen athletes for abnormal energy availability (DE/ED), DysEx, or menstrual dysfunction. Although, in association with PPE's and during routine healthcare visits, or clinical evaluation when one portion of the triad presents, are the most common cited times for screening. Additionally, there are not clear guidelines about what should happen when an athlete does screen positively for menstrual dysfunction. A complete physician evaluation is recommended, to include past medical history, past surgical history, current medications, social history, family history, and a comprehensive obstetrical and gynecologic history. Comprehensive history taking will then guide the physician concerning appropriate physical examination, laboratory testing, and radiology studies.

A national standard should be encouraged, with a supplemental questionnaire specific to females rather than questions incorporated into a standard PPE form. The athletic trainer or team physician or both should then review the tools. Physicians need to be reminded to screen female athletes for risk factors for low energy availability during routine health visits and visits for acute illness or injury. If for some reason a female athlete-specific questionnaire cannot be utilized, consideration should be given to use of a general population screening tool that is inexpensive and easily accessible. Please see Chap. 5 for more discussion surrounding management and education for MD management in athletes.

12.5 Future Directions

The sports medicine community can serve its female athletes well by developing a consensus guideline related specifically to screening for DE/ED, DysEx, and menstrual dysfunction. The challenge has been twofold: to agree on questions needing to be asked on a survey tool, and to achieve validation of any such tool. A method of rapid assessment of that tool would then allow the healthcare provider to determine whether further referral should be made the same day, or if ongoing monitoring may be needed. Incorporation of physiologic variables into a screening tool shows promise and should be further evaluated.

Simplified education programs for all people who interact with athletes should be developed based on prior efforts, distributed nationally, and assessed to evaluate their effectiveness in detection and/or prevention. Methods of screening for these conditions should be covered in these programs so that screening will become an ongoing process in both informal and formal settings where female athletes are encountered. Further, programs of education and screening should be expanded into junior high and high schools to identify issues of low energy availability as early as possible.

12.6 Concluding Remarks

Low energy availability, as a consequence of DE or ED or DysEx in female athletes, is a significant health concern. It is a key component of the female athlete triad and can lead to menstrual disorders and changes in bone health. The athletic health care community needs to address this health concern beginning in junior high school and high school and continuing through the lifetime of the active female. The best method of management is through a combined approach with screening both informally through observation and formally during pre-participation examinations and other interactions of female athletes with health care providers, in order to prevent the consequences of DE, ED, and DysEx. Pathologic eating disorders can lead to significant health complications, including death.

There is a fine line between regular and healthy exercise and excessive practice. There is not a clear relationship between high levels of exercise and other mental disorders. Although other mental illnesses may be the source, there are no studies to confirm or deny it. DysEx is more common in

high performance compared to recreational exercisers. When 15 years of experience are exceeded, the prevalence of DysEx decreases, likely because practice is highly integrated in daily life. When women display DysEx behaviors, the features are different compared to males. Features specific to women include weight preoccupation, appearance, body image, and body composition concerns. These features are closely related with DE and ED symptoms.

Menstrual dysfunction in athletes should be considered a medical issue needing further evaluation. Amenorrhea in the active female should no longer be viewed as a good thing. In addition to being a medical problem, it can be a symptom related to abnormal skeletal health. At one extreme, it may be the first warning sign of a potentially lethal ED. At the other extreme, it may be a sign of lack of proper nutritional education causing the athlete to exhibit DE, i.e., not taking in enough calories for the level of training. Prevention and early intervention are the key components to minimizing morbidity and mortality. The ideal method and timing for screening have yet to be determined. The best method is likely using a separate questionnaire-based screening tool during the preparticipation physical examination.

Screening for these disorders can be a sensitive issue. Initial screening by athletic trainers or coaches should include basic questions concerning menses, bone health, and energy availability. Once the athlete screens positively, she should be referred to medical personnel for a comprehensive evaluation. Screening tools need to be more specific and detailed, and validated for female population. Additionally, an in-depth analysis, using one or more screening tools, might be needed to prevent the female athlete triad and provide the best recommendations and/or treatment.

Appendix 1: Screening Tools

Appendix 1.1: Eating Disorders/Disordered Eating

1.1.1 General Screening Tools

EAT-26

This is the most widely used standardized self-report measure of symptoms and concerns characteristics of eating disorders specifically. It has three subscales: dieting, bulimia and food preoccupation, and oral control. EAT-26 is a refinement of the original EAT-40 that was first published in 1979. This tool is easily accessible as it is web-based and free. Scoring instructions are included on the website. It can be administered in group or individual settings and does not have to be administered by a mental health or medical professional. A score of 20 or more should prompt referral for interview by a qualified professional to determine whether diagnostic criteria for an ED exist. It is valid and reliable. Ch-EAT is the version used in children [52].

SCOFF Questionnaire

This was developed in 1999 in Great Britain as a quick and easy to remember screening tool for clinicians. The use of a mnemonic with yes/no responses, similar to the CAGE questions for alcoholism, is intended to simplify screening. There are five questions, which take between 1 and 2 min to administer. In the original study, two or more positive answers provided 100% sensitivity [60]. One question is written in Queen's English referring to weight in stones. An "Americanized" version, with the value in pounds, was developed for use in research comparing SCOFF to another screening tool [136].

Eating Disorders Exam-Questionnaire (EDE-Q)

This tool was devised in 1994 and is a self-completed questionnaire form of the EDE, which is an interview-based tool administered by a qualified professional to diagnose eating disorders. It is a widely used measure of eating disordered behavior. The tool consists of 36 items and takes about 15 min to complete. It focuses on the past 28 days and is scored using a 7-point scale. The four subscales included are restraint, eating concern, weight concern, and shape concern. It has good criterion validity. Compared to the EDE, it does tend to overestimate binge-eating frequency [22, 62, 137].

Eating Disorder Inventory-3 (EDI-3)

This was developed in 2004 as an expansion and improvement upon Eating Disorder Inventory-2 (EDI-2) from 1991 and the original EDI in 1983. At the time, EDI-2 was already recognized as a standard self-report measure for ED assessment in the international health care community. EDI-3 evaluates for psychological traits and symptoms relevant to the development and maintenance of anorexia nervosa, bulimia nervosa, and eating disorder not otherwise specified. It consists of 91 items broken into 12 subscales (ED risk scales versus psychological scales) and provides 6 composite scores. On average, it takes about 20 min to complete. This tool can be accessed through the Internet, but it is cost associated. EDI-C is available for use with children [59, 63, 64, 68].

Eating Disorder Screen for Primary Care (ESP)

This was developed in 2003 in Great Britain in an attempt to generate a short screening tool that could both rule in and rule out EDs. It consists of four questions and takes 1–2 min to complete. It is not validated. One study compared it directly to SCOFF and it was found to be equally effective [64].

Bulimia Test-Revised (BULIT-R)

This is a 28-question tool that is easy to score and is well validated. It is a revision from the original BULIT. This instrument has been shown to be a reliable and valid measure for identifying individuals who may suffer from bulimia nervosa both in clinical and nonclinical populations [51, 65].

National Eating Disorders Association (NEDA) Screening Program

This is an online eating disorder screening. There are two separate questionnaires: one for college students and one for the general population. It provides a free, anonymous self-assessment to gauge one's risk of an eating disorder. It takes only a few min and consists of a series of questions designed to indicate whether clinical help may be needed. After completing a screening, if indicated, participants will receive referral information through NEDA's Helpline for personal evaluation by a medical professional and treatment. This is considered a good resource for people who may need help or know someone who may need help and do not know where to begin. NEDA also provides the annual Collegiate Survey Project, each year in March. This is a compilation of responses from 165 colleges and universities concerning on-campus resources for eating disorder-related programs [65].

1.1.2 Eating Disorders Diagnostic Tools

Eating Disorders Exam (EDE)

This semi-structured interview is recognized as the method of choice for diagnosing eating disorders, specifically anorexia nervosa and bulimia nervosa. It was developed in 1987 and revised in 1993. The interviewer, not the subject, rates the severity of symptoms. It focuses on a 28-day time frame over the previous weeks. There are 62 items, and it can take over an hour to administer. There are two behavioral indices (overeating and methods of extreme weight control) and four subscales (restraint, eating concern, shape concern, and weight concern). Administration is by a clinician with specific training in the use of this interview [22, 51, 62].

Interview for Diagnosis of Eating Disorders (IDED)-IV

This semi-structured interview was revised in 1998, after the original in 1990, for the purpose of discriminating between eating disorders and subthreshold syndromes, which it does. It has good reliability and validity. The rater uses severity scales on a diagnostic checklist that leads directly to the differential diagnosis using DSM-IV criteria. It is a reasonable alternative to EDE [51, 52].

If a generalized screening tool will be used, EAT-26 or EDE-Q are the most widely used self-report questionnaires. When time and resources are available or an athlete screens positively, the interview-based EDE is an ideal.

1.1.3 Athlete Specific Screening Tools

Female Athlete Screening Tool (FAST)

This tool was developed in 2001 to identify disordered eating and atypical exercise and eating behaviors among female athletes. It has 33 questions. It has internal reliability and concurrent validity to EDI and BULIT-R [67].

Health, Weight, Dieting, and Menstrual History Questionnaire (HWDMHQ)

This was the first study to assess the combined prevalence of all three components of the female athlete triad. The study showed that very few athletes demonstrate all three components, but a significant number suffer from the individual disorders of the triad. It was developed from the EDI symptom checklist and EDE-Q in 2002 and revised in 2006 [3].

Physiologic Screening Test

This tool was developed in 2003 to provide a physiologic screening test, specifically for collegiate female athletes competing at a high level, in order to detect DE/ED. It takes 15 min to complete and consists of 18 items: 14 questions and 4 physiologic measurements (percent body fat, waist:hip ratio, standing diastolic blood pressure, enlarged parotid glands). It outperformed the EDI-2 and BULIT-R on the false-negative rate, negative predictive value, yield, overall accuracy, and validity [41].

Female Athlete Triad Screening Questionnaire

This is a questionnaire available, free of charge, on the Internet. The Female Athlete Triad Coalition is sponsored by several sports medicine organizations and has existed since 2002. The initial screen has 12 questions: nutrition, 8; menses, 3; bone health, 1. If positive, an in-depth evaluation with a detailed history of 19 questions and a full medical evaluation are recommended [49].

Athletic Milieu Direct Questionnaire (AMDQ)

This was designed in 2000 to assess DE/ED in female athletes. It is the first instrument to operationalize the construct of DE. It consists of 19 questions evaluating behaviors relevant to weight management, diet, and exercise. It has not been clinically validated but compared to EDI-2 and

BULIT-R it has superior results on seven of the nine epidemiologic analyses [52, 69].

Athlete

This tool was developed in 2005 to be administered to female athletes at three Division 1 universities. It is used to recognize psychological predictors of DE. There are six subscales from EDI, which were modified to athletes [69].

Low Energy Availability in Females Questionnaire (LEAF-Q)

The LEAF questionnaire was developed to assess low energy availability in female athletes with or without eating disorders. This questionnaire comprises 25 questions across domains such as injuries, dizziness, cold sensitivity, gastrointestinal function, and menstrual dysfunction on a 5-point Likert scale. Overall, the LEAF-Q is reported to be brief and easy to administer, in a study of over 80 females the LEAF-Q had an internal consistency testing outcome of 0.86, suggesting relatively high homogeneity of the LEAF-Q. The test–retest reliability was 0.79 after a 2-week interval of retesting in this sample [70].

Brief Eating Disorder in Athletes Questionnaire (BEDA-Q)

The objective of this questionnaire is to discriminate between female elite athlete with and without eating disorders in a quick and effective way. The questionnaire has 9 items as answered in a "true or false" fashion or an on a 5-point Likert scale. Questions pertain to body satisfaction, drive for thinness, and perfectionism [71].

1.1.4 Non-Gender Specific Screening Tools

College Health-Related Informational Survey (CHRIS)

This was developed in 2003 as a new screening instrument for college student athletes. It was based on the Juvenile Wellness and Health Survey. There are 32 questions broken down into four areas: mental health, 9; eating problems, 12; risk behaviors, 4; performance pressure, 6 [72].

De Palma

This was devised in 2001 as a discriminate analysis tool to identify college students and student athletes at low, moderate, or high risk of pathologic eating. It was not given any specific title so is referred to here by the first authors last name. It has 16 questions, 8 each from two different previously used instruments, diagnostic survey of eating disorders (DSED) and survey of eating disorders among athletes (SEDA). It takes about 2 min to complete and 2 min to score. The items are short and relatively nonconfrontational [38].

Survey of Eating Disorders Among Athletes (SEDA)

This is a survey of collegiate females and males, who are both athletes and students. It consists of 33 questions related to self-reported eating pathology. It has not been validated in an athletic population [73].

Standardized Pre-Participation Examination (PPE) forms are directed at both female and male athletes. There is a myriad of those types of forms available. The following will discuss two of the more commonly used forms. Additionally, NCAA sponsored universities are required to perform PPEs on all athletes. There are several of those forms available online for the athlete to complete in advance of arrival for a PPE. There is no NCAA standard for those forms so many do not have specific DE/ED questions. Many universities use a separate form such as those previously discussed as part of their student athlete evaluations. Given the health care system is moving toward a Patient Centered Medical Home (PCMH), where patient information is stored electronically with ongoing updates, online storage of electronic data recorded in a PPE form may eventually be a recommended best practice. The National Committee for Quality Assurance is promoting the PCMH to allow for organizing care around the patient, working in health teams, and coordinating and tracking care over time [45]. The ability for health care providers to access the athlete's information electronically may improve the quality of care they receive and may make research related to athletes easier.

Pre-participation Physical Evaluation, Fifth Edition

The latest revision of this form occurred in 2019. It has four questions concerning weight issues that are directed at both females and males. There are three questions related to menses [42].

International Olympic Committee Periodic Health Evaluation of Elite Athletes

This form has 11 nutrition and weight-related questions for both females and males. There are nine questions directed at the female athlete's reproductive and/or skeletal health (6 menses, 2 bone health, 1 sexually transmitted infections) [74].

When a self-report screening tool is utilized, the timing and setting for its use must be considered. The tools that appear to be most useful are FAST, AMDQ, and HWDMHQ. The Physiologic Screening Test appears to have potential. However, ongoing validation of these tools must continue to occur. If screening occurs during PPEs the use of a supplemental tool for female athletes is optimal.

Appendix 1.2: Dysfunctional Exercise Questionnaires

Obligatory Exercise Questionnaire (OEQ)

The OEQ was originally developed from questionnaires about obligatory exercise tendencies in populations of runners. Over time, authors edited the questionnaire about runners to include a broader range of questions about exercise tendencies. Eventually, the OEQ was developed as a quick and simple questionnaire to administer, taking about 5 min to complete. There are 20 items which inquire on a range of exercise habits. The participant is meant to circle the frequency with which they engage in such a behavior or have thoughts surrounding aspects of dysfunctional exercise. In 2002, this measure was psychometrically validated and the internal consistency ratio was 0.96 and the test–retest reliability was also 0.96 [12, 20].

Exercise Addiction Inventory (EAI)

The EAI tool aims to identify those at risk for exercise addiction. Authors undertook the initiative to develop a quick and easy tool to administer as they did not feel one existed. The development of the EAI was based on the work of behavioral addiction. Authors adjusted the characterization of behavior addiction in the context of exercise. It can identify individuals who are at risk, those who exhibit some symptoms, and individuals who are at no risk of dysfunctional exercise. The scale is broken down into six items which inquire about attitudes and beliefs about exercise behavior, perceived importance of exercise along with its consequences, and frequency of exercise needed to achieve the anticipated benefit. Internal consistency has been demonstrated as very good (0.84). It also showed good concurrent reliability when compared to the obligatory exercise questionnaire and the exercise dependence scale [121].

Compulsive Exercise Test (CET)

The CET was developed in order to assess the primary factors functioning to maintain dysfunctional exercise. This scale is consistent with a cognitive behavior model of behavior maintenance. It was designed to be utilized in individuals with eating disorders. The scale consists of 31 items which relate to the compulsivity, affect regulation, weight control, and exercise factors of compulsive exercise maintenance. The items are scored on a 6-item Likert scale between 0 and 5. The internal consistency for this item is good (alpha = 0.85) [122].

Exercise Dependence Questionnaire (EDQ)

The EDQ consists of 29 items covering 8 subscales which inquire on the social affects and one's motivation to exercise. This scale was found to have good psychometric properties including internal reliability and discriminate validity. However, this scale does not uniquely assess exercise dependence; its items evaluate social practices and attitudes as well [120].

Commitment to Exercise Scale (CES)

The CES was designed to assess one's pathological commitment to exercise. This measure has often been used in eating disorder research [37]. The respondents have to answer on a scale of never to always by selecting a number listed on a horizontal line between 0 and 10. High scores indicate greater pathology. This measure is well validated and has a Cronbach's alpha of 0.85 [123].

Exercise Belief Questionnaire (EBQ)

The EBQ was developed specifically to measure maladaptive beliefs about the consequences of not exercising. The scale is a 21-item self-reported tool which measures the beliefs individuals have about not being able to exercise as they regularly do. It was developed with exercisers engaging in a large variety of intensities, modalities, and settings of activities. There are four subscales established which include social desirability, physical appearance, mental and emotional functioning, vulnerability to disease, and aging. The Cronbach alphas were calculated for each of the subscales and results are as follows: social desirability (a = 0.87); physical appearance (a = 0.83); mental and emotional functioning (a = 0.89); and vulnerability to disease and aging (a = 0.67) [124].

Bodybuilding Dependence Scale (BDS)

The BDS has 9 items falling within three subscales of bodybuilding dependence, which include social dependence, training dependence, and master dependence. The internal consistency was satisfactory for each scale with Cronbach's alpha = 0.76, 0.75, and 0.78. This scale is meant to uniquely assess dependence in individuals who engaging in body building or natural fitness competitions [125].

Exercise Dependence Scale (EDS) and Exercise Dependence Scale Revised (EDS-R)

The EDS and the EDS-R are both based on the DMS IV diagnostic criteria for substance dependence. The original scale (EDS) was developed and validated in 2002. This scale was used to determine the rates of primary exercise dependence. However, in 2004, this scale was amended, and thus came to be the exercise dependence scale revised. The new scale included 21 items within seven subscales. Cronbach's alphas were all above acceptable limits for each subscale as follows: Tolerance (alpha = 0.78); withdrawal (alpha = 0.90); continuance (alpha = 0.90); lack of control (alpha = 0.80); reduction in other activities (alpha = 0.70); and time (alpha = 0.86) [18, 131].

Exercise Identity Scale (EIS)

The EIS measures the salience of an individual's identification with exercise as a part of their overall self-concept. The EIS consists of nine items which ask about how the individuals views themselves in the context of activity, motivation for exercise, and other questions which pertain to how an individual describes his/her relationship with exercise. The Cronbach's alpha was 0.93 demonstrating good reliability [127].

The Exercise Salience Scale (ESS)

The ESS aimed to offer a set of diagnostic criteria by offering 30 questions based on the following: (1) engages in regular strenuous exercise; (2) experiences a dysphoric or anxious mood when unable to exercise; (3) alters priorities so that exercise is placed above social and occupational activities; (4) holds irrational expectations regarding the amount of exercise needed to maintain a desired body shape and fitness level; (5) persists in exercise behavior in the face of physical consequences, such as bad weather and physical injury; and (6) ruminates about the effects of any decrease in exercise level. The question are answered on a 5-point Likert scale, higher numerical scores indicated higher levels of pathology. Unfortunately, this scale concluded its validity and reliability tests by stating that unless an individual was previously diagnosed as exercise dependent in a clinical setting, the ESS was in need of additional testing to be a valuable tool to investigate exercise dependence, which may be the reason this scale is not often used in today's literature [128, 129].

Exercise and Eating Disorder Questionnaire (EED-Q)

The aim of the EEDQ was to capture detailed information about exercise regimens and disturbances among clients with eating disorders. This scale includes 18 items across three subscales which include intentions to exercise, consequences of not exercising, and awareness of bodily signals. This instrument is considered easy to administer and complete. The EED-Q has been validated in both men and women with eating disorders. Cronbach's alpha was 0.92 which demonstrates satisfactory internal consistency [130].

The Exercise Dependence and Elite Athletes Scales (EDAS)

McNamara and McCabe (2013) authored the *Exercise Dependence and Elite Athletes Scale* for assessing dysfunctional exercise in elite athletes. This questionnaire was founded on characteristics identified by coaches from over 10 different sports (including endurance, ball, and aesthetic sports) as associated with DE. This self-reported tool has good validity with the athletic ED population measuring DysEx in elite athletes over a range of characterizations such as: 1) *Unhealthy Eating Behaviors*; 2) *Conflict and Dissatisfaction*; 3) *More Training*; 4) *Withdrawal;* 5) *Emotional Difficulties; and* 6) *Continuance Behaviors*. These six subscales are measured across 24 items scored on a 5-point Likert scale from 1 (Never) to 5 (Always) [92].

Athletes Relationship with Training Scale (ART)

The Athletes Relationship with Training Scale was developed in hope of creating a clinically useful, self-reported measure of unhealthy training behaviors and beliefs in athletes. The ART has a four-factor structure examining the following (a) Affect-Driven Training assessing negative affect associated with training or lack of training (b) Training Amount assessing training beyond scheduled practices and coach recommendations; (c) Training Against Medical Advice assesses training when injured or against medical recommendations; and (d) Body Dissatisfaction assesses training to acquire a certain body type. In a review of the tool in over 250 female athletes, and women with eating disorders and the ART predicted health care utilization and differences between athletes with and without eating disorders [131].

Chapter Review Questions

Eating Disorder/Disordered Eating Questions

1. The American College of Sports Medicine Position Stand on the Female Athlete Triad describes the interrelationships between:
   (a) Energy availability
   (b) Menstrual function
   (c) Bone mineral density
   (d) All of the above
2. Energy availability is the energy remaining for body functions after that used for exercise is added to total energy intake.
   (a) True
   (b) False
3. One way an athlete's available energy may be reduced is:
   (a) Decreased energy expenditure with reduced exercise
   (b) Increasing energy intake
   (c) Abnormal eating behaviors
   (d) None of the above
4. Screening for disordered eating and eating disorders can occur at a common entry point to athletic participation.
   (a) True
   (b) False
5. Once an athlete screens positively for possible low energy availability or if a concern exists, the athlete should:
   (a) Celebrate his/her positive screening
   (b) Continue his/her normal training routine

(c) Increase energy expenditure while decreasing energy intake
(d) Be referred for further medical and psychological or psychiatric evaluation

6. Properties that make a screening tool useful include:
   (a) Functionality
   (b) Validity
   (c) Reliability
   (d) All of the above
   (e) None of the above
7. A more formal screening evaluation for disordered eating/eating disorders should include:
   (a) Detailed medical, nutritional, and reproductive history
   (b) Physical examination with lab evaluation
   (c) Referral to a psychologist
   (d) All of the above
   (e) None of the above
8. The informal settings where athletes may be screened for disordered eating/eating disorders occur:
   (a) While interacting with personal trainers, family, and friends
   (b) When filling out Pre-participation Physical Exam forms
   (c) In clinical settings
   (d) None of the above
9. Physical complaints that can help diagnose an eating disorder include:
   (a) Amenorrhea
   (b) Bradycardia
   (c) Skin changes
   (d) Low body mass index
   (e) All of the above
10. The clinical tool that is recognized as the assessment of choice for diagnosing an eating disorder is:
   (a) Eating Disorders Interview (EDI)
   (b) EAT-26
   (c) Eating Disorders Exam (EDE)
   (d) Female Athlete Screening Tool (FAST)
   (e) SCOFF

Answers for ED/DE Questions

1. d
2. b
3. c
4. a
5. d
6. d
7. d
8. a
9. e
10. c

Dysfunctional Exercise Questions

1. What are the components that define dysfunctional exercise or problematic exercise?
   (a) Excessive exercise and intensity
   (b) Intensity and qualitative
   (c) Quantitative and qualitative
   (d) Quantitative and excessive exercise
2. Which is not a symptom for secondary dysfunctional exercise?
   (a) Preoccupation with exercise cannot be explained due to co-occurring with another mental disorder
   (b) Subjective awareness of a compulsion to exercise
   (c) Relief of withdrawal symptoms if exercise is restarted
   (d) Increased tolerance to exercise
3. The prevalence of Dysfunctional Exercise among those with an eating disorder range _____.
   (a) 10–30%
   (b) 15–50%
   (c) 25–60%
   (d) 26.8–80%
4. Dysfunctional exercise is less common in women who _____.
   (a) are dancers (i.e., ballet or modern dance)
   (b) participate in collaborative sports
   (c) are endurance exercise practitioners (i.e., marathon, ultra-marathon)
   (d) None of the above
5. Dysfunctional exercise is more prevalent in:
   (a) High-performance athletes
   (b) Amateur athletes
   (c) Individuals that engage in exercise with the objective to improve their health
   (d) There are no differences in dysfunctional exercise prevalence based on the level of performance
6. Quantitative component of dysfunctional exercise can be assessed using:
   (a) METs
   (b) MVPA
   (c) Frequency (per week or per day)
   (d) All the above are utilized to quantify exercise
7. The threshold for secondary dysfunctional exercise in the context of those with eating disorders (not athletes or general population) is:
   (a) >3 h/week for at least 4 weeks
   (b) >6 h/week for at least 4 weeks
   (c) >9 h/week for at least 4 weeks
   (d) >12 h/week for at least 4 weeks
8. What is screening tool is best to assess the quantitative component of dysfunctional exercise?
   (a) Accelerometry

(b) Self-report diary
(c) Observation
(d) Interview

9. Which of the following qualitative screening tools for dysfunctional exercise is only validated for adolescents and females with eating disorders?
   (a) OEQ—Obligatory Exercise Questionnaire
   (b) CES—Commitment to Exercise Scale
   (c) CET—Compulsive Exercise Test
   (d) EED—Exercise and Eating Disorders
10. Which of the following qualitative screening tools for dysfunctional exercise has been validated for males and females with eating disorders?
   (a) EIS—Exercise Identity Scale
   (b) ESS—The Exercise Salience Scale
   (c) EED—Exercise and Eating Disorders
   (d) EAI—Exercise Addiction Inventory

Answers for DysEx Questions

1. c
2. d
3. d
4. b
5. a
6. d
7. b
8. a
9. c
10. c

Menstrual Dysfunction Questions

1. Athletes who desire pregnancy, but are not ovulating can be treated with:
   (a) Clomiphene citrate for ovulation induction
   (b) Pulsatile GnRH or injected gonadotropins
   (c) Endogenous opiates
   (d) Both a and b can be used to induce ovulation
2. Which of the following statements is *false* about oral contraceptive pills (OCP)?
   (a) The use of OCPs will not normalize the metabolic factors impairing bone function, health and performance
   (b) OCP are unlikely to fully reverse low bone mineral density (BMD)
   (c) Estrogen replacement without nutritional rehabilitation will always reverse bone loss
   (d) All statements are true
3. Hormone therapy should not be used in amenorrheic adolescents younger than _____years old until after a thorough work-up has been completed.
   (a) 16
   (b) 17
   (c) 18
   (d) 21
4. Which of the following statements are true with regard to appetite in the female athlete?
   (a) Appetite is an unreliable indicator of energy requirements
   (b) Athletes should just eat when they are hungry and this will prevent low energy availability
   (c) Athletes should wait for hunger and then eat until satisfied in order to increase energy availability
   (d) All of the statements are true
5. Treating the cause of menstrual dysfunction can lead to ovulatory cycles within 12 months, but up to _____of athletes may have persistent amenorrhea.
   (a) 30%
   (b) 40%
   (c) 50%
   (d) 70%
6. _____percent of bone mass accrual occurs in the _____ years surrounding menarche.
   (a) 45%; 4
   (b) 35%; 3
   (c) 30%; 1
   (d) 25%; 2
7. In adolescent girls, about _____ of total body mineral content is accrued by 15½–18 years of age.
   (a) 60%
   (b) 70%
   (c) 80%
   (d) 90%
8. Target groups for menstrual screening should include which group(s) of women?
   (a) A normal secondary sexual development but no menarche by 15 years of age
   (b) Failure of the thelarche (breast development) by 13 years old
   (c) No menarche within 5 years after breast development that occurred less than 10 years old
   (d) All of the above-mentioned groups should be targeted
9. In 2006, National Collegiate Athletic Association Division 1 Schools adopted a standardized eating disorder and menstrual dysfunction screening tool to be used for all female athletes.
   (a) True
   (b) False
10. Which of the following characteristics is (are) true for an athlete with polycystic ovarian syndrome (PCOS)?
   (a) She will usually be at or above a normal body mass index (BMI)
   (b) She will likely be hirsute
   (c) She may show signs of insulin resistance
   (d) All of the above characteristics could be possible with PCOS

Answers for Menstrual Disorder Questions

1. d
2. c
3. b
4. a
5. a
6. d
7. d
8. d
9. b
10. d

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13 The Importance of Posture and Muscular Balance in the Body for Managing Skeletal Muscle Injuries in Active Females

Abdurrahman Fayez Kharbat, Freedom Lee Xeros Ha, Mimi Zumwalt, and Jacalyn J. Robert-McComb

Learning Objectives

After completion of this chapter, you should have an understanding of:

- The components/interaction of both the nervous and muscular systems in controlling posture
- Gender differences in the aging spine/surrounding musculature and their effects on postural stability
- Postural and muscular imbalances and how they can contribute to pain/injury
- The assessment of spinal deviation and how preventative measures aid in correcting posture to improve pain or injuries
- Various treatment modalities, emphasizing stabilization/strengthening/stretching exercises to offset postural deviations

13.1 Introduction to the Active Female and Posture

The development and maintenance of posture are one of the fascinating intersections of musculoskeletal and neurological anatomy and physiology that we identify in the human body. We often consider our voluntary movements to be mechanical movements that we undertake without much thought or effort, but the reality is that these movements are the product of incredibly sophisticated communications between our musculoskeletal and neurological control systems. In order to bring a glass of water up to your mouth, not only must your brain command your biceps brachii and associated flexors to contract, but it must also command your triceps brachii and associated extensors to relax. Moreover, the fine motor movements that allow you to tilt the glass into your open mouth without spilling the water are all attributable to the precise recruitment of muscle motor units by your nervous system. As such, exploring the relationship between the musculoskeletal and neurological systems is integral to our understanding of posture and will set the stage for our discussion of postural pathology and the prevention of postural injuries.

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13.2 Research Findings and Contemporary Understanding of the Issues

13.2.1 Components of Posture

13.2.1.1 The Musculoskeletal System

In order to understand how posture is modulated by the nervous system throughout both active and sedentary lives, one must understand the role of the pertinent groups of the musculoskeletal system in this interaction. One's trunk is erected by the interactions of truncal and spinal muscles with the spinal column, through the exertion of anterior and posterior forces on the spine's tendons and ligaments. Tendons connect muscles to bone and ligaments connect bone to bone. The spinal column is made up of 33 vertebrae that are separated by intervertebral discs (cervical, thoracic, lumbar) or are fused (sacral, coccygeal). The vertebrae themselves are held together through a myriad of structural ligaments. The natural curvature of the spine is an "S" shape, and this is maintained through antagonistic actions of anterior and posterior muscle groups connected to the spinal column by tendons. Flexion of the spine, or hunching over, is mediated through the actions of scalene, longus colli and capitis, ster-

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nocleidomastoid, and rectus abdominis. Extension of the spine, or stretching backwards, is mediated through the actions of paraspinal muscle groups, erector spinae, and multifidus. Scoliosis, kyphosis, and lordosis are structural abnormalities of the spinal column that manifest as poorly maintained postures and can be caused by congenital abnormalities or poorly maintained postures over many years. These pathologies and preventative measures to maintain the structural integrity of the spinal column will be explored in the coming sections.

13.2.1.2 The Neuromuscular Junction

The nervous system controls and modulates skeletal muscle group activation through electrical-to-chemical communication via the neuromuscular junction (NMJ). Muscles are made up of individual muscle fibers that are innervated by motor neurons, which are linked by NMJs. When one's brain commands the biceps brachii and associated flexors to contract, an electrical signal is sent from the CNS to the muscle through a motor neuron. The motor neuron's synaptic connection to the muscle is the NMJ, wherein the electrical signal is transduced into a chemical signal by the release of acetylcholine (ACh) from the motor neuron's synaptic cleft to a motor-end-plate located on the muscle. The binding of ACh to the nicotinic acetylcholine receptor (nAChR) on the motor-end-plate activates the nAChR, opening up a channel that allows cations (sodium and potassium) to enter, inducing muscular contraction. The degree to which muscles are activated depends on the recruitment of motor neurons and their associated muscle fibers, which are collectively a motor unit. Increased recruitment of motor units is modulated by the CNS depending on the degree of fine-motor movement needed. For a simple flexion of the upper extremity, less recruitment of motor units is needed as compared to bringing a glass to one's mouth for a drink of water. As such, integral to the understanding of the control of posture is the connectivity of the musculoskeletal and nervous systems in the reciprocal control of antagonistic and synergistic muscle groups, which have been explored in this section. Next, the roles of the CNS and the motor cortex (MC) in the control of posture will be explored.

13.2.1.3 The Nervous System's Role

Considering the interplay of the various control systems in the human body, one may ponder, "What is the role of the nervous system in the control of posture and movement?" Voluntary movements are controlled by signals that originate from the central nervous system (CNS), but are these signals initiated with the beginning of a movement, or do they exhibit a basal tone that is modulated through movement? What about when one is standing still, as opposed to engaging in a movement? To better understand the role of the CNS in motor control, the role of the motor cortex (MC) in posture and movement will be discussed.

Decades of research has demonstrated a divergence in the intricacies of motor control between lower mammals and more complex mammals, such as humans. In lower mammals, motor control of movement has been demonstrated to originate in subcortical regions of the CNS, as well as in spinal networks. Such origins of movement are present in humans as well, and manifest as typically automatic motor reactions. These reactions include, but are not limited to, a reflexive withdrawal of one's hand from a hot stove, or visual tracking of a moving object, such as a baseball thrown in one's direction. These same movements can be initiated voluntarily but will most often occur involuntarily and originate in subcortical CNS structures that scientists may often characterize as the primitive brain.

Let us further describe the withdrawal reflex; when one's hand touches a hot stove, a spinal reflex initiates with the intended purpose of protecting the body from a dangerous, damaging stimulus (see Fig. 13.1). The typical knee tap reflex is an interaction between the sensory neurons and motor neurons in response to stimulation of the patellar tendon. The reflex causes contraction of the quadriceps and relaxation of the hamstring musculature. The spinal reflex, also called a reflex arc, begins with a sensory neuron in the skin sensing the heat of the stove and sending afferent signals to the spinal CNS to initiate a withdrawal of the hand. The sensory neuron synapses with interneurons that act on multiple motor neurons, and some of these motor neurons

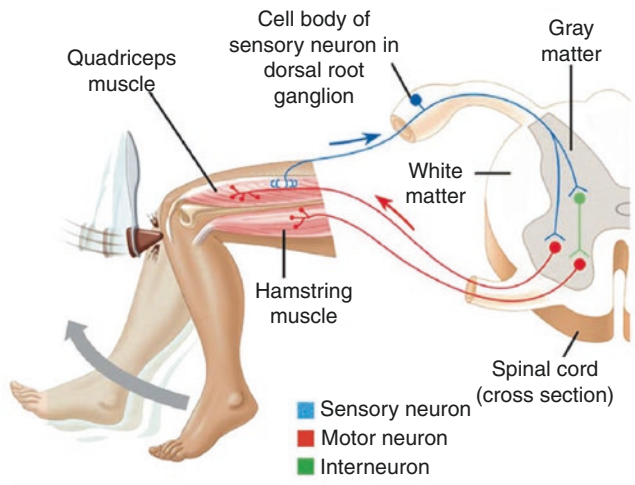


Fig. 13.1 The withdrawal reflex. The typical knee tap reflex is an interaction between the sensory neurons and motor neurons in response to stimulation of the patellar tendon. The reflex causes contraction of the quadriceps and relaxation of the hamstring musculature [1]. Reprinted from Kraemer WJ, Fleck SJ, Deschenes MR, Exercise Physiology—Chapter 5, © 2015, https://exercisescience.lwwhealthlibrary.com/book.aspx?bookid=2395, with permission from Wolters Kluwer Health, Inc.

will excite muscles of the flexor compartment, while others will inhibit muscles of the extensor compartment, all in a matter of 150 ms. This reciprocal innervation allows the reflex arc to execute the function of withdrawing the hand away from the hot stove and occurs instinctively.

It has been long understood such the role of the MC in initiating complex, voluntary movements. But what about more stereotyped locomotion such as walking? Most people do not have to think very hard about standing still or walking, or about the complexity of posturing while undertaking these tasks. The question that needs to be asked is "Does postural control occur in subcortical areas of the CNS or is this control a manifestation of the more complicated and organized MC?"

An extensive 2017 study conducted out of The BioRobotics Institute in Pisa, Italy is helping establish a novel and more accurate understanding of the neurophysical role of the MC in the mechanics of movement and locomotion [2]. A long held, traditional view of scientists was that the MC is limited in its involvement in the control of stereotyped locomotion, such as walking. However, this understanding is being challenged and is best articulated by the authors of the study themselves in their research abstract:

> "In lower mammals, locomotion seems to be mainly regulated by subcortical and spinal networks. On the contrary, recent evidence suggests that in humans the motor cortex is also significantly engaged during complex locomotion tasks. However, a detailed understanding of cortical contribution to locomotion is still lacking especially during stereotyped activities. Here, we show that cortical motor areas finely control leg muscle activation during treadmill stereotyped walking. Using a novel technique based on a combination of Reliable Independent Component Analysis, source localization and effective connectivity, and by combining electroencephalographic (EEG) and electromyographic (EMG) recordings in able-bodied adults we were able to examine for the first time cortical activation patterns and cortico-muscular connectivity including information flow direction. Results not only provided evidence of cortical activity associated with locomotion but demonstrated significant causal unidirectional drive from contralateral motor cortex to muscles in the swing leg. These insights overturn the traditional view that human cortex has a limited role in the control of stereotyped locomotion, and suggest useful hypotheses concerning mechanisms underlying gait under other conditions." [2]

The evidence presented in this research strongly suggests an active role of the MC in driving stereotyped locomotion. The implications of this study are wide and varied, but in the context of our understanding of the control of posture and movement, it presents a compelling case for researchers and clinicians to better understand the interplay of the CNS and the MC with the musculoskeletal system, which will be explored further in this section.

Crucial to the understanding of the role of the CNS in movement and posture is the understanding of the neurophysical interaction of the MC with different muscle groups, and how this interaction is controlled and modulated. To this end, the neuronal mapping, or representation, of different muscle groups within the MC, and how this representation is modulated through cortical plasticity will be explored.

Researchers use a number of techniques, such as measurements of electromyographic (EMG) activity, to understand the representation of muscle groups in the primary motor cortex (M1), which is the executive cortical area of the MC. In a 2017 study published in the Journal of Neurophysiology, Park et al. masterfully demonstrated the "representation of individual forelimb muscles in primary motor cortex" by using measurements of EMG activity in *R. macaques* monkeys that were trained to perform a reach-to-grasp task that required the coordination of multiple limb joints, which allowed the researchers to construct the aforementioned representations of individual forelimb muscles in M1 [3]. The significance of this work is best articulated in the research abstract:

> "As reported previously [3], cortical maps revealed a central core of distal muscle (wrist, digit, and intrinsic hand) representation surrounded by a horseshoe-shaped proximal (shoulder and elbow) muscle representation. In the present study, we found that shoulder and elbow flexor muscles were predominantly represented in the lateral branch of the horseshoe whereas extensors were predominantly represented in the medial branch. Distal muscles were represented within the core distal forelimb representation and showed extensive overlap. For the first time, we also show maps of inhibitory output from motor cortex, which follow many of the same organizational features as the maps of excitatory output" (Fig. 13.2).

The findings that "shoulder and elbow flexor muscles were predominantly represented in the lateral branch of the horseshoe whereas the extensors were predominantly represented in the medial branch" further contribute to an understanding of the mapping of M1 and demonstrate that the activation of muscle groups corresponds to specific activation in M1. This is of interest to researchers and clinicians alike, as it opens many avenues for questions. Ponder this for a moment: are super athletes or musicians who exhibit masterful motor dexterity wired differently, on a motor cortical level than the average person? An attempt to answer this question will be made when discussing the role of cortical plasticity in the MC.

It has been established that individual forelimb muscles are represented in M1 of the MC, but how does this representation look like in the context of a complex movement? For example, unilateral arm movements cannot take place without stabilization through bilateral contraction of the axial muscles of the trunk. If a unilateral arm movement were to occur without the coordinated stabilization of the trunk muscles, the center of gravity of the individual would shift, and without compensation, one may lose balance and fall. Given that M1 motor efferents primarily control contralateral muscle groups (with some ipsilateral control), the initiation of a unilateral arm movement and the subsequent bilateral con-

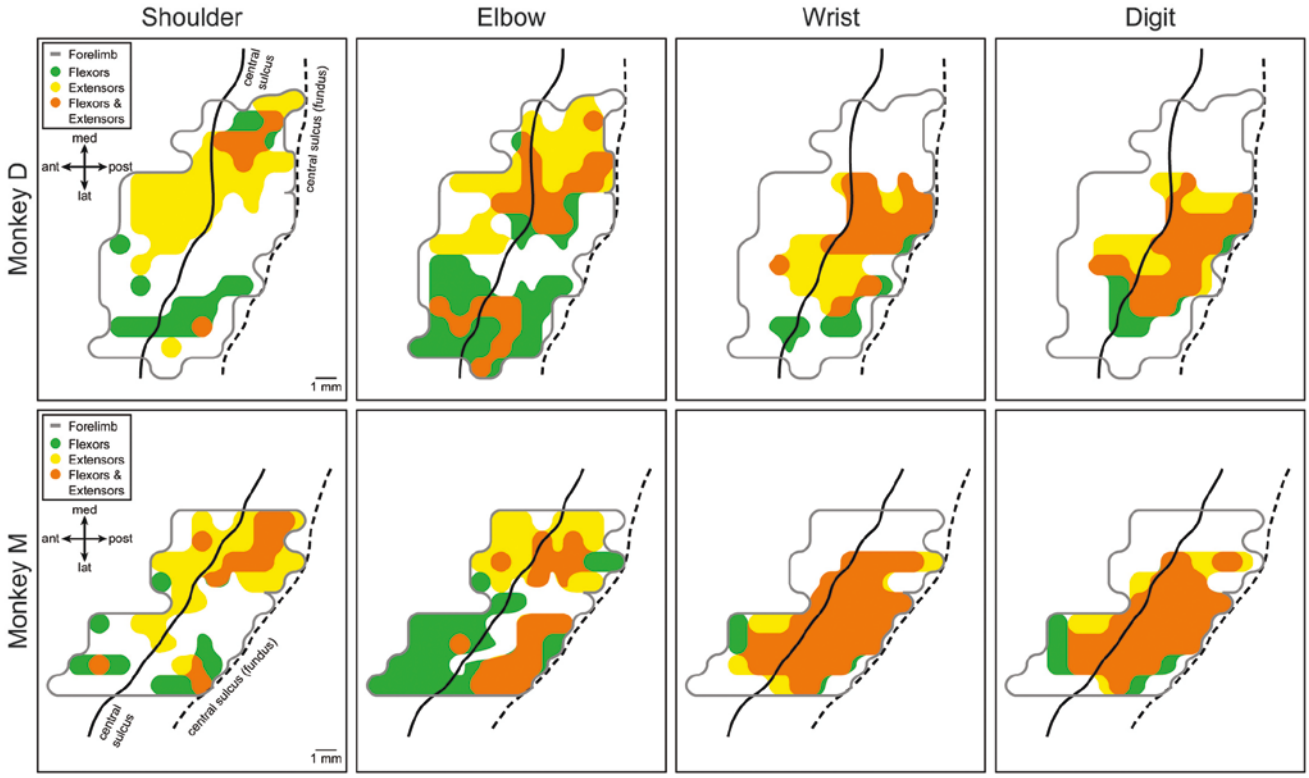


Fig. 13.2 Primary motor cortex output maps showing the representation of flexor and extensor muscles at different joints in two monkeys based on poststimulus facilitation (PStF). Intrinsic hand muscles were omitted from these maps. Green area corresponds to facilitation of flexors, yellow area corresponds to facilitation of extensors, and orange area corresponds to cofacilitation of both flexors and extensors within the joint [3]. Reprinted from Hudson HM, Park MC, Belhaj-Saïf A, Cheney PD, Representation of individual forelimb muscles in primary motor cortex, Journal of Neurophysiology, Vol. 118/Issue 1, pages 47–63, © 2017, https://journals.physiology.org/doi/full/10.1152/jn.01070.2015 with permission from the American Physiological Society

traction of trunk axial muscles raises questions about how both hemispheres of the brain respond to a unilateral movement. It has long been postulated that interhemispheric interaction M1 is responsible for these coordinated movements, and the interaction of both hemispheres through the corpus callosum has been long established. However, these mechanisms are largely unknown, which was the exigence of a 2017 study published by Barthélemy et al. in the Journal of Neurophysiology [4].

> "The mechanisms involved in the bilateral coordination of axial muscles during unilateral arm movement are poorly understood. We thus investigated the nature of interhemispheric interactions in axial muscles during arm motor tasks in healthy subjects. By combining different methodologies, we showed that trunk muscles receive both inhibitory and facilitatory cortical outputs during activation of arm muscles. We propose that inhibition may be conveyed mainly through interhemispheric mechanisms and facilitation by subcortical mechanisms or ipsilateral pathways." [4]

The findings of this study deliver a novel understanding of the mechanisms at play during unilateral arm movement and demonstrate the complexity with which M1 facilitates complex tasks and communicates between hemispheres.

> "Together, our data support that the ipsilateral cortex does not have a different modulatory effect on paraspinal muscles depending on the goal of the task (i.e., stabilizing the trunk to support arm isometric contraction vs. trunk isometric contraction). We propose that cortical representations of paraspinal muscles have stronger ipsilateral facilitatory output to favor bilateral contractions and that interhemispheric interactions might not contribute primarily to the facilitation. In this study, interhemispheric interactions were also assessed in AD, the agonist of the task, and were found to be inhibitory…" [4]

These conclusions show that not only do interhemispheric M1 cortices communicate during a movement task, but that effects also differ in ipsilateral and contralateral control of trunk axial muscles. Ipsilaterally, the output facilitates the bilateral contraction of trunk axial muscles and occurs regardless of the goal of the task. Contralaterally, the interhemispheric interaction is inhibitory, and functions to precisely modulate trunk axial muscles in order to stably execute a unilateral movement.

This demonstrated complexity in seemingly simple movements further elucidates the organizational complexity and interactivity of M1 bilaterally. Moreover, it reinforces the assertion of the importance of understanding the neurophysi-

cal interplay between the motor cortex and muscle groups, which is of great clinical importance. Ponder for a moment how difficult movement can become for patients who suffer from stroke or cerebral ischemia, and how deleterious the consequences of such ailments can be on a system-wide scale.

Now, let us explore how this neurophysical interface can be modulated by returning to the notion of cortical plasticity. Plasticity represents the changes that occur in the CNS in response to physiological or pathophysiological factors, and is often seen in normal development, learning, behavioral conditioning, and pathological processes. Cortical plasticity is well documented in the literature with respect to cortical regions involved in memory, learning, and speech. However, a 2016 study conducted by Chieffo et al. endeavored to further characterize plasticity changes in MC by investigating cortical activation asymmetry in piano players versus controls, with interesting and significant results [5] (Fig. 13.3).

The study demonstrated conclusively that pianists have a significantly reduced degree of hand skill asymmetry as compared to controls and are more likely to exhibit bilaterally symmetrical M1 cortical activity. Moreover, the "findings suggest a more symmetrical motor cortex organization in pianists, both in terms of muscle cortical representation and interhemispheric inhibition," [5]. These conclusions help to better understand the role of plasticity in creating greater MC symmetry and indicate that practice and training can have neurophysical effects on the brain, and subsequently on motor skills.

One can consider these effects of plasticity on motor function and more deeply appreciate the systemic effects that practice and training have, not only on musculoskeletal function, but also on their neurological control by the MC. Athletes may have been able to speak to the importance of practice and training since the dawn of sport, but the concrete neurophysical interplay between the CNS, MC, and different muscle groups allows one to characterize the efficacy of practice and training in scientific terms, as well as the pathogenesis of postural disorders.

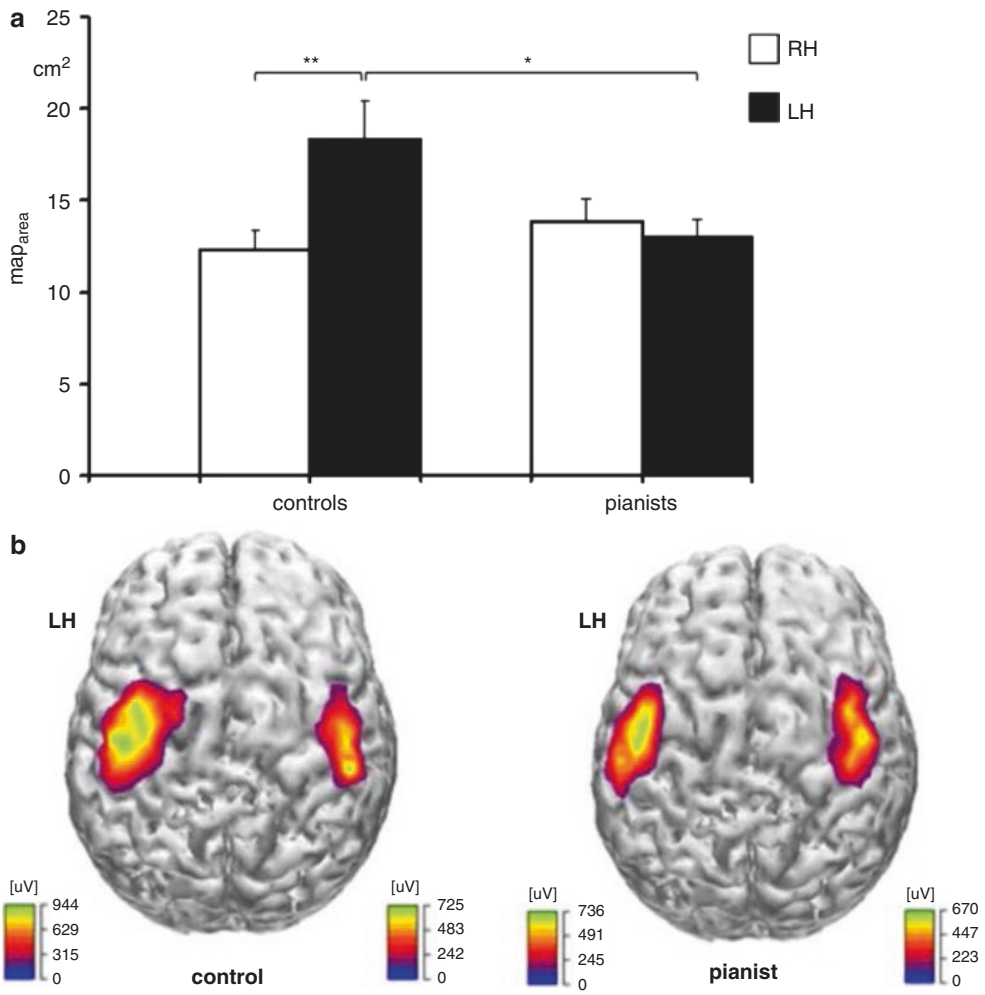


Fig. 13.3 Map area of the control group's dominant hemisphere was significantly greater than their non-dominant hemisphere and the dominant hemisphere of pianists (**a**). Cortical motor representation of the hand muscles (mean of APB, ADM, and ECR) over the dominant (LH) and nondominant (RH) hemisphere in pianists and controls (mean and standard error) (**b**) [5]. Reprinted from Chieffo R, Straffi L, Inuggi A, Gonzalez-Rosa JJ, Spagnolo F, Coppi E, et al., Motor Cortical Plasticity to Training Started in Childhood: The Example of Piano Players, Public Library of Science © 2016, 11:e0157952–e0157952, https://pubmed.ncbi.nlm.nih.gov/27336584, with open access under the Creative Commons Attribution License

13.2.2 The Effects of Postural Change

13.2.2.1 Gender and Age

Given the multifaceted nature of postural control, it is understandable that postural pathologies are often complicated by factors such as gender and age, and manifest differently between males and females; plus, the young and the elderly. In this section, focus will be on the roles of gender and age in the pathogenesis of postural disorders, as well as the subsequent effects of such disorders on muscular balance and pain. Moreover, common postural issues seen in the cervical, thoracic, and lumbar spine will be delineated.

As individuals age, postural deficits become more pronounced and can begin to affect one's quality of life by limiting functional movement structurally and/or due to pain. However, these age-dependent changes are different between males and females. As such, an attempt to explore the pathogenesis of postural disorders while taking into account both age and gender is needed in order to best understand the effects of these variables on posture.

Recent meta-analyses have elucidated a number of important conclusions regarding the postural changes seen with aging, while taking into account gender differences [6, 7]. Results indicate that, independently of aging, males tend to exhibit increased cervical lordosis and thoracic kyphosis than females. This is manifested as males raising their heads higher and bending their shoulders more forward than females. However, when incorporating aging-related variables, it is found that although aging negatively affects both males and females, the effects on posture are more pronounced in females. Between the ages of 50 and 70, the demonstrated trends for males and females are decreasing spinal angles of the neck and thorax, due to cervical lordosis and thoracic kyphosis. Yet after age 70, the neck angle has a slightly increasing trend, while the thorax does not. These results suggest that cervical lordosis and thoracic kyphosis intensify between the ages of 50 and 70, and there is cervical lordosis recovery at age 70, while there is no thoracic kyphosis recovery at this age [6].

While these trends are seen across both genders, there are pronounced differences between males and females. When accounting for gender, results indicate that males have an overall greater degree of cervical lordosis and thoracic kyphosis, but that these differences were mostly seen in younger age groups (before 60 y of age for cervical lordosis and before 70 y of age for thoracic kyphosis). After this age, the postural abnormalities are more similar between males and females. These findings present a unique and interesting perspective on the effect of aging on posture for women. It has shown that males have a greater degree of postural deficit in their younger years, yet females and males have comparable postural deficits in their old age. This indicates that females have a greater tendency to accentuate cervical lordosis and thoracic kyphosis as they age, which contribute to postural deficit. This presents a compelling case for females to understand the age-related changes in their posture, and to pursue posture-stabilizing exercises as they age in order to decrease the propensity for postural deficits [6].

Notably, although there are gender differences in posture, response to posture-correcting exercise treatment has been demonstrated to be efficacious in both males and females and should therefore be a first-line effort in the correction of posture for all people [8, 9]. However, the execution of this finding may be complicated by the fact that although posture exercises may yield comparably positive results in males and females, females suffering from postural deficits are more likely to continue to suffer from postural deficit because of a heightened fear of movement, due to greater pain intensity during activity [10]. With respect to postural correction exercises, although there is no difference in most of the static and dynamic postural control variables between genders, the higher degree of fear of movement and pain during activity in females affects their ability to correct their posture and contributes to greater postural instability and dynamic imbalance [10].

The findings presented establish a deeper understanding of the postural deficits experienced by individuals as they age and across genders. Therefore, it is suggested that individuals should undertake posture-correcting exercises and take note of the preventative measures to counteract age- and gender-related changes in postural stability, which will be explored in the coming sections. Indeed, these suggestions are echoed by studies that also emphasize the importance of introducing therapeutic exercises in nursing homes in order to combat the postural decline seen in the elderly as they lead progressively sedentary lives [11].

13.2.2.2 Muscular Imbalances

As we have demonstrated that females' postural deficits are more greatly compounded by aging, we will now explore the effects that these manifestations have on the muscular imbalances in females, and how these imbalances can cause pain and loss-of-function.

It has been established that in postmenopausal females, thoracic hyperkyphosis affects postural instability in the sagittal plane, while osteoporosis affects postural instability in the frontal plane. Moreover, decreased hip muscle strength can lead to changes in the center of pressure distance relative to the base of support. A study investigated the postural instability seen in females from both the sagittal and frontal planes by analyzing the effects of bone mineral density (BMD) and thoracic kyphosis on the center of pressure (CoP) sway and its location with respect to the base of support (BoS) [12]. The results were significant in demonstrating that in both hyperkyphotic groups (osteoporotic and normal BMD), the strength of back extension and hip adduction was

significantly decreased as compared to the normal kyphotic groups, indicating that hyperkyphosis results in loss-of-function regardless of BMD status. Moreover, in the osteoporotic groups (hyper- and normal-kyphotic), hip abduction and ankle plantar flexion were significantly weaker than individuals in the non-osteoporotic groups. In both hyperkyphotic groups (osteoporotic and normal BMD), CoP displacement velocity in the anterior-to-posterior direction was significantly higher than the young group, while in both osteoporotic groups (hyper- and normal-kyphotic), CoP displacement velocity in the mediolateral direction was significantly higher than in the young group. These findings yielded the conclusion that thoracic hyperkyphosis affects postural instability in the sagittal plane, while a decrease in BMD (due to osteoporosis) affects postural instability in the frontal plane. Due to the prevalence of hyperkyphosis and osteoporosis in elderly females, these conclusions indicate that muscular imbalances are a leading cause of postural instability for this population, and should be targeted in posture-correcting exercises, especially in the sedentary lifestyle elderly population.

13.2.2.3 Pain and Injury

Pain with activity is often concomitant to muscular imbalance in the aging female [10, 13]. However, it is important to note that pain with activity is often a complicating phenomenon that restricts females with postural deficits from remaining active, which will inevitably lead to increased atrophy of muscle groups essential to postural stability. In fact, one of the leading causes of nonspecific lower back pain in the aging female may be attributable to increasingly sedentary lifestyles that are promoted due to fear of causing pain through movement. Indeed, studies have demonstrated that sedentary lifestyles cause a decrease in lumbar muscle activation, which results in a transfer of the weight load to passive structures, such as ligaments and intervertebral discs [13]. Due to this phenomenon, the lumbar spine may become deconditioned, and this may be a reason for the prevalence of nonspecific lower back pain.

When discussing the age- and gender-dependent factors that lead to muscular imbalances and manifest in pain, it is important to understand that these issues are important to address as early as possible, in order to correct postural instability that could result in grave consequences in the elderly population. Not only are these deficits related to a decreased quality of life, but they have also been demonstrated to be significantly correlated with falling risk in elderly females, which can cause life-threatening injuries [14]. In fact, studies indicate that elderly females who have experienced falls due to postural instability displayed a significantly larger range of body sway in the sagittal plane and increased suppression of postural oscillations in the frontal plane. Moreover, these elderly females exhibited more pronounced forward inclination of the trunk due to thoracic kyphosis and a smaller degree of lumbar lordosis. All in all, elderly females with postural instability demonstrate a greater propensity for falls.

The aforementioned conclusions converge on the same notion, which is that the aging female experiences a great deal of postural changes and instability both due to gender- and age-dependent variables. Moreover, it is increasingly apparent that these changes are leading causes of muscular imbalances that manifest in pain and could lead to life-threatening falls. Therefore, it is recommended for the aging female to take greater care in performing posture-stabilizing exercises and being aware of preventative measures for these common pathologies. Such preventative measures for reducing the incidence of postural pathologies will be explored in the next section.

13.2.3 Preventative Measures

With many musculoskeletal injuries such as ligament tears, tendon ruptures, and bone fractures, there are typically two treatment options: physical therapy (PT) or surgery and PT. These types of injuries can be due to an acute event and/or chronic deterioration. Although posture also involves the musculoskeletal system along with interplay of neural elements, its deterioration can be mitigated prior to the development of negative outcomes such as chronic lower back pain. Postural stability is a natural part of our proprioceptive awareness; one has control of the musculature that supports the body frame/structure. Hence, one can learn to strengthen, activate, and increase individual overall kinesthetic awareness. There are multiple methodologies that can be implemented to address poor postural changes including exercise, muscle activation, stretching, and therapeutic modalities. Prior to prescribing a program for posture improvement, one must first assess the degree of postural deviation from the norm. A few of these assessment methods and posture improvement modalities and their as they pertain to the female population will be explored.

13.2.3.1 Assessment of Posture

Before a treatment of any disease or pathology is prescribed, the patient's current condition must be evaluated beforehand. With posture, the extent of deviation from the norm must be assessed prior to beginning a correction program. Although the most accurate way to assess spinal deviations is with radiography [15], focus will be on two noninvasive assessment methods: the flexicurve ruler and the bubble inclinometer.

Flexicurve Ruler

The flexicurve ruler is a metal ruler that can be lightly bent to follow the curvature of the spine, with subsequent measurements that determine the degree of kyphosis or lordosis. Obtaining measurements using this device is typically performed by physiotherapists, with the following steps listed below as adapted from a Flexicurve Spinal Measurement from Carleen Lindsey, PT:

1. With the subject standing up, use three fingers to palpate the posterior neck until the C7 spinous process is found. Have the patient look upwards to confirm that the C7 spinous process remains palpable and mark with a pen or sticker.
2. Palpate the posterior superior iliac spines on both sides. S2 will be in between both and palpate two vertebrate superior to reach L5 and mark the L5-S1 space with a pen or sticker.
3. From L5, count superiorly six vertebral levels to reach T12 and mark with a pen or sticker.
4. Mold flexicurve ruler along the spine of the subject, adapting to the thoracic and lumbar curvatures, ensuring no space between the ruler and the subject's skin. See Fig. 13.4 below.
5. Find where the ruler overlies the markings of C7 and L5-S1 and mark these indications accordingly on the ruler itself.
6. Remove the flexicurve ruler and place onto plain white graph paper, aligning the C7 mark and L5-S1 mark along the same vertical line.
7. Use a pen or pencil to trace the curve of the subject's spine directly onto the paper.
8. At the point where the curved spine tracing line intersects the vertical line between C7 and L5-S1, draw a perpendicular line to said vertical line (Fig. 13.5).
9. The thoracic length (TL) spans from this horizontal line to C7, and the lumbar length (LL) spans from this horizontal line to L5-S1 (Fig. 13.5).
10. The thoracic width (TW) spans from the vertical line to the widest part of the curved line above to the horizontal line. The lumbar width (LW) spans from the vertical line to the widest part of the curved line below to the horizontal line (Fig. 13.5).
11. Repeat these measurements in triplicate and average.
12. The kyphotic index (KI) and lordotic index (LI) can be calculated using the following [16]:

$$\mathbf{KI} = \mathbf{100} \times \left(\mathbf{TW} / \mathbf{TL}\right)$$
$$\mathbf{LI} = \mathbf{100} \times \left(\mathbf{LW} / \mathbf{LL}\right)$$

13. Compare KI to values below to determine the deviation from normal kyphotic index range as shown in Table 13.1.

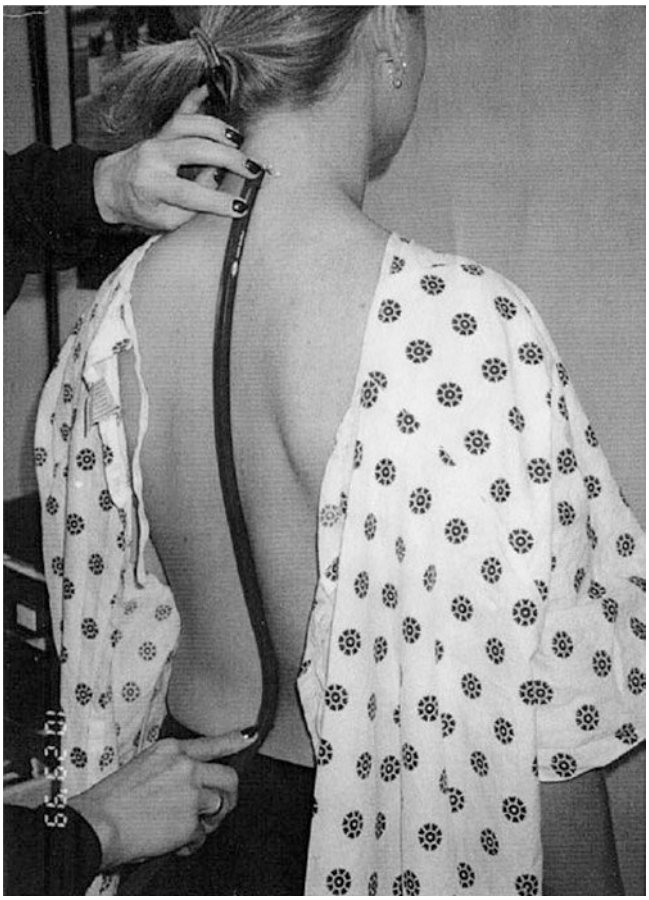


Fig. 13.4 Assessment of posture using the Flexicurve Ruler [7]. Reprinted from The Spine Journal, Vol 4/Issue 4, Hinman MR, Comparison of thoracic kyphosis and postural stiffness in younger and older women, pages 413–417, © 2004 https://www.thespinejournalonline.com/article/S1529-9430(04)00016-6/fulltext with permission from Elsevier

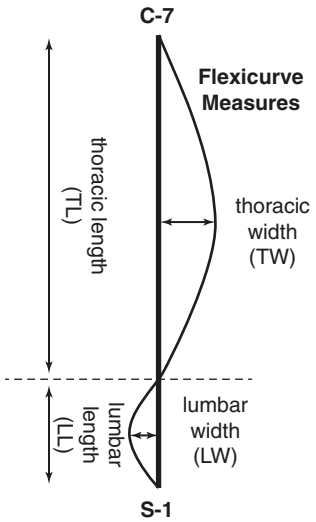


Fig. 13.5 Flexicurve schematic diagram for measurements [7]. Reprinted from The Spine Journal, Vol 4/Issue 4, Hinman MR, Comparison of thoracic kyphosis and postural stiffness in younger and older women, pages 413–417, © 2004 https://www.thespinejournalonline.com/article/S1529-9430(04)00016-6/fulltext with permission from Elsevier

Table 13.1 Kyphotic index ranges. Reference values for kyphotic index with respect to both gender and age [17]. Adapted with permission from Milne JS, Lauder IJ, Age effects in kyphosis and lordosis in adults, Annals of Human Biology, Vol 1/Issue 3, pages 327–337, © 1974 Springer Nature, https://doi.org/10.1080/03014467400000351

Kyphotic index ranges		
Age	Female	Male
20–24	7.0 ± 2.0	8.5 ± 2.0
25–29	8.5 ± 2.5	8.0 ± 2.5
30–34	7.0 ± 1.0	8.0 ± 2.5
35–39	7.5 ± 2.0	8.2 ± 1.5
40–44	7.0 ± 1.5	8.5 ± 2.5
45–49	7.0 ± 2.0	8.5 ± 2.5
50–54	9.0 ± 3.0	7.5 ± 2.0
55–59	9.5 ± 2.5	8.5 ± 3.0
60–64	11.0 ± 2.0	10.0 ± 3.0
65–69	12.0 ± 2.5	11.0 ± 3.0
70–74	12.5 ± 3.0	11.5 ± 2.5
75–79	13.5 ± 4.0	12.0 ± 4.0
80+	15.0 ± 6.0	12.0 ± 4.0

The flexicurve ruler serves as a convenient method to determine thoracic kyphosis that can have similar results as certain radiographic methods like the vertebral centroid angle, but its accuracy can decrease with increasing thoracic kyphosis [18]. Regardless, the reliability of the flexicurve ruler as noninvasive measurement of posture is unquestioned and continues to be used clinically due to is affordability, safety, and ease of use [16, 19].

Bubble Inclinometer

Another noninvasive measuring tool of thoracic kyphosis is the bubble inclinometer which is used to measure range of motion (ROM) at bodily joints. A bubble inclinometer is a set of two separate dials filled with fluid each with two processes that contact the surface to be measured (see Fig. 13.6). It has a protractor and pointer that act with gravity to read the angle of measurement tangent to the surface that it is placed on [20]. The following steps are appropriate for using inclinometers when assessing the ROM of the spine and were adapted from Blommestein et al. [20].

1. Have the subject stand upright, relaxed, and in their most natural posture.
2. Palpate for the spinous processes of vertebrae T1/T2 and T12/L1. Mark the areas with a pen or sticker.
3. Place one of the processes of the inclinometer on T1 and the other on T2 (Fig. 13.6).
4. Record the angle shown on the inclinometer. Repeat with T12 and L1.
5. Calculate the degree of kyphosis using:

$$\textbf{Kyphosis} = \left(\textbf{Angle of T1 and T2}\right) + \left(\textbf{Angle of T12 and L1}\right)$$

6. Perform measurements and calculations in triplicate and then average the values.

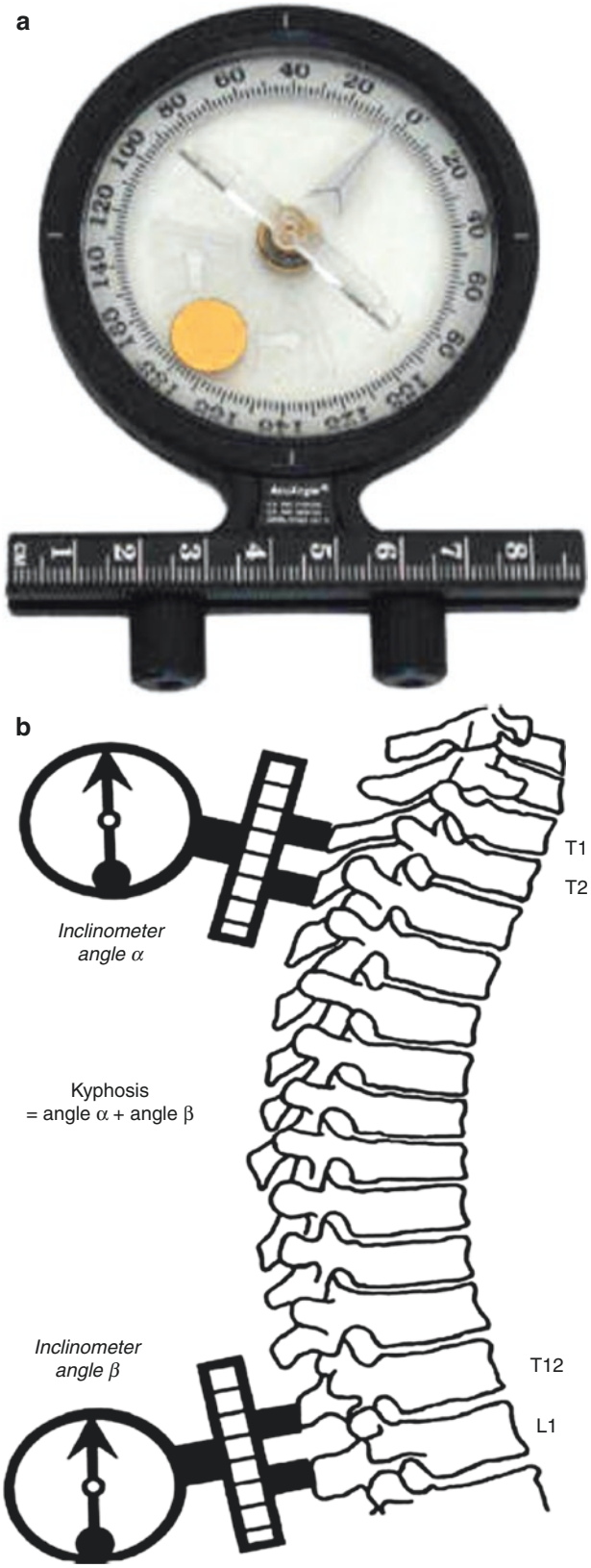


Fig. 13.6 The bubble inclinometer (**a**) and its proper placement on the spine (**b**) [20]. Reprinted from Van Blommestein AS, Lewis JS, Morrissey MC, MaCrae S, Reliability of measuring thoracic kyphosis angle, lumbar lordosis angle and straight leg raise with an inclinometer, The Open Spine Journal Vol 4, pages 10–15, © 2012, https://benthamopen.com/ABSTRACT/TOSPINEJ-4-10 with Commonwealth permission

7. The kyphotic angle tends to increase with age and thoracic hyperkyphosis is considered greater than 40° [21].

The use of inclinometers to measure thoracic kyphosis as well as lumbar lordosis is quite reliable and easy to perform [20]. Although inclinometers are reliable, they traditionally have not been considered valid for measuring spinal curvature itself as compared to radiographic methods [20]. Yet recent research has shown that inclinometers may be just as valid as imaging techniques like the Cobb angle [22].

13.2.4 Exercise and Physical Activity

The human body is designed to move. The coordinated interplay between the musculoskeletal system and the nervous system is of paramount for optimal movement patterns as well as static positions such as standing or sitting. It is well known that the more active one is, then generally tend to be healthier: lower risk of heart disease, obesity, and diabetes. When most think of exercise and physical activity, think instead of typical regimens such as cardiovascular or resistance training. Postural correction is rarely considered a part of training programs but is essential in order to correct and restore proper function of musculoskeletal elements, especially in the injured or aging individual. Engaging in physical activity has been shown to improve posture after treatment of breast cancer patients [23] and improvement of spinal range of motion in post-menopausal active women compared to sedentary women [24]. The muscles involved with maintaining proper posture of the spine and hips are numerous. For the purpose of addressing corrective exercise and training to improve posture, a brief review of the pertinent musculature for posture follows. Flexion of the spine is achieved by contraction of multiple muscles including scalene, longus colli and capitis, sternocleidomastoid, and rectus abdominis. On the posterior side of the body, the spinal extensors include paraspinal muscles, erector spinae, and multifidus (see Fig. 13.7). However, as you can see in Fig. 13.6, there are numerous muscles in the thoracic spine anteriorly, posteriorly, medially, and laterally that are involved in posture for support and the execution of movement. Excessive flexion of the spine (called hyperkyphosis) and an excessive lumbar curvature (lordosis) are the main deviations which will be addressed with corrective exercise.

Over time, the human body begins to slowly deteriorate bones become more fragile, muscles weaken, and the skin loses its elasticity. This is unavoidable; thus, the elderly demonstrates this decrease in functionality with compromised mobility and activity levels in their everyday lives. With the geriatric population, a detrimental outcome from these changes may lead to falling that can result in debilitating injury or death. It has been shown among elderly women, those who suffer from falls tend to have poorer balance and increased thoracic kyphosis [14]. As humans age, our spines begin to lose the natural "S" curve of normal thoracic kyphosis as prevalently seen throughout the elderly population, especially older women (see Fig. 13.8). This is due to multiple factors including decreased muscle mass/strength and spinal disc degeneration.

A cross-sectional study by Ball et al. first determined the age-related postural changes of 250 women aged 30–79. A one-year prospective study was then conducted on 50–59-year old females: one group performed spinal extension exercises for one year three times a week, while the other did not [27]. There was a significant positive change in kyphotic angle in the exercised group, indicating the relevance of back extensor muscle training to deter postural changes in elderly women. A more recent study from Korea implemented a corrective exercise program consisting of twice weekly 1-h sessions for 8 weeks to determine its effect on thoracic hyperkyphosis in elderly Korean women [28]. The results showed significant improvements in the angle of thoracic kyphosis, further cementing the importance of strengthening the musculature of the posterior trunk. A recent meta-analysis demonstrated the validity of such exercise programs on correcting thoracic hyperkyphosis, while no significance was seen in changing lumbar lordosis [29]. The effectiveness of corrective exercise programs for improving posture in the elderly is well known [30], but what are some of the exercises that are incorporated in such programs?

There are multiple exercises and programs that can be utilized for posture correction often constructed by physical therapists. Table 13.2 is a sample set of exercises that can be implemented in daily life to strengthen muscles involved in proper posture. Before beginning any exercise program, one should consult with a medical professional to ensure safety and prevent injury based on current state of health.

The efficacy of strengthening the posterior musculature in order to correct posture has been discussed, but what about stretching? Stretching involves either dynamic or static movements that lengthen muscle tissue in order to achieve greater flexibility, improve blood flow, and reduce pain. The sedentary lifestyle of most humans in the current era lends itself to chronic shortening of many anterior muscles including the pectoralis major and iliopsoas. The chronic shortening of such muscles can result in tight hip flexors and weakening of the antagonistic posterior muscles, resulting in underactive glutes, hamstrings, and spinal erectors. There is merit in only stretching to improve flexibility, posture, and pain [31–33] yet muscle strengthening appears to play a more significant role in improving postural changes [29]. While correction of spinal extension involves strengthening of the back extensors and stretching of the anterior flexors, improving spinal stability is also key to prevent regression back to poor posture. The musculature that surrounds the core must endure long periods of static activity such as standing, to maintain well-aligned posture as well as proper breathing. Hence, the value of stability training cannot be neglected, and has been shown to improve core endurance and spinal alignment, while reducing posture-related back pain [34]. A sample list of core exercises is also provided in Table 13.2.

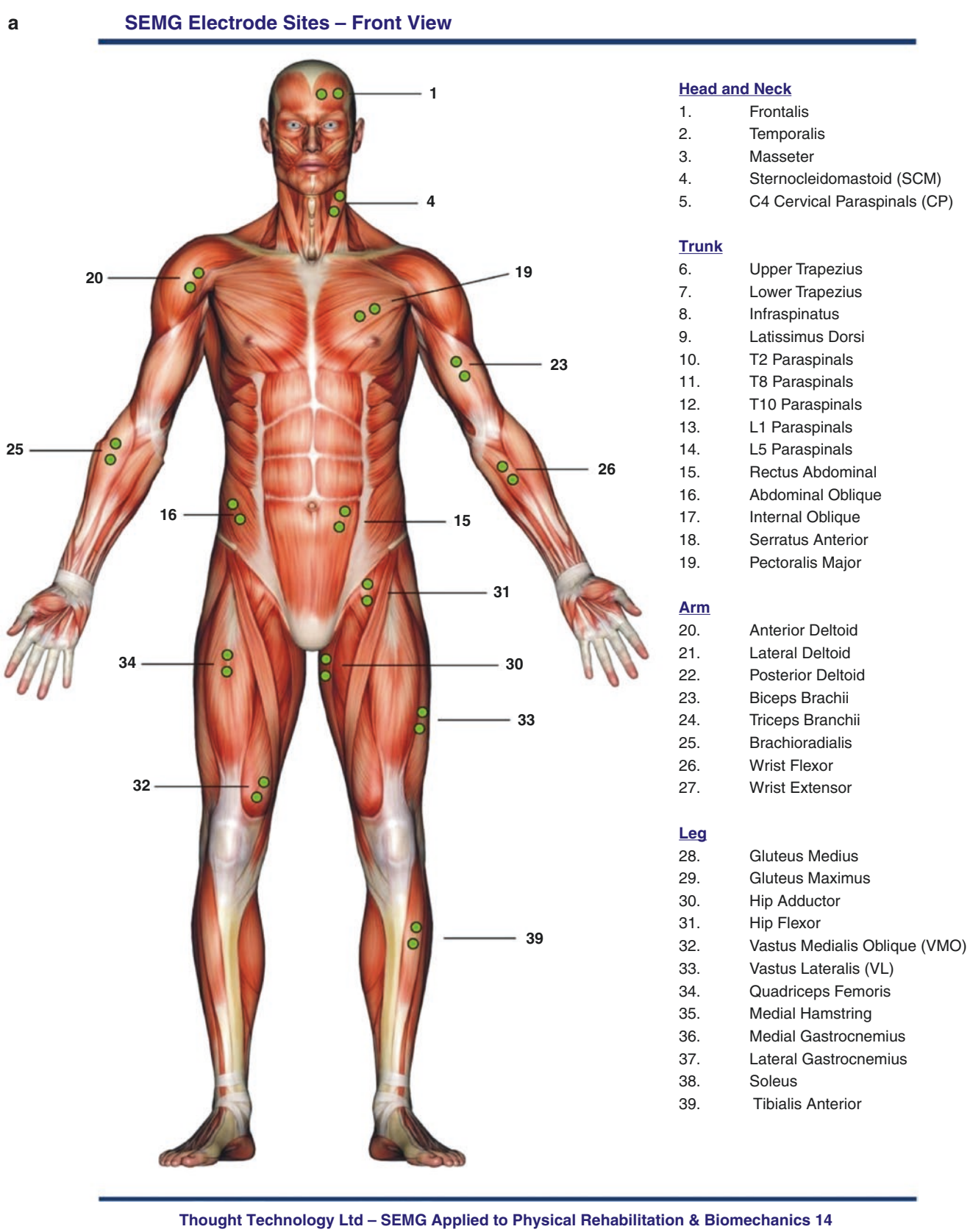
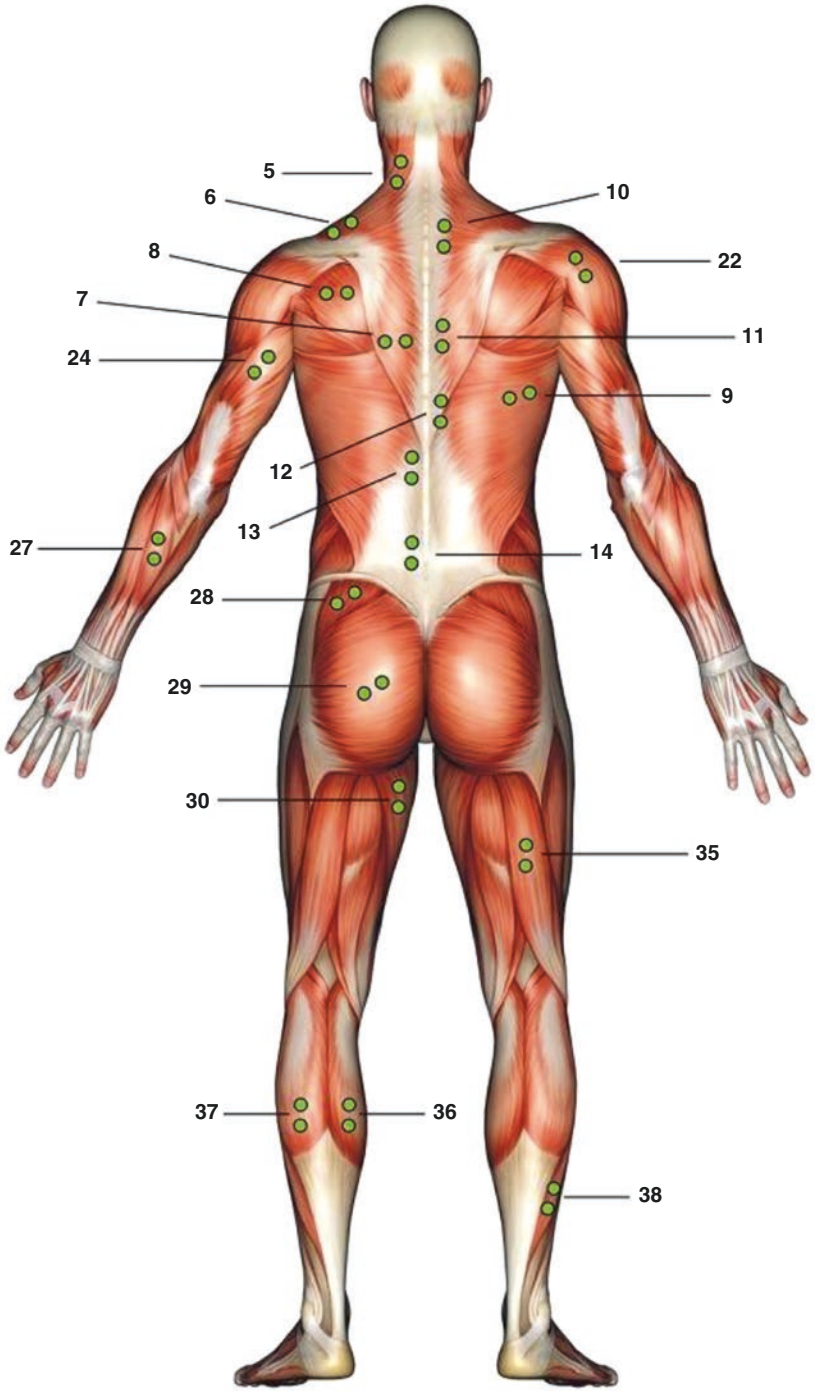


Fig. 13.7 Muscle involved with postural integrity—front (**a**), back (**b**), and side (**c**) views. Reprinted with permission from Thought Technology, Montreal, Quebec, Canada www.thoughttechnology.com [25]

b **SEMG Electrode Sites – Back View**



Head and Neck

1. Frontalis
2. Temporalis
3. Masseter
4. Sternocleidomastoid (SCM)
5. C4 Cervical Paraspinals (CP)

Trunk

6. Upper Trapezius
7. Lower Trapezius
8. Infraspinatus
9. Latissimus Dorsi
10. T2 Paraspinals
11. T8 Paraspinals
12. T10 Paraspinals
13. L1 Paraspinals
14. L5 Paraspinals
15. Rectus Abdominal
16. Abdominal Oblique
17. Internal Oblique
18. Serratus Anterior
19. Pectoralis Major

Arm

20. Anterior Deltoid
21. Lateral Deltoid
22. Posterior Deltoid
23. Biceps Brachii
24. Triceps Branchii
25. Brachioradialis
26. Wrist Flexor
27. Wrist Extensor

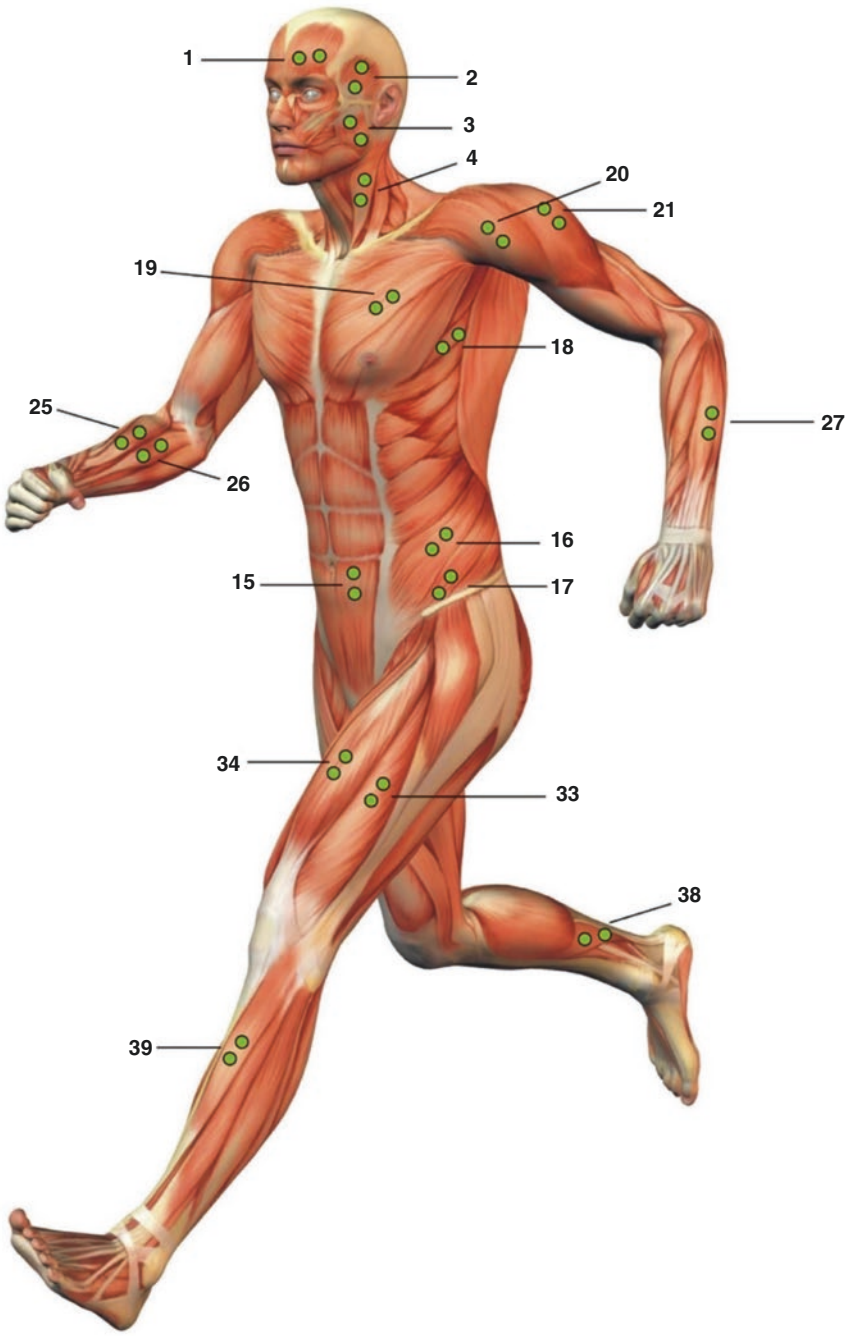
Leg

28. Gluteus Medius
29. Gluteus Maximus
30. Hip Adductor
31. Hip Flexor
32. Vastus Medialis Oblique (VMO)
33. Vastus Lateralis (VL)
34. Quadriceps Femoris
35. Medial Hamstring
36. Medial Gastrocnemius
37. Lateral Gastrocnemius
38. Soleus
39. Tibialis Anterior

Fig. 13.7 (continued)

c

SEMG Electrode Sites – Side View



Head and Neck

1. Frontalis
2. Temporalis
3. Masseter
4. Sternocleidomastoid (SCM)
5. C4 Cervical Paraspinals (CP)

Trunk

6. Upper Trapezius
7. Lower Trapezius
8. Infraspinatus
9. Latissimus Dorsi
10. T2 Paraspinals
11. T8 Paraspinals
12. T10 Paraspinals
13. L1 Paraspinals
14. L5 Paraspinals
15. Rectus Abdominal
16. Abdominal Oblique
17. Internal Oblique
18. Serratus Anterior
19. Pectoralis Major

Arm

20. Anterior Deltoid
21. Lateral Deltoid
22. Posterior Deltoid
23. Biceps Brachii
24. Triceps Branchii
25. Brachioradialis
26. Wrist Flexor
27. Wrist Extensor

Leg

28. Gluteus Medius
29. Gluteus Maximus
30. Hip Adductor
31. Hip Flexor
32. Vastus Medialis Oblique (VMO)
33. Vastus Lateralis (VL)
34. Quadriceps Femoris
35. Medial Hamstring
36. Medial Gastrocnemius
37. Lateral Gastrocnemius
38. Soleus
39. Tibialis Anterior

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Fig. 13.7 (continued)

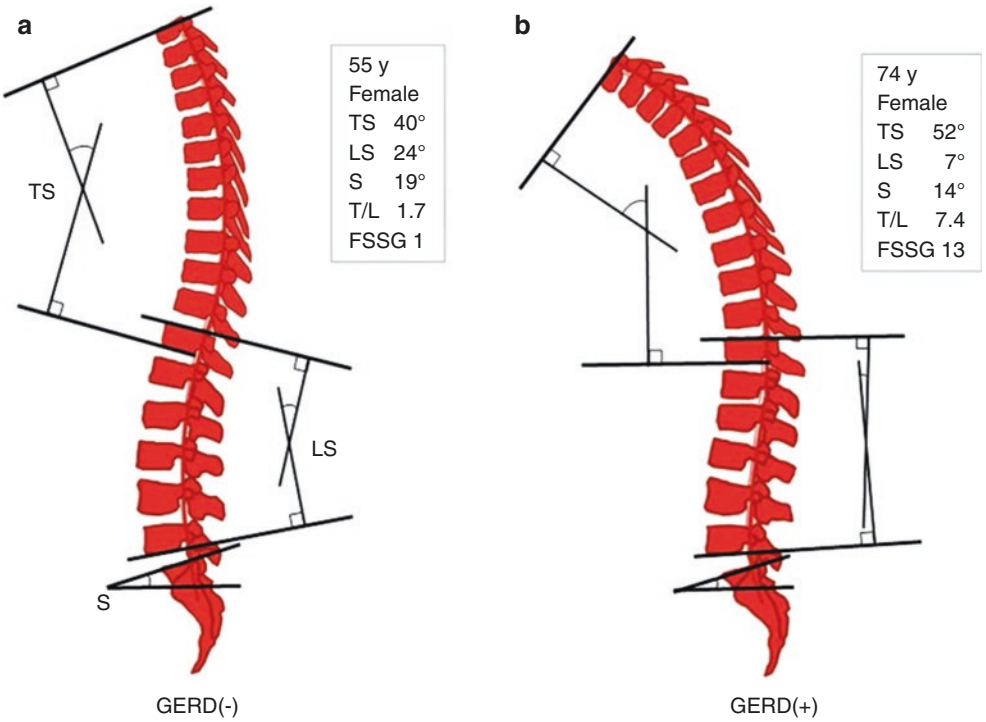

Fig. 13.8 Kyphosis of the spine in a 55y female (**a**) compared to kyphosis in a relatively older 74y female (**b**) [26]. Reprinted from Imagama S, Hasegawa Y, Wakao N, Hirano K, Hamajima N, Ishiguro N, Influence of lumbar kyphosis and back muscle strength on the symptoms of gastroesophageal reflux disease in middle-aged and elderly people, European Spine Journal, Vol 21, pages 2149–2157, © 2012, Springer Nature, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3481106/ under the terms of the Creative Commons Attribution 2.0 International License

Table 13.2 Sample exercises for postural correction

Exercise	Instructions	Purpose
Chin tucks and juts	1. Start sitting or standing with as erect posture as possible 2. Tuck the chin straight backwards without moving your chin up or down 3. Then push the chin forward without moving your chin up or down 4. Repeat this movement sequence for 3–5 sets of 8–10 repetitions	Improve head alignment with the spine and prevent excessive flexion of the cervical spine by strengthening the neck musculature
Wall tilts	1. Start standing erect with feet shoulder width apart and your heels approximately 6 inches from a wall 2. Lean backwards until your butt and upper back rest on the wall 3. Place your hand behind your lower back in the space created between your lumbar spine and the wall 4. Exhale as you contract your abdominal muscles and attempt to exert more pressure onto your hand with your lower back 5. Relax and inhale and repeat the movement 6. Repeat for 10 repetitions	Strengthen the abdominal muscles, stretch the spinal erectors, and reduce pronounced anterior pelvic tilt
Scapular retractions	1. Start sitting or standing with your chin tucked and upright posture 2. Position arms at your side or slightly bent at the elbow 3. Squeeze your scapula together toward your spine and hold for one second without shrugging your shoulders 4. Relax your scapula 5. Repeat for 3 sets of 8–10 repetitions	Strengthen the rhomboids, trapezius, and levator scapulae. Promote thoracic extension
Reverse flies	1. Mount a resistance band at eye level and place one end of the band in each hand 2. Begin standing upright with your feet shoulder width apart and your arms extended in front of you 3. Take a few steps back until you feel moderate tension in the band 4. Keeping the arms extended, pull your hands toward your pockets, attempting to keep them close the side of your body 5. Return to the start position and repeat for 3 sets of 8–10 repetitions	Strengthen the rhomboids, trapezius, and latissimus dorsi. Promote thoracic extension
Banded rows	1. Mount a resistance band at chest level and place the one end of the band in each hand 2. Begin standing upright with feet shoulder with apart 3. Take a few steps away from the mount point of the band until there is moderate tension in the band 4. Extend arms straight in front of you with your thumbs facing the ceiling 5. Keep your shoulders down and elbows close to your side as you pull your hands toward your side just below the level of the pectoralis major 6. Straighten your arms back to the start position 7. Repeat for 3 sets for 8–10 repetitions	Strengthen the rhomboids, trapezius, and latissimus dorsi. Promote thoracic extension

Table 13.2 (continued)

Exercise	Instructions	Purpose
Shoulder circles	1. Stand erect with your arms raised out to your sides in a "T" pattern, making a 90° angle at your armpit 2. Slowly turn your arm in a small circle forward 3. Continue this for 20 repetitions, increasing the size of the circles as you go 4. Repeat in the opposite direction 5. Perform both directions twice	Increase mobility of the thoracic spine
Side lying thoracic rotations	1. Begin lying down on one side with your knees bent toward your chest, creating a 90° angle at both the hip and knee 2. Place your arms in front of you and slowly lift the arm not in contact with the ground up toward the ceiling 3. Attempt to bring this arm as far to the opposing side as possible without discomfort and hold the position for 1–2 s 4. Return the arm to the start position and repeat 10–15 times 5. Switch to the other side and repeat the same movement 10–15 times	Increase mobility of the thoracic spine
Bird dogs	1. Begin on the ground on your hands and knees with eyes looking directly at the ground 2. Keeping your right arm straight, lift it up in front of your body until it is level with your head. At the same time, straighten your left leg and lift it until it is level with your hips 3. Hold this position for 1–3 s and return to the start position 4. Avoid overarching your lower back, and reduce the height of which you lift the limbs if needed to prevent it 5. Avoid allowing your hips or torso to shift from side to side 6. Perform 5–8 repetitions before switching to the other side 7. Aim to perform 2–3 sets total for each side	Strengthen the abdominal muscles and glutes. Improve both balance and spinal stability
Plank	1. Begin lying face down with your arms bent at the elbow and forearms resting on the ground parallel to your torso 2. Keep your feet about 6 inches apart with toes pushing into the ground 3. Contract your abdominal muscles and glutes as you lift your torso and legs from the ground 4. The back, hips, and legs should be in somewhat straight line as you keep your abdominals and glutes contracted to maintain proper position 5. Hold for 30 s and repeat three times	Strengthen the rectus abdominus, transverse abdominus, glutes, quadriceps, deltoids, trapezius, and erector spinae. Improve isometric core strength
Lying back extensions	1. Begin lying face down with arms extended straight toward the top of your head and toes point down 2. Contract your glutes, core, and back to lift both shoulders, arms, and legs off the ground about 6–12 inches 3. Hold this position for 2–3 s before returning to the start position 4. Repeat for 3 sets of 10 repetitions	Strengthen the trapezius, rear deltoids, spinal erectors, glutes, and hamstrings
Glute bridge	1. Begin lying down on your back with your knees bent, feet flat on the ground about 8–12 inches from your glutes, and arms on the ground at your side 2. Push your palms and feet into the ground as you contract your abdominal muscles, glutes, and hamstrings to press your hips upwards toward the ceiling 3. Hold this position for 2–3 s before returning to the start position 4. Repeat for 3 sets of 10 repetitions	Strengthen the glutes, hamstrings, and abdominal muscles. Improve control of the core and hips to stabilize the spine
Bodyweight squat	1. Begin standing upright with feet shoulder with apart, toes slightly rotated outward, and arms extended in front of your body 2. Inhale as you contract your abdominal muscles and shift your hips slightly back as you begin to squat 3. Allow your hips to descend downwards as your knees begin to bend 4. Squat as deep as possible without causing discomfort/pain or allowing your heels to come off the ground 5. After achieving the bottom of the squat, stand back up, contracting your legs and glutes until you are back to the start position 6. Repeat for 3 sets of 10 repetitions	Strengthen the quadriceps, hamstrings, calves, glutes, abdominal muscles, and erector spinae. Improve flexibility and mobility of the hips, knees, and ankles and stability of the trunk and hips

13.2.4.1 Other Therapeutic Modalities

In the last few years, athletes have adopted the use of Kinesio Taping injury susceptible muscle groups and joints. For example, a baseball player with a minor rotator cuff strain may use this taping method in an attempt to maintain shoulder girdle integrity during the rigors of a game. The idea behind this method is utilizing the tape in certain biomechanical patterns that should align the musculoskeletal elements to prevent further injury. Kinesio Taping has made its way into the mainstream in recent years, with ordinary people touting its positive effects. With respect to posture, a randomized controlled clinical trial conducted by Bulut et al. of unblinded assessments of 42 postmenopausal osteoporotic females with hyperkyphosis showed that Kinesio Taping could mitigate pain in the short term, but did not have any significant change in kyphotic angles or balance [35]. Although there have been some systematic reviews that show the positive effects of Kinesio Taping [36, 37], others have shown no overarching positive clinical outcomes from its use [38, 39]. As such, more research will need to be conducted before a recommendation on its usage is decided.

Manual therapeutic techniques include the use of tissue mobilization to improve or restore a patient's normal movement and reduce associated pain. These methods are typically performed by physical therapists and can include but are not limited to muscle and joint manipulation/mobilization. As poor posture lends itself to an imbalance in the musculoskeletal system, such therapies have their place in terms of treatment. A study out of Iran placed a group of 46 18–30-year old women with postural hyperkyphosis in two experimental groups: one that only performed stretching and strengthening of postural muscles, while the other only received manual techniques like myofascial release and mobilization [40]. Interestingly, the results showed improved thoracic kyphotic angle and improved back extensor muscle strength in both groups, indicating the effectiveness of both manual therapy and exercise in postural correction. A more involved form of manual therapy, neuromuscular manual therapy (NMT), involves more specific musculoskeletal issues, including chronic poor posture and has been shown be effective [41]. While manual therapy does have its place as a supplement, strengthening exercises remain key to making postural corrections and should form the crux of therapeutic regimen [42].

13.3 Future Directions and Concluding Remarks

As the female progresses in age, she may become less active over time, which contributes to weakening of muscles supporting the spine. This, in turn, leads to postural imbalances which then can contribute to pain, injury, and disability. Thus, to maintain spinal structural integrity, the active female must engage in/maintain a regular exercise/conditioning program targeting especially the core muscles, but just as important, balancing anterior/posterior muscle groups of the entire trunk. As such, one can help to prevent musculoskeletal injury from occurring, such as falling, which can result in disastrous consequences. It is essential to understand that treatment parallels prevention, since similar target exercises are utilized to stretch/strengthen/stabilize the entire spinal column to provide support and keep the musculoskeletal system healthy, in order to stay active and maximize athletic participation while enhancing activities of daily living.

Chapter Review Questions

1. What are the proper vertebral levels at which to measure the degree of kyphosis using the bubble inclinometer and what range of measurement is considered hyperkyphotic?
   (a) C7/T1 and T12/L1; >40°
   (b) T1/T2 and T12/L1; <40°
   (c) T1/T2 and L1/L2; >40°
   (d) T1/T2 and T12/L1; >40°
2. Which of the following exercises promotes thoracic extension and specifically involves contraction and strengthening of the upper back musculature?
   (a) Bird dogs
   (b) Banded rows
   (c) Wall tilts
   (d) Bodyweight squats
3. Which of the following correctly describes the components of a motor unit?
   (a) Motor neuron and skeletal muscle fibers innervated by that motor neuron
   (b) Motor neuron and neuromuscular junction (NMJ)
   (c) Neuromuscular junction (NMJ) and skeletal muscle fibers innervated by that NMJ
   (d) Motor neuron and muscle spindle
4. Which of the following is an example of an electrical-to-chemical signal transduction?
   (a) Presynaptic neuron → postsynaptic neuron
   (b) Motor neuron → neuromuscular junction (NMJ)
   (c) Sensory mechanoreceptor → afferent sensory nerve
   (d) Acetylcholine (ACh) → nicotinic acetylcholine receptor (nAChR)
5. Which of the following factors are involved in contributing to postural deficits in individuals?
   (a) Age
   (b) Gender
   (c) Muscular imbalances
   (d) All of the above

Answers

1. d
2. b
3. a
4. b
5. d

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Prevention and Management of Common Musculoskeletal Injuries in Skeletally Immature Female Athletes

14

Mimi Zumwalt

Learning Objectives
After completion of this chapter, you should have an understanding of:

- The important changes from prepubescence to postpubescence in females as far as anatomy and physiology of the musculoskeletal system are concerned.
- The pertinent differences AND similarities between young females and males in terms of anatomy, physiology, and biomechanics of the musculoskeletal system.
- The occurrence of various common musculoskeletal injuries more unique to young female athletes, especially during the adolescent growth spurt.
- Several measures for prevention of athletic injuries from occurring in preadolescent and adolescent females.
- Different methods of orthopedic treatment for musculoskeletal injuries incurred by young female athletes, including specific recommendations for a regular conditioning program once healing is complete in order to enhance their physical fitness profile.

14.1 Introduction

"Women are not Men; Children are not Small Adults!" This quote sums up the differences between females/males, and childhood/adulthood [1, 2]. The pubescent growth spurt, especially the period transitioning from late childhood to adolescence, represents a time of tremendous bodily transformation. Generally speaking, growth, development, and maturation play such an important role during these ever-so-important early to mid-teenage years. Specifically, growth refers to a size increase of the body or part(s) thereof, while development is the functional alterations occurring along with anatomical/structural growth. Maturation is reached when the body has achieved its full potential in terms of both growth and development, i.e., attainment of the adult form/frame. Specific organs/units involved in this early stage of life alteration include the reproductive/sexual, physiological, neurological, and musculoskeletal systems. Unique musculoskeletal conditions/injuries can occur while the body is growing, and they need to be recognized and addressed appropriately. In addition, with the increased emphasis on youth sports and more female involvement with athletic activities, this comes with a higher risk/frequency of orthopedic injuries, especially with track/field events, gymnastics, cheerleading, basketball, and soccer [2–5]. This chapter will focus on several of the more common musculoskeletal concerns of the young female athlete, along with prevention and treatment for these orthopedic issues/injuries.

14.2 Research Findings and Contemporary Understanding of the Issues

14.2.1 The Important Changes from Prepubescence to Postpubescence in Females As Far As Anatomy and Physiology of the Musculoskeletal System Are Concerned

After the initial rapid increase in height during the first 2 years of life (when 50% of adult height is attained) and up until the onset of puberty, a female's body grows steadily in terms of height and weight. Once puberty starts, growth velocity rapidly rises causing a dramatic increase in both height and weight, attaining the peak around the age of 12, after which growth begins to slow down. In girls, final adult stature is reached between the ages of 16 and 17. It is an established fact that regular exercise, along with an appropriate diet, is essential for proper bone growth in terms of width, density, and strength by mineral (calcium among others) deposition into the skeletal matrix [3, 6, 7]. In fact, at least

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30% of final adult bone mass is deposited/acquired within 3 years of peak growth velocity [8]. Alongside the bony framework providing structural support and protection for the body, musculotendinous and ligamentous attachment to the skeleton help the body synergistically by providing dynamic and static restraints while allowing motion/movement of the head, trunk, and limbs, respectively. Muscle mass also increases steadily (from hypertrophy or enlarging fiber size) in response to hormonal influence, reaching its peak between the ages of 16 and 20 years in females. As a corollary to the increase in muscle mass, an accompanied gradual rise in muscle strength occurs in conjunction as well and reaches a maximum by 20 years of age in young female adults [3]. Prior to puberty, girls and boys are comparable in terms of muscular strength. Then around 15 or 16 years old, adolescent females are only about 75% as strong as pubescent males of the same age. This strength difference is more marked in the upper versus the lower extremities [9].

In addition to longitudinal growth and gaining in body size/weight, morphologically, the young female body shape is further transformed during the adolescent growth spurt, partly in preparation for later childbearing [1, 3, 9]. Under the influence of estrogen, fat deposition increases to an amount more than doubling the percentage of total body weight present at birth (25% rather than 10–12%). Both sex-specific (surrounding breasts and hips) and subcutaneous tissue fat accumulate throughout the body of a young woman. The mechanism of adipose tissue storage, unlike that of muscle, stems from both hypertrophy (increase in the size of fat cells) and hyperplasia (increase in number of fat cells). The latter process can continue throughout one's life span, dependent on diet and activity, in addition to other factors. With continued enhancement from the developing neuromuscular and endocrine systems, motor control continues to develop; however, this process starts to plateau at the onset of pubescence in young females. Girls tend to slow down physically as a whole during adolescence, partly due to greater fat deposition [3]. To sum up, post-puberty, the adolescent female has more adipose tissue, less muscle mass, wider pelvis, more "knocked" knees, weaker upper body strength than young males, which puts them at greater risk for certain musculoskeletal injuries [1].

14.2.2 The Pertinent Differences and Similarities Between Young Females and Males in Terms of Anatomy, Physiology, and Biomechanics of the Musculoskeletal System

Before puberty, both growth and development in females and males parallel one another, i.e., same body composition. During this childhood stage, prepubescent girls and boys are similar in stature and have the same relative muscle mass and strength [2, 10]. However, at the onset of puberty, due to the differing levels of secreted sex hormones, namely, the ratio of estrogen to testosterone, body composition changes start to separate young girls and boys in terms of maturation of the musculoskeletal system. Females have an earlier onset of puberty (2 years) before males; however, teenage boys undergo puberty for a longer time period, specifically 4 years as compared to 3 years in adolescent girls [1, 11]. Puberty for females starts around age 10–13 and ends at 15–16, whereas for males, puberty begins at 12–15 years old and ends at 17–18 years of age [3, 10, 11]. Because males keep on growing for a longer period of time than females, they are on average 10% taller and 17% heavier than females by the time adulthood is attained [10].

Likewise, under the influence of a sudden ten times surge in testosterone production during puberty, boys markedly gain muscle mass at an accelerated rate, resulting in 40% of total body weight as compared to the 25% present at birth. However, muscle mass in young men does not reach its peak quantity until 18–25 years of age. Females do not undergo a significant change in muscle mass with puberty, resulting in only minor changes in muscular strength. Around age 12 or so, muscular strength in boys, and to lesser extent, in girls, starts to improve along with an increase in muscle mass [2, 3, 12, 13]. However, the rate of growth is compounded in males at a faster speed, stronger proportion, and longer duration, peaking between the ages of 20 and 30 [3, 12, 13]. Before puberty, males and females have similar muscular strength [2, 14]. However, around ages 11–12 females are 90% as strong, then between 13 and 14 years old females are 85% as strong, and by the age of 15–16, females are only 75% as strong as males. This muscular strength difference between the sexes can be accounted for by differences in body composition. Adult males have muscle mass comprising 40% of body weight, whereas females only have less than 25% of total muscle mass [14]. This difference is due to estrogen, which increases adipose tissue and has been shown to have a slight reducing effect on lean muscle [10]. In contrast, due to lower estrogen levels in addition to greater levels of androgens, males have an increase in lean tissue and do not tend to accumulate a large quantity of fat. Body fat in physically unconditioned males ultimately reaches 15% of total body weight, whereas unconditioned females average about 25% total body fat. For a conditioned male athlete, the fat percentage is lower at 7%, and for athletic females around 10–15% [10, 14].

The difference in muscle mass and adipose tissue between females and males also accounts for variation in ability, coordination, and learning of motor skills starting between the ages of 9 and 12 for both sexes. After age 12, the physical performance in males continues to accelerate and far exceeds that of adolescent females during puberty due to more mus-

cle mass/strength and less fat accumulation [3, 12]. Along the same lines, development of speed also favors adolescent males, which ultimately results in higher fitness levels as compared to teenage girls. In fact, the sprint velocity increases yearly starting at 5 years old in both sexes, but maxes out in females between the ages of 13 and 15, yet does not peak in boys until the age of 16. Two phases encompass the phenomenon of speed development; the first begins at about age 8 in both girls and boys, most likely attributed to improved coordination aided by the maturing nervous system. The second phase occurs around age 12 in females, and anywhere from 12 to 15 years old in males as a natural progression from the larger body size, muscle mass, and along with these changes, speed, strength, power, and endurance [12]. Morphologically, pubescent boys maintain their body structure similar to prepubescent girls, again affected by the ratio of testosterone to estrogen. Interestingly, more recent studies have demonstrated that neuromuscular control and preference of muscle recruitment, especially in the lower limbs of adolescent females during certain sporting activities (volleyball, softball, field hockey, basketball, and soccer in ascending order) differ from that of male athletes, potentially putting these young girls much more at risk for knee/ligament injuries [2, 15–18].

14.2.3 The Occurrence of Various Common Musculoskeletal Injuries More Unique to Young Female Athletes Especially During the Adolescent Growth Spurt

As previously outlined, the transition from prepubescence to postpubescence in females brings on a multitude of bodily changes, the majority of which involves the musculoskeletal system. While the skeleton is growing rapidly, muscles, tendons, ligaments, and other connective tissues must also grow to accommodate this accelerated bony growth. In fact, under endocrine and neural influence, locomotion and movement must be coordinated plus adapted to the transforming skeletal framework in order to carry out life tasks and other physical endeavors, such as recreational athletics or competitive sports. Consequently, teenage female athletes involved in certain sporting activities are exposed to a higher risk of orthopedic injuries. This is partly due to a marked rise in the number of school-aged females playing sports, from one female participating in competition compared to 27 male athletes in 1972 to the ratio of one female athlete competing to three males more than 30 years later. Half of all children aged 5–18 years in the USA are thought to participate in interscholastic organized athletic programs [11]. This number of scholastic athletes comprises over five million, in addition to another 30 million kids (6–21 years of age) involved in non-scholastic sporting activities [1, 19].

Epidemiological studies in the US from the previous literature have reported on close to 12,000 young active children/adolescents between 5 and 17 years of age found that over 35% with injuries stemmed from recreational and athletic activities. The annual occurrence of sports-related trauma adds up to over four million, with close to half (two million) is of a serious nature. The ratio of injured female to male is 1:~2. A majority of traumatic cases are due to overuse. Typically, sports riskier for injury in pre-adolescent and adolescent female athletes are basketball, gymnastics, and cheerleading, with the latter needing to seek medical and/or surgical treatment the most [1]. As for sites of injury, the lower extremities (especially knee and ankle) exceed both truncal and upper limbs in occurrence for the majority of sports, especially soccer [1, 20]. Similarly, young active females also tend to sustain more upper extremity injuries in cheerleading and gymnastics since they must use their arms as weight-bearing entities while performing stunts or for lifting up teammates [1].

Sports-related injuries (SRIs) comprise the top reason for emergency room (ER) visits in adolescents [2, 4]. Safe Kids Worldwide ER survey in 2013 noted that 1.35 million kids per year are afflicted with this type of trauma, which translates to 1 out of 5 children is being brought in for medical care every 25 s! Sports such as basketball/soccer involve participation of both boys and girls, with the latter sustaining more concussions [4]. Head injuries also occur more frequently after falls while skating, skateboarding, and bicycle riding [1]. However, according to the Center for Disease Control and Prevention (CDC), about 50% of sports injuries in young athletes can be predicted/prevented [2]. As for demographics of sports-related injuries, literature from surveys of almost 650 Portuguese youth 10–17 years of age shows that inactive kids and girls who have just undergone the "growth spurt" are at higher risk of musculoskeletal trauma. Similarly, very specialized, competitive, young scholastic athletes also are more vulnerable (2/3 up to greater than 2 times) to overuse type of orthopedic ailments, especially if the duration of sports participation exceeds 10–15 h weekly [4, 5]. In terms of location of musculoskeletal complaints, a review of Denmark population/clinical studies shows that painful ankle/foot issues are more prevalent in children up to 12 years old versus knee symptoms in those up to 19 years of age. Non-traumatic, minor cases outnumber injuries involving the lower limb (2 times), as compared to a higher number of trauma-inciting events in the upper extremities [21]. Similarly, ankle, head, hand, and knee lead the list as far as athletic injuries in youth are concerned [4].

More recently, authors in 2015 summed up similar gender differences in SRIs after reviewing retrospectively more than 3800 medical charts of over 1600 young patients 5–17 years of age in a span of 9 years. Females comprise about 50% of all musculoskeletal trauma, over half from overuse, with

~60% affecting the lower limb. Sports with more SRIs include cheerleading, gymnastics, running (track and field), dancing, swimming, and tennis. A greater proportion of females (~60%) sustain overuse injuries as compared to males (40%). A majority of the latter played team sports (which portends greater than 5 times at risk) especially involving contact/collision with other players [22]. Within the same timeframe, overuse trauma in US high school athletes was reviewed over 5 years via an online reporting survey, demonstrating the incidence of 1.5 per 10,000 sports-related exposures, which varied according to sport and sex. Girls involved in field hockey/track and field sustained more overuse injuries, with the lower limb being the most frequent area of trauma. Boys suffered more injuries when playing ice hockey or if involved in diving/swimming [23].

Susceptibility to musculoskeletal trauma results from both intrinsic and extrinsic factors. Intrinsic factors include age, gender, strength, flexibility, and prior injury. Extrinsic factors include movement biomechanics, skill level, equipment, environment, training schedule, and intensity of activity. Both intrinsic and extrinsic factors can work together or against each other to provide either a mechanism of trauma or prevention of injury [2, 18, 24]. For example, the repetitive nature of throwing and the acquired high velocity are coupled to cause chronic repetitive injury over time. Trauma can result from direct impact (such as a collision with another player) or via an indirect mechanism (such as a force transmitted through an extremity being loaded causing injury at a different site) [2, 18, 22, 24] (Fig. 14.1).

Aside from acute trauma occurring by sudden explosive episodes, more gradual, chronic bouts of repeated force over and over can also cause microdamage to bone and soft tissues of the musculoskeletal system, resulting in overuse injuries, which comprise close to 50% of all sports-related orthopedic issues, and can eventually progress to stress fractures [2, 18, 24]. After a physical insult, inflammation is the body's natural response to tissue trauma, which can develop in response to an acute injury or from repeated, chronic mechanical irritation. The primary functions of this physiologic reaction are to protect the body from harmful histamines being released, dispose of dead/dying tissue, and promote repair/regeneration of new tissue. The first step of inflammation is an increase in blood flow and capillary permeability at the site of injury due to the release of chemicals by injured tissue cells. This causes swelling or edema with a subsequent rise in osmotic pressure, in turn causing an increase in the movement of proteins, white blood cells, and fluid to the area of trauma. Edema and associated chemicals heighten the sensitivity of pain receptors, causing an increase in painful sensation of the involved area. The next step after the initial vascular response is coagulation, causing fluid to be trapped at the injured site. This captured liquid, also known as exudate, dilutes and inactivates toxins, provides nutrients for cells, and contains antibodies. The final phase of inflammation is the breakdown of coagulation cascade products by a decrease in osmotic pressure causing chemicals, toxins, and dead cells to leave the site of injury [18].

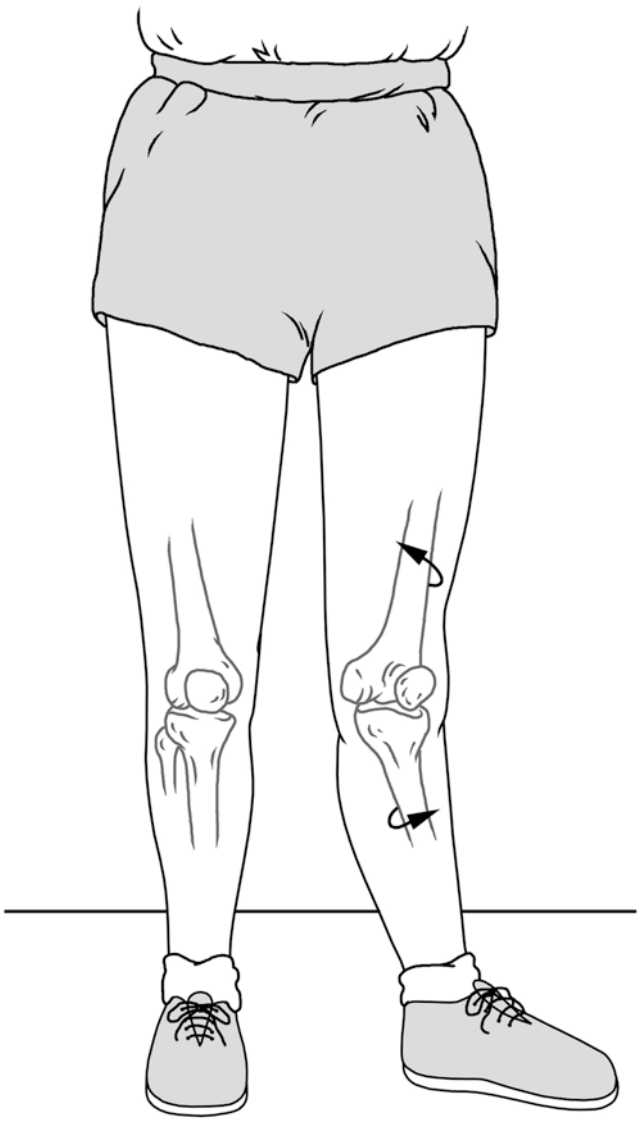

Fig. 14.1 Risky limb landing attitude

The greatest difference between the immature skeleton and the adult skeleton is the presence of physes or open growth plates. The physes is comprised of cartilage cells that proliferate to create longitudinal bony growth. Apophysis is a similar structure but differs in that it is in close proximity to the tendinous attachment on bone but does not contribute much to skeletal length [14] (Fig. 14.2).

As discussed in previously, there is an inherent weakness of the physes, especially prior to 12 years of age and during the peak height velocity (PHV) or adolescent growth spurt because the maximal height speed is obtained prior to peak bone mass. These growing anatomical structures (primarily

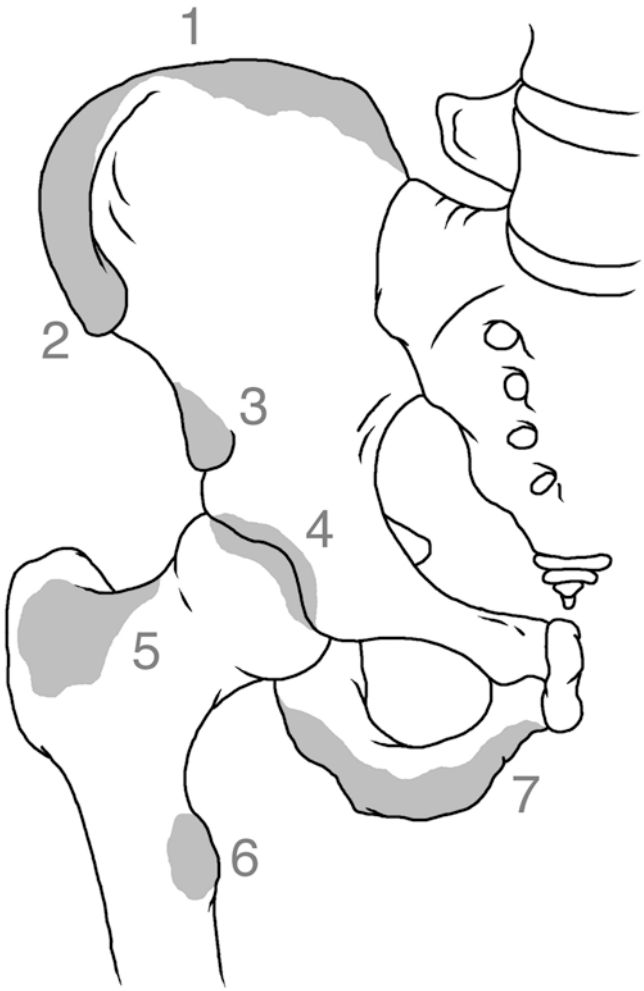

Fig. 14.2 Pelvic apophyses

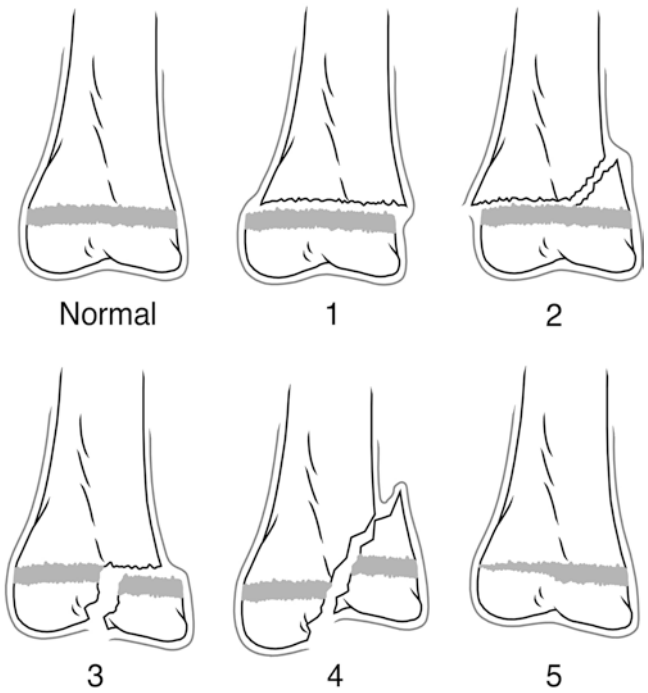

Fig. 14.3 Growth plate injuries

at the ends of long bones) are also at more risk of injury when exposed to excessive force because they are immature-inherently weaker than the surrounding ligaments and tendons [1, 14, 19, 25]. The enveloping tissue, including capsules (connective tissue around joints), has sufficient strength thus can resist an application of force better than the more tenuous physeal plate along with adjacent cartilage and bone. Consequently, any stress of sufficient magnitude to tear ligaments in adults tends to disrupt the physeal cartilage in bones of younger children, resulting in growth plate injuries or avulsion fractures (Fig. 14.3). Additionally, during the PHV phase, a temporary decline in bone mineral density occurs, placing growing skeletal tissue more at risk for acute injury or chronic overuse trauma, i.e., stress fractures [25]. In other words, younger children (5–12 years old) are at less risk of overuse injuries as compared to older teens/adolescents (13–17 years of age) [23].

In terms of fracture avulsions (small fragment of bone with attached soft tissue), this type of acute trauma results from sudden violent muscular contractions transmitted through various tendons inserted onto a bone. Physeal injuries account for about 15% of all fractures in children; with girls more prone to injury from 9 to 12 years old and boys from 12 to 15 years of age [1, 19, 26]. Physiologic fusion of growth plates begins during the preteen years and is completed by the early twenties, occurring several years earlier in girls than boys. Prior to completion of the final fusing process, any physeal damage incurred while the body is changing/transitioning may lead to temporary or even permanent growth disturbance, which could result in leg length discrepancy or angular deformity of the affected limb [2, 14, 26].

Bone of the immature skeleton is more porous and not as dense as adult bone due to the fact it is more vascular with less mineral content, which translates to being more flexible but inherently structurally weaker, since linear skeletal growth exceeds bone mineralization [14, 23, 25, 26]. As a result, prior to puberty, young children tend to suffer skeletal trauma/fractures more frequently, whereas active adolescents often sustain a higher number of soft tissue injuries [23, 25]. The offset of this characteristic, however, is that the periosteum or envelope surrounding growing bones is thicker, stronger, and biologically more active; thus, greatly promotes the process of healing at a much faster rate in children as compared to adults [14, 26].

As previously noted, the most common musculoskeletal injury found in pubescent athletes involves chronic, repetitive, submaximal mechanical load applied to the same area, causing tissue micro-damage. Continued microtrauma culminates in bursitis of soft tissues, strains of tendons, sprains

of ligaments, and stress reactions or even frank fractures of bones. This type of orthopedic injury tends to occur more often in the lower rather than upper extremities and results primarily from overtraining [1, 24]. The anatomical sites that are more prone to fatigue/stress fractures depend on the types of movement performed in specific athletic activities causing mechanical overloading on cortical bone, with the tibia, fibula, and metatarsals being more common sites [19, 24]. For example, in the lower extremity, volleyball and basketball players are at increased risk of stress injury to the tibial metadiaphyseal junction due to repeated jumping/landing. Long distance runners, especially those athletes engaged in training over 20 miles weekly, can suffer stress fractures to their femoral neck or fibula from excessive impact from running. In a similar fashion, because ballerinas have to be "en pointe" while dancing on the tips of their toes, they tend to sustain stress fractures of the second metatarsal more readily [24].

Stress injury can also occur in the upper extremities from microtrauma due to overuse. Stress fractures are commonly seen involving the ribcage, shoulder girdle, and bones distal to the elbow such as the ulna [2, 24]. The latter occurs from participation in tennis and in fast-pitch softball players due to the nature of their racquet striking the ball or mechanism of pitching with their forearms, respectively [24]. Over 50% of young female tennis players are afflicted with dominant shoulder/wrist or low back issues at some point as compared to ~30% of boys [2]. Along the same lines, the risk of overuse injuries involving the capitellum is frequent since it receives 60% of compressive force, and also radial fatigue fractures is higher in female gymnasts as a result of repetitive impact-weight/load-bearing maneuvers on their elbows and wrists, respectively [1, 19, 24]. Similarly, peripubertal 10- to 14-year-old female gymnasts (Tanner Stages 2 and 3) experience chronic wrist pain more often than post-pubescent teenage girls [25]. Although quite rare, swimmers can injure their humeri from repeated overhead striking the water [24].

Furthermore, other athletic activities involving repetitive back extension maneuvers, i.e., dance, skating, cheerleading, and gymnastics can potentially place excessive load on the lumbar spine, resulting in a stress fracture of the pars interarticularis (spondylolysis) [1, 9] (Fig. 14.4). This location for SRIs is common for back trauma that affect a large portion of adolescents and female athletes. They include spondylolysis and spondylolisthesis involving the lumbar vertebrae, particularly at L4–L5 and L5–S1 levels. Spondylolysis is characterized by a defect in the lamina between the superior and inferior articular facets, while spondylolisthesis is the translational motion between adjacent vertebral bodies. There are different classifications of injury for these two mechanisms; however, for the young athlete, repetitive axial loading or hyperextension force causes microfractures and eventually progresses to complete bone failure [14, 27]. Treatment for both of these lumbar spine injuries consists of back bracing

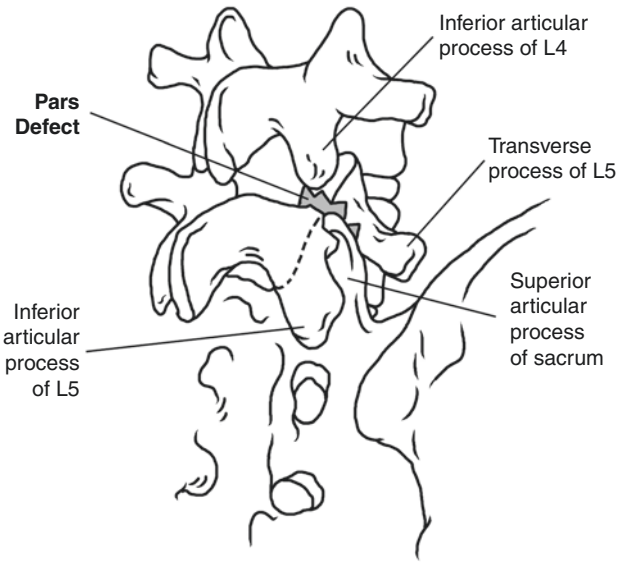

Fig. 14.4 Spondylolysis

and hamstring stretching. Acute trauma to the back and neck (cervical spine) can result from high impact collisions and acrobatic sports. While it is uncommon to see fractures of the thoracic spine (since it is protected by the ribcage), when this traumatic injury does occur, it can result in devastating consequences [27].

Additional variables contributing to other overuse type of musculoskeletal trauma include external environmental factors such as inadequate playing equipment, difficult/uneven surface terrain, faulty footwear, and inappropriate technique. The internal body environment such as genetics, anatomic variation, and previous trauma to certain structures also contributes to overuse injuries. Females in particular have altered internal endocrine milieu due to monthly hormonal changes (as discussed in a previous chapter). Varying hormones in the circulation have different effects on soft tissue, timing of muscular contraction, and stability of joints. For instance, with the upper extremity, structural differences in young female athletes place them more at a mechanical disadvantage and, therefore, at an increased risk for certain types of overuse injuries. This stems from a shorter humerus compared to total arm length, less muscular strength, and more joint laxity. Consequently, sports involving excessive overhead activity such as throwing, swimming, etc. (tennis, softball, volleyball, handball) can contribute to rotator cuff tendinosis and shoulder subluxation from overstretching of the anterior capsule with repetitive movements [1, 2, 18, 19].

Rotator cuff injuries are uncommon in adolescent athletes. However, injury to the shoulder is common in overhead sports. For example, Little League's shoulder causes pain in the proximal humerus due to repetitive throwing. This is thought to be an overuse injury involving the physes and is not only limited to male baseball players, but is also

seen in females playing other overhead sports such as softball, swimming, gymnastics, volleyball, and tennis [2, 11, 19]. Treatment consists of relative rest, ice, and anti-inflammatory medications. Even though traumatic shoulder dislocations are rare in adolescents, it is the most common dislocated large joint involving athletes in general, with males exceeding females by 2 to 1 in incidence [14, 28]. Dislocation usually results from an indirect force caused by landing on an abducted and externally rotated arm [9]. After a shoulder dislocation, the issue of recurrence arises especially in young athletes. One study found recurrence rates of at least 75% in athletes younger than 20 years of age primarily in males [29]. On the other hand, active young females are more at risk of having atraumatic multidirectional shoulder instability due to inherent glenoid morphology and generalized ligamentous laxity [28].

As for another upper extremity location affected by overuse trauma, injuries to the wrist joint can occur from repetitive impact forces. The radius and ulna comprise bones of the forearm. The relative length difference between these two bony structures is known as ulnar variance (UV). When the ulna is longer than the radius, UV is positive; and vice versa when the radius is longer than the ulna, UV is negative [14]. Youths of adolescent age tend to have negative UV, contributing to impingement on the carpus especially with impact forces [19]. Variation in UV is determined by age, gender, ethnicity, and physical loading history. While the wrist is not designed to be a load-bearing joint, in sports such as gymnastics or tumbling in cheerleading, a great amount of force in applied to the wrist then transmitted to both the ulna and radius, with the radius receiving 80% of the load. Particularly in those young athletes with immature bones, repeated loading of the wrist can cause premature closing of the distal radial growth plate. As the athlete matures, the ulna continues to grow, thus causing a positive UV. Continual impact loads on the wrist causes other issues such as ulnar impaction syndrome, with progressive degeneration of the fibrocartilage and bones of the ulnar-sided carpus [14].

Lateral ankle sprains are among the most common adolescent sports-related injury occurring in the lower extremity of young active females [14, 30]. This injury usually results from inversion of a plantar-flexed foot injuring the anterior talofibular ligament (ATFL) and the calcaneofibular ligament (CFL). Symptoms of an ankle sprain include swelling, bruising, tenderness, and decreased range of motion. Studies have shown that bony tenderness in adolescent sprains is correlated with fracture; therefore, any ankle injury with extreme pain and difficulty upon weight bearing should be radiographed to detect fractures. Treatment for ankle sprains consists of relative rest, ice, elevation, and compression, with progression to rehab exercises as tolerated [14].

The "miserable malalignment syndrome" is quite unique to young female athletes and is a constellation of lower extremity anatomical structures being misaligned. This syndrome involving the lower limbs is associated with primary quadriceps neuromuscular dominance, placing the knee at an increased risk, especially anterior cruciate ligament (ACL) injuries during various sporting activities [12, 16, 18]. The lower limb structural malalignment consists of a widened pelvis, genu valgum, increased internal tibial torsion, and pes planus. The Q-angle is accentuated, contributing to patellar maltracking which can cause anterior knee pain as well [9] (Fig. 14.5).

In fact, the incidence of patellofemoral syndrome (PFS) is three times greater in active adolescent females as compared to male athletes [28]. This common source of knee pain is localized anteriorly, centered around the patella, caused by activities such as repetitive knee flexion, jumping, climbing stairs, and sitting for long periods of time [9]. Treatment for PFPS includes strengthening the quadriceps (especially the vastus medialis oblique-VMO), restraint bracing, and patel-

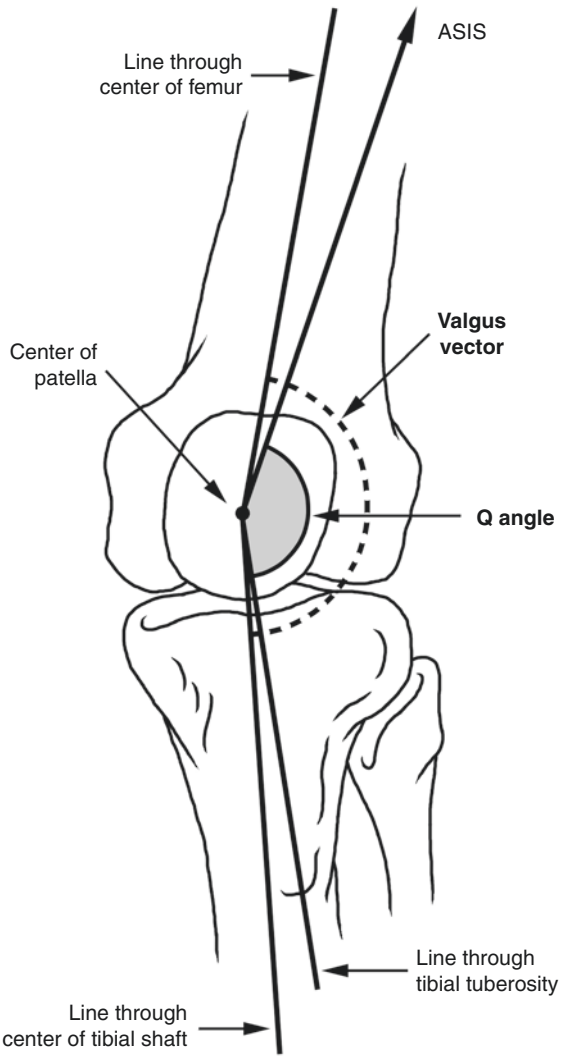

Fig. 14.5 Alignment/forces across the knee joint

lar taping. A group of researchers found that, for adolescent female athletes, the use of orthotics for excessive pronation can help to relieve anterior knee pain as well [31]. In extreme cases, surgery might be needed to correct PFPS such as lateral release, proximal patellar realignment, and medial tibial tubercle transposition to address variation of aberrant anatomy [32] (Fig. 14.6).

Dislocation of the patella is another knee injury more commonly found in active teenage females aged 14–18 years, most often occurring laterally. The cause of this acute trauma is usually due to internal rotation of the femur with a fixed foot causing the quadriceps to pull the patella in the lateral direction. A less common mechanism is a medial blow to the knee causing lateral patellar dislocation. The dislocated patella, in general, usually spontaneously reduces; however, if it does not relocate on its own, slow extension of the knee with medial force on the lateralized patella will result in reduction [14]. The occurrence of subsequent patellar dislocations is between 15 and 44%, with higher rates being associated with younger age of the affected female [32].

Yet another condition in growing children causing anterior knee pain is Osgood–Schlatter disease (traction apophysitis of the tibial tuberosity). This entity is commonly seen in young athletes aged 8–15 years, between 8 and 12 in girls and from 12 to 15 years of age in boys. The patella tendon transfers high amounts of force generated by quadriceps contraction to the bony attachment of the anterior proximal tibia, causing micro-avulsions of the tendinous insertion. In particular, muscular contractions from sprinting and jumping activities create high forces repeatedly irritating the tibial tubercle, causing it to become tender and painful with subsequent quadriceps contraction. Increased force can also stimulate bone growth, increasing the size of the tuberosity as well. Prominence of the tibial tubercle s is seen around the adolescent growth spurt. Treatment for Osgood–Schlatter disease is conservative with stretching, ice, anti-inflammatory drugs, and rest. After the adolescent growth spurt, knee symptoms begin to abate then sequester, and this affliction associated with growth disappears upon closure of the physes [1, 11, 19, 33].

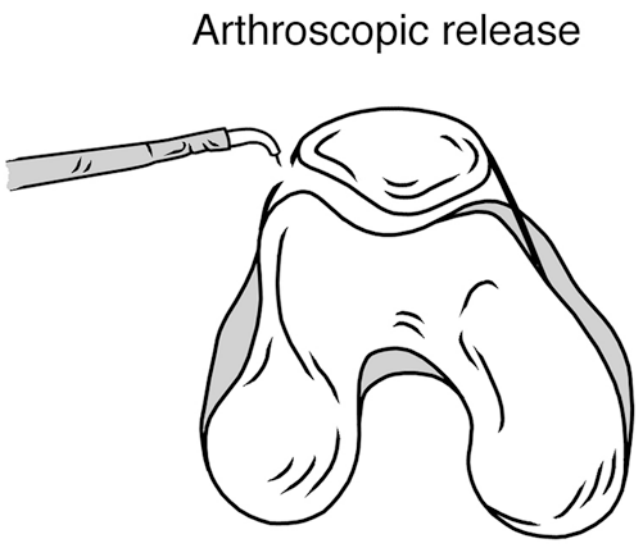

Fig. 14.6 Surgical treatment for patellofemoral joint incongruency

Additionally, differential neuromuscular differences exist between boys and postpubescent girls. Adolescent female athletes tend to recruit their quadriceps muscle group prior to their hamstrings (the reverse occurs in males) when they land from a jump, along with a decrease in hip and knee flexion and an elevated valgus knee moment upon contacting the ground. The resulting misalignment of the lower body places a higher anterior shear force on the tibia upon landing which puts more strain on the knee joint, leading to one of the theories behind a several fold increased incidence of ACL tears in females involved in certain sports, i.e., basketball, soccer, handball, and softball [28, 34, 35] (Fig. 14.7).

Anterior cruciate ligament (ACL) injuries are not seen as often in pre-adolescent athletes. The occurrence of ACL ruptures is rare before age 11 but the incidence increases with age. Female athletes experience ACL rupture at least 2–8 times more often than males [2, 14, 28]. This is most likely due to sex-specific hormones, ligament strength and size, anatomical structure/alignment, and landing differences (discussed further in Chap. 15). Injury to the ACL is seen in deceleration maneuvers, change in direction (cutting), and in hyperextension during single leg landing from a jump (straighter hip/knee position) [2, 28, 36]. In skeletally immature athletes, issues arise in terms of ligament surgery because most surgical techniques for reconstruction involve crossing the growth plate. Alterations/disturbance of the physes create concern for potential premature closure of the growth plate. Therefore, delay in ligament reconstruction is common in adolescent athletes until the physes have closed. However, delaying surgical treatment can cause an increase in knee injuries to cartilage from subsequent decline of joint stability [14]. In fact, young athletes surgically treated 12 weeks after ACL injury are four times more likely to have developed medial meniscal tears and 11 times more likely to have lateral compartment chondral injuries at the time of surgery [36]. Nonsurgical intervention can include knee bracing and reducing physical activity to help minimize ongoing knee joint deterioration (especially the meniscus). Studies have found that ACL-injured adolescents treated with knee bracing alone have higher rates of further meniscal damage and in the long term, earlier osteoarthritis (OA) [37]. The risk of early posttraumatic OA increases substantially over time, 5% in intact knees to greater than 50% of traumatized knee joints 10–20 years post ACL/meniscal injury [2].

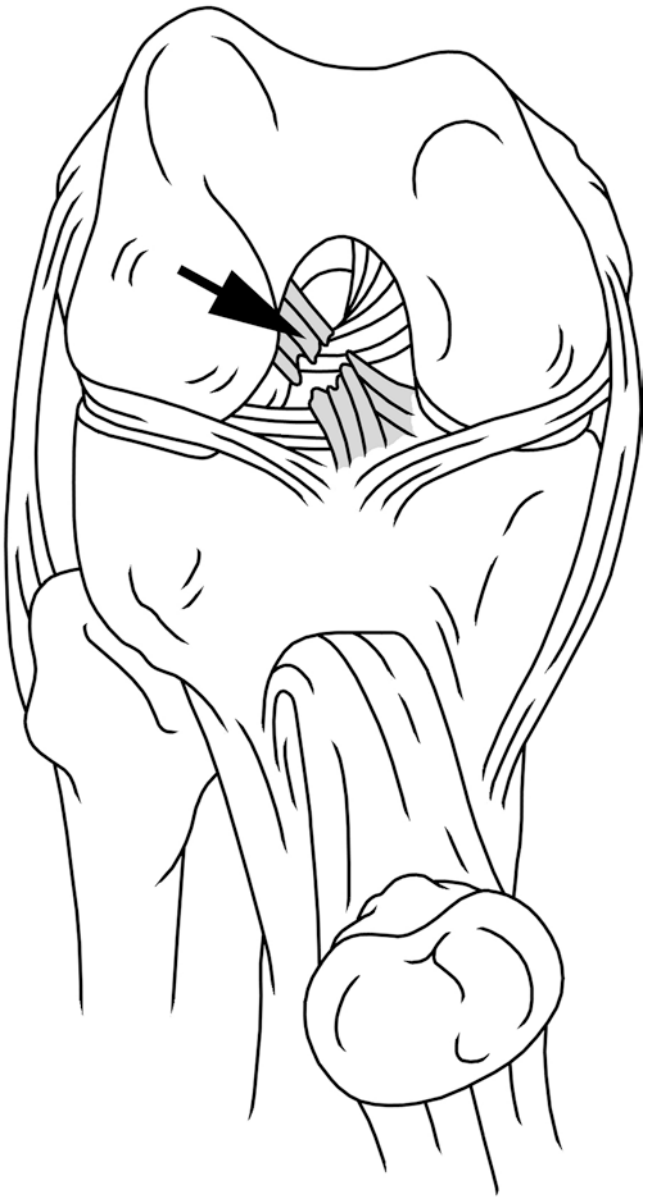

Fig. 14.7 Anterior cruciate ligament (ACL) tear

14.2.4 Several Measures for Prevention of Athletic Injuries from Occurring in Preadolescent and Adolescent Females

The first step in musculoskeletal injuries for adolescent female athletes is "attention to prevention" [2, 38]. Part of the preventive process includes recognizing risk factors for sports-related injuries. The strongest association of future trauma is a history of prior injury [25, 39]. This piece of vital information could be obtained during the pre-participation evaluation, done before an athlete is allowed to participate in any sporting activity [25]. As discussed above, there are different types of orthopedic trauma incurred by these females during various athletic activities. Acute injuries while playing team sports are difficult to control since other players are involved. However, preventive measures should include employing appropriate safety equipment and avoiding extreme surrounding environmental conditions during practice or competition. In terms of the more chronic type of overuse injury, consider instituting and/or modifying the six S's: altered Structure or anatomic malalignment; Shoe wear pattern or status; Surface type or irregular topography; Stretching for flexibility; Strengthening of imbalanced muscle groups; and avoiding too much Speed too soon. As an example, for those participating in track and field events, appropriately fitted footwear, along with correct running stride mechanics is extremely important in the prevention of uneven force distribution and excessive stress transmission through the feet with regard to shoe–ground interaction [38]. Beyond these external variables, the main factors which can be modified through training are correct technique/appropriate skill level, altered parameter of play, and physical condition of the athlete [15, 40, 41]. For example, at the beginning of the regular sports season, athletes should not increase the volume of their workouts more than 10% weekly to avoid overtraining [18].

The other key factor to consider for minimizing risk factors to help prevent musculoskeletal trauma is whether young female athletes are involved with multiple or exclusively just one sporting activity. Sports specialization at an early age has been found to contribute toward overuse athletic injuries. Physical participation patterns most at risk for active girls include the following: at least 8 out of 12 months of continuous training, playing/practicing/competing in only a single sport, and stopping any other sports. This intense degree of specific sports specialization should be avoided until mid-adolescent age in order to allow enough rest for the young body; and/or cross-training to maximize conditioning for physical fitness enhancement [42].

Another very important variable to consider as far as prevention of musculoskeletal trauma in adolescent female athletes is their individual fitness profile. Studies have shown that preseason (several weeks) workouts targeting key muscle groups surrounding several joints, i.e., strength, endurance, conditioning, and plyometrics programs can increase physical fitness/athletic performance (vertical jump height/improved sports technique) and help in decreasing the risk of knee/ACL injuries [2, 41, 43, 44]. A previous study has shown that even only 8 weeks of training in preadolescents can result in increased muscle strength of ~75% [13]. Since the period of physical conditioning is relatively short (6 weeks), these regimens represent the initial physiologic adaptations involving the neuromuscular system, incorporating resistance/flexibility/proprioception (balance or position sense)/core stabilization exercises, jumping/landing/sports-specific skills/drills, and speed/agility maneuvers/movement patterns; all of these training measures contribute toward improving muscular strength/endurance, anaerobic power,

Fig. 14.8 Risky versus safe landing positions

and sprint velocity [3, 45]. Additionally, one of the most crucial elements involved with typical conditioning programs is education/practice-teaching an athlete how to land with the lower limbs in a "safer" position to help protect against potentially devastating ACL injuries [2, 16, 44] (Fig. 14.8).

Different governing bodies such as the National Athletic Trainers Association (NATA) and others have teamed up to provide guidelines for injury prevention taken from available literature to counsel/assist those personnel involved with training young athletes. This evidence-based advice (SORT) Strength of Recommendation Taxonomy serves as professional suggestions to help protect active children from being excessively engaged in sporting activities, in hopes of shielding them from overtraining/musculoskeletal trauma. For a detailed list, please refer to citation in reference page at the end of this chapter [42].

14.2.5 Different Methods of Orthopedic Treatment for Musculoskeletal Injuries Incurred by Young Female Athletes, Including Specific Recommendations for a Regular Conditioning Program Once Healing Is Complete in Order to Enhance Their Physical Fitness Profile

Once a female athlete has sustained an acute or overuse type of injury, proper treatment is imperative for a full recovery. Conservative steps in management can be implemented if the injury is acute. First, strive to follow PRICE: pain control and Protect the injured part from further harm; relative Rest for the limb (not absolute immobility since the surrounding joints will become stiff) while maintaining gentle ROM (range of motion); apply intermittent Ice for inflammation (20–30 min every 4–6 h); use Compression wraps for swelling; and Elevate the limb above heart level to limit edema. This is basic first-aid type treatment for any kind of soft tissue trauma. If a fracture occurs, whether due to a sudden force or from gradual, repeated stress application, then add the following precaution: no weight bearing on the injured extremity and, if deemed severe enough, strict immobilization with external splinting/bracing or casting. For more specialized management, proceed toward orthopedic consultation. If the fracture displacement is of sufficient magnitude, it could ultimately require surgical internal fixation [18].

Administration of medications may help with pain and speed up recovery of the injured body part. Over-the-counter nonsteroidal anti-inflammatory drugs (NSAIDs) can be used for swelling and pain; however, caution needs to be taken as not to remove the body's natural protective mechanism (masking effect). Another consideration is the medication's potential toward a delayed healing response due to blunting of the body's natural process of inflammation. In other words, try not to use NSAIDs too much or too soon. Administration of vitamin C has been shown as a strong anti-inflammatory supplement plus aids in the process of bone building and scar tissue formation. Vitamin C is also an anti-oxidant, which helps in the repair of tissues. However, results are contradictory as far as the role of vitamin C in exercise recovery. In a similar fashion, previous studies have shown both anti-inflammatory as well as anabolic effects of Omega-3s, seen particularly in fish oil. Like NSAIDs, caution needs to be taken when consuming these minerals as not to remove the body's natural response to inflammation and subsequent healing [18].

After an injury has occurred, modification of the training regimen must be made as to not add further insult to the already injured extremity. The first step is reduction in the levels of training, i.e., magnitude, intensity, duration, and/or frequency to allow for full-functional recovery after tissue healing. Cross-training with a low or no impact type of activity (such as swimming or stationary bicycling) can be beneficial to keep from losing cardiorespiratory fitness. Administration of a formal physical therapy rehabilitation program to regain joint range of motion plus muscular strength/endurance should begin and aimed to progress toward sports-specific exercises after the initial period of recovery. Once functional testing of the affected extremity documents the restoration of objective measures of strength, girth, flexibility, endurance, among other parameters, demonstrating that an athlete is indeed physically recovered back

to pre-injury status and again ready to participate in sports, clearance can be granted for gradual return to play [18].

After musculoskeletal trauma, of utmost importance is the prevention of another injury to the same site; therefore, a conditioning program should be instituted prior to and continued throughout the sports season, as well as extended through the off-season to help maximize performance and minimize injury [17, 18]. Training regimens should not be "one size fits all," but geared toward age/physical level/athletic skill/type of sport(s) played [2]. Warming up before any exercise by directing blood flow to/activating muscles around the involved joints appears to afford some protection from risk of injury due to improved proprioception of surrounding soft tissue restraints. However, there is debate on what type of warm-up is most beneficial in terms of maximizing performance and injury prevention. Trend of movements in the athletic world have steered away from any type of passive, static stretching in favor of more dynamic, active motion. In fact, studies have found that static passive stretching can inhibit neural muscular feedback and decrease peak muscular force up to 120 min after the stretch session [46]. Another study looked at the differences between static and dynamic stretching in 200-m race times; they found that runners who performed dynamic stretches before the race ran faster than those who stretched passively [47]. Contradiction exists in research regarding stretching as injury prevention; some studies have found stretching has a minimal prophylactic protective effect [48, 49], while others have shown better protective results [50].

Several studies have demonstrated the beneficial effects of strength training in children and adolescents in terms of enhancing athletic performance; with minimal risk of trauma or growth disturbance as long as these programs are well supervised and submaximal exercises are being performed. Strict/safe techniques of weight lifting should be followed, along with proper breathing/controlled movements [11, 12, 17, 51–53]. Specific guidelines regarding a resistance program for building muscular strength include the following: begin at age 7 or 8; add warm-up and cool down periods prior to and after exercise; use own body weight, light medicine balls or dumbbells; perform workouts that last between 20 and 30 min for no more than 2–4 days/week (with rest days in between); initially, start with 1 set of 10–15 repetitions 2 times a week; progress to 1–3 sets of 6–15 repetitions concentrating on 6–8 different exercises, focusing on major muscle groups with mild tension/resistance while learning the correct technique of lifting; finally, sequentially accelerate training by small increments of weight (2–5 pounds), or 5–10% increase in the exercise load weekly once the amount lifted is no longer challenging/fatiguing. For those young athletes who desire to maximize performance in various competitions, they should also practice sports-specific moves/skills as well. Additionally, engaging in any type of aerobic or other endurance-type training is also well advised to enhance overall cardiorespiratory health in the long term [11, 13, 40, 41, 52]. The only caveat to this principle is that once training stops, regression or detraining occurs after a few to several weeks of inactivity, so the athlete must continue with the conditioning program to retain the highest level of fitness benefits. For all adolescent athletes, powerlifting type maneuvers/drills (i.e., single maximal lifts) should be avoided in order to avoid the potential of growth plate injury to their limbs [11, 40, 41, 51]. In other words, the stereotyped slogan of "no pain, no gain" should not be followed in young weight lifters since it could cause more harm to their developing bodies [51].

14.3 Future Directions and Concluding Remarks

In summary, young females, during the time span from childhood to adolescence, is accompanied by a myriad of bodily alterations, some of which resemble the physical changes experienced by males, while others are completely different. The main components involved with this early life transition period of puberty include reproductive, hormonal, nervous, and musculoskeletal systems. The latter change undergoes an extreme makeover to involve morphological and neuromuscular transitions. Growth, development, and then eventually maturation into the adult form/shape is faced with an inherent risk, mainly orthopedic trauma from soft tissues (ligament, joint and musculotendinous structures) lagging behind the fast-growing skeletal system (bones). Acute and chronic overuse injuries may occur in preadolescent and adolescent female athletes participating in certain sporting activities. It is important to recognize these unique patterns of musculoskeletal trauma in order to protect the athlete and prevent initial injury from occurring, plus treat the offending problem if need be. When in doubt or if the injury is severe, seek appropriate orthopedic consultation. The bottom line lies in helping to maximize gains and minimize risks by involving these young females in a well-supervised maintenance training regimen/conditioning program for the musculoskeletal system. As such, they can participate, perform/compete at their best, while adapting to their ever-changing body during their teenage years and even further beyond that into adulthood.

Chapter Review Questions with Scenario

Scenario

You are a pediatrician who has just recently completed a primary care sports medicine fellowship and decided to join a multispecialty group practice in a suburban town. One of your partner's physician's assistants (PA) has been involved with taking care of a local youth girls' soccer team. These young female athletes are under tremendous pressure to win as their team will disband if they do not make the playoffs this season; as a result, these female soccer players have been required to "train" extra hard every weekday before and after practice. Their training program consists of running for a couple of miles around the track, then lifting weights for strength and power, and then run again for another mile or so. Evidently, their coach used to work with male football players, and he is incorporating the majority of football drills into the regular sports workout during the competitive season for these young female athletes. As far as he is concerned, the heavier weight moved the better. "Work through the pain!" echoes his motto. As much as these teenage girls want a good chance at the championship trophy, they are beginning to get discouraged, mainly because they cannot seem to get rid of their muscle aches and pains despite resting on the weekends and taking over-the-counter medications. In fact, their performances during the games have also started to deteriorate a bit, which makes their coach exercise them even harder. The PA is coming to you for advice concerning this group of adolescent females.

Questions

1. What do you think is happening to these young female athletes?
2. What questions should you ask of these athletes and how will you go about approaching the coach about his female soccer players' problems?
3. What elements of the history, physical exam, and diagnostic studies should you obtain to help you evaluate and treat these young female athletes?
4. What initial measures should you institute?
5. Who else should you consult for assistance in the management of their musculoskeletal concerns?

Plausible Answers

1. It appears as though the soccer coach is employing training techniques that are more specific to a different sport and group of athletes and do not fit these adolescent female athletes' training needs. Their complaints of pain may be coming from overuse injuries because of working out too much and too frequently.
2. You may want to inquire about other types of athletic activity, along with the specifics of the exercises these females are performing. Then, go talk to their trainer before discussing the situation with their coach. Approach him in a nonthreatening manner, explain the fact that his players are trying as hard as they can, but their bodies are not quite used to the rigors of his method of training yet.
3. Pertinent questions you will want to ask about these athletes' histories should include their previous playing experience, whether it is their first competitive season (rookie) or are they veterans at this game. You also would want to know about their past and present physical fitness profile to determine if indeed they are in good enough shape to undergo rigorous training outside of their soccer workouts. Try to rule out alternative causes of musculoskeletal complaints other than strains and sprains, such as stress reactions or fractures. Perform a thorough physical exam of the involved bones and joints. Obtain radiographs and, if these are negative, then order bone scans and/or magnetic resonance imaging to further delineate details of the orthopedic pathology. Check out laboratory blood work to see if any abnormal indices are present to indicate a metabolic or endocrine source contributing to their problem.
4. As for the initial treatment of these soccer players, institute the PRICE principle after talking things over with their trainer and coach. Discuss decreasing the training volume and intensity, cross-train with other activities so as not to stress the injured extremities, and hopefully maintain physical fitness. Avoid provocative exercise maneuvers while attempting to modify regular practice so that these athletes do not become completely deconditioned in the meantime. Once they are over the acute inflammatory stage, gradually increase their training to tolerance to help get them back into the game.
5. Do hold the affected young females back from any sort of impact activity and seek consultation from an orthopedist or surgical sports specialist if they are not responding to your treatment, especially if you are worried about stress fractures.

Chapter Review Questions

1. When is the final adult stature attained in females?
   (a) 12–13
   (b) 14–15
   (c) 16–17
   (d) 18–19
2. Neuromuscular control and development most specifically target which anatomical structure in adolescent

females, as compared to males as far as injury is concerned?
(a) Shoulder
(b) Knee
(c) Wrist
(d) Hip

3. What anatomical structures are involved with the "miserable malalignment syndrome"?
(a) Pelvis and knee
(b) Knee and foot
(c) Hip and leg
(d) All of the above
4. Name different ways to help prevent musculoskeletal injuries.
(a) Go as hard and fast as possible to build up strength and stamina
(b) Use other players' equipment and play in bad weather
(c) Wear fancy name brand running shoes
(d) None of the above
5. What are the best recommended first-aid measures for musculoskeletal injury management?
(a) Rest, ice, compression, elevation
(b) Rest, ice, compression, elevation, medication
(c) Protect, rest, ice, compression, elevation
(d) ROM, rest, ice, compression, elevation
6. Which of the following intrinsic factors make a person more susceptible to injuries?
(a) Movement skills
(b) Intensity of activity
(c) Previous injury
(d) Equipment
7. Which structure of tibia is affected by Osgood–Schlatter's disease?
(a) Tibial plateau
(b) Tibial tuberosity
(c) Tibial plafond
(d) Tibial shaft
8. Dislocation of patella is most commonly seen in females aged
(a) 6–10 years
(b) 10–14 years
(c) 14–18 years
(d) 18–22 years
9. Which is the most common ligament injured in lateral ankle sprains?
(a) Deltoid ligament
(b) Calcaneonavicular
(c) Posterior talofibular
(d) Anterior talofibular
10. Spondylolysis in spine is defined as
(a) A defect in the lamina between the superior and inferior articular facets
(b) Translational movements between vertebral bodies
(c) Disc protrusion between two vertebral segments
(d) Trabecular defect within the vertebral bone

Answers

1. c
2. b
3. d
4. d
5. c
6. c
7. b
8. c
9. d
10. a

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Prevention and Management of Common Musculoskeletal Injuries in the Adult Female Athlete

15

Mimi Zumwalt

Learning Objectives
After completion of this chapter, you should have an understanding of:

- The fundamental differences in the anatomy, physiology, and body composition between adolescent and adult females in terms of the musculoskeletal system.
- The relative similarities and pertinent differences between adult males and females concerning the anatomy, body composition, and biomechanics of the musculoskeletal system.
- Various more common types of orthopedic injuries sustained by adult females involved in certain athletic activities.
- Several measures for prevention of musculoskeletal injuries incurred by adult female athletes.
- Different modes of treatment for orthopedic injuries sustained by adult females participating in certain sporting activities.

15.1 Introduction

As growth proceeds from childhood through adolescence and then finally culminates into adulthood, the developing female body carries along with it a multitude of changes. Not only does a mature woman have to face morphologic challenges, but she must also adapt to structural, hormonal, and metabolic alterations as well. Indeed, the musculoskeletal system is certainly no exception to this growing rule throughout the different life stages. Although it is healthy to be engaged in a regular exercise program, participating in multiple athletic competitions and sporting activities can leave the active adult female more vulnerable to orthopedic injuries; especially if she is not sufficiently fit to perform her best in extremely demanding levels of physical play.

This chapter focuses on several anatomical features unique to the adult female athlete; different types of musculoskeletal trauma tend to be more common for women participating in sports, along with methods of injury prevention and how to go about treating these orthopedic issues once they do occur.

15.2 Research Findings and Contemporary Understanding of the Issues

15.2.1 The Fundamental Differences in Anatomy, Physiology, and Body Composition Between Adolescent and Adult Females in Terms of the Musculoskeletal System

To recap some of the similarities and differences between young females and adult women, the following anatomical changes are found to be fairly consistent: breast tissue development, fat deposition around the hips, thighs, and buttocks, along with broadening of the pelvis, all of which herald the onset of puberty under the influence of the female sex hormone, estrogen [1–3] (Fig. 15.1). In fact, estrogen receptors have been found on ALL tissues of the musculoskeletal system, including bone, muscle, tendon, ligament, and cartilage, thus playing a role in the regulation of tissue metabolism [4].

This transition stage of pubertal development usually occurs between the ages of 12 and 14 in young females. Estrogen also brings about longitudinal skeletal growth, with the final bone length achieved between 2 and 4 years after pubescence. A woman's body composition continues to fluctuate during the teenage years, then at some point in the mid-20s, more adipose tissue is accumulated and muscle mass starts to decline, at a rate of about 3 kg per decade (greater than a one-half pound per year). The rise in total body fat along with loss in the quantity of fat-free mass is due to

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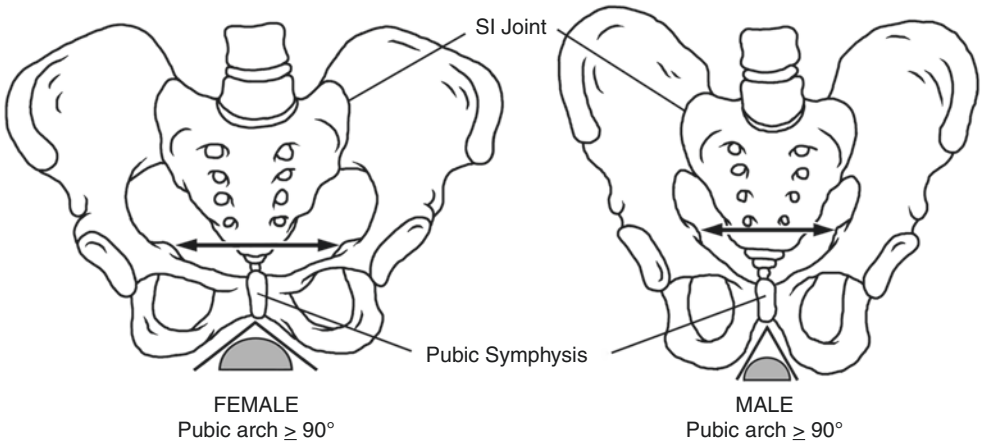

Fig. 15.1 Pelvis morphology

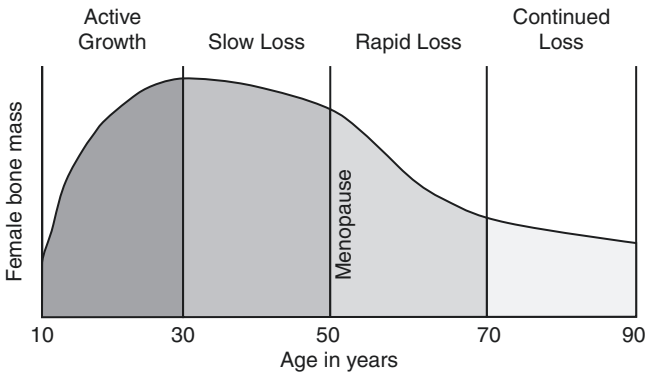

Fig. 15.2 Rate of bone loss through a woman's lifetime

lower levels of physical activity, relative lack of testosterone, and consuming the same quantity of caloric intake [2]. In terms of skeletal density and associated bony integrity, calcium, among other essential minerals, continues to be deposited into the skeleton to build up more bone as the body is steadily growing. This process of calcium deposition into the bone bank results in increasing the quantity of bone gained, becomes accelerated during the adolescent growth spurt of puberty spanning the teenage years, and then finally reaches its peak in the early 20s in terms of maximal bone mass acquisition. After this period of very rapid bone deposition, bone loss naturally begins to occur gradually during the late 20s or early 30s depending on both nutritional and hormonal status, along with the quantity of applied mechanical stimuli [5] (Fig. 15.2).

15.2.2 The Relative Similarities and Pertinent Differences Between Adult Males and Females Concerning the Anatomy, Body Composition, and Biomechanics of the Musculoskeletal System

Up until the onset of puberty, anatomical structure and body composition between males and females are fairly similar in terms of height, weight, girth, bone width, and subcutaneous fat. The body build, shape, and size of both sexes begin to diverge once the endocrine system starts to undergo hormonal changes. Two sex-specific hormones, estrogen in females and testosterone in males, start to take over to influence the development of adolescent features, separating teenage girls and boys in terms of anatomy as well as the function of the musculoskeletal system [1, 2]. During the adolescent growth spurt, females tend to deposit more fat around the breasts, hips, and thighs. This gender-related adipose tissue deposition, in addition to that surrounding internal organs, is termed as essential fat. Essential fat in females composes about 9–12% of total body weight, as compared to only 3% in males. The other type of adipose tissue is storage fat, which is comparable in both sexes, comprising about 15% of body weight [2, 6–8]. At physiological maturation, the average adult female non-athlete carries between 18 and 26% of adipose tissue, whereas mature men on average contain only about 12–16% body fat [6, 7]. However, for those female athletes who are engaged in intense exercise, especially long-distance runners who train and compete over 100 miles per week, their percentage of body fat can be reduced

to well below 10% [6, 8]. In fact, some elite endurance athletes can eventually drop body fat down to only around 6–8%. Alarmingly, it is estimated that dropping body fat below 11% in women is enough to cause amenorrhea which in turn can impair bone health [2].

Males tend to carry more adipose tissue in the abdomen/flank and upper body versus females, who store fat mostly around their hips and lower body [2]. The difference in body fat distribution between men and women tends to affect their athletic performance. For example, because female bodies have greater fat content, they have increased buoyancy in water. This is deemed advantageous while competing in water sports due to decreasing drag and lowering energy expenditure by 20%. However, the higher fat percentage in females is thought to hinder physical performance in many endurance sports on land from having to carry the excess body weight (though hard evidence is somewhat lacking) [6–8].

Generally speaking, both muscle mass and fiber composition differ between females and males [9]. In terms of muscular strength, between 11 and 12 years of age, girls are approximately 90% as strong as boys. By the time they are 15–16 years old, females are only about 75% as strong as males [6, 8]. When adjustments are made for body mass, men are at least one-third stronger than women [7]. Specifically, females are only 50% as strong in the upper and 75% in the lower body as compared to males [8]. When muscle mass is taken into account, relative leg strength is similar in both sexes, but upper extremity strength in females still lags behind that of males [1, 6, 8]. This is due to men having more muscle mass relative to body weight than women, 40% as compared to below 25%. The lack of muscle strength stems from women having decreased fiber size (15–40% less), making the cross-sectional area about 60–85% smaller as well [6, 8]. In fact, this relative difference in fat-free mass tends to be lower in females from age 7 until 25 years of age. After the mid-20s, lean muscle mass begins to decline in both sexes, at a rate of one-fourth to one-half pound yearly [2]. In correlation to a greater amount of lean muscle mass in men, the skeletal framework in males is larger as well. Additionally, from undergoing a longer period of growth, they also mature later and attain higher final height (taller) and weight (heavier) than females [8]. However, under estrogen's effect, the relative growth rate of the female skeleton is greatly accelerated, culminating in achieving the final bone length earlier, i.e., only a few years after the onset of puberty. In other words, females tend to start growing and also cease to grow faster as well, thus their body and bones reach a plateau after 2–4 years of fairly rapid growth. Therefore, men reach final skeletal maturity later at about 21 or 22 years old, versus 17–19 years of age in women [2].

In terms of bony and articular differences, females' bones are smaller as well thus their joints have less surface area.

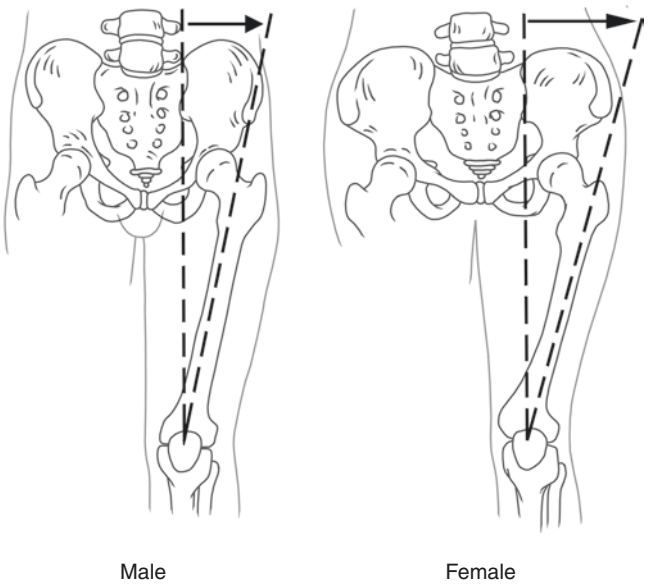

Fig. 15.3 Hip–knee angular difference

Women have shorter and smaller limbs relative to body height as compared to men. The length of lower extremities in women is about 50% of total height versus approximately 55% in men [10]. Additionally, structurally speaking, men have broader shoulders, larger chests, and narrower hips; women, on the other hand, have wider pelvis, more varus hip, and higher knee valgus angles (Fig. 15.3).

This anatomical/structural difference, combined with an overall smaller stature and wider pelvis, gives the female body a lower center of gravity. The increased angular inclination starting in the pelvis connecting the lower limbs of women causes an asymmetrical force distribution/transmission through the extremity's overall alignment from the hips to the ankles, and subsequently can contribute to a myriad of overuse type of musculoskeletal injuries incurred in active females [1–3].

In addition, after puberty, neuromuscular recruitment, primarily in the lower extremities in women differs from that of men, especially during landing tasks [6, 11–15]. This altered neuromuscular differential control has been linked to increased risk for lower limb injury during certain athletic activities. Furthermore, women also have increased joint laxity, which is partially attributed to reduced lean muscle mass available that can restrain excessive joint motion thus providing less dynamic stability [16]. Along the same lines, other researchers have found that gender differences exist involving surrounding muscle groups effecting knee-joint movement, namely the quadriceps and hamstrings. Upon applied angular forces to the distal aspect of the lower limb, as compared to males, female subjects showed decreased active muscle stiffness. In other words, dynamic muscular contraction as a reflexive reaction to torque imparted to the female

Fig. 15.4 Risky versus safe landing positions

knee demonstrated reduced moment (approximately 55–75% less) versus male subjects resulting in less joint stability [17]. Besides the knee, joint laxity differences are also most profound around/within the ankle and elbow articulations. Studies have shown that this increase in joint laxity along with differential neuromuscular recruitment upon landing may be responsible for the greater incidence of ACL injury in females as compared to males [3, 15] (Fig. 15.4).

15.2.3 Various More Common Types of Orthopedic Injuries Sustained by Adult Females Involved in Certain Athletic Activities

From an epidemiology point of view, involvement of women in athletic activities, ranging from light exercise to elite physical performance, has skyrocketed over the past 100 years. This comes from a change in social norms and attitudes toward females as well as legislature ensuring equal opportunity for active women. In the US, this surge of female athletes participating in scholastic sports stemmed from the passage of Title IX in 1972, mandating equal federal funding for both genders involved with school athletic programs. This effort was aimed at preventing sex discrimination for females involved with athletics in educational settings [5–8, 18–22]. Subsequently, by the year 2000, the number of high school/collegiate females playing sports rose from about 300,000 to close to three million in 3 decades; 1 out of 3 and more than 1/3 of athletes, including US Olympic elite competitors were women [23]. Thus, over the past 40 years, the role of women in athletic competition has been revolutionized, from sitting in the stands to standing on the sidelines, and of course playing in similar sporting events as men. Alongside the tremendous rise in female sports participation, comes with that visible gender differences between males and females, especially in the different types of musculoskeletal injuries incurred, alongside other unique orthopedic issues occurring in athletics [5–8, 18–22].

Report from the National Sporting Goods Association (NSGA) estimated that more than 37 million US adult women participate in some sort of cardio activity twice weekly. These aerobic type exercises include walking (most frequent), dancing, cycling, swimming, calisthenics, running, and using exercising machines. Since the 1980s, during the time of fitness boom peak height, a myriad of exercise-related injuries has begun to surface, primarily stemming from activities involving weight-bearing and/or impact maneuvers [23]. The following depicts several musculoskeletal conditions more commonly seen in female athletes that may vary in types and incidence according to different sporting activities. Even recreational events such as running can bring about 25–65% of injuries severe enough to keep women away from training. In fact, about half of these female runners must seek medical care for their musculoskeletal problems. Other modes of physical activity, which portend a similar rate of injury risk, include group exercise participants, soccer players, basketball players, and team handball players [20]. In fact, head and knee trauma both can be caused by poor balancing technique/landing mechanics coming from innate lower body structural alterations involved with development from teenage into adulthood. By recognizing risk factors contributing to musculoskeletal injuries, training/conditioning may be adjusted to target specific bodily issues to hopefully help toward prevention of future orthopedic trauma [18].

As previously discussed in Chap. 14, overuse injuries to the musculoskeletal system are extremely common in the female athlete from chronic repetitive microtrauma imparted to bone or soft tissues over time. The rise in overuse injuries can be contributed to the relatively greater number of females involved in athletics as well as an increase in intensity (high loading rates) along with year-round sports participation [18, 24]. As for sporting activities more prone toward this type of overuse trauma, long distance running portends a relatively high risk, close to between 20 and 80%, especially involving the low back and leg. Unlike muscles, other supporting soft tissues such as cartilage, tendon, and ligament lack vascular perfusion, thus are more apt to sustain damage from repeated

applied forces since they cannot absorb shock/adapt as well to high levels of mechanical loading [25]. Other researchers have also found that female runners tend to have twice as many running-related musculoskeletal disorders as compared to males. Most of these conditions are localized to the lower limb, such as tibial stress fractures, iliotibial band friction syndrome, and especially patellofemoral pain. Etiology/contributing factors to this gender difference of the latter lies in the increased hip width versus femoral length ratio resulting in larger angulation of the femur, which in turns adds to knee valgus inclination/higher Q-angle (11° more genu valgum during the stance phase of gait). Additionally, active females engaged in impact activity demonstrate greater vertical free moments and ground reaction forces (GRF) as well, resulting in more load/torques imparted to the lower limb/leg bones upon foot contact with the surface below, ultimately ending in skeletal overload [26].

Bone stress injuries (BSIs), in particular, are most problematic since time lost from play could be longer due to extended duration while awaiting skeletal healing/functional recovery. Sports involving prolonged impact activity such as cross-country running tend to result in the highest rate of BSIs (two- to sixfold increase). Annually, 1 out of 5 female collegiate long-distance runners is at risk for sustaining a stress reaction or frank fracture of the lower extremity [18]. The risk is even higher in light of the "Female Athlete Triad (FAT) or Relative Energy Deficiency of Sport (RED-S)," discussed in a separate chapter. This constellation of menstrual dysfunction/disordered eating/bone mineral density alteration with associated elevated BSI risk is frequently found in females involved with sporting events emphasizing leanness/aesthetics (diving, gymnastics, dancing/ballet) or with weight-class categories (rowing, wrestling, bodybuilding) and endurance (lacrosse, cycling, running, swimming) (25% to almost 80%) [18, 27]. Other intrinsic factors contributing to increased risk for BSIs include lower limb misalignment, along with femoral adductor and free tibial moments. However, neuromuscular retraining may help to offset potentially injurious reaction to inherent anatomy upon landing during sports participation. Specifically speaking, conditioning regimen should include hip musculature/gluteal strengthening, focusing on dynamic stability to combat reactive ground forces [18] (Fig. 15.4).

Bone is dynamic, continually being broken down then built back up depending on loading/physiological/endocrine status. Overuse injuries to skeletal tissue causing stress reactions eventually resulting in fractures are due to mechanical stimuli exceeding the ability of the skeleton to rebuild itself, especially in active females with FAT/RED-S since the bone is already structurally weaker [23, 27]. The resulting stress fractures can occur in both men and women involved with impact sporting activity such as running and jumping, with the tibia being most common bone fractured (33–55%)

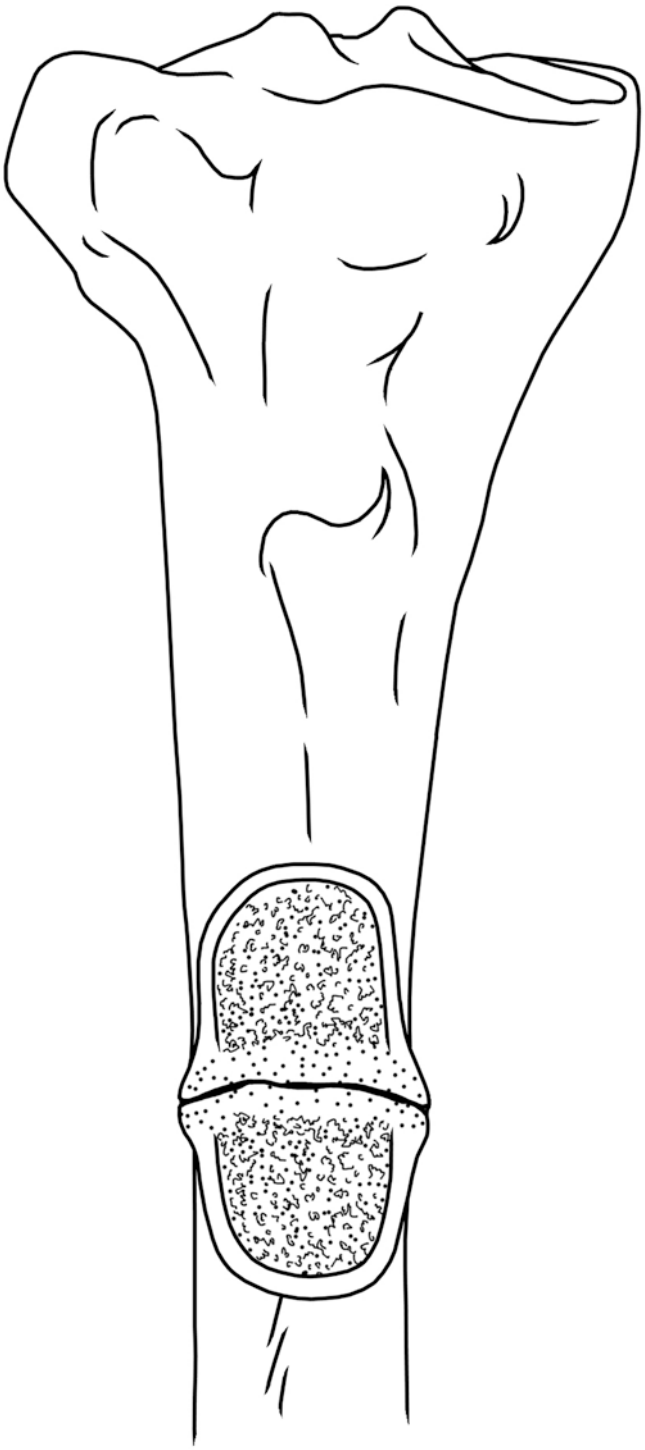

Fig. 15.5 Tibial stress fracture

(Fig. 15.5). However, fractures to the femoral neck, tarsal navicular, metatarsal, and pelvis are more commonly seen in the female athlete [24]. Specific sites of stress fracture are also dependent on the type of sport; for example, high jumpers most commonly fracture their medial malleolus and tarsal navicular [28]. Associated risk factors for BSIs can be

due to genetic predisposition/internal body structure/function, including muscle imbalance, limb malalignment, and fluctuating hormones; or attributed to external factors such as the type of footwear, running style, and training errors (exercise mode/frequency/intensity/volume). Additional contributors to the increased risk of stress fractures can involve psychological and medical issues (personal health/lifestyle habits), including inadequate/inappropriate nutrition, disordered eating, osteopenia, and hormonal irregularity [1, 6, 7, 11, 25, 29]. The presence of stress fracture shows itself as gradual onset of pain induced by activity as well as tenderness to the bony site when palpated. Radiographic and if needed MR imaging should be utilized to determine if a stress fracture is present. General treatment for a stress fracture is reduction in the offending activity and relative rest; however, if the stress fracture does not respond to resting or casting, a surgical procedure to fix the problem may be necessary. Non-impact exercise without axial loading on the lower extremity can be beneficial during the "rest" period to help maintain cardiovascular fitness. For example, cross-training activities such as swimming, aquatic running, and bicycling can also be beneficial toward preventing complete physical deconditioning while awaiting fracture healing [18, 24, 25, 28, 29].

One of the most common acute injuries in female athletes is trauma to the knee, specifically the anterior cruciate ligament (ACL). The incidence of ACL injury in women competitors can range anywhere from 2 up to 10 times higher than male athletes [5–8, 11, 15, 16, 18, 20, 27, 30] (Fig. 15.6). Annually, between 100 and 300,000 ACL ruptures occur in the US (costing at least $1 billion), primarily in active women (50% younger than 25), after which 4 out of 5 of females will develop early posttraumatic knee arthritis within 10–15 years, and all will have early degenerative joint disease by 20 years post initial injury independent of treatment [15, 30–32]. Additionally, prospective studies have also found that once the ACL is injured, the rate of reinjury to the same knee or suffering a contralateral ACL tear tends to be higher in active women as well (20% within 3 years if returning to play). Even in those female athletes undergoing surgical reconstruction, they are also less likely to return to prior level of sporting activity as compared to males [27, 31, 33].

The specific type of sports portends different rates of ACL tear/injury, especially those activities which involve pivoting/jumping [3]. For example, collegiate female soccer players are about 2.5 times more likely to sustain an ACL injury as compared to males, whereas women basketball players are 3–5.75 times more likely to have an ACL tear [27, 34]. Injuries to the ACL are also commonly seen in gymnastics, downhill skiing, field hockey, team handball, netball, and lacrosse. While it has not been clearly defined as to why there is an increased risk of ACL injury in women, the etiology of this gender-specific phenomenon is theorized to be multifactorial, including genetics (presence of *COL5A1* gene coding for collagen alpha chains), anatomical (BMI), hormonal, biomechanical, neuromuscular, and environmental. Intrinsic/innate factors cannot be modified, such as small notch/ligament size and steep tibial slope (Fig. 15.7). However, extrinsic factors such as neuromuscular retraining may be addressed to help protect the ACL from further harm. Other external contributing factors may include skill level, physical condition, imbalanced thigh musculature (especially hamstring weakness as compared to the quadriceps), increased flexibility, and decreased proprioceptive capability [6, 7, 12, 27, 32, 33]. Risky positions when landing have

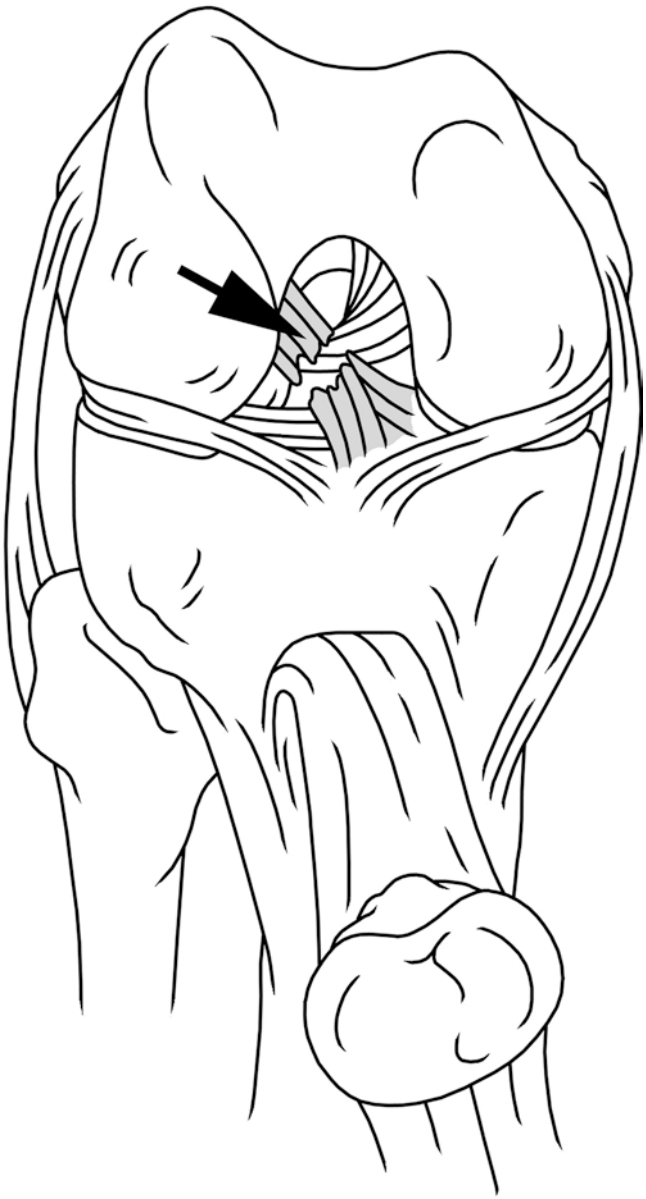

Fig. 15.6 ACL (anterior cruciate ligament) tear

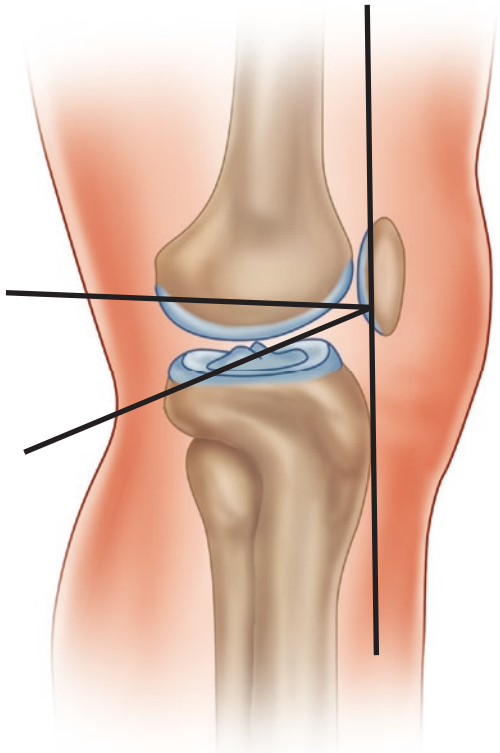

Fig. 15.7 Increased posterior tibial slope. Image courtesy of Aiswarya J. Pillai, University of Texas at El Paso

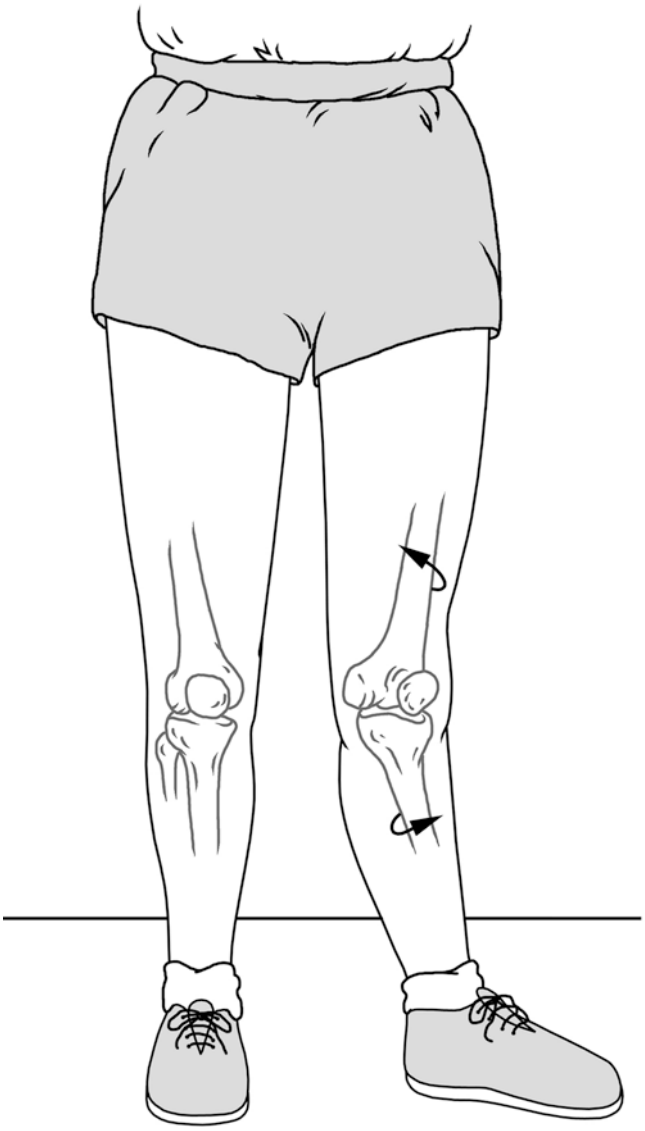

Fig. 15.8 Risky limb landing attitude

been previously alluded to and usually involves an off-balance body position especially on one limb upon impact with the ground.

Injury mechanism for ACL ruptures usually is noncontact (75–85%) while running or jumping, one-step stop, plant and cut (pivot), or stiff-legged landing from a jump [3, 30, 31]. Traumatic force to the knee joint in women occurs most often in response to a medial directed load with hip internal rotation and external tibial rotation as seen in cutting maneuvers, and can be exacerbated if an external lateral stress is applied to the joint. In other words, upon landing, females demonstrate a quadriceps dominant position (knee extended) along with dynamic moment causing valgus collapse at the knees (frontal plane), both are additive toward increased strain on the ACL [27, 34, 35, 36]. The other, less common mechanism for ACL injuries occurs during knee hyperextension with external tibial rotation while foot is planted, which tends to be more predominant in basketball and gymnastics [3, 34] (Fig. 15.8). In addition, gender and within same sex differences have also been shown in soccer players as far as which limb is more prone to be injured by noncontact mechanisms. Males tend to injure their preferred kicking leg versus females who usually sustain trauma to their nondominant, supporting leg (3/4 vs 1/3 upon ACL rupture) [37]. Interestingly, other researchers have discovered that female dancers demonstrate better trunk stability as comparted to women participating in team sports upon single-leg landing. Female team players/athletes showed more valgus inclination at the knee when contacting the ground below as well, subjecting the ACL to higher injury risk [38].

Joint stiffness and stability can be maintained by active contractile soft tissues. Stiffness is the resistance of bodily structures in response to a force, and active joint stability can be controlled by voluntary muscle contraction. Researchers have measured anterior tibial translation and muscular contraction to an externally applied stress, they found that translation was decreased with increased muscular co-contraction. However, findings also revealed that women naturally have decreased joint stiffness, indicating a reduced ability to protect the knee from external forces. On an interesting side note,

females sustain more ligament ruptures but less muscle injuries as compared to males [3, 4, 17, 33, 36]. Recent studies have looked into the possibility of joint laxity/stiffness reduction due to fluctuating hormones during the menstrual cycle, especially before or during ovulation [4, 33]. Others have proposed that the rate of ACL injury increases during the initial and late follicular phase, accompanied by a surge in estrogen. Receptors for this female hormone along with other reproductive hormones such as androgen and relaxin have been discovered in ACL fibroblasts [33, 39]. In addition, increased relaxin blood levels have been noted in females with ACL tears. Most likely relaxin works synergistically with estrogen in women to regulate collagen cross-links/turnover (degradation and synthesis), contributing to ligamentous laxity. On the other hand, testosterone in men has been found to stimulate production of collagen fibroblast, which may augment ACL strength [9, 18]. However, there has been no consensus as to whether hormonal changes during menses directly cause an increased risk of ACL injury; thus, more research needs to be conducted as far as menses influencing ligament properties is concerned [27, 33, 40].

As discussed previously, the timing and power of neuromuscular firing are different in women during landing tasks and thus can be linked to ACL injury. Some studies have shown that stabilizing muscles surrounding the knee, primarily anterolateral group, especially rectus femoris and tensor fascia lata, tend to fire more upon single-leg landing. Furthermore, knee joint flexion/abduction angles also differ between men and women in response to ground contact, adding to the gender difference in ACL tear rates [33]. Similarly, other researchers have found that female athletes initially activate their quadriceps for joint stabilization, whereas males recruit their hamstrings first. They also showed female athletes taking longer to generate maximum hamstring muscle torque as compared to males [3, 40]. More recently, research trends have shifted from looking at hamstring and quadriceps to analyzing the effect of activation and strength of hip musculature in relation to ACL injuries. When the knee is loaded, biomechanically, the hip abductors and external rotators are activated which prevents hip adduction and internal rotation, causing a valgus force imparted to the knee [41]. Failure of the hip abductors and external rotators to fire causes an increase in the Q-angle which subsequently adds more load to the knee joint [33, 42]. Other researchers found a reduction of hip abduction strength in females during cutting maneuvers, suggesting that a decrease in muscular contraction at the hip joint can lead to an ACL injury at the knee [33, 43]. Other postural positioning/bodyweight shifting which contribute to ACL tear risk involve the "lumbopelvic-hip complex," i.e., body center of mass being posterior along with side trunk motion (leaning toward injured limb) and lateral foot placement (instead of directly underneath the body) upon ground contact [8, 30, 32].

Patellofemoral disorders are also more commonly found in the active adult female. Contributing factors to anterior knee pain and dysfunction stem from static structural misalignment from the pelvis to the feet, dynamic imbalance of limb muscular strength, excessive soft tissue pliability or extreme stiffness, or a combination thereof [3, 11]. Specifically speaking, this entity is alternatively named the "Miserable Malalignment Syndrome." This lower extremity condition is associated with an increase in hip external rotation plus femoral anteversion coupled with a higher Q-angle, genu valgum, tibia vara, hypermobile patella, accentuated by knee recurvatum/hypoplastic vastus medialis oblique/trochlear groove any or all of which can contribute to patellar instability [1, 3, 6, 8, 22] (Fig. 15.9).

The body, as an attempt to center the knee under the hips and above the ankle, compensates by internally rotating the femur, along with externally rotating the tibia and pronating

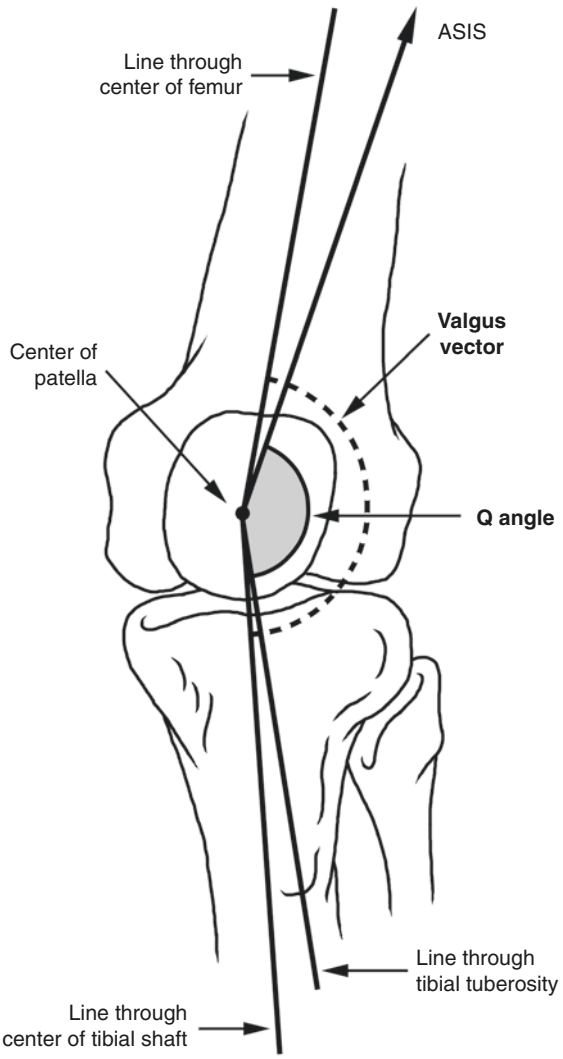

Fig. 15.9 "Miserable malalignment syndrome"

the foot, which also asymmetrically loads the patellofemoral joint with resultant anterior knee symptoms [42, 44].

Patellofemoral pain syndrome (PFPS) is very common in female athletes, especially runners, occurring in 20% of females as compared to about 7.5% in males, i.e., almost three times higher [27, 45]. The higher rates of PFPS in women are thought to be due to structural alignment as well as biomechanical and hormonal differences. However, the exact mechanism for injury with pain is still unclear and seems to vary between athletes. Three major factors contributing to the development of PFPS are lower extremity and/or patellofemoral malalignment, quadriceps muscle imbalance and/or weakness, plus physical overload of the patellofemoral joint (PFJ) [3, 44]. As previously eluded to, PFJ malalignment can be caused by increased pressure from excessive tightness of the lateral patellar retinaculum (soft tissue restraint) or from bony incongruity, i.e., shallow trochlear groove of the distal femur and/or high/low riding patella, all of which can contribute to PFPS and anterior knee pain as well [1, 3, 8, 22] (Fig. 15.10).

Furthermore, as females flex their knee joints from full extension to about 30°, the femoral condyles do not fully support the patella, contributing to a more lateral riding position. Sports such as cycling or running on hills, or those involving repeated strikes to the anterior knee region (volleyball) tend to place more stress across the patellofemoral joint, in turn causing an increased incidence of experiencing painful knee symptoms [6]. Malalignment can also contribute to increased risk for subluxation or frank dislocation of the patella [3]. A common mechanism of patellar dislocation stems from internal rotation of the femur with a fixed foot causing the quadriceps to pull the patella laterally which may be a result of an acute, traumatic episode or from chronic, repetitive type of activity [1, 6, 24]. The dislocated patella, in general, usually spontaneously reduces; however, if it doesn't reduce, slow extension of the knee with medial force on the lateral patella will cause patellar reduction [34]. Treatment of symptoms localizing to the patellofemoral joint (PFJ) includes closed chain quadriceps/hamstring strengthening/stretching exercises along with addressing muscle imbalance of the entire lower limb from the foot to the hip. Use of peripatellar taping and/or bracing as an adjunct to physical rehabilitation may also be helpful for anterior knee pain as well [3].

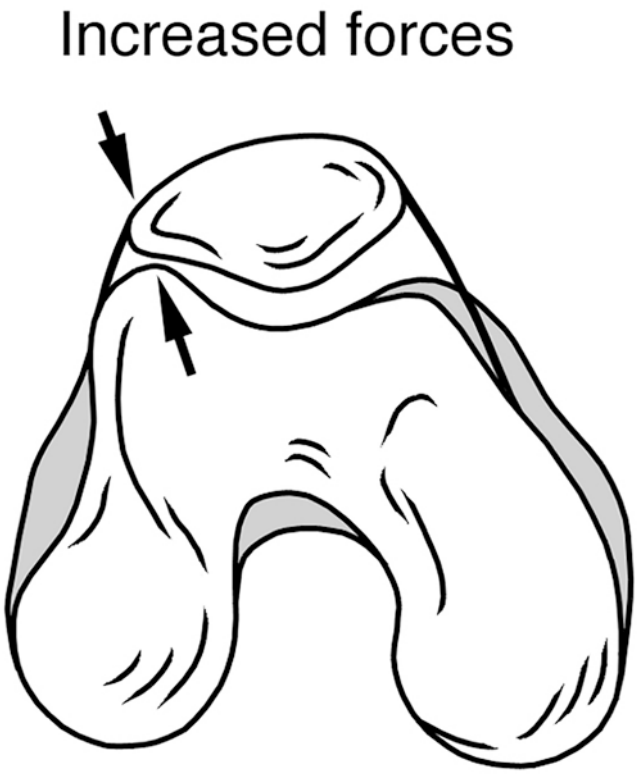

Fig. 15.10 Patellofemoral joint incongruency

Iliotibial band syndrome (ITBS) is another very common overuse knee injury in female athletes. The incidence of ITBS is sports dependent and most commonly found in long distance runners at a rate of ~4.4 to 7.5%. This friction type knee condition is a result of inflammation and irritation of the distal attachment of the iliotibial band that runs alongside the lateral femoral condyle. The inflammatory process is exacerbated by repetitive knee flexion and extension motions, as seen in running and bicycling. Anatomical factors which are thought to increase the risk of developing ITBS are excessive tibial internal rotation, genu varum, and increased foot pronation. It has also been suggested that weakness of hip abductor muscles can also contribute to the development of ITBS. Treatment of ITBS is generally conservative, consisting of rest, heat alternating with ice to decrease inflammation, stretching of the hamstrings, quadriceps, and ITB, along with physical therapy for muscle strengthening, similar to PFJ pain management. In extreme intractable cases, surgical intervention to increase the length of or partially release the tight tendinous band might be required [6, 22].

Another more proximal lower limb condition due to overuse activity with gender differences involves the hip resulting in pain/mechanical symptoms from femoroacetabular impingement (FAI)/labral tears. The excessive hip movements over time cause irregular bone formation/articular incongruency on one and/or both sides of this joint upon physeal closure, especially when exposed to repetitive rotational maneuvers in sports. Restricted range of motion (ROM), painful catching/popping localized to the groin is brought on by hip flexion and/or pivoting motions. Females tend to have less bony abnormalities associated with anterior hip pain which may be attributed to less muscle mass, more lax soft tissue restraints, and increased ROM versus males (Fig. 15.11). Ultimately, management for persistent hip symptoms failing conservative measures will involve

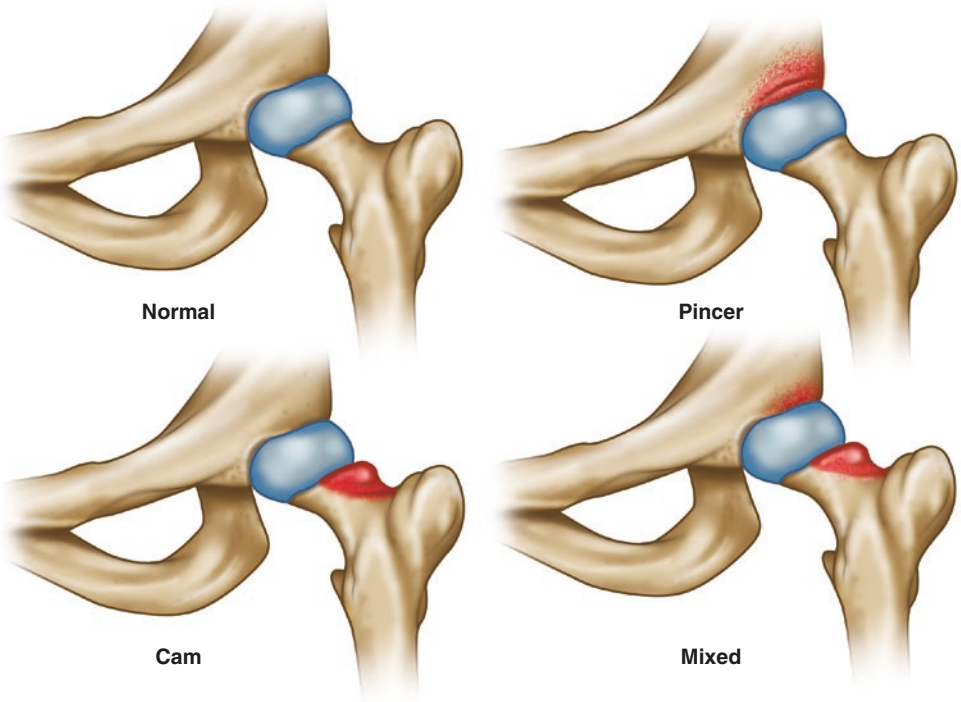

Fig. 15.11 Types of FAI. Image courtesy of Aiswarya J. Pillai, University of Texas at El Paso

arthroscopic resection of irregular bone on either side of the joint and/or labral repairs [27].

Other lower extremity conditions more prevalent in active females involve the feet, especially if specialized type shoe wear is deemed necessary for athletic participation. The other factor playing a contributory role toward female foot problems lies in the type of sporting activity consisting of frequent starts, decelerations, and sudden stops such as basketball, causing excessive forward and backward movements of the foot inside the shoe resulting in friction around the lesser toes. Again, this overuse condition is exacerbated by wearing sports shoes originally designed for males, not taking into account that a female's foot has different morphology, shaped wider in front (forefoot) and narrower in the back (hindfoot). Since athletic footwear do not conform/accommodate pedal form, the foot is "shucked" up/down plus back and forth. This sizing mismatch with subsequent excessive motion inside the shoe causes uneven contact upon the lesser toes, resulting in pressure sores/structural deformity [1, 3, 6, 8].

In a similar fashion, bunion (or hallux valgus bony deformity) formation results from bursitis overlying the first metatarsal head of the great toe. Bunions are very common in female athletes by at least 2 times in incidence (strong maternal inheritance component). In fact, exceed males in terms of needing corrective surgical procedures by about 9 times [9]. More than half of women in the USA have a bunion. Again, this great toe condition is due to a wide forefoot shape combined with wearing a narrow shoe toe box, causing excessive contact pressure and therefore more frictional wear, resulting in inflammation and pain. This inflammatory entity is aggravated by midfoot pronation or flat arches plus wearing high heels, and can cause transfer lesions/calluses to other toes or plantar aspect of the foot [1, 3, 6, 22]. Treatment for painful bunions is first and foremost properly fitting shoes. Appropriate footwear designed with a wide toe box are ideal for women suffering from bunion symptoms. Orthotics can also be worn to alleviate pain and provide extra comfort, support, and protection. Other modalities for pain relief include bunion shields, splints, and bandages. However, if bunion pain becomes unbearable, a surgical procedure can be performed to correct the bony protuberance. Bunionectomy will remove the bony outgrowth plus realign the affected bone(s) and soft tissues, with the caveat that this may change mechanics with resultant foot problems elsewhere [3, 22].

As for upper extremity trauma, the shoulder girdle complex in active females tends to be more prone to orthopedic injuries, especially when engaging in higher risk overhead athletic activities such as gymnastics, swimming, diving, throwing/pitching maneuvers, tennis, and volleyball. Again, etiology of this upper limb trauma could also be acute or chronic, with anatomical malalignment, structural imbalance, poor posture, muscular weakness, soft tissue inflexibility or excessive laxity, all contributing to the incidence and severity of injury. Biomechanically speaking, female athletes performing in sports requiring above the head activities are subjected to undue stress on soft tissue stabilizers (both static *and* dynamic) surrounding the shoulder girdle articulations,

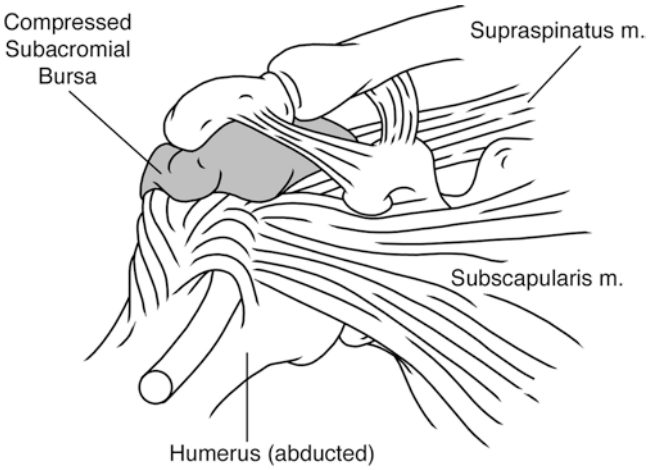

Fig. 15.12 Shoulder impingement syndrome

resulting in bursitis and rotator cuff tendinosis, leading to inflammation and pain (impingement syndrome) [1, 3, 6, 8] (Fig. 15.12).

Along the same line, shoulder issues occur frequently in female swimmers, since their bodies and arm lengths are generally shorter; they must utilize more strokes across the water to cover the same distance as men, increasing the number of repetitive insults placed across the glenohumeral joint. Surrounding muscles of the upper extremity in women are also not as strong as males, thus they must also exert more physically to produce similar forces needed to perform similar activities. In addition, the female glenoid cavity morphology is smaller—tall/thin (oval) plus tilted with a higher inclination angle, as compared to being short/wide (rounder) and not as angled in males. This smaller shape along with more tilt provides less surface area thus lends itself to being less stable as part of the glenohumeral articulation. Another cause of shoulder problems in overhead female athletes is due to increased laxity of the joint capsule, allowing the humeral head to "ride" out and back in over the glenoid, making the dynamic stabilizers such as the rotator cuff muscles work that much harder to keep the "ball" centered in the "socket," again causing painful symptoms [1, 3, 6, 8, 27, 33] (Fig. 15.13).

Similarly, for throwing mechanics, since humeral length is less in women but forearm length is the same as men, along with having narrower shoulder girdles, the lever arm is shorter as well, making overhead winding motions more difficult for athletic females, placing differential forces on supportive musculature surrounding the shoulder joint, increasing risk of microtrauma [6]. Treatment for shoulder impingement/instability hinges upon strengthening periscapular and rotator cuff muscles to help stabilize the entire shoulder girdle along with correcting techniques of each specific athletic activity [3].

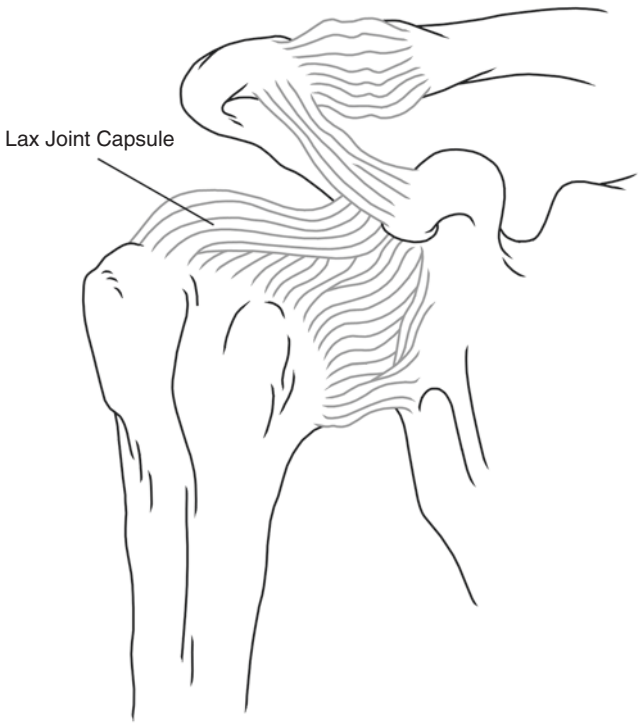

Fig. 15.13 Shoulder instability

The elbow joint is also more susceptible to "wear and tear" in active females primarily between 42 and 46 years of age, with an incidence of 10% versus 1–5% in males. Lateral epicondylitis, also known as tendinosis or tennis elbow, is degeneration of the tendons attaching to the lateral humeral epicondyle. This overuse condition is due to repetitive forearm rotation affecting the extensor muscles (poor mechanics while swinging a racquet). Symptoms consist of pain with usage and point tenderness to touch at the lateral epicondyle. Treatment is limited to rest, ice, and counterforce forearm bracing which are recommended initially, then a trial of steroid injections, with surgical debridement reserved for only recalcitrant cases [6].

As for another part of the body more prone to musculoskeletal trauma, spondylolysis is a back-stress injury to the spine commonly seen in female athletes, particularly affecting the fourth and fifth lumbar vertebrae (L4–L5). This L-spine stress fracture usually occurs at the junction between the superior and inferior process or pars interarticularis. Injury rates are higher in women participating in gymnastics, figure skating, and dance (all involving repetitive spinal hyperextension maneuvers/stunts). The presenting symptom is unilateral lower back pain, exacerbated by lumbar extension. Confirmation of this type of stress injury is obtained through X-ray, although sometimes plain radiographs cannot detect the injured site. In these cases, other imaging modalities such as an MRI are needed to reveal the damaged area.

Treatment for spondylolysis is mainly conservative, primarily with rest and/or bracing, with surgery only in extremely rare cases [1, 6, 8].

15.2.4 Several Measures for Prevention of Musculoskeletal Injuries Incurred by Adult Female Athletes

Again, the focus remains prevention of potential orthopedic issues for the active female involved in athletics/sporting activities. As previously stated, as compared to males, both intrinsic and extrinsic factors contribute to the increased incidence and varied types of injuries incurred along with musculoskeletal conditions occurring in adult female athletes. Intrinsic factors include sex-specific changes in musculoskeletal anatomy, endocrine, and physiology affecting relative limb length, lower extremity alignment, body composition, muscle mass/strength, and neurological recruitment. Extrinsic factors involve individual physical fitness, proprioception, playing level, competitive environmental conditions, sporting equipment, athletic wear, especially shoes, along with interaction/friction between footwear and ground surfaces [1, 2, 7, 8, 46]. Generally speaking, altering intrinsic conditions is virtually impossible because this is inherited/inherent within the athlete's genetic make-up. However, neuromuscular control can be modified through training and conditioning to affect the manner by which muscles are recruited and the force they produce. This can affect the way the female athlete lands during certain sporting activities, thus potentially decreasing the risk of lower extremity injury. Additionally, strengthening exercises for the hip (gluteus extensors/abductors/adductors), thigh (quadriceps/hamstrings), and leg (gastrocsoleus) muscle groups can be instituted to help support key joints of the lower limb (hip–knee–ankle), respectively [8, 47]. The importance of physical training lies in balancing the anterior (ventral) and posterior (dorsal) musculature to optimize muscular contraction upon neurological activation while playing sports. Furthermore, other aspects of the workout program should be considered, such as stretching for flexibility, unilateral single leg stance exercises for balance/proprioception, core conditioning for trunk stabilization, plyometrics for anaerobic power, and agility drills for speed/coordination. As discussed in Chap.14, the different types of warm-up, in particular static stretching, to potentially prevent injury and enhance performance, is being highly debated. Trends are now moving toward actively recruiting specific muscles and increasing blood flow in preparation for physical activity as opposed to passively stretching muscle groups [8].

To be extremely effective, physical conditioning programs must be at least 20–30 min per session, 6 weeks long, and workout sessions must be more frequent than once a week [7, 8, 48, 49, 50]. Sports-specific exercises should also be integrated into the training regimen to ensure that correct/appropriate and strict technique is maintained. Similar conditioning programming can also be applied to the upper body, enhancing physical fitness ability and minimizing injurious mechanisms. The training program needs to focus on deficits in range of motion of joints/stiffness of surrounding soft tissues and strength of the shoulder girdle region, especially the rotator cuff muscles. Other musculotendinous units surrounding this upper extremity articulation, such as the pectoral muscles (major and minor), latissimus dorsi, deltoids, triceps, and biceps brachii, should also be strengthened for added limb support, along with stretching tight musculotendinous units to minimize other muscular compensation leading to strains/sprains [1, 6, 8].

Control of external factors can also contribute to the prevention of musculoskeletal injury. Modification of environmental conditions may be done to a certain extent, by ensuring that playing equipment is adjusted to body size/shape, and making sure that athletic gear, especially shoes, are well padded/fitted to the foot in order to decrease risk of orthopedic trauma. As far as preventive measures for stress injury are concerned, avoidance of excessive, repeated bouts of impact activity will help to reduce this and other types of overuse musculoskeletal conditions. Furthermore, do cling to the principle of gradual moderation when increasing training intensity, duration, and frequency to aid in optimizing athletic performance and minimizing orthopedic injury [1, 8, 20, 22].

In short, the majority of extrinsic factors contributing to active adult female orthopedic conditions can be modified to decrease the incidence of musculoskeletal trauma. The mainstay of this prevention strategy lies in physical conditioning programs, training women athletes to keep their body in balance as far as strength, flexibility, and proprioception are concerned, along with maximizing other factors such as speed/agility, coordination, and power. However, the exercise regimen must be individualized to match the female athlete's fitness profile and progression should be gradual in order to minimize overtraining, attrition, and injury rates [7, 46, 48, 51].

15.2.5 Different Modes of Treatment for Orthopedic Injuries Sustained by Adult Females Participating in Certain Sporting Activities

Once orthopedic trauma has occurred, proper management of musculoskeletal injury should be done in order for optimal recovery in a timely manner. The following general principles (PRICE) hold when addressing orthopedic issues: *P*rotection from further harm to the injured extremity; rela-

tive *R*est for the affected limb(s) to maintain range of motion (ROM) thus minimize stiffness; *I*ce to aid in reducing soft tissue inflammation; even/equal distribution *C*ompression wrap (not to tight) to help decrease edema; and *E*levation above heart level as much as possible to control swelling. In other words, utilize appropriate first aid measures initially to hopefully halt the progression of the injurious process and minimize painful symptoms. As far as treatment for specific injuries is concerned, tendon strains, muscle "pulls," and ligament sprains, dependent upon the degree of damage, will usually respond to avoidance of provocative/exacerbating maneuvers and first aid treatment initially [49].

Administration of targeted medications may help with symptomatology and speed up recovery. Over-the-counter nonsteroidal anti-inflammatory drugs (NSAIDs) can be used for inflammation, swelling and pain; however, caution needs to be taken as not to remove the body's inherent protective mechanism since these medications may be masking symptoms. Another consideration is the medication's potential toward delaying the healing response due to blunting of the body's natural process of acute inflammation as the stimulus toward the healing cascade. Administration of vitamin C has been shown to provide a strong anti-inflammatory effect and aids in the stages of bone formation and scar tissue healing. Vitamin C is also an antioxidant, which also assists in the repair of damaged tissues. However, results are contradictory as far as the role of vitamin C in terms of helping with exercise recovery. Similarly, other studies have shown anti-inflammatory as well as anabolic effects of Omega-3 fatty acids, particularly of those contained in fish oil. Like NSAIDs, however, caution needs to be taken when consuming these minerals as not to remove the body's natural inflammatory response and subsequent tissue healing [8].

Along the same line, electrical stimulation devices may also be used to help treat symptoms of musculoskeletal injury, but only as an adjunct to neuromuscular retraining. In terms of orthotics for the feet, the custom molded ones tend to be better than those off the shelf as far as helping to distribute load more evenly inside the shoe [6, 22]. As for bracing of the limbs, use these judiciously as well, since muscles can become deconditioned if braces are worn too frequently, and no studies thus far have shown conclusive evidence that they can prophylactically prevent any type of knee injuries [1, 8, 22]. Moreover, relatively recent studies have found that improper bracing can, in fact, increase the risk of trauma because lack of motion in one articulation will cause load transfer to be distributed to the adjacent joint(s). Therefore, caution needs to be taken when using limb braces as protective or preventative measures. Similarly, athletic taping, although helpful in terms of joint stability, tends to take away the protective proprioceptive capability of soft tissues surrounding the involved joint. In addition, the tape or brace loosens up within about 20–30 min of play, rendering taping/bracing almost completely ineffective after that length of time [6, 8, 22].

As for treatment of more devasting injuries in active females, such extreme trauma to the limb warrants absolute immediate immobilization plus radiologic studies are definitely needed to quickly rule out displaced fractures. Musculoskeletal insults of this severity require an orthopedic consultation and could culminate eventually in surgical fixation if the injury is severe enough [7, 46]. Otherwise, as far as nonoperative management of musculoskeletal conditions in the adult female is concerned, as soon as the athlete has a pain-free extremity and joint ROM is regained, progression of activities should be instituted to include therapeutic physical rehabilitation exercises. The rehab program should encompass conditioning workouts previously outlined to include strength, flexibility, power, speed, and agility. In addition, other elements including core stabilization, neuromuscular coordination, and balancing/proprioception should also be integrated as part of the physical training regimen. Furthermore, any faulty body biomechanics should be adjusted when engaging in movement/motion to minimize additional unintended physical stress as part of the kinetic chain adding insult to the already injured limb. Finally, sports-specific drills need to be added gradually once prior physical milestones have been mastered. From this point on, functional exercises are emphasized in this phase of recovery in order to return the athlete to her pre-injury physical condition status and level of play [7, 8, 20, 46, 51].

15.3 Future Directions and Concluding Remarks

In summary, the adult female athlete, through the growing years of development from adolescence into more mature stages in life, has to face not only morphologic changes of the entire musculoskeletal system, but also must deal with sex-specific hormonal alterations influencing body composition as well. Prior to the early 1970s, involvement of women in sports was sparse until congress intervened, mandating equality for females participating in educational programs involving academic/athletic competitions. Paralleling the exponential rise in female sporting events, the rate of orthopedic injuries/conditions also became much more prevalent exceeding the incidence in males, affecting especially the knee joint and namely the ACL. Different factors, both intrinsic and extrinsic, contribute to the increased occurrence of musculoskeletal injury in athletic women. What appears to be fairly effective in preventing certain orthopedic conditions in female athletes consists of engaging in physical conditioning programs to enhance strength, flexibility, agility, speed, proprioception, coordination, plyometrics, and power. Once musculoskeletal injuries

have occurred, however, it is prudent to recognize/diagnose the offending problem early in order to protect the affected athlete from further harm. In addition, initial first-aid type measures can be instituted to help decrease symptoms plus maximize healing and recovery. Physical rehabilitation exercises with individualized gradual progression as tolerated can be added once the athlete responds to these first-line modalities. However, if the injury becomes recalcitrant to conservative management, orthopedic consultation should be sought after for further evaluation and more definitive treatment such as surgery. The ultimate goal for any injured female athlete is to provide aid promptly and hasten rapid recovery as much as possible in order to return her to play, whether it is in elite competitions or recreational sports.

Chapter Review Questions with Scenario

Scenario

You are a fairly new athletic trainer for a collegiate level female basketball team in a mid-size town. This is your first season working with these women athletes. One half is composed of rookies (junior varsity) and the other half veterans (varsity) players. Recently you have noticed that not all of these females show up every day for practice and that several have had more "off" than "on" days in terms of "scrimmage" games. You have also been providing daily "treatments" as far as local modalities and physical therapy rehab exercises in the training room for over a third of these female athletes for various musculoskeletal complaints. In fact, the majority of the problem lies in the lower extremity and most notably the tibia and knee regions. A couple of females are improving in terms of their symptoms, but the rest is still not making any appreciable gains. Alarmingly, some are actually getting worse. The regular sports season will begin in about 2 months and you are quite concerned that some players may not be able to "start" in their best physical condition.

Review Questions

1. Initially, how should you go about discovering the root of these female athletes' problem?
2. What specific questions should you pose to each woman about her complaints/symptoms?
3. What physical sign(s) of overuse injury should you look for to point you toward a potential stress fracture?
4. What further actions, if any, should be taken to manage these athletes' problems?
5. How can you ensure that these females will recover in time to start playing basketball once the regular sports season begins?

Plausible Answers

1. First of all, you want to gain the athletes' confidence as their trainer and confidant. Approach each female in private, chat with her as a friend, and try to find out the underlying reason, i.e., real deal behind them missing practice(s). They may be having problems with their studies at school or issues with their family at home. Allow each athlete to air her concerns, be understanding and supportive.
2. You may want to investigate each athlete's current fitness condition, i.e., previous formal training as she may be deconditioned to begin with; also inquire about other physical activities outside of basketball practices in which she may be participating, such as running, jogging, or other impact maneuvers. Ask specific questions about timing, location, quality, intensity, duration, and associated symptoms.
3. Watch for indications of overuse injury, such as pain that does not resolve with rest, persistent pain despite activity/exercise modification, and especially pain with weight bearing.
4. Once you have determined the extent of each athlete's orthopedic injury, talk it over with your head coach before approaching/consulting the team physician about the next step in diagnosis and treatment. Institute "PRICE" measures and depending on their level of response, proceed with the physical therapy rehab program to the level of each athlete's tolerance.
5. Progress with an appropriate conditioning program once the acute symptoms subside, concentrating on body mechanics, muscle balancing, and especially running and landing techniques. If indeed the affected females are engaged in excessive training/workouts beyond their practices, educate them on the importance of not "overdoing it" so that they can maximize their chance of recovery. Gradually incorporate sports-specific drills after they master the "basics." This way, these athletes' musculoskeletal injuries can heal in time and they will be physically ready to participate/compete with their teammates.

Chapter Review Questions

1. What is the percentage of essential fat in males versus females?
   (a) 5% and 10–15%
   (b) 2–4% and 10–12%
   (c) 3% and 9–12%
   (d) None of the above
2. Which sports tend to have a higher rate of musculoskeletal injuries in females?
   (a) Handball and lacrosse
   (b) Soccer and basketball

(c) Gymnastics and volleyball
(d) All of the above

3. Which bones are more commonly involved as far as stress fractures in female athletes are concerned?
   (a) Tibia
   (b) Hip and pelvis
   (c) Ankle and foot
   (d) B and C
4. Cite the incidence and specific anatomical structure which is more readily injured in females vs. males.
   (a) Five times higher, knee
   (b) 2–10 times higher, ACL
   (c) 2–10 times higher, MCL
   (d) Five times higher, ACL
5. Athletic taping becomes ineffective for joint stability after what amount of time?
   (a) 20 min
   (b) 10 min
   (c) 15 min
   (d) 30 min
6. Which is the most common mechanism of ACL injury in women athletes?
   (a) Hip external rotation and tibial internal rotation
   (b) Hip internal rotation and tibial external rotation
   (c) Hip and tibial internal rotation
   (d) Hip and tibial external rotation
7. Miserable malalignment syndrome is associated with
   (a) Decreased Q-angle
   (b) Genu varum
   (c) Hypomobile patella
   (d) Increased femoral anteversion
8. ITB syndrome is associated with
   (a) Weak gluteus medius muscle
   (b) Excessive tibial external rotation
   (c) Genu recurvatum
   (d) Reduced foot pronation
9. The most common level of spinal segments affected by spondylolysis is
   (a) L1–L2
   (b) L2–L3
   (c) L3–L4
   (d) L4–L5
10. Which of the following should not be adopted as a rehabilitation regimen after an acute injury?
   (a) Maintaining ROM
   (b) PRICE
   (c) Plyometrics
   (d) Muscle strengthening

Answers

1. c
2. d
3. d
4. b
5. a
6. b
7. d
8. a
9. d
10. c

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Prevention and Management of Common Musculoskeletal Injuries in the Aging Female Athlete

16

Mimi Zumwalt

Learning Objectives
After completion of this chapter, you should have an understanding of:

- The hormonal, physiological, and anatomical/musculoskeletal changes in female athletes as they transition from young adulthood into middle age and beyond.
- The differences and similarities between older males and females in terms of their body composition, musculoskeletal components, and athletic performance.
- Various musculoskeletal injuries and orthopedic conditions more common to aging and fairly unique to older female athletes.
- Several measures of prevention to keep musculoskeletal injuries in older active females from occurring.
- Different methods of treatment for orthopedic conditions incurred in aging female athletes to include an exercise prescription as recommended by various nationally recognized organizations.

16.1 Introduction

Throughout the lifespan, females undergo a multitude of changes to include structural, hormonal, physiological, neurological, and musculoskeletal. In a woman's lifetime, there are two most dramatic stages. One occurs early—pubescence during the teen years, and one happens several decades later—senescence after menopause. It appears that certain aspects of a woman's body come around full circle to the point where she started shortly after birth; she then eventually ends up in a similar state ultimately near the end of life. In particular, these endocrine alterations affect the quality of bones, making the skeleton so fragile that even the slightest bit of trauma could result in osteoporotic or fragility fractures, and if not addressed promptly/appropriately, could eventually result in dangerous demise. However, it is possible for an older woman to effectively fight against some of the negative effects of aging with several positive actions. The primary combatant to aging involves keeping the main muscular components strong in order to protect the skeletal system. The aging female must remain relatively active physically to guard herself from unintended harm. However, this may open her up to incurring potential orthopaedic trauma to the body. Exercise does not necessarily reverse the effects of time, but hopefully will slow it down to the point of allowing an older woman to more effectively cope with the inevitable bodily changes of life.

This chapter will address different issues of biological alterations within a woman's body as she ages, as well as various musculoskeletal/orthopedic injuries more common in the master female athlete, along with strategies for the prevention and management of these acute plus chronic traumatic conditions.

16.2 Research Findings and Contemporary Understanding of the Issues

16.2.1 The Hormonal, Physiological, Anatomical/Musculoskeletal Changes in Female Athletes as they Transition from Young Adulthood into the Middle Age and Beyond

In the past century, the number of elderly adults has increased from 1 to ~30%. In the USA alone, the number of people 65 years or older was estimated at more than 39 million in 2009. This value translates to ~13% of the US population or one in every eight Americans [1]. In 2010, the world's population had an estimation of nearly 525 million people older than 65 years of age [2]. Advances in healthcare, medicine, and standard of living have greatly contributed to this exten-

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sion in life expectancy. Most Americans maintain a healthy lifestyle for 85% of their lifespan; however, in the last 15% of their final years, the majority of older people are limited significantly with degenerative diseases along with impaired mobility. However, the leading causes of death related to lifestyle can often be preventable. Exercise has been shown to help enhance and even prolong the life cycle. Elderly people can still be adaptable, and thus will respond to endurance and strength training. Endurance training helps to maintain cardiovascular function, enhances exercise capacity, and reduces risk factors for certain diseases [3]. Strength training aids in the prevention of loss of muscle mass and strength associated with aging, to help minimize morbidity resulting from sarcopenia/muscular weakness [2–4].

Natural aging in humans is accompanied by gradual, progressive, irreversible changes in the body due to alterations involving multiple systems, affecting hormonal/biochemical/physiological, morphological/structural, and functional characteristics/capacity. Bodily changes are also affected by genetics, lifestyle and nutrition. Deficiency in calcium/Vitamin D, cigarette smoking and drinking alcohol all can contribute toward bone loss [2]. At the start of the third decade, the musculoskeletal system in both men and women begins to decline in integrity due to natural age-related changes. All tissues are affected, bone, joint, and muscle, with the former accelerating in females post menopause [2, 4]. First of all, skeletal-wise, bone quantity (mass)/density, volume, and mineral content are all altered/reduced, becoming demineralized/decalcified. As a result, bone tissue of the skeleton becomes thinner and more brittle/fragile, thus can be easily fractured due to osteopenia/osteoporosis [5].

Secondly, in a similar fashion, proteoglycans of articular cartilage also change constituents, become less resilient, unable to resist applied load as effectively, and thus are more vulnerable to injury. The articulating surfaces then become less congruent, causing frictional wear with motion/activity, resulting in pain and ultimately ends up with degenerative joint disease/osteoarthritis. In addition, the connective tissues (ligaments/tendons) surrounding aging joints also are less pliable/turn stiffer as well from a decline in elasticity, which then restricts the range of motion plus provides less support during activity/usage [4, 5]. For example, certain lower extremity joints in older females can lose up to ½ of their flexibility from the mid-50s to mid-80s [5]. Thus, a regular program of static stretching can help to offset soft tissue stiffness and maintain range of motion (ROM)/functional mobility [6].

Thirdly, loss of muscle mass also occurs due to various factors, exacerbated by a decline in circulating anabolic hormone levels around the middle age onward. Peak mass and strength of muscles are attained by second to third decade, after which a gradual reduction occurs until the sixth decade, then this atrophic process is accelerated, more so in women due to loss of estrogen [4, 7]. Causes of senile sarcopenia are multifactorial i.e. endocrine/biochemical/neurological/functional, along with medical co-morbidities, reduced caloric intake, poor blood flow, disuse and weight loss. The latter is due to physiological anorexia, resulting in 2% muscle/bone loss and 75% of fat loss [2]. The loss of motor neurons associated with aging contributes to sarcopenia, muscular weakness and slower reaction time [2, 5]. In other words, muscle force AND speed both decline with age [5]. Skeletal muscle also undergoes alterations beyond the tissue level. A gradual decline in quantity and quality of fibers occurs along with morphologic changes in fiber size (atrophy) as one ages over time. This loss of muscle mass and strength i.e. sarcopenia, means that the affected joints receive less structural support and thus end up being unstable. As a result, this may put the lower extremity at risk during weight bearing activity predisposing the elderly to falls. Additionally, the number of fast-twitch (explosive Type II) muscle fibers declines at a faster rate than slow-twitch (endurance Type I) fibers, meaning that muscular contraction also slows down during the process of aging [4, 5]. Furthermore, muscles in bodies of advanced age are "old and worn out", more prone to trauma plus less able to heal thus take more time to recover as well due to less available satellite cells for differentiation [5].

As mentioned previously, after peak bone mass is reached in the mid-twenties (earlier in females), the quantity of bone in the skeleton starts to gradually decline at a rate of 0.3–2% per year until the fourth decade. After menopause, bone loss is accelerated to over 3% yearly for 5–10 years. This increased rate of bone loss places elderly women at increased risk for osteoporosis [8–13] (Fig. 16.1). This skeletal manifestation is due to a precipitous drop in female sex hormone levels, namely, estrogen, which had been previously protective in terms of bone-building earlier in life [2, 5, 13]. In fact, by the eighth decade, only 50% of bone remains in the skeleton as compared to the peak quantity achieved by the second decade [5].

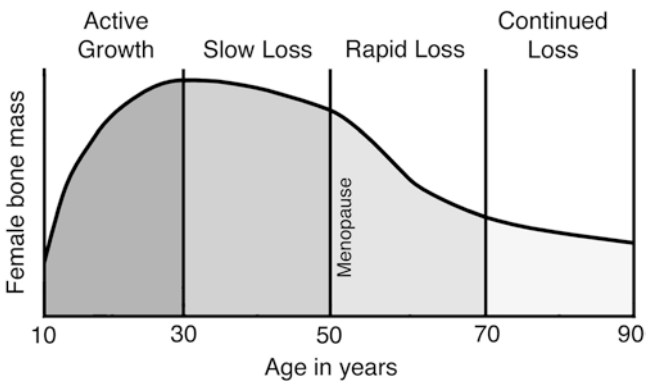

Fig. 16.1 Rate of bone loss through a women's lifetime

Additionally, as a female athlete ages, endurance performance, aerobic capacity, and cardiorespiratory functions all deteriorate, whether due to a reduction in relative physical activity or to the natural resultant effects of aging [8, 14, 15]. No matter how well a female athlete takes care of herself, all bodily processes are affected by age. However, the extent of physiological deterioration varies between individuals. Genetic factors have a great influence on both length and quality of life. For example, in females, maximum oxygen uptake tends to decrease approximately 10% per decade starting in the mid-twenties [16]. However, if training intensity and volume are maintained as compared to their younger counterparts, master female athletes will only lose 1–2% of their previous aerobic capacity yearly until 50 years of age [8, 9, 15].

Although body weight gradually increases with age from 20 to 70 years old, during 5–10 years prior to menopause, the amount of fat-free mass undergoes a drastic reduction while the percentage of body fat rises (5–10 kg in the mid-30s to mid-40s). The increase in the extent of body fat is greater in more sedentary women [8, 14, 15]. For example, in highly trained female runners around mid-40s of age, the body fat percentage is about 18%, as compared to 26% in their sedentary counterparts. Similarly, women swimmers also remain slimmer, although not as marked as runners, with body fat staying around 23%, which is still lower than inactive age-matched females. The average woman's body fat in her youth is approximately 25%, which rises to over 35% by age 50. The reasoning behind the increase in body fat is threefold: more dietary intake, less physical activity, and decreased ability to mobilize adipose tissue [15, 17]. Researchers have shown that a correlation exists between musculoskeletal pain and increased fat mass, along with gender differences. Both obesity-higher body mass index (BMI-weight/height^2) and female sex are associated with painful orthopaedic conditions, especially after the fifth decade of life. Etiology is partially due to adipose tissue acting as an endocrine organ, with secretions which promote low-level inflammatory effects on the entire body, with or without the presence of associated metabolic syndrome [18].

In terms of muscular strength, the absolute level required to perform activities of daily living stays the same throughout one's lifetime. On the other hand, the maximal level of muscular strength declines at a steady rate from young adulthood (highest level achieved between age 25 and 35) proceeding onto later years, with an accelerated loss after 60 years of age [5, 8, 9, 14, 15]. As a parallel occurrence, the basal metabolic rate (BMR) also decreases (beginning about the second decade) in conjunction with loss of skeletal muscle. From the third decade onward, the human body loses 3–8% of muscle mass every 10 years. Both of these changes are additive toward the increase in fat storage from excess calories, especially if one doesn't remain physically active while maintaining the same caloric intake [5].

Thus, if physical activity declines or is absent in later years, the loss of muscular strength starts to occur gradually after the third decade, then up to 15% per decade between the fifth and seventh decades, progressing more quickly in subsequent years, at a rate of up to 30% per decade [4, 9]. About 25% of peak force is lost by the time a woman reaches her mid-60s. This age-related loss in strength stems from a reduced mass of primarily skeletal muscle (sarcopenia), which in turn affects the basal metabolic rate (10–20% decline from early adulthood to beyond middle age), and/or restricted physical activity levels as mentioned above [5, 8, 10, 13, 15]. The latter functional disuse condition, hypokinesia, accounts for 50% of the physiological weakness of muscles and bones [12]. This decline in muscular strength seems to affect the lower extremity to a greater extent than the upper extremity [8]. Specifically speaking, after peaking in the third to fourth decade, the loss of lean muscle mass is attributed to both a reduction in size and number of muscle fibers [8, 14, 15, 17]. After the fifth decade of life, about 1% of the total number of muscle fibers are lost per year from atrophic (wasting) changes [15]. Beyond the sixth decade, approximately 15% of muscle strength is lost each subsequent decade [10]. In fact, midlife adults not involved in strength training lose about 5–7 pounds of muscle every 10 years [14]. In addition, the nervous system's ability to process information and activate the musculoskeletal system is altered as well, resulting in slower response times with both complex and simple movements [15]. Resistance training can, however, counteract and partially offset ongoing biological muscular weakness by increasing both muscle size and strength [10, 15].

Furthermore, as previously mentioned, older adults who are more sedentary also gain a substantial amount of fat in their subcutaneous tissue, contributing to the natural decline in physical function associated with aging [10, 19]. As a corollary, the skeletal system in an older female gradually becomes quite frail as well, leading to thinning bones and increased risk of osteoporosis/fracture [10–12, 19] (Fig. 16.2). However, mechanical loading of the skeleton, especially exercising while weight bearing (standing upright) will also help to build bone according to Wolff's law, thus counteracting the continuing bone loss due to inactivity and aging [12, 13, 20]. Even though the age-related decline is inevitable, by participating in regular workouts and exercise,

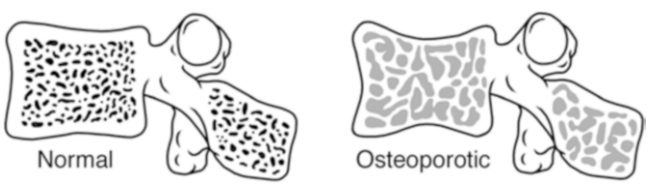

Fig. 16.2 Normal versus osteoporotic bone

older females can fend off some of the inevitable decrements in musculoskeletal strength, power, and endurance [10, 15].

16.2.2 The Differences and Similarities Between Older Males Versus Females in Terms of Their Body Composition, Musculoskeletal Components, and Athletic Performance

The aging process in both men and women is associated with a decline in muscle mass and strength, resulting in a loss of physical function, occurring as early as 30 years of age. Sarcopenia (previously described) is a term coined to describe such changes. Sarcopenia results in decreased mobility, increased fatigue, and higher risk for falling [4, 21]. It is estimated that humans lose 20–40% of skeletal muscle mass and strength from age 20 to 80. A decline in muscle mass is related to weakness, decreased performance, functional impairment, physical disability, and falls [22]. As mentioned above, sarcopenia is also associated with a relative increase in body fat along with a decrease in proprioception, coordination, strength (both muscular and skeletal), power, flexibility (pliability of soft tissues such as joint capsules, articular cartilage, tendons, and ligaments), speed of reaction, and aerobic capacity [9, 15, 23, 24].

Between the second and seventh decades of life, muscular strength decreases about 30%, along with an approximate 40% decline in muscle mass. The loss in muscular strength associated with aging is primarily attributed to this great reduction in muscle mass. Research has shown that with advancing age, there is a decrease in the number of alpha motor neurons, total nerve fibers, and neuromuscular junctions in skeletal muscle [21]. Various studies which have been conducted on both animals and humans find similar results as well. After the age of 60, there is a decrease of up to 50% of motor neurons in these older individuals as compared to younger populations [25]. Other scientists have calculated the total number of motor neurons in the spinal cord of the lumbosacral region in 47 subjects ages 13–95. They determined that after age 60, there was a decline of motor neurons, with some subjects having 50% less than the number found in younger counterparts [26]. Similar results have been shown in a study on the biceps brachii where older subjects over 60 years of age have 50% less motor neurons as compared to those in younger age groups [27].

As previously eluded to, other evidence has shown that with aging there is a loss of motor neurons for both slow and fast twitch muscles, with a greater loss in fast motor units [21]. However, most fibers are reinnervated by other motor neurons, thus affecting a greater loss of muscle fibers within a motor unit. Studies conducted on human and animal subjects have demonstrated that the muscle fibers are reinnervated with different motor neurons [28]. A couple of research scientists used a rat model to show a decline in motor neurons as well as a decrease in Type II fibers in the hind limb muscles of older rats [29]. Two more researchers found an increase in Type I muscle fibers in the plantaris muscle of aged rats [30]. Similarly, another group of scientists also used rats to demonstrate a 22% decline in Type II motor neurons and a 15% increase in Type I motor units in the medial gastrocnemius of older rats as compared to younger rats [31]. As aging occurs, there is a greater tendency to lose motor neurons innervating Type II fibers, thus reinnervation tends to be by Type I motor neurons. There is a general shift in the type of muscle from fast twitch to slow twitch fibers as an animal ages over time [21].

Other studies have found that with age, there is little change in the average cross-sectional area (CSA) of Type I fiber. However, the total muscle CSA innervated by Type I increases with aging, and the total CSA for Type II plus power decline rapidly with age. As the innervation for fast motor units decreases, the concentration of muscle work switches over to existing slower motor units [21]. It has also been found that there is an increased density of muscle fibers belonging to a motor neuron with advancing age [32]. A decrease in Type II fibers causes a decline in the muscle's capacity for power [21]. A major contributor to muscle weakness is the decrease in the CSA of active muscle tissue. Research in animals has shown that as rats increase in age, there is a subsequent decline in CSA and Type II muscles fibers [29]. A similar study also found that with aging, there was a decrease in tension produced in the medial gastrocnemius in older rats. As a corollary for translating over to humans, the decline in power in the elderly can be attributed to the loss of Type II fibers, which is reflected in actions such as rising from a chair, climbing stairs, or regaining limb/postural balance after a gait disturbance [21]. Specifically speaking, another scientist found velocity at maximal power to decrease by roughly 18% between the ages 20–29 and 50–59, with a further 20% decline in subjects aged 60–69 plus 80–89 [33].

Muscular strength gains of more than 100% can be made in men (60–72 years of age) after lifting weights for about 3 months. Similar studies in both males and females demonstrate that people older than 90 or even 100 years of age participating in strength training could also become physically stronger (~125%), with a concomitant increase in lean muscle mass (10%) [23]. One study has shown that an 8-week resistance program in men and women ranging in age between 89 and 92 years old affected an increase in quadriceps strength of 175% [8, 24]. Likewise, a similar study in women ages 87–96 years of age demonstrated an increase of strength three times over baseline values, along with a 10% gain in muscle size [14]. This rise in muscular strength has been shown to translate into enhancing physical function, decreasing limita-

tions, and increasing mobility, such as speed of gait and stair climbing [20, 23]. Although relative strength gains are comparable for men and women engaged in the same sort of conditioning program, the absolute rise of muscular strength in females is only 50% that of males [8, 23]. Muscular weakness also occurs earlier in females; thus, it is extremely important to implement and continue a regular resistance training regimen throughout a woman's lifetime [8].

Furthermore, older adults can make great gains in their capacity to generate muscle force by participating in a regular weight-lifting program. In fact, even as late as the eighth decade of life, intensive physical training can minimize or even reverse the age-related effects of ongoing muscle weakness [9, 10, 23]. However, improvements made in muscular strength far exceed the enhancement in the quantity of lean muscle mass, meaning that neural activation is primarily responsible for the strength increase [23]. The exception lies in the quality of muscular integrity in men and the ability of their skeletal muscles to retain the capacity for endurance training. Despite the loss of muscle mass over time in males, the remaining muscle still retains 85–90% of the enzymatic activities required for aerobic-type sports [15]. Unfortunately, the amount of strength gains needed to effect a meaningful change in athletic performance is still unknown. What has been shown, however, is the fact that muscular strength appears to improve physical function qualitatively and partially offset age-related bone loss [12, 20, 23]. Therefore, having more muscle mass as aging occurs over time tends to positively affect bone mineral density in later years [12].

Beyond maintaining muscle strength with aging, physical and physiological aspects in the body such as range of motion, coordination, reaction time, and cardiorespiratory fitness can also be improved with exercises specifically aimed at enhancing these parameters. For example, men and women in their 60s and early 70s can improve their aerobic capacity by over 20% after engaging in 9 months of endurance training [23]. Similarly, another study found that older subjects 65–90 years of age can also effectively increase the flexibility of several large joints after participation in a 12-week program of dancing plus stretching exercises [24].

In terms of body composition/metabolism, as one reaches an advanced age over time, the decrease in muscle mass is accompanied by an increase in adipose tissue [25]. The percentage of fat in women on average changes from about 35% at 17 years old to approximately 40% at 60 years of age [3]. However, this change is highly variable and is much less evident in active females. There are a few possible mechanisms that can contribute to this alteration in relative soft tissue comparison. It is thought that due to the loss of muscle mass and strength, there is a subsequent decrease in VO_{2max}, which affects physical activity levels in the elderly. This decline in daily activity will cause a decrease in energy expenditure, which in turn causes an increase in adipose tissue in visceral organs and muscle tissue, as well as total body fat [34]. Furthermore, an increase in fat content in muscles that occurs with aging is associated with a decrease in muscle strength [35]. This age-related increase in muscle weakness translates to a decrease of almost 50% in isometric knee extension torque strength from age 30 to 80 years old. Even when corrected for decreased muscle mass, there is a decrease in peak torque, indicating a decline in the quality of the muscle contraction or a reduction in the efficiency of muscle strength with an increase in age [25].

As for engaging in recreational/competitive physical activities, the absolute level also suffers as aging occurs. In spite of being able to keep the percentage of body fat low, athletic performance of events comprising endurance plus strength in both males and females inevitably experiences a decline of about 1–2% per year after the third decade. Research on more than 500 subjects (men and women) between the ages of 30- and 70-years old shows that maximal running velocity gradually decreases by approximately 8.5% per decade independent of distance. Similarly, for cycling performance, speed for both male and female cyclists between 20 and 65 years of age undergoes a gradual drop of about 0.7% per year. There are some exceptions in sports dependent on athletic skill for successful completion such as golf, equestrian and swimming performance, which continues to improve after years of experience, along with strength/endurance. Thus, the former two types of athletes (golfing/riding horses) max out in the third decade, but master swimmers may peak and perform their best as late as 45–50 years of age [8, 15]. In contrast, gymnasts usually peak very early in their teens as far as athletic performance, since flexibility is of paramount importance for this type of sport which tends to decline gradually over time [8].

As for the structural aspect of the musculoskeletal system, with advancing age, the gradual bone loss causes a decrease in bone density and tensile strength, thus eventually resulting in osteoporosis, as previously outlined [3]. Unfortunately, osteoporosis increases the risk of fragility fractures. Skeletal bone loss is a serious problem in the aging population, affecting women earlier and much more so than men. Osteoporotic changes affect both males and females as a natural process of aging. However, women are affected at a younger age (females start to lose bone mass at age 30 versus males at age 50), while fewer men (only 20% compared to 80% of women) are affected; and even then, males tend to experience a lesser degree of total bone loss than females. After the fourth decade, men lose bone mass at a rate of 0.5–0.75% per year, while the bone density decline in women is twice that rate—1.5–2% per year, increasing to at least 3% per year after the onset of menopause. It is not until after the sixth decade that the rate of bone loss in males begins to parallel that of females [8, 10, 11, 13, 17, 24, 36]. Postmenopausal women lose bone density more rapidly in the vertebrae, pelvis, and distal radius. After menopause, there is less cortical

bone loss in the long bones of females [37]. A group of researchers conducted a cross-sectional study of women aged 20–97 years and found large decreases in lumbar spine bone density. The reduction in density was due to the loss of vertebral trabecular bone (spongy bone with higher surface area, but less dense) starting in the third decade, whereas cortical bone loss did not begin until the middle age [38]. Another sign of normal aging in women's bones is an increase in the cross-sectional area of the femoral neck in the hip and distal radius of the wrist due to the formation of trabecular bone in those skeletal areas [37]. To sum up, as far as bone mass is concerned while growing, there is a greater periosteal expansion in males, resulting in 35% to over 40% larger bone area (longer/wider bones) than females by young adulthood. As time progresses, loss of cancellous bone is similar in both sexes; however, the rate of cortical bone being resorbed is faster in elderly women (25%) as compared to less than 20% in older men [39].

Gender-wise, age-related changes in bone density are associated with an increased risk of osteoporotic fractures in women. According to the World Health Organization (WHO), in the USA, approximately 15% of postmenopausal Caucasian women and at least 30–35% of females older than 65 are affected by osteoporosis [11, 40]. Several studies have shown that the incidence of Colles' fracture (distal radius) increases in women after menopause [37]. Epidemiology also demonstrates that, after the fifth decade of life, about 40–60% of Caucasian females and 13% of Caucasian males will suffer one or more clinically significant osteoporotic-related fractures in their lifetime, with more than 7% of them experiencing permanent disability, especially when it involves the hip [11, 12, 36, 40]. Nine out of ten elderly individuals who sustain a hip fracture are 70 years of age or older [5] (Fig. 16.3). Alarmingly, if an osteoporotic fracture occurs between the ages of 20 and 50, then the risk for another fragility fracture increases to almost 75% [41].

However, it has been shown that men and women older than 65 who are involved in 10–12 weeks of physical activity such as Tai Chi (Chinese exercise program consisting of repetitive, rhythmic body balancing movements) or other low-intensity workouts can enhance athletic performance, improve physical balance, and decrease the chance of falling [10, 23] (Fig. 16.4). Other studies have demonstrated that this martial art exercising technique if practiced for at least a few months, can be very effective in reducing the risk of falls by almost 50% [11, 12].

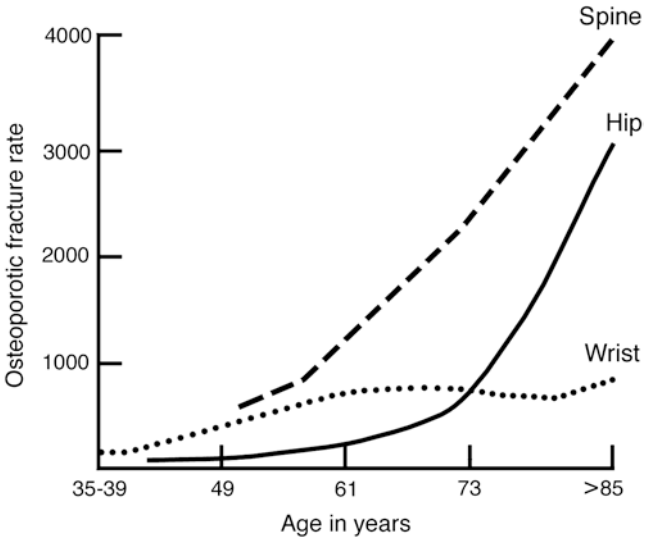

Fig. 16.3 Osteoporotic fracture rate versus age

16.2.3 Various Musculoskeletal Injuries and Orthopedic Conditions More Common to Aging and Fairly Unique in Older Female Athletes

Because the average life expectancy has increased by more than 30 years within the past century, elderly people, especially women, currently are more involved in all sorts of athletic endeavors. Along with this increased participation in physical activity has surfaced different types of musculoskeletal issues, some of which are due to the hormonal changes associated with the female sex, while others occur as a result of the natural aging process [9, 14]. One study has shown that the incidence of exercise-related injuries in the elderly (60–90 years old) is about 15%, which is within the range than reported by others (5–20%) [42]. Similarly, the rate of activity-related musculoskeletal (MSK) trauma is about 20% in adult females. Modes of physical activity associated with MSK injuries include: walking/jogging/running (most often); weight training-bearing/calisthenics/floor workouts; swimming/bicycling/treadmill at the least [43]. As for the location of MSK trauma, the lower extremity (similar to younger age groups) and type tend to be overused as well, but the frequency is higher in older subjects [42]. Another article reports the frequency of low back pain (LBP) is increased in females after menopause as compared to males, partially due to the faster rate of spinal disc degeneration [44].

Fig. 16.4 Tai Chi

The collagen in ligaments and tendons-collectively termed sinew, gradually becomes less elastic with aging due to loss of water content among other ultrastructural alterations, contributing to increased stiffness, especially upon the decline in estrogen experienced by postmenopausal women [7, 21]. As a result, this type of connective tissue is less able to adapt to mechanical "wear and tear," making it more susceptible to injury along with having less capability for healing. A similar phenomenon happens in cartilaginous tissue, such as the menisci within the knee joint or articular cartilage surrounding ends of long bones. These "capping/interpositional" connective tissues are unable to distribute force efficiently over time, especially when subjected to repetitive high-impact loading. The resultant cumulative microtrauma has an additive effect of joint destruction and cartilaginous degeneration, leading to progressive osteoarthritis (OA) and resultant disability. This type of mechanical breakdown is more marked in large weight-bearing joints such as the hip and knee [21].

Fortunately, the incidence of acute orthopaedic trauma (third leading cause of death especially in younger age groups) in the master female athlete is extremely low. Only about 1% of those athletic women hospitalized for sports-related injuries are over 55 years of age [9, 45]. However, the development of OA is much more common. The site-affected joint degeneration varies between each individual based on genetics, articular structure, patterns of mechanical loading, and injury [46].

The most common joint disorder in the aging population is osteoarthritis (OA), also known as osteoarthrosis or degenerative joint disease (DJD). In the US, 13% of females and 10% of males older than 60 years of age are afflicted with symptomatic knee degenerative arthritis [5]. A common misconception is that OA is an arthritic disease fraught with inflammation. On the contrary, because it is not manifested as an inflammatory condition, it is considered more of a degenerating process. Osteoarthritis begins with the softening of articular cartilage due to a decrease in matrix proteoglycan content. The cartilage thins out, becoming rougher with ulceration, pitting, and fissuring. Continued degeneration is manifested by subchondral bone necrosis and osteophyte formation at the joint margin. The severity of OA is generally classified by the degree of joint space narrowing, osteophyte formation, sclerosis, and bony deformity [47]. The initial presentation of OA varies at different joint sites and generally is first manifested at the metatarsophalangeal joints, followed by the wrist and spine, next in the interphalangeal articulation, carpometacarpal joints, then in tibiofemoral (knee), and lastly seen in the hip joint [11, 12, 36, 47].

However, middle-aged athletes participating in intense physical activity are more than eight times as likely to develop degenerative arthrosis of their hips [21]. Gender differences also exist in knee osteoarthritis, which tends to develop more often in females (especially after menopause) versus males. The annual rate of articular cartilage loss in women exceeds men by four times. Furthermore, patellofemoral joint degeneration is found more frequent along with being more severe in females as well [39]. The effects of arthritis are accelerated and exacerbated by previous episodes of injury and/or surgical reconstruction/removal of certain intra-articular structures, i.e. procedures done for anterior cruciate ligament tear or partial meniscectomy in the knee respectively, resulting in posttraumatic arthropathy. Fortunately, unlike the aforementioned soft tissues where one must succumb to natural progressive deterioration, the physiological decline in muscle function due to sarcopenia

can be counteracted somewhat by engaging in an intense resistance training program. This is possible since muscular contractility is not influenced to the same extent as loss of muscle mass with aging, enabling maintenance of muscular strength through ongoing exercises [21].

As discussed in Chaps. 14 and 15, the most noted orthopaedic injury occurring in sports participants is the overuse type of microtrauma, such as tendinosis/bursitis/tendonitis affecting the shoulder (rotator cuff disorder/impingement syndrome) and elbow (lateral and medial epicondylitis/tendinosis), and foot (Achilles tendonitis). This type of traumatic condition, resulting from chronic, repetitive loading, accounts for 70% of veteran athletes beyond the sixth decade versus only ~40% of younger athletes in their twenties. In addition, 20% of these overuse injuries can last much longer in older sports participants (up to 2 years), affecting their ability to train and/or compete in athletic activity [9].

A very frequent injury which tends to occur in older female athletes is muscular strain even with only moderate exercise, one example being performing an eccentric muscle contraction. This is can be related to the fact that the aging musculotendinous unit is not as flexible as in younger age groups when much more force is needed to inflict trauma [24]. However, the musculotendinous junction can be affected in a similar manner when compared to other types of connective tissues in terms of relative inflexibility; thus, it is important to also incorporate a stretching routine into the workout regimen in order to decrease the risk of injury [9, 24].

As for vertebral disorders, kyphosis is manifested more often in aging females. This degenerative spinal condition, known in layman's terms as "dowager's hump," is a sagittal plane deformity which is characterized by excessive forward spinal flexion, generally in the thoracic region. As opposed to an orthopaedic injury, this is a naturally occurring entity that tends to be especially prominent in women of advancing age. Specifically, postmenopausal females are at much greater risk for this type of vertebral deformity because of the association between kyphosis and osteoporosis. Supporting evidence was reported by a group of researchers, who showed that there is a higher degree of kyphosis in osteoporotic elderly women. They also found a negative correlation between bone mineral density (BMD) and the severity of the kyphotic deformity. On the other hand, it was noted that women who participate in a regular exercise regime tend to have a lower incidence of thoracic kyphosis [48] (Fig. 16.5).

The most prevalent type of musculoskeletal trauma occurring in the geriatric female is a fragility fracture from low energy loading due to osteoporosis with excessive bone thinning [5, 45]. In fact, about one out of 3 elderly individuals fall each year in the US, from lower limb muscle weakness/stiffness affecting gait/balance [49]. The number of women aged 50 years old with osteoporotic bone is 2–5%, which

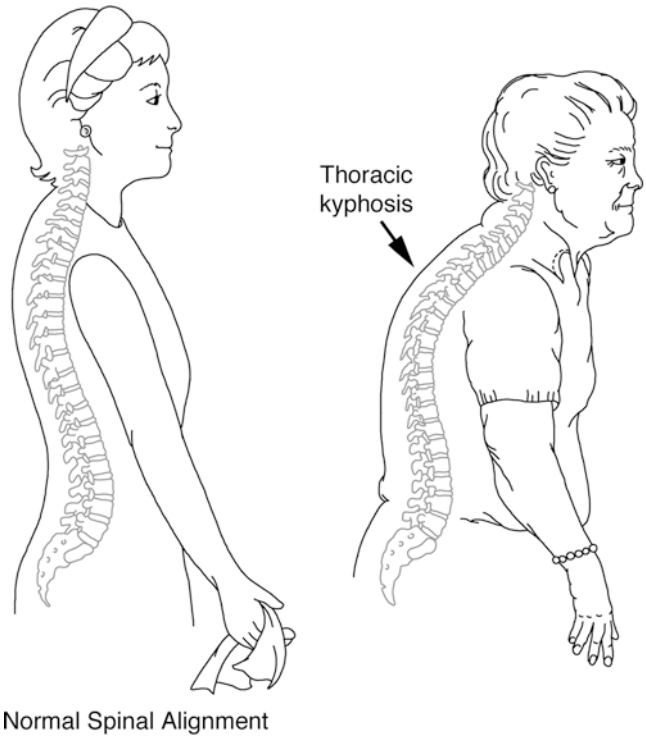

Fig. 16.5 "Dowager's hump"

rises exponentially to 25% by 80 years of age [5, 45]. The amount of bone loss can be quantified by obtaining a bone density study, with dual-energy x-ray absorptiometry (DEXA) being the current gold standard. Alarmingly, once osteoporosis sets in, even minimal amounts of force inherent in activities of daily living such as bending over and lifting objects can subject osteopenic bone to potentially injurious loads [11, 12, 36].

Osteoporotic bone is more porous and thus weaker structurally, which can increase the likelihood of a fragility fracture. Compared to younger people, the femur of an older person is only half as strong and has merely a third of the energy-absorbing capability before failure [11]. Dynamic models have found that falling and striking the surface below create peak hip trochanteric forces ranging from 2.9 to 9.99 kN, which are sufficient to cause a fracture even in healthy bone [50]. Over 90% of hip fractures occur in older adults beyond the seventh decade of age [10]. Osteoporosis is a contributing factor to hip fractures; however, other sources need to be considered such as bone quality, muscular strength, soft tissue characteristics, and neuromuscular coordination. Hip fracture generally occurs due to direct impact such as landing on the ground after a fall or during car accidents. While rare in younger populations, proximal femur fractures, usually incurred from more violent forces, increase in frequency with age. In fact, 90% of hip fractures can occur just by falls from only a standing height [47, 50]. Women outnumber men by 3 to 1, along with incurring this injury

7 years earlier as well, especially after the sixth decade [5, 45]. Alarmingly, after sustaining a hip fracture, hospitalization is necessary at 100% with resultant permanent disability in 50%, and mortality in 20%. Less than 1/3 of those who fracture their hips recover fully afterwards [45].

Previous longitudinal studies have found a decrease in hip fractures for both men and women from 1990 to 2006, but the factors for this decline are largely unknown [46]. However, women are still 3–4 times more likely to suffer from a hip fracture than men. In America, the prevalence of osteoporosis of the hip/spine in males is 4%, as compared to 16% in females older than 50 years of age [39]. Interestingly, hip fracture rates are lower in people with higher body mass index (BMI) [47]. Along the same line, vertebral fractures become more of a concern in the elderly population as well. If an older woman has a height loss of more than 2 in., then this should raise the suspicion of one or more spinal compression fractures resulting from osteoporotic bone [11]. Similar to hip fractures in the lower extremity, upper extremity wrist fractures also herald the early onset of osteoporosis and tend to occur much more often in women between the ages of 50 and 65 years old [29]. In fact, the prevalence of distal radius fractures from low-energy trauma is 6 times higher in females as compared to older males [39]. If they occur after the mid-60s, then the risk of other types of osteoporotic fracture tends to increase in the future [36].

16.2.4 Several Measures of Prevention to Keep Musculoskeletal Injuries in Older Active Females from Occurring

By the time the female reaches adulthood, the physical condition of her body is a by-product of prior decades of living. Lifestyle and activity choices affect the body's condition in later years. Participation in athletic activities has positive as well as negative consequences in terms of affecting the overall physical body condition. While aging is inevitable, the extent it affects the body is highly regulated by the ability to maintain and preserve muscle mass and bone density along with other components of the musculoskeletal system throughout one's life [8, 10].

Previous research has proven that resistance training exercises have the benefits of increasing muscle/bone mass, muscle/bone strength, joint flexibility, balance, and basal metabolic rate (BMR) [51]. On the other hand, participation in endurance training maximizes cardiorespiratory function [9–11, 23]. Any type of weight-bearing workout, such as dancing, playing volleyball, basketball, walking, jogging, and stair climbing, are beneficial for building muscle and bone as well as improving/maintaining cardiorespiratory fitness [11–13]. A recent study has demonstrated that in individuals between 65 and 85 years of age, those who are more active i.e. takes at least 1000 steps per day tend to have better balance and overall musculoskeletal fitness, as measured by a few standardized physical tests [52]. Other moderate but lower impact exercises, including calisthenics, weight-supported swimming or water aerobics, bicycling, and Tai Chi, also help in enhancing overall physical fitness while protecting problematic joints [8, 10, 12, 13] (Fig. 16.4). The latter Chinese Martial Art technique, when practiced for 6 months by subjects beyond the seventh decade, resulted in improvement of physical performance/functional balance, in addition to decreasing fear/risk of falling and the number of falls [2]. A similar regimen targeting fall prevention in the elderly is the 10-week Combined Balance and Step Training Program. This showed promise in improving proprioception, gait, and functional mobility comparable to Tai Chi [49]. Another study has also found that quadriceps muscle strength of greater than 75 pounds is protective against falling in participants older than 70 years of age as well, thus supporting the benefits of strength training in the elderly [53].

However, certain sporting activities should be avoided by older women athletes. These include skiing and rock climbing, as these types of sports tend to place the body at increased risk of falling, thus causing damage to the already thinning bones and stiffer connective tissues [24]. Similarly, avoidance of contact team sports involving a potential collision with stationary objects or opponents is also prudent and well advised to protect the body of an aging active female [8].

16.2.5 Different Methods of Treatment for Orthopedic Conditions Incurred in Aging Female Athletes, Including Exercise Prescription as Recommended by Various Nationally Recognized Organizations

Injury is not completely avoidable in the active female, no matter what age she may be. Once the master female athlete has suffered a musculoskeletal injury, the first step is prompt initiation of "PRICE" first aid measures: (1) Protect and prevent the damaged area from further harm; (2) Relative rest for the involved limb while maintaining range of motion to counteract stiffness; (3) apply Ice intermittently to the injured extremity to help with inflammation; (4) use Compression wrap to minimize edema; and (5) Elevate above the heart to aid in swelling. These primary first-line measures are implemented to hopefully alleviate pain and other associated symptoms [24, 54]. Administration of medications such as mild analgesics and nonsteroidal anti-inflammatory drugs (NSAIDS) can be used temporarily for inflammation and pain. Sports supplements have not been shown conclusively to improve the joint condition or enhance athletic performance. In fact, the associated side effects of certain supple-

ments to internal organs far outweighs the touted benefits of any commercial supplement [9]. Oral consumption of glucosamine and chondroitin has been widely debated on its benefits in increasing cartilage components within joints. Some studies have reported that a 1500 mg daily dose of glucosamine sulfate significantly reduces symptoms of osteoarthritis in certain joints of the lower limbs by reducing pain and aiding in functional improvement [55]. However, other articles have shown that glucosamine provides no clinical effect on pain or joint function [56].

Prescribed medications can be administered by a physician/healthcare provider for the prevention and treatment of osteoporosis in older women, which helps to slow the rate of bone breakdown. Controversy centers on whether treatment with calcium and vitamin D for bone building is an effective modality in combating osteoporosis. A study conducted in England on over 5300 men and women over age 70 found that daily supplementation of calcium, vitamin D, or a combination of both did not significantly affect the fracture rate between groups [57]. On the other hand, another scientist studied a group of French women living in a nursing home setting who were given a daily dose of vitamin D and calcium for 12 months. This research found a reduction in the number of hip and non-vertebral fractures by 23% and, by 18 months, increased bone density in the femoral neck of those taking calcium and vitamin D [58]. While there is still debate on the effectiveness of vitamin D and calcium supplementation in elderly women in terms of bone density, there has been no suggestion that it will decrease bone density. On the other hand, fish oil supplements have been shown to provide anti-inflammatory effects on soft tissues. A study conducted on 45 women with median age 64 years old, found supplementation with fish oils combined with a strength-training regime produced greater improvements in muscle strength and functional capacity compared to strength training alone [59].

Once the pain from an injury has subsided, an intensive rehabilitation program should be incorporated, along with an exercise regimen designed to maximize recovery and return to pre-injury status [12, 23, 24]. A structured, balanced workout program should include the following elements: resistive training, cardiovascular endurance activity, flexibility, and balance/proprioception. Various exercise programs are endorsed by different national organizations, including the World Health Organization (WHO), American Heart Association (AHA), American College of Sports Medicine (ACSM), and the American Academy of Orthopaedic Surgeons (AAOS) [23, 60]. Specifically speaking, the exercise prescription should involve the following three elements for each workout session: FIT(T)—frequency, intensity, time or duration, and type of physical activity. The WHO, ACSM and Center for Disease Control and Prevention (CDC) recommend at least 20–60 min of moderate to intense activity 5–7 days per week. Bouts of aerobic type activity should be 10 min or more; balancing exercises should be performed at least 3 days/week; strength training is done at least 2 days/week. Physical activity should be executed at an intensity level high enough to burn more than 4200 calories weekly to effect healthy bodily changes [10, 12, 13, 16, 60]. The mode of exercise is dependent on a woman's most current physical fitness level and/or associated musculoskeletal problems. In older females with healthy bones, running in place and other weight-bearing types of mechanical loading can be performed with attention paid toward correct form and technique [13]. However, for those who are frail or women who are already inflicted with arthritic joints, low or minimal-impact activities should be chosen, such as exercises done in a pool and bicycling in a seated or recumbent position [8, 10, 12, 13]. On the contrary, to benefit osteoporotic bone, workouts should be done in the standing or weightbearing position/erect posture (climbing stairs or walking) to best load the skeleton, especially the spine to optimize bone building [10, 12, 13]. To maximize cardiovascular/aerobic fitness, the target heart rate range should be 40–80% of the maximal heart rate of 220 minus age while exercising [10, 13] (see Table 16.1).

In addition to aerobic conditioning, resistance training needs to be incorporated into the workout routine as well to minimize loss of muscle strength and mass, stabilize joints, and maintain bone density in the aging active woman [1, 2, 10, 12, 24, 61]. Research has shown that in older adults, 6 months of resistance workouts 3 times per week will effectively increase lean muscle mass by 1–3 pounds. Similarly, 3 months of strength training in subjects older than 75 years of age resulted in more fat-free mass involving muscles of the entire body. As compared to alternative types of exercise, resistance training is most effective at maintaining muscle mass and physical performance [2]. The effect of exercise on bone mass is quite specific in terms of the skeletal building; therefore, a training program needs to include both the lower and upper extremities [12, 13]. When the older female athlete first starts the training program, she should begin with mild resistance/light weights (10–12 repetitions for 1–2 sets), then gradually increase the amount of weight lifted as tolerated. She can then work up to 12–15 reps for 2–3 sets, 3–4 sessions per week, for all major muscle groups, concentrating on trunk extensors and the lower extremity muscles to help with body stability and dynamic balance. To ensure appropriate body alignment, especially while performing the

Table 16.1 Target heart rate (THR) ranges

Age	THR (bpm)
50 years old	102–136
60 years old	96–128
70 years old	90–120
80 years old	84–112

(*bpm*) beats per min

structural type of strength training using multiple muscle groups, along with directing force through the hip and spine, she can make use of such exercises as free-standing squats, deadlifts, and lunges [13]. Additionally, neighboring joints and musculature close to/surrounding the injured one(s) should also be included in the rehabilitation phase [24].

As already mentioned, to help prevent injurious landing/decelerate falls, balance and stability training need to also be part of the exercise regime. Stretching (several short sessions per day are better than one long episode) has been shown to maintain flexibility, balance, and proprioception [10, 13, 24]. Static, passive, and active-assisted stretches for major musculotendinous units should be done on most days of the week. A group of researchers studied 50 women aged 65 years or older and divided them into three groups: stretching, strengthening, and control. They found that after 8 weeks, both the stretching and strengthening groups had improved posture as compared to the control group [62]. As for balance and stability training, the following drills are effective: getting up from a chair without arm usage, alternating one-legged stance, walking backward, and negotiating various obstacles set up on a course. In addition, physio-balls can be used for strengthening core muscles, promoting a neutral spine, and improving postural control as well [13].

"Physical activity IS Medicine" [60]. A regular training program for elderly woman will promote mobility while decreasing the risk of falling, which are the sixth leading cause of death [12]. In effect, exercising will maximize residual function and even reduce biological age by as much as two decades [8]. Even as little as participating in one exercise class a week along with doing some workouts at home will not only maintain but enhance muscle strength by almost 30% [5]. If all conservative management strategies fail to heal the injured extremity, radiographs should be ordered and orthopaedic consultation should be sought since invasive procedures may be warranted at this point [9, 24].

16.3 Future Directions and Concluding Remarks

As the active female proceeds from childhood through adolescence into adulthood, she must constantly try to slow down her biological clock as far as the body is concerned in general and the musculoskeletal system in particular. The old adage of "use it or lose it" applies when speaking about maintaining physical fitness in order to continue participating in different athletic activities. However, as time passes, both the muscular and skeletal systems start to gradually decline in terms of strength and integrity. Furthermore, higher risks of potential injuries exist to challenge the master female athlete as well as a slower course of recovery after sustaining traumatic episodes. Ideally, the best method of treatment for orthopaedic trauma is of course prevention but certain situations are beyond a woman's control. In that case, measures to protect the injured extremity are of prime importance so she can rehabilitate and physically recover in a timely fashion. The recovery course might last several days to a couple of weeks but may take as long as a few months depending on the extent of the injury. In addition, a regular workout program should be instituted, targeting the affected limb but also incorporating resistance training plus aerobic endurance exercises, along with balance and flexibility elements. This way, the aging female can regain strength, function, and mobility to hopefully return to competitive sports or any other athletic endeavor of her choosing.

Chapter Review Questions with Scenario

Scenario

You are a nurse practitioner for an internist in a midsize town. Your adult patient population ranges from young adults to senior citizens. You see an array of patients with different clinical entities ranging from the simple common cold to complicated cardiopulmonary disease. One of your hobbies is playing recreational tennis in a "female over fifty" league at the YWCA. You meet with your teammates twice a week and you serve as the team captain for these female athletes. Another pastime for you is working out at a local health club three to five times a week. Your doubles tennis partner is 55 years of age and is an avid runner and climber, physically active as well. She pretty much participates in some sort of sporting activity every single day of the week. Lately, she has been frequently absent, sending in a substitute player and complaining of vague, achy shoulder, and deep knee pain. Unfortunately, before you could help her sort things out, she suffered a fall, sustained a wrist fracture on her dominant side (opposite of her involved shoulder), and finally made it to your clinic for evaluation and treatment. You have known this woman for several years, and she refuses to let anything slow her down in terms of exercise. She is extremely frustrated with her injuries and wants to heal really fast and get on with her active life again as soon as possible.

Review Questions

1. First of all, what pertinent questions should you ask about your patient's medical history and what modalities should you utilize for diagnosis?
2. What should you advise her about the shoulder/knee complaints and wrist injury?
3. What other medical specialist(s) should you consult and why?

4. What other factors should you consider prior to sending her back to athletic activity after healing?
5. How soon after she heals from her injury should you allow her to return to tennis? Will you let her go back to running; how about rock climbing?

Plausible Answers

1. First of all, you should take a detailed history of your patient's physiological status and physical fitness profile, including the frequency, intensity, and duration of each athletic endeavor in which she has been involved, to see if indeed she is overtrained and also, how she fell to begin with that is, was it from one of her climbs or stumbling elsewhere? Then, order radiographs of the shoulder, knee, and wrist, and a DEXA scan to evaluate her bone density because she is most likely postmenopausal.
2. It seems as though your partner has not allowed her body to recover, jumping from one sport to another, lending herself to be involved with risky athletic activities. Her knee pain may be coming from early degenerative changes aggravated by the excessive impact of running. On the contrary, it also appears that rock climbing and tennis may not be compatible, because both sports require repetitive overhead maneuvers that may overload the shoulder joint, causing an overuse-type impingement syndrome. As for the wrist injury, you must advise her to stop all sporting activities requiring upper extremity use. This will force her to rest her shoulder and knee as well, but have her move the surrounding joints gently so she would not get too stiff. Also make sure she institutes first-aid measures, such as the PRICE principle, which was discussed in this chapter.
3. You should discuss her case with your internist, then seek a consult from an orthopedic or sports medicine surgeon, especially for the fractured wrist, because she may need casting and/or surgery. She/he can address the shoulder and knee conditions as well, which most likely will need some sort of physical rehabilitation exercises. In addition, an endocrinologist should be sought out to see about the best course of medicinal or other therapy beyond calcium and vitamin D for her bone density.
4. After clearance from her orthopedist and more information from the endocrinologist, you should sit down with your patient and make sure she understands that most likely the wrist fracture stems from osteoporosis and that the risk of other similar skeletal injuries will increase several folds. Therefore, she should be extremely careful from now on and avoid risky-type sports.
5. In terms of allowing your patient to return to competitive athletic activities, she must have a pain-free ROM and good strength of both her upper and lower extremities, as documented by a physical therapist before she can even practice tennis. This may take several weeks to a few months or more. She should also modify her workouts at the gym to maximize muscular endurance, skeletal strength, and proprioception, along with cardiorespiratory capacity. In addition, she needs to perform a low-impact-type aerobic activity so as not to stress her arthritic joint or osteoporotic bone. As far as running goes, if she must, she can jog on alternate days on the treadmill so as not to overload weightbearing joints. As for rock climbing, again stress to her the importance of keeping away from activities that would increase the potential for repetitive trauma, so obviously give her an emphatic NO!

Chapter Review Questions

1. What are some of the musculoskeletal manifestations which occur over the years of aging?
   (a) Hypokinesia
   (b) Sarcopenia
   (c) Osteoporosis
   (d) All of the above
2. Age-related sarcopenia is associated with
   (a) Decreased metabolic rate
   (b) Decreased soft tissue flexibility
   (c) Increased body fat
   (d) All of the above
3. Kyphosis is a ___ plane deformity.
   (a) Sagittal
   (b) Coronal
   (c) Horizontal
   (d) None of the above
4. Osteoarthritis is first manifested in which of the following joint?
   (a) Tibiofemoral
   (b) Carpometacarpal
   (c) Interphalangeal
   (d) Metacarpophalangeal
5. Name some common sites of osteoporotic fractures affecting postmenopausal women.
   (a) Spine and wrist
   (b) Wrist and hip
   (c) Spine, wrist, and hip
   (d) None of the above
6. What are some indicators of potential osteoporotic fractures?
   (a) 2″ loss in height
   (b) Hip pain after falling from standing height
   (c) Low BMI
   (d) a and b
7. Which types of exercise have been found to be beneficial in older, active females?
   (a) Bicycling, aquatic aerobics
   (b) Skiing, rock climbing

(c) Dancing, jogging
(d) a and c

8. What treatment modalities have been shown to benefit musculoskeletal health in the master athlete?
   (a) Glucosamine/chondroitin sulfate
   (b) Fish oil supplements
   (c) Calcium/vitamin D
   (d) Sports supplements
9. ACSM and CDC recommend ___ of moderate-intensity exercise 3–7 days/week.
   (a) 5–10 min
   (b) 20–60 min
   (c) 70–90 min
   (d) 90–120 min
10. To maximize aerobic fitness, the target heart rate range should be ___ of maximal heart rate.
   (a) 20–30%
   (b) 80–100%
   (c) 40–80%
   (d) All of the above

Answers

1. d
2. d
3. a
4. d
5. c
6. d
7. d
8. b
9. b
10. c

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Prevention and Management of Osteoporosis Through Exercise

17

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Learning Objectives
After completing this chapter, you should have an understanding of:

- How osteoporosis is diagnosed and measured.
- Bone histology and pathophysiology of osteoporosis.
- Risk factors in the development of osteoporosis.
- The effectiveness of different types of exercise in the prevention and management of osteoporosis.
- Confounding factors, including estrogen availability and nutrition, could affect bone accrual with exercise.

17.1 Introduction and Background

In 2006, osteoporosis or "porous bones" was estimated to affect 200 million women worldwide [1]. This prevalence has since risen, due to demographic changes and lifestyle habits that are unfavorable to bone health [2], and is likely to rise even further with increasing life expectancy. Osteoporosis is characterized by low bone mass, compromised bone strength, and structural deterioration of the bone tissue, which leads to bone fragility and increased susceptibility to fractures [3], most commonly of the wrist (distal radius), hip (femoral neck) and spine (especially in the lumbar vertebrae) [1]. These fragility fractures lead to a decreased quality of life and a staggering economic burden [4, 5]. For US women 55 years and older, hospitalization due to osteoporotic fracture is higher than for myocardial infarction, stroke and breast cancer combined, amounting to $5.1 billion annually [6]. The primary goal of prevention and treatment, to lessen the economic burden and to improve quality of life, is to reduce the risk of osteoporosis and associated fracture by increasing or maintaining bone strength. The purpose of this chapter is to focus on how exercise can be used to prevent and manage osteoporosis for active female.

17.1.1 Diagnosis and Measurement of Osteoporosis

The World Health Organization (WHO) criteria for diagnosing osteoporosis and osteopenia (decreased bone mineral content) are based on measuring bone mineral density (BMD) using dual-energy X-ray absorptiometry (DXA), then comparing the individual's BMD with that of a reference group [7]. Bone mineral density is expressed using T-scores that represent standard deviations from the average peak bone mass of same sex, young, healthy adults. Based on the WHO international reference standards, a T-score of −2.5 or lower at the femoral neck is diagnostic of osteoporosis, while a T score of between −1 and −2.5 indicates osteopenia [8, 9].

In younger women, the Z-score may be more useful in identifying women who may need to undergo a workup for secondary causes of osteoporosis. The Z-score represents the difference in the number of standard deviations between an individual's BMD and the BMD of a population adjusted for age, sex and race. Osteoporosis should be suspected if the Z-score is >1.5 SD below the mean [8, 9].

Dual-energy X-ray absorptiometry remains the clinical gold standard for diagnosing osteoporosis, having high accuracy, precision, reproducibility and validity, although is user-dependent [10]. Bone strength, which is a term used to describe how resistant the bone is to fracture, is not just a result of BMD, but also a result of bone geometry, bone turnover and architectural structure, which can be assessed using other techniques. For instance, peripheral quantitative computed tomography (pQCT), which assesses volumetric

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BMD, can distinguish cortical and trabecular bone. Quantitative ultrasound has been effectively used to monitor changes that occur with exercise and, unlike DXA, involves no ionizing radiation [11]. Acute changes in bone turnover in response to exercise can be identified by blood markers of bone formation (such as osteocalcin and bone-specific alkaline phosphatase) and bone resorption (such as cross-linked C-telopeptide of type I collagen and tartrate-resistant acid phosphatase 5b); however, blood markers are not site-specific and are influenced by biological rhythms, such as time of day and menstrual cycle phase. Alongside DXA scanning, FRAX® can be used to calculate the 10-year probability of fracture, particularly for postmenopausal women. While osteoporosis is most often diagnosed by DXA, it is important to realize that there are other techniques which successfully measure the effectiveness of exercise on promoting bone strength as well as the effect of exercise on the prevention and management of osteoporosis.

It is not just bone strength that increases the risk of fragility fracture; other factors, such as muscular strength, genetic factors and age-related changes that occur in the bone are also involved [12]. Using DXA, BMD can predict the *risk* of fracture but will not necessarily determine whether someone will actually sustain a fracture or not [13], because low-impact fractures are multi-factorial in nature, being dependent on things like muscular strength, proprioception, environmental conditions, balance and agility. That said, with each SD decrease in DXA BMD, the lifetime risk of osteoporotic-related fracture increases 1.5 to 3 times. Thus, DXA remains important for assessing fracture risk [14].

It is recommended that BMD testing be performed on: (a) all women ≥65 years of age regardless of risk factors; (b) postmenopausal women or perimenopausal women aged 50–69 who have clinical risk factors; (c) women aged 50 and older who have suffered an adult fragility fracture; and (d) women with a condition (such as rheumatoid arthritis) or who are on medication (such as glucocorticoids) associated with low bone mass or bone loss [14].

All women should have their risk factors for osteoporosis assessed at the time of each annual physical. A thorough medical history should include a review of hormonal status, nutritional status (specifically to include vitamin D, calcium and protein intake), low trauma fractures and lifestyle factors (include smoking, alcohol intake, and physical activity level). Family history should be reviewed for height loss with age, compression fractures and hip fractures. Height should be measured annually and compared to self-reported maximum height. Radiographic studies of the lateral spine are indicated if a compression fracture is suspected or spinal deformity is present. Biochemical tests may be evaluated, particularly if a secondary cause of osteoporosis is suspected. Labs should include serum chemistries, complete blood count, thyroid function tests and a 24-h urine collection for calcium excretion. Further testing may include level of parathyroid hormone, urinary free cortisol, erythrocyte sedimentation rate, serum protein electrophoresis, serum 25-hydroxyvitamin D concentration and other biochemical markers of bone turnover [15].

In a study by Pickhardt et al., it was found that abdominal computed tomography (CT) images, obtained for other reasons, that included the lumbar spine, could be used to delineate between osteoporosis, osteopenia, and normal BMD with a 90% sensitivity and specificity without additional radiation exposure or cost [16]. This study was based upon data that showed nearly half of all female Medicare beneficiaries had never undergone BMD testing and more than 80% of all persons with a major osteoporosis-related fracture did not have BMD testing or receive pharmacologic agents to reduce fracture risk. In 2011, there were more than 80 million CT scans performed in the USA, all of which may carry potentially useful information about BMD. The study of Pickhardt, however, did not assess the potential benefits and costs of using CT primarily to evaluate BMD.

17.1.2 Bone Histology and Pathophysiology of Osteoporosis

There are five main types of bone cells: osteoblasts, osteocytes, osteoclasts, osteoprogenitor cells and bone-lining cells [15]. Osteoblasts are the bone-forming cells. They produce "osteoid" or uncalcified bone tissue, composed of bone collagen and various proteins. Osteoclasts are responsible for bone resorption, but also play a role in skeletal homeostasis. Osteocytes are mature osteoblasts that become trapped within the bone matrix in small lacunae (spaces) and canaliculi (canals); these are the most abundant bone cells in the adult skeleton. Osteocytes have long dendrites that play a major role in sensing loading on the bone; hence, osteocytes have been termed the "mechanotransductors" since they detect and transmit mechanical signals for bone remodeling [17]. Osteoprogenitor cells are derived from mesenchymal stem cells, which differentiate into specialized cells, namely osteoblasts and osteocytes. Bone-lining cells exist on the bone surface when there is no active bone growth, termed the quiescent phase. Although associated with quiescence, bone-lining cells can also differentiate into osteogenic cells and can be a major source of osteoblasts during adulthood [18].

Cortical and trabecular bone are two distinct types of bone tissue that differ in terms of their structure, function and location. Cortical bone, also called compact bone, exists on the outer surfaces of most bones and in the shaft of long bones. The structural unit of cortical bone is the Haversian system or osteon, which consists of concentric layers or lamellae of collagen fibrils running the length of the bone. This structural arrangement is designed to withstand consid-

erable torque. Trabecular bone, also called "spongy" or "cancellous" bone, is found at the epiphysis of long bones and in the internal portions of other bones like the spine, pelvis, wrist, heel, ribs and skull. Trabecular bone is designed to withstand compressive load owing to the arrangement of bone tissue in a mesh-like pattern. Trabecular bone is the site of hematopoiesis and mineral (calcium and phosphate) metabolism. The skeleton consists of approximately 80% cortical bone and 20% trabecular bone [19].

Osteoporosis mainly affects trabecular bone because this is where most bone remodeling takes place. Trabecular bone is also more sensitive to estrogen deficiency [20]. Osteoporosis can be present within cortical bone but the turnover rate within cortical bone is much slower resulting in osteoporosis being less progressive [19].

The process of bone remodeling occurs throughout the lifecycle, occurring naturally as a means of maintaining bone's structural integrity and strength. The initiation of the bone remodeling response ensues as a result of various stresses, including exercise, calcium balance in the blood, endocrine changes, and in response to microtears within the bone's structural matrix. The remodeling process takes place in basic multicellular units (MCUs) and involves the action of osteoblasts, osteoclasts and osteocytes. Through the activity of osteoclasts, bone is broken down to form a resorption pit or cavity, to which osteoblasts are attracted and, through various signaling processes, bone is reformed (Fig. 17.1). At any given time, millions of MCUs are operating to regenerate bone throughout the skeleton. The entire bone turnover process takes around 3–6 months. In healthy bone tissue, the activity of osteoclasts is balanced by the activity of osteoblasts. In osteoporotic bone, however, there is an imbalance in the two processes of bone remodeling. The result is a net loss of bone tissue with associated changes in bone microarchitecture.

17.1.3 Changes in Bone Mass Through the Active Female's Lifespan

Bone growth is greatest during childhood and around puberty. Peak bone mass for the female is usually reached by the age of 30, although the exact time is dependent on bone type and location. For instance, peak bone mass of the femoral neck is reached by age 16 but does not occur at the lumbar spine until females are in their third decade [21]. Similarly,

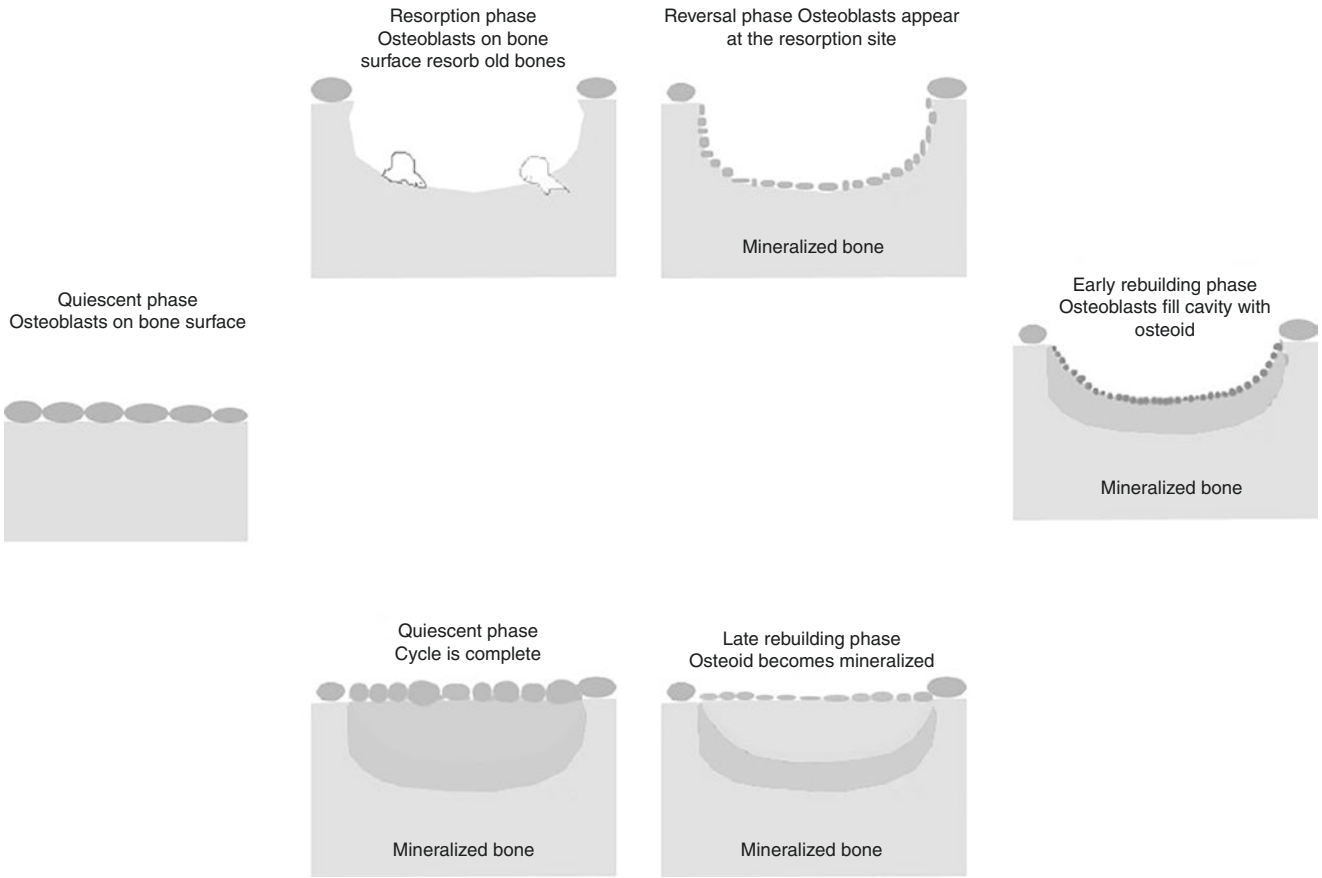

Fig. 17.1 Schematic representation of the bone remodeling process

rates of bone loss differ by site, but the overall loss is approximately 1% per year beginning in the third decade [22]. Trabecular bone degenerates first, starting in the third decade, while the cortical bone continues to increase into the fifth decade and beyond [22, 23], becoming more brittle and weaker with a reduced thickness thereafter. In a woman's life, the most rapid bone loss, where bone resorption outstrips the pace of bone accrual, occurs in the perimenopausal and menopausal periods [24, 25], associated with a loss of estrogen. Further age-related declines are also associated with increased oxidative stress, which increases osteocyte apoptosis, independent of estrogen availability, leading to reduced bone signaling, reduced vascularity and dehydration [12]. A more in-depth discussion of changes in bone mass and the various processes involved is provided in a review by Boskey and Coleman [26]. The role of estrogen in the bone turnover process is further discussed in Chap. 4 of this book.

17.1.4 Risk Factors in the Development of Osteoporosis

Osteoporosis is associated with several risk factors, some modifiable and some nonmodifiable. Nonmodifiable factors include female sex, Asian or Caucasian ethnicity, advancing age, a family history of fragility fracture, a personal history of fracture, and genetic predisposition for low bone health. Regarding the latter, 500 gene variants have been identified, which could predispose individuals to osteoporosis [27].

Chronic medical conditions, which may contribute to bone loss include, but are not limited to, hemophilia, thalassemia, Cushing's syndrome, hypothyroidism, Type 1 diabetes mellitus, chronic liver disease, malabsorption syndromes (e.g., celiac disease), lymphoma, leukemia, disordered eating (e.g., anorexia nervosa), rheumatoid arthritis and primary hyperparathyroidism [28]. Medication therapies or drugs used to treat endocrine, gastrointestinal, neoplastic, renal, or rheumatologic disorders can also lead to osteoporosis. Glucocorticoids used to treat a variety of diseases including autoimmune disorders, inhibit intestinal calcium absorption, increase osteoclastic activity, and may also increase renal excretion of calcium. Other commonly prescribed drugs associated with bone loss include anticoagulants, lithium, anticonvulsants, cytotoxic drugs, gonadotropin-releasing hormone agonists, vitamin A and Tamoxifen [28].

Nonmodifiable factors require that the individual receive education on these risk factors and avoid exacerbating their risk of fracture by altering any of the modifiable risk factors. Modifiable factors include poor nutrition with an inadequate intake of vitamin D and calcium, malnutrition, estrogen deficiency, sedentary lifestyle, smoking, excessive alcohol consumption, limited time spent outdoors in the sun, drug use and a body mass index of $\leq$19 kg/m^2 [29, 30]. In addition, the epidemic of heavy consumption of carbonated and caffeinated drinks in the US continues to place younger women at risk of not reaching their genetically determined peak bone mass [30]. Perhaps the most difficult task that a health care provider may deal with is encouraging and successfully changing behaviors which predispose individuals to osteoporosis.

17.2 Research Findings

17.2.1 Prevention and Management of Osteoporosis Through Exercise: Overview

It is well established that osteoporosis can be prevented and managed through exercise [31, 32]. Certain types of exercise are, however, more effective at promoting bone strength than others—it is not simply a case of just keeping active—exercise needs to be specific and targeted. For instance, participation in weight-supported endurance sports, such as cycling and swimming, is associated with low bone mass [33, 34]. Continued commitment and reassessment throughout the lifespan are also important. For example, maximizing peak bone mass during in childhood and adolescence may offset the inevitable age-related decline in bone mass [31, 35]. During the premenopausal years, emphasis should then be on maintaining peak bone strength. Once in the perimenopausal and postmenopausal period, the focus should be turned to using exercise to reduce the rate of bone loss to avoid osteoporotic fracture. If osteoporosis is diagnosed, exercise needs to continue to promote bone strength, as well as to improve balance and posture. In this section, an overview is given on the cellular responses to bone loading, the recommended types of exercise required to maximize bone strength, and the confounding factors that inhibit the bone-loading response to exercise. Focus is primarily on osteoporosis prevention through promoting bone strength, although attention is also given to exercise for treating and managing osteoporosis.

17.2.2 Exercise-Related Mechanisms Leading to Bone Accrual

Weight-bearing exercise increases bone health through an internal skeletal sensor that then adjusts bone remodeling in accordance with the mechanical forces imposed [36]. The mechanism is known as the mechanostat theory. In this theory, it is proposed that coordination of modeling and remodeling is required for the survival of the skeleton and that the magnitude and rate of application of force are important for the bone to adapt. At the cellular level, when a bone is loaded,

viscous extracellular fluid is pushed back and forth through the extracellular spaces surrounding the osteocytes, creating shear stress [37]. This shear stress then triggers the mechano-sensing-osteocytes to release signaling molecules, such as intracellular calcium ions (Ca^{2+}) and extracellular adenosine triphosphate (ATP). The intracellular Ca^{2+} creates mechano-transduction to other cells through gap junctions, while extracellular ATP acts as a paracrine signal. Other signaling molecules include prostaglandin E2, cyclo-oxygenase 2, various kinases, RUNX2 and nitric oxide. Canonical wingless-related integration site (Wnt) protein signaling also plays a part in bone homeostasis. Loading the bone decreases sclerostin expression via osteocytes, which increases bone formation via attenuating the inhibition of Wnt signaling in osteoblasts [38]. Regulation of osteoprotegerin (OPG) also occurs, which suppresses osteoclast resorption. Sclerostin-independent changes in bone formation and osteoblasts also play a role. Ultimately, the result is an increase in the production of the bone matrix.

Largely based on animal studies, mechanical loading that involves high strain magnitudes, high strain rates, dynamic rather than static loads, and rapid strain reversal have the greatest osteogenic effects [39–41]. The duration of load and the number of loading cycles have relatively less importance. For instance, fewer loading cycles bring about similar or sometimes greater osteogenic benefits compared to a larger number of loading cycles. As few as five loading cycles per day can produce an osteogenic effect, while bone loses its mechanosensitivity after 20 loading cycles [42]. The amount of rest between loading cycles and between bouts of loading is also important for optimizing bone accrual [43]. Unloaded rest periods are required so that the bone re-sensitizes. Hence, loading interspersed with 10-s rest intervals, and then recovery of several hours between loading sessions, heightens bone mechanosensitivity and leads to greater gains in bone strength. The other key factor in terms of promoting bone strength, is that loading needs to differ from normal or customary daily strain patterns, so unusual frequency distributions are the most osteogenic [41]. It is possible, however, to overload the bone resulting in no adaptation or even maladaptation. A combination of high magnitude and high-frequency loading can result in the load being too excessive. In summary, the bone has unique properties that require specific loading patterns for adaptation to take place.

Bone can be loaded in different directions which results in compressive, tensile, shear and torsion forces. Compression forces act on the bone longitudinally with opposing forces operating towards each other, compressing the bone material. Tension is developed through the bone when forces pull away from each other (positive elongation). Shear is the name given to unaligned forces pushing in one direction on one part of the bone, and in the opposite direction on another part of the bone. Torsion refers to twisting forces along the bone's long axis. All types of loading have the ability to adapt to the bone and may occur at the same time and at the same location.

17.2.3 Exercise Interventions for Preventing and Managing Osteoporosis: Jumping or Hopping

Exercise interventions with loading patterns that mimic those identified in animal studies, as described above, have been found to be the most successful for ameliorating bone strength. For example,, high and rapid strain magnitudes can be induced through activities such as jumping and hopping. Studies in which jumping has been used as the intervention have, therefore, shown an increase in bone strength [44]. Unilateral jumping or hopping is also appropriate during menopause and beyond, with few adverse events having been reported [45].

Jumps and hops can be adapted and performed in a variety of ways to suit stages in an active female's life. For instance, one intervention for prepubescent children involved school children jumping from a 61-cm-high box, producing a ground reaction force of nearly nine times body weight [46]. The children performed 100 two-footed jumps three times per week in addition to their normal school physical education lessons. Jumpers had significantly greater changes in lumbar spine BMD compared to control participants who undertook a stretching program of equivalent duration. Another study, this time for adolescent girls, used a variety of plyometric exercises, including depth jumps onto and off a box [47]. The exercises were performed three times per week and resulted in significant increases in bone mass of the greater trochanter. Jumping exercise for children and adolescents, therefore, requires significant jumping and landing forces to induce favorable effects in the bone, especially among already active children.

For premenopausal women, jumping just 10 times per day, three times per week, with a 10-s rest interval between jumps has shown a BMD benefit [48]. Jumps were performed without shoes on a hard surface. The six-month intervention improved bone health (as measured by QUS) of the calcaneus, even among participants who had lower estrogen levels. In an older population, single-leg hops were not only well tolerated, but also resulted in significant improvements in femoral neck BMD and a reduction in the risk of falls [45, 48].

It seems, therefore, that jumping and hopping interventions can promote bone strength, although these improvements are specific to the lower body. The jumping load should be adjusted to suit the age, experience and bone status of the female; jumps with higher landing forces (e.g., from boxes) are tolerated by already active children and adoles-

cents, while jumps with lower landing forces (as achieved from hopping, low-level jumps, heel drops and stamping) may be more tolerable for older adults or with individuals with osteoporosis [32, 45]. As with animal studies, exercises which induce low frequency and high magnitude forces, such as the high ground-reaction forces and explosive action elicited by jumping and hopping, tend to demonstrate significant improvements in bone strength.

The interventions described above were specifically designed to induce a response in the bone, and for time efficiency, such jumping/hopping programs should be incorporated into the active female's exercise program. If jumping-related exercises are already being performed, then adding a jumping/hopping program is unlikely to accrue supplementary benefits. Sports with jumping-related activities such as basketball, soccer, gymnastics, dance and volleyball have exhibited improved bone strength in young females [49].

Despite interventions with jumping and equivalent high-impact activity, showing positive results in terms of improvement in bone strength, these might not be suitable for all individuals due to joint weakness, biomechanical, or anatomical factors that predispose the individual to injury. In postmenopausal populations, jumping interventions have not always been successful, probably owing to the lack of estrogen availability [50, 51]; however, these two studies both used loading cycles greater than recommended based on animal studies. Jumping/hopping should be progressive, starting with ground-level jumps using support if needed, to box jumps and plyometrics with multi-directions when the individual feels able to do. For a further synopsis of the efficacy of high-impact interventions such as jumping, the meta-analyses of Babatunde et al., Martyn-St James & Carroll and Zhao et al. should be referred to [44, 52, 53].

17.2.4 Exercise Interventions for Preventing and Managing Osteoporosis: Resistance Training

Thus far, we have discussed stress and load placed on bone in the scope of impact via gravitational forces; however, in everyday life, muscle contraction produces most of the strain on the bone [54]. In fact, muscle and bone are inextricably linked mechanically as well as molecularly and biochemically through cell signaling and endocrine processes [55]. Consequently, resistance training as an exercise modality has been a focus for promoting bone strength.

There have been several studies conducted, where a favorable effect on bone strength has been shown as a result of progressive, high-intensity resistance training in a range of populations including adolescent females [56] and premenopausal women, although the majority of studies have been carried out on postmenopausal populations [57–61]. There is still, however, conflicting evidence regarding the efficacy of resistance training for improving bone strength [62, 63]. Resistance training is commonly found to be more effective when combined with high-intensity or weight-bearing exercise [52, 60, 62, 64–66] or, for menopausal populations, when estrogen is taken exogenously in the form of hormone-replacement therapy [67]. The reason why resistance training may be less osteogenic than other, more high-impact forms of exercise, is because the strain caused by muscle contraction forces is less than that imposed by ground-reaction forces [40]. In parallel with the findings from animal studies, resistance training that involves unusual frequency distributions or unusual loading patterns may, however, have greater effects. For instance, power training, whereby high velocities result in high strain rates and frequencies, has been found to maximize the osteogenic process [68].

The advantage of progressive resistance training over high-impact exercises like jumping, though, is the opportunity to target not only the weight-bearing joints like the hip or spine but the whole body, including non-weight-bearing bones such as the radius and ulna. Resistance training also provides an opportunity to improve posture, balance and functional movement, while avoiding impact that may be painful due to cartilage loss or that may be hazardous due to poor coordination.

Since bone strengthening is site-specific, a whole-body approach is required. In fact, studies in which high-impact exercises such as jumping and high-intensity, progressive resistance training have been combined seem to be the most effective for bone strength enhancement and are often recommended in national guidelines [58, 69, 70]. More research is needed to establish whether progressive, high-intensity resistance training is indeed effective for all populations and whether resistance training can be manipulated to target the bone more specifically.

17.2.5 Exercise Interventions for Preventing and Treating Osteoporosis: Avoiding Low-Impact Exercise

Walking is generally ineffective for enhancing bone parameters [52, 57, 58], however, might be suitable for improving bone mass if the individual is sedentary [71, 72], has osteoporosis, or if the walking is more than 5 km/h or very brisk [73, 74]. Walking may increase the risk of falls if the individual is already at a high risk of falls, so walking in such a population should be complemented with balance training [75]. For more active females, the desensitization that occurs through the repetitive action and the low threshold for impact makes walking improve bone health insubstantially.

Similarly, jogging might not be enough to exceed the threshold for bone adaptation, as evidenced by comparisons of BMD in joggers and sprinters, where sprinters have been found to have a significantly greater BMD than that of joggers [76]. To prevent osteoporosis, active females who engage only in walking or jogging therefore need to add more impact or non-routine exercises to their regime, since the habitual nature of these exercises leads to failure of the bone to further adapt.

Swimmers and cyclists have notoriously poor BMD, despite the amount of exercise or training that some athletes do. These types of exercise involve a large part of the training where the body's weight is supported [33, 34]. Gravitational forces are necessary for promoting bone strength, as has been demonstrated from studies on spaceflight [77]. It is, therefore, important that the female who keeps active by cycling or swimming, should incorporate high-impact exercises such as jumping and hopping, and/or high-intensity resistance training into their exercise regime.

17.2.6 Exercise Interventions for Preventing Osteoporosis: Whole-Body Vibration

There has been some interest in whether whole-body vibration (WBV) training can result in improvements in BMD. Whole-body vibration training usually involves the participant standing on or being in contact with a machine that produces oscillations at high frequencies. It is hypothesized that the oscillations activate muscle tissue, induce endocrine responses, and create shear flow (independent of muscle activation), which simulate the bone's mechanoreceptors. Increases in BMD of the lumbar spine have been seen among children, adolescents and postmenopausal populations, although the optimal frequency, amplitude and duration are still open to debate [78] and require further research. Investigations into performing exercises on the platform (as opposed to just standing) have not led to additional increases in BMD as of yet [79]. More research is also needed on whether this form of training can be used for individuals with diagnosed osteoporosis.

17.2.7 Exercise Interventions for Preventing and Treating Osteoporosis: Site Specificity

Exercise for promoting bone strength is site-specific since bone responds exclusively to the location at which the strain is applied. This site-specific nature of bone loading is evidenced in studies on racket sports, where the BMD of the dominant arm in female racket players is usually much greater than that of the non-dominant arm [80]. Similarly, the leg bones of female runners are stronger than non-loaded sites like the upper body [81], and bone properties of the upper body in female gymnasts are greater than those in non-gymnasts [82].

Fragility fractures most commonly occur in the hip followed by the spine, ankle, wrist and shoulder [83]. Because of the site-specific nature of bone accrual, it is important that the active female loads bone of both the upper and lower skeleton. There are far fewer studies that have been carried out on the effect of upper body exercise on promoting upper body bone strength than the lower body, likely because of the increased morbidity and mortality associated with lower body fractures. In a systematic review and meta-analysis on the effect of upper body exercise on forearm bone strength, exercises were categorized into high-intensity resistance training (HIRT), low-intensity resistance training (LIRT) and impact exercise [84]. The HIRT consisted of a typical progressive resistance training program using barbells and dumbbells, at an intensity around 80% of one repetition maximum repeated 8–12 times for 2–3 sets. Exercises categorized as LIRT consisted mainly of circuit-style exercises of high repetitions using low resistance applied via bodyweight, small dumbbells or elastic bands. The two impact exercises [85, 86] that were included in the meta-analysis both consisted of falls against a wall onto outstretched arms from a little over arms-length away. Although all types of exercise improved bone mass of the forearm, it was the LIRT group that tended to generate the most osteogenic effects, which contradicts the findings of other meta-analyses of the lower extremity and spine, where high-intensity, as opposed to low-intensity, progressive resistance training is the most osteogenic (as already highlighted). It was thought that the greater benefit from the LIRT group was a result of the exercises generally being more varied, novel and targeted. There was not enough evidence in this review to suggest that impact exercise was effective for promoting bone strength as only two studies formed part of the impact grouping. It is, therefore, clear that more work is needed in this area to inform practitioners of methods to prevent and treat low bone strength in the upper body.

17.2.8 Exercise Interventions Specifically for Treating Osteoporosis

Although studies in the above section include individuals with low BMD, it is important to ensure that exercises are suitable for individuals who have already suffered from fragility fractures. There has been concern expressed, from both health professionals and patients, about what exercise is appropriate for those with osteoporosis [87], although for the majority of people, the exercises described above are generally considered safe and well tolerated [59, 88, 89].

Obviously, individuals need to progress their exercise according to their ability, previous experience and comorbidities. In particular, those with vertebral or multiple fragility fractures may need some caution with certain types of exercise. For instance, exercises that involve rapid, weighted, end-range movement, such as might occur with lifting heavy weights, performing full-range sit-ups, or certain yoga movements, should be completed with caution [32, 69, 88]. These individuals may opt for supervised, lower-impact exercise programs. Improving balance and strength of the back muscles is also recommended for improved posture, reduced muscle spasms and pain relief [32, 88]. Despite minor cautions such as these, there seems to be little evidence to suggest that exercise (even the more intense exercises described earlier) can make things worse. Older or frail individuals may not be able to undertake exercise or may be reluctant to exercise for fear of further injury or falls, yet exercise for frail individuals is still efficacious [90]. Furthermore, both weight-bearing and non-weight-bearing exercise programs have been shown to significantly improve the overall quality of life, cognition, depression symptoms, feelings of loneliness and feelings of isolation, which are common in the elderly population [91].

Adverse events occurring in frail and osteoporotic populations when undertaking exercise seem to be minor, consisting of typical muscle soreness and strains only, although reporting of adverse events in the literature is often subject to bias. One population-based study of over 400,000 adults by the National Center for Health Statistics investigated fall-related injuries requiring medical attention [92]. The overall incidence rate by place of injury was 2 and 36 per 10,000 person-years for indoor sporting facilities and outdoor park/recreation area/sporting facilities, respectively, compared with 137 while at home (129 inside, 8 outside). This data however, included younger individuals as well as men. When exclusively examining data for women over 65 years of age, the incidence rate was 14 per 10,000 person-years for outdoor park/recreational area/sporting facilities and no data were reported for indoor sporting facilities (categories with fewer than 5 for age-sex groups were not reported). When turning attention to activity during the injury, the incidence rate for women over 65 years of age while playing sports or exercising was only 13 per 10,000 person-years compared with 36 while walking, 9 standing up/sitting down, 9 going upstairs/downstairs, 5 standing, and 2 carrying. This information indicates that individuals may be less likely to sustain a fall-related injury (and possibly fracture) while participating in a structured program at a sporting facility than at home, and additionally may be less likely to sustain an injury while exercising (although many of these movements are performed while exercising). Further information on exercise prescriptions for osteoporosis as well as how exercise can be used to prevent falls can be obtained from reviews, national clinical guidelines, and consensus statements [32, 75, 93, 94].

17.2.9 Exercise Through the Lifespan

Exercising and taking part in high-impact sports in childhood can lead to age-related attenuation of osteoporosis [31, 35]. Puberty and maturational status, however, play a role in determining how bone responds to exercise [95], with bone being more responsive in early pubescence [96, 97]. There is evidence to suggest that bone strength gained while young can be retained with age despite a reduction in exercise, although there is also evidence to suggest that maintaining exercise across the female's lifespan is important. For instance, although older individuals who had taken up tennis later in life had improved bone strength (as measured by pQCT of the forearm), the bone strength of those who had played tennis from an early age and through their lifespan was more substantial [98]. To ensure optimal bone strength, exercise should be encouraged throughout the lifespan.

17.2.10 Subsidiary Benefits of Bone-Loading Exercise

The use of 'exercise as medicine' for preventing and treating osteoporosis has been criticized owing to the lack of evidence on its effects on reducing the risk of fracture [65, 89] and the relatively modest effects on bone when compared to pharmacologic treatments [99]. However, when compared to complete bedrest, the results look more dramatic, since complete bedrest results in major losses in bone strength [100]. Exercise interventions reported in the literature are often carried out on individuals who are already healthy, which could explain the modest improvements in BMD. Motivation, adherence and compliance to the exercise intervention may also play a factor in why interventions have not shown substantial increases in bone mass [99]. As well as imposing strain, exercise also results in a strengthening of muscle tissue and improvements in balance, coordination and postural stability, all of which contribute to a decrease in fall risk [75]. Not only that, but exercise increases fitness and is beneficial for overall health. Although exercise might be considered inferior to pharmacologic treatments in terms of its effects on bone, ancillary benefits can be obtained.

17.3 Contemporary Understanding of the Issues

Individual-specific confounding factors cause no single type of exercise to fit all. Bone adapts differently according to genetic factors, age, and for women in particular, due to estrogen availability [31]. A personalized approach should, therefore, be used when prescribing exercise. In this section, an exploration of the contemporary understanding of confounding factors, such as estrogen and nutritional status that impact bone turnover, is given.

17.3.1 Estrogen as a Confounding Factor for Bone Strength

For the active female, one factor that may curtail the positive exercise-induced effects of bone, is estrogen availability. Exercise, when combined with estrogen, results in a greater osteogenic response than either exercise alone or estrogen alone [101]. Conversely, when estrogen levels are suboptimal, exercise might not be at a sufficient intensity, impact, or dose to attenuate the increased osteoclastic activity associated with the decreased estrogen. The exact mechanism by which estrogen interferes with the exercise-induced strain is unclear, but certainly signaling pathways are at play.

Estrogen deficiency might explain why some research interventions on estrogen-depleted postmenopausal women show no beneficial effects of exercise [50, 102]. Even with interventions that have included high-impact loading and jumping, improvements in BMD have been modest [103]. There is a tendency for exercise prescription in the postmenopausal period to be "gentle," but a greater exercise stimulus may be needed. For instance, in the trials considered by Kelley and Kelley [102], most interventions included in their meta-analysis consisted of walking or upper body exercises, which explains why BMD at the femoral neck was not improved. There is also evidence that in an older female population, bone adapts differently by increasing cortical thickness [104, 105]. For example, jumping led to thickening of the bone cortex, but not an increase in the lumbar spine or femoral neck BMD [106], and even low-impact exercise was found to maintain cortical and trabecular volumetric BMD, as assessed using pQCT [107]. Further studies are, however, needed to characterize the structural changes (whether cortical or trabecular) that occur with exercise in a postmenopausal population or in the absence of estrogen, and what loading patterns are required to meet the threshold for bone adaptation.

Any activity that decreases estrogen can lead to a reduction in bone health, as highlighted in Chap. 4 of this textbook. Causes include amenorrhea, synthetic hormone intake, delayed menarche, early hysterectomy and premature menopause. Amenorrhea, defined as an absence of menstruation for three consecutive months or more, results in low estrogen; amenorrhea is prevalent among active females [108]. Active females with amenorrhea have lower BMD when compared to their normally menstruating counterparts and even sedentary controls, despite the amount of exercise undertaken [109]. Menstrual dysfunction, which includes irregular menstrual periods that could occur with "excessive exercise," can also lead to significant decreases in BMD among exercising females [109, 110]. For the active female, ensuring the regular menstrual function is, therefore, important for optimal bone health.

The active female may use hormone-based contraception, which has the potential to modify bone turnover. There are many different types of hormonal-based contraceptives available for women, including combined oral contraceptives, contraceptive patches, progesterone-only oral contraceptives, subdermal implant systems and injections. Designed to inhibit conception, these contraceptives generally lower the amount of available estrogen. Exercise when combined with oral contraceptive may, however, not necessarily be beneficial to bone. In a study by Weaver et al. [111], for instance, it was found that the combination of exercise with use of oral contraceptives containing estrogen compounds, spine BMD and bone mineral content (BMC) was lower than when contraceptive users did no exercise. Similarly, Hartard et al. [112] found that in long-term oral contraceptive users (≥3 years) who exercised (≥2 h per week), BMD was comparable to that of non-users who did less exercise. These findings might, however, be specific to and be explained by the ratio of progesterone to estradiol found in the oral contraceptive preparations [113]. Depot Medroxyprogesterone Acetate (DMPA), also known via its trade name Depo Provera®, is a progesterone-only contraception that can cause detrimental effects to the bone, especially with prolonged use, among adolescents and older individuals [114]. As with the findings on oral contraceptives [111, 112], combining DMPA use with high levels of exercise may be detrimental to bone strength [115]. The lack of estrogen may counteract the effect of exercise by inhibiting bone formation in response to mechanical stress [116]. For the active female, a lifetime of contraceptive use, combined with menstrual disturbances, which result in low levels of estrogen, may increase the prevalence of osteoporotic fractures. It is, therefore, important to regulate hormone-based contraceptive use and to check bone strength and estrogen status regularly.

Exercise could have the potential to counteract the negative effects of hypoestrogenism, but it must be targeted. As indicated earlier, successful programs are those that follow findings from animal studies, inducing high strain loads and magnitudes, such as jumping, hopping and skipping. These studies show such exercises are successful, even when estro-

gen levels are suboptimal, such as among oligomenorrheic and amenorrhoeic athletes [117], oral contraceptive users [118], and menopausal women [50, 56]. Discrepancies in the studies, in which differences in the effect of exercise on bone health when estrogen is low or absent, may be due to the different exercise interventions, starting point of BMD, or the availability of estrogen.

17.3.2 The Confounding Effects of Nutrition on Bone Health

Nutrition is an important modifiable strategy for the prevention and management of osteoporosis [31]. Although the majority of the content of this chapter is focused on exercise, getting nutrition right is an important, modifiable lifestyle factor that goes hand in hand with exercise, especially with regards to energy availability. Some of the vitamins and minerals that are important in the maintenance of bone homeostasis are discussed here.

Calcium can compromise the effect of loading on the bone [58]. The daily recommended dose of calcium, as recommended by the Institute of Medicine (IOM) in the US, is 1300 mg/day during puberty and pregnancy, 1000 mg/day for premenopausal women, and 1200 mg/day for postmenopausal women due to the decreased calcium absorption with age [119]. A diet rich in calcium would include any of the following calcium-rich foods: dairy products such as milk, yogurt, cheese, cottage cheese, and ice cream; dark green vegetables such as broccoli, kale, Chinese cabbage, collard greens, turnip greens; calcium-fortified foods such as orange juice, bread, tofu, and cereals; and certain types of fish and shellfish. Sardines and salmon are a good source of calcium especially if the bones are consumed with the fish. Homemade chicken or turkey soup can provide another excellent source of calcium, if the poultry is boiled with the bones in place, thus allowing the calcium to leach out of the bones and into the broth. Ideally, sources from the diet should be considered prior to supplement since excessive calcium supplementation may lead to a small increased risk of cardiovascular disease, although this is still debated [120, 121].

Vitamin D is required for adequate intestinal absorption of calcium. The recommended dose of vitamin D for women at all life stages is 400–600 IU/day [119]. The elderly, chronically ill, homebound, or institutionalized patient is at the greatest risk for vitamin D deficiency and therefore benefits the most from additional vitamin D in the diet or via exposure to sunlight. Outdoor exposure to the sunshine for 10–15 min with one-third of the skin exposed without sunscreen most days of the week [122] will provide the vast majority of the daily recommended dose of vitamin D and will lead to an improvement in bone mass [123]. Sun-exposed skin, however,, creates the additional risk of sunburn and skin cancer. Sunscreen of 30 SPF or more and full-body clothing reduces exposure to UVB rays that are essential for making vitamin D, and reduces vitamin D production by 95–98% [124]. Lucas et al. investigated the risks and benefits of sun exposure on a global scale and found that there may be twice as much risk to health and well-being from lack of sun exposure than from too much [125]. Oral supplementation with vitamin D has not been found to have a clinically relevant effect on increasing BMD or reducing fracture risk [126, 127], therefore, natural sources of vitamin D should be encouraged.

Vitamin K is a fat-soluble vitamin and consists of subtypes, K1 (phylloquinone) and K2 (menaquinones). A deficiency in this vitamin has been linked to an increased risk of osteoporosis and supplementation has been found to improve BMD [128, 129], especially vitamin K2. A good source of phylloquinone is found in green leafy vegetables. Menaquinones are synthesized by bacteria in the liver, with good food sources including butter, egg yolk, chicken, certain cheeses (e.g., Gouda cheese, blue cheese) and natto, which is a traditional Japanese fermented soybean food [130]. Vitamin K plays a role as a co-enzyme during the synthesis of osteocalcin, a protein derived from osteoblasts in bone formation [131]. With reduced vitamin K, osteocalcin does not undergo complete gamma-carboxylation, which leads to net bone loss.

There is accumulating evidence to suggest that prunes can positively impact bone metabolism [132]. Prunes, rich in (poly)phenolic compounds, act on bone by inhibiting Receptor Activator of Necrosis factor-Kappa B-Ligand (RANKL) expression by osteoclasts and increasing OPG, ultimately reducing bone resorption [133]. Dried plums also contain dietary fiber, minerals (e.g., boron, copper, magnesium, manganese, potassium) and vitamin K, which have been shown to slow bone turnover and subsequently decrease the rate of bone loss [132, 134].

Although there is little to report in terms of studies on the effect of a combination of exercise and vitamin intake on bone strength, a balanced, healthy diet with adequate calcium, vitamin D, vitamin K, and other bone-enhancing minerals (such as magnesium and zinc) is important for ensuring that the positive effects of exercise are not attenuated through a lack of nutrients [58, 135]. Further analysis of nutritional components important in attaining peak bone mass is given in the National Osteoporosis Foundation position statement [31].

17.4 Future Directions

Despite the considerable work in the area of exercise and its effects on bone strength, the specific type, mode, intensity and duration of exercise to optimize bone strength is not fully elu-

cidated, partly because of confounding factors such as estrogen, nutrition, age and genetic predisposition. However, generally speaking, exercise that is of high-impact, high-intensity, and low frequency with rest insertion as well as exercise that is unaccustomed will optimize the osteogenic response. Further work needs to be carried out to explore the exact dose of exercise that is required for all populations and how estrogen, genetics, age and nutrition can modify this dose by changing bone turnover mechanisms.

17.5 Concluding Remarks

Early prevention of bone loss is the key to reducing a woman's lifetime risk of developing osteoporosis and fracture. Women should be encouraged to educate themselves with information on healthy habits in terms of exercise and diet, and to be aware of their personal modifiable and non-modifiable risk factors. Changing one's modifiable risks by avoiding or discontinuing personal habits that are known to damage bone is vitally important to bone health. Although numerous effective pharmacologic therapies for the treatment of osteoporosis are readily available in a variety of forms, maintaining a healthy lifestyle with proper, balanced nutrition and targeted, bone-loading exercise should be paramount for all women. In particular, exercise should be dynamic (not static), of high impact or intensity (but low frequency/duration), unusual or unaccustomed, combined with a rest interval, and performed at the site where bone strength is required. A combination of weight-supported exercise, high-intensity progressive resistance training, and high-impact exercise that focus on all parts of the skeleton should be the goal. The intensity and impact should be adapted according to the individual, taking into account frailty, lack of exercise experience, and history of multiple fragility fractures and/or vertebral fracture(s).

Chapter Review Questions

1. Which of the following puts an individual at increased risk for osteoporosis?
   (a) Drinking too much alcohol
   (b) Family history
   (c) Smoking
   (d) All the above
2. What diagnostic study is the gold standard for diagnosing osteoporosis?
   (a) Dual-energy x-ray absorptiometry (DXA)
   (b) Blood test
   (c) Peripheral quantitative computed tomography
   (d) FRAX®
3. Out of the following, which type of exercise is believed to be the most osteogenic?
   (a) Cycling
   (b) Swimming
   (c) Resistance training
   (d) Jumping
4. Which of these diseases is associated with an increased risk of osteoporosis?
   (a) Rheumatoid arthritis
   (b) Diabetes
   (c) Disordered eating
   (d) All of the above
5. Which of the following foods is highest in vitamin K?
   (a) Soymilk
   (b) Blue cheese
   (c) Shellfish
   (d) Oranges
6. Which confounding factor is likely to modify bone's response to exercise?
   (a) Age
   (b) Estrogen deficiency
   (c) Genetics
   (d) All of the above
7. A 63-year-old patient presets with a dual-energy x-ray absorptiometry T-score of −1.1 SD and a Z-score of −1.3 SD. These values correlate with what diagnosis?
   (a) Normal
   (b) Osteopenia
   (c) Osteoporosis
   (d) Fragility fracture
8. What is the Institute of Medicine's (IOM's) minimum daily recommended intake for calcium in a postmenopausal woman?
   (a) 800 mg/day
   (b) 1000 mg/day
   (c) 1200 mg/day
   (d) 1500 mg/day
9. A 61-year-old female sustains a hip fracture after a ground-level fall. Following appropriate treatment of the fracture, what additional test should be ordered?
   (a) MRI
   (b) DXA scan
   (c) CT scan
   (d) Urine calcium
10. Osteoporosis primarily loses mechanical strength in what type of bone?
    (a) Cortical only
    (b) Trabecular only

(c) Cortical more than trabecular
(d) Trabecular more than cortical

Answers

1. d
2. a
3. d
4. d
5. b
6. d
7. b
8. c
9. b
10. d

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Part IV

Nutrition, Energy Balance, and Energy Availability in Active Females

Estimating Energy Requirements

18

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Learning Objectives

After completing this chapter, you should have an understanding of:

- The components of total daily energy expenditure;
- The difference between the terms: resting energy expenditure (REE), resting metabolic rate (RMR), basal energy expenditure (BEE), and basal metabolic rate (BMR);
- Adaptive thermogenesis and non-exercise activity thermogenesis (NEAT); and
- Practical methods of estimating TDEE.

18.1 Introduction

Energy is defined as *the capacity to do work*. Energy requirements are based on the energy needs for optimal growth and development for each individual at their stage in life in order to maximize long-term good health. Energy requirements for humans are not the same as nutritional requirements (nutritional requirements are discussed in other chapters in this book). Even though we do discuss the difference between nutritional requirements and energy requirements briefly, the focus of this chapter is on the estimation of energy requirements. The Food and Agricultural Organization of the United Nations (FAO) report (*FAO Food and Nutrition Technical Report Series 1*) defines energy requirements as:

> the amount of food energy needed to balance energy expenditure in order to maintain body size, body composition and a level of necessary and desirable physical activity consistent with long-term good health. This includes the energy needed for the optimal growth and development of children, for the deposition of tissues during pregnancy, and for the secretion of milk during lactation consistent with the good health of mother and child [1].

18.2 Research Findings and Nutritional Terminology

It can be confusing for the novice reader when terms are readily exchanged from one source to another when discussing energy. The terms *Calorie*, *calorie*, *and kcal* are often used when discussing energy. Other interchangeably used terms when discussing *total daily energy expenditure* (TDEE) are *basal metabolic rate* (BMR) rather than *basal energy expenditure* (BEE), and *resting metabolic rate* (RMR) rather than *resting energy expenditure* (REE). In the section that follows, we will clarify some of the terms used when discussing energy requirements.

18.2.1 Terms Used when Discussing Total Daily Energy Expenditure (TDEE)

18.2.1.1 Calorie (Capital C or Uppercase C), Calories (Lowercase c), and Kilocalorie

The difference in expressing heat energy with an uppercase *C*, *Calorie*, or a lowercase c, *calorie*, can be a source of confusion. The calorie (lowercase c) is defined as the amount of energy required to raise the temperature of 1 mL or 1 g of water at 15 °C by 1 °C, or from 14.5 to 15.5 °C. In the context of foods and nutrition, "large calorie" (i.e., Calorie) with an uppercase C has been used traditionally [2]. When an uppercase C is used to

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express "Calorie" it is 1000 cal and is referred to as a kilocalorie (abbreviated as kcal). A Calorie or kcal expresses the quantity of heat needed to raise the temperature of 1 kg (1 L) of water to 1 °C (specifically from 14.5 to 15.5 °C). The term kcal is used in the context of food and nutrition because the amount of energy involved in the metabolism of food is fairly large. Nonetheless, the international unit of energy is the Joule (1 kJ = 0.239006 kcal); however, we will use the term kcal because is the classical term utilized in nutritional sciences.

18.2.1.2 Basal Metabolic Rate (BMR)

Most simply stated, the BMR describes the rate of energy expenditure that occurs in the postabsorptive state (after an overnight fast with no food consumption for 12–14 h), resting comfortably, supine, awake, and motionless in a thermoneutral environment. In this state, food and physical activity have minimal influence on metabolism. The BMR thus reflects the energy needed to sustain the metabolic activities of cells and tissues, plus the energy needed to maintain blood circulation, respiration, and gastrointestinal and renal processing (i.e., the basal cost of living). BMR thus includes the energy cost associated with remaining awake (the cost of arousal). The sleeping metabolic rate (SMR) during the morning is 5–10% lower than BMR during the morning hours [3]. The verbatim definition for BMR that appears in the *FAO Food and Nutrition Technical Report Series 1* is as follows:

> The amount of energy used for basal metabolism in a period of time is called the basal metabolic rate (BMR), and is measured under standard conditions that include being awake in the supine position after 10–12 h of fasting and eight hrs of physical rest, and being in a state of mental relaxation in an ambient environmental temperature that does not elicit heat-generating or heat-dissipating processes [1].

From a physiological point of view, the concept of BMR is:

> … the amount of energy in basal (humans) or standard (animals) state, when no work is done and all energy is dissipated ….
>
> the steady-state rate of heat production by a whole organism under a set of "standard" conditions … these conditions are that the individual is an adult and is awake but resting, stress free, not digesting food, and maintained at a temperature that elicits no thermoregulatory effect on heat production … BMR is measured either as heat production, or indirectly as oxygen consumption from which it can be accurately predicted [4].

18.2.1.3 Basal Energy Expenditure (BEE)

The BMR is commonly extrapolated to 24 h to be more meaningful, and it is then referred to as BEE, expressed as kcal/24 h. It is most simply defined as the minimal amount of energy in kcal that is compatible with a healthy homeostasis over a 24 h period. All of the conditions associated with BMR (no food consumption for 12–14 h, resting comfortably, supine, awake, and motionless in a thermoneutral environment) must be met for BEE [2].

18.2.1.4 Resting Metabolic Rate (RMR)

RMR has traditionally been proposed to be a surrogate of BMR. If any of the conditions for BMR have not been met (early morning assessment following a 12–14 h fast, no physical exercise following awakening, remaining awake but motionless, supine, comfortable and in a thermoneutral environment) then energy expenditure is referred to as RMR. Resting metabolic rate energy expenditure under resting conditions tends to be somewhat higher (10–20%) than under basal conditions due to increases in energy expenditure caused by recent food intake (i.e., by the "thermic effect of food") or by the delayed effect of recently completed physical activity [2].

18.2.1.5 Resting Energy Expenditure (REE)

When RMR is extrapolated to 24 h, then it is referred to as REE, expressed as kcal/24 h. It is most simply defined as resting energy expenditure expressed in kcal over a 24 h period. This term is used when all of the standard conditions required for BMR have not been met; nevertheless, in the scientific and clinical literature RMR is considered a similar variable like BMR, except by the fact that the participant/patient does not sleep in the facility where the assessment is performed (usually he/she commutes early in the morning in fasting conditions) [4].

18.2.1.6 Thermic Effect of Food

The thermic effect of food (TEF) is the energy we spend to digest, absorb, distribute and store the nutrients ingested [2]. The type of food that you eat will have an effect on TEF, for example, spicy foods and meals high in protein increase TEF.

18.2.1.7 Energy Balance

Energy balance (EB) is described by the difference between energy intake and energy expenditure in kilocalories per day (EB = Energy Intake − TEE). Daily EB fluctuates considerably, yet over the long term, energy balance is very precise. Positive and negative energy balances result in weight gain and weight loss, accordingly, mainly in the form of fat (about 2/3 of weight loss comes from fat mass (FM)). The amount of fat stored in an adult of normal weight commonly ranges from 13.2 to 44 lb. (6–20 kg). Body fat energy reserves range from approximately 50,000–200,000 kcal since 1 g of fat provides 9.4 kcal. This vast store of energy reserves provides a large buffer capacity as well as the ability to provide energy to survive for several months of severe food deprivation. Large deviations of energy balance, both positive and negative, occur daily by several hundred kcal/day in both normal and overweight subjects. Yet over the long term, energy balance is maintained implying that the cumulative error in adjusting energy intake to expenditure amounts to less than 2% of energy expenditure [5] There are more complex definitions of EB (see next sections).

18.2.1.8 Energy Efficiency from Digestion to Exercise

Nutritional needs are affected by the ratios between energy intake, energy expended, and mechanical work accomplished (internal or external). As a rule of thumb, we must understand that the human body does not work as a perfect machine and not all ingested energy (gross energy) will be effectively used in energetic metabolism; also, we expend more energy than we need to perform exercise or work. Altogether, these relationships are generally defined as efficiency and will determine part of the individual variability of our energy needs.

The first concept related with the efficiency in the nutritional field is associated with the amount of energy taken from the food, which involves digestion/absorption and fermentation (the latter determined by our microbiota). After all digestive/intestinal processes, the human body will obtain a lower amount of energy than the energy contained in the foods, which is determined by the *Digestibility*: "proportion of combustible energy that is absorbed over the entire length of gastrointestinal tract." [6]. From the digestibility concept derives another related concept, *Digestible Energy* (DE): "is estimated as the difference between the combustible energy present in ingested food and that present in feces + combustible gases." [6]. All these previous concepts are highly relevant to quantify the true EB and may be an important source of error when calculating energy needs [5]. However, the actual amount of energy available from the food to perform metabolic processes is not equivalent to DE, and it is better known as *Metabolizable Energy* (ME); it can be defined as follow: "ME is the component of DE that produces heat during oxidative metabolism. It does not include energy that is lost to urine (combustible urinary energy; for example, urea, which is a partially combusted end product of protein metabolism) or body surfaces [combustible surface energy (for example, desquamated cells, hair loss, perspiration), because this energy is not used in metabolism" [6]. Still, there is an additional concept, Net ME, which accounts for differences in the real energy available from the substrates or efficiency. This concept is more complex than the two previous concepts as it relates to the Adenosine triphosphate (ATP) equivalents generated during oxidation and the moles of ATP gained through oxidative pathways [6].

Muscular Efficiency during exercise (exercise efficiency) has several definitions relying on the methodology utilized to measure it. The most common definition is: "Muscular efficiency of an individual during steady-rate exercise is expressed as the ratio of the work accomplished to energy expended" [7]; in other words, the ratio between work energy output (EE_{WO}) over body metabolic energy output or exercise energy expenditure (EE_E) and is expressed as a percentage ([EE_{WO}: EE_E] × 100). Exercise efficiency may change not only as a result of exercise training but also, after weight loss [8]; which may affect energy requirements.

18.2.1.9 Energy Availability

The last concept related to the ones from the previous paragraph is energy availability (EA), which is the energy available for organs and tissue to support physiological functions. In physical activity and sports settings, EA can be defined as The residual energy available to support body functions, once EE_E is subtracted from EI. Usually, EA is −expressed by kilogram of fat-free mass (FFM) [9]:

$$\mathrm{EA} = \frac{\left(\mathrm{EE} - \mathrm{EE}_E\right)}{\mathrm{FFM}}. \tag{18.1}$$

18.2.1.10 Estimated Energy Requirement

According to the Dietary Reference Intakes [2], the Estimated Energy Requirement (EER) is defined as "the average dietary energy intake that is predicted to maintain energy balance in a healthy, adult of a defined age, gender, weight, height, and level of physical activity consistent with good health." An improved calculation of the energy balance can be obtained by relying on body composition assessment and energy expenditure, which will permit us to estimate energy needs by fixing the classical energy balance equation to the dynamic equation of energy balance [10]:

$$\begin{aligned} &\mathrm{EB} = \text{Change in energy stores} - \text{Change in TDEE} \\ &\text{Change in energy stores}\left(\frac{\mathrm{kcal}}{\mathrm{day}}\right) = 1100\frac{\mathrm{kcal}}{\mathrm{kg}} \cdot \left(\frac{\Delta \mathrm{FFM}}{\Delta t}\right) + \frac{9300\mathrm{kcal}}{\mathrm{kg}} \cdot \left(\frac{\Delta \mathrm{FM}}{\Delta t}\right) \end{aligned} \tag{18.2}$$

18.2.1.11 Metabolic Equivalent

The Metabolic Equivalent of Task (MET), or simply metabolic equivalent, is a physiological measure expressing the energy cost of physical activities and is defined as the ratio of metabolic rate (and therefore the rate of energy consumption) during a specific physical activity to a reference metabolic rate, set by convention to 3.5 mL O_2 kg^{-1} min^{-1} or equivalently, 1 MET = 1 kcal kg^{-1} h^{-1} [11]. MET is used as a means of expressing the intensity and energy expenditure of activities in a way comparable among persons of different weights. If someone is working at 10 METs, it is implied that they are working ten times above their REE.

18.2.1.12 Compendium of Physical Activities

The *Compendium of Physical Activities* was developed for use in epidemiologic studies to standardize the assignment of MET intensities in physical activity questionnaires. Compendium activities are classified by a 5-digit code that identifies the category (heading) as the first two digits and the type (description) of activity as the last three digits. Metabolic equivalents are listed for each activity. The calculation from METs to calories is very easy since 1 MET = 1 kcal kg^{-1} h^{-1}. For example, if an activity has a MET value of 7 METs then 7 METs = 7 kcal kg^{-1} h^{-1}. The compendium has been used in studies worldwide to assign intensity units to physical activity questionnaires and to develop innovative ways to assess energy expenditure in physical activity studies. The compendium was published in 1993 and updated in 2000 and 2011 [11]. Appendix 1 has the updated version published in 2011: You can also find the compendium and modified versions of the compendium at https://sites.google.com/site/compendiumofphysicalactivities/ [12]. Children and adolescents have higher REE and different energy efficiency for several physical activities, so the classical compendium cannot be applied to them and specific MET values have been developed for the most common activities [13, 14] (See Appendices 2 and 3).

18.2.2 Energy Requirements Versus Nutrient Requirements

Recommendations for nutrient intakes are generally set to provide an ample supply of the various nutrients needed for all healthy individuals in a given life stage and gender group. Recommended intakes are thus set to correspond to the median amounts sufficient to meet a specific criterion of adequacy plus two standard deviations to meet the needs of nearly all healthy individuals.

However, this is not the case with energy. Excess energy cannot be eliminated, and this energy is eventually deposited in the form of body fat. This reserve provides a mean to maintain metabolism during periods of limited food intake, but it can also result in obesity.

An excellent reference text entitled, Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients) [2] details the nutrient and energy needs of individuals at all stages of life. This project was funded in part by the United States Department of Health and Human Services Office of Disease Prevention and Health Promotion. A free PDF copy can be downloaded at http://www.nap.edu/catalog.php?record_id=10490 [15].

18.2.3 Energy Requirements

Energy requirements are directly related to the components of energy expenditure. In 1985, The World Health Organization stated that "as a matter of principle, we believe the estimates of energy requirements should, as far as possible, be based on estimates of energy expenditure." [16]. Several modifications are proposed in the updated *FAO Food and Nutrition Technical Report Series 1* published in 2004 from the former report published in 1985 [1, 16]. The 2004 report is a result of an expert consultation held in Rome, October 17–24 in 2001. Representing agencies included The United Nations University, World Health Organization and The Food and Agriculture Organization of the United Nations. This report can be downloaded free of charge at www.who.int/nutrition/publications/nutrientrequirements/9251052123/en/ [17].

18.2.4 The Components of Energy Expenditure

In the human body, TDEE is the sum of (1) BEE, which includes a small component associated with arousal, as compared to sleeping; (2) TEF which is the energy we spend to digest, absorb, distribute and store the nutrients ingested; (3) PAEE which is the energy expended in physical activity; and (4) the energy expended in depositing new tissues and in producing milk. Figure 18.1 depicts the components of TEE using the doubly labeled water technique method. Total energy expenditure from doubly labeled water does not include the energy content of tissue development during normal growth and pregnancy or the milk produced during lactation. Some sources may state that TDEE is composed of: (1) resting energy expenditure (REE); (2) TEF; and (3) PAEE [18]. If all of the conditions required for BEE have not been met then the term REE is used.

Regardless of the term used, the resting or basal component of energy expenditure constitutes the largest portion (60–75%) of the TDEE [19]. The only exception to this would be in extremely active individuals. The TEF represents approximately 10% of the total daily energy expenditure, although it depends on the macronutrient content of the food ingested. The most variable component of TDEE is the contribution of physical activity (PAEE) which varies from approximately 15–30% depending on the activity level of the individual [19, 20].

Many factors affect the components that make up TDEE (BEE:TEF:PAEE) whether or not that refers to BEE, REE, BMR, or RMR. From a practical point of view, RMR is usu-

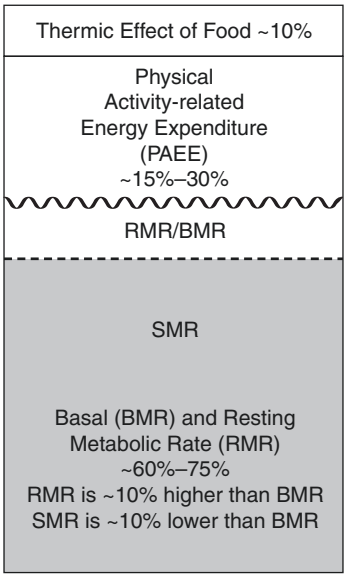

Fig. 18.1 Components of total energy expenditure from the doubly labeled water method (DLW). *Total daily energy expenditure* (TDEE) from DWL does not include the energy content of the maturing tissue constituents during normal growth and pregnancy or the milk produced during lactation. Sleeping energy expenditure (SEE) is included here for illustrative purposes; however, it can be only measured inside a whole room indirect calorimeter (WRIC)

ally used in equations to estimate TDEE, therefore our discussion will center on the factors that affect REE (RMR extrapolated to a 24 h period) or RMR rather than BEE or BMR. We will also discuss the factors that affect TEF and PAEE.

18.2.4.1 Factors Affecting Resting Energy Expenditure

Numerous factors cause the REE to vary among individuals. Interestingly, three factors, age, sex and FFM, account for about 80% of the variability in REE [21]. Additional contributing variables include: (1) body size and weight [body surface area (BSA)]; (2) hormonal status [22, 23]; (3) age [24]; (4) sex [3, 25]; and (5) FM [26]. Age, sex, and FFM are highly correlated and usually, the differences in EE between age groups and male/female are not significant after adjusting the values to FFM [21, 27]; so, in equations where FFM is included, age and sex do not add any prediction power. However, when we do not have a good assessment of FFM variables like sex, age, weight, BMI or body surface area (BSA) are good resources to estimate REE. For example, body surface area is computed from height and weight; taller individuals who weigh more will have the greatest surface area and the greatest metabolic rate. Therefore, an accurate calculation of BSA is a key factor to estimate RMR. Various BSA formulas have been developed over the years; although, there is debate about which is the best formula to use since there is no standardization of formulas at this time. Mosteller's formula is gaining support as a common standard because it is much simpler and can be easily calculated with a handheld calculator. Additionally, a website that can be used to estimate BSA is called Body Surface Area Calculator for medication doses (see http://www.halls.md/body-surface-area/bsa.htm) [28] (Table 18.1).

As stated previously, one of the main determinants of REE is FFM or lean body mass (LBM). However, it has not been demonstrated that individuals with larger relative amounts of FFM (%FFM), like athletes or people who are extremely fit, have higher REE or BMR than nonathletic individuals with the same absolute FFM (kg of FFM). Moreover, there are several physiological processes that contribute to reduce FFM energy consumption after exercise training; for example, resting heart rate is typically lowered after aerobic training, which may reflect an improved heart pumping efficiency; also, futile cycles operating inside the mitochondrion (f.e. activity of uncoupling proteins (UCPs)) may slow down their activities in response to increased physical activity [4]. In addition, an analysis of several studies conducted by John Speakman was not able to find significant differences in REE between participants in several types of PA (aerobic and resistance exercise) after adjusting to FFM by regression analysis [29]. These previous observations may rule out the hypothesis of exercise training equal to increased FFM equal to increased REE. Some of these adaptive thermogenic mechanisms are explained in deep in the following sections. Early observations of increased REE in athletes or trained individuals could have been associated with the acute effect of the last workout; in this regard, the most common described adaptation is an increased excess post-exercise oxygen consumption (EPOC), which can be elevated until 48 h after the last workout [29]. In summary, the parallel observation of an increase in REE/RMR/BMR

Table 18.1 Equations to estimate body surface area. (Adapted from Body Surface Area Calculator for medication doses at https://halls.md/body-surface-area/bsa.htm [24])

Name of formula	Formula
Boyd	
Haycock	BSA (m^2) = 0.024265 × Height (cm)$^{0.3964}$ × Weight (kg)$^{0.5378}$
DuBois and DuBois	BSA (m^2) = 0.20247 × Height (m)$^{0.725}$ × Weight (kg)$^{0.425}$
Gehan and George	BSA (m^2) = 0.0235 × Height (cm)$^{0.42246}$ × Weight (kg)$^{0.51456}$
Mosteller	BSA (m^2) = ([Height (cm) × Weight (kg)]/3600)^{½}
	or in inches and pounds: BSA (m^2) = ([Height (in.) × Weight (lb.)]/3131)^{½}

BSA body surface area

and FFM must not be a causal relationship but casual association related with the last exercise session EPOC; to describe the true adaptation of REE/BMR/RMR to exercise training all REE/RMR/BMR assessments (by indirect calorimetry) must guarantee at least 48 h free of intensive PA and exercise training.

The effect age has on REE is highly correlated with FFM. Resting energy expenditure is the highest during periods of rapid growth, chiefly during the first and second years of life, and peaks throughout adolescence and puberty [30]. As a child becomes older, the caloric requirement for growth is reduced to about 1% of the total energy expended. Resting energy expenditure continues to decline with increasing age in adulthood. The loss of FFM with aging can be attenuated with exercise [31]; however, exercise cannot completely negate the effects of age. There is approximately a 2–3% decline in REE after early adulthood largely due to loss of FFM [32–34]. Some authors also account for the reduction in brain weight with age on REE or basal metabolism, since it is an extremely metabolically active organ. In fact, the brain is more metabolically active than muscle tissue during rest [32]. Henry also states that "the fall in BMR with ageing may be less dramatic than previously perceived. Indeed, some subjects may show an increase in BMR with ageing." [32]; although, this latter is an unusual adaptation and old people may lose not only organ mass [34], but the resting metabolic rate per kg of FFM is also reduced.

Sex differences in metabolic rates are primarily contributed to differences in body size and composition. Women have approximately 5–10% lower REE than men primarily due to differences in LBM [3, 25].

The hormonal status also has an effect on the metabolic rate. The hormones associated with the sympathetic nervous system or those involved in the fight or flight response such as epinephrine and norepinephrine increase metabolic rate [35]. Probably the hormones most closely aligned with REE are the thyroid hormones since these hormones are considered to be the permissive hormones and allow other hormones to exert their full effect [36, 37]. Also, the metabolic rate of women fluctuates with the menstrual cycle, during the luteal phase EE appears to be elevated in the majority of women in parallel with an increased energy intake [22, 23]; for example, the lowest SMR is observed in the late follicular phase and the highest in the late luteal. An average difference between luteal and follicular phases are: 6.1–7.7% for SMR and 2.5–11.5% for 24-h TDEE [38]; these differences represent 89–279 kcal/day from 1 week before ovulation and just before the onset of menstruation [38].

18.2.4.2 Factors Affecting the Thermic Effect of Food

The TEF accounts for approximately 10% of the TDEE. The TEF varies with the composition of the diet and is greater after the consumption of and proteins than after carbohydrates and fat [39]. Spicy foods enhance and prolong the effect of TEF. Caffeine and nicotine also stimulate the TEF [40, 41].

18.2.4.3 Factors Affecting the Energy Expended in Physical Activity and Exercise

Before we begin our discussion of energy during physical activity and exercise, we need to define and differentiate the terms physical activity and exercise. According to Caspersen et al. [42]:

> Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure. The energy expenditure can be measured in kilocalories. Physical activity in daily life can be categorized into occupational, sports, conditioning, household, or other activities. Exercise is a subset of physical activity that is planned, structured, and repetitive and has as a final or an intermediate objective the improvement or maintenance of physical fitness.

In this chapter, when we speak of physical activity, we include the subset exercise. The energy expended in physical activity (PAEE) is the most variable component of TDEE. To illustrate this point think of this, the basal oxygen (O_2) consumption rate of adults is approximately 250 mL/min while elite athletes, such as marathon runners, can sustain O_2 consumption rates of 5000 mL/min [43]. So you can see quite easily that the scale of metabolic responses to exercise varies over a 20-fold range. The PAEE not only includes the energy cost of the movement but also includes energy during these activities such as shivering and maintaining postural control; this activity usually makes part of light physical activity and it constitutes the largest part of the non-exercise activity thermogenesis (NEAT) [44].

Energy cost of physical activity is related to intensity, duration, skill level, and FFM. As the intensity of the physical activity and or duration of the activity increases, so does the energy expenditure. All else being equal, individuals with less skill in performing an activity will expend more energy in performing the movement. Also, individuals with greater FFM will expend more energy at the same intensity and or duration of the exercise. In order to estimate the energy cost associated with activity or exercise, we will refer to the Compendium of Physical Activity [11] that can be found in Appendix 1 [12], where the MET value for each

Table 18.2 Examples of MET values by physical activity levels. (Modified with permission from Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR, Jr., Tudor-Locke C, et al. The Compendium of Physical Activities tracking guide: Healthy Lifestyles Research Center, College of Nursing & Health Innovation, Arizona State University; retrieved Aug from https:// sites.google.com/site/compendiumofphysicalactivities. Project supported by the University of Arizona and the National Cancer Institute [12])

Physical activity intensity	MET
Sedentary time	<1.5
Sleeping	0.9
Watching television	1.8
Light intensity activities	1.5–<3
Writing, desk work, typing	1.8
Walking, 1.7 mph (2.7 km/h), level ground, strolling, very slow	2.3
Stand, playing with animal, light effort, only active peridps	2.8
Moderate intensity activities	3–6
Bicycling, stationary, 50 W, very light effort	3.0
Walking 3.0 mph (4.8 km/h)	3.3
Calisthenics, home exercise, light or moderate effort, general	3.5
Gardening, general, moderate effort	3.8
Bicycling, <10 mph (16 km/h), leisure, to work or for pleasure	4.0
Bicycling, stationary, 100 W, light effort	5.5
Vigorous intensity activities	>6
Jogging, general	7.0
Skating, ice, general	7.0
Running jogging, in place	8.0
Calisthenics (e.g., push-ups, sit-ups, pull-ups, jumping jacks), heavy, vigorous effort	8.0
Carrying moderate loads upstairs, moving boxes 25–49 lbs.	8.0
Rope jumping	10.0

activity is listed. These values can then be converted to kcal by using the formula 1 MET = 1 kcal kg^{-1} h^{-1}. We also have a more generalized version of activity categories in Table 18.2 [3] for the sake of simplicity.

18.3 Contemporary Understanding of the Issues

18.3.1 Methods of Measuring Energy Expenditure

The Doubly Labeled Water Technique (DLW) is currently considered the most accurate technique for measuring TDEE in free-living individuals. The DLW for measuring TDEE in free-living people uses two stable isotopes of water (deuterium [^2H_2O] and oxygen-18 [$H_2{}^{18}O$]); the difference in the turnover rates of the two isotopes measures the carbon dioxide production rate, from which total energy expenditure can be calculated [45]. The premise of the method is that the O_2 atoms in expired CO_2 have isotopically equilibrated atoms. Thus, after a loading dose of water labeled with 2H and 18O, the 2H is eliminated from the body as water, whereas the 18O is eliminated from the body as water and CO_2. The difference between the elimination rates is therefore proportional to CO_2 production and hence energy expenditure can be estimated using calculated O_2 from the equation of respiratory quotient ($RQ = VCO_2/VO_2$); RQ is estimated from the respiratory quotient of diet (called food quotient (FQ)) or assumed to be 0.85 (Western diet). The primary advantage of this technique is its accuracy (2–8% precision) and that it provides a measure of energy expenditure that incorporates all the components of TDEE [18, 45]. Also, it can be used to measure free-living energy expenditure, while subjects engage in normal daily activities. It is for these reasons, that the DLW technique and direct calorimetry have been used for validation studies and to generate data to develop prediction equations [46, 47]. Normally, estimates of PAEE using different techniques are validated against the DLW technique. However, the expense of the technique makes it impractical for routine use by clinicians; therefore, additional techniques have been validated to estimate or calculate EE, such as indirect calorimetry, accelerometers, heart rate monitors and questionnaires.

Direct calorimetry is a method for measuring the amount of energy expended by monitoring the rate at which a person loses heat from the body using a facility called a whole-room calorimeter. Direct calorimetry provides a measure of energy expended in the form of heat but does not provide information on the type of fuel being oxidized.

Indirect calorimetry is a method of estimating energy expenditure by measuring oxygen consumption and carbon dioxide output utilizing a whole room indirect calorimeter, respirator gas-exchange canopy or ventilation hood. The amount of heat produced by oxidation of a nutrient is proportional to the consumed O_2 and the CO_2 produced. The energy per liter of oxygen will be converted to kilocalories of heat produced and extrapolated to energy expenditure per unit of time. Data obtained from indirect calorimetry permit the calculation of the respiratory quotient (RQ), which is calculated as the ratio of moles CO_2 expired/moles O_2 consumed. The volume of O_2 used and CO_2 produced and the amount of heat released in the oxidative process, depending on the type of nutrient being oxidized. This allows determining the proportion of each substrate being used, ranging normally from 1 (only carbohydrates) to 0.7. It is assumed that all the O_2 consumed is used to oxidize substrates, that all the CO_2 produced can be recovered, and that the proteins are not involved primarily in energy production [18].

Accelerometers detect body displacement electronically, using piezo-resistive or piezo-electric sensors, with varying degrees of sensitivity; the triaxial monitor uses three different axes to measure movement rather than a single vertical axis, as in the uniaxial monitor and is more accurate than the

uniaxial monitor [48]. Portable uniaxial accelerometer units have been widely used to detect physical activity, but these instruments are not sufficiently sensitive to quantify the PAEE of a given free-living subject, although they are valuable for comparing activity levels between groups of subjects [49–51].

Minute-by-minute heart rate monitors are valid in estimating habitual TDEE in certain populations but not in individuals, at least in the absence of exercise [52]. Variance in other factors that also affect heart rate, such as emotion, also impacts this relationship. According to Levine [53]:

> In humans, there is a significant relationship between heart rate and energy expenditure, at least in the absence of exercise. The conceptual limitation is that energy expenditure and heart rate are not linearly related for an individual in part because cardiac stroke volume changes with changing heart rate and even posture.

Many questionnaires have been developed to measure physical activity in adults. Currently, the most widely used are the different versions of the International Physical Activity Questionnaire (IPAQ). Van Poppel et al. [54] reviewed the validity, reliability and responsiveness of 85 PA (physical activity) questionnaires, including the IPAQ. In light of their results, these authors conclude that no questionnaire or type of questionnaire for assessing PA was superior and therefore could not be strongly recommended above others. Furthermore, they observed that there is a clear lack of standardization of PA questionnaires, resulting in many variations not being well described and validated. Thus, researchers should decide which questionnaire best fits their purposes of estimating TDEE considering the content of the questionnaire, the nature of the sample and the available validation studies [53, 55].

More recently, Bonn et al. [56] developed the Web-based questionnaire, Active-Q. The authors validate their questionnaire against DLW and conclude that Active-Q is a valid method for estimating total energy expenditure, and is also reproducible and user-friendly method. However, many methodological limitations make this conclusion perhaps too audacious.

18.3.2 Estimated Energy Expenditure Prediction Equations

The Harris–Benedict formula published in 1919 [57] is one of the most widely used formulas to determine RMR. Results of the accuracy of the prediction equation are mixed. Daly et al. [58] suggested that it overestimates RMR by 7–24% in many contemporary populations. However, Hasson et al. [59] compared predicted RMR derived from commonly used prediction regression equations to measured RMR in a diverse group of individuals and found that the Harris–Benedict equation was the most likely to predict RMR to within 10% of measured RMR. In addition, the Harris–Benedict equation accurately predicted RMR in both sexes, all body mass index (BMI) categories, individuals aged 30–60 years and all racial/ethnic groups. Table 18.3 includes the original Harris–Benedict prediction equation published in 1919 [57] and a 1984 Harris–Benedict equations revised by Roza and Shizgal [60] completed with practical applications.

The 1985 predictive equations included in the Technical Report Series 724 [16] were developed from a meta-analysis of about 100 studies conducted over a long time period (1914–1980), including the subjects studied by Harris and Benedict. The current predictive equations published in 2004 can be found in the *FAO Food and Nutrition Technical Report Series* [1]. The full report can be downloaded free of charge at the World Health Organization Web site (see http://www.who.int/nutrition/publications/nutrientrequirements/9251052123/en/index.html) [17]. However, Henry et al. [61] found that the equations published in the *FAO Food and Nutrition Technical Report Series* overestimated REE.

Frankenfield et al. [62] examined the validity of RMR prediction equations applied to the general public and concluded that the Mifflin–St. Jeor equation is the most likely to

Table 18.3 Harris–Benedict prediction equations [57, 60] and practical examples to calculate weight stability

Step 1: *calculating the BMR*	
The original Harris–Benedict equations published in 1918 and 1919 [57]	
Men	BMR = 66.4730 + 13.7516 × weight (kg) + 5.0033 × height (cm) − 6.7550 × age (years)
Women	BMR = 655.0955 + 9.5634 × weight (kg) + 1.8496 × height (cm) − 4.6756 × age (years)
The Harris–Benedict equations revised by Roza and Shizgal in 1984 [60]	
Men	BMR = 88.362 + 13.397 × weight (kg) + 4.799 × height (cm) − 5.677 × age (years)
Women	BMR = 447.593 + 9.247 × weight (kg) + 3.098 × height (cm) − 4.330 × age (years)
Step 2: *applying the Harris–Benedict Principle*	
The following table enables calculation of an individual's recommended daily calorie intake to maintain current weight	
Little to no exercise	Daily calories needed = BMR × 1.2
Light exercise (1–3 days/week)	Daily calories needed = BMR × 1.375
Moderate exercise (3–5 days/week)	Daily calories needed = BMR × 1.55
Heavy exercise (6–7 days/week)	Daily calories needed = BMR × 1.725
Very heavy exercise (twice/day, extra heavy workouts)	Daily calories needed = BMR × 1.9

BMR basal metabolic rate

estimate RMR within 10% of that measured RMR. However, noteworthy limitations exist when it is generalized to a certain age and ethnic groups. This equation is presented in Table 18.4 [63] with an example to estimate TDEE.

Hasson et al. [59] highlighted that one limitation of the Frankenfield et al. [62] systematic review of predictive equations for RMR was the absence of a direct comparison of these regression equations to a criterion measure. Results from Hasson's study [59] suggest the Mifflin–St Jeor equation is primarily useful in overweight/obese groups, whereas the equations in the *FAO Food and Nutrition Technical Report Series* 1 may be optimal in younger adults aged 18–49 years.

A considerable number of prediction equations have been developed since 1990. Most of the equations have not been adequately validated and the equations have a poor predictive value for individuals. The basis of several prediction methods is an estimation of REE to which is added a "stress" or "injury" factor [61]. The main advantage of these "newly" developed prediction equations to estimate energy expenditure (EE) is that they are easy to use and inexpensive [69].

The Standing Committee on the Scientific Evaluation of Dietary Reference Intakes of the Food and Nutrition Board, Institute of Medicine, and the National Academies, in collaboration with Health Canada developed prediction equations to estimate energy requirements (EER) for people according to their life-stage group [2]. The EER incorporates age, weight, height, gender, and level of physical activity for individuals in various life stages. The equations for girls and women published in the 2005 Dietary Reference Intakes for Energy Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids can be found in Table 18.5. Equations for both genders can be downloaded free of charge online at The National Academies Press at http://www.nap.edu/catalog.php?record_id=10490 [15].

Table 18.4 An estimated energy expenditure prediction using the Mifflin–St Jeor equation to determine resting metabolic rate (Adapted from Mifflin MD, St. Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals. Am J Clin Nutr. 1990;51(2), 241–7, © 1990, with permission from Oxford University Press [63])

Step 1: Obtain demographic data: Age and sex from the subject and measure height and weight	
Step 2: *Calculate resting metabolic rate* (*RMR*) *using the Mifflin–St Jeor equation* [63]	
RMR = 9.99 × weight (kg) + 6.25 × height (cm) − 4.92 × age (year) + 166 × sex (males, 1; females, 0) − 161	
Step 3: *Determine additional caloric requirements based on level of activity and weight loss category*	
Physical activity level	Fraction activity factor above or below RMR
Sleeping	0.86 [64]
Bed rest	0.94 [65]
Quiet rest	1.1
Light PA	1.38 [66]
Moderate PA	1.53 [66]
Weight loss mainteIner	1.75 [67]
Heavy activity (female runner/10-mile/day)	2.0 [68]
Heavy activity (synchronized swimmer)	2.2 [68]
Additional caloric requirements (ACR) = 1 − (RMR × fraction activity factor)	
Step 4: *Determine predicted total energy expenditure* (*TEE*)	
TDEE = RMR + ACR + TEF ((ACR + RMR) × 0.1)	

RMR resting metabolic rate, *PA* physical activity, *TDEE* total daily energy expenditure, *TEF* thermic effect of food (assumed to be 10% of TEE when in energy balance [39])

Table 18.5 Physical activity level index (PAL) and physical activity coefficient (PA) were used to derive estimated energy requirements (EER) for women [2] (Adapted from A report of the panel on macronutrients, subcommittees on upper reference levels of nutrients and interpretation and uses of dietary reference intakes, and the standing committee on the scientific evaluation of dietary reference intakes. Dietary reference intakes for energy carbohydrates, fiber, fat, fatty acids, cholesterol, protein, and amino acids (*macronutrients*). Washington DC: National Academy Press; 2005 [2])

PAL	Sedentary (1.0–1.39)	Low active (1.4–1.59)	Active (1.6–1.89)	Very active (1.9–2.5)
	Typical daily living activities (e.g., household tasks, walking to the bus)	Typical daily living activities PLUS 30–60 min of daily moderate activities (e.g., walking at 5–7 km/h)	Typical daily living activities PLUS at least 60 min of daily moderate activities	Typical daily living activities PLUS at least 60 min of daily moderate activities an additional 60 min of vigorous activity or 120 min of moderate activity
PA	PA (level 1)	PA (level 2)	PA (level 3)	PA (level 4)
Girls 3–18 year	1.00	1.16	1.31	1.56
Women 19 year+	1.00	1.12	1.27	1.45
Equations to estimate energy requirement (EER) using the PA				
	Infants and young children			
	Estimated energy requirement (kcal/day) = Total energy expenditure + Energy deposition			
0–3 months	EER = (89 × weight [kg] − 100) + 175			
4–6 months	EER = (89 × weight [kg] − 100) + 56			
7–12 months	EER = (89 × weight [kg] − 100) + 22			
13–35 months	EER = (89 × weight [kg] − 100) + 20			
	Children and adolescents 3–18 years			
	Estimated energy requirement (kcal/day) = Total energy expenditure + Energy deposition			

(continued)

Table 18.5 (continued)

	Girls
3–8 years	EER = 135.3 − (30.8 × age [year]) + PA × [(10.0 × weight [kg]) + (934 × height [m])] + 20
9–18 years	EER = 135.3 − (30.8 × age [year]) + PA × [(10.0 × weight [kg]) + (934 × height [m])] + 25
	Adults 19 years and older
	Estimated energy requirement (kcal/day) = Total energy expenditure
Women	EER = 354 − (6.91 × age [year]) + PA × [(9.36 × weight [kg]) + (726 × height [m])]
	Pregnancy
	Estimated energy requirement (kcal/day) = Nonpregnant EER + Pregnancy energy deposition
First trimester	EER = Nonpregnant EER + 0
Second trimester	EER = Nonpregnant EER + 340
Third trimester	EER = Nonpregnant EER + 452
	Lactation
	Estimated energy requirement (kcal/day) = Nonpregnant EER + Milk energy output − Weight loss
0–6 months postpartum	EER = Nonpregnant EER + 500 − 170
7–12 months postpartum	EER = Nonpregnant EER + 400 − 0

Note: These equations provide an estimate of energy requirement. Relative body weight (i.e., loss, stable, gain) is the preferred indicator of energy adequacy
PAL Physical activity level or physical activity index, *PA* Physical activity coefficient, *EER* Estimated energy requirement

18.4 Future Directions

Recommendations for energy expenditure used by exercise physiologists incorporate a thermic constant in exercise physiology. One of the most commonly used thermic constants of exercise physiology is the MET [11]. TDEE can be estimated after quantifying daily common activities (sleeping, home activities, etc.) and multiplying by a specific MET-activity value (see an example in the case study at end of the chapter). MET-activity values can also be found in Table 18.2 and Appendix 1. You can also find the compendium and modified versions of the compendium at https://sites.google.com/site/compendiumofphysicalactivities/ [12]. A noteworthy comment about the compendium taken directly from their Web site is as follows:

> When using the Compendium to estimate the energy cost of activities, investigators should remind participants to recall only the time spent in movement. The Compendium was not developed to determine the precise energy cost of physical activity within individuals, but rather to provide a classification system that standardizes the MET intensities of physical activities used in survey research. The values in the Compendium do not estimate the energy cost of physical activity in individuals in ways that account for differences in body mass, adiposity, age, sex, efficiency of movement, geographic and environmental conditions in which the activities are performed. Thus, individual differences in energy expenditure for the same activity can be large and the true energy cost for an individual may or may not be close to the stated mean MET level as presented in the Compendium [12].

When estimating energy requirements using the compendium, individuals must take into account factors that affect the RMR as well as a concept called adaptive thermogenesis. In the information that ensues, these factors are discussed as well as the concept called NEAT. Formulas and examples of how to estimate energy using the compendium are also presented.

18.4.1 Resting Metabolic Rate and Adaptive Thermogenesis

RMR represents at least 60% of TDEE in non-highly-active population [18, 70]. Measurements of RMR have been performed extensively on animals and humans using traditional calorimeters [71]. Several definitions of RMR have been reported in animals and humans [4]. As discussed in this chapter equations to estimate RMR are in widespread use. Since the first models created by Harris and Benedict [57] several equations have been created using anthropometric variables [72], body composition models [26, 27], or VO_{2max} [25] as predictors of RMR. Nevertheless, FFM continues to be the most important predictor in large heterogeneous samples [73].

FFM is composed of skeletal muscle mass, bone, internal organs, and residual mass, and each one has specific metabolic rates [70]. The latter presents a high variability between subjects of different height, age, and weight body [74]. Indeed, 1 kg of FFM must have a different RMR between individuals with the same FFM but different height, age, or gender, and particularly in obese adults [75]. In order to resolve this conundrum, new models, which estimate individual masses of internal organs and tissues, have been developed to apply specific-organ metabolic rates to predict RMR [34, 74, 75], whereas older equations, which used anthropometric and two-compartment body composition models, have shown poor validity in predicting RMR in several populations, mainly among overweight and obese peo-

Table 18.6 Equations to estimate resting metabolic rate (RMR) in women using body composition variables as paradigm [25–27, 72, 76]

Author	Equation (kcal/day)
Schofield [72][a]	*<3 years*: RMR = 16.252 W + 1023.2 H − 413.5
	3–10 years: RMR = 16.969 W + 161.8 H + 371.2
	10–18 years: RMR = 8.365 W + 465.6 H + 200.0
	18–30 years: RMR = 13.623 W + 283.0 H + 98.2
	30–65 years: RMR = 8.126 W + 1.43 H + 843.7
	>65 years: RMR = 7.887 W + 458.2 H − 17.7
Arciero et al. [25]	RMR = 13.7 FFM + 3.3 FM + 74 VO_{2max} − 50 + 596
Smith et al. [76]	RMR = 3.39 FFM + 0.45 VO_{2max} + 77.41 (kJ/dia)[b]
Wang et al. [27]	RMR = 24.6 FFM + 175
Bosy-Westphal et al. [26][c]	*%FM between >10* and *30*: RMR = 11.8 FFM + 14.4 FM + 629.2
	%FM between >30 and *40*: RMR = 5.5 FFM + 19.3 FM + 926.3
	%FM between >40 and *50*: RMR = 12.0 FFM + 10.4 FM + 886
	%FM >50: RMR = 11.5 FFM + 7.1 FM + 1097.2

W weight (kg), *H* height (m), *FFM* fat free mass (kg), *FM* fat mass (%), VO_{2max} maximal oxygen uptake (L.min[1])

[a]A specific model for each person must be selected after classifying women inside of age grade

[b]To convert kJ to kcal, divide by 4.18

[c]A specific model for each person must be selected after classifying women inside of %FM grade

ple [62, 72, 75]. Although body composition-based equations should be the best approach, we propose several solutions for different assessment contexts (see Table 18.6).

18.4.1.1 Adaptive Thermogenesis

Equations developed to estimate RMR have been validated from cross-sectional studies, so those must not always fit to apply in longitudinal interventions, where qualitative and quantitative changes of FFM may result. Alterations in all components of energy expenditure may occur following weight loss programs with either energy restriction alone, exercise alone or a combination of both [77]. When these alterations are above or below the predictions we can say that an "adaptive thermogenesis" (AT) has occurred. The operational definition of adaptive thermogenesis is: "heat production in response to environmental temperature or diet, and serves the purpose of protecting the organism from cold exposure or regulating energy balance after changes in diet" [78]. Adaptive thermogenesis has been considered to be the result of adaptation to diet and temperature. Traditionally, adaptive thermogenesis was thought to occur principally in human brown adipose tissue. Since studies have shown that exercise training can modify the energy efficiency of skeletal muscle mass [79], it may be possible that exercise training promotes adaptive thermogenesis in skeletal muscle and other lean organs. While brown adipose tissue is scarce in adult humans, we cannot completely forget the contribution of skeletal muscle to adaptive thermogenesis. Even, the activity of brown adipose tissue deposits has recently been effectively demonstrated in humans [80], and the relationship between brown adipose tissue and RMR has been described [81]. However, the human brown adipose tissue must not be representative to contribute significantly to TDEE; although, it may have important implications for energy expenditure regulation [82, 83].

Although by definition AT is a concept principally related to RMR, AT could also affect other components of TDEE. Thus, the term "improved energy efficiency" (reduction of the ratio; kJ or kcal of work output/kJ or kcal of internal work) has been coined in the past to explain the phenomenon of reduced EE after physical activity or exercise interventions. However, changes in energy efficiency are conceptually different to the changes of adaptive thermogenesis (See Sect. 18.2).

In this chapter, we only use the term "adaptive thermogenesis" in connection with RMR; even though reductions in walking EE after exercise training may be a form of adaptive thermogenesis. Considering previous paragraphs, AT can be result of increased or decreased EE. Herein, our interest is focused on suppressed adaptive thermogenesis. The importance of adaptive thermogenesis has generated some controversies in the field of the physiology of energy expenditure regulation. Some authors have postulated that alterations on RMR are explained by changes on FFM [77]; moreover, some have proposed that after exercise training RMR is conserved [84]. Since the concept of AT is governed by reductions in RMR, which are not explained by changes on body composition [8], an AT must not be expected after exercise training, and so RMR will have not any impact on weight control [84]. On the other hand, small alterations in any component of TDEE can lead to a substantial impact on daily energy balance [85], and adaptive thermogenesis has been confirmed in a number of reports [86]. Furthermore, it has been demonstrated that AT has a clinically significant impact on TDEE [83]. However, the assessment of AT is difficult and requires good experimental control, large sample size and high accuracy, as small differences can be clinically important in the long term [85].

Traditionally, a reduction in RMR after weight loss has been associated with a parallel reduction in FFM. Nonetheless, several studies have shown that this adaptation is mostly dependent on FM [87] and the distribution of FM and FFM [88], since the reductions in FFM-adjusted RMR present a

close relationship either with reductions of FM and FFM after interventions with energy intake restriction [89]. Also, in several studies where exercise and diet were used, a reduction in RMR was confirmed even though FFM was conserved [29]; therefore, AT must trade on some component of FFM possibly skeletal muscle.

Several molecular mechanisms have been suggested to explain an uncoupling between heat produced and synthesized ATP, which may be responsible for AT at the skeletal muscle mass level. The proposed molecular mechanisms include leakage of protons back across the mitochondrial inner membrane which is catalyzed by UCPs [83]; decreased proton pumping by cytochrome oxidase by complex IV [88]; contribution of Na^+, K^+, and Ca^{2+} ion leaks, and substrate cycles like protein turnover which consume ATP [78]. Considering the previous arguments the study of AT is an exciting research area; however, the effect of exercise training and weight loss has not been fully explored yet.

The estimation of AT requires the assessment of changes in RMR and body composition (FM and FFM) following interventions, and statistical procedures must be performed to create equations to estimate RMR of studied sample from data at baseline, where physiological conditions must be in steady-state. In this way, the changes in RMR can be predicted using simple linear regression models, which were created using body composition variables at baseline as independent variables (FM and FFM). AT can be calculated as proposed by Doucet et al. [90]:

$$\begin{aligned} \mathrm{AT} &= \left[\mathrm{EE}_{\mathrm{measured}} - \mathrm{EE}_{\mathrm{estimated}}\right]_{\mathrm{after\ intervention}} \\ &\quad - \left[\mathrm{EE}_{\mathrm{measured}} - \mathrm{EE}_{\mathrm{estimated}}\right]_{\mathrm{baseline\ values}} \end{aligned} \tag{18.3}$$

Where, AT, adaptive thermogenesis; EE was energy expenditure either during resting; $EE_{estimated}$ *was calculated by stepwise simple linear regression, using FFM and/or FM has also been explained using the starvation paradigm* [90]. However, some questions remain unanswered. The exclusive effects of exercise or the influence of specific protocols of training remain to be determined.

18.4.2 NEAT Definition

Another concept that the reader may come across when discussing TDEE is the term non-exercise activity thermogenesis (NEAT). When used in the equations to estimate TDEE, NEAT is a highly variable component of TDEE, ranging from about 15% in sedentary population to >50% in highly active people [44]. NEAT is composed of spontaneous physical activity (SPA), which is included and lifestyle physical activities. So NEAT includes the energy expenditure of occupation, leisure, sitting, standing, walking, talking, toe-tapping, shopping, household activities, etc. There is a close relationship between change in NEAT and FM gain. Since the EE of different activities which are included in NEAT can change after stimuli such as overfeeding or exercise, a theory whereby an improved energetic efficiency after weight loss interventions has been postulated [44], and several neuroendocrine mechanisms have been described to bind NEAT with resistance to loss fat and weight [91].

Although the concept of NEAT is interesting, its assessment requires measurement of TDEE which only can be measured directly by the isotopic technique of DLW which is highly expensive to apply in large cohorts (see previous sections). Nonetheless, estimations of NEAT could be performed using some wearables such as accelerometers or multisensor devices.

Physical activity recalls and pedometer can also be used to perform estimations of NEAT assuming the next paradigm:

- PAEE = ExEE + NEAT (MVEE + LEE).
- ExEE = EE from exercise training physical activities.
- MVEE = physical activities which are performed commonly all days, as a job or compulsory transportation, but with moderate/vigorous EE.
- LEE = energy expenditure from light intensity physical activity (LIPA), any activity between 1.5 and <3.0 METs.

To calculate NEAT, we need to quantify total daily movement (using a well-calibrated pedometer). Additionally, a record of ExEE and MVEE + LEE hours must be carried out, also steps during ExEE need to be registered. So an estimation of NEAT can be obtained from the difference between total daily movement (steps) and ExEE (steps). A similar approach could be done using accelerometers although more expertise is needed to manage the data.

On the other hand, NEAT can be calculated by a tight recall of daily activities to calculate TDEE, afterwards, the PAEE components can be obtained in order to estimate NEAT (see case study). Note that all these methods must provide different NEAT values (for example, the PA recalls may collect PAEE from activities like cycling, which is not the case for accelerometers worn on the waist). It is important to differentiate the concepts of NEAT and non-exercise physical activity (NEPA); the latter represents a quantification of the minutes related with NEAT, and it is possible a reduction in NEAT without a significant reduction in NEPA. The paradigm suggested to calculate NEAT in the previous paragraphs assumes a linear relationship between NEAT and NEPA; however, this may not be true after certain interventions that affect exercise efficiency. In summary, NEAT is any energy expenditure above sedentary EE but not related with formal exercise/PA; NEPA is a surrogate of NEAT.

18.4.3 Estimating TEE Using the Compendium of PA

When estimating TEE using these steps, the reader can use the MET values from Table 18.2 or can refer to Appendix 1 for a more detailed list. The MET values listed are from the *Compendium of Physical Activities* which can be found in Appendix 1 or at https://sites.google.com/site/compendiumofphysicalactivities/ [12].

18.4.3.1 Estimating TEE: A Case Study

Alice is a 37-year-old woman, weight 75 kg, and 12% of FM. She wants to know what is her TEE and PAL, in order to know if her TDEE is enough to maintain the energy balance. Using a recall of one typical day. Calculate TDEE of this woman who does not perform any exercise training. Follow the next steps of our example and apply them to a real person:

First step. Calculate RMR/24 h = kcal/h.

Second step. To count hours sleeping.

Third step. To count hours sitting. Check different activities.

Fourth step. To count hours with house activities.

Fifth step. To count hours with physical activities.

Note: The sum of total Hours must be equal to 24 h (Table 18.7).

Table 18.7 Summary of daily activities from the case study

Hours	Code	kcal
24	PA	450 kcal/day
23	PA	
22	PA	
21	HA	563 kcal/day
20	HA	
19	HA	
18	ST	1418 kcal/day
17	ST	
16	ST	
15	ST	
14	ST	
13	ST	
12	ST	
11	ST	
10	ST	
9	ST	
8	ST	
7	ST	
6	ST	
5	S	337 kcal/day
4	S	
3	S	
2	S	
1	S	

S sleeping, *ST* sitting, *HA* home activities, *PA* habitual physical activity

First step. To calculate RMR by hour (it will be useful in order to calculate EE of sleeping):

RMR (kcal/day) = 24.6 × FFM (kg) + 175.
FFM = BW (kg) − (%FM (%) × BW (kg)).
FFM = 75 − (0.12 × 75) = 75–9 = 66 kg.
RMR = 24.6 × (66 kg) + 175 = 1799 kcal/day.
RMR (kcal/h) = 1799/24 = 74.94 kcal/h.

Second step. EE of sleeping:

1. Hours sleeping = 5 h.
2. EE of sleeping = 0.9 × RMR (kcal/h) or 0.9 METs.
3. EE of sleeping = 0.9 × 74.94 kcal/h = 67.45 kcal/h.
   Total EE of sleeping = 67.45 × 5 = 337 kcal/day.

Third step. EE of sitting hours:

1. Hours to eat = 0.5 breakfast + 1 lunch + 0.5 dinner.
2. Hours working = 8 h.
3. Hours watching TV or something like that = 3 h.
   Total = 13 h/day.

Use the compendium of PA METs in Appendix 1 to calculate EE:

1. *13030* self care = eating, sitting = *1.5 METs*.
2. *07022* inactivity quiet/light lying = sitting quietly, fidgeting, general, fidgeting hands = *1.5 METs* (or 11770 = 1.3).
3. *07020* inactivity quiet/light lying = sitting and watching television = *1.3 METs*.

Calculations:

1. EE to eat = 2 h × 1.5 METs = 3 kcal/kg × 75 kg = 225 kcal/day.
2. EE to work = 8 h × 1.5 METs = 12 kcal/kg × 75 kg = 900 kcal/day.
3. EE during sedentary leisure = 3 h × 1.3 METs = 3.9 kcal/kg × 75 kg = 293 kcal/day.
   Total daily EE of sitting hours = 1418 kcal/day.

Fourth step. EE of home activities:

1. Cleaning = 1 h.
2. Cooking = 1 h.
3. Self-care = 1 h.
   Total = 3 h/day.

Use the compendium of PA METs in Appendix 1 to calculate EE:

1. *05026 3.5* home activities = multiple household tasks all at once, moderate effort.

2. *05050 2.0* home activities = cooking or food preparation-standing or sitting or in general (not broken into stand/walk components), manual appliances, light effort.
3. *13,040 2.0* self-care = grooming, washing hands, shaving, brushing teeth/showering, toweling off, standing.

Calculations:

1. EE to clean home = 1 h × 3.5 METs = 3.5 kcal/kg × 75 kg = 263 kcal/day.
2. EE to cook = 1 h × 2.0 METs = 2 kcal/kg × 75 kg = 150 kcal/day.
3. EE during sedentary leisure = 1 h × 2.0 METs = 2 kcal/kg × 75 kg = 150 kcal/day.
   Total Daily EE of Home activities = 563 kcal/day.

Fifth step. EE of other physical, leisure, or transportation activities:

1. Reading = 2 h.
2. Walking = 0.5 h.
3. Walking for transportation = 0.5 h.

Total = 3 h/day.

Use the compendium of PA METs in Appendix 1 to calculate EE:

1. *11580 1.5* occupation = sitting tasks, light effort (e.g., office work, chemistry lab work, computer work, light assembly repair, watch repair, reading, desk work).
2. *17161 2.5* walking = walking from house to car or bus, from car or bus to go places, from car or bus to and from the worksite.
3. *16060 3.5* transportation = walking for transportation, 2.8–3.2 mph, level, moderate pace, firm surface.

Calculations:

1. EE during sedentary leisure = 2.0 h × 1.5 METs = 3.0 kcal/kg × 75 kg = 225 kcal/day.
2. EE during public transportation = 0.5 h × 3.5 METs = 1.75 kcal/kg × 75 kg = 131 kcal/day.
3. Walking EE to pick up public transportation or from = 0.5 h × 2.5 METs = 1.25 kcal/kg × 75 kg = 94 kcal/day.
   Total Daily EE of PA or transportation = 450 kcal/day.

Sixth step. TEE and PAL Calculations:

Final results TEE = 2768 kcal/day.
PAL = 2768 kcal/day/1799 kcal/day = 1.54.

Table 18.8 Table of physical activity levels (PAL) [1] (Adapted from FAO/WHO/UNU. *Human energy requirements Report of a Joint FAO/WHO/UNU Expert Consultation*. FAO Food and Nutrition Technical Report Series 2004. http://www.fao.org/3/y5686e/y5686e00.htm#Contents)

Classification	PAL range
Sedentary or light active lifestyle	1.40–1.69
Active or moderately active lifestyle	1.70–1.99
Highly active lifestyle	2.00–2.40

As suggested in the literature her PAL is equivalent to a sedentary lifestyle, moreover, in order to prevent herself from weight gain, a minimum PAL of 1.70 has been reported (Table 18.8) [1].

18.4.4 Estimating NEAT

18.4.4.1 NEAT Estimation

We will use the data from the previous section to calculate NEAT.

Components of PAEE:

- PAEE = ExEE + NEAT (MVEE+LEE).
- NEAT = PAEE − ExEE.
- Where:
- ExEE = 0 kcal/day (she does not perform any exercise training).
- MVEE = 0 kcal/day (she is not involved in moderate or vigorous physical activity, which is mandatory).
- NEAT = 563 kcal/day (home activities) + 450 kcal/day (other activities, include only walking and walking for transportation) = 1013 kcal/day.

Since MET units include RMR we need to subtract the latter factor in order to obtain the final net PAEE. All together NEAT physical activities lasted 6 h, and RMR was 74.94 kcal/h. So we need to multiply 6 h × 74.94 kcal/h in order to calculate kcal that were expended for resting during NEAT activities, which were 450 kcal. So final net NEAT was 563 kcal during a day.

$$\text{Final NEAT results}: 1013\,\text{kcal/day} - 450\,\text{kcal} = 563\,\text{kcal/day}$$

18.5 Concluding Remarks

The equations presented in this chapter should only be used as a guide to promote optimal energy balance; each individual should be monitored closely to adjust caloric intake based on target goals and changes in body mass [5]. As in all

prediction equations, standard errors are inherent [58, 62, 92]. Most of the equations have been developed to maintain the current body weight for the participant's current activity level; these equations have not been developed during the weight loss/gain processes [93].

Even though numerous energy prediction equations cited here to promote energy balance are widely cited in the literature, the errors mentioned above limit the use of these equations. Further validation studies of these predictive equations are needed to minimize prediction error in certain age and ethnic groups. Also, older adults and US-residing ethnic minorities have been underrepresented both in the development of predictive equations and in validation studies [20, 59, 62].

Another methodological problem is related with measuring energy balance; in particular assessment of energy intake, where study participants report lower energy intake than physiologically required, noted as underreporting. Under reporting of energy intake is expressed as a ratio of reported energy intake to estimated BMR [92]. Underreporting is especially problematic in the obese, but also occurs in the relatively lean population also [94].

A clinical decision of whether an accurate metabolic rate by direct measurement is required to provide nutritional care and counseling should be made on a case-by-case basis. If the target goals are not being met, the client should be monitored closely utilizing any dietary intake records, energy expenditure logs, and physiological measurements of body mass and or weight change. Indirect calorimetry may be an important tool when, in the judgment of the clinician, the predictive methods fail in a clinically relevant way. In addition to these methodologies, the developed modeling methods to estimate weight loss are useful tracking tools to optimize the energy needs [95, 96]; scientists at the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) of National Institutes of Health (NIH) have developed a free-access online platform to predict weight loss/gain relying upon demographic, body composition and metabolic variables (energy expenditure and energy intake) (https://www.niddk.nih.gov/health-information/weight-management/body-weight-planner) [97]. The modelling techniques may be one of the most improved methodologies to quantify energy requirements.

Appendix 1 2011 Compendium of Physical Activities [12] (Reprinted with permission from Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR, Jr., Tudor-Locke C, et al. The Compendium of Physical Activities tracking guide: Healthy Lifestyles Research Center, College of Nursing & Health Innovation, Arizona State University; retrieved Aug from https://sites.google.com/site/compendiumofphysicalactivities. Project supported by University of Arizona and the National Cancer Institute [12])

Code	METs	Major heading	Specific activities
01003	14.0	Bicycling	Bicycling, mountain, uphill, vigorous
01004	16.0	Bicycling	Bicycling, mountain, competitive, racing
01008	*8.5*	Bicycling	Bicycling, BMX
01009	*8.5*	Bicycling	Bicycling, mountain, general
01010	4.0	Bicycling	Bicycling, <10 mph, leisure, to work or for pleasure (Taylor Code 115)
01011	6.8	Bicycling	Bicycling, to/from work, self-selected pace
01013	5.8	Bicycling	Bicycling, on dirt or farm road, moderate pace
01015	7.5	Bicycling	Bicycling, general
01018	3.5	Bicycling	Bicycling, leisure, 5.5 mph
01019	5.8	Bicycling	Bicycling, leisure, 9.4 mph
01020	6.8	Bicycling	Bicycling, 10–11.9 mph, leisure, slow, light effort
01030	8.0	Bicycling	Bicycling, 12–13.9 mph, leisure, moderate effort
01040	10.0	Bicycling	Bicycling, 14–15.9 mph, racing or leisure, fast, vigorous effort
01050	*12.0*	Bicycling	Bicycling, 16–19 mph, racing/not drafting or >19 mph drafting, very fast, racing general
01060	15.8	Bicycling	Bicycling, >20 mph, racing, not drafting
01065	8.5	Bicycling	Bicycling, 12 mph, seated, hands on brake hoods or bar drops, 80 rpm
01066	9.0	Bicycling	Bicycling, 12 mph, standing, hands on brake hoods, 60 rpm
01070	*5.0*	Bicycling	Unicycling
02001	2.3	Conditioning exercise	Activity promoting video game (e.g., Wii Fit), light effort (e.g., balance, yoga)

Code	METs	Major heading	Specific activities
02003	3.8	Conditioning exercise	Activity promoting video game (e.g., Wii Fit), moderate effort (e.g., aerobic, resistance)
02005	7.2	Conditioning exercise	Activity promoting video/arcade game (e.g., Exergaming, Dance Dance Revolution), vigorous effort
02008	5.0	Conditioning exercise	Army-type obstacle course exercise, boot camp training program
02010	*7.0*	Conditioning exercise	Bicycling, stationary, general
02011	3.5	Conditioning exercise	Bicycling, stationary, 30–50 W, very light to light effort
02012	6.8	Conditioning exercise	Bicycling, stationary, 90–100 W, moderate to vigorous effort
02013	8.8	Conditioning exercise	Bicycling, stationary, 101–160 W, vigorous effort
02014	11.0	Conditioning exercise	Bicycling, stationary, 161–200 W, vigorous effort
02015	14.0	Conditioning exercise	Bicycling, stationary, 201–270 W, very vigorous effort
02017	4.8	Conditioning exercise	Bicycling, stationary, 51–89 W, light-to-moderate effort
02019	8.5	Conditioning exercise	Bicycling, stationary, RPM/Spin bike class
02020	*8.0*	Conditioning exercise	Calisthenics (e.g., push-ups, sit-ups, pull-ups, jumping jacks), vigorous effort
02022	3.8	Conditioning exercise	Calisthenics (e.g., push-ups, sit-ups, pull-ups, lunges), moderate effort
02024	2.8	Conditioning exercise	Calisthenics (e.g., sit-ups, abdominal crunches), light effort
02030	3.5	Conditioning exercise	Calisthenics, light or moderate effort, general (e.g., back exercises), going up and down from floor (Taylor Code 150)
02035	4.3	Conditioning exercise	Circuit training, moderate effort
02040	8.0	Conditioning exercise	Circuit training, including kettle bells, some aerobic movement with minimal rest, general, vigorous intensity
02045	3.5	Conditioning exercise	Curves TM exercise routines in women
02048	5.0	Conditioning exercise	Elliptical trainer, moderate effort
02050	6.0	Conditioning exercise	Resistance training (weightlifting, free weight, nautilus or universal), power lifting or body building, vigorous effort (Taylor Code 210)
02052	5.0	Conditioning exercise	Resistance (weight) training, squats, slow or explosive effort
02054	3.5	Conditioning exercise	Resistance (weight) training, multiple exercises, 8–15 repetitions at varied resistance
02060	5.5	Conditioning exercise	Health club exercise, general (Taylor Code 160)
02061	5.0	Conditioning exercise	Health club exercise classes, general, gym/weight training combined in one visit
02062	7.8	Conditioning exercise	Health club exercise, conditioning classes
02064	3.8	Conditioning exercise	Home exercise, general
02065	*9.0*	Conditioning exercise	Stair-treadmill ergometer, general
02068	12.3	Conditioning exercise	Rope skipping, general
02070	*6.0*	Conditioning exercise	Rowing, stationary ergometer, general, vigorous effort
02071	4.8	Conditioning exercise	Rowing, stationary, general, moderate effort
02072	*7.0*	Conditioning exercise	Rowing, stationary, 100 W, moderate effort
02073	*8.5*	Conditioning exercise	Rowing, stationary, 150 W, vigorous effort
02074	*12.0*	Conditioning exercise	Rowing, stationary, 200 W, very vigorous effort
02080	6.8	Conditioning exercise	Ski machine, general
02085	11.0	Conditioning exercise	Slide board exercise, general
02090	*6.0*	Conditioning exercise	Slimnastics, jazzercise
02101	2.3	Conditioning exercise	Stretching, mild
02105	3.0	Conditioning exercise	Pilates, general
02110	6.8	Conditioning exercise	Teaching exercise class (e.g., aerobic, water)
02112	2.8	Conditioning exercise	Therapeutic exercise ball, Fit ball exercise
02115	2.8	Conditioning exercise	Upper body exercise, arm ergometer
02117	4.3	Conditioning exercise	Upper body exercise, Stationary bicycle—Air dyne (arms only) 40 rpm, moderate
02120	5.3	Conditioning exercise	Water aerobics, water calisthenics, water exercise
02135	*1.3*	Conditioning exercise	Whirlpool, sitting
02140	*2.3*	Conditioning exercise	Video exercise workouts, TV conditioning programs (e.g., yoga, stretching), light effort
02143	*4.0*	Conditioning exercise	Video exercise workouts, TV conditioning programs (e.g., cardio-resistance), moderate effort
02146	6.0	Conditioning exercise	Video exercise workouts, TV conditioning programs (e.g., cardio-resistance), vigorous effort
02150	2.5	Conditioning exercise	Yoga, Hatha
02160	*4.0*	Conditioning exercise	Yoga, Power
02170	2.0	Conditioning exercise	Yoga, Nadi sodhana
02180	3.3	Conditioning exercise	Yoga, Surya Namaskar
02200	5.3	Conditioning exercise	Native New Zealander physical activities (e.g., Haka Powhiri, Moteatea, Waiata Tira, Whakawatea), general, moderate effort

Code	METs	Major heading	Specific activities
02205	6.8	Conditioning exercise	Native New Zealander physical activities (e.g., Haka, Taiahab), general, vigorous effort
03010	5.0	Dancing	Ballet, modern, or jazz, general, rehearsal or class
03012	6.8	Dancing	Ballet, modern, or jazz, performance, vigorous effort
03014	4.8	Dancing	Tap
03015	7.3	Dancing	Aerobic, general
03016	7.5	Dancing	Aerobic, step, with 6–8 in. step
03017	9.5	Dancing	Aerobic, step, with 10–12 in. step
03018	5.5	Dancing	Aerobic, step, with 4-in. step
03019	8.5	Dancing	Bench step class, general
03020	*5.0*	Dancing	Aerobic, low impact
03021	7.3	Dancing	Aerobic, high impact
03022	10.0	Dancing	Aerobic dance wearing 10–15 lb. weights
03025	*4.5*	Dancing	Ethnic or cultural dancing (e.g., Greek, Middle Eastern, hula, salsa, merengue, bomba y plena, flamenco, belly, and swing)
03030	5.5	Dancing	Ballroom, fast (Taylor Code 125)
03031	7.8	Dancing	General dancing (e.g., disco, folk, Irish step dancing, line dancing, polka, contra, country)
03038	11.3	Dancing	Ballroom dancing, competitive, general
03040	*3.0*	Dancing	Ballroom, slow (e.g., waltz, foxtrot, slow dancing, samba, tango, nineteenth century dance, mambo, cha-cha)
03050	5.5	Dancing	Anishinaabe Jingle Dancing
03060	3.5	Dancing	Caribbean dance (Abakua, Beguine, Bellair, Bongo, Brukin's, Caribbean Quadrills, Dinki Mini, Gere, Gumbay, Ibo, Jonkonnu, Kumina, Oreisha, Jambu)
04001	3.5	Fishing and hunting	Fishing, general
04005	4.5	Fishing and hunting	Fishing, crab fishing
04007	4.0	Fishing and hunting	Fishing, catching fish with hands
04010	4.3	Fishing and hunting	Fishing related, digging worms, with shovel
04020	*4.0*	Fishing and hunting	Fishing from river bank and walking
04030	*2.0*	Fishing and hunting	Fishing from boat or canoe, sitting
04040	*3.5*	Fishing and hunting	Fishing from river bank, standing (Taylor Code 660)
04050	*6.0*	Fishing and hunting	Fishing in stream, in waders (Taylor Code 670)
04060	*2.0*	Fishing and hunting	Fishing, ice, sitting
04061	1.8	Fishing and hunting	Fishing, jog or line, standing, general
04062	*3.5*	Fishing and hunting	Fishing, dip net, setting net and retrieving fish, general
04063	3.8	Fishing and hunting	Fishing, set net, setting net and retrieving fish, general
04064	*3.0*	Fishing and hunting	Fishing, fishing wheel, setting net and retrieving fish, general
04065	2.3	Fishing and hunting	Fishing with a spear, standing
04070	*2.5*	Fishing and hunting	Hunting, bow and arrow, or crossbow
04080	6.0	Fishing and hunting	Hunting, deer, elk, large game (Taylor Code 170)
04081	11.3	Fishing and hunting	Hunting large game, dragging carcass
04083	*4.0*	Fishing and hunting	Hunting large marine animals
04085	*2.5*	Fishing and hunting	Hunting large game, from a hunting stand, limited walking
04086	*2.0*	Fishing and hunting	Hunting large game from a car, plane, or boat
04090	*2.5*	Fishing and hunting	Hunting, duck, wading
04095	3.0	Fishing and hunting	Hunting, flying fox, squirrel
04100	*5.0*	Fishing and hunting	Hunting, general
04110	6.0	Fishing and hunting	Hunting, pheasants or grouse (Taylor Code 680)
04115	3.3	Fishing and hunting	Hunting, birds
04120	5.0	Fishing and hunting	Hunting, rabbit, squirrel, prairie chick, raccoon, small game (Taylor Code 690)
04123	3.3	Fishing and hunting	Hunting, pigs, wild
04124	*2.0*	Fishing and hunting	Trapping game, general
04125	9.5	Fishing and hunting	Hunting, hiking with hunting gear
04130	*2.5*	Fishing and hunting	Pistol shooting or trap shooting, standing
04140	2.3	Fishing and hunting	Rifle exercises, shooting, lying down
04145	2.5	Fishing and hunting	Rifle exercises, shooting, kneeling or standing
05010	3.3	Home activities	Cleaning, sweeping carpet or floors, general
05011	2.3	Home activities	Cleaning, sweeping, slow, light effort
05012	3.8	Home activities	Cleaning, sweeping, slow, moderate effort
05020	*3.5*	Home activities	Cleaning, heavy or major (e.g., wash car, wash windows, clean garage), moderate effort
05021	3.5	Home activities	Cleaning, mopping, standing, moderate effort
05022	3.2	Home activities	Cleaning windows, washing windows, general
05023	2.5	Home activities	Mopping, standing, light effort
05024	4.5	Home activities	Polishing floors, standing, walking slowly, using electric polishing machine
05025	2.8	Home activities	Multiple household tasks all at once, light effort

Code	METs	Major heading	Specific activities
05026	*3.5*	Home activities	Multiple household tasks all at once, moderate effort
05027	4.3	Home activities	Multiple household tasks all at once, vigorous effort
05030	3.3	Home activities	Cleaning, house or cabin, general, moderate effort
05032	2.3	Home activities	Dusting or polishing furniture, general
05035	3.3	Home activities	Kitchen activity, general (e.g., cooking, washing dishes, cleaning up), moderate effort
05040	2.5	Home activities	Cleaning, general (straightening up, changing linen, carrying out trash), light effort
05041	1.8	Home activities	Wash dishes, standing or in general (not broken into stand/walk components)
05042	*2.5*	Home activities	Wash dishes, clearing dishes from table, walking, light effort
05043	3.3	Home activities	Vacuuming, general, moderate effort
05044	*3.0*	Home activities	Butchering animals, small
05045	*6.0*	Home activities	Butchering animal, large, vigorous effort
05046	*2.3*	Home activities	Cutting and smoking fish, drying fish or meat
05048	*4.0*	Home activities	Tanning hides, general
05049	3.5	Home activities	Cooking or food preparation, moderate effort
05050	2.0	Home activities	Cooking or food preparation—standing or sitting or in general (not broken into stand/walk components), manual appliances, light effort
05051	*2.5*	Home activities	Serving food, setting table, implied walking or standing
05052	*2.5*	Home activities	Cooking or food preparation, walking
05053	*2.5*	Home activities	Feeding household animals
05055	*2.5*	Home activities	Putting away groceries (e.g., carrying groceries, shopping without a grocery cart), carrying packages
05056	*7.5*	Home activities	Carrying groceries upstairs
05057	*3.0*	Home activities	Cooking Indian bread on an outside stove
05060	2.3	Home activities	Food shopping with or without a grocery cart, standing or walking
05065	*2.3*	Home activities	Non-food shopping, with or without a cart, standing or walking
05070	1.8	Home activities	Ironing
05080	1.3	Home activities	Knitting, sewing, light effort, wrapping presents, sitting
05082	2.8	Home activities	Sewing with a machine
05090	2.0	Home activities	Laundry, fold or hang clothes, put clothes in washer or dryer, packing suitcase, washing clothes by hand, implied standing, light effort
05092	4.0	Home activities	Laundry, hanging wash, washing clothes by hand, moderate effort
05095	*2.3*	Home activities	Laundry, putting away clothes, gathering clothes to pack, putting away laundry, implied walking
05100	3.3	Home activities	Making bed, changing linens
05110	5.0	Home activities	Maple syruping/sugar bushing (including carrying buckets, carrying wood)
05120	5.8	Home activities	Moving furniture, household items, carrying boxes
05121	5.0	Home activities	Moving, lifting light loads
05125	4.8	Home activities	Organizing room
05130	3.5	Home activities	Scrubbing floors, on hands and knees, scrubbing bathroom, bathtub, moderate effort
05131	2.0	Home activities	Scrubbing floors, on hands and knees, scrubbing bathroom, bathtub, light effort
05132	6.5	Home activities	Scrubbing floors, on hands and knees, scrubbing bathroom, bathtub, vigorous effort
05140	*4.0*	Home activities	Sweeping garage, side walk or outside of house
05146	*3.5*	Home activities	Standing, packing/unpacking boxes, occasional lifting of light weight household items, loading or unloading items in car, moderate effort
05147	*3.0*	Home activities	Implied walking, putting away household items, moderate effort
05148	*2.5*	Home activities	Watering plants
05149	*2.5*	Home activities	Building a fire inside
05150	*9.0*	Home activities	Moving household items upstairs, carrying boxes or furniture
05160	*2.0*	Home activities	Standing, light effort tasks (pump gas, change light bulb, etc.)
05165	3.5	Home activities	Walking, moderate effort tasks, non-cleaning (readying to leave, shut/lock doors, close windows, etc.)
05170	2.2	Home activities	Sitting, playing with child(ren), light effort, only active periods
05171	*2.8*	Home activities	Standing, playing with child(ren) light effort, only active periods
05175	3.5	Home activities	Walking/running, playing with child(ren), moderate effort, only active periods
05180	5.8	Home activities	Walking/running, playing with child(ren), vigorous effort, only active periods

Code	METs	Major heading	Specific activities
05181	*3.0*	Home activities	Walking and carrying small child, child weighing 15 lb. or more
05182	2.3	Home activities	Walking and carrying small child, child weighing less than 15 lb.
05183	2.0	Home activities	Standing, holding child
05184	2.5	Home activities	Child care, infant, general
05185	2.0	Home activities	Child care, sitting/kneeling (e.g., dressing, bathing, grooming, feeding, occasional lifting of child), light effort, general
05186	*3.0*	Home activities	Child care, standing (e.g., dressing, bathing, grooming, feeding, occasional lifting of child), moderate effort
05188	*1.5*	Home activities	Reclining with baby
05189	2.0	Home activities	Breastfeeding, sitting or reclining
05190	*2.5*	Home activities	Sit, playing with animals, light effort, only active periods
05191	*2.8*	Home activities	Stand, playing with animals, light effort, only active periods
05192	3.0	Home activities	Walk/run, playing with animals, general, light effort, only active periods
05193	*4.0*	Home activities	Walk/run, playing with animals, moderate effort, only active periods
05194	*5.0*	Home activities	Walk/run, playing with animals, vigorous effort, only active periods
05195	*3.5*	Home activities	Standing, bathing dog
05197	*2.3*	Home activities	Animal care, household animals, general
05200	*4.0*	Home activities	Elder care, disabled adult, bathing, dressing, moving into and out of bed, only active periods
05205	*2.3*	Home activities	Elder care, disabled adult, feeding, combing hair, light effort, only active periods
06010	*3.0*	Home repair	Airplane repair
06020	*4.0*	Home repair	Automobile body work
06030	3.3	Home repair	Automobile repair, light or moderate effort
06040	3.0	Home repair	Carpentry, general, workshop (Taylor Code 620)
06050	6.0	Home repair	Carpentry, outside house, installing rain gutters (Taylor Code 640), carpentry, outside house, building a fence
06052	3.8	Home repair	Carpentry, outside house, building a fence
06060	3.3	Home repair	Carpentry, finishing or refinishing cabinets or furniture
06070	6.0	Home repair	Carpentry, sawing hardwood
06072	4.0	Home repair	Carpentry, home remodeling tasks, moderate effort
06074	2.3	Home repair	Carpentry, home remodeling tasks, light effort
06080	*5.0*	Home repair	Caulking, chinking log cabin
06090	*4.5*	Home repair	Caulking, except log cabin
06100	*5.0*	Home repair	Cleaning gutters
06110	*5.0*	Home repair	Excavating garage
06120	*5.0*	Home repair	Hanging storm windows
06122	*5.0*	Home repair	Hanging sheetrock inside house
06124	3.0	Home repair	Hammering nails
06126	*2.5*	Home repair	Home repair, general, light effort
06127	*4.5*	Home repair	Home repair, general, moderate effort
06128	*6.0*	Home repair	Home repair, general, vigorous effort
06130	*4.5*	Home repair	Laying or removing carpet
06140	3.8	Home repair	Laying tile or linoleum, repairing appliances
06144	*3.0*	Home repair	Repairing appliances
06150	5.0	Home repair	Painting, outside home (Taylor Code 650)
06160	3.3	Home repair	Painting inside house, wallpapering, scraping paint
06165	4.5	Home repair	Painting (Taylor Code 630)
06167	*3.0*	Home repair	Plumbing, general
06170	*3.0*	Home repair	Put on and removal of tarp—sailboat
06180	*6.0*	Home repair	Roofing
06190	*4.5*	Home repair	Sanding floors with a power sander
06200	*4.5*	Home repair	Scraping and painting sailboat or powerboat
06205	2.0	Home repair	Sharpening tools
06210	*5.0*	Home repair	Spreading dirt with a shovel
06220	*4.5*	Home repair	Washing and waxing hull of sailboat or airplane
06225	2.0	Home repair	Washing and waxing car
06230	*4.5*	Home repair	Washing fence, painting fence, moderate effort
06240	3.3	Home repair	Wiring, tapping-splicing
07010	*1.0*	Inactivity quiet/light	Lying quietly and watching television
07011	1.3	Inactivity quiet/light	Lying quietly, doing nothing, lying in bed awake, listening to music (not talking or reading)
07020	1.3	Inactivity quiet/light	Sitting quietly and watching television
07021	1.3	Inactivity quiet/light	Sitting quietly, general
07022	1.5	Inactivity quiet/light	Sitting quietly, fidgeting, general, fidgeting hands
07023	1.8	Inactivity quiet/light	Sitting, fidgeting feet
07024	*1.3*	Inactivity quiet/light	Sitting, smoking
07025	1.5	Inactivity quiet/light	Sitting, listening to music (not talking or reading) or watching a movie in a theater
07026	1.3	Inactivity quiet/light	Sitting at a desk, resting head in hands
07030	0.95	Inactivity quiet/light	Sleeping

Code	METs	Major heading	Specific activities
07040	1.3	Inactivity quiet/light	Standing quietly, standing in a line
07041	1.8	Inactivity quiet/light	Standing, fidgeting
07050	*1.3*	Inactivity quiet/light	Reclining, writing
07060	*1.3*	Inactivity quiet/light	Reclining, talking or talking on phone
07070	1.3	Inactivity quiet/light	Reclining, reading
07075	*1.0*	Inactivity quiet/light	Meditating
08009	3.3	Lawn and garden	Carrying, loading or stacking wood, loading/unloading or carrying lumber, light-to-moderate effort
08010	5.5	Lawn and garden	Carrying, loading or stacking wood, loading/unloading or carrying lumber
08019	4.5	Lawn and garden	Chopping wood, splitting logs, moderate effort
08020	6.3	Lawn and garden	Chopping wood, splitting logs, vigorous effort
08025	3.5	Lawn and garden	Clearing light brush, thinning garden, moderate effort
08030	6.3	Lawn and garden	Clearing brush/land, undergrowth, or ground, hauling branches, wheelbarrow chores, vigorous effort
08040	5.0	Lawn and garden	Digging sandbox, shoveling sand
08045	3.5	Lawn and garden	Digging, spading, filling garden, composting, light-to-moderate effort
08050	5.0	Lawn and garden	Digging, spading, filling garden, compositing (Taylor Code 590)
08052	7.8	Lawn and garden	Digging, spading, filling garden, composting, vigorous effort
08055	2.8	Lawn and garden	Driving tractor
08057	8.3	Lawn and garden	Felling trees, large size
08058	5.3	Lawn and garden	Felling trees, small-medium size
08060	5.8	Lawn and garden	Gardening with heavy power tools, tilling a garden, chain saw
08065	2.3	Lawn and garden	Gardening, using containers, older adults >60 years
08070	4.0	Lawn and garden	Irrigation channels, opening and closing ports
08080	6.3	Lawn and garden	Laying crushed rock
08090	*5.0*	Lawn and garden	Laying sod
08095	5.5	Lawn and garden	Mowing lawn, general
08100	2.5	Lawn and garden	Mowing lawn, riding mower (Taylor Code 550)
08110	6.0	Lawn and garden	Mowing lawn, walk, hand mower (Taylor Code 570)
08120	5.0	Lawn and garden	Mowing lawn, walk, power mower, moderate or vigorous effort
08125	4.5	Lawn and garden	Mowing lawn, power mower, light or moderate effort (Taylor Code 590)
08130	2.5	Lawn and garden	Operating snow blower, walking
08135	2.0	Lawn and garden	Planting, potting, transplanting seedlings or plants, light effort
08140	4.3	Lawn and garden	Planting seedlings, shrub, stooping, moderate effort
08145	4.3	Lawn and garden	Planting crops or garden, stooping, moderate effort
08150	*4.5*	Lawn and garden	Planting trees
08160	3.8	Lawn and garden	Raking lawn or leaves, moderate effort
08165	4.0	Lawn and garden	Raking lawn (Taylor Code 600)
08170	*4.0*	Lawn and garden	Raking roof with snow rake
08180	*3.0*	Lawn and garden	Riding snow blower
08190	*4.0*	Lawn and garden	Sacking grass, leaves
08192	5.5	Lawn and garden	Shoveling dirt or mud
08195	5.3	Lawn and garden	Shoveling snow, by hand, moderate effort
08200	6.0	Lawn and garden	Shoveling snow, by hand (Taylor Code 610)
08202	7.5	Lawn and garden	Shoveling snow, by hand, vigorous effort
08210	4.0	Lawn and garden	Trimming shrubs or trees, manual cutter
08215	3.5	Lawn and garden	Trimming shrubs or trees, power cutter, using leaf blower, edge, moderate effort
08220	3.0	Lawn and garden	Walking, applying fertilizer or seeding a lawn, push applicator
08230	*1.5*	Lawn and garden	Watering lawn or garden, standing or walking
08239	3.5	Lawn and garden	Weeding, cultivating garden, light-to-moderate effort
08240	4.5	Lawn and garden	Weeding, cultivating garden (Taylor Code 580)
08241	5.0	Lawn and garden	Weeding, cultivating garden, using a hoe, moderate-to-vigorous effort
08245	3.8	Lawn and garden	Gardening, general, moderate effort
08246	3.5	Lawn and garden	Picking fruit off trees, picking fruits/vegetables, moderate effort
08248	4.5	Lawn and garden	Picking fruit off trees, gleaning fruits, picking fruits/vegetables, climbing ladder to pick fruit, vigorous effort
08250	3.3	Lawn and garden	Implied walking/standing—picking up yard, light, picking flowers or vegetables
08251	*3.0*	Lawn and garden	Walking, gathering gardening tools
08255	5.5	Lawn and garden	Wheelbarrow, pushing garden cart or wheelbarrow

Code	METs	Major heading	Specific activities
08260	3.0	Lawn and garden	Yard work, general, light effort
08261	4.0	Lawn and garden	Yard work, general, moderate effort
08262	6.0	Lawn and garden	Yard work, general, vigorous effort
09000	*1.5*	Miscellaneous	Board game playing, sitting
09005	*2.5*	Miscellaneous	Casino gambling, standing
09010	1.5	Miscellaneous	Card playing, sitting
09013	1.5	Miscellaneous	Chess game, sitting
09015	1.5	Miscellaneous	Copying documents, standing
09020	1.8	Miscellaneous	Drawing, writing, painting, standing
09025	1.0	Miscellaneous	Laughing, sitting
09030	1.3	Miscellaneous	Sitting, reading, book, newspaper, etc.
09040	1.3	Miscellaneous	Sitting, writing, deskwork, typing
09045	1.0	Miscellaneous	Sitting, playing traditional video game, computer game
09050	*1.8*	Miscellaneous	Standing, talking in person, on the phone, computer, or text messaging, light effort
09055	*1.5*	Miscellaneous	Sitting, talking in person, on the phone, computer, or text messaging, light effort
09060	1.3	Miscellaneous	Sitting, studying, general, including reading and/or writing, light effort
09065	1.8	Miscellaneous	Sitting, in class, general, including note-taking or class discussion
09070	*1.8*	Miscellaneous	Standing, reading
09071	2.5	Miscellaneous	Standing, miscellaneous
09075	1.8	Miscellaneous	Sitting, arts and crafts, carving wood, weaving, spinning wool, light effort
09080	*3.0*	Miscellaneous	Sitting, arts and crafts, carving wood, weaving, spinning wool, moderate effort
09085	2.5	Miscellaneous	Standing, arts and crafts, sand painting, carving, weaving, light effort
09090	*3.3*	Miscellaneous	Standing, arts and crafts, sand painting, carving, weaving, moderate effort
09095	*3.5*	Miscellaneous	Standing, arts and crafts, sand painting, carving, weaving, vigorous effort
09100	1.8	Miscellaneous	Retreat/family reunion activities involving sitting, relaxing, talking, eating
09101	3.0	Miscellaneous	Retreat/family reunion activities involving playing games with children
09105	*2.0*	Miscellaneous	Touring/traveling/vacation involving riding in a vehicle
09106	*3.5*	Miscellaneous	Touring/traveling/vacation involving walking
09110	*2.5*	Miscellaneous	Camping involving standing, walking, sitting, light-to-moderate effort
09115	*1.5*	Miscellaneous	Sitting at a sporting event, spectator
10010	1.8	Music playing	Accordion, sitting
10020	2.3	Music playing	Cello, sitting
10030	2.3	Music playing	Conducting orchestra, standing
10035	2.5	Music playing	Double bass, standing
10040	3.8	Music playing	Drums, sitting
10045	3.0	Music playing	Drumming (e.g., bongo, conga, bembe), moderate, sitting
10050	2.0	Music playing	Flute, sitting
10060	1.8	Music playing	Horn, standing
10070	2.3	Music playing	Piano, sitting
10074	2.0	Music playing	Playing musical instruments, general
10077	2.0	Music playing	Organ, sitting
10080	3.5	Music playing	Trombone, standing
10090	1.8	Music playing	Trumpet, standing
10100	2.5	Music playing	Violin, sitting
10110	1.8	Music playing	Woodwind, sitting
10120	*2.0*	Music playing	Guitar, classical, folk, sitting
10125	*3.0*	Music playing	Guitar, rock and roll band, standing
10130	*4.0*	Music playing	Marching band, baton twirling, walking, moderate pace, general
10131	5.5	Music playing	Marching band, playing an instrument, walking, brisk pace, general
10135	*3.5*	Music playing	Marching band, drum major, walking
11003	2.3	Occupation	Active workstation, treadmill desk, walking
11006	3.0	Occupation	Airline flight attendant
11010	*4.0*	Occupation	Bakery, general, moderate effort
11015	2.0	Occupation	Bakery, light effort
11020	2.3	Occupation	Bookbinding
11030	*6.0*	Occupation	Building road, driving heavy machinery
11035	*2.0*	Occupation	Building road, directing traffic, standing
11038	2.5	Occupation	Carpentry, general, light effort
11040	4.3	Occupation	Carpentry, general, moderate effort
11042	7.0	Occupation	Carpentry, general, heavy or vigorous effort
11050	*8.0*	Occupation	Carrying heavy loads (e.g., bricks, tools)
11060	*8.0*	Occupation	Carrying moderate loads up stairs, moving boxes 25–49 lb.
11070	4.0	Occupation	Chambermaid, hotel housekeeper, making bed, cleaning bathroom, pushing cart
11080	5.3	Occupation	Coalmining, drilling coal, rock
11090	5.0	Occupation	Coalmining, erecting supports
11100	5.5	Occupation	Coalmining, general
11110	6.3	Occupation	Coalmining, shoveling coal
11115	2.5	Occupation	Cook, chef
11120	4.0	Occupation	Construction, outside, remodeling, new structures (e.g., roof repair, miscellaneous)
11125	2.3	Occupation	Custodial work, light effort (e.g., cleaning sink and toilet, dusting, vacuuming, light cleaning)
11126	3.8	Occupation	Custodial work, moderate effort (e.g., electric buffer, feathering arena floors, mopping, taking out trash, vacuuming)

Code	METs	Major heading	Specific activities
11128	2.0	Occupation	Driving delivery truck, taxi, shuttle bus, school bus
11130	3.3	Occupation	Electrical work (e.g., hookup wire, tapping-splicing)
11135	1.8	Occupation	Engineer (e.g., mechanical or electrical)
11145	7.8	Occupation	Farming, vigorous effort (e.g., baling hay, cleaning barn)
11146	4.8	Occupation	Farming, moderate effort (e.g., feeding animals, chasing cattle by walking and/or horseback, spreading manure, harvesting crops)
11147	2.0	Occupation	Farming, light effort (e.g., cleaning animal sheds, preparing animal feed)
11170	2.8	Occupation	Farming, driving tasks (e.g., driving tractor or harvester)
11180	3.5	Occupation	Farming, feeding small animals
11190	4.3	Occupation	Farming, feeding cattle, horses
11191	4.3	Occupation	Farming, hauling water for animals, general hauling water, farming, general hauling water
11192	4.5	Occupation	Farming, taking care of animals (e.g., grooming, brushing, shearing sheep, assisting with birthing, medical care, branding), general
11195	3.8	Occupation	Farming, rice, planting, grain milling activities
11210	3.5	Occupation	Farming, milking by hand, cleaning pails, moderate effort
11220	1.3	Occupation	Farming, milking by machine, light effort
11240	8.0	Occupation	Fire fighter, general
11244	6.8	Occupation	Fire fighter, rescue victim, automobile accident, using pike pole
11245	8.0	Occupation	Fire fighter, raising and climbing ladder with full gear, simulated fire suppression
11246	9.0	Occupation	Fire fighter, hauling hoses on ground, carrying/hoisting equipment, breaking down walls etc., wearing full gear
11247	*3.5*	Occupation	Fishing, commercial, light effort
11248	*5.0*	Occupation	Fishing, commercial, moderate effort
11249	*7.0*	Occupation	Fishing, commercial, vigorous effort
11250	17.5	Occupation	Forestry, ax chopping, very fast, 1.25 kg ax, 51 blows/min, extremely vigorous effort
11260	5.0	Occupation	Forestry, ax chopping, slow, 1.25 kg ax, 19 blows/min, moderate effort
11262	8.0	Occupation	Forestry, ax chopping, fast, 1.25 kg ax, 35 blows/min, vigorous effort
11264	4.5	Occupation	Forestry, moderate effort (e.g., sawing wood with power saw, weeding, hoeing)
11266	8.0	Occupation	Forestry, vigorous effort (e.g., barking, felling, or trimming trees, carrying or stacking logs, planting seeds, sawing lumber by hand)
11370	4.5	Occupation	Furriery
11375	4.0	Occupation	Garbage collector, walking, dumping bins into truck
11378	1.8	Occupation	Hairstylist (e.g., plaiting hair, manicure, make-up artist)
11380	7.3	Occupation	Horse grooming, including feeding, cleaning stalls, bathing, brushing, clipping, lunging, and exercising horses
11381	*4.3*	Occupation	Horse, feeding, watering, cleaning stalls, implied walking and lifting loads
11390	7.3	Occupation	Horse racing, galloping
11400	5.8	Occupation	Horse racing, trotting
11410	3.8	Occupation	Horse racing, walking
11413	3.0	Occupation	Kitchen maid
11415	4.0	Occupation	Lawn keeper, yard work, general
11418	3.3	Occupation	Laundry worker
11420	3.0	Occupation	Locksmith
11430	3.0	Occupation	Machine tooling (e.g., machining, working sheet metal, machine fitter, operating lathe, welding) light-to-moderate effort
11450	5.0	Occupation	Machine tooling, operating punch press, moderate effort
11472	1.8	Occupation	Manager, property
11475	*2.8*	Occupation	Manual or unskilled labor, general, light effort
11476	*4.5*	Occupation	Manual or unskilled labor, general, moderate effort
11477	*6.5*	Occupation	Manual or unskilled labor, general, vigorous effort
11480	4.3	Occupation	Masonry, concrete, moderate effort
11482	2.5	Occupation	Masonry, concrete, light effort
11485	*4.0*	Occupation	Massage therapist, standing
11490	*7.5*	Occupation	Moving, carrying or pushing heavy objects, 75 lb. or more, only active time (e.g., desks, moving van work)
11495	*12.0*	Occupation	Skin diving or SCUBA diving as a frogman, Navy Seal
11500	*2.5*	Occupation	Operating heavy duty equipment, automated, not driving
11510	4.5	Occupation	Orange grove work, picking fruit
11514	3.3	Occupation	Painting, house, furniture, moderate effort
11516	*3.0*	Occupation	Plumbing activities
11520	2.0	Occupation	Printing, paper industry worker, standing
11525	*2.5*	Occupation	Police, directing traffic, standing
11526	2.5	Occupation	Police, driving a squad car, sitting
11527	1.3	Occupation	Police, riding in a squad car, sitting
11528	*4.0*	Occupation	Police, making an arrest, standing
11529	2.3	Occupation	Postal carrier, walking to deliver mail
11530	2.0	Occupation	Shoe repair, general
11540	7.8	Occupation	Shoveling, digging ditches
11550	8.8	Occupation	Shoveling, more than 16 lb./min, deep digging, vigorous effort
11560	5.0	Occupation	Shoveling, less than 10 lb./min, moderate effort

Code	METs	Major heading	Specific activities
11570	6.5	Occupation	Shoveling, 10–15 lb./min, vigorous effort
11580	1.5	Occupation	Sitting tasks, light effort (e.g., office work, chemistry lab work, computer work, light assembly repair, watch repair, reading, deskwork)
11585	1.5	Occupation	Sitting meetings, light effort, general, and/or with talking involved (e.g., eating at a business meeting)
11590	*2.5*	Occupation	Sitting tasks, moderate effort (e.g., pushing heavy levers, riding mower/forklift, crane operation)
11593	*2.8*	Occupation	Sitting, teaching stretching or yoga, or light effort exercise class
11600	3.0	Occupation	Standing tasks, light effort (e.g., bartending, store clerk, assembling, filing, duplicating, librarian, putting up a Christmas tree, standing and talking at work, changing clothes when teaching physical education, standing)
11610	*3.0*	Occupation	Standing, light/moderate effort (e.g., assemble/repair heavy parts, welding, stocking parts, auto repair, standing, packing boxes, nursing patient care)
11615	4.5	Occupation	Standing, moderate effort, lifting items continuously, 10–20 lb., with limited walking or resting
11620	3.5	Occupation	Standing, moderate effort, intermittent lifting 50 lb., hitch/twisting ropes
11630	4.5	Occupation	Standing, moderate/heavy tasks (e.g., lifting more than 50 lb., masonry, painting, paper hanging)
11708	5.3	Occupation	Steel mill, moderate effort (e.g., fettling, forging, tipping molds)
11710	8.3	Occupation	Steel mill, vigorous effort (e.g., hand rolling, merchant mill rolling, removing slag, tending furnace)
11720	2.3	Occupation	Tailoring, cutting fabric
11730	2.5	Occupation	Tailoring, general
11740	1.8	Occupation	Tailoring, hand sewing
11750	2.5	Occupation	Tailoring, machine sewing
11760	3.5	Occupation	Tailoring, pressing
11763	2.0	Occupation	Tailoring, weaving, light effort (e.g., finishing operations, washing, dyeing, inspecting cloth, counting yards, paperwork)
11765	4.0	Occupation	Tailoring, weaving, moderate effort (e.g., spinning and weaving operations, delivering boxes of yam to spinners, loading of warp bean, pin winding, cone winding, warping, cloth cutting)
11766	*6.5*	Occupation	Truck driving, loading and unloading truck, tying down load, standing, walking and carrying heavy loads
11767	2.0	Occupation	Truck, driving delivery truck, taxi, shuttle bus, school bus
11770	1.3	Occupation	Typing, electric, manual or computer
11780	6.3	Occupation	Using heavy power tools such as pneumatic tools (e.g., jackhammers, drills)
11790	8.0	Occupation	Using heavy tools (not power) such as shovel, pick, tunnel bar, spade
11791	2.0	Occupation	Walking on job, less than 2.0 mph, very slow speed, in office or lab area
11792	3.5	Occupation	Walking on job, 3.0 mph, in office, moderate speed, not carrying anything
11793	4.3	Occupation	Walking on job, 3.5 mph, in office, brisk speed, not carrying anything
11795	3.5	Occupation	Walking on job, 2.5 mph, slow speed and carrying light objects less than 25 lb
11796	*3.0*	Occupation	Walking, gathering things at work, ready to leave
11797	3.8	Occupation	Walking, 2.5 mph, slows peed, carrying heavy objects more than 25 lb.
11800	4.5	Occupation	Walking, 3.0 mph, moderately and carrying light objects less than 25 lb.
11805	3.5	Occupation	Walking, pushing a wheelchair
11810	*4.8*	Occupation	Walking, 3.5 mph, briskly and carrying objects less than 25 lb.
11820	*5.0*	Occupation	Walking or walk downstairs or standing, carrying objects about 25–49 lb.
11830	*6.5*	Occupation	Walking or walk downstairs or standing, carrying objects about 50–74 lb.
11840	*7.5*	Occupation	Walking or walk downstairs or standing, carrying objects about 75–99 lb.
11850	*8.5*	Occupation	Walking or walk downstairs or standing, carrying objects about 100 lb. or more
11870	*3.0*	Occupation	Working in scene shop, theater actor, backstage employee
12010	6.0	Running	Jog/walk combination (jogging component of less than 10 min) (Taylor Code 180)
12020	*7.0*	Running	Jogging, general
12025	*8.0*	Running	Jogging, in place
12027	*4.5*	Running	Jogging, on a mini-tramp
12029	6.0	Running	Running, 4 mph (13 min/mile)
12030	8.3	Running	Running, 5 mph (12 min/mile)
12040	*9.0*	Running	Running, 5.2 mph (11.5 min/mile)
12050	9.8	Running	Running, 6 mph (10 min/mile)
12060	10.5	Running	Running, 6.7 mph (9 min/mile)
12070	11.0	Running	Running, 7 mph (8.5 min/mile)
12080	11.5	Running	Running, 7.5 mph (8 min/mile)
12090	11.8	Running	Running, 8 mph (7.5 min/mile)
12100	*12.3*	Running	Running, 8.6 mph (7 min/mile)
12110	12.8	Running	Running, 9 mph (6.5 min/mile)
12120	14.5	Running	Running, 10 mph (6 min/mile)
12130	16.0	Running	Running, 11 mph (5.5 min/mile)

Code	METs	Major heading	Specific activities
12132	19.0	Running	Running, 12 mph (5 min/mile)
12134	19.8	Running	Running, 13 mph (4.6 min/mile)
12135	23.0	Running	Running, 14 mph (4.3 min/mile)
12140	9.0	Running	Running, cross country
12150	8.0	Running	Running (Taylor code 200)
12170	*15.0*	Running	Running, stairs, up
12180	*10.0*	Running	Running, on a track, team practice
12190	*8.0*	Running	Running, training, pushing a wheelchair or baby carrier
12200	13.3	Running	Running, marathon
13000	2.3	Self care	Getting ready for bed, general, standing
13009	1.8	Self care	Sitting on toilet, eliminating while standing or squatting
13010	*1.5*	Self care	Bathing, sitting
13020	2.5	Self care	Dressing, undressing, standing or sitting
13030	1.5	Self care	Eating, sitting
13035	*2.0*	Self care	Talking and eating or eating only, standing
13036	*1.5*	Self care	Taking medication, sitting or standing
13040	2.0	Self care	Grooming, washing hands, shaving, brushing teeth, putting on make-up, sitting or standing
13045	*2.5*	Self care	Hairstyling, standing
13046	*1.3*	Self-care	Having hair or nails done by someone else, sitting
13050	*2.0*	Self-care	Showering, toweling off, standing
14010	2.8	Sexual activity	Active, vigorous effort
14020	1.8	Sexual activity	General, moderate effort
14030	1.3	Sexual activity	Passive, light effort, kissing, hugging
15000	*5.5*	Sports	Alaska Native Games, Eskimo Olympics, general
15010	4.3	Sports	Archery, non-hunting
15020	7.0	Sports	Badminton, competitive (Taylor Code 450)
15030	5.5	Sports	Badminton, social singles and doubles, general
15040	8.0	Sports	Basketball, game (Taylor Code 490)
15050	6.0	Sports	Basketball, non-game, general (Taylor Code 480)
15055	6.5	Sports	Basketball, general
15060	7.0	Sports	Basketball, officiating (Taylor Code 500)
15070	*4.5*	Sports	Basketball, shooting baskets
15072	9.3	Sports	Basketball, drills, practice
15075	7.8	Sports	Basketball, wheelchair
15080	2.5	Sports	Billiards
15090	3.0	Sports	Bowling (Taylor Code 390)
15092	3.8	Sports	Bowling, indoor, bowling alley
15100	12.8	Sports	Boxing, in ring, general
15110	5.5	Sports	Boxing, punching bag
15120	7.8	Sports	Boxing, sparring
15130	*7.0*	Sports	Broomball
15135	5.8	Sports	Children's games, adults playing (e.g., hopscotch, 4-square, dodge ball, playground apparatus, t-ball, tetherball, marbles, arcade games), moderate effort
15138	*6.0*	Sports	Cheerleading, gymnastic moves, competitive
15140	*4.0*	Sports	Coaching, football, soccer, basketball, baseball, swimming, etc.
15142	8.0	Sports	Coaching, actively playing sport with players
15150	4.8	Sports	Cricket, batting, bowling, fielding
15160	3.3	Sports	Croquet
15170	*4.0*	Sports	Curling
15180	*2.5*	Sports	Darts, wall or lawn
15190	*6.0*	Sports	Drag racing, pushing or driving a car
15192	8.5	Sports	Auto racing, open wheel
15200	*6.0*	Sports	Fencing
15210	8.0	Sports	Football, competitive
15230	8.0	Sports	Football, touch, flag, general (Taylor Code 510)
15232	*4.0*	Sports	Football, touch, flag, light effort
15235	*2.5*	Sports	Football or baseball, playing catch
15240	*3.0*	Sports	Frisbee playing, general
15250	*8.0*	Sports	Frisbee, ultimate
15255	4.8	Sports	Golf, general
15265	4.3	Sports	Golf, walking, carrying clubs
15270	*3.0*	Sports	Golf, miniature, driving range
15285	5.3	Sports	Golf, walking, pulling clubs
15290	3.5	Sports	Golf, using power cart (Taylor Code 070)
15300	3.8	Sports	Gymnastics, general
15310	*4.0*	Sports	Hacky sack
15320	12.0	Sports	Handball, general (Taylor Code 520)
15330	*8.0*	Sports	Handball, team
15335	4.0	Sports	High ropes course, multiple elements
15340	*3.5*	Sports	Hang gliding
15350	7.8	Sports	Hockey, field
15360	*8.0*	Sports	Hockey, ice, general
15362	*10.0*	Sports	Hockey, ice, competitive
15370	5.5	Sports	Horseback riding, general
15375	*4.3*	Sports	Horse chores, feeding, watering, cleaning stalls, implied walking and lifting loads
15380	4.5	Sports	Saddling, cleaning, grooming, harnessing and unharnessing horse
15390	5.8	Sports	Horseback riding, trotting
15395	7.3	Sports	Horseback riding, canter or gallop
15400	3.8	Sports	Horseback riding, walking
15402	9.0	Sports	Horseback riding, jumping
15408	1.8	Sports	Horse cart, driving, standing or sitting
15410	*3.0*	Sports	Horseshoe pitching, quoits
15420	*12.0*	Sports	Jai alai
15425	5.3	Sports	Martial arts, different types, slower pace, novice performers, practice
15430	10.3	Sports	Martial arts, different types, moderate pace (e.g., judo, jujitsu, karate, kickboxing, taekwondo, Tae Bo, Muay Thai boxing)
15440	*4.0*	Sports	Juggling
15450	*7.0*	Sports	Kickball
15460	*8.0*	Sports	Lacrosse

Code	METs	Major heading	Specific activities
15465	3.3	Sports	Lawn bowling, bocce ball, outdoor
15470	*4.0*	Sports	Moto-cross, off-road motor sports, all-terrain vehicle, general
15480	*9.0*	Sports	Orienteering
15490	*10.0*	Sports	Paddleball, competitive
15500	6.0	Sports	Paddleball, casual, general (Taylor Code 460)
15510	*8.0*	Sports	Polo, on horseback
15520	*10.0*	Sports	Racquetball, competitive
15530	7.0	Sports	Racquetball, general (Taylor Code 470)
15533	8.0	Sports	Rock or mountain climbing (Taylor Code 470)(*Formerly code = 17120*)
15535	7.5	Sports	Rock climbing, ascending rock, high difficulty
15537	5.8	Sports	Rock climbing, ascending or traversing rock, low-to-moderate difficulty
15540	*5.0*	Sports	Rock climbing, rappelling
15542	*4.0*	Sports	Rodeo sports, general, light effort
15544	*5.5*	Sports	Rodeo sports, general, moderate effort
15546	*7.0*	Sports	Rodeo sports, general, vigorous effort
15550	12.3	Sports	Rope jumping, fast pace, 120–160 skips/min
15551	11.8	Sports	Rope jumping, moderate pace, 100–120 skips/min, general, 2 foot skip, plain bounce
15552	8.8	Sports	Rope jumping, slow pace, <100 skips/min, 2 foot skip, rhythm bounce
15560	8.3	Sports	Rugby, union, team, competitive
15562	6.3	Sports	Rugby, touch, non-competitive
15570	*3.0*	Sports	Shuffleboard
15580	*5.0*	Sports	Skateboarding, general, moderate effort
15582	*6.0*	Sports	Skateboarding, competitive, vigorous effort
15590	7.0	Sports	Skating, roller (Taylor Code 360)
15591	7.5	Sports	Rollerblading, in-line skating, 14.4 km/h (9.0 mph), recreational pace
15592	9.8	Sports	Rollerblading, in-line skating, 17.7 km/h (11.0 mph), moderate pace, exercise training
15593	12.3	Sports	Rollerblading, in-line skating, 21.0–21.7 km/h (13.0–13.6 mph), fast pace, exercise training
15594	14.0	Sports	Rollerblading, in-line skating, 24.0 km/h (15.0 mph), maximal effort
15600	*3.5*	Sports	Skydiving, base jumping, bungee jumping
15605	10.0	Sports	Soccer, competitive
15610	7.0	Sports	Soccer, casual, general (Taylor Code 540)
15620	5.0	Sports	Softball or baseball, fast or slow pitch, general (Taylor Code 440)
15625	4.0	Sports	Softball, practice
15630	*4.0*	Sports	Softball, officiating
15640	*6.0*	Sports	Softball, pitching
15645	3.3	Sports	Sports spectator, very excited, emotional, physically moving
15650	12.0	Sports	Squash (Taylor Code 530)
15652	7.3	Sports	Squash, general
15660	4.0	Sports	Table tennis, ping pong (Taylor Code 410)
15670	3.0	Sports	Tai chi, qigong, general
15672	1.5	Sports	Tai chi, qigong, sitting, light effort
15675	7.3	Sports	Tennis, general
15680	6.0	Sports	Tennis, doubles (Taylor Code 430)
15685	4.5	Sports	Tennis, doubles
15690	8.0	Sports	Tennis, singles (Taylor Code 420)
15695	*5.0*	Sports	Tennis, hitting balls, non-game play, moderate effort
15700	*3.5*	Sports	Trampoline, recreational
15702	*4.5*	Sports	Trampoline, competitive
15710	4.0	Sports	Volleyball (Taylor Code 400)
15711	6.0	Sports	Volleyball, competitive, in gymnasium
15720	3.0	Sports	Volleyball, non-competitive, 6–9 member team, general
15725	*8.0*	Sports	Volleyball, beach, in sand
15730	*6.0*	Sports	Wrestling (one match = 5 min)
15731	*7.0*	Sports	Wallyball, general
15732	*4.0*	Sports	Track and field (e.g., shot, discus, hammer throw)
15733	*6.0*	Sports	Track and field (e.g., high jump, long jump, triple jump, javelin, pole vault)
15734	*10.0*	Sports	Track and field (e.g., steeplechase, hurdles)
16010	2.5	Transportation	Automobile or light truck (nota semi) driving
16015	1.3	Transportation	Riding in a car or truck
16016	1.3	Transportation	Riding in a bus or train
16020	1.8	Transportation	Flying airplane or helicopter
16030	3.5	Transportation	Motor scooter, motorcycle
16035	6.3	Transportation	Pulling rickshaw
16040	*6.0*	Transportation	Pushing plane in and out of hangar
16050	2.5	Transportation	Truck, semi, tractor, >1 ton, or bus, driving
16060	3.5	Transportation	Walking for transportation, 2.8–3.2 mph, level, moderate pace, firm surface
17010	7.0	Walking	Backpacking (Taylor Code 050)
17012	7.8	Walking	Backpacking, hiking or organized walking with a daypack
17020	5.0	Walking	Carrying 15 lb. load (e.g., suitcase), level ground or downstairs
17021	2.3	Walking	Carrying 15 lb. child, slow walking
17025	*8.3*	Walking	Carrying load upstairs, general
17026	*5.0*	Walking	Carrying 1–15 lb. load, upstairs
17027	*6.0*	Walking	Carrying 16–24 lb. load, upstairs
17028	*8.0*	Walking	Carrying 25–49 lb. load, upstairs
17029	*10.0*	Walking	Carrying 50–74 lb. load, upstairs
17030	*12.0*	Walking	Carrying >74 lb. load, upstairs
17031	*3.5*	Walking	Loading/unloading a car, implied walking
17033	6.3	Walking	Climbing hills, no load

Code	METs	Major heading	Specific activities
17035	6.5	Walking	Climbing hills with 0–9 lb. load
17040	7.3	Walking	Climbing hills with 10–20 lb. load
17050	8.3	Walking	Climbing hills with 21–42 lb. load
17060	*9.0*	Walking	Climbing hills with 42+ lb. load
17070	3.5	Walking	Descending stairs
17080	6.0	Walking	Hiking, cross country (Taylor Code 040)
17082	5.3	Walking	Hiking or walking at a normal pace through fields and hillsides
17085	*2.5*	Walking	Bird watching, slow walk
17088	4.5	Walking	Marching, moderate speed, military, no pack
17090	8.0	Walking	Marching rapidly, military, no pack
17100	4.0	Walking	Pushing or pulling stroller with child or walking with children, 2.5–3.1 mph
17105	3.8	Walking	Pushing a wheelchair, non-occupational
17110	*6.5*	Walking	Race walking
17130	8.0	Walking	Stair climbing, using or climbing up ladder (Taylor Code 030)
17133	4.0	Walking	Stair climbing, slow pace
17134	8.8	Walking	Stair climbing, fast pace
17140	5.0	Walking	Using crutches
17150	*2.0*	Walking	Walking, household
17151	2.0	Walking	Walking, less than 2.0 mph, level, strolling, very slow
17152	2.8	Walking	Walking, 2.0 mph, level, slow pace, firm surface
17160	3.5	Walking	Walking for pleasure (Taylor Code 010)
17161	*2.5*	Walking	Walking from house to car or bus, from car or bus to go places, from car or bus to and from the worksite
17162	*2.5*	Walking	Walking to neighbor's house or family's house for social reasons
17165	*3.0*	Walking	Walking the dog
17170	3.0	Walking	Walking, 2.5 mph, level, firm surface
17180	3.3	Walking	Walking, 2.5 mph, downhill
17190	3.5	Walking	Walking, 2.8–3.2 mph, level, moderate pace, firm surface
17200	4.3	Walking	Walking, 3.5 mph, level, brisk, firm surface, walking for exercise
17210	5.3	Walking	Walking, 2.9–3.5 mph, uphill, 1–5% grade
17211	8.0	Walking	Walking, 2.9–3.5 mph, uphill, 6–15% grade
17220	5.0	Walking	Walking, 4.0 mph, level, firm surface, very brisk pace
17230	7.0	Walking	Walking, 4.5 mph, level, firm surface, very, very brisk
17231	8.3	Walking	Walking, 5.0 mph, level, firm surface
17235	9.8	Walking	Walking, 5.0 mph, uphill, 3% grade
17250	3.5	Walking	Walking, for pleasure, work break
17260	4.8	Walking	Walking, grass track
17262	4.5	Walking	Walking, normal pace, plowed field or sand
17270	4.0	Walking	Walking, to work or class (Taylor Code 015)
17280	*2.5*	Walking	Walking, to and from an outhouse
17302	4.8	Walking	Walking, for exercise, 3.5–4 mph, with ski poles, Nordic walking, level, moderate pace
17305	9.5	Walking	Walking, for exercise, 5.0 mph, with ski poles, Nordic walking, level, fast pace
17310	*6.8*	Walking	Walking, for exercise, with ski poles, Nordic walking, uphill
17320	6.0	Walking	Walking, backwards, 3.5 mph, level
17325	8.0	Walking	Walking, backwards, 3.5 mph, uphill, 5% grade
18010	*2.5*	Water activities	Boating, power, driving
18012	*1.3*	Water activities	Boating, power, passenger, light
18020	4.0	Water activities	Canoeing, on camping trip (Taylor Code 270)
18025	3.3	Water activities	Canoeing, harvesting wild rice, knocking rice off the stalks
18030	*7.0*	Water activities	Canoeing, portaging
18040	2.8	Water activities	Canoeing, rowing, 2.0–3.9 mph, light effort
18050	5.8	Water activities	Canoeing, rowing, 4.0–5.9 mph, moderate effort
18060	12.5	Water activities	Canoeing, rowing, kayaking, competition, >6 mph, vigorous effort
18070	3.5	Water activities	Canoeing, rowing, for pleasure, general (Taylor Code 250)
18080	12.0	Water activities	Canoeing, rowing, in competition, or crew or sculling (Taylor Code 260)
18090	*3.0*	Water activities	Diving, springboard or platform
18100	5.0	Water activities	Kayaking, moderate effort
18110	4.0	Water activities	Paddleboat
18120	3.0	Water activities	Sailing, boat and board sailing, windsurfing, ice sailing, general (Taylor Code 235)
18130	4.5	Water activities	Sailing, in competition
18140	3.3	Water activities	Sailing, Sunfish/Laser/Hobby Cat, Keelboats, ocean sailing, yachting, leisure
18150	6.0	Water activities	Skiing, water or wakeboarding (Taylor Code 220)
18160	7.0	Water activities	Jet skiing, driving, in water
18180	15.8	Water activities	Skin diving, fast
18190	11.8	Water activities	Skin diving, moderate
18200	7.0	Water activities	Skin diving, scuba diving, general (Taylor Code 310)
18210	5.0	Water activities	Snorkeling (Taylor Code 310)
18220	*3.0*	Water activities	Surfing, body or board, general

Code	METs	Major heading	Specific activities
18222	*5.0*	Water activities	Surfing, body or board, competitive
18225	*6.0*	Water activities	Paddle boarding, standing
18230	9.8	Water activities	Swimming laps, freestyle, fast, vigorous effort
18240	5.8	Water activities	Swimming laps, freestyle, front crawl, slow, light or moderate effort
18250	9.5	Water activities	Swimming, backstroke, general, training or competition
18255	4.8	Water activities	Swimming, backstroke, recreational
18260	10.3	Water activities	Swimming, breaststroke, general, training or competition
18265	5.3	Water activities	Swimming, breaststroke, recreational
18270	13.8	Water activities	Swimming, butterfly, general
18280	10.0	Water activities	Swimming, crawl, fast speed, ~75 yards/min, vigorous effort
18290	8.3	Water activities	Swimming, crawl, medium speed, ~50 yards/min, vigorous effort
18300	6.0	Water activities	Swimming, lake, ocean, river (Taylor Codes 280, 295)
18310	*6.0*	Water activities	Swimming, leisurely, not lap swimming, general
18320	7.0	Water activities	Swimming, sidestroke, general
18330	*8.0*	Water activities	Swimming, synchronized
18340	9.8	Water activities	Swimming, treading water, fast, vigorous effort
18350	3.5	Water activities	Swimming, treading water, moderate effort, general
18352	*2.3*	Water activities	Tubing, floating on a river, general
18355	5.5	Water activities	Water aerobics, water calisthenics
18360	*10.0*	Water activities	Water polo
18365	*3.0*	Water activities	Water volleyball
18366	9.8	Water activities	Water jogging
18367	2.5	Water activities	Water walking, light effort, slow pace
18368	4.5	Water activities	Water walking, moderate effort, moderate pace
18369	6.8	Water activities	Water walking, vigorous effort, brisk pace
18370	*5.0*	Water activities	Whitewater rafting, kayaking, or canoeing
18380	5.0	Water activities	Windsurfing, not pumping for speed
18385	11.0	Water activities	Windsurfing or kite surfing, crossing trial
18390	13.5	Water activities	Windsurfing, competition, pumping for speed
19005	*7.5*	Winter activities	Dog sledding, mushing
19006	*2.5*	Winter activities	Dog sledding, passenger
19010	*6.0*	Winter activities	Moving ice house, set up/drill holes
19011	*2.0*	Winter activities	Ice fishing, sitting
19018	14.0	Winter activities	Skating, ice dancing
19020	*5.5*	Winter activities	Skating, ice, 9 mph or less
19030	7.0	Winter activities	Skating, ice, general (Taylor Code 360)
19040	*9.0*	Winter activities	Skating, ice, rapidly, more than 9 mph, not competitive
19050	13.3	Winter activities	Skating, speed, competitive
19060	*7.0*	Winter activities	Ski jumping, climb up carrying skis
19075	*7.0*	Winter activities	Skiing, general
19080	6.8	Winter activities	Skiing, cross country, 2.5 mph, slow or light effort, ski walking
19090	9.0	Winter activities	Skiing, cross country, 4.0–4.9 mph, moderate speed and effort, general
19100	12.5	Winter activities	Skiing, cross country, 5.0–7.9 mph, brisk speed, vigorous effort
19110	15.0	Winter activities	Skiing, cross country, >8.0 mph, elite skier, racing
19130	15.5	Winter activities	Skiing, cross country, hard snow, uphill, maximum, snow mountaineering
19135	13.3	Winter activities	Skiing, cross-country, skating
19140	13.5	Winter activities	Skiing, cross-country, biathlon, skating technique
19150	4.3	Winter activities	Skiing, downhill, alpine or snowboarding, light effort, active time only
19160	5.3	Winter activities	Skiing, downhill, alpine or snowboarding, moderate effort, general, active time only
19170	*8.0*	Winter activities	Skiing, downhill, vigorous effort, racing
19175	12.5	Winter activities	Skiing, roller, elite racers
19180	7.0	Winter activities	Sledding, tobogganing, bobsledding, luge (Taylor Code 370)
19190	5.3	Winter activities	Snowshoeing, moderate effort
19192	10.0	Winter activities	Snowshoeing, vigorous effort
19200	*3.5*	Winter activities	Snowmobiling, driving, moderate
19202	*2.0*	Winter activities	Snowmobiling, passenger
19252	5.3	Winter activities	Snow shoveling, by hand, moderate effort
19254	7.5	Winter activities	Snow shoveling, by hand, vigorous effort

Code	METs	Major heading	Specific activities
19260	2.5	Winter activities	Snow blower, walking and pushing
20000	1.3	Religious activities	Sitting in church, in service, attending a ceremony, sitting quietly
20001	2.0	Religious activities	Sitting, playing an instrument at church
20005	1.8	Religious activities	Sitting in church, talking or singing, attending a ceremony, sitting, active participation
20010	1.3	Religious activities	Sitting, reading religious materials at home
20015	1.3	Religious activities	Standing quietly in church, attending a ceremony
20020	*2.0*	Religious activities	Standing, singing in church, attending a ceremony, standing, active participation
20025	*1.3*	Religious activities	Kneeling in church or at home, praying
20030	1.8	Religious activities	Standing, talking in church
20035	2.0	Religious activities	Walking in church
20036	2.0	Religious activities	Walking, less than 2.0 mph, very slow
20037	3.5	Religious activities	Walking, 3.0 mph, moderate speed, not carrying anything
20038	4.3	Religious activities	Walking, 3.5 mph, brisk speed, not carrying anything
20039	*2.0*	Religious activities	Walk–stand combination for religious purposes, usher
20040	*5.0*	Religious activities	Praise with dance or run, spiritual dancing in church
20045	2.5	Religious activities	Serving food at church
20046	2.0	Religious activities	Preparing food at church
20047	3.3	Religious activities	Washing dishes, cleaning kitchen at church
20050	1.5	Religious activities	Eating at church
20055	2.0	Religious activities	Eating/talking at church or standing eating, American Indian Feast days
20060	3.3	Religious activities	Cleaning church
20061	4.0	Religious activities	General yard work at church
20065	3.5	Religious activities	Standing, moderate effort (e.g., lifting heavy objects, assembling at fast rate)
20095	4.5	Religious activities	Standing, moderate-to-heavy effort, manual labor, lifting ≥50 lb., heavy maintenance
20100	1.3	Religious activities	Typing, electric, manual, or computer
21000	1.5	Volunteer activities	Sitting, meeting, general, and/or with talking involved
21005	1.5	Volunteer activities	Sitting, light office work, in general
21010	2.5	Volunteer activities	Sitting, moderate work
21015	2.3	Volunteer activities	Standing, light work (filing, talking, assembling)
21016	2.0	Volunteer activities	Sitting, child care, only active periods
21017	3.0	Volunteer activities	Standing, child care, only active periods
21018	3.5	Volunteer activities	Walk/run play with children, moderate, only active periods
21019	5.8	Volunteer activities	Walk/run play with children, vigorous, only active periods
21020	3.0	Volunteer activities	Standing, light/moderate work (e.g., pack boxes, assemble/repair, setup chairs/furniture)
21025	3.5	Volunteer activities	Standing, moderate (lifting 50 lb., assembling at fast rate)
21030	4.5	Volunteer activities	Standing, moderate/heavy work
21035	1.3	Volunteer activities	Typing, electric, manual, or computer
21040	2.0	Volunteer activities	Walking, less than 2.0 mph, very slow
21045	3.5	Volunteer activities	Walking, 3.0 mph, moderate speed, not carrying anything
21050	4.3	Volunteer activities	Walking, 3.5 mph, brisk speed, not carrying anything
21055	3.5	Volunteer activities	Walking, 2.5 mph slowly and carrying objects less than 25 lb
21060	4.5	Volunteer activities	Walking, 3.0 mph moderately and carrying objects less than 25 lb., pushing something
21065	4.8	Volunteer activities	Walking, 3.5 mph, briskly and carrying objects less than 25 lb
21070	3.0	Volunteer activities	Walk–stand combination, for volunteer purposes

Italicized codes and METs are estimated values

Appendix 2 2005 Compendium of Physical Activities for Children and Adolescents by Age Group and Sex [14] (Adapted with permission from Harrell JS, McMurray RG, Baggett CD, Pennell ML, Pearce PF, Bangdiwala SI. Energy costs of physical activities in children and adolescents. Med Sci Sports Exerc. 2005;37(2):329–36)

Age group[a]	METs	Activity	Specific activities
1	2.15	Sedentary activities	Board games
2	1.67		
3	1.50		
1	2.03	Sedentary activities	Math test
2	1.62		
3	1.40		
1	1.87	Sedentary activities	Home work/Reading
2	1.49		
3	1.27		
1	1.72	Sedentary activities	TV watching
2	1.37		
3	1.21		
1	2.02	Sedentary activities	Video game (sitting)
2	1.37		
3	1.21		
1	2.38	Sedentary activities	Video game (standing)
2	1.86		
3	1.65		
1	2.15	Low-moderate intensity activities	Board games
2	1.67		
3	1.50		
1	2.03	Low-moderate intensity activities	Math test
2	1.62		
3	1.40		
1	2.99	Low-moderate intensity activities	Bench press
2	3.08		
3	2.94		
1	3.44	Low-moderate intensity activities	Leg press
2	3.62		
3	3.19		
1	5.84	Low-moderate intensity activities	Shoveling
2	4.95		
3	3.87		
1	3.33	Low-moderate intensity activities	Stretching
2	2.82		
3	2.45		
1	4.92	Low-moderate intensity activities	Sweeping
2	3.96		
3	3.29		
1	6.02	Low-moderate intensity activities	Vacuuming
2	4.77		
3	3.80		
1	5.22	Low-moderate intensity activities	Walking (4 kph/2.5 mph)
2	4.33		
3	3.67		
1	10.10	High intensity activities	Rope skipping
2	10.06		
3	8.42		
1	11.00	High intensity activities	Running (8 kph/ 5 mph)
2	10.35		
3	9.16		
1	8.75	High intensity activities	Stairclimbing
2	8.11		
3	7.28		
1	7.02	High intensity activities	Walking (5.6 kph/ 3.5 mph)
2	5.78		
3	4.99		

[a]Age group 1 = 8–12 years for boys, 8–11 years for girls
Age group 2 = 13–15 years for boys, 12–14 years for girls
Age group 3 = 16–18 years for boys, 15–18 years for girls

Appendix 3 2018 Compendium of Physical Activities for Children and Adolescents by Age Group and Sex [13] (Adapted with permission from Butte NF, Watson KB, Ridley K, Zakeri IF, McMurray RG, Pfeiffer KA, et al. A Youth Compendium of Physical Activities: Activity Codes and Metabolic Intensities. Med Sci Sports Exerc. 2018;50(2):246–56)

Code	Activity category	Specific activity	MET_y			
			Ages 6–9	Ages 10–12	Ages 13–15	Ages 16–18
10100X	ACTIVE PLAY	BALL GAMES—BOUNCING, KICKING, DRIBBLING BALL, REACTION BALL (MODERATE INTENSITY)	6.0	6.2	6.3	6.5
10120X	ACTIVE PLAY	BALL GAMES—BOUNCING, KICKING, DRIBBLING BALL, REACTION BALL (VIGOROUS INTENSITY)	6.1	6.3	6.4	6.6
10140X	ACTIVE PLAY	DODGEBALL TYPE GAMES (E.G., CASTLES, HOT FEET)	5.8	6.0	6.1	6.3
10160X	ACTIVE PLAY	FREE PLAY (BASKETBALL, ROPE, HOOP, CLIMB, LADDER, FRISBEE)	5.7	5.9	6.0	6.1
10180X	ACTIVE PLAY	FREEZE/ZONE TAG (MODERATE INTENSITY)	6.3	6.5	6.6	6.7
10200X	ACTIVE PLAY	FREEZE/ZONE TAG (VIGOROUS INTENSITY)	6.4	6.6	6.7	6.9
10220X	ACTIVE PLAY	HIKING	5.8	6.0	6.1	6.2
10240X	ACTIVE PLAY	HOPSCOTCH	6.3	6.5	6.7	6.8
10260X	ACTIVE PLAY	JUMP ROPE	6.9	7.1	7.2	7.4
10280X	ACTIVE PLAY	MARCHING—75M.MIN INSTRUMENTS	5.0	5.2	5.3	5.5
10300X	ACTIVE PLAY	MARCHING—75M.MIN NO INSTRUMENTS	3.9	4.1	4.2	4.4
10320X	ACTIVE PLAY	MARCHING—91M.MIN NO INSTRUMENTS	5.1	5.3	5.4	5.6
10340X	ACTIVE PLAY	MISCELLANEOUS GAMES—VIGOROUS (E.G., SLAP THE BALL, BUILDERS AND BULLDOZERS, CLEAN THE ROOM)	6.4	6.6	6.7	6.9
10360X	ACTIVE PLAY	MISCELLANEOUS GAMES—MODERATE (E.G., SIMON'S SPOTLIGHT)	6.9	7.1	7.3	7.4
10380X	ACTIVE PLAY	OBSTACLE/LOCOMOTOR COURSE—MODERATE	5.9	6.1	6.2	6.4
10400X	ACTIVE PLAY	OBSTACLE/LOCOMOTOR COURSE—VIGOROUS	7.2	7.4	7.6	7.7
10420X	ACTIVE PLAY	PLAYING GAMES (CATCH AND THROW BALLS, JUMPING JACKS)	5.9	6.1	6.2	6.4
10440X	ACTIVE PLAY	PLAYING TAG—MODERATE	6.1	6.3	6.4	6.6
10460X	ACTIVE PLAY	PLAYING TAG-VIGOROUS	7.4	7.6	7.8	7.9
10480X	ACTIVE PLAY	RELAY	6.8	6.9	7.1	7.3
10500X	ACTIVE PLAY	SHARKS AND MINOOWS	5.8	6.0	6.1	6.2
10520X	ACTIVE PLAY	TRAMPOLINE	7.0	7.1	7.3	7.5
15100X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—ACTION RUNNING	4.8	5.9	6.8	7.7
15120X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—BASEBALL	3.7	4.7	5.7	6.6
15140X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—BOXING	3.0	4.0	4.9	5.8
15160X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—CATCHING TARGETS	2.6	3.6	4.5	5.4
15180X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—DANCE	2.3	3.3	4.1	5.0
15200X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—HOVERBOARD	1.8	1.8	2.6	3.4
15220X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—KINECT ADVENTURE GAMES AND SPORTS	3.1	4.2	5.1	5.9
15240X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—LIGHTSPACE	3.2	4.2	5.1	6.0

Code	Activity category	Specific activity	MET_y			
			Ages 6–9	Ages 10–12	Ages 13–15	Ages 16–18
15260X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—OLYMPIC GAMES	2.6	3.6	4.5	5.4
15280X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—SPORTWALL	3.8	4.8	5.7	6.6
15300X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—TRAZER	2.8	3.8	4.7	5.5
15320X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WALKING ON TREADMILL AND BOWLING	2.8	3.9	4.8	5.7
15340X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WATCHING TV/DVD—WALKING	2.2	3.2	4.0	4.9
15360X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII AEROBICS	2.2	3.2	4.1	4.9
15380X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII BOXING/TENNIS	2.1	3.1	3.9	4.8
15400X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII HOCKEY	1.4	2.4	3.2	4.0
15420X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII MUSCLE CONDITIONING	1.3	2.2	3.0	3.8
15440X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII SKIING	1.7	2.6	3.5	4.3
15460X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII STEP	2.5	3.6	4.4	5.3
15480X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII TENNIS	1.6	2.5	3.2	4.0
15500X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—WII YOGA	1.9	1.9	2.7	3.5
15520X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES—XAVIX	4.2	5.3	6.2	7.1
15540X	ACTIVE VIDEO GAMES (FULL BODY)	ACTIVE VIDEO GAMES (COMPILATION OF GAMES)	3.9	4.9	5.8	6.7
15560X	ACTIVE VIDEO GAMES (FULL BODY)	ARCADE VIDEO GAME—AIR HOCKEY	2.4	3.4	4.3	5.1
15580X	ACTIVE VIDEO GAMES (FULL BODY)	ARCADE VIDEO GAME—HORSE RIDING SIMULATION	4.1	5.2	6.1	7.0
20100X	ACTIVE VIDEO GAMES (UPPER BODY)	ACTIVE VIDEO GAMES—BOWLING	2.1	2.3	2.4	2.5
20120X	ACTIVE VIDEO GAMES (UPPER BODY)	ACTIVE VIDEO GAMES—DRIVING SIMULATOR	2.1	2.2	2.3	2.5
20140X	ACTIVE VIDEO GAMES (UPPER BODY)	ACTIVE VIDEO GAMES—WII (COMPILATION OF GAMES)	2.3	2.4	2.6	2.7
20160X	ACTIVE VIDEO GAMES (UPPER BODY)	ACTIVE VIDEO GAMES—WII BALANCE	2.2	2.3	2.5	2.6
20180X	ACTIVE VIDEO GAMES (UPPER BODY)	ACTIVE VIDEO GAMES—WII BASKETBALL	2.2	2.3	2.4	2.6
20200X	ACTIVE VIDEO GAMES (UPPER BODY)	ACTIVE VIDEO GAMES—WII GOLF	2.0	2.2	2.3	2.4
20220X	ACTIVE VIDEO GAMES (UPPER BODY)	ARCADE VIDEO GAME—DRIVING SIMULATION	2.0	2.2	2.3	2.4
20240X	ACTIVE VIDEO GAMES (UPPER BODY)	ARCADE VIDEO GAME—SHOOTING HOOPS	2.3	2.5	2.6	2.8
25100X	BIKE/SCOOTER RIDING	RIDING A BIKE—FAST SPEED	–[a]	6.5	7.3	8.1
25120X	BIKE/SCOOTER RIDING	RIDING A BIKE—MEDIUM SPEED	4.7	5.3	5.8	6.4
25140X	BIKE/SCOOTER RIDING	RIDING A BIKE—SELF PACED	4.6	5.3	5.8	6.4
25160X	BIKE/SCOOTER RIDING	RIDING A BIKE—SLOW SPEED	3.7	3.9	4.0	4.2
25180X	BIKE/SCOOTER RIDING	RIDING A MINI—SCOOTER	5.7	6.7	7.6	8.4
25200X	BIKE/SCOOTER RIDING	RIDING SCOOTER	4.9	5.6	6.2	6.8
30100X	CALISTHENICS/ GYMNASTICS	ACTIVE CLASSROOM INSTRUCTION	4.3	4.4	4.4	4.5
30120X	CALISTHENICS/ GYMNASTICS	BROADCAST CALISTHENICS—'COLOURFUL SUNSHINE'	4.0	4.1	4.1	4.1

Code	Activity category	Specific activity	MET_y			
			Ages 6–9	Ages 10–12	Ages 13–15	Ages 16–18
30140X	CALISTHENICS/ GYMNASTICS	BROADCAST CALISTHENICS—'FLOURISHING YOUTH'	4.1	4.2	4.2	4.3
30160X	CALISTHENICS/ GYMNASTICS	BROADCAST CALISTHENICS—'FLYING IDEAL'	3.6	3.7	3.7	3.7
30180X	CALISTHENICS/ GYMNASTICS	BROADCAST CALISTHENICS—'HOPEFUL SAIL'	3.8	3.8	3.9	3.9
30200X	CALISTHENICS/ GYMNASTICS	CALISTHENICS—LIGHT	4.0	4.1	4.1	4.2
30220X	CALISTHENICS/ GYMNASTICS	GYMNASTICS	2.7	2.7	2.7	2.7
30240X	CALISTHENICS/ GYMNASTICS	JUMPING JACKS	4.6	4.7	4.7	4.8
30260X	CALISTHENICS/ GYMNASTICS	RADIO GYMNASTICS	3.5	3.5	3.5	3.6
30280X	CALISTHENICS/ GYMNASTICS	STRENGTH EXERCISES—CURL-UPS	2.4	2.4	2.4	2.4
30300X	CALISTHENICS/ GYMNASTICS	STRENGTH EXERCISES—PUSH-UPS	3.9	4.0	4.0	4.1
35100X	COMPUTER/VIDEO GAMES (SITTING)	COMPUTER GAMES (COMPILATION OF GAMES)	1.4	1.5	1.5	1.5
35120X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—BOWLING	1.4	1.5	1.5	1.5
35140X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—DRIVING SIMULATOR	1.4	1.5	1.5	1.5
35160X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—GAMEBOY	1.4	1.5	1.5	1.5
35180X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—GAMEPAD	1.4	1.5	1.5	1.5
35200X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—HANDHELD	1.4	1.5	1.5	1.5
35220X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—MOBILE PHONE	1.4	1.5	1.5	1.5
35240X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—NINTENDO	1.4	1.5	1.5	1.5
35260X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—PS2	1.4	1.5	1.5	1.5
35280X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—PS3	1.4	1.5	1.5	1.5
35300X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES—XBOX360	1.4	1.5	1.5	1.5
35320X	COMPUTER/VIDEO GAMES (SITTING)	VIDEO GAMES (COMPILATION OF GAMES)	1.4	1.5	1.5	1.5
40100X	DANCE/AEROBICS/STEPS	AEROBIC DANCE/DANCE	3.6	4.1	4.5	4.8
40120X	DANCE/AEROBICS/STEPS	STAIR WALKING—ASCENDING	4.6	5.2	5.8	6.3
40140X	DANCE/AEROBICS/STEPS	STAIR WALKING—ASCENDING 80 STEPS/MIN	5.3	6.0	6.6	7.1
40160X	DANCE/AEROBICS/STEPS	STAIR WALKING—ASCENDING/DESCENDING	5.5	6.3	7.0	7.7
40180X	DANCE/AEROBICS/STEPS	STAIR WALKING—DESCENDING	3.0	3.4	3.8	4.1
40200X	DANCE/AEROBICS/STEPS	STEP BOARD	4.5	5.2	5.7	6.2
40220X	DANCE/AEROBICS/STEPS	STEPPING—HEIGHT 30–50% LEG LENGTH	3.9	4.4	4.9	5.3
45100X	HOUSEKEEPING/WORK	BEDMAKING	3.4	3.3	3.1	3.0
45120X	HOUSEKEEPING/WORK	CARPENTRY	2.9	2.7	2.6	2.4
45140X	HOUSEKEEPING/WORK	DRESSING AND UNDRESSING	3.4	3.2	3.1	2.9
45160X	HOUSEKEEPING/WORK	DUSTING	3.7	3.6	3.4	3.3
45180X	HOUSEKEEPING/WORK	DUSTING AND SWEEPING	3.4	3.3	3.1	3.0
45200X	HOUSEKEEPING/WORK	HANGING OUT WASHING	3.5	3.3	3.2	3.1
45220X	HOUSEKEEPING/WORK	HOUSEWORK	4.2	4.0	3.9	3.8
45240X	HOUSEKEEPING/WORK	LAUNDRY	3.7	3.5	3.4	3.3
45260X	HOUSEKEEPING/WORK	LOADING/UNLOADING BOXES	3.6	3.4	3.3	3.1
45280X	HOUSEKEEPING/WORK	SETTING THE TABLE	2.8	2.6	2.5	2.3

Code	Activity category	Specific activity	MET_y			
			Ages 6–9	Ages 10–12	Ages 13–15	Ages 16–18
45300X	HOUSEKEEPING/WORK	SHOVELLING	4.1	4.0	3.8	3.7
45320X	HOUSEKEEPING/WORK	SWEEPING	3.6	3.5	3.3	3.2
45340X	HOUSEKEEPING/WORK	VACUUMING	3.9	3.7	3.6	3.4
45360X	HOUSEKEEPING/WORK	WASHING THE DISHES	1.9	1.7	1.6	1.4
50100X	LYING	QUIETLY LYING	1.2	1.2	1.1	1.1
50120X	LYING	WATCHING TV/DVD—LYING	1.2	1.1	1.1	1.0
55100X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	ARTS AND CRAFTS	1.6	1.6	1.5	1.5
55120X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	BOARD GAMES	1.5	1.5	1.4	1.4
55140X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	COLORING, READING WRITING, INTERNET	1.6	1.6	1.5	1.5
55160X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	COMPUTER WORK	1.5	1.5	1.4	1.4
55180X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	GIVING A SPEECH	1.5	1.5	1.4	1.4
55200X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	LISTENING TO RADIO	1.4	1.4	1.3	1.3
55220X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	LISTENING TO STORY	1.4	1.4	1.3	1.3
55240X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	PLAYING QUIETLY	1.5	1.5	1.5	1.4
55260X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	PLAYING STRINGED INSTRUMENT	1.4	1.3	1.3	1.3
55280X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	PLAYING WITH BRICKS	1.3	1.3	1.2	1.2
55300X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	PLAYING WITH TOYS (CARDS, PUZZLES, CARS, TRAINS)	1.5	1.5	1.4	1.4
55320X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	PUZZLES	1.3	1.3	1.2	1.2
55340X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	QUIETLY SITTING	1.4	1.3	1.3	1.2
55360X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	READING	1.3	1.3	1.2	1.2
55380X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	READING A BOOK AND LISTENING TO MUSIC	1.4	1.3	1.3	1.3
55400X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	SCHOOLWORK	1.6	1.5	1.5	1.4
55420X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	SEWING	1.5	1.5	1.4	1.4
55440X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	SINGING	1.4	1.4	1.3	1.3

Code	Activity category	Specific activity	MET_y			
			Ages 6–9	Ages 10–12	Ages 13–15	Ages 16–18
55460X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	TALKING WITH FRIEND	1.4	1.4	1.4	1.3
55480X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	WATCHING TV/DVD—SITTING	1.4	1.3	1.3	1.2
55500X	QUIET PLAY/ SCHOOLWORK/TV (SITTING)	WRITING	1.4	1.4	1.3	1.3
60100X	RUNNING	JOG—FAST	7.2	7.9	8.5	8.8
60120X	RUNNING	JOG—SLOW	5.5	5.9	6.3	6.7
60140X	RUNNING	JOG SELF-PACED	6.8	7.4	7.9	8.4
60160X	RUNNING	RUN 3.0	5.3	6.0	--a	--a
60180X	RUNNING	RUN 3.5	6.4	7.0	7.5	8.0
60200X	RUNNING	RUN 4.0	6.5	7.2	7.7	8.3
60220X	RUNNING	RUN 4.5	6.7	7.4	8.0	8.6
60240X	RUNNING	RUN 5.0	7.2	8.0	8.6	9.3
60260X	RUNNING	RUN 5.5	7.3	8.1	8.8	9.5
60280X	RUNNING	RUN 6.0	8.2	9.1	9.8	10.5
60300X	RUNNING	RUN 6.5	8.9	9.9	10.9	11.8
60320X	RUNNING	RUN 7.0	9.3	10.2	11.0	11.8
60340X	RUNNING	RUN 7.5	10.0	10.7	11.3	11.9
60360X	RUNNING	RUN 8.0	10.6	11.5	12.4	13.2
60380X	RUNNING	RUN SELF-PACED	7.8	8.5	9.1	9.8
65100X	SPORTS/GAMES	BASKETBALL—GAME	6.7	7.0	7.2	7.5
65120X	SPORTS/GAMES	BASKETBALL—SHOOTING AND RETRIEVING A BASKETBALL, CONTINUOUSLY, WITHOUT STOPPING	5.9	6.2	6.4	6.6
65140X	SPORTS/GAMES	BASKETBALL GAME (MINI BASKETBALL)	4.9	5.0	5.1	5.2
65160X	SPORTS/GAMES	BOWLING—GAME	5.2	5.4	5.6	5.7
65180X	SPORTS/GAMES	BOXING—PUNCHING BAG AND GLOVES	4.9	5.0	5.0	5.1
65200X	SPORTS/GAMES	CATCH/THROW BALL	4.1	4.1	4.1	4.1
65220X	SPORTS/GAMES	GOLF—GAME (MINI GOLF)	4.0	3.9	3.9	3.9
65240X	SPORTS/GAMES	HANDBALL	5.4	5.6	5.7	5.8
65260X	SPORTS/GAMES	HOCKEY—GAME (MINI FLOOR HOCKEY)	3.8	3.7	3.7	3.6
65280X	SPORTS/GAMES	JUGGLING	6.2	6.4	6.6	6.8
65300X	SPORTS/GAMES	KICKBALL, CONTINUOUS MOVEMENT	8.2	8.3	8.4	8.6
65320X	SPORTS/GAMES	ROLLERBLADING	5.2	5.2	5.3	5.4
65340X	SPORTS/GAMES	SKIING	5.6	5.8	6.0	6.2
65360X	SPORTS/GAMES	SLIDE BOARD—40 SLIDES/MIN	4.9	5.0	5.0	5.1
65380X	SPORTS/GAMES	SLIDE BOARD—50 SLIDES/MIN	5.4	5.5	5.7	5.8
65400X	SPORTS/GAMES	SLIDE BOARD—60 SLIDES/MIN	5.6	5.8	5.9	6.1
65420X	SPORTS/GAMES	SLIDE BOARD—70 SLIDES/MIN	6.0	6.2	6.3	6.5
65440X	SPORTS/GAMES	SLIDE BOARD—80 SLIDES/MIN	5.9	6.1	6.3	6.4
65460X	SPORTS/GAMES	SOCCER—AROUND CONES	5.4	5.6	5.7	5.8
65480X	SPORTS/GAMES	SOCCER—GAME	7.7	8.1	8.4	8.7
65500X	SPORTS/GAMES	TABLE TENNIS	4.2	4.2	4.2	4.2
65520X	SPORTS/GAMES	TENNIS PRACTICE AND GAMES	6.1	6.3	6.5	6.7
65540X	SPORTS/GAMES	ULTIMATE FRISBBE	5.6	5.8	5.9	6.1
65560X	SPORTS/GAMES	VOLLEYBALL	5.0	5.1	5.2	5.3
70100X	STANDING	ARCADE GAMES—TABLE FOOTBALL	1.9	1.9	1.9	1.8
70120X	STANDING	BOARD GAMES—STANDING	2.0	2.0	1.9	1.9
70140X	STANDING	DRAWING, COLORING—STANDING	1.8	1.7	1.7	1.7
70160X	STANDING	SINGING—STANDING	1.8	1.8	1.7	1.7
70180X	STANDING	STACKING CUPS	1.6	1.5	1.5	1.5
70200X	STANDING	STANDING	1.7	1.7	1.7	1.6
70220X	STANDING	VIDEO GAMES—STANDING	1.8	1.8	1.7	1.7
70240X	STANDING	WATCHING TV/DVD—STANDING	1.8	1.8	1.8	1.8
75100X	SWIMMING	SWIMMING—200M	10.6	10.4	10.3	10.1
75120X	SWIMMING	SWIMMING—FRONT CRAWL 0.9 M.SEC	9.7	9.4	9.1	8.8

Code	Activity category	Specific activity	MET_y			
			Ages 6–9	Ages 10–12	Ages 13–15	Ages 16–18
75140X	SWIMMING	SWIMMING—FRONT CRAWL 1.0 M.SEC	10.0	9.7	9.4	9.2
75160X	SWIMMING	SWIMMING—FRONT CRAWL 1.1 M.SEC	10.6	10.4	10.2	10.1
75180X	SWIMMING	SWIMMING—SELF-SELECTED PACE	9.5	9.1	8.9	8.6
75200X	SWIMMING	SYNCHRONISED SWIMMING	10.1	9.9	9.7	9.5
80100X	WALKING	WALK 0.5	2.5	2.5	2.6	2.6
80120X	WALKING	WALK 1.0	2.5	2.6	2.7	2.8
80140X	WALKING	WALK 1.5	2.5	2.7	2.9	3.1
80160X	WALKING	WALK 2.0	2.8	3.0	3.2	3.4
80180X	WALKING	WALK 2.5	3.3	3.5	3.6	3.7
80200X	WALKING	WALK 3.0	3.8	4.1	4.3	4.5
80220X	WALKING	WALK 3.5	4.6	5.0	5.3	5.5
80240X	WALKING	WALK 4.0	4.8	5.2	5.6	6.0
80260X	WALKING	WALK 4.5	–[a]	–[a]	6.6	7.2
80280X	WALKING	WALK 5.0	–[a]	–[a]	7.2	7.8
80300X	WALKING	WALK SELF-PACED BRISK	4.6	4.9	5.1	5.4
80320X	WALKING	WALK SELF-PACED CASUAL	3.6	3.9	4.2	4.4
85100X	WEIGHT LIFTING	HAND WEIGHTS EXERCISES	3.0	3.0	2.9	2.9
85120X	WEIGHT LIFTING[b]	STRENGTH EXERCISES—BENCH PRESS	2.0	2.0	1.9	1.8
85140X	WEIGHT LIFTING[b]	STRENGTH EXERCISES—LEG PRESS	2.6	2.7	2.7	2.7

[a] Activity not deemed reasonable for this age-group
[b] Energy cost of anaerobic activities may be underestimated by MET values

Chapter Review Questions

1. Resting metabolic rate energy expenditure under resting conditions tends to be somewhat higher _____than basal metabolic rate:
   (a) 10–20%
   (b) 25–30%
   (c) 1–2%
   (d) It is lower.
2. In the scientific and clinical fields RMR and BMR are considered similar concepts, except by the fact that:
   (a) Patient gets an injection
   (b) Participant sleeps in the same place where the assessment is carried out.
   (c) Patient provides a urine sample to assess her urinary nitrogen.
   (d) All of the above
3. A women had a gross daily energy intake of 2000 kcals, she eliminated 100 calories in her stools, she lost 20 kcals in form of urinary glucose and her total daily energy expenditure is 1800 kcals. What is her estimated metabolizable energy?
   (a) 1900 kcals
   (b) 200 kcals
   (c) 1880 kcals
   (d) 1980 kcals
4. The residual energy available to support body functions, once exercise EE is removed from the energy intake is:
   (a) Energy balance
   (b) Energy availability
   (c) Energy Efficiency
   (d) Resting metabolic rate
5. How many METs are 450 kcals of exercise performed in 45 min by a woman of 59 kg?
   (a) 10.17
   (b) 1.017
   (c) 101.7
   (d) 2.10
6. Which one best defines the concept of NEAT.
   (a) NEAT = Total daily EE − RMR
   (b) NEAT = Total daily physical activity − Exercise physical activity
   (c) NEAT = Total daily EE/RMR
   (d) NEAT = Total daily EE – RMR – Exercise EE − Thermic effect of food
7. The main determinant of resting metabolic rate is:
   (a) Total daily physical activity
   (b) Fat free mass
   (c) Weight
   (d) NEAT
8. The gold standard method to quantify free-living total daily energy expenditure is:
   (a) Accelerometry
   (b) Indirect calorimetry
   (c) Watch monitor
   (d) Doubly Labelled water
9. A leakage of protons back across the mitochondrial inner membrane which is catalyzed by uncoupling proteins is one of the mechanisms suggested to be responsible for:
   (a) NEAT
   (b) Adaptive thermogenesis
   (c) RQ
   (d) Thermic effect of food

10. An exercise training program can increase skeletal muscle mass and:
    (a) Increase resting metabolic rate
    (b) Not affect significantly resting metabolic rate
    (c) Reduce exercise efficiency
    (d) Exercise does not increase skeletal muscle mass

Answers

1. a
2. b
3. c
4. b
5. a
6. d
7. b
8. d
9. b
10. b

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Nutritional Guidelines for Active Children

19

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Learning Objectives
After completion of this chapter, it is expected to understand the following:

- Dietary Guidelines for Americans particularly for children.
- MyPlate Food Guidance System: main food groups and their encompassed food items.
- Recommendations of daily calorie intake for children.
- The role of macronutrients (carbohydrates, proteins, and fats) as sources of energy.
- The importance of micronutrient incorporation (vitamins and minerals) and water in children's diet.

19.1 Introduction

Proper nutrition and adequate physical activity are the main two components of participating in a healthy lifestyle. Lack of either or both would jeopardize the chances of maintaining one's wellness throughout the lifespan. Developing a healthful routine begins from childhood years and continues to have persistent effects on both physical and mental health through adulthood and beyond. For instance, improper nutrition may lead to permanent and irreversible impairments in brain development, behavior changes and delayed psychomotor development, altered immune function, decreased levels of physical activity, decreased social interaction and curiosity, and decreased cognitive functioning in children [1, 2]. In 2017–2018, an estimated 19.3% of U.S. children and adolescents aged 2–19 years had obesity, including 6.1% with severe obesity, and 16.1% who were overweight [3, 4]. The prevalence of chronic diseases, including but not limited to obesity and asthma that were once found in adults, are now being seen in younger ages [5]. It is unfortunate to observe that the prevalence of overweight and obesity in children and adolescents has reached epidemic levels which is mainly due to increased caloric and fat intake through larger portions of processed and ready-to-eat foods along with a decrease in physical activity [6]. An increase in moderate physical activity is an important goal for reducing such health problems [7]. Along with physiological and psychological benefits, engaging in physical activity at a young age can lead to continued activity into adulthood. Participating in competitive sports and school-based physical education are good predictors of later physical activity in children. Creating a lifestyle with physical activity can have many benefits, and the recommendations for adults and children change to reflect the ever-changing culture and progressive research. Recommendations for children (aged 6–17) include 60 min or more of at least moderate-intensity physical activity per day, including vigorous-intensity aerobic activities that can improve bone density and muscle strength [7].

Creating and maintaining a nourishing lifestyle that supports proper growth and development in children and adolescents requires adequate exposure to the principles of proper nutrition in early stages of life. Such exposure and preparation are most likely attainable if parents and/or caretakers have access to, understand and apply such principles around their children. The Dietary Guidelines for Americans (DGA) set forth by the United States Department of Agriculture (USDA) and the U.S. Department of Health and Human Services (HHS) [8] were created both for children and adults to improve growth and development and to prevent nutrition-

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related chronic diseases (NRCDs) including, but not limited to, obesity, diabetes, cardiovascular disease (CVD), and several types of cancers [4].

19.2 Research Findings

19.2.1 Dietary Guidelines for Americans (DGA)

According to the US Department of Agriculture (USDA) and the U.S. Department of Health and Human Services (HHS), the Dietary Guidelines for Americans (DGA) are revised every 5 years and the most recent version (2020–2025) [8] is based on the most up-to-date scientific evidence. Every updated edition of the DGA goes through three vital steps to ensure accurate information. Stage one brings about a scientific approach where scientists and researchers conduct an analysis on new scientific information on health and fitness. The second stage targets policymakers, nutrition educators, health-care providers, etc. The final stage prepares information to be presented to the general public [9]. The guidelines provide advice on choosing a healthy eating pattern and are intended to be used as educational material for policymakers, for the general public, and for specific audiences such as children [8, 10].

According to the DGA, the Dietary reference intakes (DRI) offer recommendations of macronutrients, minerals, and vitamins to consume daily considering the life stage, sex, and activity level. An example of recommended macronutrient proportions by age is seen in Appendix 1.

19.2.2 Macronutrients

The three macronutrients that are included in a healthy diet are carbohydrates, proteins, and fats. Carbohydrates are the primary energy source for our body, with the brain and red blood cells solely depending on carbohydrates to live and function. Dietary carbohydrates contain 4 kcal of energy per gram and are categorized into two main groups: simple carbohydrates, commonly known as sugars; and complex carbohydrates including starch and fiber. The main food sources of carbohydrates include grains, beans and peas, vegetables, and fruits. For all children above the age of 1 year old, it is recommended that 45–65% of their daily calories come from carbohydrates. Whole grains may reduce the risk of heart disease, improve constipation, and help maintain a healthy weight. Over-consumption of simple carbohydrates that mainly provide energy rather than other functional nutrients such as vitamins, minerals and fiber, can lead to weight gain and should be avoided in a healthy diet [8, 11]. Including fiber in a diet facilitates digestion by regulating bowel movements and has other beneficial physiological functions. Dietary fiber cannot be digested; therefore, it passes through the small intestine into the large intestine where it is fermented by the gut bacteria and helps maintain regularity and bowel health. Insoluble fiber does not dissolve in water, so it helps move material through the colon. This is helpful for those children who suffer from constipation. Diets high in insoluble fiber may decrease the risk of diabetes and can be found in foods such as whole grains, nuts, wheat bran, and vegetables. Soluble fibers absorb water and can help soften stool. Foods rich in soluble fiber include oats, apples, flaxseed, and legumes. Appendix 1 shows the daily recommendation for fiber consumption in children [12]. Functional fibers such as cellulose, guar gum, pectin, and psyllium are extracted from plants and are added to certain foods. In addition to foods that naturally contain functional fibers, those foods that are fortified with such fibers are known to have beneficial physiological effects in humans [13].

The second of the three macronutrients is protein. One gram of protein yields 4 kcal of energy and is the major functional and structural component of all cells within the body. Protein, which is not a primary energy source, is composed of amino acids binding together with peptide bonds and is necessary for the growth and repair of our body tissues. There are 20 amino acids that can form proteins, eight of which are essential in adults, with a few other amino acids being essential in early childhood. Essential amino acids cannot be synthesized in the human body and therefore should be consumed in the diet. Paying attention to the dietary protein quality is important in order to ensure that all the essential amino acids are consumed. High-quality proteins are mainly found in animal-based foods such as eggs, meats, seafood, and dairy products. A combination of a variety of plant-based protein sources might also provide the essential amino acids that the body requires. Those plant-based sources include legumes, nuts, seeds and some vegetables such as broccoli, artichoke and spinach.

Recommended daily consumption of protein for children aged 1–3 years old is 5–20% of total daily calories. Children aged 4–18 years old can increase their protein consumption to 10–30% of their daily caloric intake. A variety of proteins is important for a healthy diet. Examples of foods with a high protein content include lean meats and poultry, seafood, dairy products, beans and peas, soy products, nuts and seeds [13].

Fats, the third of the macronutrients, yields 9 kcal of energy per gram and should make up 30–40% of the daily calories consumed in children aged 1–3 years old. Children 4–18 years of age should consume 25–35% of their total daily calories as fat. Although fats should be consumed in moderation, it is an important nutrient needed in an overall healthy diet. Fats could be found in several different forms and locations in the human body that exert a wide range of functions including but not limited to providing structure and protection to the body's tissues, nerves, and cell membranes.

Fats are categorized into monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), and saturated fatty acids (SFAs). MUFAs can be found in foods such as nuts, olive oil, and some pork derivatives. Of all the PUFAs, the two main types with significant nutritional roles are omega-6 and omega-3 fatty acids. Omega-6 and omega-3 fatty acids can be found in foods such as liquid vegetable oils, flaxseed, and some fish and shellfish. It is recommended to replace saturated fatty acids with MUFAs and PUFAs. Saturated fats are found in palm and coconut oil and in animal-based products including butter, bacon, ice cream, cheese and fatty cuts of meat. As previously mentioned, a diet high in saturated fats and cholesterol can elevate LDL levels in the blood which leads to an increased risk for CVD. It is recommended to consume less than 10% of daily fat intake from saturated fats and less than 300 mg of cholesterol per day. *Trans*-fatty acids are harmful by-products of industrial conversion of unsaturated fatty acids into saturated fatty acids and can be found in shortening, commercially prepared baked foods, fried foods, and snack foods. A diet high in *trans*-fatty acids may lead to an increased risk for CVD. Most Americans consume higher than advised amounts of saturated and *trans*-fatty acids with inadequate amounts of unsaturated fatty acids [14].

19.2.3 Micronutrients and Water

Unlike macronutrients, micronutrients do not provide energy and are comprised of two main nutrient groups: vitamins and minerals. Vitamins are essential to at least one vital process within the human body. Vitamins can be categorized into two groups: fat soluble and water soluble. Vitamins A, D, E, and K are fat-soluble and can be stored in the body. In addition to this categorization according to one of their physicochemical properties, vitamins can also be grouped based on their function as coenzymes, antioxidants, or hormones. Food sources for fat-soluble vitamins include dairy products, oily fish, dark green leafy vegetables, yellow vegetables, whole grains, legumes, fortified milk, and egg yolk [15]. Eating colorful fruits and vegetables can increase the availability of different vitamins [16, 17]. Water-soluble vitamins, including B vitamins and vitamin C, are involved in energy metabolism and maintenance of bones, cartilage, and connective tissues. Food sources that contain water-soluble vitamins include, but are not limited to, eggs, meat, poultry, milk products, beans, nuts, cereals, fruits and vegetables. Vitamin recommendations for children are found in Appendix 1 [12].

Minerals are important components of our daily diet. Minerals are required to support human biochemical processes by aiding in tissue building, fluid balance, carrying oxygen needed for metabolism, and removal of metabolic by-products from working tissues. Recommendations for daily mineral consumption for children are listed in Appendix 1.

Examples of food sources rich in minerals include dairy products, green leafy vegetables or sardines for calcium, red meat and some legumes for iron, foods of marine origin for iodine, or fish, cereals, and grains for selenium, just to mention a few minerals [12]. It is important to note that a certain food could be considered a poor dietary source of a specific mineral despite containing relatively high amounts of that mineral. This is due to the extremely low bioavailability of the mineral in that food (i.e., high amounts of calcium in spinach with low bioavailability). Bioavailability refers to the proportion of a nutrient that absorbs into the bloodstream once consumed through food and so can exert its effects.

Approximately 50–70% of an adult's body weight and as high as 79% of children's body weight is comprised of water. Water is essential for almost all bodily functions. Water helps regulate body temperature, lubrication, and transportation of compounds within the body. Extreme loss of body fluids due to inadequate intake, sweating or illness; known as dehydration; can lead to serious adverse outcomes including heat cramps, heat exhaustion, and/or heat stroke. Hydration could be achieved through adequate water and fluid intake as well as fluid found in some foods. On average, consuming 64 ounces per day is necessary for the body's needs and these levels would increase as the physical activity levels increase. Specific water requirements could vary from one person to another; however, in most individuals, responding to the thirst signal along with drinking beverages and meals would provide the body with the fluid amounts it needs [12].

19.2.4 Nutritional Responsibility

Reversing the U.S. obesity epidemic is of utmost importance considering the several types of chronic diseases that either originate from or are exacerbated by obesity in some shape or form. The dramatic increase in childhood obesity rates occurred from the early 1970s to 2008, when the prevalence of obesity rose to 20% in children aged 6–11 years and to 18% in those aged 12–19 years. To date, the very high rates of overweight and obesity in children continue to be alarming since most children with these conditions maintain the excess weight and carry it over into their adulthood. Therefore, as a parent or a caregiver, it is important to provide a foundation of healthy eating patterns and regular physical activity for children. The lifestyle children engage in can influence their lifestyle as an adult and in later stages of life. Studies show those who engage in an unhealthy lifestyle are more at risk for developing overweight or obesity as an adult [18] and suffer from many other metabolic diseases such as type 2 diabetes. Strategies that can create a healthy lifestyle include, but are not limited to, ensuring schools and

childcare facilities are following DGA for all meals and snacks, providing the public with physical activity and nutrition education, encouraging physical activity within the school system, reducing children's screen and/or the technology exposure time, and developing marketing tactics focused on healthy food and beverages for children [8, 19, 20].

19.3 Contemporary Understanding of the Issue

For almost 20 years, the United States Department of Agriculture (USDA) used the food pyramid to represent a healthy diet [21]. In 2011, the USDA replaced the MyPyramid with MyPlate since the pyramid was too complex as a nutritional guide for American families [22]. Nutritionists, dietitians, economists, and policy experts at the USDA designed the MyPlate to help individuals understand portion sizes with a familiar image, a plate [15]. This design reminds the National Food Guide (commonly called "The Basic Seven") published back in the 1940s, as well as food guides from countries all over the world, such as Mexico, Portugal, Great Britain, or Spain, that have been using the same idea for several decades.

The MyPlate icon shows the five major groups; fruits, vegetables, grains, protein foods, and dairy; all of which are the vital building blocks of a healthy diet. The information given to consumers about healthy eating choices is based on recommendations for Americans 2 years of age and older (DGA). Policy experts at the USDA aimed to not only provide tangible nutrition information but to actively and gradually alter unhealthy eating behaviors among the Americans. The online platform created specifically for MyPlate, https://www.myplate.gov/, allows individuals to gain knowledge of healthy food choices and habits to live by as well as interactive games for children to learn what types of foods to eat and those they should avoid. Additionally, the website explains each group and shows healthy choices and the recommendations or serving sizes within each group [15]. The main purpose of this new icon is to encourage individuals to eat smaller portions and to fill at least half of their plates with fruits and vegetables.

Focusing on fruit consumptions is very important; any whole fruit or 100% fruit juice counts as part of the fruit group. The fruit food gallery on the USDA website shows common fruits consumed and the amount of fruit needed every day. The daily fruit recommendations for children can be found in Table 19.1. These amounts are appropriate for children who get less than 30 min per day of moderate physical activity. Those who are more physically active may be able to consume more while staying within their caloric needs [23].

The vegetable group includes any vegetable or 100% vegetable juice and is separated into five subgroups since this is a very diverse group that includes both macronutrient-free and carbohydrate- and/or protein-containing vegetables. The MyPlate's vegetable food gallery lists the groups as dark green vegetables, red and orange vegetables, beans, peas, lentils, starchy vegetables, and others. Recommended amounts of vegetables vary with age, sex, and level of physical activity. The vegetable recommendations for children for subgroups are listed as weekly consumption amounts (Table 19.2). These amounts are appropriate for children who get less than 30 min per day of moderate physical activity, and the calorie levels for each age group are similar to those listed for fruit recommendations in Table 19.1. Note that although it is not necessary to eat vegetables from each subgroup every day, it is important to eat from each subgroup on a weekly basis.

Table 19.1 Daily fruit recommendations (Adapted from U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020–2025. 9th ed. https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf [8])

Sex	Age (years)	Calorie level (kcal)	Fruits (cup eq/day)
Males	2–3	1000–1400	1–1½
	4–8	1400–1600	1½
	9–13	1800–2200	1½–2
	14–18	2400–2800	2–2½
Females	2–3	1000–1200	1
	4–8	1400–1600	1½
	9–13	1600–2000	1½–2
	14–18	2000	2

Table 19.2 Weekly vegetable recommendations (Adapted from U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020–2025. 9th ed. https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf [8])

		Vegetables (cup eq/wk)				
Sex	Age (years)	Dark greens	Red and orange	Beans, peas, lentils	Starchy	Other
Males	2–3	½–1	2½–3	½	2–3½	1½–2½
	4–8	1–1½	3–4	½–1	3½–4	2½–3½
	9–13	1½–2	5½–6	1½–2	5–6	4–5
	14–18	2–2½	6–7	2–2½	6–7	5–5½
Females	2–3	½–1	2½–3	½	2–3½	1½–2½
	4–8	1–1½	3–4	½–1	3½–4	2½–3½
	9–13	1½	4–5½	1–1½	4–5	3½–4
	14–18	1½	5½	1½	5	4

It is recommended to build your meal with fruits and vegetables filling up 50% of the plate. It is important for children to consume a variety of fruits and vegetables that will provide the nutrients needed for proper growth and development that would in turn reduce the risk of developing nutrition-related diseases. MyPlate not only offers food choices with recommended serving sizes but also explains the health benefits and nutrients found in fruits and vegetables. A diet including recommended amounts of fruits and vegetables may reduce the risk for certain hypokinetic diseases including heart attacks, stroke, type 2 diabetes, high blood pressure, kidney stones, bone loss, obesity, and certain types of cancer [24].

Incorporating grains into one's diet is important in providing the necessary macro- and micronutrients that would provide caloric and physiological benefits and would reduce the risk for certain diseases. Some grains may reduce the risk for heart disease, improve constipation, help maintain a healthy body weight, and when fortified with folate, could help prevent neural tube defects in the fetus when consumed during pregnancy. However, indiscriminate folate fortification is a very controversial topic. Excessive folate intake could have serious consequences, especially for those populations with a misbalanced diet or with deficient intake of other metabolically related vitamins. Grains are categorized into two groups: whole grains and refined grains. Whole grains contain the entire grain kernel and are found in foods such as whole-wheat flour, bulgur, oatmeal, whole cornmeal, and brown rice. Although refined grains are milled to give the product a finer texture and longer shelf life, the process removes important dietary fiber, iron, and many B vitamins [25]. Some dietary sources of refined grains include white flour, degermed cornmeal, white bread, and white rice. A list of commonly eaten whole and refined grains can be found on the MyPlate website [25].

Most American adults and children consume enough grains, but a small percentage is whole grains. It is recommended that at least half of the grains in the diet are whole grains. Table 19.3 lists the daily recommended amounts of grains and the daily minimum amounts of whole grains for children. These amounts are appropriate for children who get less than 30 min per day of moderate physical activity, and the calorie levels for each age group are similar to those listed for fruit recommendations in Table 19.1. Daily recommendations for grains are given in ounces. Examples of one ounce of grain include one slice of bread and 1/2 cup of cooked pasta or cooked cereal. A list of commonly eaten foods and their equivalent to one ounce can be found on the MyPlate website [25].

A healthy diet includes foods from the protein group. Foods including meat, poultry, seafood, beans and peas, eggs, soy products, nuts, and seeds are all good dietary sources that would satisfy the recommendations of the protein group. The inclusion of certain foods such as beans, peas and nuts in this group is rather controversial since some are richer in carbohydrates and/or fat rather than protein. The name assigned to this group itself is also confusing and inconsistent with the rest of the groups included in this food guide, as it refers to a nutrient (protein) rather than a food group, which limits its value as a nutrition education tool by generating confusion about basic nutrition concepts, such as the difference between nutrients and foods. Consuming a variety of protein sources is important while leaning towards lean or low-fat choices. Certain seafoods that are rich in omega-3 fatty acids are recommended to be included in a healthy diet. Processed meats such as deli meats should be limited due to their high sodium content. The protein foods subgroups are meats, poultry, eggs, seafood, nuts, seeds, and soy products. Protein requirements are different depending on age, sex, and physical activity level. Table 19.4 contains the daily recommendations for protein consumption for children. These amounts are appropriate for children who get less than 30 min per day of moderate physical activity, and the calorie levels for each age group are similar to those listed for fruit recommendations in Table 19.1. Protein recommendations are given in ounces. Examples of one ounce

Table 19.3 Daily grain recommendations (Adapted from U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020–2025. 9th ed. https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf [8])

Sex	Age (years)	Whole grains (ounce eq/day)
Males	2–3	1½–2½
	4–8	2½–3
	9–13	3–3½
	14–18	4–5
Females	2–3	1½–2
	4–8	2½–3
	9–13	3
	14–18	3

Table 19.4 Daily protein recommendations (Adapted from U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020–2025. 9th ed. https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf [8])

		Protein foods (ounce eq/day)		
Sex	Age (years)	Meats, poultry, eggs	Seafood	Nuts, seeds, soy products
Males	2–3	10–19	2–6	2–3
	4–8	19–23	6–8	3–4
	9–13	23–28	8–9	4–5
	14–18	31–33	10	5–6
Females	2–3	10–14	2–4	2
	4–8	19–23	6–8	3–4
	9–13	23–26	8	4–5
	14–18	26	8	5

of protein include one egg, one can of tuna, or approximately twelve almonds [26].

The last food group included in the MyPlate is the dairy group. Most dairy that is consumed is recommended to be fat-free or low in fat. Commonly eaten dairy products are listed on the MyPlate website which includes milk, milk-based desserts, calcium-fortified soymilk, cheese, and yogurt. Age is a large determinant of the amount of dairy requirements. The daily recommended amount of dairy to consume could be found in Table 19.5. These amounts are appropriate for children who get less than 30 min per day of moderate physical activity, and the calorie levels for each age group are similar to those listed for fruit recommendations in Table 19.1. A diet that includes dairy can provide many health benefits such as improving bone health, particularly during childhood and adolescence when the bone mass is being built. Dairy products can also reduce the risk of certain diseases such as CVD and type 2 diabetes and may lower blood pressure [27].

Although fats exert a wide range of functions in the body, they should be consumed in moderation. A low intake of saturated fatty acids (SFA) and an adequate intake of unsaturated fatty acids (MUFAs and PUFAs) have been largely associated with a healthier lipid profile (triglycerides, total cholesterol, LDL, HDL) and a lower risk of CVD [8, 28]. Most plant-based oils (sunflower, flaxseed, corn, rapeseed, olive oil, etc.) are high in unsaturated fatty acids. Regardless of the fatty acid composition, most oils contain around 120 kcal per tablespoon and are therefore frequently recommended to be limited in a healthy diet [8]. However, it should also be considered that a more classic paradigm of a healthy diet, such as the Mediterranean diet, was originally a high-fat diet, including almost 40% of daily calories from healthy fats, especially MUFAs and PUFAs. For instance, a Mediterranean diet recommends the use of olive oil for cooking while avoiding other SFA-rich sources like butter. This means that the fatty acid composition of a dietary fat source outweighs its calorie content.

Along with the dietary MyPlate guidelines, the MyPlate website offers additional resources for children such as tips for making healthy foods more fun for children and tips to decrease added sugars. Being exposed to a healthy routine and interacting with properly educated parents, caregivers and teachers are crucial in teaching children how to cultivate a healthy lifestyle. Bringing healthy meals to the table for the whole family, shopping for healthy food items especially when children are present and participating in group physical activities are among the behaviors that can model a healthy lifestyle [20, 29]. It is important to include foods from all the above-mentioned food groups in a balanced, yet moderate, fashion. Daily caloric recommendations vary depending on age, sex, and activity level. A chart estimating the caloric daily needs for children based on their activity level can be viewed in Appendix 2 [8, 13].

Table 19.5 Daily dairy recommendations (Adapted from U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020–2025. 9th ed. https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf [8])

Sex	Age (years)	Dairy (cup eq/day)
Males and females	2–3	2–2½
	4–8	2½
	9–13	3
	14–18	3

19.4 Future Directions

The relationship between diet, physical activity, and health has been extensively analyzed both in the short- and long-term studies. However, due to the growing prevalence of diet-related chronic and degenerative diseases, further investigation is needed, especially on the following subjects:

- The biological and psychosocial factors that determine the adherence (or not) to the dietary guidelines and recommendations on exercise in children.
- The influence of education about proper nutrition on the prevalence of chronic diseases such as obesity and type 2 diabetes in children and adults.
- Examining the transparency and effectiveness of the newer dietary guide, MyPlate, in promoting healthy eating choices in children.
- The role of parents, caregivers, school systems, and policymakers in promoting healthy eating and physical activity habits in decreasing the rate of nutrition-related chronic diseases.

19.5 Concluding Remarks

Educating children on healthy dietary choices would prepare them for a healthy lifestyle. In general, it is suggested that half of the plate in a healthy meal should consist of fruits and a variety of vegetables, while the other half incorporates lean meats, whole grains, and fat-free and/or low-fat dairy products. Limiting the intake of simple sugars along with saturated and *trans*-fatty acids is also emphasized by the USDA guidelines. Understanding and following such guidelines by parents and caregivers along with creating an environment that fosters engagement in regular physical activity would provide children with proper exposure and experience to cultivate and maintain a healthy lifestyle into adulthood and later stages of life [30].

Appendix 1

Nutritional goals for age–gender groups, based on dietary reference intakes and dietary guidelines (Adapted from U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary guidelines for Americans, 2020–2025. 9th ed. https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf [8])

Nutrient (units)	Source of goal[a]	Child 2–3	Female 4–8	Male 4–8	Female 9–13	Male 9–13	Female 14–18	Male 14–18	Female 19–30	Male 19–30	Female 31–50	Male 31–50	Female 51+	Male 51+
Macronutrients														
Protein (g)	RDA[b]	13	19	19	34	34	46	52	46	56	46	56	46	56
(% of calories)	AMDR[c]	5–20	10–30	10–30	10–30	10–30	10–30	10–30	10–35	10–35	10–35	10–35	10–35	10–35
Carbohydrate (g)	RDA	130	130	130	130	130	130	130	130	130	130	130	130	130
(% of calories)	AMDR	45–65	45–65	45–65	45–65	45–65	45–65	45–65	45–65	45–65	45–65	45–65	45–65	45–65
Total fiber (g)	IOM[d]	14	17	20	22	25	25	31	28	34	25	31	22	28
Total fat (% of calories)	AMDR	30–40	25–35	25–35	25–35	25–35	25–35	25–35	20–35	20–35	20–35	20–35	20–35	20–35
Saturated fat (% of calories)	DG[e]	<10%	<10%	<10%	<10%	<10%	<10%	<10%	<10%	<10%	<10%	<10%	<10%	<10%
Linoleic acid (g)	AI[f]	7	10	10	10	12	11	16	12	17	12	17	11	14
(% of calories)	AMDR	5–10	5–10	5–10	5–10	5–10	5–10	5–10	5–10	5–10	5–10	5–10	5–10	5–10
Alpha-linolenic acid (g)	AI	0.7	0.9	0.9	1.0	1.2	1.1	1.6	1.1	1.6	1.1	1.6	1.1	1.6
(% of calories)	AMDR	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2	0.6–1.2
Cholesterol (mg)	DG	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300	<300
Minerals														
Calcium (mg)	RDA	700	1000	1000	1300	1300	1300	1300	1000	1000	1000	1000	1200	1200
Iron (mg)	RDA	7	10	10	8	8	15	11	18	8	18	8	8	8
Magnesium (mg)	RDA	80	130	130	240	240	360	410	310	400	320	420	320	420
Phosphorus (mg)	RDA	460	500	500	1250	1250	1250	1250	700	700	700	700	700	700
Potassium (mg)	AI	3000	3800	3800	4500	4500	4700	4700	4700	4700	4700	4700	4700	4700
Sodium (mg)	UL[g]	<1500	<1900	<1900	<2200	<2200	<2300	<2300	<2300	<2300	<2300	<2300	<2300	<2300
Zinc (mg)	RDA	3	5	5	8	8	9	11	8	11	8	11	8	11
Copper (mcg)	RDA	340	440	440	700	700	890	890	900	900	900	900	900	900
Selenium (mcg)	RDA	20	30	30	40	40	55	55	55	55	55	55	55	55
Vitamins														
Vitamin A (mcg RAE)	RDA	300	400	400	600	600	700	900	700	900	700	900	700	900
Vitamin D[h] (mcg)	RDA	15	15	15	15	15	15	15	15	15	15	15	15	15
Vitamin E (mg AT)	RDA	6	7	7	11	11	15	15	15	15	15	15	15	15
Vitamin C (mg)	RDA	15	25	25	45	45	65	75	75	90	75	90	75	90
Thiamin (mg)	RDA	0.5	0.6	0.6	0.9	0.9	1.0	1.2	1.1	1.2	1.1	1.2	1.1	1.2
Riboflavin (mg)	RDA	0.5	0.6	0.6	0.9	0.9	1.0	1.3	1.1	1.3	1.1	1.3	1.1	1.3
Niacin (mg)	RDA	6	8	8	12	12	14	16	14	16	14	16	14	16
Folate (mcg)	RDA	150	200	200	300	300	400	400	400	400	400	400	400	400
Vitamin B6 (mg)	RDA	0.5	0.6	0.6	1.0	1.0	1.2	1.3	1.3	1.3	1.3	1.3	1.5	1.7
Vitamin B12 (mcg)	RDA	0.9	1.2	1.2	1.8	1.8	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Choline (mg)	AI	200	250	250	375	375	400	550	425	550	425	550	425	550
Vitamin K (mcg)	AI	30	55	55	60	60	75	75	90	120	90	120	90	120

AT Alpha-tocopherol, *DFE* Dietary folate equivalents, *RAE* Retinol activity equivalents

[a]Dietary guidelines recommendations are used when no quantitative dietary reference intake value is available; apply to ages 2 years and older

[b]Recommended dietary allowance, IOM

[c]Acceptable macronutrient distribution range, IOM

[d]14 g per 1000 cal, IOM

[e]Dietary guidelines recommendation

[f]Adequate intake, IOM

[g]Upper limit, IOM

[h]1 mcg of vitamin D is equivalent to 40 IU

Appendix 2

Estimated calorie needs per day by age, gender, and physical activity level (detailed). (Adapted from U.S. Department of Agriculture, Food and Nutrition Service Estimated Calorie Needs per Day by Age, Gender, and Physical Activity Level. Washington, D.C. Available at: https://www.fns.usda.gov/estimated-calorie-needs-day-age-gender-and-physical-activity-level [23]). Estimated amounts of calories[a] needed to maintain calorie balance for various gender and age groups at three different levels of physical activity. The estimates are rounded to the nearest 200 cal. An individual's calorie needs may be higher or lower than these averages

Gender/activity level[b]	Male/sedentary	Male/moderately active	Male/active	Female[c]/sedentary	Female[c]/moderately active	Female[c]/active
Age (years)						
2	1000	1000	1000	1000	1000	1000
3	1200	1400	1400	1000	1200	1400
4	1200	1400	1600	1200	1400	1400
5	1200	1400	1600	1200	1400	1600
6	1400	1600	1800	1200	1400	1600
7	1400	1600	1800	1200	1600	1800
8	1400	1600	2000	1400	1600	1800
9	1600	1800	2000	1400	1600	1800
10	1600	1800	2200	1400	1800	2000
11	1800	2000	2200	1600	1800	2000
12	1800	2200	2400	1600	2000	2200
13	2000	2200	2600	1600	2000	2200
14	2000	2400	2800	1800	2000	2400
15	2200	2600	3000	1800	2000	2400
16	2400	2800	3200	1800	2000	2400
17	2400	2800	3200	1800	2000	2400
18	2400	2800	3200	1800	2000	2400
19–20	2600	2800	3000	2000	2200	2400
21–25	2400	2800	3000	2000	2200	2400
26–30	2400	2600	3000	1800	2000	2400
31–35	2400	2600	3000	1800	2000	2200
36–40	2400	2600	2800	1800	2000	2200
41–45	2200	2600	2800	1800	2000	2200
46–50	2200	2400	2800	1800	2000	2200
51–55	2200	2400	2800	1600	1800	2200
56–60	2200	2400	2600	1600	1800	2200
61–65	2000	2400	2600	1600	1800	2000
66–70	2000	2200	2600	1600	1800	2000
71–75	2000	2200	2600	1600	1800	2000
76+	2000	2200	2400	1600	1800	2000

[a] Based on Estimated Energy Requirements (EER) equations, using reference heights (average) and reference weights (healthy) for each age–gender sex group. For children and adolescents, reference height and weight vary. For adults, the reference man is 5 ft. 10 in. tall and weighs 154 pounds. The reference woman is 5 ft. 4 in. tall and weighs 126 pounds. EER equations are from the Institute of Medicine. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington (DC): The National Academies Press; 2002 [12]

[b] Sedentary means a lifestyle that includes only the light physical activity associated with typical day-to-day life. Moderately active means a lifestyle that includes physical activity equivalent to walking about 1.5–3 miles per day at 3–4 miles per hour, in addition to the light physical activity associated with typical day-to-day life. Active means a lifestyle that includes physical activity equivalent to walking more than 3 miles per day at 3–4 miles per hour, in addition to the light physical activity associated with typical day-to-day life

[c] Estimates for females do not include women who are pregnant or breastfeeding. Source: Britten P, Marcoe K, Yamini S, Davis C. Development of food intake patterns for the MyPyramid Food Guidance System. J Nutr Educ Behav 2006;38(6 Suppl):S78–92 [31]

Chapter Review Questions

1. As of 2017–1018, approximately what percentage of Americans aged 2–19 years are overweight or have obesity?
   (a) 66%
   (b) 13%
   (c) 35%
   (d) 9%
2. Dietary reference intake (DRI) offers recommendations based on all the following EXCEPT?
   (a) Sex
   (b) Life stage
   (c) Activity level
   (d) All are used to create DRIs
3. According to the estimated calorie needs per day, how many calories should a ten-year-old active female consume?
   (a) 1000
   (b) 1400
   (c) 2000
   (d) 2200
4. According to the new MyPlate, you should fill at least half of your plate with:
   (a) Whole grains
   (b) Fruits and vegetables
   (c) Lean proteins
   (d) Low-fat dairy products
5. Which of the following is an example of a recommended whole grain?
   (a) White bread
   (b) Brown rice
   (c) White spaghetti noodles
   (d) De-germed cornmeal
6. Daily dairy recommendations for children 2–3 years old are:
   (a) One cup
   (b) Two cups
   (c) Three cups
   (d) Two and a half cups
7. For all age groups, carbohydrates should make up _____% of the daily recommended calorie intake.
   (a) <10%
   (b) 10–35%
   (c) 25–35%
   (d) 45–65%
8. Which of the following is not a characteristic of protein?
   (a) Composed of amino acids
   (b) Protein foods group solely include lean meats and poultry
   (c) Necessary for growth and repair of our body's tissues
   (d) Primary energy source
9. It is recommended that most of dietary fats consumed should be:
   (a) Saturated fatty acids
   (b) Polyunsaturated fatty acids
   (c) Trans fatty acids
   (d) Cholesterol
10. Which of the following is NOT a micronutrient?
   (a) Cholesterol
   (b) Vitamin D
   (c) Iron
   (d) Sodium

Answers

1. c
2. d
3. c
4. b
5. b
6. b
7. d
8. d
9. b
10. a

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20 Nutritional Guidelines Including Hydration Recommendations and Energy Needs for the Female Athlete: Preventing Low Energy Availability and Functional Amenorrhea Through Nutritional Therapy

Ángela García-González and Jacalyn J. Robert-McComb

Learning Objectives

After completing this chapter, you should have an understanding of the following:

- The term female athlete triad (Triad), and functional hypothalamic amenorrhea (FHA).
- The energy availability hypothesis and FHA.
- Energy availability estimations.
- Nutritional therapeutic guidelines for the female athlete.
- The importance of hydration before, during, and after exercise.

20.1 Introduction

Studies have repeatedly shown that female athletes, especially females who participate in endurance and weight-sensitive disciplines and/or sports, do not take in enough calories to meet the exercise challenges they have imposed on their bodies. This may or may not be due to disordered eating patterns, but may simply be a result of fatigue resulting from the training required for the sport [1]. Energy deficiency (either intentional or unintentional) may emerge through extreme exercise energy expenditure (EEE) alone if it is not accompanied by a commensurate increase in energy intake. Even moderate dietary restriction and moderate EEE may result in energy deficiency.

The female athlete TRIAD (also referred to as triad, or Triad) was first described in 1997 as a syndrome common in female athletes that included three interconnected medical disorders: eating disorders, amenorrhea, and osteoporosis. The TRIAD term was then redefined in 2007 as the interrelationship between energy availability (EA), menstrual function and bone health. In 2014, the International Olympic Committee (IOC) defined the concept: Relative Energy Deficiency in Sports (RED-S). According to the IOC, RED-S occurs when an individual's dietary energy intake is insufficient to support the energy expenditure required for health, function and daily living, once the cost of exercise and sporting activities is taken into account, a fact that is not unique to women [2–4]. The new concept (RED-S) is, nevertheless, still controversial and is not accepted by all of the scientific community, as some experts believe it is not evidence-based knowledge [5, 6].

In this chapter, we review the research that has focused on the female athlete and a triad of disorders related to insufficient energy intake. Specifically, we focus on EA and functional amenorrhea. We also discuss the dietary needs as well as hydration recommendations for the female athlete to prevent the cascade of disorders as well as disorders related to hydration status.

20.2 Research Findings

Energy availability also referred to as EA has been defined as daily energy intake (DEI, kcal) minus exercise energy expenditure (EEE, kcal) divided by fat-free mass (FFM, kg) [7]. Both dietary restriction and exercise diminish the availability of utilizable fuels for body functions. During extended periods of deficient metabolic fuel, the body sustains functions necessary for life by diverting scarce metabolic fuels to essential cellular maintenance: The less critical functions not necessary for individual survival, such as reproductive function, are compromised [8]. A longitudinal pattern of disorders in the young athletic female population has been

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observed. Noteworthy is that the observed disorders may not be considered clinical or even subclinical to be harmful to the long-term health of the athlete. These behaviors have been observed in recreational athletes as well as elite athletes [9–11]. There seemed to be a relationship between the disorders that had an effect on reproductive function in the short term and possible osteoporosis later in life. It was thought that one disorder led to another disorder and that this pattern of disorders has a domino effect which has been referred to as a cascade of disorders. Furthermore, bone loss is a natural aging phenomenon, and if the young female athlete never achieved peak bone mass in her 20's then this natural bone loss in later years may result in osteoporosis [12] (Fig. 20.1).

It is now understood that low EA can occur with or without disordered eating and that the menstrual disorder included in the Triad is very specific. The menstrual disorder referred to in the Triad is known as functional hypothalamic amenorrhea (FHA). For the female athlete, the term FHA is used because it is a functional problem, not an anatomical one (i.e., altered hormonal patterns, rather than an anatomical problem), and it is reversible [8, 13, 14].

Although the definitions of amenorrhea are somewhat arbitrary, amenorrhea can be described as primary or secondary. Primary amenorrhea (delayed menarche) is the absence of menstruation by age 15 in a girl with secondary sex characteristics [15]. Secondary amenorrhea is the absence of three or more consecutive menstrual cycles or a period of 3 months without menses after menarche or after cycles have been established [15].

The prevalence of secondary amenorrhea, in athletes, varies widely with sport, age, training volume, and body weight. Studies over different athletic populations report rates of menstrual disorders ranging from 1 to 69%, and of the menstrual disorders reported, 70% are for subclinical ovarian disturbances. Contrasting a nonathletic population, studies show that only about 2–15% of sedentary youth women have menstrual irregularities [1, 16–23].

Warren (1980) was the first to suggest that menstrual disorders in female athletes are caused by an energy drain [24]. Winterer et al. (1985) hypothesized that failure to provide sufficient metabolic fuels to meet the energy requirements of the brain causes an alteration in brain function that disrupts the gonadotropin-releasing hormone (GnRH) pulse mechanism [25]. Reproductive function critically depends on the pulsatile release of GnRH from GnRH neurons in the arcuate nucleus of the hypothalamus and on the consequent pulsatile release of luteinizing hormone (LH) from the pituitary [26]. Figure 20.2 depicts the biochemical axis for menses to occur. This axis is known as the hypothalamus-pituitary-ovarian axis [27].

A series of well-controlled studies by Loucks at Ohio University demonstrated that normal menstrual cycling was altered if there is a restriction in EA [26, 28–31]. In the athletic female, *energy drain* can occur either by not taking in enough calories to meet the metabolic needs of the body or by over-exercising and not compensating for the energy cost of the exercise by taking in additional calories. It should be noted that EA (DEI − EEE/FFM) is not the same as energy balance, and that low EA does not always lead to weight loss. Energy balance is defined as DEI minus total energy expenditure (TEE or total daily energy expenditure TDEE) or heat from all cellular functions [basal metabolic rate (BMR), thermal effect of food (TEF), thermal effect of activity (TEA)], not just EEE. When EA is too low, physiological

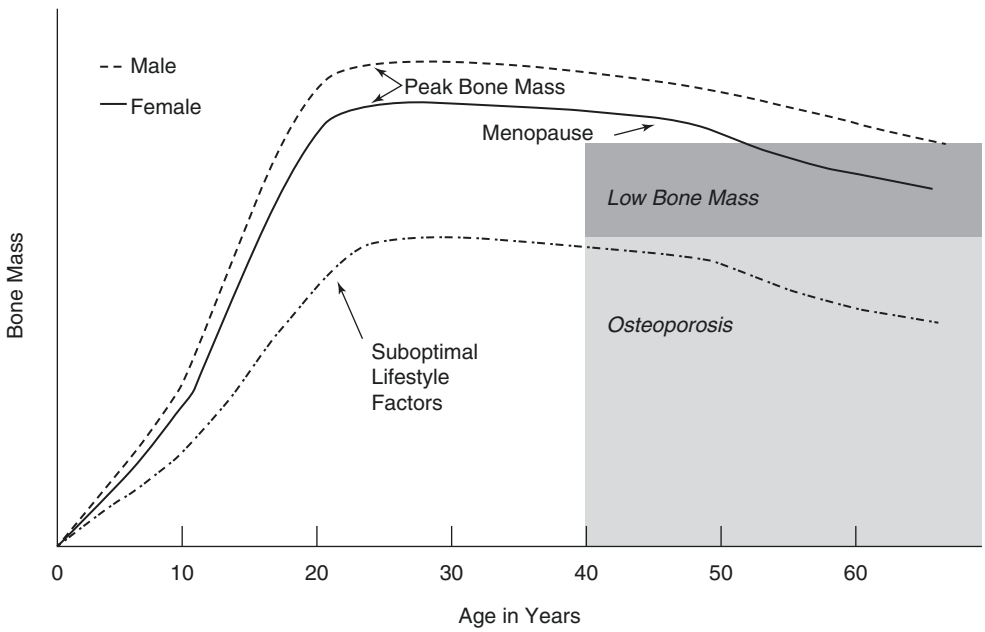

Fig. 20.1 Change in bone mass with age in optimal and suboptimal conditions. (Reprinted by permission from Springer Nature, Osteoporosis International, The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations, CM, Gordon CM, Janz KF, Kalkwarf HJ, Lappe JM, Lewis R, et al., Vol. 27/ Number 4, pages 1281–1386, © 2016 [12])

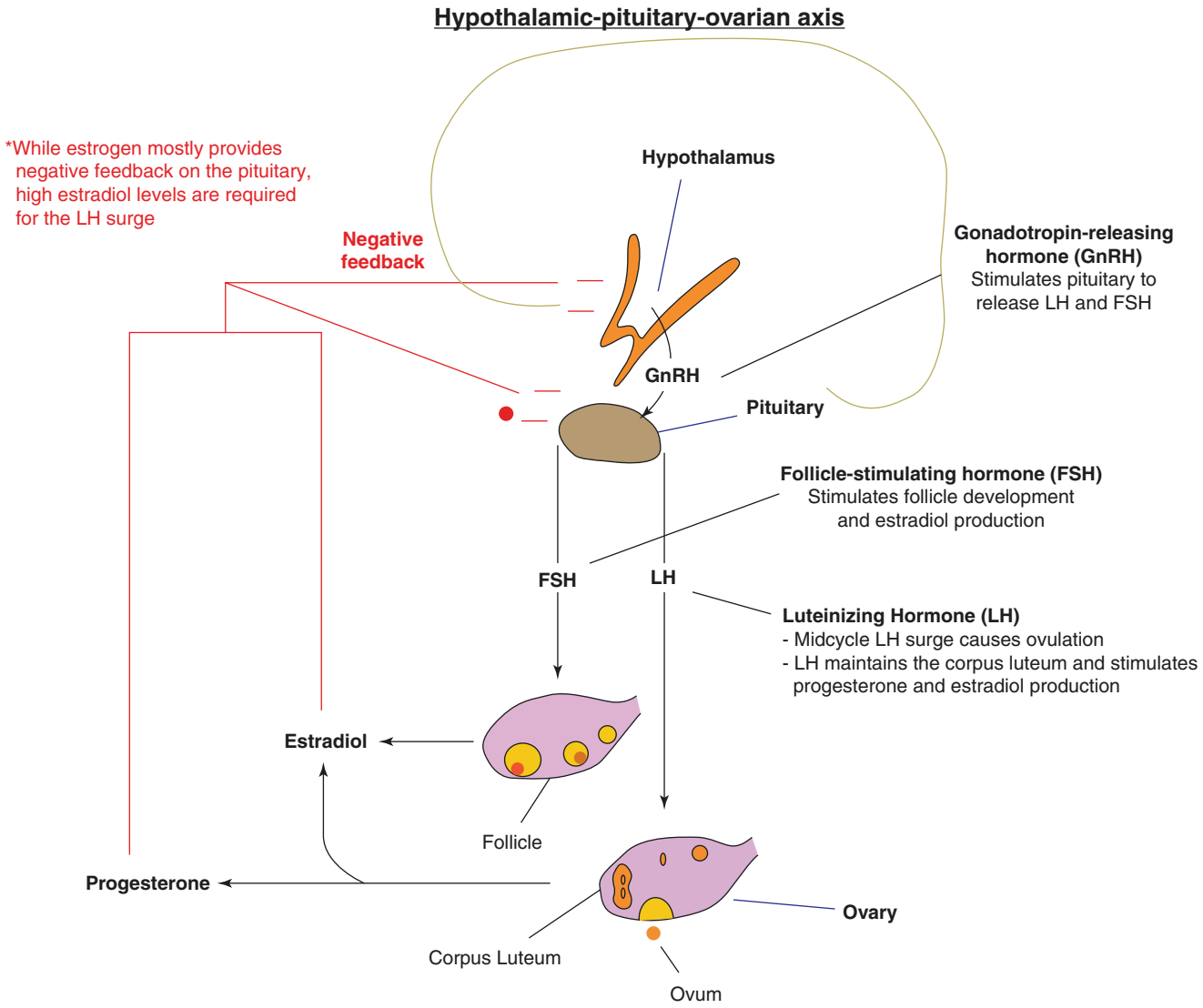

Fig. 20.2 Hypothalamic-pituitary-ovarian-axis. (Courtesy of Straight Healthcare—www.straighthealthcare.com [27])

mechanisms reduce the amount of energy used for cellular maintenance, thermoregulation, growth, and reproduction. This compensation tends to maintain energy balance (by slowing down metabolism, etc. and not providing energy for noncritical functions such as reproduction). The compensation also helps maintain the current weight and promotes survival but impairs general overall health [17]. An athlete may be weight stable but nevertheless, suffer the metabolic consequences of low EA.

For the female athlete, who does not take in enough calories, either intentionally or unintentionally, behaviorally controlled restricted dietary energy intake has an effect on the cellular availability of oxidizable metabolic fuels and reproductive function such as glucose [14]. Glucose is an important metabolic fuel needed for the maintenance of bodily functions and survival.

The adult female human brain oxidizes approximately 80 g of glucose each day at a continuous rate, and this must be provided daily by dietary carbohydrates, because the brain's rate of energy expenditure can deplete liver glycogen stores in less than 1 day [32]. Moderate exercise oxidizes that much glucose in an hour [26]. On the basis of respiratory quotients measured during exercise training, 62–88% of the energy expended during exercise was derived from carbohydrates, principally glucose [30]. Thus, the special demand that aerobic exercise places on glucose stores suggests that the failure of women to sufficiently increase dietary glucose intake, specifically, in compensation for the energy cost of the exercise may lower glucose availability to the brain below a critical threshold necessary for the normal neuroendocrine function of the thyroid, reproductive, and other endocrine axes [33].

Interestingly, Loucks et al. found that fuel utilization is affected during a restricted dietary energy state and that the fuel for EEE is altered to maintain adequate brain glucose availability [28]. In their experiment, they found that skeletal muscle-derived much less energy from carbohydrate oxidation in the deprived EA treatment than in the balanced EA treatment (49 versus 73%) [28]. This alteration in fuel utilization during the deprived energy state conserved approximately 70% of the brain's daily glucose requirement. Their conclusion from this study was that prolonged exercise had no disruptive effect on LH pulsatility in women—apart from the impact of its energy cost on EA or glucose availability. Reproductive function critically depends on the pulsatile release of GnRH from GnRH neurons in the arcuate nucleus of the hypothalamus and on the consequent pulsatile release of LH from the pituitary [26]. Please refer to Fig. 20.3 for a visual understanding of the menstrual cycle and the importance of the pulsatile release of LH [34].

The inference from Louck's study was that LH pulsatility was disturbed less by EEE than by dietary energy restriction alone [28]. The basis of this inference was the demonstration that during exercise, muscles altered carbohydrate fuel utilization by 33% during a deprived energy state as opposed to a balanced energy state (73% balanced energy state versus 49% energy-deprived state).

In a subsequent study, Loucks and Thuma found that LH pulsatility was disrupted abruptly at a threshold of EA less than 30 kcal/kg of lean body mass (LBM) per day [26]. The subjects in their experiment were regularly menstruating, habitually sedentary young women of normal body composition. Interestingly, they found that there were thresholds for physiological functioning to be impaired; yet the relation-

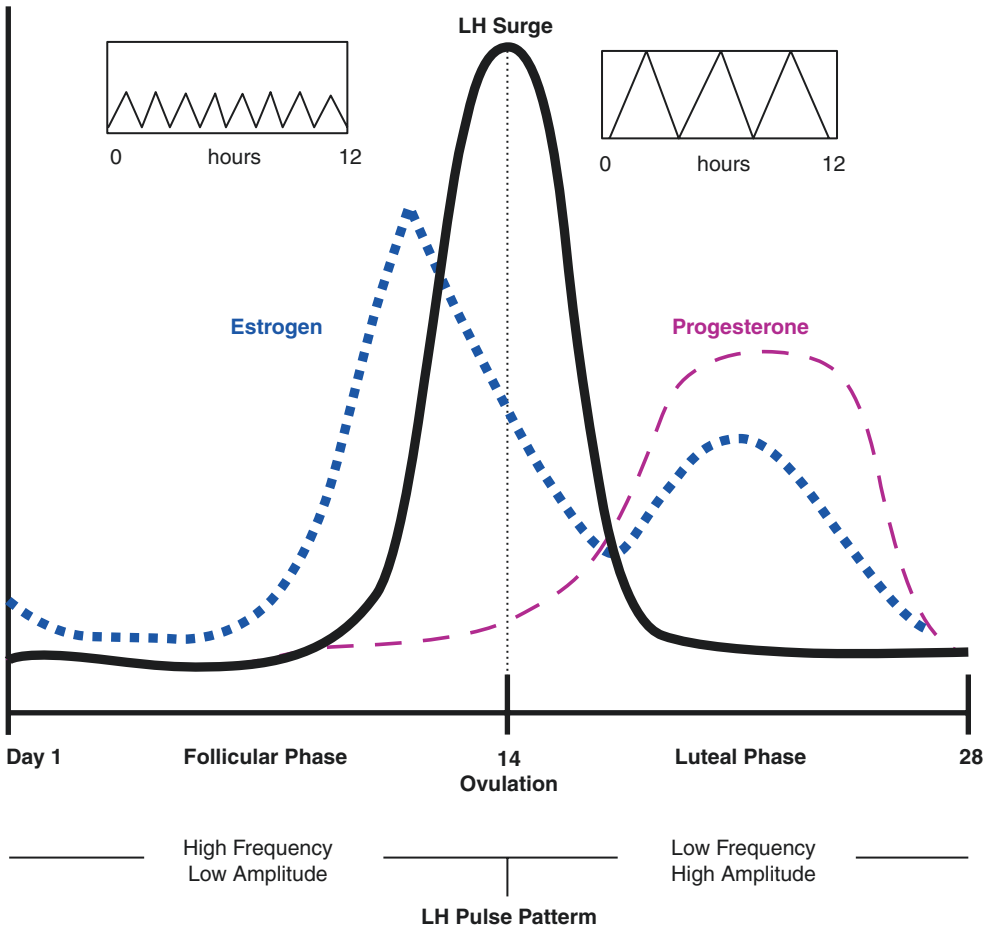

Fig. 20.3 Patterns of hormone secretion across the normal menstrual cycle. A luteinizing hormone (LH) surge occurs at the time of ovulation and marks the division between the follicular phase (days 1–14) and the luteal phase (days 15–28). LH pulse paternal, so changes across the menstrual cycle; pulse frequency decreases from the follicular phase (−65- to 80-min intervals) to the luteal phase (−185- to 200-min intervals), whereas pulse amplitude increases from the follicular phase (−5 miU/mL) to the luteal phase (−12 miU/mL) [34]. (Adapted by Amber McCord, Texas Tech University, from Robert-McComb J, García González Á. Nutritional guidelines and energy needs in the female athlete preventing low energy and functional amenhorrea through diet. In: Robert-McComb J, Norman R, Zumwalt M, editors. The active female: Health issues throughout the lifespan. New York, NY: Springer Science + Business Media; 2014. p. 463–489)

ship between EA and altered hormonal and metabolic responses was not linear. Importantly, not all females had the same threshold for EA; but if this threshold fell below a critical threshold, hormonal alterations would result They found that the incremental effects of restricted EA on LH pulse frequency and amplitude most closely resembled the incremental effects of restricted EA on metabolic substrates and hormones such as plasma glucose, cortisol, 3-hydroxybutyrate (beta HOB), and growth hormone. Worth mentioning is that this association did not imply that any of the metabolic substrates and hormones were involved in the mechanism mediating the effects of EA on LH pulsatility. If EA was approximately 30 kcal/kg LBM·day, the responses of various metabolic hormones [insulin, cortisol, insulin-like growth factor (IGF)-I; IGF Binging Protein (BP)-1; IGHBP-3; leptin; and Triiodothyronine (T_3)] maintained plasma glucose levels to within 3% of normal. Many of these hormones block glucose entry into the cell to maintain a normal glucose level. Conversely, leptin and T_3 were substantially suppressed by a restricted EA of 30 kcal/kg LBM·d; T_3 was further depressed by a reduction in EA of 20 kcal/kg LBM·day. Triiodothyronine is a thyroid hormone that plays vital roles in the body's metabolic rate, heart and digestive functions, muscle control, brain development, and maintenance of bones. Leptin is a hormone that plays a key role in regulating energy intake and energy expenditure, including appetite and metabolism. It is one of the most important adipose-derived hormones. They also found that the disruptive effects of subthreshold EA were bimodal or appeared as two distinct peaks, with substantially larger effects occurring in subjects with the shortest luteal phases. Their results suggested that women with short luteal phases (11 days) might be at a higher risk than others for the suppression of ovarian function and skeletal demineralization by energy deficiency.

20.3 Contemporary Understanding of the Issues

20.3.1 Energy Availability and Functional Amenorrhea

As illustrated in Fig. 20.4 [34] reproductive function may be altered at the level of the hypothalamus because of energy drain, insufficient EA, or negative energy balance [25, 26, 28–31, 33]. More than one term has been used in the literature to present the same concept. More simply stated, it could be called energy or nutritional stress. Stress may even be psychological for reproduction to be altered from stress; however, in this chapter, we are focusing on insufficient EA. In this illustration, GnrH is not released at the level of the hypothalamus because of activation of the hypothalamic-pituitary-adrenal (HPA) axis. This axis is sometimes called the stress axis. The diagram depicts activation of the HPA axis in which the hypothalamus releases corticotropin-releasing hormone (CRH) which inhibits GnRH and suppresses the hypothalamic-pituitary-gonadal (HPG) axis. Ultimately LH pulsatility is affected if EA falls to a certain threshold or if there is a very low negative energy balance [26]. Menses then cease resulting in what is termed simply functional amenorrhea or more precisely FHA. FHA is defined as a nonorganic and reversible disorder in which the impairment of GnRH pulsatile secretion plays a key role in LH pulsatility. LH pulsatility can be suppressed by a combination of strenuous exercise and caloric restriction [28]. There is a threshold of EA, roughly 30 kcal/kg LBM·day for most women, that must be met for normal menstrual cycling. The threshold of EA is not the same for all women: But if that threshold is met, the restoration of cycling will occur if previously energy deficient and functionally oligo/amenor-

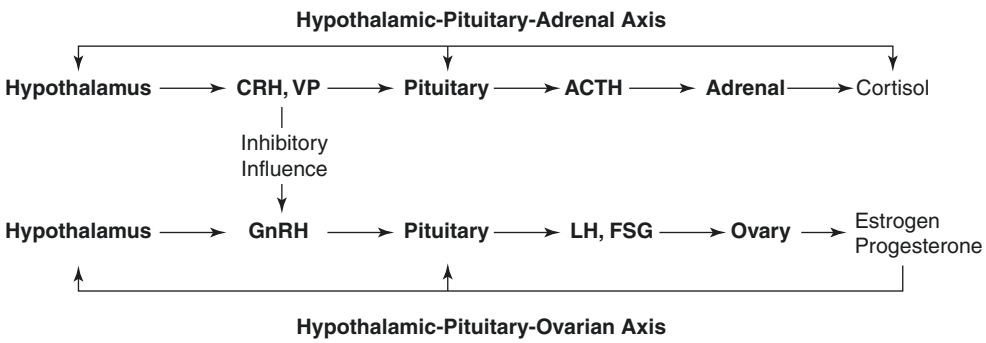

Fig. 20.4 Suppression of the hypothalamic-pituitary-ovarian (HPO) from energy stress by the hypothalamic-pituitary-adrenal (HPA) axis [34]. (Adapted by Amber McCord, Texas Tech University, from Robert-McComb J, García González Á. Nutritional guidelines and energy needs in the female athlete preventing low energy and functional amenorrhea through diet. In: Robert-McComb J, Norman R, Zumwalt M, editors. The active female: Health issues throughout the lifespan. New York, NY: Springer Science + Business Media; 2014. p. 463–489)

rheic [29]. So, functional amenorrhea as termed in the Triad of disorders is reversible if the individual's threshold for EA is met, which seems to be roughly [30].

20.3.2 Hormonal Regulation of Food Intake

Food intake and energy expenditure are regulated centrally and peripherally by a plethora of hormones and neuropeptides. The role of some gut hormones, such as ghrelin or peptide YY and adipose-derived hormones such as leptin, on eating control after exercise practice continues to be investigated by scientists [35–40]. Figure 20.5 graphically illustrates the role of these hormones in appetite control.

Ghrelin is a unique circulating peripheral orexigenic hormone that is currently being investigated and deserves attention [41]. Ghrelin is a gastrointestinal hormone secreted by endocrine cells in the stomach. It can cross the blood–brain barrier and activate special receptors in the arcuate nucleus in the hypothalamus of the brain leading to a cascade of processes that end in an increase in hunger and food intake. Through this central mechanism (crossing the blood barrier and activating receptors in the brain), ghrelin has been proposed to play a role in short-term energy homeostasis.

Conflicting findings have been reported regarding exercise training on ghrelin release: (a) some studies found no changes in ghrelin levels after the practice of sport [35, 42]; (b) some studies found a transitional suppression of the acylated form of the hormone [36, 43], the form of the hormone thought to be responsible for appetite stimulation [41]; (c) while other studies found some increase in ghrelin [35, 36, 44, 45]. Yet, even the studies that reported increases in ghrelin ciphers in exercising women with functional amenorrhea, found no subsequent increase in appetite or food intake, a fact which may be hypothetically due to some degree of ghrelin resistance [46].

Intense exercise expenditure (without a compensatory intake in calories) is able to induce a short-term negative energy balance during vigorous exercise, a phenomenon that has been described as "exercise-induced anorexia" [36, 37, 46]. Even if ghrelin is secreted, which should signal hunger, there are opposing hormones that are secreted when there is a negative energy balance. If ingestion is not enough to compensate the EEE, a relative negative energy balance will result, and this negative energy balance will induce pancreatic peptide YY (PYY) release which in turn will induce satiety and less hunger sensation. This phenomenon may be associated with some other molecules in addition to PYY such as glucagon-like peptide-1 (GLP-1) [35].

There has been a marked increase in our understanding of the importance of gut hormones in the regulation of energy homeostasis. Pancreatic PYY is a hormone which is secreted from endocrine cells called L-cells in the small intestine. It can also cross the blood barrier and act centrally in the control of food intake decreasing hunger and thus food intake. PYY is released after eating, circulates in the blood, and works by binding to receptors in the brain. These receptors then cause a decreased appetite and make people feel full after eating. PYY also acts in the stomach and intestine to slow down the movement of food through the digestive tract. Pancreatic PYY concentrations rise postprandial in proportion to caloric intake and stay elevated for several hours while fasting. Concentrations are regulated by general caloric intake and negatively correlated with body mass index, suggesting a role of this molecule in long-term energy homeostasis [47]. Additionally, because of the observed changes in the levels of gastrointestinal hormones in women with functional amenorrhea and because their receptors are

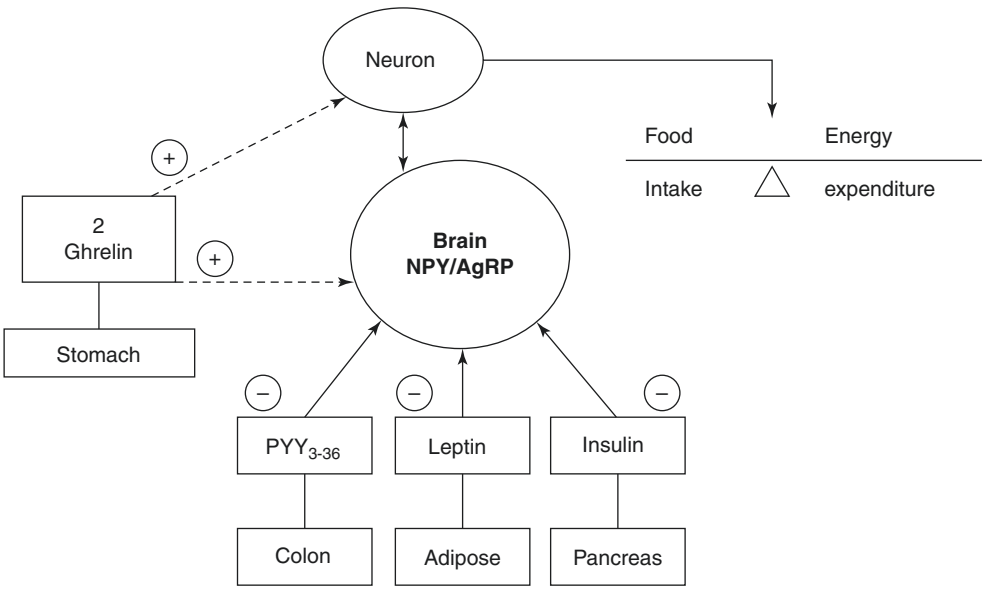

Fig. 20.5 Neural control of appetite [34]. (Reprinted from Robert-McComb J, García González Á. Nutritional guidelines and energy needs in the female athlete preventing low energy and functional amenhorrea through diet. In: Robert-McComb J, Norman R, Zumwalt M, editors. The active female: Health issues throughout the lifespan. New York, NY: Springer Science + Business Media; 2014. p. 463–489. May not be needed as direct from prior)

closely related to the hypothalamic-pituitary-ovarian (HPO) axis, some authors have hypothesized a direct role of gastrointestinal hormones in the etiology of functional amenorrhea although more studies are needed to determine the exact role of ghrelin, PYY, and adipokines in this pathology [35, 40, 48].

Other interesting hormones related with appetite control that have been studied in athletes with menstrual problems, are GLP-1 and Oxytocin. GLP-1 is a hormone produced in the intestinal epithelial endocrine L-cells released in response to meal intake. The main actions of GLP-1 are to stimulate insulin secretion and to inhibit glucagon secretion and it also appears to be a physiological regulator of appetite and food intake. Decreased secretion of GLP-1 may contribute to the development of obesity, and exaggerated secretion may be responsible for postprandial reactive hypoglycemia [49]. Oxytocin is a hormone produced by the hypothalamus and released by the pituitary. It is released into the bloodstream in response to stretching of the cervix and uterus during labor and with stimulation of the nipples from breastfeeding. More recently, oxytocin has been implicated in inhibiting reward-related eating behaviors, suppressing the HPA axis activity, and modifying the glucoregulatory response to caloric consumption [50]. Some studies have reported that amenorrheic athletes had lower overnight oxytocin secretion than regularly menstruating nonathletes and also a positive relationship between fasting oxytocin levels and EA. [40, 51, 52]. Further studies are needed to elucidate the role of GLP-1 and Oxytocin may play in the interaction between appetite control, amenorrhea and exercise.

In conclusion, during extended periods of reduced EA, the body prioritizes by fueling the activities necessary for survival such as thermoregulation and locomotion; therefore, less critical processes such as reproductive function may be compromised. The restoration of normal menstrual cycling has been demonstrated to reoccur when the individual's threshold for EA is sequentially met [29]. However, observations suggest that appetite may be an inadequate indicator of energy balance during athletic training, just as thirst is an insensitive indicator of water balance during athletic competition. Athletes may need to eat by discipline rather than by appetite during training to prevent reproductive disorders [28].

20.3.3 Estimating Energy and Nutritional Intake

Studies consistently show that female athletes are not consuming enough energy to support their activity level [53–57]. Research with elite female swimmers, using the doubly labeled water technique, noted that total daily energy increased to 5593 kcal daily during high-volume training. This is the highest caloric expenditure of female athletes reported [58]. However, their intake averaged only 3136 kcal, implying a negative energy balance. The energy intake of well-trained female athletes ranges from 1931 to 3573 kcal [59]. Consequently, their intake of essential vitamins and minerals is lower than the recommended daily allowance. Female athletes' diets have been found to be low in iron, calcium, zinc, vitamin D, and folate [60].

Low energy and nutrient intake place these athletes at a greater risk for nutrition-related disorders such as amenorrhea, osteoporosis, iron-deficiency anemia, and eating disorders [3, 7, 57]. It must be emphasized that all women participating in high-level competitive sports must remain vigilant and take in enough calories to meet their energy demands. It is not *only* athletes who practice sports with tightly regulated weight control practices who are at risk of suffering the complications of the Triad. All female athletes must have an awareness of the importance of adequate caloric intake to meet energy demands.

Even if the equation to calculate EA looks simple, the evaluation of each of its components in a free-living situation is not easy. First, by definition, EA calculation requires information about fat-free-mass (FFM) which to be accurately measured requires techniques such as Dual-energy X-ray absorptiometry (DXA) not commonly available. DXA can be substituted by other techniques such as anthropometry or bioimpedance. Nevertheless, all body composition techniques, including DXA, are affected by acute confounder factors, such as hydration status, immediate exercise practice or drink and food intake. All of these factors contribute to errors in the FFM estimation [61–63].

The second factor in the EA equation, DEI, is also difficult to calculate. The first point to be solved in the DEI estimation is to know the number of days that adequately represent the athlete's intake (and energy expenditure). For sedentary people, it is generally agreed that a register of 3–4 days is adequate and considered standard practice. However, it is not so well established the length of days that should be registered to determine an accurate energy intake or expenditure for athletes [61, 64]. Sports researchers and practitioners, usually evaluate 3–7 days.

Traditionally, recommendations for energy requirements have been based on self-recorded estimates of food intake by different dietary assessment records [64]. Currently, there is no gold standard or agreed-upon method that is routinely applied in the assessment of the energy intake of athletes. The food-record is the most commonly used tool to assess energy intake for athletes and is considered to be valid if limitations are acknowledged [64]. All methods of dietary intake assessment have advantages and disadvantages which must be considered when deciding which tool to use. To improve accuracy, a combination of more than one method is recommended [65]. New technologies, such as tablets, cellular phone cameras, online tools, etc. reduce the burden of

recording and enhance the quality of the recorded data [65–67]. However, it is generally agreed upon by professionals that these self-recorded records are misleading [65, 68, 69]. The percentage of people who underestimate their food intake ranges from 10 to 45% [64, 69] and the mean of underreporting corresponds to approximately 2500 kJ (600 kcal) or 19% of total energy intake [64].

The third factor in the EA equation, EEE is even more affected by individual aspects which make the evaluation more specific and difficult [61, 63]. EEE has been estimated by different methods such as training records and heart rate monitors, accelerometers or activity diaries, all of them implying a substantial burden for observer and participant and are highly biased [61]. But the question is not only how to measure EEE but "what" must be measured and considered "exercise". There is not a consensus if leisure and/or transporting activities should also be included as "exercise" or even if sedentary activities should be included [61]. As stated by Guebels, standardized guidelines are needed since the use of different parameters in the same population can lead to different calculations and interpretations of EA [70].

The determination of TEE considering the physical activity and state of health are very important to fit the calculation of the nutritional needs for every individual. Since the advent of the doubly labeled water (DLW) technique for measuring TEE, scientists have established energy requirements based on the actual measurement of TEE in free-living individuals [71]. In practice, nutritionists and health care professionals estimate TEE by using different equations. Those equations should include the estimation of resting metabolic rate (RMR) as well as endogenous thermogenesis and EEE.

Scientists have admitted that some of the commonly used formulas used to estimate energy requirements, such as the Harris–Benedict Equation, are not accurate as originally defined in 1929 and underestimate or overestimate requirements [72, 73].The Mifflin–St Jeor equation is more likely than other equations to estimate RMR within 10% of the actual measured RMR when estimated from weight, height, and age [74] Multiple-regression analyses were employed to drive relationships between RMR and weight, height, and age for both sexes ($R^2 = 0.71$), but separation by sex did not affect its predictive value. RMR = 9.99 × weight (kg) + 6.25 × height (cm) − 4.92 × age (year) + 166 × sex (males, 1; females, 0) − 161. The Mifflin–St Jeor formula can be found in Table 20.1.

The United States Department of Agriculture (USDA) National Agricultural Library (NAL) is a leader in online global nutrition information including caloric expenditure equations for specific populations. The USDA NAL website can be accessed at https://www.nal.usda.gov/main/ [75]. The information found on the US USDA NAL provides sound nutritional guidance and assessment tools for evaluation. The tools provided on this site are interactive, and there is no charge for them. In fact, the government encourages people to use them, especially in light of the problems with healthy weight maintenance issues for all people. There are many links within this website that provide useful information. We will refer to a few important links within this website and list the URL for each specific site. The Food and Nutrition Information Center (FNIC) can be accessed at the USDA NAL website, or more specifically please see https://www.nal.usda.gov/fnic [76]. The FNIC website contains over 2500 links to current and reliable nutrition information. Dietary Reference Intake (DRI) developed by the United States Department of Health and Human Services (HHS) National Institute of Health (NIH) Office of Dietary Supplements can be accessed at https://ods.od.nih.gov/Health_Information/Dietary_Reference_Intakes.aspx [77]. Additional information on the DRI's can also be found at a link called Dietary Reference Intakes on the USDA NAL website, please see https://www.nal.usda.gov/fnic/dietary-reference-intakes) [78]. The Institute of Medicine (IOM) at one time developed caloric expenditure equations depending on activity level, gender, and age. The IOM has been changed to the National Academy of Medicine (NAM) and is now one of three academies that make up the National Academies of Sciences, Engineering, and Medicine (the National Academies) in the United States. Equations to estimate energy expenditure can be found at Calculators and Counters, https://www.nal.usda.gov/fnic/calculators-and-counters within the USDA NAL website [79].

Recommendations for caloric intake to maintain weight will vary depending on a person's age, sex, size, and level of physical activity and are provided in the Dietary Reference Intakes. This information can be downloaded in a PDF file

Table 20.1 An estimated energy expenditure prediction equation using the Mifflin–St. Jeor equation to determine resting metabolic rate (Adapted from Mifflin MD, St. Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals. Am J Clin Nutr. 1990;51:241–7 [74])

Step 1: *Estimate resting metabolic rate (RMR) using the Mifflin–St. Jeor equation*	
RMR = 9.99 × weight (kg) + 6.25 × height (cm) − 4.92 × age (year) + 166 × sex (males, 1; females, 0) − 161	
Step 2: *Determine additional caloric requirements based on level of activity*	
Physical activity level	Percentage above resting level
Bed rest	10
Quiet rest	30
Light activity	
Moderate activity	60–80
Heavy activity	100
Additional caloric requirements = RMR × percentage above resting level	
Step 3: *Determine predicted total energy expenditure (TEE)*	
TEE = RMR + additional caloric requirements based on activity	

Table 20.2 Physical activity level (PAL) index and physical activity coefficient (PA) used to derive estimated energy requirements (EER) for women. (Adapted from Food and Nutrition Board. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients) National Academy Press; Washington (DC): 2005 [81])

PAL	Sedentary (1.0–1.39)	Low active (1.4–1.59)	Active (1.6–1.89)	Very active (1.9–2.5)
	Typical daily living activities (e.g., household tasks, walking to the bus)	Typical daily living activities + 30–60 min of daily moderate activities (e.g., walking at 5–7 km/h)	Typical daily living activities + at least 60 min of daily moderate activities	Typical daily living activities + at least 60 min of daily moderate activities and an additional 60 min of vigorous activity or 120 min of moderate activity
PA at 4 levels	*PA (level 1)*	*PA (level 2)*	*PA (level 3)*	*PA (level 4)*
Girls 3–18 years	1.00	1.16	1.31	
Women 19 years+	1.00	1.12	1.27	1.45

entitled, *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements,* from the IOM at https://doi.org/10.17226/11537 or purchased as a book from this site [80]. Tables 20.2 and 20.3 list equations for females from the Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids Consensus Report [81]. Appendix 1 lists the estimated caloric needs based on activity levels from the IOM's Dietary Reference Intakes Research Synthesis: Workshop Summary [81].

Although a self-reported food nutritional assessment may misrepresent total caloric intake because of underreporting, it does provide valuable information to aid in nutritional counseling. Table 20.4 provides guidelines for an exercise nutritionist to help physically active individuals, particularly competitive athletes, achieve energy balance. These guidelines are from the American College of Sports Medicine, the American Dietetic Association, and the Dietitian of Canada Joint Position Statement [82].

A nutritional assessment consists of collecting and evaluating a number of types of information. These include a brief patient history; results of a physical examination (performed by a physician); anthropometric data such as height, weight, body mass index, and percentage of body fat; and finally, some biochemical data that are obtained through blood evaluation. This laboratory testing focuses on serum proteins such as albumin, prealbumin, and retinol-binding protein; creatinine height index; and overall immune status. The initial review process serves a number of functions. It allows for the identification of nutritional and medical risk factors, existing nutritional deficiencies, and past nutritional problems.

The next step is a dietary assessment. The purpose of the dietary assessment is to identify a person's eating habits and to estimate their average daily nutrient intake. Through a variety of methods, information should be obtained on the amount and variety of foods eaten. As already mentioned, the simplest method of assessment is to have the individual keep a daily dietary intake record. Because intake tends to vary from day to day, a 3-day food record is more accurate than a 24-h recall. The dietary intake recording is more accurate if the recalled period is longer. However, more coopera-

Table 20.3 Equations to estimate energy requirement. (Adapted from Food and Nutrition Board. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients) National Academy Press; Washington (DC): 2005 [81])

Children and adolescents 3–18 years	
Estimated energy requirement (kcal/d) = Total energy expenditure + energy deposition	
Girls	
3–8 years	
EER = 135.3 − (30.8 × age [year]) + PA × [(10.0 × weight [kg]) + (934 × height [m])] + 20	
9–18 years	
EER = 135.3 − (30.8 × age [year]) + PA × [(10.0 × weight [kg]) + (934 × height [m])] + 25	
Adults 19 years and older	
Estimated energy requirement (kcal/d) = Total energy expenditure	
Women	
EER = 354 − (6.91 × age [year]) + PA × [(9.36 × weight [kg]) + (726 × height [m])]	
Pregnancy	
Estimated energy requirement (kcal/d) = Nonpregnant EER + pregnancy energy deposition	
1st trimester	EER = Nonpregnant EER + 0
2nd trimester	EER = Nonpregnant EER + 340
3rd trimester	EER = Nonpregnant EER + 452
Lactation	
Estimated energy requirement (kcal/d) = Nonpregnant EER + Milk energy output − Weight loss	
0–6 months postpartum	EER = Nonpregnant EER + 500–170
7–12 months postpartum	EER = Nonpregnant EER + 400–0

Note: These equations provide an estimate of energy requirements. Relative body weight (i.e., loss, stability, gain) is the preferred indicator of energy adequacy. *EER* estimated energy requirement, *PA* physical activity coefficient. See Table 20.2 to find the appropriate PA value to use in these equations

Table 20.4 How exercise nutritionists can help female athletes maintain energy balance. (Adapted from Thomas DT, Erdman KA, Burke LM. American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. Med Sci Sports Exerc. 2016;48 (3):543–68 [82])

An athlete's energy requirements depend on the periodized training and competition cycle and will vary from d to d throughout the yearly training plan, relative to changes in training volume and intensity. Factors that increase energy needs above normal baseline levels include: exposure to cold or heat, fear, stress, high altitude exposure, some physical injuries, specific drugs or medications Athletes should be educated about energy requirements for their sport and the role of food in fueling the body. Female athletes should be educated about the female athlete triad and the long-term health consequences of inadequate energy intake. Energy availability, which considers energy intake in relation to the energy cost of exercise, sets an important foundation for health and the success of sports nutrition strategies
Unrealistic weight and body composition goals should be discouraged and a single and rigid "optimal" body composition should not be recommended for any event or group of athletes. Extreme methods of weight control can be detrimental to health and performance. Athletes need assistance in setting appropriate short-term and long-term weight goals and understanding nutritional practices that can safely and effectively increase muscle mass or reduce body fat/weight. Weight loss strategies should be aimed to achieve a slightly negative energy balance leading to a slow rather than rapid rate of weight loss. An intake of approximately minus 250–500 kcal/d while either maintaining or slightly increasing energy expenditure and increasing can achieve progress towards short-term body composition goals over approximately 3–6 weeks. Increasing dietary protein intake (2.3 vs 1 g/kg/d) will help to retain muscle mass while losing weight and body fat. Fat-free mass and performance would be better preserved in athletes who minimize weekly weight loss to <1% per week
Athletes should consume diets that provide at least the recommended dietary allowance and adequate intake of all micronutrients. Athletes who restrict energy intake or use severe weight-loss practices, eliminate complete food groups from their diet, or follow other extreme dietary philosophies are at the greatest risk of micronutrient deficiencies
In general, vitamin and mineral supplements are unnecessary for the athlete who consumes a diet providing high energy availability from a variety of nutrient-dense foods. If an athlete is following an energy-restricted diet or is unwilling or unable to consume sufficient dietary variety, supplementation may be necessary, but supplementation should be appropriately individualized by their sports dietitian
Vegetarian athletes may be at risk for low intakes of energy as well as protein, fat, creatine, carnosine, n-3 fatty acids, and key micronutrients such as iron, calcium, riboflavin, zinc, and vitamin B-12, so athletes choosing this option need further advice and close monitoring by their sports dietitian

tion and collaboration are needed. Based on experience, the optimum dietary evaluation recall should be 4 days in length, which should include a holiday (weekend day). If a longer period is needed for more information about the intake of special micronutrients, a 4-day period should be repeated as many times as needed in order to have the required length of time for the analysis. This method allows the practitioner to be able to gather information about changes in food habits because of seasonality [83]. However, methods only reflect the person's current diet, not eating habits, established over a long period of time. It is important to recognize that self-reported estimates of food intake are biased and many times do not provide an accurate estimation of food intake; therefore, these should only be used as a guide. A food frequency questionnaire is also helpful to determine eating habits. Appendices 2 and 3 [84] provide examples of nutrition and food frequency questionnaires, respectively, that can be used to gather information.

If the practitioner or the athlete has access to the Internet, there is actually no need to buy a computer program to assess nutritional adequacy. However, nutritional programs should be used for an athlete's diet. As stated earlier in the chapter, dietary assessment tools can be found at the USDA NAL FNIC at https://www.nal.usda.gov/fnic [76]. The tools at this site range from a nutritional analysis tool to an activity calorie counter.

If there is a need to install a dietary assessment tool on a lab or a personal computer, there are numerous nutritional assessment software programs on the market—most are under $60.00. Most of these programs contain more than 23,000 food items and are upgradable to allow new food items to be entered by the user. One such program is the Diet Analysis Plus Online Product tenth Edition by Diet Analysis which has a software download for Windows and Mac products. This program allows for a 7-day food intake per individual. It takes into account height, weight, and activity level. It also computes daily and weekly values for recommended daily allowance (RDA) and energy expenditure. In addition, it gives a specific breakdown of nutrients and has the ability to generate graphs, charts, and reports. These programs allow a nutritional novice to enter their own data concerning their individual diet and nutrition and receive easy-to-understand information. The use of nutritional assessment software is relatively widespread because of its low cost and availability. Many of these tools and online programs are perfect devices for coaching young women to be aware of their nutritional and caloric needs.

Even though the determination of energy needs is relatively straightforward, behavior change is complex and not so readily understood. Nutritional educational projects must be carefully designed by a multi-professional team to be successful in facilitating athletes to change their behavior [23, 85–88]. The education should involve not only the sportive women but also coaches and family so that skills are learned for adopting healthy eating habits for all involved in the behavior change.

20.4 Future Directions

20.4.1 Nutritional Guidelines for the Female Athlete

20.4.1.1 Priority Is Meeting Energy Needs

Meeting energy needs is the first priority for the female athlete. Studies consistently state that female athletes do not take in enough calories. Despite the known causal relation between low EA and menstrual disturbances, appropriate practical guidelines for optimal energy balance in exercising women remain largely undefined and specific for each female (to maintain correct ovarian function). As stated earlier in this chapter EA, (DEI − EEE)/FFM is not the same as energy balance. Simplistically, energy balance is defined as DEI minus TEE, not just EEE. More specifically, energy balance is defined as a state when energy intake (the sum of energy from foods, fluids, and supplement products) equals energy expenditure (the sum of energy expended for basal metabolism, the thermal effect of food, and the thermal effect of any voluntary physical activity including exercise).

An international consortium of professionals dedicated to optimizing the health of female athletes once known as the Female Athlete Triad Coalition, now known as the Female and Male Athlete Triad Coalition provides information for the general public and professionals on their website, https://www.femaleandmaleathletetriad.org [89], to prevent deleterious health outcomes from inadequate energy intake whether that pertains to EA or energy balance. Table 20.5 shows some recommendations for athletes to help maintain optimal energy intake [90].

When low EA is present, dietetic treatment should involve increasing energy intake, reduction in EEE or both. To do so, individual preferences should be taken into account. Treatments will also depend on the competition period. Introducing a resting day to the training program is of help but decreasing the training load is not always well accepted by all athletes and coaches. Energy increase can be done through common food or by energy-rich food supplements and it is advised to be gradual, beginning with an approximately 20–30% increase in caloric intake over baseline energy needs or the amount of energy required to gain approximately 0.5 kg every 7–10 days). This would represent a gradual increase of 300 to 600 kcal/day (1.2–2.4 MJ/day). The energy intake target should be around 45 kcal/kg FFM/day [3, 91].

Table 20.5 Recommendations to get enough energy for active women. (Adapted from Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, Warren MP. American College of Sports Medicine Position stand. The female athlete triad. Med Sci Sports Exerc. Oct 2007;39(10):1867–1882 [90])

Balance calories
Enjoy your food but eat less. Be aware of hunger and fullness cues. Avoid oversize portions
Make half your plate of fruits and vegetables
Switch to fat-free or low-fat milk and dairy products
Make half your grain whole grains
Cut back on foods high in solid fats, added sugar, and salt
Choose low-sodium products. Read nutritional labels
Drink water instead of sugary drinks

20.4.1.2 Macro and Micronutrients for Athletes

A joint position statement by the American College of Sports Medicine, the American Dietetic Association, and the Dietitians of Canada stated that a diet substantially different from that recommended in the Dietary Guidelines for Americans or the Nutrition Recommendations for Canadians (55–58% of energy from carbohydrate, 12–15% of energy from protein, and 25–30% of energy from fat) is not needed for athletes [59]. It is generally recommended that an athlete's diet should be composed of approximately 55–60% carbohydrate, 20–25% fat, and 12–15% protein [59]. In 2016, the American College of Sports Medicine and the Academy of Nutrition and Dietetics Dietitians of Canada again issued a Joint Position Statement on Nutrition and Athletic Performance. There were four themes: (1) Nutrition for Athlete Preparation; (2) Performance Nutrition: Strategies to Optimize Performance and Recovery for Competition and Key Training Sessions; (3) Special Populations and Environments; and (4) Roles and Responsibilities of the Sports Dietitian [82]. Table 20.6 summarizes the evidence in the 2016 Joint Position Statement [82].

The Dietary Guidelines for Americans is published jointly every 5 years by the Department of Health and Human Services (HHS) and the USDA. The 2020–2025 Dietary Guidelines for Americans can be downloaded at https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025 [92]. The Dietary Guidelines describe a healthy diet as one that emphasizes fruits, vegetables, whole grains, and fat-free or low-fat milk and milk products; includes lean meats, poultry, fish, beans, eggs, and nuts; and is low in saturated fats, trans fats, cholesterol, salt (sodium), and sugar [93]. Although there are general food group categories, there are specific recommendations based on age, gender, and activity level.

The USDA ChooseMyplate Website (https://www.choosemyplate.gov/MyPlatePlan) [94] provides online tools that aid and allow one to customize according to age, gender, and physical activity level. Table 20.7 summarizes the recommendations for a healthy diet according to Choose my Plate (USDA) for a standard active female of 25 years.

A basic premise of the Dietary Guidelines is that food guidance should encourage individuals to achieve the most recent nutrient intake recommendations, referred to collectively as the DRIs. Online DRIs are provided for all age

Table 20.6 Joint position statement on nutrition and athletic performance. (Reprinted with permission from Thomas DT, Erdman KA, Burke LM. American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance, Medicine & Science in Sports & Exercise, 48(3), 543–568, ©2016, https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx [82])

• Athletes need to consume energy that is adequate in amount and timing of intake during periods of high-intensity and/or long-duration training to maintain health and maximize training outcomes. Low energy availability can result in unwanted loss of muscle mass; menstrual dysfunction and hormonal disturbances; sub-optimal bone density; an in- creased risk of fatigue, injury, and illness; impaired adaptation and a prolonged recovery process
• The primary goal of the training diet is to provide nutritional support to allow the athlete to stay healthy and injury-free while maximizing the functional and metabolic adaptations to a periodized exercise program that prepares him or her to better achieve the performance demands of the event. While some nutrition strategies allow the athlete to train hard and recover quickly, others may target an enhanced training stimulus or adaptation
• The optimal physique, including body size, shape and composition (e.g., muscle mass and body fat levels), depends upon the sex, age, and heredity of the athlete, and maybe sport- and event-specific. Physique assessment techniques have inherent limitations of reliability and validity, but with standardized measurement protocols and careful interpretation of results, they may provide useful information. Where significant manipulation of body composition is required, it should ideally take place well before the competitive season to minimize the impact on event performance or reliance on rapid weight loss techniques
• Body carbohydrate stores provide an important fuel source for the brain and muscle during exercise and are manipulated by exercise and dietary intake. Recommendations for carbohydrate intake typically range from 3–10 g/kg BM/d (and up to 12 g/kg BM/d for extreme and prolonged activities), depending on the fuel demands of training or competition, the balance between performance and training adaptation goals, the athletes total energy requirements and body composition goals. Targets should be individualized to the athlete and his or her event, and also periodized over the week, and training cycles of the seasonal calendar according to changes in exercise volume and the importance of high carbohydrate availability for different exercise sessions
• Recommendations for protein intake typically range from 1.2–2.0 g/kg BM/d but have more recently been expressed in terms of the regular spacing of intakes of modest amounts of high-quality protein (0.3 g/kg BM) after exercise and throughout the d. Such in- takes can generally be met from food sources. Adequate energy is needed to optimize protein metabolism, and when energy availability is reduced (e.g., to reduce BM/fat), higher protein intakes are needed to support MPS and retention of FFM
• For most athletes, fat intakes associated with eating styles that accommodate dietary goals typically range from 20 to 35% of total EI. Consuming 20% of energy intake from fat does not benefit performance and extreme restriction of fat intake may limit the food range needed to meet overall health and performance goals. Claims that extremely high-fat, carbohydrate-restricted diets provide a benefit to the performance of competitive athletes are not supported by current literature
• Athletes should consume diets that provide at least the recommended dietary allowance (RDA)/adequate intake (AI) for all micronutrients. Athletes who restrict energy intake or use severe weight-loss practices, eliminate complete food groups from their diet, or follow other extreme dietary philosophies are at the greatest risk of micronutrient deficiencies
• A primary goal of competition nutrition is to address nutrition-related factors that may limit performance by causing fatigue and a deterioration in skill or concentration over the course of the event. For example, in events that are dependent on muscle carbohydrate availability, meals eaten in the day(s) leading up to an event should provide sufficient carbohydrates to achieve glycogen stores that are commensurate with the fuel needs of the event. Exercise taper and a carbohydrate-rich diet (7–12 g/kg BM/d) can normalize muscle glycogen levels within ~24 h while extending this to 48 h can achieve glycogen super-compensation
• Foods and fluids consumed in the 1–4 h prior to an event should contribute to body carbohydrate stores (particularly, in the case of early morning events to re- store liver glycogen after the overnight fast), ensure appropriate hydration status and maintain gastrointestinal comfort throughout the event. The type, timing and amount of foods and fluids included in this pre-event meal and/or snack should be well trialed and individualized according to the preferences, tolerance, and experiences of each athlete
• Dehydration/hypohydration can increase the perception of effort and impair exercise performance; thus, appropriate fluid intake before, during, and after exercise is important for health and optimal performance. The goal of drinking during exercise is to address sweat losses which occur to assist thermoregulation. Individualized fluid plans should be developed to use the opportunities to drink during a workout or competitive event to replace as much of the sweat loss as is practical; neither drinking in excess of sweat rate nor allowing dehydration to reach problematic levels. After exercise, the athlete should restore fluid balance by drinking a volume of fluid that is equivalent to ~125–150% of the remaining fluid deficit (e.g., 1.25–1.5 L fluid for every 1 kg BM lost)
• An additional nutritional strategy for events of greater than 60 min duration is to consume carbohydrates according to their potential to enhance performance. These benefits are achieved via a variety of mechanisms which may occur independently or simultaneously and are generally divided into metabolic (providing fuel to the muscle) and central (supporting the central nervous system). Typically, an intake of 30–60 g/h provides benefits by contributing to muscle fuel needs and maintaining blood glucose concentrations, although, in very prolonged events (2.5+ h) or other scenarios where endogenous carbohydrate stores are substantially depleted, higher intakes (up to 90 g/h) are associated with better performance. Even in sustained high-intensity events of 45–75 min where there is little need for carbohydrates intake to play a metabolic role, frequent exposure of the mouth and oral cavity to small amounts of carbohydrates can still enhance performance via stimulation of the brain and central nervous system
• Rapid restoration of performance between physiologically demanding training sessions or competitive events requires an appropriate intake of fluids, electrolytes, energy, and carbohydrates to promote rehydration and restore muscle glycogen. A carbohydrate intake of ~1.0–1.2 g/kg/h, commencing during the early recovery phase and continuing for 4 to 6 h, will optimize rates of resynthesis of muscle glycogen. The available evidence suggests that the early intake of high-quality protein sources (0.25–0.3 g/kg BM) will provide amino acids to build and repair muscle tissue and may enhance glycogen storage in situations where carbohydrate intake is sub-optimal.
• In general, vitamin and mineral supplements are unnecessary for the athlete who consumes a diet providing high-energy availability from a variety of nutrient-dense foods. A multivitamin/mineral supplement may be appropriate in some cases when these conditions do not exist; for example, if an athlete is following an energy-restricted diet or is unwilling or unable to consume sufficient dietary variety. Supple- mentation recommendations should be individualized, realizing that targeted supplementation may be indicated to treat or prevent deficiency (e.g., iron, vitamin D, etc.)
• Athletes should be counseled regarding the appropriate use of sports foods and nutritional ergogenic aids. Such products should only be used after careful evaluation for safety, efficacy, potency and compliance with relevant anti-doping codes and legal requirements
• Vegetarian athletes may be at risk for low intakes of energy, protein, fat, creatine, carnosine, n-3 fatty acids, and key micronutrients such as iron, calcium, riboflavin, zinc, and vitamin B-12

Table 20.7 Example of specific recommendations for physically active females from 19 to 30 years from the US Department of Health and Human Services and the US Department of Agriculture, Dietary Guidelines for Americans. Example of personal plan designed using the SuperTracker tool from the USDA (https://www.choosemyplate.gov/MyPlatePlan) [94] for a woman 25 years old, with a BMI of 23 and who practices more than 60 min of moderate physical activity per day [93]

Calories	Allowance		
Total calories	2400 per d		
Food group	Food group amount	"What counts as"	Tips
Grains	8 ounces per d	1 ounce of grains equals:	Eat at least half of all the grains whole grains (4 ounces) Find whole grains by reading the nutrition facts label and ingredients list
		1 slice of bread	
		½ cup of cooked pasta, rice, or cereal	
		1 tortilla	
		1 pancake	
		1 ounce ready to eat cereal	
Vegetables	3 cups per d	1 cup of vegetables equals:	Choose a variety of colorful fresh, fresh frozen and canned vegetables- make sure to include dark green, red and orange choices
		1 cup raw or cooked vegetable	
		1 cup 100% vegetable juice	
		2 cup leafy salad green	
Fruits	2 cups per d	1 cup of fruit equals:	Select fresh, frozen, canned, and dried fruit more often than juice
		1 cup raw or cooked fruit	Maximize taste and freshness by adapting your choice to what's in season
		1 cup 100% fruit juice	Use fruits as snacks or dessert; add them to salads
		½ dried fruit	
Dairy	3 cups per d	1 cup dairy	Choose fat-free milk, yogurt, and soy beverages (soy milk) to cut back on your saturated fat
		1 cup milk	
		1 cup fortified soymilk	
		1 cup yogurt	
		1 ½ ounces natural cheese	
		2 ounces processed cheese	
Protein foods	6 ½ ounces per d	1 ounce of protein foods equals:	
		1 ounce lean meat, poultry, or seafood	Mix up your protein foods to include, seafood, beans and peas, unsalted nuts and seeds, soy products, eggs and lean meats and poultry
		1 egg	
		1 tablespoon peanut butter	
		½ ounce nuts or seeds	
		¼ cup beans or peas	
LIMIT Sodium to 2300 mg/d Saturated fat to 27 g/d Added sugars to 60 g/d			

groups and can be found at the USDA NAL website at https://www.nal.usda.gov/fnic/dietary-reference-intakes [77]. These nutrient intake levels should be achieved if there is a balance of macronutrients in the female athlete's diet and the foods that are chosen are nutrient-dense.

Even though the fuel burned during exercise depends on the intensity and duration of the exercise, the sex of the athlete and prior nutritional status, an increase in the intensity of the exercise will increase the contribution of carbohydrates. A low-carbohydrate diet rapidly compromises energy reserves for vigorous physical activity or regular training. As the length of the exercise continues, the source of the carbohydrate may shift from the muscle glycogen pool to circulating blood glucose, but if the blood glucose cannot be

maintained, the intensity of the exercise will decrease [32]. Additionally, carbohydrate plays an important role as a protein sparer during exercise. Carbohydrate availability inhibits protein catabolism in exercise [95], although studies have documented that females have a greater capacity for lipid oxidation during exercise. This fact allows them to maintain normoglycemia (the presence of a normal concentration of glucose in the blood) and preserve muscle glucose during long sports events. If an athlete consumes 60–65% of their calories from carbohydrates and energy balance is being maintained, sufficient muscle glycogen stores should be maintained from day to day. The athlete also has a lower amino acid breakdown during exercise if carbohydrate intake is 60–65% of their total caloric intake [96].

Nutritional strategies are needed for optimal recovery of fuel deposits following exercise. Studies have demonstrated improved glycogen repletion when carbohydrates were consumed immediately after exercise instead of some hours later [32]. Carbohydrate-rich meals are recommended during recovery, preferably with a high glycemic index. Amino acids act synergistically when co-ingested with carbohydrates to potentiate insulin secretion and glycogen storage [97] Adding 0.2–0.5 g of protein per day per kg of BM to carbohydrates in a 3:1 (carbohydrate:protein) ratio is recommended [98, 99]. Appropriate recovery foods with a favorable mix of carbohydrates and protein include yogurt with granola; crackers, cheese, and fruit; a small smoothie; a bagel with soy nut, almond, or peanut butter; and jam or honey [98]. No difference has been observed in terms of glycogen repletion whether the sources of carbohydrates are solid or liquid [32].

Protein requirements are slightly increased in highly active people and recommended intakes range between 1.2 and 2.0 g/kg/day [82]; that is around 10–35% of calorie intake [59]. Protein requirements for endurance athletes are 1.2–1.4 g/kg BM per day whereas those for resistance-trained and strength-trained athletes may be as high as 1.6–1.7 g/kg of BM per day. In case of energy restriction or during periods of sudden inactivity recommendations increase to 1.6–2.4 g/kg [99]. Foods containing proteins with high biological availability (a high retention and utilization rate by the body) should be emphasized [99]. Muscular protein synthesis is optimized in response to exercise by the consumption of high biological value protein, providing ~10 g of essential amino acids in the early recovery phase (0–2 h after exercise) [81, 100]; which is equivalent to a recommended protein intake of 0.25–0.3 g/kg BM. Research suggests that consuming 20 g of protein (or an equivalent of 0.3–0.4 g/kg) 5–6 times per day may be preferable to a larger protein intake less frequently [100, 101]. This amount should be increased to 0.4–0.5 g/kg in the case of mixed meals that slow protein digestion/absorption [100]. Meats, fish, eggs, and dairy products offer complete sources of protein (providing all essential amino acids) [102].

Fat intake should not be restricted provided that the fat intake is low in saturated fats and trans fats; there is no benefit in consuming a diet with less than 15% of energy from fat as compared with 20–25% [59]. In a similar way, to date, there is not enough evidence to recommend high-fat low carbohydrate diets [82, 101] Even if some research propose that the shift to fatty acids and ketones as primary fuels when dietary carbohydrate is restricted, could be of benefit for some athletes, especially for endurance sports practitioners [103, 104] the actual evidence shows that in general high fat-low carbohydrate diet appear to reduce rather than enhance metabolic flexibility by reducing carbohydrate availability and capacity to use it effectively as an exercise substrate [82]. To maintain BM the majority of athletes need an energy intake of around 40–50 kcal/kg/day which in practical terms is very hard to obtain solely by increasing carbohydrate consumption; some authors remark that such a large shift is likely to lead to a deficit in some essential proteins and lipids and compromise nitrogen balance necessary to maintain normal sexual steroid hormone levels. So for athletes, the acceptable range of fat intake is from 10 to 35% of caloric intake [59].

Micronutrients play an important role in energy production, hemoglobin synthesis, maintenance of bone health, adequate immune function, and protection of the body against oxidative damage. Routine exercise may also increase the turnover and loss of these micronutrients from the body. As a result, greater intakes of micronutrients may be required to cover increased needs for the building, repair, and maintenance of lean body mass in athletes [98].

Vitamins B1, B2, B3, and B6, pantothenic acid, and biotin are crucial in energy metabolism, and many athletes have a diet low in those vitamins although few research has been made about the consequences of vitamin B-deficient diets in athletes either for their health or for sports performance. Low intakes of folic acid or vitamin B12 can lead to anemia. Furthermore, some recent research points out that increasing evidence exists for a possible fourth component of the triad, *endothelial dysfunction*, and this finding is a cause for concern because the sentinel event in cardiovascular disease pathogenesis is impaired endothelial function [3, 105–108].

It has been documented that folic acid supplementation can improve endothelium-dependent vasodilation, and some researchers showed that supplementation with 10 mg/day of folic acid for 4–6 weeks significantly improved flow-mediated dilation in eumenorrheic and amenorrhoeic athletes [109–111]. More research is needed to define the optimal dosage and length of treatment with folic acid in athletes with endothelial dysfunction.

Exercise increases oxygen consumption by 10- to 15-fold, thus increasing oxidative stress. Even though short-term exercise may increase the levels of lipid peroxide by-products, habitual exercise has been shown to result in an augmented antioxidant system and reduced lipid peroxida-

tion [82, 112, 113]. Thus, a well-trained athlete may have a more developed endogenous antioxidant system than a sedentary person. Whether exercise increases the need for antioxidant nutrients remains controversial. There is little evidence that antioxidant supplements enhance physical performance. Nevertheless, a suboptimal dietary intake of antioxidants such as vitamin E, vitamin C, or selenium may lead to health problems [114, 115].

Vitamin D status is another important factor in preserving bone health. Athletes who live in northern latitudes or who train primarily indoors throughout the year, such as gymnasts and figure skaters, are at risk for poor vitamin D status, especially if they do not consume foods fortified with vitamin D [82, 116]. While there is still limited evidence to support vitamin D as a performance enhancer, it should be considered the important to optimal vitamin D status to prevent stress fractures and muscle injury [117] Supplementation with calcium and vitamin D should be determined after nutrition assessment. Current recommendations for athletes with disordered eating, amenorrhea, and risk for early osteoporosis are 1000–1300 mg of elemental calcium and 400–800 IU of vitamin D per day [91].

Iron is required for the formation of oxygen-carrying proteins, hemoglobin and myoglobin, and for enzymes involved in energy production. Iron depletion (low iron stores) is one of the most prevalent nutrient deficiencies observed among female athletes [118]. Iron deficiency, with or without anemia, can impair muscle function and limit work capacity. Low-energy diets or vegetarian diets, with poor availability sources of iron, are common causes of iron-deficit anemia. Nutritional assessment and counseling should be done before anemia appears and supplements recommended if needed. Table 20.8 summarizes key points regarding nutritional recommendations for the physically active person [34].

Research in exercise nutrition indicates that the large number of teenagers and adults, including competitive athletes, who exercise regularly to keep fit do not require additional nutrients beyond those obtained through the regular intake of a nutritionally well-balanced diet if energy needs are being met [59]. Athletes should be advised that the intake of vitamin and mineral supplements does not improve performance unless a deficiency has been previously accurately diagnosed [82, 119].

20.4.2 The Importance of Hydration Before, During, and After Exercise

Water balance is essential for a good health. As we do not have a real "water body store" we need to replace water losses on a day-to-day basis. Exercise increments body temperature and can elicit high sweat rates and water and electrolyte losses, particularly in warm-hot weather.

Table 20.8 Summary of recommendations for macronutrients and energy intake for the physically active female [34]

• Diets should be rich in nutrient-dense foods and emphasize fruits and vegetables, cereals and whole grains, nonfat and low-fat dairy products, legumes, nuts, fish, poultry, and lean meats. Female athletes' diets have been found to be low on iron, calcium, zinc, vitamin B6, and folate. They should make sure that their diet contains foods that contain these vitamins and minerals
• The intensity of daily physical activity largely determines energy intake requirements
• Studies consistently show that female athletes are not consuming enough energy to support their activity levels. Energy intakes of well-trained female athletes range from 1931 to 3573 kcal. However, during high-volume training, such as in swimming, total daily energy may increase to 5593 kcal daily. Low energy and nutrient intake places athletes at greater risk for nutrition-related disorders such as amenorrhea, osteoporosis, iron-deficiency anemia, and eating disorders. A minimum of 30–40 kcal/kg/LBM/d are needed to avoid functional amenorrhea
• Precise recommendations do not exist for daily lipid and carbohydrate intake
• Fat intake should not be restricted provided that the fat intake is low in saturated fats and trans fats; there is no benefit in consuming a diet with less than 15% of energy from fat as compared to 20–25%. An acceptable lipid intake for physically active individuals ranges from 10 to 35% of caloric intake
• Carbohydrate intake is important for the physically active person. General recommendations for carbohydrates range between 6 and 10 g/kg of BM per d. This range represents approximately 55–65% carbohydrate intake. Carbohydrates should be predominantly starches from fiber-rich, unprocessed grains, fruits, and vegetables. A low-carbohydrate diet rapidly compromises energy reserves for vigorous physical activity or regular training. Successive days of hard training gradually deplete carbohydrate reserves, even when maintaining the recommended carbohydrate intake. This could lead to "staleness," making continued training more difficult
• Studies have demonstrated improved glycogen repletion when carbohydrates were consumed immediately after exercise instead of some hours later. Carbohydrate-rich meals are recommended during recovery, preferably meals with a high glycemic index. Adding 0.2–0.5 g of protein per d per kg of BM to carbohydrates in a 3:1 (carbohydrate:protein) ratio is recommended
• Protein requirements are slightly increased in highly active people. Protein requirements for endurance athletes are 1.2–1.4 g/kg BM per d whereas those for resistance- and strength-trained athletes may be as high as 1.6–1.7 g/kg of BM per d. According to the dietary reference intakes, acceptable macronutrient distribution ranges of protein for adults are 10–25%
• Excessive sweating during exercise causes loss of body water and related minerals. Mineral loss should be replaced following exercise through well-balanced meals. Athletes should be well hydrated before beginning to exercise. During exercise, optimal hydration can be facilitated by drinking 150–350 mL (6–12 oz.) of fluid at 15–20-min intervals, beginning at the start of the exercise. Consuming up to 150% of the weight lost during an exercise session may be necessary to cover losses in sweat and urine excretion. Enhancing the palatability of the ingested fluid is one way to help promote fluid consumption, before, during, or after exercise. Fluid palatability is influenced by several factors including temperature, sodium content, and flavoring. The preferred water temperature is often between 15 and 21 °C, but this and flavor preference vary greatly between individuals and cultures

There is considerable variability in water and electrolyte losses between individuals and between different activities, and if sweat water and electrolyte losses are not replaced, then the person will dehydrate. Dehydration can impair exercise performance, contribute to serious health problems such as heat illness, and exacerbate symptomatic rhabdomyolysis [120, 121]. An excess of water intake is also possible but less common. Excessive water intake leads to hyponatremia with severe health consequences [120].

Athletes should be well hydrated before beginning to exercise. In addition to drinking generous amounts of fluid in the 24 h before an exercise session, and 4-h pre-exercise, they should consume 5–7 mL/kg BM. Consuming beverages with sodium (20–50 mEqI/L) and/or small amounts of salted snacks or sodium-containing foods at meals will help to stimulate thirst and retain the consumed fluids [82, 120]. During exercise, individuals should periodically drink depending on environmental conditions, exercise intensity and duration, and opportunities to drink. Optimal hydration can be facilitated by drinking 150–350 mL (6–12 oz) of fluid at 15- to 20-min intervals, beginning at the start of the exercise [122, 123]. In most cases, athletes do not consume enough fluids during exercise to balance fluid losses and thus complete their exercise sessions dehydrated to some extent. Consuming up to 150% of the weight lost during an exercise session may be necessary to cover losses in sweat and urine excretion [124].

Over-hydration is typically seen in recreational athletes since their work outputs and sweat rates are lower than competitive athletes, while their opportunities and belief in the need to drink, are usually greater. Women generally have a smaller body size and lower sweat rates than males and appear to be at greater risk of overdrinking, which is the primary cause of hyponatremia (blood sodium <135 mmol/L), to prevent this sodium should be ingested during exercise when large sweat sodium losses occur [82].

Following exercise, the goal is to fully replace any fluid and electrolyte deficit. The general guidelines are to consume 20 oz. of fluid (only fluid or fluid plus foods with a high % of water) for every lb lost during exercise [98]. If the recovery time is sufficient, consumption of normal meals and snacks with a sufficient volume of plain water will be enough, provided the food contains sufficient sodium to replace sweat losses. When more rapid rehydration is warranted, a sports beverage is preferred because it provides fluid, carbohydrates, and electrolytes.

The composition of the consumed fluids can be important. The IOM provided general guidance for the composition of "sports beverages" for persons performing prolonged physical activity in hot weather. They recommend that these types of fluid replacement beverages might contain approximately 20–30 meq/L sodium (chloride as the anion), 2–5 meq/L potassium, and 5–10% carbohydrate. These components also can be consumed by nonfluid sources such as gels, energy bars, and other foods [124, 125].

20.5 Concluding Remarks

For female athletes, energy balance must be maintained for optimum health and athletic performance. The minimum amount of calories a female should consume to prevent functional amenorrhea is 30 kcal/kg/LBM. A caloric intake less than this affects many of the hormones involved in glucose availability, metabolism, and reproduction. Historically, female athletes, competing in sports where leanness increases performance, have not taken in enough calories to meet their energy needs. A joint position statement by the American College of Sports Medicine, the American Dietetic Association, and the Dietitians of Canada states that a diet substantially different from that recommended in the Dietary Guidelines for Americans or the Nutrition Recommendations for Canadians is not needed for athletes [82]. It is recommended that an athlete's diet should consist of nutrient-dense food and beverages within and among the basic good groups while choosing foods that limit the intake of saturated and trans fats, cholesterol, added sugars, salt, and alcohol. Athletes should also be well hydrated before beginning to exercise and should drink enough fluid during and after exercise to balance fluid losses.

Appendix 1

Estimated calorie requirements (in kilocalories) for specific age groups at three levels of physical activity[a] using the Institute of Medicine equations [80] (Adapted from National Academies of Sciences, Engineering and Medicine. Institute of Medicine. Dietary reference intakes: the essential guide to nutrient requirements. Washington, DC: The National Academies Press. 2006)

		Activity level[b, c, d]		
Gender	Age (years)	Sedentary[b]	Moderately active[c]	Active[d]
Child	2–3	1000	1000–1400[e]	1000–1400[e]
Female	4–8	1200	1400–1600	1400–1800
	9–13	1600	1600–2000	1800–2000
	14–18	1800	2200	2400
	19–30	2000	2000–2200	2400
	31–50	1800	2000	2200
	51+	1600	1800	2000–2200
Male	4–8	1400	1400–1600	1600–2000
	9–13	1800	1800–2200	2000–2600
	14–18	2200	2400–2800	2800–3200
	19–30	2400	2600–2800	3000
	31–50	2200	2200–2600	2800–3000
	51+	2000	2200–2400	2400–2800

[a] These levels are based on estimated energy requirements (EER) from the Institute of Medicine Food and Nutrition Board. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients) National Academy Press;

Washington (DC): 2005. https://doi.org/10.17226/10490 Accessed July 15, 2020 [80]

These estimated caloric requirements are calculated by gender, age, and activity level for reference-sized individuals. "Reference size," as determined by IOM, is based on median height and weight for ages up to 18 years and median height and weight for that height to give a BMI of 21.5 for adult females and 22.5 for adult males. The estimates are rounded to the nearest 200 calories

[b] Sedentary means a lifestyle that includes only the light physical activity associated with typical day-to-day life

[c] Moderately active means a lifestyle that includes physical activity equivalent to walking about 1.5 to 3 miles per day at 3 to 4 miles per hour, in addition to the light physical activity associated with typical day-to-day life

[d] Active means a lifestyle that includes physical activity equivalent to walking more than 3 miles per day at 3 to 4 miles per hour, in addition to the light physical activity associated with typical day-to-day life

Appendix 2 Nutrition questionnaire with 3-day recall (Adapted from Dynamics of nutrition support: assessment, evaluation, and implementation. Krey SH, Murray RL, Appleton-Century-Crofts, 1986 [84])

1. Name _____
2. Age _____ Circle: Male or Female
3. Height _____ Weight _____
4. Usual wt. _____ Desired wt. _____
5. Have you lost weight in the last month? Yes No
   If yes how much _____
6. Have you gained weight in the last month? Yes No
   If yes how much _____
7. Please circle activity level:
   Sedentary (sit most of the day)
   Active (move most of the day)
   Very active (aerobic exercise 3× a week)
   Athletic (aerobic exercise 5× a week)
8. Do you have any food allergies or intolerance? If yes, what are they?

   _____
9. Does your medical history include any of the following: (circle any that apply)
   Diabetes, Ulcers, Heart Disease, Hypertension, Stroke, Vascular disease, Renal disease, or Gastrointestinal disease

   _____
10. Has your physician recommended any special diet? If so, what type of diet?

    _____
11. What type of surgeries have you had?

    _____
12. Are you currently taking any medication(s)? Please specify them all. (Please include all over-the-counter medication and/or all vitamin, mineral, or herbal supplements.)

    _____

    _____
13. Do you restrict any foods due to religious beliefs? If yes, what type?

    _____
14. Please write a food diary of everything that you ate in the past 3 days (or the last 72-h period). Include portion size of foods eaten, the type of food, and how it was prepared. Be specific: 1 cup skim milk, baked chicken breast, ½ cup green beans, etc.

Day One:

Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____

Day Two:

Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
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Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____

Day Three:

Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____

Item: _____ Amount: _____
Item: _____ Amount: _____
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Item: _____ Amount: _____
Item: _____ Amount: _____
Item: _____ Amount: _____

Appendix 3 Food Frequency Questionnaire (Adapted from Dynamics of nutrition support: assessment, evaluation, and implementation. Krey SH, Murray RL, Appleton-Century-Crofts, 1986 [84])

The following questionnaire is designed to help the dietician determine the frequency of food use. It should be used in conjunction with a 3-day recall of food intake. Record as accurately as possible. Amounts should be recorded in measurable amounts (e.g., cups, pounds, teaspoons), and frequencies should be recorded in measurable amounts of time (e.g., 1 day, 3 months, 2 weeks).

1. Do you drink milk? If so, what kind?
   _____Whole
   _____ 2 %
   _____Skim
   _____Other
   How much? _____
2. Do you use fats? If so, what kinds?
   _____Butter
   _____Margarine
   _____ Oil
   _____Other
   How much? _____
3. How often do you eat meat? _____
   Poultry?_____ Fish?_____
   Eggs? _____ Cheese? _____ Cold cuts? _____
   Peanut butter? _____ Dried beans? _____
4. Do you eat snack foods? If so which ones? _____
   _____
   How often? _____
   How much? _____
5. What vegetables do you eat? How often?
   (a) Broccoli _____,
   Green peppers _____,
   Cooked greens _____,
   Carrots _____,
   Sweet potatoes _____,
   Winter squash _____
   (b) Tomatoes _____,
   Raw cabbage _____,
   White potatoes _____,
   Other raw vegetables _____
   (c) Asparagus _____, beets _____, cauliflower _____, corn _____, celery _____, peas _____, lettuce _____, green beans_____
6. What fruits do you eat? How often?
   (a) Apples/applesauce_____, apricots _____, bananas _____, berries _____, cherries _____, grapes _____, peaches _____, pears _____, plums _____, pineapple _____, raisins _____, others_____
   (b) Oranges/orange juice _____, grapefruits/grapefruit juice _____
7. Bread and cereal products?
   (a) How much bread do you eat with meals? _____
   Between meals? _____
   _____
   (b) Do you eat cereal daily? _____ Weekly? _____ Cooked? _____ Dry? _____
   (c) How often do you eat foods such as rice, macaroni, and spaghetti? _____
8. Do you eat canned soup? _____
   Homemade soup? _____
   What kinds? _____
   How often? _____
9. Do you use salt? _____ Do you salt foods before you taste them? _____
   Do you cook with salt? _____ Do you crave salt/salty foods? _____
10. How many teaspoons of sugar or honey do you use per day? (Include sugar used on cereals, toast, fruit, and bever-ages)_____
11. Do you drink any of the following?
    Water? _____ How much? _____
    Coffee, tea, decaf, etc.?_____ How much? _____
    Carbonated beverages_____ How much? _____
    Beer, wine, liquor?_____ How much? _____
    Others?_____ How much? _____

12. Are there any other foods not listed that you eat frequently?
    _____
    _____
    _____
13. Please rank how you determine your choice of frequently eaten foods?
    Caloric content _____
    Taste _____
    Availability _____
    Price _____
    Nutrient content (fat, carbohydrate, protein) _____

Chapter Review Questions

1. The adult female human brain oxidizes approximately _____ of glucose each day at a continuous rate, and this must be provided daily by dietary _____, because the brain's rate of energy expenditure can deplete liver glycogen stores in <1 day.
   (a) ~50 g, carbohydrate
   (b) ~30 g, protein
   (c) ~80 g, carbohydrate
   (d) ~40 g, fat
2. According to Loucks et al. (1998, 2003), functional amenorrhea, in young exercising women occurs primarily because of:
   (a) excessive exercise stress
   (b) excessive psychological stress related to competition and performance
   (c) dietary energy restriction or 'energy drain'
   (d) protein availability
3. Reproductive function in women critically depends on the pulsatile release of _____ from neurons in the arcuate nucleus of the hypothalamus and on the consequent pulsatile release of _____ from the pituitary.
   (a) follicle stimulating hormone (FSH), progesterone
   (b) gonadotropin releasing hormone (GnRH), lutenizing hormone (LH)
   (c) lutenizing hormone (LH), gonadotropin releasing hormone (GnRH)
   (d) follicle stimulating hormone (FSH), estrogen
4. A joint position statement by the American College of Sports Medicine, the American Dietetic Association, and the Dietitians of Canada stated that a diet substantially different from that recommended in the Dietary Guidelines for Americans or the Nutrition Recommendations for Canadians is needed for athletes.
   (a) true
   (b) false
5. Loucks and Thuma found that LH pulsatility was disrupted abruptly at a threshold of energy availability of less than _____kcal/kg of lean body mass per day (LBM·day).
   (a) 45
   (b) 60
   (c) 20
   (d) 30
6. Research consistently shows that female athletes:
   (a) tend to take in more calories than they need
   (b) eat a well-balanced diet
   (c) eat at fast food restaurants like McDonalds and Burger King for most of their meals
   (d) take in fewer calories than they actually need
7. Which of the following is truth about protein intake recommendations for athletes …
   (a) Research suggests that consuming 20 g of protein (or an equivalent to 0.3–0.4 g/kg) 5–6 times per day may be preferable to larger protein intake less frequently
   (b) The intake of proteins should provide about a 50% of total energy intake
   (c) In case of energy restriction or during periods of sudden inactivity protein intake recommendations decrease about 1.6–2.4 g/kg
   (d) The content in aminoacids is not important when choosing the appropriate food source for proteins
8. Endothelial dysfunction has been proposed as a potential fourth component of the Triad. To prevent endothelial damage _____ supplements can be used
   (a) Vitamin D
   (b) Iron
   (c) Folic acid
   (d) Vitamin B1 and B6
9. Consuming water sources up to _____ of the weight lost during an exercise session may be necessary to cover losses in sweat and urine excretion
   (a) 50%
   (b) 250%
   (c) 25%
   (d) 150%
10. Energy Availability is defined as
    (a) daily energy intake (DEI, kcal) minus total energy expenditure (TEE, kcal) divided by fat-free mass (FFM, kg)
    (b) daily energy intake (DEI, kcal) minus total energy expenditure (TEE, kcal) divided by body mass (BM/kg)
    (c) daily energy intake (DEI, kcal) minus exercise energy expenditure (EEE, kcal) divided by fat-free mass (FFM, kg)
    (d) daily energy intake (DEI, kcal) minus exercise energy expenditure (EEE, kcal)

Answers

1. c
2. c
3. b
4. b
5. d
6. d
7. a
8. c
9. d
10. c

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Nutritional Guidelines and Energy Needs During Pregnancy and Lactation for Active Women

21

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Learning Objectives

After completing this chapter, you should understand the following:

- Nutritional guidelines during pregnancy and lactation
- Energy requirements during pregnancy and lactation for active and sedentary women
- Important nutrients, vitamins, and minerals for optimal pregnancy and infancy outcomes
- Vegetarian diets during pregnancy and lactation
- Needs for supplementation during pregnancy and lactation

21.1 Introduction

Prior to conception and throughout pregnancy and lactation, the diet and lifestyle of the mother are important in the health and well-being of the mother and the proper development and overall health of the offspring. Moreover, the American College of Obstetricians and Gynecologists encourages women with uncomplicated pregnancies to engage in regular physical activities during and after pregnancy, as physical activity helps with weight management, reduces the risk of gestational diabetes and enhances psychological wellbeing [1]. Therefore, it is crucial that dietary recommendations are well perceived in this population to optimize the health of both mother and child and to uphold energy and nutrient requirements necessary for physical activity.

There are essential nutrients that pregnant and lactating women must obtain through either a well-balanced nutrient-dense diet (preferred) or through supplements [2]. Notably, current research indicates that the timeframe between conception and 2 years of age is crucial for the prevention of noncommunicable diseases, including obesity-related and cardiometabolic chronic diseases in the offspring [3]. Body weight (BW) of the mother, particularly excessive weight gain prior to conception or throughout the pregnancy, has been linked with metabolic issues in offspring into adulthood [4]. Therefore, understanding the components of a well-balanced and healthy diet and required energy intake throughout pregnancy is necessary for both the health of mother and child. Complications and considerations associated with maternal obesity are discussed in Chap. 31, Maternal Obesity and its Epigenetic Effects by Moustaid-Moussa et al. in this book. Exercise and Nutritional Guidelines for Weight Loss and Weight Maintenance in the Obese Female (Chap. 32 by Perry et al.) is another chapter that would be helpful to understand how to safely lose excessive weight associated with pregnancy.

The World Health Organization (WHO) recognizes breastfeeding as the gold standard for infant feeding, recommended exclusively for the first 6 months of infant life and in addition to nutritionally adequate and appropriate infant foods for up to 2 years of age and beyond. While certainly beneficial to the child, breastfeeding also contributes to the health and well-being of the mother. For example, breastfeeding reduces the risk of breast and ovarian cancers [5, 6]. As with pregnancy, there are special nutritional considerations throughout lactation, which are also varied with activity level.

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21.1.1 Nutritional Guidelines During Pregnancy and Lactation

General dietary guidelines for pregnant women are similar to guidelines recommended for nonpregnant women for optimum health; however, the recommended levels of certain essential nutrients are higher than that of the nonpregnant woman. Per recommendations from the Health and Medicine Division of the National Academies of Sciences, Engineering and Medicine and European Food Safety Authority (EFSA), Dietary Reference Intakes (DRI) for pregnant and lactating women can be found and personalized (according to BW, age, and trimester) at:

- https://www.nal.usda.gov/fnic/dri-calculator/ [7] and/or
- https://www.efsa.europa.eu/en/interactive-pages/drvs [8]

The Dietary Guidelines for Americans (DGA) 2020–2025 [2] include the following key recommendations for all population groups, which will support healthy BW and may prevent and reduce the occurrence of chronic diseases throughout periods of growth, development and aging, including during pregnancy:

Consume a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level. A healthy eating pattern includes:

- A variety of vegetables from all of the subgroups—dark green, red and orange, legumes (beans and peas), starchy, and other;
- Fruits, especially whole fruits;
- Grains, at least half of which are whole grains;
- Fat-free or low-fat dairy, including milk, yogurt, cheese, and/or fortified soy beverages;
- A variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), nuts, seeds, and soy products; and
- Oils from foods such as seafood and nuts as well as vegetable oils.

A healthy eating pattern limits:

- Saturated fats and trans fats;
- Added sugars;
- Sodium; and
- Alcoholic beverages.

The DGA 2020–2025 [2] lists the following special pregnancy considerations:

- Before becoming pregnant, women are encouraged to achieve and maintain a healthy weight, and women who are pregnant are encouraged to gain weight within gestational weight gain guidelines set by the Institute of Medicine and National Research Council [9].
- Women capable of becoming pregnant should choose foods that supply heme iron, which is more readily absorbed by the body. They should consume additional iron sources as well as enhancers of iron absorption such as vitamin C-rich foods. Women who are pregnant are advised to take an iron supplement when recommended by an obstetrician or other health care provider.
- Women capable of becoming pregnant should consume 400 micrograms (mcg) per day of Dietary Folate Equivalents (DFE). During pregnancy, women need 600 mcg DFE daily from all sources, including synthetic folic acid and food folate.
- Women who are pregnant or breastfeeding should ensure that the salt they are consuming is iodized. Iodine supplements may be necessary.
- Women are encouraged to consume a variety of choline-containing foods, including dairy and protein food groups. Many prenatal supplements do not contain adequate amounts of choline.
- Women who are pregnant or breastfeeding should consume at least 8 ounces and up to 12 ounces of seafood per week from a variety of seafood types that are lower in methyl mercury and good sources of docosahexaenoic acid (DHA), which is associated with improved infant health outcomes.
- Women who are pregnant or breastfeeding should not eat certain types of fish that are high in methyl mercury. More information can be found here: https://www.epa.gov/choose-fish-and-shellfish-wisely [10].
- Women who are pregnant should only eat foods containing seafood, meat, poultry, or eggs that have been cooked to recommended safe minimum internal temperatures. They also should take special precautions not to consume unpasteurized (raw) juice or milk or foods made from unpasteurized milk, like some soft cheeses.
- Women who are capable of becoming pregnant or who are trying to, or who are pregnant, and those who are breastfeeding should consult their health care providers for advice concerning caffeine consumption.
- Women who are or who may be pregnant should not drink alcohol. Drinking during pregnancy, especially in the first months of pregnancy, may result in negative behavioral or neurological consequences of the offspring. Women who are breastfeeding should consult with their health care provider regarding alcohol consumption.

Selecting a variety of foods can provide the full range of essential nutrients and fiber necessary during pregnancy and lactation without excessive calories. The oils contained in seafood, nuts and seeds, and vegetable oils added to foods also contribute essential nutrients. Additionally, seafood is

an excellent source of protein, omega-3 polyunsaturated fatty acids, vitamin B_{12}, vitamin D, iron and other minerals. Due to their methyl mercury content, limit white (albacore) tuna to 6 oz. per week and do not eat the following types of fish: tilefish, shark, swordfish, and king mackerel, marlin, orange roughy, and bigeye tuna [11].

According to general recommendations for all population groups, cooking foods to recommended safe minimum internal temperatures and consuming only pasteurized dairy products are the best ways to reduce the risk of foodborne illness from animal products [2]. Pregnant women are more susceptible than the general population to the effects of foodborne illnesses, which can be severe or even fatal and have been associated with miscarriage, stillbirth and preterm birth [12, 13]. Feta, queso blanco, queso fresco, Brie, Camembert cheeses, blue-veined cheeses, and Penela are soft cheeses made from unpasteurized milk and should be avoided during pregnancy. Hot dogs, deli and luncheon meats should be cooked or reheated to steaming hot temperatures to kill bacteria associated with foodborne illnesses. Lastly, raw sprouts should not be consumed during pregnancy since these also carry these harmful bacteria [2]. Additional details regarding dietary recommendations can be found in the DGA 2020–2025 at: https://www.dietaryguidelines.gov/sites/default/files/2021-03/Dietary_Guidelines_for_Americans-2020-2025.pdf [2].

21.2 Research Findings and Contemporary Understanding of the Issues

21.2.1 Energy Requirements and Important Nutrients for Optimal Pregnancy/Lactation and Infant Outcomes

Estimated energy recommendations (EER) from the National Research Council for pregnant and lactating women can be found in the dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients) [14]. The EER is defined as the average dietary energy intake that is predicted to maintain energy balance in a healthy adult of a defined age, gender, weight, height, and level of physical activity, consistent with good health. Appendix 1 [15] contains referenced equations for pregnant and lactating women.

Total caloric intake throughout pregnancy will vary according to body mass index (BMI) prior to conception, age, number of fetuses, and trimester, but the average recommendation is 2500 kcal/day [16]. An approximate addition of 350–450 kcal/day is necessary during pregnancy and should be met by choosing nutrient-dense foods that meet the increase in micronutrient needs (discussed below). Notably, excess caloric intake and excessive weight gain during pregnancy have shown to be as detrimental to the offspring as nutrient deficiencies [17].

Milk production requires approximately 700–800 kcal/day. Recommendations for energy intake vary from an additional (to prepregnancy requirements) 330–500 kcal per day during the first 6 months of breastfeeding and approximately 400 kcal/day thereafter [15, 18]. Although it is important to meet energy needs in order to produce milk, the energy deficit described above will aid in gradually returning to prepregnancy BW.

21.2.1.1 Energy Requirements

The energy requirements of pregnancy are those needed for adequate maternal gain to ensure the growth of the fetus, placenta, and associated maternal tissues, and to provide for the increased metabolic demands of pregnancy, in addition to the energy needed to maintain adequate maternal weight, body composition, and physical activity throughout the gestational period, as well as for sufficient energy stores to assist in proper lactation after delivery. Recommendations for energy intake of pregnant women should be population specific, because of differences in body size, lifestyle, and underlying nutritional status. Special considerations must be considered for women who are underweight or overweight when entering into the pregnancy period. Additionally, it is generally recommended that an additional 300 kcal and 10 g of protein per fetus are standard [19], although the exact caloric requirements for multiple gestations have not been well described.

The EER from the National Research Council [14] is based on the components of total energy expenditure (TEE), which include (a) basal metabolic rate (BMR) or basal metabolism (including thermoregulation) over 24 h (the BEE); for convenience, resting metabolic rate (RMR) is sometimes used or energy expenditure under resting conditions (note: it is not the same as BMR) extrapolated to 24 h (REE); (b) the thermic effect of food (TEF) or diet-induced thermogenesis (DIT); and (c) energy expended for physical activity, which is commonly described as the ratio of total to basal daily energy expenditure (TEE/BEE). This ratio is known as the physical activity level (PAL) or the physical activity index. For detailed explanations of these acronyms, see the chapter in this book entitled Estimating Energy Requirements.

Physical activity level, or PAL, in a nonpregnant state must be computed for the equations using age, weight, height, and gender. The PAL values obtained in pregnant women, especially during the second part of pregnancy, are lower than values obtained in nonpregnant individuals. Pregnancy is often associated with a comparatively large increase in BMR, whereas the effect of pregnancy on energy expenditure when performing many specific activities tends to be rather small [20]. Table 21.1 has PAL values for woman of varying weights (kg) and uses the terms Sedentary, Active,

Table 21.1 Physical activity level categories and walking equivalence [15]. (Reprinted with permission from the Institute of Medicine. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: The National Academies Press; 2005. 1358 p)

			Walking equivalence (mi/d at 3–4 mph)		
Category	PAL range		Lightweight individual (44 kg)	Middleweight individual (70 kg)	Heavyweight individual (120 kg)
Sedentary	1.0–1.39	1.25	~0	~0	~0
Low active	1.4–1.59				
Mean		1.5	2.9	2.2	1.5
Active	1.6–1.89				
Minimum		1.6	5.8	4.4	3.0
Mean		1.75	9.9	7.3	5.3
Very active	1.9–2.49				
Minimum		1.9	14.0	10.3	17.5
Mean		2.2	22.5	16.7	12.3
Maximum		2.5	31.0	23.0	17.0

Table 21.2 Doubly labeled water pregnancy studies [16–20]

Mean pregravid weight	Mean gestational weight gain	Mean total energy expenditure	Mean physical activity level	Mean activity energy expenditure
61.3 kg	12.3 kg	2500 (kcal/d)	1.63 (active)	956(kcal/d)

Table 21.3 Doubly labeled water lactation studies [16–18, 21]

Total energy expenditure	Basal estimation	Physical activity level	Energy expenditure	Milk energy output
2310 (kcal/day) 33.1 (kcal/kg/day)	1378 (kcal/d)	1.67 (active)	827(kcal/d)	520 (kcal/d)

and Very Active to help readers understand what the PAL value means. The number of miles walked per day can be understood by most individuals, the PAL value is matched with the number of miles walked per day for a reference point. For example, a PAL value of 2.0 is classified as very active and corresponds with an average of 12.3 miles per day for a 120 kg woman.

In addition to energy spent for the generally unscheduled activities that are part of a normal daily life, the low, middle, and high miles/day values apply to relatively heavyweight (120 kg), midweight (70 kg), and lightweight (44 kg) individuals, respectively.

Doubly labeled water studies have also been conducted using well-nourished pregnant women (Table 21.2) and lactating women (Table 21.3) and reported an average TEE of 2500 kcal/day during pregnancy, with a mean weight gain of 12.3 kg and a mean activity energy expenditure of 950 (kcal/day) [16–20]. When similar studies are conducted during lactation [16–18, 21], the evaluated TEE (kcal/day) was 2310 (38 kcal/kg/day). This amount of energy includes a mean activity energy expenditure of 945 kcal/day and a mean of 520 kcal/day used in milk production. This book can be downloaded for free at https://www.nap.edu/catalog/10490/dietary-reference-intakes-for-energy-carbohydrate-fiber-fat-fatty-acids-cholesterol-protein-and-amino-acids [15].

21.2.1.2 Macronutrients

Macronutrients provide the necessary energy and components for building tissue that is required during pregnancy and an adequate and nutrient-dense milk supply required during lactation. General macronutrient recommendations for healthy women, including pregnant women, include 45–65% of energy intake from carbohydrates, 10–35% of total energy intake from protein, and 20–35% of energy from fat. According to the American Dietetic Association, an example would include nine servings of cereals, three servings of fruits, four servings of vegetables, two to three servings of dairy products, and four servings of meats, beans, or nuts [21].

Carbohydrate

Both pregnancy and lactation require additional energy; thus, adequate carbohydrate, an energy-supplying macronutrient (primary function), is of concern. Glucose is the primary metabolic fuel for the fetus; however, choosing a variety of carbohydrates and foods with little added sugars can aid in blood glucose maintenance, avoidance of gestational diabetes, and proper fetal development [22]. Carbohydrate needs are met with a variety of food groups. Based on a 2000-calorie level and for the general, healthy population, the DGA recommends 2½ cup-equivalents of vegetables, 2 cup-equivalents of fruits and 6 ounce-equivalents of grains per day, with at least half being whole grains [2]. The Recommended Dietary Allowance (RDA) for carbohydrates during pregnancy is 175 g/day and increased to 210 g/day during lactation [15]. Additional carbohydrates may be necessary for the physically active female. Daily carbohydrate needs vary according to activity type and stage (before, during or after exercise) [23]; however, recommendations for the active and pregnant or lactating females have not been reported.

Protein

Adequate dietary protein throughout pregnancy is of great concern due to the increased protein synthesis necessary to increase maternal blood volume, uterine and breast tissue, in addition to placental development and fetal growth. As outlined above, protein needs should be met by a variety of sources, including seafood, lean meats and poultry, eggs, legumes (beans and peas), nuts, seeds, and soy products. Although, it should be noted that protein quality, including amino acid digestibility/bioavailability and composition, varies by protein source (animal versus plant sources), and is thus another issue to consider in meeting protein requirements. Animal protein sources are considered higher quality (complete proteins) since they contain all essential amino acids [24]. Issues regarding plant sources of protein as part of a vegetarian diet throughout pregnancy are discussed later in this chapter, but in general, can be overcome by choosing a variety of plant protein sources with variations in limiting amino acids [25].

Based on a 2000-calorie level, the DGA recommends 5½ ounce equivalents of protein foods per day for the general, healthy population [2]. The RDA for protein is adjusted for BW (in kilograms (kg), activity level and vegetarianism: 0.8 g/kg of BW per day is sufficient for sedentary individuals [15]. Table 21.4 lists protein recommendations based on activity level and dietary choices from a 2009 position statement. It has more recently been accepted that 1.2–2.0 g/kg/day is recognized as sufficient to support health and protein turnover during physical activity [23]. However, the joint position statement from the American College of Sports Medicine, Academy of Nutrition and Dietetics and Dietitians of Canada does not mention protein needs for the active female during pregnancy or lactation.

Recent recommendations, aligned with the current RDAs for protein, estimate that 1.1 g/day of protein per kg of BW (pre-pregnancy weight) is sufficient throughout the duration of the pregnancy and during lactation, equating to an approximate addition of 25 g of protein per day. The RDA for protein is listed as 71 g/day, although this number should be individualized [15]. For example, a pregnant woman weighing 130 pounds (lbs) or 59.09 kg, would need approximately 65 g of protein per day. It should be noted that most women, especially those who consume the typical Western diet, consume 1.1 g/kg/day; thus, protein is not considered a nutrient of concern for most pregnant and lactating women [25].

Table 21.4 Protein recommendations[a] [26]

Group	Protein intake (g/kg/d)
Nonvegetarian endurance athletes	1.2–1.4
Nonvegetarian strength athletes	1.2–1.7
Vegetarian endurance athletes	1.3–1.5
Vegetarian strength athletes	1.3–1.8

[a] Recommendations for healthy non-pregnant/lactating athletes

However, too much dietary protein or low protein intake is of significant concern throughout pregnancy. Both low and high maternal protein intake can result in intra-uterine growth restriction and embryonic loss. Additionally, high protein intake may result in toxic byproducts, including ammonia and/or certain amino acids, such as homocysteine [27]. Recent studies have reported high maternal protein intake to be associated with elevated risk and development of gestational diabetes mellitus, particularly in the Asian population [28–30], with one study identifying a whole-grain and seafood food pattern as a major contributor [31].

Fat

Fats play a variety of important roles, including acting as components of cell membranes, and is crucial to the proper development of cells and tissues. Therefore, meeting needs for dietary fat intake is also important, especially during pregnancy. Dietary fats are composed of varying types of fats: monounsaturated, polyunsaturated and saturated fatty acids. As mentioned above, it is generally recommended to consume more mono- and polyunsaturated fats and to limit intake of saturated and *trans* fats, which are linked with an elevated risk of obesity- and metabolic-related diseases [32]. Based on a 2000-calorie level and for the general, healthy population, the DGA recommends 27 g or 5 teaspoons of oils (mainly composed of mono- and polyunsaturated fats as opposed to margarine or butter) per day [2]. While AMDRs are suggested for fat recommendations, an AMDR and Adequate Intake (AI) are provided for omega-6 polyunsaturated fatty acids (n-6 PUFA) and omega-3 polyunsaturated fatty acids (n-3 PUFA), which are essential to the diet. The AMDR for n-6 PUFA is 5–10%, and the AI is 13 g/day during both pregnancy and lactation. The AMDR for n-3 PUFA is 0.6–1.2% during both pregnancy and lactation, and the AI is 1.4 g/day during pregnancy and decreased to 1.3 g/day during lactation [15]. It is recommended that omega-3 polyunsaturated fatty acid (EPA and DHA) intake be increased during pregnancy. Guidelines now suggest that pregnant women consume at least 200 mg of DHA a day. Most the fetal brain development occurs during the second half of pregnancy, so DHA intake is especially important during this time, as it is linked to improved brain and eye development of the fetus [33, 34].

21.2.1.3 Micronutrients

As the need for energy (macronutrients) increases during pregnancy, and at some points throughout lactation, there is a corresponding increase in micronutrients necessary for the proper physiological adaptation of the mother as well as the proper development of the fetus. Table 21.5 lists the micronutrients that increase during pregnancy and lactation. Few micronutrient recommendations increase during lactation (compared to pregnancy recommendations), including vita-

Table 21.5 Micronutrient recommendations during pregnancy and lactation[a] [35–37]

Micronutrient	Pre-pregnancy	Pregnancy	Lactation
Vitamin A, mcg	700	770	1300
Vitamin C, mg	75	85	120
Vitamin E, mg	15	15	19
Vitamin B_{12}, mcg	2.4	2.6	2.8
Folate, mcg	400	600	500
Riboflavin, mg	1.1	1.4	1.6
Iron, mg	18	27	9
Zinc, mg	8	11	12
Iodine, mcg	150	220	290
Copper, mcg	900	1000	1000
Chromium, mcg	25	30	45
Manganese, mg[b]	1.8	2.0	2.6
Selenium, mcg	55	60	70

[a] Recommendations for healthy female 19+years, recommendations for pregnant or lactating female adolescents vary
[b] Recommendations based on adequate intake

mins A, C, E, riboflavin, B_{12}, biotin, and minerals, including chromium, copper, iodine, manganese, selenium, and zinc. Folate and iron recommendations both decrease during lactation [35]. Selected micronutrients of significant concern, particularly throughout pregnancy, are discussed below, including folate, iron, iodine and vitamin D.

Micronutrient status is another potential problem for an active pregnancy. For example, athletes usually have lower iron tissue stores before pregnancy and are more likely to have iron deficiencies. Vitamin D and calcium status can also be a problem [38–40]. However, increased nutrient absorption and enhanced efficiency of nutrient utilization that occur in pregnancy are generally adequate to meet the needs for most nutrients when a variety of foods are chosen and enough calories are consumed to meet energy needs. If all of the necessary nutrients can be consumed in the daily diet, then supplements are generally not needed during pregnancy or lactation [2]. Yet, studies consistently show that many women, even in industrialized countries, may have vitamin and mineral deficiencies that could have an adverse effect on infant development, child delivery, and the health of the mother [14, 21, 41–43]. Therefore, education on nutrient requirements is important and supplementation may be necessary.

Folic Acid (Folate)

Folate is a water-soluble vitamin present in leafy green vegetables, legumes and citrus fruits. Enriched cereal grains (cereal, bread, rice, pasta) are also a good source of folate, in the form of folic acid, in the United States and other countries where mandatory cereal fortification policies are implemented [44]. According to the DGA [2], folic acid fortification of enriched grain products in the United States has been successful in reducing the incidence of neural tube defects (NTDs), birth defects of the brain, and spinal cord. Although the RDAs for folate are based on the prevention of folate deficiency, not on the prevention of NTDs, it is recommended that all women capable of becoming pregnant consume 400 mcg of synthetic folic acid daily. This recommendation is for an intake of synthetic folic acid in addition to the amounts of food folate contained in a healthy eating pattern due to differences in folate/folic acid bioavailability. Food folate is less bioavailable than folic acid. Dietary Folate Equivalents (DFE) adjust for this difference. The RDA for women during pregnancy increases to 600 mcg DFE daily from all sources. 1 DFE = 1 mcg food folate = 0.6 mcg folic acid from supplements and fortified foods taken with meals [2, 36].

Total folic acid intake (diet + supplements) should be monitored especially in those countries where folic fortification of cereals is mandatory, as some deleterious effects have been attributed to high folic acid intake. High amounts of circulating folic acid are associated with reduced natural killer cell cytotoxicity and thus increase the risk of cancer development [45]. Moreover, high levels of folic acid, after the first trimester, have been associated with future childhood allergic disease, asthma and eczema [46–48]. Other undesirable side effects include masking a vitamin B_{12} deficit [49]. Despite this, on the balance of benefits and risk, an adequate intake of folate by diet and/or supplements is strongly recommended during pregnancy [6, 16].

It is well established that periconceptional supplementation with folic acid can reduce the incidence of neural tube defects (NTD) by 50%. Data are available to advise all women who are capable of becoming pregnant to have periconceptional folic acid or multivitamin (including 0.4–0.8 mg of folic acid) supplementation to reduce the occurrence of NTDs. The use of multivitamins containing folic acid and other B vitamins [50–52] showed a higher efficacy (90%) in the reduction of NTDs than using a high dose of folic acid alone (70%) [53] or a low dose of folic acid (41–79%) [54]. Red blood cell folate concentrations over 100 nmol/L are optimal for NTD prevention [55]. However, evidence supporting the use of folic acid for preventing other pregnancy complications is less clear [41, 44, 49].

Folic acid supplementation should also continue 3 months into the postconception period. Additionally, breastfeeding women have higher folate requirements due to the folate supplied through breast milk. A higher folate intake will maintain a normal folate status for the mother. Generally, the folate concentration in human milk is tightly regulated and not affected by maternal folate status, except in clinically folate-deficient mothers. For example, an infant consumes about 0.8 L/day of breast milk with an average concentration of 831 mcg/L, so the mother loses through the milk about 66 mcg/L folate, which implies an additional requirement of 133 mcg/day of folate [56].

Interestingly, epidemiological evidence suggests that the development of NTDs is not primarily because of the lack of sufficient folate in the diet, but arises from genetically determined changes in the uptake, in metabolism, or in maternal and, particularly fetal cells [57]. Therefore, the gene–environmental interaction between vitamin dependency and nutrition may have a causal role in NTDs [58]. Supplementation with folic acid alone may cause an increase in folate metabolite concentrations of tissue fluids which may overcome the failure of the local metabolite supply.

Iron

There are two different types of iron: heme iron and non-heme iron. Heme iron, mainly found in hemoglobin and myoglobin from red meats, fish, and poultry, is absorbed two to threefold more readily than non-heme iron. Meat also contains organic compounds that promote the absorption of iron from other less bioavailable non-heme iron sources, including legumes (beans and peas) and dark-green vegetables, as well as foods enriched with iron, such as many loaves of bread and ready-to-eat cereals. The intake of other nutrients, such as vitamin C, may significantly enhance iron absorption from non-heme foods [59].

Physiological iron requirements increase throughout pregnancy with approximately 360 mg needed for the development of the embryo and placenta, 500 mg for hematopoiesis, and 150 mg to account for the blood loss during childbirth [60]. Ideally, to meet iron needs during gestation, women should have 300 mg or more of iron reserves prior to conception [61]. Adequate iron reserves can be achieved by (a) an adequate diet, (b) food fortification, or (c) preventive iron supplementation (low daily doses or weekly doses) [62]. Studies have shown that the best outcome conditions (birth weight, delivery time, and maternal health) have been reported to occur when hemoglobin level at term is between 931 and 1231 g/L [63, 64].

According to the DGA [2], substantial numbers of women who are capable of becoming pregnant, including adolescent girls are at risk of iron-deficiency anemia due to low intakes of iron. Maternal anemia is defined as a hemoglobin level of less than 11 g/dL during the first and third trimesters and less than 10.5 g/dL in the second trimester [65]. An estimated 38.2% of pregnant women globally are anemic [66], but the percentage varies among countries. Prevalence is particularly high in Southern Asia (80%) and Africa (40%) due to poor diets, parasites and chronic blood loss. Prevalence is less frequent in the United States (18%) and Europe (26%); although in developed countries, this data is difficult to gather due to routine iron supplementation [66, 67]. Correction of anemia during pregnancy is difficult and should be prevented if possible.

Even though routine iron supplementation in pregnancy is widely practiced, its effects on both pregnancy and infants are uncertain, and currently, experts worldwide diverge on whether iron supplementation should be routine during pregnancy [62]. According to WHO Recommendations on Antenatal Care for a Positive Pregnancy Experience, periconceptional (3 months prior to conception) supplementation with 30–60 mg/day of elemental iron is recommended to prevent anemia during pregnancy [6]. On the other hand, an important literature review performed by the US Preventive Services Task Force failed to show any benefit to routine iron supplementation in pregnancy for women in developed countries, with some studies, indicating that supplementation could lead to iron overload, which may negatively influence both pregnant women and their offspring [41, 62]. Despite this, any woman with existing iron deficiency or elevated risk of bleeding should receive iron supplements throughout pregnancy. Moreover, when the mother is anemic or from a population in which anemia prevalence is high, iron supplementation during pregnancy increases maternal iron status and stores and improves pregnancy outcomes [68, 69]. Thus, the IOM recommends a daily supplement containing 16–20 mg of iron during pregnancy for healthy women with a mixed diet [70].

Iodine

According to the Iodine Global Network (IGN) Global Scorecard of Iodine Nutrition 2017, pregnant women in the USA have insufficient iodine intake, with approximately 2.2 million women having a low or deficient iodine intake [71, 72]. Moreover, nearly two-thirds of the 600 million people in Western and Central Europe live in regions of mild to severe iodine deficiency [73]. The removal of iodate conditioners in store-bought bread, the recommendations to reduce salt and egg intake, the use of non-iodized salt in manufactured foods, and the reduction of meals made at home have reduced the population's iodine intake [71]. For nearly all countries, the primary strategy for the sustainable elimination of iodine deficiency is universal salt iodization.

In 2007, the World Health Organization/The United Nations Children's Fund/The International Council for the Control of Iodine Deficiency Disorders (WHO/UNICEF/ICCIDD) increased the recommended nutrient intake for iodine, during pregnancy, from 200 to 250 mcg, but stated clearly that more data are needed to establish the level of iodine intake that ensures maternal and newborn euthyroidism, or normal serum levels of thyroid hormone [74]. Iodine deficiency during pregnancy and lactation has important repercussions for both mother and fetus.

Pregnancy causes an increase in thyroid hormone requirements that can only be met by a proportional increase in hormone production, which directly depends upon the availability of dietary iodine. This fact, together with an increase in urine losses due to higher glomerular filtration during pregnancy, explains why gestation is a goitrogenic

situation. Goitrogens are substances that suppress the function of the thyroid gland by interfering with iodine uptake, which can, as a result, cause an enlargement of the thyroid, i.e., a goiter. When iodine intake is restricted, even moderately, physiological adaptations lead to excessive glandular stimulation, hypothyroxinemia, and goiter formation. These conditions may only partially regress after childbirth.

The fetal brain is particularly vulnerable to maternal hypothyroidism. Even subclinical hypothyroidism during pregnancy can impair the mental development of the newborn and increase infant mortality and growth retardation [75, 76]. Thyroid hormones are fundamental in neuron migration to the brain cortex and for fetal central nervous system development [77–80]. Although iodine supplementation (150 mcg/day) may be prescribed, caution should be utilized as long-term undesirable consequences for the newborn may occur [81, 82].

Vitamin D

Plasma levels of vitamin D depend on sunlight exposure and intake of food; however, deficiencies may result from inadequate cutaneous synthesis, limited dietary intake of vitamin D, or vitamin D pathway impairment [83]. Circulating serum 25(OH)D levels are currently the best available indicator of the net-incoming contributions from cutaneous synthesis and total intake (foods and supplements). The amount of sunlight sufficient to achieve optimal vitamin D status varies depending on a host of factors, such as time of day, time of year, latitude, degree of skin pigmentation, clothing, and body surface area exposed. Fifteen minutes (min) of sun exposure to the face and bare arms, without sunscreen, three times a week is the recommendation to have good vitamin D synthesis through the skin [84–86]. Additionally, there are not many natural foods rich in vitamin D. Apart from cold water fish (salmon, mackerel, sardines, etc.), fortified foods are the main food sources of Vitamin D. Both agencies, The Institute of Medicine and the European Food Safety Agency (EFSA) recommend 15 mcg/day or 600 IU during pregnancy and lactation, which is the same as recommended for healthy non-pregnant females 19–50 years [87, 88].

Vitamin D deficiency is defined as blood levels of 25(OH)D <20 ng/mL [89] and is a recent health problem worldwide. Deficiency prevalence in pregnant women in the United States, varies between 27 and 91% in disadvantaged subpopulations with limited sun exposure, while in Northern Europe, deficiency may occur in 100% of pregnancies [90–92]. Obesity is also a risk factor for developing vitamin D deficiency. Vitamin D is absorbed with fat as part of chylomicrons and is taken up first by peripheral tissues that express lipoprotein lipase, especially adipose tissue and skeletal muscle. This pathway predicts that increased adiposity may lead to lower serum 25(OH)D levels [93]. Please refer to Chap. 31 Maternal Obesity and its Epigenetic Effects by Moustaid-Moussa et al. and Chap. 32 Exercise and Nutritional Guidelines for Weight Loss and Weight Maintenance in the Obese Female by Perry et al. for a better understanding of obesity.

Throughout gestation, vitamin D deficiency appears to impact fetal bone health more than maternal [94–96]. Such deficiency in pregnant women can lead to rickets, hypocalcemia, delayed ossification, abnormal enamel formation in children and osteoporosis, osteomalacia, and bone fractures in adults [90, 97–99]. Few studies suggest that the impact of vitamin D deficiency on immunity is stronger than the one on calcium metabolism and bone health [100–102]. For example, the risk of rickets increases significantly when the total circulating 25(OH)D falls below 10 ng/mL (231 nmol/L), whereas cathelicidin mRNA expression, a marker of immune function, continues to be suppressed until 25(OH)D-circulating levels reach at least 20 ng/mL (310 nmol/L) [103], suggesting the limit should be higher.

Vitamin D deficiency is also associated with other pregnancy complications, such as preeclampsia, gestational diabetes, small for gestational age, and preterm births [104, 105], but it must be pointed out that these findings are mainly from observational studies [105]. More clinical trials are needed to identify effective preventive strategies during pregnancy through vitamin D supplementation [106].

During lactation, only a small amount of vitamin D is transferred to breast milk, approximately 20% of maternal 25(OH)D serum concentration [86, 105]. Thus, in order to meet vitamin D needs of the infant, it is recommended to give supplements to the infant under the guidance of their pediatrician [107].

21.3 Concerns During Pregnancy and Lactation

21.3.1 Weight Gain During Pregnancy

Weight gain during pregnancy is attributed to the products of conception (fetus, placenta, amniotic fluid), growth of various maternal tissues (uterus, breasts), and increases in the blood, extracellular fluid, and maternal fat stores. Inadequate weight gain is associated with intrauterine growth retardation, preterm birth, preeclampsia, eclampsia, and postpartum hemorrhage as well as obesity of the offspring and mother [108, 109]. More information can be downloaded free at https://www.nap.edu/catalog/12584/weight-gain-during-pregnancy-reexamining-the-guidelines [110] (Table 21.6).

The impact of maternal weight gain in the second trimester is most important for fetal development and is protective of fetal growth even if the overall weight gain is poor. In the USA, excessive weight gain during gestation remains of predominant concern, as 60% of obese women gain more than

Table 21.6 Weight gain recommendations [110]

Group	BMI (kg/m^2)	Weight gain (lbs)
Normal weight	18.5–24.9	25–35
Underweight	<18.5	28–40
Overweight	25–29.9	15–25
Obese	>30	11–20

Note: listed weight gain is appropriate for a single fetus

recommended, also, approximately 40% of normal-weight women gain more than recommended [111]. Please refer to Chap. 31 Maternal Obesity and its Epigenetic Effects by Moustaid-Moussa et al. and Chap. 32 Exercise and Nutritional Guidelines for Weight Loss and Weight Maintenance in the Obese Female by Perry et al. for a better understanding of obesity and how to safely lose weight.

Very few well-designed studies have been performed under free-living conditions to understand the impact of physical activity on weight gain during pregnancy [112, 113]. Most of the research studies find a lack of correlation between food intake and weight gain, a matter that can be attributed to the fact that most pregnant women reduce their physical activity [112]. On the other hand, longitudinal studies showed that women meeting the physical activity guidelines (more than 30 min/day) had 29% lower odds of gaining weight beyond recommendations [114]. Moreover, higher pre-pregnancy physical activity levels have been associated with less gestational weight gain and quicker postpartum weight loss [115]. Athletes should expect to return to their pre-pregnancy weight within 6 months; although, energy recommendations to meet the needs of lactation must be considered [116].

21.3.2 Vegetarianism and Pregnancy: A New Issue

The percentage of vegetarians and vegans in the general population has increased in recent years due to various beliefs, including environmental concerns, socioeconomic considerations and ethical/religious beliefs [117–119]. Vegetarian diets include grains, nuts, seeds, fruits and vegetables. Most vegetarians also have milk, eggs and honey, while vegans exclude any kind of animal products. Some other plant-based dietary options are pescatarian (that includes fish) or flexitarian (mostly vegetarian by including meat and fish occasionally) [120, 121]. Most dietetic associations agree that a well-planned vegetarian or vegan diet can be a healthy choice for adults; however, the nutrient adequacy of these diets for pregnant or lactating women is more controversial [119, 122, 123]. For example, protein quality together with the amount of iron, calcium, vitamin D and vitamin B_{12} are potentially the most problematic nutritional issues during pregnancy and lactation for women who choose these types of diets.

Proteins from vegetable sources have a lower digestibility and low biological value compared to those of animal origin. In order to fulfill pregnancy needs, vegetarian mothers should have a protein intake 20% higher than those who follow an omnivorous diet [124, 125]. Vegetarians should also make a good combination of foods (cereals + legumes) to assure good protein complementation and a correct intake of essential amino acids [126]. Adding 1.5 servings of lentils or 2.5 servings of soy milk a day can help reach protein needs during pregnancy and lactation. Additionally, including pseudocereals, such as quinoa or amaranth, will enhance the biological value of the proteins in the diet [125].

Additionally, vegetarian diets are associated with iron deficiency but not with iron deficiency anemia. In fact, iron absorption in a vegetarian diet is approximately 10% and approximately 18% in an omnivorous diet [25]. A well-planned diet rich in legumes, soy or beans, nuts and green leafy vegetables, in combination with vitamin C-rich fruits and vegetables and adequate cooking methods all increase non-heme iron bioavailability [127]. As in non-vegetarian mothers, iron supplementation should be considered in women at risk.

Calcium from plants is less absorbed; thus, vegetarian and vegan mothers should consume 1200–1500 mg/day (approximately 20% more than omnivorous women). This amount of calcium can be obtained with six to eight portions of calcium-rich vegetable foods: green leafy vegetables low in oxalates, cruciferous vegetables, sesame seeds, almonds, fortified plant-based milk and plant-based yogurts, soy, or tempeh. Calcium from water has a high bioavailability (23.6–47.5%), so tap water (average calcium 100 mg/L) and calcium-rich mineral water (300–350 mg/L) may also help vegans in reaching their daily requirements [122, 125, 128].

Regardless of the type of diet, vitamin B_{12} deficiency often occurs during pregnancy due to elevated demands and storage depletion [129]. A sufficient amount of vitamin B_{12} cannot be found in plant foods so pregnant and lactating vegan mothers should be encouraged to take an individual B_{12}, not multivitamin, supplement of 250 mcg/day [130]. Fortified foods, such as meat substitute products, breakfast cereals, soy milk and tofu can help to maintain B_{12} stores [129].

In summary, it is possible to maintain a vegetarian or vegan diet during pregnancy and lactation. However, since both situations are nutrient demanding, the diet must be well-planned in order to provide all energy requirements and meet critical nutrient needs that may be deficient in vegetarian/vegan foods. Professional guidance by a dietitian is recommended in order to avoid nutrient deficiencies and resulting complications.

21.4 Future Directions

In the XXI Century, pregnancy and motherhood, career, and sport can be no longer mutually exclusive. The percentage of women in the workforce has increased, and more women engage in physically demanding lines of work (such as police officers, fire fighters, and military personnel), and the number of women that decide to be mothers in the middle of their sportive careers is increasing [131]. According to one study, approximately 41–61% of women continue participating in regular leisure physical activity during pregnancy [38]. However, limited information is available on macro or micronutrient needs or adjustments that may be needed for the active and pregnant or lactating female. More research is needed in this population in order to avoid nutrient deficiencies and associated harm to mother and child. Moreover, with the increased interest and usage of supplements (macro and micronutrients), more research is needed to approve the safety and efficacy of these supplements, particularly those used to enhance physical performance, while pregnant or lactating.

Women who are active during their pregnancy need extra calories for exercise. This additional energy should come from added servings of carbohydrate, which meets the growth needs of the fetus and provides energy for exercise [132]. However, recent guidelines provide carbohydrate and protein recommendations based on stage (before, during and after) of physical activity for athletes, with no specific consideration for pregnancy and lactation. For example, recent recommendations suggest that muscle adaptation can be maximized by consuming 0.3 g/kg BW post-exercise and every 3–5 h over multiple meals [23]. Therefore, the combination of energy demands for childbearing necessities, and the additional energy needed for an active lifestyle, may require personal and customized dietary advice for active pregnant women. Based on new guidelines regarding macronutrient timing, more research is required in this population.

Moderate evidence indicates that intake of omega-3 fatty acids, in particular DHA, from at least 8 oz. of seafood per week for women who are pregnant or breastfeeding is associated with improved infant health outcomes, such as visual and cognitive development [34]. However, recent studies suggest that seafood consumption may be linked to the onset of gestational diabetes in certain ethnicities [133]. Therefore, recommendations regarding seafood consumption during pregnancy need to be further evaluated and other sources of omega-3 may need to be recommended to this population. However, further research is needed and is necessary, given the importance of omega-3 in the developing infant brain.

As discussed, there are key micronutrients of concern during pregnancy and lactation: including iron and folic acid, which are both often considered for supplementation. It is thought that prepregnancy iron reserves can be achieved by an adequate diet, food fortification, or preventive iron supplementation (low daily doses or weekly doses). Ideally, the last two types of intervention should include folate and, if needed, other nutrients such as vitamin A and zinc [41].

Even for nonpregnant women, long-term weekly supplementation with iron and folic acid can bring benefits in terms of the prevention of NTDs and hyperhomocysteinemia early in pregnancy [134]. It appears that small daily doses, as recommended by the Food and Drug Administration [135] and the Food and Nutrition Board and IOM [134], as well as weekly dosing starting early in pregnancy are safer and essentially as efficacious as daily iron supplementation in preventing iron deficiency [49]. For example, therapy consists of 60–120 mg of ferrous iron in divided doses throughout the day for females with iron deficiency anemia [135]. The therapeutic dose depends on the hemoglobin level of the pregnant woman. For more complete guidelines, please refer to the guidelines for the assessment of iron deficiency in women of childbearing age and the IOM recommended guidelines for the prevention, detection, and management among women of childbearing age for iron deficiency anemia [135, 136].

There is not a universal consensus regarding the type of supplementation and the dose of folic acid; thus, further research is necessary. Even though the mandatory fortification of standardized enriched cereal grain products in the USA in 1998 resulted in a substantial increase in blood folate concentrations and a concomitant decrease in 36% of NTD prevalence, mandatory fortifications have raised concerns about the consequences of excessive intakes. Excessively high intakes of folic acid may cause harmful effects, including (1) progression of nerve damage in B_{12}-deficient persons, (2) excess intake in children, (3) accumulation of unmetabolized folic acid, (4) blunting of antifolate therapy (methotrexate and phenytoin), (5) accelerated cognitive decline in the elderly, (6) epigenetic hypermethylation, and (7) cancer promotion [137]. These findings are mainly attributed to an excess of folate intake and to the presence of no metabolized folic acid in the plasma of people receiving very high doses of folic acid [56]. More data are needed to determine requirements based on balancing fortification and supplementation.

Lastly, girls under the age of 17 are at increased risk for preterm delivery, perinatal mortality, and low BW. Specifically, girls within 2 years of menarche may require additional energy, protein, and calcium, to meet their nutritional needs for maternal and fetal growth. The erratic use of vitamin supplementation, poor nutrition, and body image issues for this specific population suggests that additional counseling may be warranted [43]. These special concerns highlight the need for nutritional guidelines for physical

activity and proper nutrition during pregnancy and lactation in this population.

21.5 Concluding Remarks

The overall quality of a woman's diet affects her needs for supplementation and nutritional counseling advice. Excess or deficiency of any nutrient is a concern during pregnancy and lactation. Optimal pregnancy outcomes occur when women maintain a balanced diet prior to conception and throughout pregnancy and lactation. Therefore, all women of childbearing age should be encouraged to consume a variety of nutrient-dense foods and beverages within and among the basic food groups while choosing foods that limit the intake of saturated and trans fats, cholesterol, added sugars, salt, and alcohol. Specifically, women of childbearing age who may become pregnant should eat foods high in heme iron and/or consume iron-rich plant foods or iron-fortified foods with an enhancer of iron absorption, such as vitamin C-rich foods, as well as assure adequate folic acid/folate daily to avoid neural tube defects (NTDs).

Pregnancy and lactation require modest increases in most macro- and micronutrients. Additional energy (macronutrients) varies based on appropriate weight gain and prepregnancy BMI. Women who are active during their pregnancy may need extra calories for exercise. Ideally, this additional energy should come from added servings of carbohydrates since carbohydrate intake meets the growth needs of the fetus and provides energy for exercise [132].

Appendix 1

Estimated energy expenditure* prediction equations at four physical activity levels [15]

EER for infants and young children 0–3 years
TEE (kcal/d) = 89 (±3 [standard error]) × weight of the child (kg) − 100 (±56 [standard error]) EER = TEE + energy deposition 0–3 months (89 × weight of infant [kg] − 100) + 175 (kcal for energy deposition) 4–6 months (89 × weight of infant [kg] − 100) + 56 (kcal for energy deposition) 7–12 months (89 × weight of infant [kg] − 100) + 22 (kcal for energy deposition) 13–36 months (89 × weight of child [kg] − 100) + 20 (kcal for energy deposition) Where PA = physical activity coefficient: PA = 1.0 if PAL is estimated to be ≥1.0 < 1.4 (sedentary) PA = 1.13 if PAL is estimated to be ≥1.4 < 1.6 (low active) PA = 1.26 if PAL is estimated to be ≥1.6 < 1.9 (active) PA = 1.42 if PAL is estimated to be ≥1.9 < 2.5 (very active)
EER for girls 3–8 years
TEE = see doubly labeled water data used to predict energy expenditure for standard error in the dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients) at http://www.nap.edu/openbook.php?isbn=0309085373 [15] EER = TEE + energy deposition EER = 135.3 − (30.8 × age [years]) + PA × (10 × weight [kg] + 934 × height [m]) + 20 (kcal for energy deposition) Where PA = physical activity coefficient: PA = 1.0 if PAL is estimated to be ≥1.0 < 1.4 (sedentary) PA = 1.16 if PAL is estimated to be ≥1.4 < 1.6 (low active) PA = 1.31 if PAL is estimated to be ≥1.6 < 1.9 (active) PA = 1.56 if PAL is estimated to be ≥1.9 < 2.5 (very active)
EER for girls 9–18 years
TEE = see doubly labeled water data used to predict energy expenditure for standard error in the dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients) at http://www.nap.edu/openbook.php?isbn=0309085373 [15] EER = TEE + energy depositions EER = 135.3 − (30.8 × age [years]) + PA × (19 × weight [kg] + 934c height [m]) + 25 (kcal for energy deposition) Where PA = physical activity coefficient: PA = 1.0 if PAL is estimated to be ≥1.0 < 1.4 (sedentary) PA = 1.16 if PAL is estimated to be ≥1.4 < 1.6 (low active) PA = 1.31 if PAL is estimated to be ≥1.6 < 1.9 (active) PA = 1.56 if PAL is estimated to be ≥1.9 < 2.5 (very active)
EER for women 19 years and older
EER = 354 − (6.91 × age [years]) + PA × (9.36 × weight [kg] + 726 × height [m]) Where PA = physical activity coefficient: PA = 1.0 if PAL is estimated to be ≥1.0 < 1.4 (sedentary) PA = 1.12 if PAL is estimated to be ≥1.4 < 1.6 (low active) PA = 1.27 if PAL is estimated to be ≥1.6 < 1.9 (active) PA = 1.45 if PAL is estimated to be ≥1.9 < 2.5 (very active)
EER for pregnant women (14–18 years)
$EER_{pregnant}$ = adolescent $EER_{nonpregnant}$ + additional energy expended during pregnancy + energy deposition First trimester = adolescent EER + 0 + 0 Second trimester = adolescent EER + 160 kcal (8 kcal/week × 20 week) + 180 kcal Third trimester = adolescent EER + 272 kcal (8 kcal/week × 24 week) + 180 kcal
EER for pregnant women (19–50 years)
$EER_{pregnant}$ = adult $EER_{nonpregnant}$ + additional energy expanded during pregnancy + energy deposition First trimester = adult EER + 0 + 0 Second trimester = adult EER + 160 kcal (8 kcal/week × 20 week) + 180 kcal Third trimester = adult EER +272 kcal (8 kcal/week × 34 week) + 180 kcal
EER for lactating women (14–18 years)
$EER_{lactation}$ = adolescent $EER_{prepregnancy}$ + milk energy output − weight loss First 6 months = adolescent EER + 500–170 Second 6 months = adolescent EER + 400 − 0
EER for lactating women (19–50 years)
$EER_{lactation}$=adult $EER_{prepregnancy}$ + milk energy output − weight loss First 6 months = adult EER + 500–170 Second 6 months = adult EER + 400–0
Weight maintenance TEE in overweight girls 3–18 years or at risk of a high

TEE=389 − (41.2 × age [years]) + PA × (15.0 × weight [kg] + 701.6 × height [m]) Where PA = physical activity coefficient: PA = 1.0 if PAL is estimated to be ≥1.0 < 1.4 (sedentary) PA = 1.12 if PAL is estimated to be ≥1.4 < 1.6 (low active) PA = 1.24 if PAL is estimated to be ≥1.6 < 1.9 (active) PA = 1.45 if PAL is estimated to be ≥1.9 < 2.5 (very active)
Overweight and obese women 19 years and older
TEE = 448 − (7.95 × age [years]) + PA × (11.4 × weight [kg] + 619 × height [m]) Where PA is the physical activity coefficient: PA = 1.0 if PAL is estimated to be ≥1.0 < 1.4 (sedentary) PA = 1.16 if PAL is estimated to be ≥1.4 < 1.6 (low active) PA = 1.27 if PAL is estimated to be ≥1.6 < 1.9 (active) PA = 1.44 if PAL is estimated to be ≥1.9 < 2.5 (very active)
Normal and overweight or obese women 19 years and older
TEE = 387 − (7.31 × age [years]) + PA × (10.9 × weight [kg] + 600.7 × height [m]) Where PA is the physical activity coefficient: PA = 1.0 if PAL is estimated to be ≥1.0 < 1.4 (sedentary) PA = 1.14 if PAL is estimated to be ≥1.4 < 1.6 (low active) PA = 1.27 if PAL is estimated to be ≥1.6 < 1.9 (active) PA = 1.45 if PAL is estimated to be ≥1.9 < 2.5 (very active)

[a] Estimated energy expenditure (EER) is the average dietary energy intake that is predicted to maintain energy balance in a healthy adult of a defined age, gender, weight, height, and level of physical activity consistent with good health. In children and pregnant and lactating women, the EER includes the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health

Physical activity level (PAL) is the physical activity level that is the ratio of the total energy expenditure to the basal energy expenditure

Total energy expenditure (TEE) is the sum of the resting energy expenditure, energy expended in physical activity, and the thermic effect of food

Body mass index (BMI) is determined by dividing the weight (in kilograms) by the square of the height (in meters)

Chapter Review Questions

1. By what percentage and the caloric amount should basic energy needs in pregnancy be increased over the non-pregnant state in a normal woman?
   (a) 5% increase and an additional 300 kcal/day
   (b) 12% increase and an additional 200 kcal/day
   (c) 17% increase and an additional 300 kcal/day
   (d) 20% increase and an additional 200 kcal/day
2. During pregnancy, protein/fat/carbohydrate consumption should consist of:
   (a) 10% protein/25% fat/65% carbohydrate
   (b) 25% protein/25% fat/50% carbohydrate
   (c) 30% protein/20% fat/50% carbohydrate
   (d) 20% protein/30% fat/50% carbohydrate
3. For how many months prior to conception and post-conception should a woman supplement with folic acid?
   (a) 3 months prior and 1-month post-conception
   (b) 3 months prior and 3 months post-conception
   (c) 1 month prior and 6 months post-conception
   (d) 1 month prior and 1-month post-conception
4. Which of the following is not a good source of iron for pregnant women?
   (a) Oysters
   (b) Beef meat
   (c) Spinach
   (d) Legumes
5. Vitamin D deficiencies in pregnant women can lead to all of the following in children except:
   (a) Rickets
   (b) Hypocalcemia
   (c) Obesity
   (d) Delayed ossification
6. Food fortification with which two nutrients have been shown to reduce the incidence of neural tube defects?
   (a) Vitamin A and Vitamin C
   (b) Folic Acid and B vitamins
   (c) Vitamin K and Magnesium
   (d) Potassium and Vitamin E
7. In diabetic women who become pregnant, how many times greater is the risk of congenital malformations related to poor control of diabetes?
   (a) Four times
   (b) Three times
   (c) Two times
   (d) None of the above
8. Pregnant vegetarians:
   (a) Should change to an omnivorous diet during pregnancy and lactation to improve their baby's health
   (b) Have to eat 20% more protein than pregnant omnivores
   (c) Do not need to change their usual intake of anything as their diet is healthier than those of omnivorous women
   (d) Need to be aware of their intake of vitamin C as it can be toxic for the baby
9. Eating fish during pregnancy:
   (a) Is the best way to get the right amount of DHA, which is essential for the correct brain development
   (b) Is banned because the because of the danger of poisoning due to methyl mercury contamination
   (c) Can lead to heart problems in mother and child because of the high intake of SFA
   (d) Must not include shellfish of any kind as only big fish are recommended
10. During Pregnancy athletes:
    (a) Should stop training completely for the health of the baby
    (b) Can continue training but should stop during the breastfeeding period
    (c) Should be careful with the supplements they take, especially with ergogenic aids
    (d) Are less at risk of developing anemia due to the cessation of menstruation

Answers

1. c
2. d
3. b
4. a
5. c
6. b
7. a
8. b
9. a
10. c

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Nutritional Guidelines, Energy Balance, and Weight Control: Issues for the Aging Active Female

22

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Learning Objectives
After completing this chapter, you should have an understanding of:

- Energy balance and weight control.
- Dietary guidelines for the mature woman.
- Important nutrients, vitamins, and minerals for physically active women.

22.1 Introduction

The nutritional needs of an aging population require special attention. Energy expenditure declines with age; thus, to achieve energy balance, less energy needs to be consumed. The reduction in energy intake can have adverse effects on the nutritional status of older people unless high nutritional quality foods are eaten or assimilation and is part of the malnutrition etiologic [1, 2]. Worldwide, the micronutrient status of women is inadequate for several micronutrients. The rationale for micronutrient adequacy in the individual woman has been well defined for many micronutrients such as iron, calcium, iodine, folate, and vitamins A and D. However, for older women, especially those living beyond their 80s, more research about nutritional requirements is needed. Important micronutrients for aging are discussed in this chapter as well as the dietary guidelines for the mature woman.

The decline in energy intake associated with aging also increases the risk of frailty and mortality [3] in people with low body mass index (BMI). However, obesity is now common in older women. Obesity is also associated with an increase in the prevalence of disability. Conversely, weight loss in overweight older women has been associated with increases in quality of life. Issues in energy balance and weight control are also highlighted in this chapter.

The Food and Nutrition Information Center (FNIC) is a leader in online global nutrition information. It is located at the National Agricultural Library (NAL) of the United States Department of Agricultural (USDA). The FNIC Web site contains over 2500 links to current and reliable nutrition information. The FNIC provides links to the Dietary Reference Intakes (DRI) tables and reports discussed in this chapter. These tables and reports have been developed by the Institute of Medicine's Food and Nutrition Board, and contain a list of valuable information that you can assess at https://www.nal.usda.gov/fnic/dietary-guidance-0 [4]. See Appendix 1 for some of the Dietary Reference Reports available.

22.2 Research Findings

22.2.1 Energy Balance and Weight Control

Generally, positive energy balance leads to weight gain and negative balance to weight loss. Changes in body composition are due to alterations in energy balance; however, this is not as simple as it seems. The aging process brings about many changes in body composition, often without concomitant changes in body weight and BMI. In the aging, body fat percentage (%BF) increases and lean body mass (LBM) and bone mineral density (BMD) decrease [5]. BMD declines with age beginning at about age 50. In the 5–7 years following menopause, women may lose up to 20% of bone mass [6]. Data from the NHANES cohort showed that women of European American and African American descent lose less than 1% of total fat-free mass (FFM) (measured by Dual-energy X-ray absorptiometry or DEXA) during menopause but this figure decreases to 12% and 9% respectively between

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the age group of 40–49 and ≥75 years [5]. The increase in fat mass (FM) is distributed more specifically in the abdominal region, an area associated with cardiovascular disease and diabetes [7]. Additionally, there is a difference in FM and body fat distribution between the sexes. Women are more efficient in conserving and storing energy as fat. It is also known that postmenopausal women experience an increase in the waist-to-hip ratio [8]. Parallel to changes in FFM with aging, there is also a redistribution of FM mainly in the visceral component, but fat deposits are also observed in skeletal muscles and in the liver [5]. Women lose less FFM compared with men with similar weight loss (27.3% vs. 25.4% for men and women, respectively). Supporting this notion is the recognition that women must reduce their dietary intake by a higher proportion to achieve the same degree of weight loss as men [8].

Following the age of 40 years, total energy expenditure (TEE) begins to decline quite dramatically. Women 75 years old or more experience TEE levels similar to a 7–11-year-old, despite having greater body mass. In order to fully understand TEE, some definitions need to be clarified using a single authoritative source [9]. In the research literature, terms are sometimes expressed with slight variations.

- The *basal metabolic rate* (*BMR*) describes as the rate of energy expenditure that occurs in the postabsorptive state.
- The BMR is commonly extrapolated to 24 h to be more meaningful, and it is then referred to as *basal energy expenditure* (*BEE*), expressed as kcal/24 h.
- *Resting metabolic rate* (*RMR*), energy expenditure under resting conditions, tends to be somewhat higher (10–20%) than under basal conditions due to increases in energy expenditure caused by recent food intake (i.e., by the "thermic effect of food") or by the delayed effect of recently completed physical activity.
- *Resting energy expenditure* (*REE*) is RMR extrapolated to 24 h.
- *The thermic effect of food* (*TEF*) also, called diet-induced thermogenesis, represents approximately 8–15% of TEE [10]. The intensity and duration of meal-induced TEF are determined primarily by the amount and composition of the foods consumed and the associated metabolic costs.
- The *physical activity level of the index* (*PAL*) is a way to express a person's daily physical activity as a number, and is used to estimate a person's TEE. The PAL is defined for a non-pregnant, non-lactating adult as that person's TEE in a 24-h period, divided by his or her BEE or RMR, PAL = TEE/BEE.
- The *physical activity coefficient* (*PA*) is used in the formula found in Table 22.3 to determine estimated energy requirements (EER) where PA for girls 3–18 years old is as follows:

  PA = 1.00 if PAL is estimated to be ≥1.0 < 1.4 (sedentary);
  PA = 1.16 if PAL is estimated to be ≥1.4 < 1.6 (low active);
  PA = 1.31 if PAL is estimated to be ≥1.6 < 1.9 (active);
  PA = 1.56 if PAL is estimated to be ≥1.9 < 2.5 (very active).
- The *PA* is used in the formula found in Table 22.3 to determine estimated energy requirements (EER)where PA for women 19+ years is as follows:

  PA = 1.00 if PAL is estimated to be ≥1.0 < 1.4 (sedentary)
  PA = 1.12 if PAL is estimated to be ≥1.4 < 1.6 (low active)
  PA = 1.27 if PAL is estimated to be ≥1.6 < 1.9 (active)
  PA = 1.45 if PAL is estimated to be ≥1.9 < 2.5 (very active)
- *TEE* is the sum of BEE, which includes a small component associated with arousal, as compared to sleeping, the TEF, physical activity, thermoregulation, and the energy expended in depositing new tissues and in producing milk.
- The *estimated energy requirement* (*EER*) is the average dietary energy intake that is predicted to maintain energy balance in a healthy adult of a defined age, gender, weight, height, and level of physical activity consistent with good health. In children and pregnant and lactating women, the EER is taken to include the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.

Thus, it is important to distinguish between BMR and RMR. Because RMR is much easier to measure than BMR, RMR is frequently seen in the literature as a component of TEE. TEE is thus comprised of RMR, the TEF, and activity energy expenditure (AEE) [13]. Activity energy expenditure (AEE) is the modifiable component of TEE derived from all activities, both volitional and nonvolitional. Thus, TEE (kcal/day) = RMR + AEE + TEF [14].

With increasing age, TEE decreases for both RMR and AEE. This decrease in TEE with age is associated with reductions in body mass and FFM [13]. TEE decreases by 6% per decade for women, as a result of decreases in physical activity and energy expenditure [15]. TEE remains higher for men than for women. However, when adjusted for FMM, TEE is higher for women than for men [16].

RMR is one of the largest components of TEE, comprising 50–80%, and it has previously been estimated to decline 1–2% per decade after 20 years. This decline in RMR with age may not be linear, breakpoint decline quickly becomes apparent around 50 years in women; this may be due to an accelerated loss of FFM during menopause [17, 18]. Longitudinal studies indicated 3% reductions in RMR per

decade in women respectively, and the rate of decline in RMR was faster at age 70–80 years than at age 40–50 years [15]. Aging is associated with a decrease in almost all components of the equation: ↓RMR (change in FM and FFM), AEE (change in activity level), as well as energy intake. Yet, it remains unclear what factor initiates the change. The TEF contributes 8–15% to TEE and does not decline with aging per se [17] and the degree of processing or refinement of foods can influence their thermic effect [10]. In many circumstances, aging and diseases might contribute to a decrease or increase in RMR [13]. The lower RMR of older adults may be due in part to slowed organ metabolic rates, and this may contribute to changes in FM, FFM, and fat distribution [17]. This could also be due, for example, to morphological changes like infiltration of the organs with fat, edema, or cystic structures [19] and changes in fat oxidation. However, the decline in RMR is not entirely due to changes in body composition [7]. Decreased RMR as a consequence of loss of metabolically active FFM, reduced physical activity and increased sedentary time all contribute to the development of obesity in women from mid-to old age [5].

Older women maintain lower levels of AEE than men (576 kcal/day vs. 769 kcal/day) until the seventh decade of their life (the 70s). During their 70s, older women have similar physical activity levels (PAL) as men [18, 20].

Older women may ameliorate the age-related decrease in RMR, through increased physical activity to preserve body composition. There is a strong association [18] between physical activity levels and FFM [13, 14].

The use of a measure or an estimate of TEE to validate instruments that measure food intake is dependent on the principle of energy balance. That is, in weight-stable adults, energy intake must equal TEE. In a balanced state, TEE corresponds to EER.

Recommendations for caloric intake to maintain weight will vary depending on a person's age, sex, size, and level of physical activity. Specific equations for estimating caloric needs are provided in the Dietary Reference Intakes for Energy Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids [9]. These reports can be found in the USDA's NAL and can be downloaded free of charge in a PDF file (https://www.nal.usda.gov/fnic/dri-nutrient-reports) [21]. Web pages change with time, if the page is no longer available, type in DRI reports in the search box at https://www.nal.usda.gov/fnic.

The most accurate way to assess TEE is through the doubly labeled water technique (DLW). The DLW technique is considered the gold standard measure of free-living activity expenditure in conjunction with direct calorimetric for the measurement of RMR. However, this method is expensive and impractical in many healthcare settings, and therefore predictive equations are used to estimate RMR in most clinical and inpatient care practices.

Table 22.1 An estimated energy expenditure prediction equation using the Mifflin–St Jeor equation to determine resting metabolic rate (RMR) [26]. (Adapted from Physiology of fitness (3rd ed.) (p. 359) by B. J. Sharkey, 1990, Champaign, IL: Human Kinetics)

Step 1: *Estimate resting metabolic rate* (*RMR*) *using the Mifflin–St Jeor equation*	
RMR = 9.99 × weight (kg) + 6.25 × height (cm) − 4.92 × age (year) + 166 × sex (males, 1; females, 0) – 161	
Step 2: *Determine additional caloric requirements based on level of activity*	
Physical activity level	Percentage above resting level
Bed rest	10
Quiet rest	30
Light activity	40–60
Moderate activity	60–80
Heavy activity	100
Additional caloric requirements = RMR × Percentage above resting level	
Step 3: *Determine predicted total energy expenditure* (*TEE*)	
TEE = RMR + Additional caloric requirements based on activity	
TEE = predicted energy expenditure in kcal/day	

The Mifflin–St Jeor equation is more likely than other equations to estimate RMR with a smaller bias but the largest variability in adults aged ≥65 years and by subgroups 65–70 years and ≥80 years [22, 23], is estimated from weight, height, and age. Multiple-regression analyses were employed to drive relationships between RMR and weight, height, and age for both sexes ($R^2 = 0.71$), the separation by sex did not affect its predictive value.

RMR = 9.99 × weight (kg) + 6.25 × height (cm) − 4.92 × age (year) + 166 × sex (males, 1; females, 0) − 161 [24]. This equation has also been validated in the obese population [25]. Table 22.1 details the process to estimate total caloric needs depending on activity level using the Mifflin–St Jeor multiple regression equation to estimate RMR. For example, if a person's RMR was 1000 and they were doing a heavy activity, you would multiply 1000 times the percentage above rest 100% or 1.00 and add that value to their estimated RMR, 1000 (RMR) + 1000 (1000 × 1 for additional calories above rest) = 2000. This value would be their estimated energy expenditure in kcal/day using the method presented in Table 22.1.

The PAL can be used as an indirect index of physical activity and is useful in recommending energy intakes based on RMR and a PAL value [27]. In this instance, PAL is calculated as TEE/RMR [20]. The PAL value establishes the difference between a sedentary and a very active person (the greater the value, the greater level of activity) [20]. The PAL value establishes categories for PA coefficient defined as sedentary = 1.0; low active = 1.12;

Table 22.2 Physical activity level index (PAL) and physical activity coefficient (PA) used to derive estimated energy requirements (EER) for women. (Adapted from the Institute of Medicine. 2005. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: The National Academies Press. https://doi.org/10.17226/10490 [11] and the Global RPH—the clinicians ultimate reference. https://globalrph.com/medcalcs/estimated-energy-requirement-eer-equation/ [12])

PAL	Sedentary (1.0–1.39)	Low active (1.4–1.59)	Active (1.6–1.89)	Very active (1.9–2.5)
	Typical daily living activities (e.g., household tasks, walking to the bus)	Typical daily living activities PLUS 30–60 min of daily moderate activities (e.g., walking at 3–4 mph)	Typical daily living activities PLUS at least 60 min of daily moderate activities	Typical daily living activities PLUS at least 60 min of daily moderate activities and an additional 60 min of vigorous activity (e.g. jogging, skating, swimming) or 120 min of moderate activity
PA	PA (level 1)	PA (level 2)	PA (level 3)	PA (level 4)
Girls 3–18 year	1.00	1.16	1.31	1.56
Women 19 year+	1.00	1.12	1.27	1.45

PAL Physical activity level or physical activity index, *PA* Physical activity coefficient

active = 1.27; and 1.45 very active for adult women >19 years and older [11, 28].

The EER of mature persons using their PAL (as multiples of RMR), provides a convenient and practical way of controlling age, sex, body weight, and body composition, and the energy intake needs of a wide range of people in a quick way [29].

A Report of the Panel on Macronutrients, Subcommittees on Upper Reference Levels of Nutrients and Interpretation and Uses of Dietary Reference Intakes, and the Standing Committee on the Scientific Evaluation of Dietary Reference [11] provides equations for calculating EER based on sex, age, height, weight, and PA coefficient. The equation for adult women >19 years and older is as follows:

$$\mathrm{EER} = 354 - \left(6.91 \times \mathrm{AGE}\right) + \mathrm{PA} \times \left(9.36 \times \mathrm{WT} + 726 \times \mathrm{HT}\right).$$

TEE measured from DLW and the equations in the referenced report [11] were highly correlated.

Table 22.3 Equations to estimate energy requirement. (Adapted from the Institute of Medicine. 2005. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: The National Academies Press. https://doi.org/10.17226/10490 [11] and Global RPH—the clinicians ultimate reference. https://globalrph.com/medcalcs/estimated-energy-requirement-eer-equation/ [12])

Infants and young children	
Estimated energy requirement (kcal/day) = Total energy expenditure + Energy deposition	
0–3 months	EER = (89 × weight [kg] − 100) + 175
4–6 months	EER = (89 × weight [kg] − 100) + 56
7–12 months	EER = (89 × weight [kg] − 100) + 22
13–35 months	EER = (89 × weight [kg] − 100) + 20
Children and adolescents 3–18 years	
Estimated energy requirement (kcal/day) = Total energy expenditure + Energy deposition	
Girls	
3–8 years	
EER = 135.3 − (30.8 × age [year]) + PA × [(10.0 × weight [kg]) + (934 × height [m])] + 20	
9–18 years	
EER = 135.3 − (30.8 × age [year]) + PA × [(10.0 × weight [kg]) + (934 × height [m])] + 25	
Adults 19 years and older	
Estimated energy requirement (kcal/day) = Total energy expenditure	
Women	
EER = 354 − (6.91 × age [year]) + PA × [(9.36 × weight [kg]) + (726 × height [m])]	
Pregnancy	
Estimated energy requirement (kcal/day) = Nonpregnant EER + Pregnancy energy deposition	
First trimester	EER = Nonpregnant EER + 0
Second trimester	EER = Nonpregnant EER + 340
Third trimester	EER = Nonpregnant EER + 452
Lactation	
Estimated energy requirement (kcal/day) = Nonpregnant EER + Milk energy output − Weight loss	
0–6 months postpartum	EER = Nonpregnant EER + 500–170
7–12 months postpartum	EER = Nonpregnant EER + 400–0

Note: These equations provide an estimate of energy requirement. Relative body weight (i.e., loss, stable, gain) is the preferred indicator of energy adequacy

Note: See Table 22.2 to find the appropriate PA value to use in these equations

EER Estimated Energy Requirement, *PA* Physical Activity Coefficient

Tables 22.2 and 22.3 contain the information to calculate EER using PA coefficient, weight, sex, age, and height for female infants, girls and women. The equations were vali-

dated in terms of their intended use to estimate EER for healthy individuals but the equations were not validated for use in nutritional epidemiology or surveillance studies [16].

22.3 Contemporary Understanding of the Issues

22.3.1 Dietary Guidelines for the Mature Woman

The aim of food-based dietary guidelines is to reduce chronic malnutrition, micronutrient malnutrition, and diet-related communicable and non-communicable diseases. Food-based dietary guidelines allow the principles of nutrition education to be expressed, qualitatively and quantitatively [2]. However, a healthy diet could be attained with many patterns adaptable to personal and cultural preferences [30]. The Dietary Guidelines of Americans are published jointly every 5 years by the Department of Health and Human Services (HHS) and the USDA. The 2020–2025 Dietary Guidelines for Americans, was released in December 2020 and can be downloaded at: https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials [31].

The Dietary Guidelines for Americans, 2020–2025 focuses on four overarching goals for healthy eating patterns for Americans [31].

- Follow a healthy dietary pattern at every life stage.
- Customize and enjoy nutrient-dense food and beverage choices to reflect personal preferences, cultural traditions, and budgetary considerations.
- Focus on meeting food group needs with nutrient-dense foods and beverages, and stay within calorie limits.
- Limit foods and beverages higher in added sugars, saturated fat, and sodium, and limit alcoholic beverages.

Furthermore, the Dietary Guidelines for Americans, 2020–2025 include key recommendations for the general population and additional key recommendations for specific population groups [31]. According to research, the diet quality of Americans aged 65 and older did not significantly improve in the past decade. To improve diet quality, the USDA suggests that older Americans need to increase their intake of whole grains, dark green and orange vegetables, legumes, and milk. They also need to choose more nutrient-dense forms of foods. These changes, if made, would provide substantial health benefits [30]. The intention of the new dietary recommendations is to stimulate people to make more thoughtful choices-choices that will reflect healthier foods and portion sizes that are appropriate for their caloric needs. It is also hoped that the physical activity of Americans is increased along with healthier food choices, thereby reducing the risk of developing the diet-related chronic disease [32].

The nutrition information found in the ninth edition of the Dietary Guidelines for Americans, 2020–2025 (https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials) will help the aging woman choose nutrient-dense foods for an adequate diet [31]. Appendix 2 displays the USDA food groups and recommended sub-groups to select in your diet. Appendix 3 outlines the USDA's healthy choices for the desired caloric intake. The patterns of behaviors correlated with healthy body weight are as follows:

- focus on the total number of calories consumed;
- monitor food intake;
- when eating out, choose smaller portions or lower-caloric options;
- prepare, serve, and consume smaller portions of foods and beverages, especially those high in calories;
- eat a nutrient-dense breakfast; and
- limit screen time

The total number of calories a person needs each day varies depending on a number of factors. These factors include age, weight, gender, height, and level of physical activity. Generally one of the significant age-associated changes is that the need for energy decreases [33]. In order to maintain, lose or gain weight, the caloric needs of an individual should be known. However, even when caloric needs are known, many women find it impossible to lose weight or maintain a healthy weight after weight loss. A growing body of research has begun to describe overall eating patterns that help promote caloric balance and weight management. One researched aspect of these eating patterns is the concept of energy density or the amount of calories provided per unit of food weight [34].

Energy density (ED) is the amount of energy per weight of food or beverage (kilojoules/g [kJ/g] or kilocalories/gram [kcal/g]). Foods high in water and/or fiber are lower in ED, while foods high in fat are higher in ED, increasing calorie intakes. Choosing foods that have a lower ED may also be associated with a lower risk of type 2 diabetes in adults [35, 36].

Weight gains following menopause may be an indicator of relapses in weight reduction. More than 50% of women in the menopausal period attempt to restrict their calories in an attempt to lose weight; however, they are unsuccessful at weight loss maintenance. Peak body weight gain is observed around age 50 [37].

From a clinical point of view, this fact is of great interest. Diets that are reduced in calories must also have macronutrient proportions that are within the ranges recommended in

the Dietary References Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Proteins, and Amino Acids (protein: 10–35%; carbohydrate: 45–65%; fat: 20–35%) [9]. Furthermore, ED is also an important component of choosing the right food combinations that helps you lose weight and maintain weight loss [38, 39]. Nutritional goals for females 31–50 and +50 years based on dietary reference intakes and dietary guidelines recommendations are presented in Table 22.4.

MyPlate is an initiative to implement the Dietary Guidelines to build healthy eating patterns and more appropriate portions across the food groups. The USDA provides a Website in which a food plan can be customized, at (http://www.ChooseMyPlate.gov/) [41]. This Web site helps consumers choose a healthy personal eating plan. Physical activity is also emphasized based on the recommendations of the American College of Sports Medicine (ACSM) [42], and as a complement, the USDA generated the second edition of the Physical Activity Guidelines for Americans where it is possible to find resources with information about benefits and tips to be more physically active [43].

Table 22.4 Nutritional goals for female groups and age, based on dietary reference intakes and dietary guidelines recommendations. (Sources: Britten P, Marcoe K, Yamini S, Davis C. Development of food intake patterns for the MyPyramid Food Guidance System. J Nutr Educ Behav 2006;38(6 Suppl): S78–S92 [28] and IOM. Dietary reference intakes: the essential guide to nutrient requirements. Washington (DC): The National Academies Press; 2006 [40]. The complete report can be viewed and downloaded at the US Department of Health and Human Services and USDA. Dietary guidelines for Americans 2020–2025. https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials [31])

Nutrient (units)	Female 31–50 (1800 cal)	Female 51+ (1600 cal)	Source of goal[a]
Macronutrients			
Protein	46 g	46 g	RDA[b]
Calories	10–35%	10–35%	AMDR[c]
Carbohydrate	130 g	130 g	RDA
Calories	45–65%	45–65%	AMDR
Total fiber	25 g	22 g	IOM[d]
Total fat (calories)	20–35%	20–35%	AMDR
Saturated fat (calories)	<10%	<10%	DGA[e]
Linoleic acid	12 g	11 g	AI[f]
Calories	5–10%	5–10%	AMDR
Alpha-linolenic acid	1.1 g	1.1 g	AI
Calories	0.6–1.2%	0.6–1.2%	AMDR

[a] Dietary guidelines recommendations are used when no quantitative Dietary Reference Intake value is available; apply to ages 2 years and older
[b] Recommended dietary allowance, IOM
[c] Acceptable macronutrient distribution range, IOM
[d] 14 g per 1,000 cal, IOM
[e] Dietary guidelines recommendation
[f] Adequate intake, IOM

Topics such as *what is physical activity*, *why is physical activity important*, *how much physical activity do I need* can be answered on this site.

Solid fats are abundant in the diets of Americans and contribute significantly to excess caloric intake and weight gain. A fat intake recommendation for older women is 20–35% of total daily calories. These ranges are associated with reduced risk of chronic diseases, such as cardiovascular disease while providing for adequate intake of essential nutrients. The recommendation is to keep *trans* fatty acid consumption as low as possible, especially by limiting foods that contain synthetic sources of *trans* fats, such as partially hydrogenated oils, and by limiting other solid fats. All individuals, not just older women, should consume less than 10% of their daily calories from saturated fatty acids. Saturated fatty acids should be replaced with monounsaturated and polyunsaturated fatty acids [31].

Among the significant age-associated changes in nutrient requirements is that the need for protein increases with age [29]. The protein requirements of older adults may be higher than the current recommended level of 0.8 g/kg/day. Despite an estimated increase in mean protein requirements for older adults, a recent study indicated that there is no difference between the young and old when the protein requirements are expressed per kilogram FFM. The recommended level is now 0.85 g/kg/day for both young and old adults [44]. Using the indicator amino acid oxidation (IAAO) method, the protein requirements in both elderly men and women are 0.9 and 1.2 g/kg/day, and suggest that the current protein recommendations by DRI are underestimated by ~30% [45]. The consumption of high-quality proteins that are easily digestible and contain a high proportion of essential amino acids provides support for a beneficial effect of increased protein in elderly populations [46]. In a study, women who met guidelines for physical activity had good dietary habits in general and emphasized the importance of protein intake to infer additional benefits on constructs of physical function, showed the promotion of healthy aging [47]. Determining the appropriate protein intake for older women is important because inadequate intake contributes to increased risk for common age-associated problems, such as sarcopenia, osteoporosis, and impaired immune responses [32].

There are a wide variety of recommendations about the specific value of protein requirements; however, the data is non-conclusive with regard to the best recommendation. Nevertheless, dairy products digest quickly and have high biological levels of protein that contain essential amino acids (meaning that the human body cannot synthesize it, and it, therefore, must be ingested) such as leucine. Milk, a good source of high biological value protein, is particularly rich in essential and branched-chain amino acids. Protein metabolites, such as small peptides, have been shown to have bioac-

tive properties [48]. Bioactive describes something that can have an effect on living tissue, such as the effect of the sun's rays on the skin.

In the USA, the total consumption of sugar has increased substantially in recent decades [49]. The obesity epidemic has focused attention on the relationship between sugars and sugar-sweetened beverages (SSB)—particularly glucose, sucrose, and fructose, e.g., high-fructose corn syrup [50, 51]. Higher consumption of carbohydrates has been associated with dyslipidemia, a lipid profile known to increase cardiovascular disease risk including lower HDL-C levels, higher triglyceride levels, and higher ratios of triglycerides to HDL-C. The consumption of large amounts of added sugars, a prominent source of low-nutrient calories, is a relatively new phenomenon. For mature women, it is advised to limit their added sugars to fewer than 100 cal daily (approximately 5% of total energy intake) [49].

Daily sodium intake should be reduced to less than 2300 mg. Adults of any age who have hypertension, diabetes, or chronic kidney disease should also work to reduce their sodium intake to lower their risk of cardiovascular disease [31].

Since hypertension is a major public health problem affecting millions of adult women, the Dietary Approach to Stop Hypertension (DASH) diet has been created. This diet plan, DASH, is designed to: reduce the intake of saturated fat, total fat, sodium, and cholesterol; increase the intake of fruits and vegetables; and increase the consumption of potassium, calcium, magnesium, fiber, and protein. Adherence to DASH is a key component of controlling blood pressure [52]. Table 22.5 compares the usual US intake, the recommended DASH pattern, Mediterranean diet pattern, vegetarian diet pattern, and the USDA food patterns adjusted to a 2000 cal level. Table 22.6 presents three different caloric intakes according to the DASH eating plan.

Adverse Blood Pressure (BP)—prevalent worldwide—is an independent major risk factor for cardiovascular diseases (CVD). Established modifiable risk factors for elevated BP are high sodium intake, inadequate potassium intake, high body mass index (BMI), and excessive alcohol intake [50]. Sodium and potassium have opposing effects on arterial vasodilation [48].

Table 22.5 Healthy Food Pattern comparison: usual US intake, DASH, Mediterranean, vegetarian, and USDA Food Patterns, average daily intake at or adjusted to a 2000 cal level ages 2 and over (a, b, c, d, e) (See [31, 53] for details by age for usual US adult intake)

Pattern	Usual US intake adults [53]		DASH [54]	USDA food pattern [31, 53]	Mediterranean food pattern [31]	Vegetarian food pattern [31]	Amounts to compare [31]
Food groups							
Vegetables	1.37		2–2.5 cups	2.5 cups	2.5 cups	2.5 cups	1 cup eq: 1 cup raw or cooked vegetable; 1 cup vegetable; 2 cups leafy salad greens; ½ cup vegetable
Fruits	0.88 cups		2–2.5 cups	2.0 cups	2.5 cups	2.0 cups	1 cup eq: 1 cup raw or cooked fruit; 1 cup fruit juice; ½ cup dried fruit
Grains	5.69 oz		6–8 oz eq	6.0 oz	6.0 oz	6.5 oz	1 ounce eq: ½ cup cooked rice, pasta, or cereal; 1 ounce dry pasta or rice; 1 medium (1 ounce) slice bread, tortilla, or flatbread; 1 ounce of ready-to-eat cereal (about 1 cup of flaked cereal)
Whole grains	0.75 oz		3.0 oz	3 oz	3.5 oz		
Milk and milk products/Dairy products	1.34 cups	2–3 cups	3.0 cups	2.0 cups	3.0 cups		1 cup eq: 1 cup milk, yogurt, or fortified soymilk; 1½ ounces natural cheese such as cheddar cheese or 2 ounces of processed cheese
Protein food	3.62 oz avg (meat, poultry, seafood)	6 oz or less (meat, poultry, fish)	5½ oz	6½ oz	3½ oz		1 ounce-eq.: 1 ounce lean meat, poultry, or seafood; 1 egg; ¼ cup cooked beans or tofu; 1 Tbsp peanut butter; ½ ounce nuts or seeds
Fish/seafood	0.48 oz	≤6 oz (meat, poultry, seafood, eggs)	8 oz	15 oz eq/ week			1 ounce-eq.: 1 ounce seafood; 6 ½ oz eq/day; 3 ½ oz eq/day; 1 ounce lean meats, poultry, or seafood; 1 egg; ¼ cup cooked beans or tofu; 1 tbsp nut or seed butter; ½ ounce nuts or seeds
Meats, Poultry, Eggs	2.94	≤6 oz	26 oz-eq/ week	26 oz eq/ week	3 oz eq/week (eggs)		1 ounce-eq.: 1 ounce lean meat or poultry, 1 egg

(continued)

Table 22.5 (continued)

Pattern	Usual US intake adults [53]		DASH [54]	USDA food pattern [31, 53]	Mediterranean food pattern [31]	Vegetarian food pattern [31]	Amounts to compare [31]
Nuts, seeds, and soy products	0.75 oz	4–5 servings/ week	5 oz-eq/ week	5 oz eq/ week	15 oz		1 Tbsp peanut butter; ½ ounce nuts or seeds
Legumes (beans & peas)[a]	0.45	Included above	1½ cups eq/week	1½ cups eq/week	6 cups eq/week		¼ cup cooked beans: Legumes include kidney beans, pinto beans, white beans, black beans, garbanzo beans (chickpeas), lima beans (mature, dried), split peas, lentils, and edamame (green soybeans)
Oils	25.91 g	8–12 g	27 g	27 g	27 g		1 tsp. of oil can be found in: • 1 tbsp. low-fat mayo • 2 tbsp. light salad dressing • 1 tsp. vegetable oil
Maximum "empty" calories from solid fats and added sugars	31.67 g fats/15.09 tsp. sugars	2 tsp. (5 tbsp or less/ week)	240 kcal/ day 12%	240 kcal/ day 12%	250 kcal/day 13%		1 tbsp. added sugar can be found in: • 1/2 ounce jelly beans • 8 ounces lemonade
Maximum sodium limit		2300 mg/ day					

[a] Food intake pattern at 2000 calories
[b] Foods in each group and subgroup are listed in Appendix 2
[c] Food group amounts shown in cup-(c) or ounce-equivalents (oz-eq). Oils are shown in grams (g)
[d] All foods are assumed to be in nutrient-dense forms, lean or low-fat and prepared without added fats, sugars, refined starches, or salt. If all food choices to meet food group recommendations are in nutrient-dense forms, a small number of calories remain within the overall calorie limit of the Pattern (i.e., a limit on calories for other uses). The number of these calories depends on the overall calorie limit in the Pattern and the amounts of food from each food group required to meet nutritional goals. The overall eating Pattern also should not exceed the limits of less than 10% of calories from added sugars and less than 10% of calories from saturated fats. At most calorie levels, amounts that can be accommodated are less than these limits
[e] Values may be rounded
Sources: U.S. Department of Agriculture, Agricultural Research Service. 2018. Food Patterns Equivalents Intakes from Food: Mean Amounts Consumed per Individual, by Gender and Age, What We Eat in America, NHANES 2017–2018. www.ars.usda.gov/nea/bhnrc/fsrg [53], DASH Parent Tips. USDA Food Pattern and The DASH Easting Plan. We Can! Ways to Enhance Children's Activity & Nutrition, We Can!, and the We Can! logos are registered trademarks of the U.S. Department of Health & Human Services (DHHS) https://www.nhlbi.nih.gov/health/educational/wecan/downloads/intake.pdf [54] and US Department of Health and Human Services and U.S. Department of Agriculture. Dietary guidelines for Americans 2020-2025, ninth edition https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials [31]
[a] Amounts included in vegetables as well

Table 22.6 The DASH eating plan at various calorie levels. (The number of daily servings in a food group varies depending on caloric needs The DASH eating Patterns from 1600 to 3100 cal meets the nutritional needs of children 9 years and older and adults). Source: NIH/National Heart, Lung, and Blood Institute Following the DASH Eating Plan https://www.nhlbi.nih.gov/education/dash/following-dash [55]

Calories	1600	1800	2000			
Food groups	Servings			Serving sizes	Examples	Notes
Vegetables	3–4	4–5	4–5	1 cup raw leafy vegetable, ½ cup cut-up raw or cooked vegetable, ½ cup vegetable juice	Broccoli, carrots, collards, green beans, green peas, kale, lima beans, potatoes, spinach, squash, sweet potatoes, tomatoes	Rich sources of potassium, magnesium, and fiber
Fruit	4	4–5	4–5	1 medium fruit, ¼ cup dried fruit ½ cup fresh, frozen, or canned fruit, ½ cup fruit juice	Apples, apricots, bananas, dates, grapes, oranges, grapefruit, grapefruit juice, mangoes, melons, peaches, pineapples, raisins, strawberries, tangerines	Important sources of potassium, magnesium, and fiber
Grains [a]	6	6	6–8	1 slice bread 1 oz dry cereal [b] ½ cup cooked rice, pasta, or cereal [b]	Whole-wheat bread and rolls, whole-wheat pasta, English muffin, pita bread, bagel, cereals, grits, oatmeal, brown rice, unsalted pretzels and popcorn	Major sources of energy and fiber

Table 22.6 (continued)

Calories	1600	1800	2000			
Food groups	Servings			Serving sizes	Examples	Notes
Fat-free or low-fat milk and milk products [b]	2–3	2–3	2–3	1 cup milk or yogurt, 1½ oz cheese	Fat-free milk or buttermilk; fat-free, low-fat, or reduced-fat cheese; fat-free/low-fat regular or frozen yogurt	Major sources of calcium and protein
Lean meats, poultry, and fish	3–4 or less	6 or less	6 or less	1 oz cooked meats, poultry, or fish, 1 egg	Select only lean; trim away visible fats; broil, roast, or poach; remove skin from poultry	Rich sources of protein and magnesium
Nuts, seeds, and legumes	3–4 per week	4 per week	4–5 per week	1/3 cup or 1½ oz nuts, 2 Tbsp peanut butter, 2 Tbsp or ½ oz seeds, ½ cup cooked legumes (dried beans, peas)	Almonds, filberts, mixed nuts, peanuts, walnuts, sunflower seeds, peanut butter, kidney beans, lentils, split peas	Rich sources of energy, magnesium, protein, and fiber
Fats and oils [c]	2	2–3	2–3	1 tsp. soft margarine, 1 tsp. vegetable oil, 1 Tbsp mayonnaise, 1 Tbsp salad dressing	Soft margarine, vegetable oil (canola, corn, olive, safflower), low-fat mayonnaise, light salad dressing	The DASH study had 27% of calories as fat, including fat in or added to foods
Sweets and added sugars	3 or less per week	5 or less per week	5 or less per week	1 Tbsp sugar, 1 Tbsp jelly or jam, ½ cup sorbet, gelatin dessert,1 cup lemonade	Fruit-flavored gelatin, fruit punch, hard candy, jelly, maple syrup, sorbet and ices, sugar	Sweets should be low in fat
Maximum sodium limit [d]	2300 mg/day	2300 mg/day	2300 mg/day			

[a] Whole grains are recommended for most grain servings as a good source of fiber and nutrients
[b] For lactose intolerance, try either lactase enzyme pills with dairy products or lactose-free or lactose-reduced milk
[c] Fat content changes the serving amount for fats and oils. For example, 1 Tbsp regular salad dressing = one serving; 1 Tbsp low-fat dressing = one-half serving; 1 Tbsp fat-free dressing = zero servings
[d] The DASH eating plan has a sodium limit of either 2300 mg or 1500 mg per day

22.3.2 Important Nutrients, Vitamins, and Minerals for Physically Active Women

The micronutrient and macronutrient needs of individuals, men and women alike, who are physically active, have always been a subject of debate. The intensity, duration, and frequency of the physical activity as well as the overall nutrient intake of the individual have an impact on whether or not micronutrients and macronutrients are required in greater amounts. The Dietary Reference Intakes (DRIs) for macronutrients, vitamins, and minerals for females of all ages, regardless of the level of physical activity, as established by the Food and Nutrition Board, Institute of Medicine, and National Academies can be found in the Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients) [11].

Generally, the vitamin and mineral needs of active individuals are not greater than those who are not active, if the DRIs are being met. However, it has been shown that frequently women, of all ages, do not meet their nutrient needs through diet alone, and therefore supplementation may be necessary. Older adults are at even greater risk for nutritional deficiencies than younger adults due to physiologic changes associated with aging. Therefore, it is recommended that individuals 50 years and older consume food-fortified cereals, or dietary supplements [31]. Nonetheless, mega-dosing with one vitamin and/or mineral can impair the functions of other vitamins and minerals.

The DRIs suggest dietary carbohydrates should be in the range of 45–65% of total calories. Using the recommendations of 5–7 g/kg/day for general training needs, a 54.4 kg (120 lb) woman would need roughly 272–380 g of carbohydrates. The typical US diet provides 4–5 g/kg/day, and athletes who train daily and compete at high intensity need more carbohydrates [56]. Therefore, women who train daily would need more carbohydrates than the typical US diet would provide.

In recent years, dietary fiber is a key substrate for the gut microbiota, so alteration of dietary fiber intake has an immediate and direct impact on the gut microbial population and immune system is closely linked with gut microbiota. The adequate fiber is 14 g of total fiber per 1000 kcal or 25 g for adult women [36].

22.4 Future Directions

As individuals are living longer than the lifespan expectancies of their parents, for the most part, supplementation may be needed for the aging woman who wants to be vital and competitive in recreational sports and activities. Among the micronutrients, the significant ones that may be associated with deficiencies in mature active women include vitamin B-12, vitamin A, vitamin C, vitamin D, calcium, iron, zinc, and other trace minerals [57]. Since essential fatty acids help in the absorption of the fat-soluble vitamins A, D, E, and K, it is important that women intake healthy levels of fats ranging from 20 to 35% of total daily calories (<10% saturated).

Vitamin D has been found in neuronal and glial cells and has been shown to affect the expression of neurotrophins to brain function. A longitudinal study on elderly, showed that vitamin D concentration <25 nmol/L was associated with a significant decline in tests of executive function over time [58]. The dietary RDA for Vitamin D is 15 ug/day for those aged 51–70 years and 20 ug/day for those aged >70 years.

Taking antioxidants including carotenoids, vitamin C, flavonoids, and other polyphenols through vegetables is important because of an associated beneficial decrease in CVD risk. Natural antioxidants are present in the human diet in many different chemical forms [59]. The need for energy-adjusted antioxidant intake from diet increases with age and exercise level (except for flavonoids). Furthermore, the need for antioxidant intake is higher in older very active women (supplementation may be necessary). Interestingly, low total serum carotenoid concentrations are associated with low walking speed and a greater decline in walking speed [60]. Thus, fortified foods and supplements may be needed in order to meet the DRIs of these micronutrients in older women.

Multi-nutrient supplementation may improve indices of inflammation and help exercise recovery in active older women. In addition to improving energy, supplements may prolong functionality and physiological performance with age. Thus supplements may allow older women to maintain an active lifestyle and promote a cycle of anti-inflammatory and anti-aging activity [61].

With regard to the effects of exercise on vitamin and minerals needs, irrespective of age, thiamin, vitamin C, E, calcium, and iron are discussed in more detail in this chapter since research has shown that the DRI for these micronutrients may be greater in exercising individuals. Vitamin B_{12}, folate, and vitamin A are discussed because of the importance of these micronutrients from a health perspective for the older woman.

22.4.1 Vitamin B_{12} and Folate

The benefits of vitamin B_{12} and folic acid fortification/supplementation are not only applicable to women throughout the lifecycle but also to all sectors of the population due to vitamin B_{12}'s ability to lower homocysteine level [62]. Folic acid is also emerging as important in lowering the risk of certain types of cancers [63].

On average, Americans 50 years and older consume adequate levels of vitamin B_{12}. Nonetheless, a substantial proportion of individuals 50 years and older may have a reduced ability to naturally absorb vitamin B_{12}. They are encouraged to include foods fortified with vitamin B_{12}, such as fortified cereals, or take dietary supplements [31]. Supplement B_{12} is easily available, adequately absorbed, and well tolerated in older adults.

Even if adequate supplementation raises the level to an acceptable range, a physician should assess the individual with the deficiency because the deficiency may be caused by disease. Vitamin B_{12} deficits are associated with impaired peripheral nerve function and the development of anemia. Nerve function impairment may lead to declines in physical function and disability in older adults [64]. There is strong evidence for omega 3 fatty acids with fish as a major source, and for optimal B vitamins, long known to be required for optimal neurological function. There is also growing evidence for that of vitamin D. Several B vitamins are associated with cognitive function in older adults, especially folate, vitamin B_6 and vitamin B_{12} [58].

22.4.2 Vitamin A

Vitamin A has many roles in the maintenance of health; it is important to maintain normal vision, cell differentiation, efficient immune function, and genetic expression. Obtaining supplemental vitamin A in its precursor form β-carotene appears to be considerably safer, more effective, and has not been associated with adverse or unanticipated side effects. Physical activity and total serum carotenoids are strong and independent predictors of survival in older women [65, 66]. It is important for active women to maintain high intakes of fruit and vegetables. Consuming a diet rich in fruits and vegetables is a reasonable way to meet vitamin A needs in older adults as well as providing a good source of dietary fiber [57]. Together with robust levels of physical activity, high total serum carotenoid concentration offers women some added health protection [64].

22.4.3 Thiamin

Thiamin, also known as vitamin B1 and aneurin (a less common name for thiamin), functions as a coenzyme in the metabolism of carbohydrates and branched-chain amino acids [9]. The DRI for women aged 19–70 is 1.1 mg/day. For women who are pregnant or following the birth of their child, during lactation, the requirement is higher, 1.4 mg/day. However, those who engage in physically demanding occu-

pations or who spend much time training for active sports may require increased levels of thiamin intake [67].

22.4.4 Vitamin C

Women tend to have higher blood levels of vitamin C than men of the same age, even when intake levels are the same, making the requirements for women lower than for men. However, pregnant women who smoke, abuse drugs or alcohol, or regularly take aspirin may have increased requirements for vitamin C. If an individual has adequate C status, supplementation with vitamin C does not enhance performance. However, strenuous and prolonged exercise has been shown to increase the need for vitamin C, and physical performance can be compromised with marginal vitamin C status or deficiency. Athletes who participate in habitual prolonged, strenuous exercise should consume 100–1000 mg of vitamin C [68]. Both of these values are greater than the established DRIs [9].

The major food sources of dietary vitamin C in the USA are citrus fruit juice, citrus fruits, fruitades, potatoes, tomatoes, and other vegetables. The dietary intake of vitamin C in the USA is less than in Europe. The difference can be explained by the fact that fruit and vegetable intake in Europe on average is higher compared with intake in the USA [59].

22.4.5 Vitamin E

Because endurance exercise results in increased oxygen consumption and thus increased oxidative stress, it seems logical that vitamin E supplementation might be beneficial for people who exercise. Although vitamin E has been shown to sequester free radicals in exercising individuals (by decreasing membrane disruption) [68], there have been no reports that vitamin E actually improves exercise performance. Nonetheless, vitamin E's role in the prevention of oxidative damage due to exercise may be noteworthy. However, more long-term research is needed to make solid claims about the role that vitamin E plays in decreasing oxidative stress. A study of tocopherols in brain tissue found that concentrations of α-tocopherol were associated with effective effects on Alzheimer's neuropathology only when y-tocopherol was also high [69].

22.4.6 Calcium

Presently, the DRIs for calcium for adult women are 1200 mg/day calcium but there have been suggestions that daily intakes of 1500 mg/day may be appropriate for postmenopausal women or women over age 65 [57]. Calcium recommendations may be achieved by consuming recommended levels of fat-free or low-fat milk and milk products and/or consuming alternative calcium sources [31]. Individuals should avoid calcium supplements containing bone meal, oyster shells, and shark cartilage due to the increased lead content in these supplements, which can result in toxic effects on the body.

Calcium supplements are best absorbed if taken in 500 mg or less between meals. For older women, calcium citrate is the best supplement [63, 70]. It is advisable for any calcium intake to be accompanied by vitamin D supplementation in order to increase absorption rates [9], especially in postmenopausal women. Fortunately, vitamin D levels can also be improved from moderate skin sun exposure, since it is produced from cholesterol molecules in skin cells.

22.4.7 Iron

Studies show that iron status is often marginal or inadequate in many individuals, particularly females, who engage in regular, intense physical activity. The requirement of these individuals may be as much as 30–70% greater than those who do not participate in regular strenuous exercise.

There are two forms of dietary iron: heme and nonheme. Heme iron is derived from hemoglobin, the protein in red blood cells that delivers oxygen to cells. Heme iron is found in animal foods that originally contained hemoglobin, such as red meats, fish, and poultry. Iron in plant foods such as lentils and beans is arranged in a chemical structure called nonheme iron. This is the form of iron added to iron-enriched and iron-fortified foods. Heme iron is absorbed better than nonheme iron, but most dietary iron is nonheme iron.

Plant-based foods, such as vegetables, fruits, whole-grain bread, or whole-grain pasta contain 0.1–1.4 mg of nonheme iron per serving. Fortified products, including bread, cereals, and breakfast bars can contribute high amounts of nonheme iron to the diet [9]. Therefore, exercising women should consume high levels of food containing both heme and nonheme iron. Consuming iron-enriched and iron-fortified foods as well as supplementation may be necessary to achieve the level required for highly active individuals.

22.5 Concluding Remarks

A food-based approach is ideal for meeting the macronutrient and micronutrient needs of women. However, with food-based approaches only, women are not attaining the intake level needed for optimal health and performance in the USA and worldwide [71]. Consideration must be given to fortified foods and/or supplements to meet the recommended daily allowances for optimal health and performance. Among the

micronutrients, the significant ones that may be associated with deficiencies in older women include vitamin B-12, vitamin A, vitamin C, calcium, iron, zinc, and other trace minerals [57].

Appendix 1 Dietary Reference Intakes (DRIs) Reports

The Food and Nutrition Information Center (FNIC) is a leader in online global nutrition information. Located at the National Agricultural Library (NAL) of USDA, the FNIC Web site contains over 2500 links to current and reliable nutrition information.

FNIC provides links to the DRI Tables, developed by the Institute of Medicine's Food and Nutrition Board. To view these tables or download these tables in a PDF file, please go to: https://www.nal.usda.gov/fnic/dietary-reference-intakes [72].

Dietary Reference Intakes: Recommended Intakes for Individuals

Comprehensive DRI tables for vitamins, minerals, and macronutrients; organized by age and gender. Includes the 2010 updated recommendations for calcium and vitamin D.

Dietary Reference Intakes: RDA and AI for Vitamins and Elements

DRI tables for recommended dietary allowances (RDA) and adequate intakes (AI) of vitamins and elements, including the 2010 updated recommendations for calcium and vitamin D.

Dietary Reference Intakes: UL for Vitamins and Elements

DRI table for tolerable upper intake levels (UL) of vitamins and elements, including the 2010 updated recommendations for calcium and vitamin D.

Dietary Reference Intakes: Macronutrients

DRI table for carbohydrates, fiber, fat, fatty acids, and protein.

Dietary Reference Intakes: Estimated Average Requirements

DRI table for nutrients that have an estimated average requirement (EAR), the average daily nutrient intake level estimated to meet the requirements of half of the healthy individuals in a group.

Dietary Reference Intakes: Electrolytes and Water

DRI table for sodium, chloride, potassium, inorganic sulfate, and water.

Dietary Reference Intakes for Calcium and Vitamin D

Report brief on new DRIs for calcium and vitamin D, revised in November 2010.

Dietary Reference Intakes: The Essential Guide to Nutrient Requirements

All eight volumes of the DRIs are summarized in one reference volume, organized by nutrient, which reviews function in the body, food sources, usual dietary intakes, and effects of deficiencies and excessive intakes.

Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride

Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)

Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline

Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc

Dietary Reference Intakes: Proposed Definition of Dietary Fiber

Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids

Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate

Dietary Reference Intakes: Guiding Principles for Nutrition Labeling and Fortification

Dietary Reference Intakes: Applications in Dietary Planning

Dietary Reference Intakes: Applications in Dietary Assessment

Dietary Reference Intakes Research Synthesis Workshop Summary

Dietary Reference Intakes: Proposed Definition and Plan for Review of Dietary Antioxidants and Related Compounds

Dietary Reference Intakes: A Risk Assessment Model for Establishing Upper Intake Levels for Nutrients

Appendix 2 USDA Food Patterns—Food Groups and Subgroups

Information from US Department of Health and Human Services and USDA. Dietary guidelines for Americans 2020–2025. U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2020. https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials [31]

Food group	Subgroups and examples
Vegetables	*Dark-green vegetables*: All fresh, frozen, and canned dark-green leafy vegetables and broccoli, cooked or raw: for example, broccoli; spinach; romaine; kale; collard, turnip, and mustard greens
	Red and orange vegetables: All fresh, frozen, and canned red and orange vegetables or juice, cooked or raw: for example, tomatoes, tomato juice, red peppers, carrots, sweet potatoes, winter squash, and pumpkin
	Legumes (beans and peas): All cooked from dry or canned beans and peas: for example, kidney beans, white beans, black beans, lentils, chickpeas, pinto beans, split peas, and edamame (green soybeans). Does not include green beans or green peas
	Starchy vegetables: All fresh, frozen, and canned starchy vegetables: for example, white potatoes, corn, green peas, green lima beans, plantains, and cassava
	Other vegetables: All other fresh, frozen, and canned other vegetables, cooked or raw: for example, iceberg lettuce, green beans, onions, cucumbers, cabbage, celery, summer squash including zucchini, mushrooms, avocado, cauliflower, eggplant, garlic, bean sprouts, olives, beets, asparagus, snowpeas, and green peppers
Fruits	All fresh, frozen, canned, and dried fruits and fruit juices: for example, oranges and orange juice, apples and apple juice, bananas, grapes, melons, berries, and raisins
Grains	*Whole grains*: All whole-grain products and whole grains used as ingredients: for example, whole-wheat bread, whole-grain cereals and crackers, oatmeal, quinoa, popcorn and brown rice
	Enriched refined-grains: All enriched refined-grain products and enriched refined grains used as ingredients: for example, white bread, enriched grain cereals and crackers, enriched pasta, and white rice. Refined grain choices should be enriched
Dairy products	All milks, including lactose-free and lactose-reduced products and fortified soy beverages; yogurts; frozen yogurts; dairy desserts; and cheeses. Most choices should be fat-free or low-fat. Cream, sour cream, and cream cheese are not included due to their low calcium content
Protein foods	All seafood, meats, poultry, eggs, soy products, nuts, and seeds. Meats and poultry should be lean or low-fat and nuts should be unsalted. Legumes (beans and peas) can be considered part of this group as well as the vegetable group, but should be counted in one group only

Appendix 3 Healthy U.S.-Style Eating Pattern: Recommended Amounts of Food from Each Food Group at 12 Calorie Levels

For each food group or subgroup, recommended average daily intake amountsb at all calorie levels. Recommended intakes from vegetable and protein foods subgroups are per week.

Information reprinted from the US Department of Health and Human Services and USDA. Dietary guidelines for Americans 2020–2025. U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2020. https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials [31]

Calorie level of pattern [a]	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200
Fruits (cup eq./day)	1 c	1 c	1½ c	1½c	1½c	2 c	2 c	2 c	2 c	2½ c	2½ c	2½ c
Vegetables (cup eq./day)	1 c	1½c	1½c	2 c	2½c	2½c	3 c	3 c	3½ c	3½ c	4 c	4 c
Dark-green vegetables (cup eq./week)	½ c	1 c	1 c	1½ c	1½ c	1½ c	2 c	2 c	2½ c	2½ c	2½ c	2½ c
Red and orange vegetables (cup eq./week)	2½ c	3 c	3 c	4 c	5½ c	5½ c	6 c	6 c	7 c	7 c	7½ c	7½ c
Beans, peas, lentils (cup eq./week)	½ c	½ c	½ c	1 c	1½ c	1½ c	2 c	2 c	2½ c	2½ c	3 c	3 c
Starchy vegetables (cup eq./week)	2 c	3½ c	3½ c	4 c	5 c	5 c	6 c	6 c	7 c	7 c	8 c	8 c
Other vegetables (cup eq./week)	1½ c	2½ c	2½ c	3½c	4 c	4 c	5 c	5 c	5½ c	5½ c	7 c	7 c
Grains (oz-eq./day)	3 oz	4 oz	5 oz	5 oz	6 oz	6 oz	7 oz	8 oz	9 oz	10 oz	10 oz	10 oz

Whole grains (oz-eq./day)	1½ oz	2 oz	2½ oz	3 oz	3 oz	3 oz	3½ oz	4 oz	4½ oz	5 oz	5 oz	5 oz
Refined grains (oz-eq./day)	1½ oz	2 oz	2½ oz	2 oz	3 oz	3 oz	3½ oz	4 oz	4½ oz	5 oz	5 oz	5 oz
Protein foods (oz-eq./day)	2 oz	3 oz	4 oz	5 oz	5 oz	5½ oz	6 oz	6½ oz	6½ oz	7 oz	7 oz	7 oz
Seafood (oz-eq./week)	2–3 oz	4 oz	6 oz	8 oz	8 oz	8 oz	9 oz	10 oz	10 oz	10 oz	10 oz	10 oz
Meat, poultry, eggs (oz-eq./week)	10 oz	14 oz/	19 oz	23 oz	23 oz	26 oz	28 oz	31 oz	31 oz	33 oz	33 oz	33 oz
Nuts, seeds, soy products (oz-eq./week)	2 oz	2 oz	3 oz	4 oz	4 oz	5 oz	5 oz	5 oz	5 oz	6 oz	6 oz	6 oz
Dairy (cup eq./day)	2 c	2½ c	2½ c	3 c	3 c	3 c	3 c	3 c	3 c	3 c	3 c	3 c
Oils (grams/day)	15 g	17 g	17 g	22 g	24 g	27 g	29 g	31 g	34 g	36 g	44 g	51 g
Limit on calories for other uses (kilocal)	130[b]	80	90	100	140	240	250	320	350	370	440	580
Limit on calories for other uses (% of calories)	(13%)	(7%)	(6%)	(6%)	(8%)	(11%)	(11%)	(13%)	(13%)	(13%)	(15%)	(18%)

All foods are assumed to be in nutrient-dense forms, lean or low-fat and prepared without added fats, sugars, refined starches, or salt. If all food choices to meet food group recommendations are in nutrient-dense forms, a small number of calories remain within the overall calorie limit of the Pattern (i.e., limit on calories for other uses). The number of these calories depends on the overall calorie limit in the Pattern and the amounts of food from each food group required to meet nutritional goals. Nutritional goals are higher for the 1200- to 1600-calorie Patterns than for the 1000-calorie Pattern, so the limit on calories for other uses is lower in the 1200- to 1600-calorie Patterns. Calories up to the specified limit can be used for added sugars, added refined starches, solid fats, alcohol, or to eat more than the recommended amount of food in a food group. The overall eating Pattern also should not exceed the limits of less than 10% of calories from added sugars and less than 10% of calories from saturated fats. At most calorie levels, amounts that can be accommodated are less than these limits. Calories from protein, carbohydrate, and total fats should be within the Acceptable Macronutrient Distribution Ranges (AMDRs). Values are rounded.

[a] Food group amounts shown in cup-(c) or ounce-equivalents (oz-eq). Oils are shown in grams (g). Quantity equivalents for each food group are:

- **Vegetables and fruits**, 1 cup-equivalent is: 1 cup raw or cooked vegetable or fruit, 1 cup vegetable or fruit juice, 2 cups leafy salad greens, ½ cup dried fruit or vegetable.
  - **Dark-Green Vegetables:** All fresh, frozen, and canned dark-green leafy vegetables and broccoli, cooked or raw: for example, amaranth leaves, basil, beet greens, bitter melon leaves, bok choy, broccoli, chamnamul, chrysanthemum leaves, chard, cilantro, collards, cress, dandelion greens, kale, lambsquarters, mustard greens, poke greens, romaine lettuce, spinach, nettles, taro leaves, turnip greens, and watercress.
  - **Red and Orange Vegetables:** All fresh, frozen, and canned red and orange vegetables or juice, cooked or raw: for example, calabaza, carrots, red chili peppers, red or orange bell peppers, pimento/pimiento, sweet potatoes, tomatoes, 100% tomato juice, and winter squash such as acorn, butternut, kabocha, and pumpkin.
  - **Beans, Peas, Lentils:** All cooked from dry or canned beans, peas, chickpeas, and lentils: for example, black beans, black-eyed peas, bayo beans, brown beans, chickpeas (garbanzo beans), cowpeas, edamame, fava beans, kidney beans, lentils, lima beans, mung beans, navy beans, pigeon peas, pink beans, pinto beans, split peas, soybeans, and white beans. Does not include green beans or green peas.
  - **Starchy Vegetables:** All fresh, frozen, and canned starchy vegetables: for example, breadfruit, burdock root, cassava, corn, jicama, lotus root, lima beans, immature or raw (not dried) peas (e.g., cowpeas, black-eyed peas, green peas, pigeon peas), plantains, white potatoes, salsify, tapioca, taro root (dasheen or yautia), water chestnuts, yam, and yucca.
  - **Other Vegetables:** All other fresh, frozen, and canned vegetables, cooked or raw: for example, artichoke, asparagus, avocado, bamboo shoots, bean sprouts, beets, bitter melon (bitter gourd, balsam pear), broccoflower, Brussels sprouts, cabbage (green, red, napa, savoy), cactus pads (nopales), cauliflower, celeriac, celery, chayote (mirliton), chives, cucumber, eggplant, fennel bulb, garlic, ginger root, green beans, iceberg lettuce, kohlrabi, leeks, luffa (Chinese okra), mushrooms, okra, onions, peppers (chili and bell types that are not red or orange in color), radicchio, sprouted beans (e.g. sprouted mung beans), radish, rutabaga, seaweed, snow peas, summer squash, tomatillos, turnips, and winter melons.
  - **Fruits:** All fresh, frozen, canned, and dried fruits and 100% fruit juices: for example, apples, apricots, Asian pears, bananas, berries (e.g., blackberries, blueberries, cranberries, currants, dewberries, huckleberries, kiwifruit, loganberries, mulberries, raspberries, and strawberries); citrus fruit (e.g., calamondin, grapefruit, kumquats, lemons, limes, mandarin oranges, pomelos, tangerines, and tangelos); cherries, dates, figs, grapes, guava, jackfruit, lychee, mangoes, melons (e.g., cantaloupe, casaba, honeydew, and watermelon); nectarines, papaya, passion fruit, peaches, pears, persimmons, pineapple, plums, pomegranates, prunes, raisins, rhubarb, sapote, soursop, starfruit, and tamarind.
- **Grains,** 1 ounce-equivalent is ½ cup cooked rice, pasta, or cereal; 1 ounce dry pasta or rice; 1 medium (1 ounce) slice bread; 1 ounce of ready-to-eat cereal (about 1 cup of flaked cereal).
  - **Whole Grains:** All whole-grain products and whole grains used as ingredients: for example, amaranth, barley (not pearled), brown rice, buckwheat, bulgur, millet, oats, popcorn, quinoa, dark rye, triticale, whole-grain cornmeal, whole-wheat bread, whole-wheat chapati, whole-grain cereals and crackers, and wild rice.

  - **Refined Grains:** All refined-grain products and refined grains used as ingredients: for example, white bread, refined-grain cereals and crackers, corn grits, cream of rice, cream of wheat, barley (pearled), masa, pasta, and white rice. Refined-grain choices should be enriched.
- **Dairy**, 1 cup-equivalent is 1 cup milk, yogurt, or fortified soymilk; 1½ ounces natural cheese such as cheddar cheese or 2 ounces of processed cheese.
  - All fluid, dry, or evaporated milk, including lactose-free and lactose-reduced products and fortified soy beverages (soy milk), buttermilk, yogurt, kefir, frozen yogurt, dairy desserts, and cheeses (e.g., brie, camembert, cheddar, cottage cheese, colby, edam, feta, fontina, goat, gouda, gruyere, limburger, Mexican cheeses [queso anejo, queso asadero, queso chihuahua], monterey, mozzarella, muenster, parmesan, provolone, ricotta, and Swiss). Most choices should be fat-free or low-fat. Cream, sour cream, and cream cheese are not included due to their low calcium content.
- **Protein Foods,** 1 ounce-equivalent is 1 ounce lean meat, poultry, or seafood; 1 egg; ¼ cup cooked beans or tofu; 1 Tbsp peanut butter; ½ ounce nuts or seeds.
  - **Meats, Poultry, Eggs:** Meats include beef, goat, lamb, pork, and game meat (e.g., bear, bison, deer, elk, moose, opossum, rabbit, raccoon, squirrel). Poultry includes chicken, Cornish hens, dove, duck, game birds (e.g., ostrich, pheasant, and quail), goose, and turkey. Organ meats include brain, chitterlings, giblets, gizzard, heart, kidney, liver, stomach, sweetbreads, tongue, and tripe. Eggs include chicken eggs and other birds' eggs. Meats and poultry should be lean or low-fat.
  - **Seafood:** Seafood examples that are lower in methylmercury include: anchovy, black sea bass, catfish, clams, cod, crab, crawfish, flounder, haddock, hake, herring, lobster, mackerel, mullet, oyster, perch, pollock, salmon, sardine, scallop, shrimp, sole, squid, tilapia, freshwater trout, light tuna, and whiting.
  - **Nuts, Seeds, Soy Products:** Nuts and seeds include all nuts (tree nuts and peanuts), nut butter, seeds (e.g., chia, flax, pumpkin, sesame, and sunflower), and seed butter (e.g., sesame or tahini and sunflower). Soy includes tofu, tempeh, and products made from soy flour, soy protein isolate, and soy concentrate. Nuts should be unsalted.
  - **Beans, Peas, Lentils:** Can be considered part of the protein foods group as well as the vegetable group, but should be counted in one group only.
- **Oils** and soft margarines include vegetable, nut, and fish oils and soft vegetable oil table spreads that have no trans fats.

[b] Food intake patterns at 1000, 1200, and 1400 kcal levels are designed to meet the nutritional needs of children ages 2 through 8 years. Patterns from 1600 to 3200 kcal are designed to meet the nutritional needs of children 9 years and older and adults. If a child 4 through 8 years of age needs more energy and, therefore, is following a pattern at 1600 calories or more, his/her recommended amount from the dairy group should be 2½ cup eq per day. The amount of dairy for children ages 9 through 18 is 3 cup eq per day regardless of calorie level. The 1000 and 1200 kcal level patterns are not intended for children 9 and older or adults. The 1400 kcal level is not intended for children ages 10 and older or adults

SoFAS are calories from solid fats and added sugars. The limit for SoFAS is the remaining amount of calories in each food pattern after selecting the specified amounts in each food group in nutrient-dense forms (forms that are fat-free or low-fat and with no added sugars). The number of SoFAS is lower in the 1200, 1400, and 1600 cal patterns than in the 1000 cal pattern. The nutrient goals for the 1200–1600 cal patterns are higher and require that more calories be used for nutrient-dense foods from the food groups

Appendix 4 Age Recommendations for Activity

Key Activity Guidelines for Adults [43]

These guidelines are the same for adults (18–64 years) and older adults (65 years and older):

- Adults should move more and sit less throughout the day. Some physical activity is better than none. Adults who sit less and do any amount of moderate-to-vigorous physical activity gain some health benefits.
- For substantial health benefits, adults should do at least 150 min (2 h and 30 min) to 300 min (5 h) a week of moderate-intensity, or 75 min (1 h and 15 min) to 150 min (2 h and 30 min) a week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Preferably, aerobic activity should be spread throughout the week.
- Additional health benefits are gained by engaging in physical activity beyond the equivalent of 300 min (5 h) of moderate-intensity physical activity a week.
- Adults should also do muscle-strengthening activities of moderate or greater intensity that involve all major muscle groups on 2 or more days a week, as these activities provide additional health benefits.

Guidelines Just for Older Adults

- As part of their weekly physical activity, older adults should do multicomponent physical activity that includes balance training as well as aerobic and muscle-strengthening activities.
- Older adults should determine their level of effort for physical activity relative to their level of fitness.
- Older adults with chronic conditions should understand whether and how their conditions affect their ability to do regular physical activity safely.
- When older adults cannot do 150 minutes of moderate-intensity aerobic activity a week because of chronic conditions, they should be as physically active as their abilities and conditions allow.

Information and chart from Physical Activity Guidelines for Americans 2nd edition, U.S. Department of Health and Human Services. Physical Activity Guidelines for Americans, 2nd edition. Washington, DC: U.S. Department of Health and Human Services; 2018.https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf [43].

Examples of Physical Activities for Older Adults [43]

Aerobic activities	Muscle-strengthening activities
Walking/hiking	Strengthening exercises using exercise bands, weight machines, or hand-held weights
Dancing	Body-weight exercises (ex. Push-ups, lunges)
Swimming	Digging, lifting, and carrying as part of gardening
Water aerobics	Carrying groceries
Jogging or running	Some yoga postures
Aerobic exercise classes	Some forms of tai-chi
Some forms of yoga	
Bicycling (stationary or outdoors)	
Some yard work, such as raking and pushing a lawn mower	
Sports like tennis or basketball	

Note: The intensity of these activities can be either relatively moderate or relatively vigorous, depending upon an older adult's level of fitness

Information and chart from Physical Activity Guidelines for Americans 2nd edition, U.S. Department of Health and Human Services. Physical Activity Guidelines for Americans, 2nd edition. Washington, DC: U.S. Department of Health and Human Services; 2018.https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf [43]

Health Benefits Associated with Regular Physical Activity [43]

Adults and Older Adults

Lower risk of all-cause mortality
Lower risk of cardiovascular disease mortality
Lower risk of cardiovascular disease (including heart disease and stroke)
Lower risk of hypertension
Lower risk of type 2 diabetes
Lower risk of adverse blood lipid profile
Lower risk of cancers of the bladder, breast, colon, endometrium, esophagus, kidney, lung, and stomach
Improved cognition*
Reduced risk of dementia (including Alzheimer's disease)
Improved quality of life
Reduced anxiety
Reduced risk of depression
Improved sleep
Slowed or reduced weight gain
Weight loss, particularly when combined with reduced calorie intake
Prevention of weight regain following initial weight loss
Improved bone health
Improved physical function
Lower risk of falls (older adults)
Lower risk of fall-related injuries (older adults)

Note: The Advisory Committee rated the evidence of health benefits of physical activity as strong, moderate, limited, or grade not assignable. Only outcomes with strong or moderate evidence of effect are included in this table. Information from Physical Activity Guidelines for Americans second edition, U.S. Department of Health and Human Services. Physical Activity Guidelines for Americans, second edition. Washington, DC: U.S. Department of Health and Human Services; 2018.https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf [43]

Appendix 5 Ideas for Activity

Some Websites for Being Active

Exercise and Physical Activity	NIH National Institute on Aging	https://www.nia.nih.gov/health/exercise-physical-activity [73]
National Physical Activity Plan (NPAP)*	NPAP Alliance	www.physicalactivityplan.org [74]
Physical activity page	US Department of Health and Human Services/ Office of Disease Prevention and Health Promotion	http://www.health.gov/paguidelines [75]
Healthy People 2030	US Department of Health and Human Services/ Office of Disease Prevention and Health Promotion	http://www.healthypeople.gov/ [76]
Dietary guidelines for Americans	President's Council on Sports, Fitness, & Nutrition	https://www.hhs.gov/fitness/eat-healthy/dietary-guidelines-for-americans/index.html [77]

Exercise programs that promote senior fitness	National Council on Aging (NCOA)	https://www.ncoa.org/center-for-healthy-aging/basics-of-evidence-based-programs/physical-activity-programs-for-older-adults/ [78]
Health and fitness 50+	AARP	https://www.aarp.org/health/fitness/info-03-2011/fitness-50.html [79]
Exercise examples and videos	USDA Nutrition.gov	https://www.nutrition.gov/topics/exercise-and-fitness/exercise-examples-and-videos [80]
How much physical activity do older adults need?	CDC	https://www.cdc.gov/physicalactivity/basics/older_adults/index.htm [81]

Appendix 6 Estimated Calorie Needs Per Day by Age and Activity Level [31]

Information from US Department of Health and Human Services and USDA. Dietary guidelines for Americans 2020–2025. U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2020. https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials. (Original Source: Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Washington (DC): The National Academies Press; 2003 [67])

Age	Sedentary[a]	Moderately Active[b]	Active[c]
31–35	1800	2000	2200
36–40	1800	2000	2200
41–45	1800	2000	2200
46–50	1800	2000	2200
51–55	1600	1800	2200
56–60	1600	1800	2200
61–65	1600	1800	2000
66–70	1600	1800	2000
71–75	1600	1800	2000
76 & Up	1600	1800	2000

[a] Sedentary means a lifestyle that includes only the physical activity of independent living

[b] Moderately Active means a lifestyle that includes physical activity equivalent to walking about 1.5–3 miles per day at 3–4 miles per hour, in addition to the activities of independent living

[c] Active means a lifestyle that includes physical activity equivalent to walking more than 3 miles per day at 3–4 miles per hour, in addition to the activities of independent living

Chapter Review Questions

1. The patterns of behaviors correlated with a healthy body weight are:
   (a) Monitor food intake, focus on the total number of calories consumed, choose smaller portions/lower calorie options to consume, eat a nutrient-poor breakfast, and limit screen time
   (b) Monitor food intake, focus on the total number of calories consumed, choose smaller portions/lower calorie options to consume, eat a nutrient-dense breakfast, and limit screen time
   (c) Monitor food intake, focus on the total number of calories consumed at dinner, choose smaller portions/lower calorie options to consume at home but eat what you want when you dine out, eat a nutrient-dense breakfast, and limit screen time
   (d) Monitor food intake sporadically, focus on the total number of calories consumed, choose smaller portions/lower calorie options to consume, skip breakfast, and increase screen time and exercise
2. There are two forms of dietary iron: heme and non-heme. Heme iron is found in:
   (a) Fortified products, including bread, cereals, and breakfast to the diet.
   (b) Fruits, whole-grain bread, or whole-grain pasta
   (c) Red meats, fish, and poultry
   (d) Dried fruit: apples, raisins, figs, and prunes
3. Adults should do at least _____ for substantial health benefits:
   (a) 30–90 min of moderate-intensity exercise or 30–60 min of vigorous-intensity exercise a week
   (b) 30–90 min of moderate-intensity exercise or 90–120 min of vigorous-intensity exercise a week
   (c) 150–300 min of moderate-intensity exercise or 75–150 min of vigorous-intensity exercise a week
   (d) 30–90 min of moderate-intensity exercise or 150–300 min of vigorous-intensity exercise a week
4. Health benefits associated with regular physical activity include:
   (a) Lower risk of cardiovascular disease and hypertension
   (b) Improved quality of life, improved sleep, reduced anxiety and risk of depression
   (c) Improved bone health
   (d) All of the above
5. Although there are some exceptions, aging is associated with changes in body composition, which of the following statements is false?
   (a) %BF increases
   (b) LBM decreases
   (c) BMD decreases
   (d) There is a redistribution of FM resulting in increased LBM

6. Which factors determine the need for adequate caloric intake, more than one answer may be correct?
   (a) Weight and gender
   (b) Height and age
   (c) Physical activity level
   (d) All of the above determine caloric intake
7. Using the equation of Miffin-St Jeor for RMR.
   RMR = 9.99 × weight (kg) + 6.25 × height (cm) − 4.92 × age (years) + 166 × [sex (males—1; females—0)] − 161.
   Age = 75 years; Weight = 72 kg; Height = 1.74 m; Additional Caloric Requirements = 80% (moderate activity).
   TEE for Older woman:
   (a) 2300 kcal/day
   (b) 2296 kcal/day
   (c) 1957 kcal/day
   (d) 2298 kcal/day
   Note: 1.74 m = 174 cm
8. Using the equation for Estimated Energy Requirements (EER)
   EER = 354 − [6.91 × age (years)] + PA × ([9.36 × weight (kg)] + [726 × height (m)])
   EER Older woman:
   Age = 75 years; Weight = 72 kg; Height = 1.74 m; PA = 1.27
   EER needs:
   (a) 1856 kcal/day
   (b) 2296 kcal/day
   (c) 2657 kcal/day
   (d) 2585 kcal/day
9. In older people, Vitamin B12 deficiency is influenced by:
   (a) Difficulty in the absorption of vitamins
   (b) Low sun exposure
   (c) Older people do not consume foods containing vitamins with B12
   (d) Difficulty in chewing food
10. Taking antioxidants in carotenoids, vitamin C, flavonoids and other polyphenols is important for:
    (a) Decreased cardiovascular risk
    (b) Decrease cancer risk
    (c) Decreased mortality
    (d) Increased morbidity

Answers

1. b
2. c
3. c
4. d
5. d
6. d
7. d
8. b
9. a
10. a

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Ergogenic Aids and the Female Athlete

23

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Learning Objectives
After completing this chapter, you should understand:

- Reasons why female athletes take supplements
- Various supplements female athletes are likely to take
- Ergogenic and ergolytic effects of these supplements
- Protein sources and recommendations
- Variations within certain supplements and standard dosages
- That nutritional supplements may be contaminated with banned substances

23.1 Introduction

Ergogenic aids, by definition, are items or substances which enhance performance. Female athletes tend to choose their supplements for different reasons than their male counterparts. Collegiate female athletes report taking supplements "for their health," to make up for an inadequate diet, or to have more energy [1, 2]. Interestingly, while many athletes report using energy drinks and calorie replacement bars or drinks, most of them did not consider these products to be supplements [2]. The subsequent sections will provide insight into the mechanisms and possible benefits (or lack thereof) of ergogenic aids that female athletes commonly cite ingesting.

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23.2 Research Findings

23.2.1 What Supplements Are Female Athletes Taking?

When compared to female nonathletes, female athletes consume similar amounts of substances thought to be performance-enhancing (25.2%–29.8%, respectively) [3]. Female athletes reported using performance-enhancing substances 21.5% of the time during a competitive season and 25.9% during the off season [3]. Multivitamins, herbal substances, protein supplements, amino acids, creatine, fat burners/weight-loss products, caffeine, iron, and calcium are the most frequently used products reported by female athletes [1–3]. Performance-enhancing substances include all of the above, some of which an athlete may not consider a supplement or performance-enhancing (e.g., multivitamin or an herbal supplement). Many female athletes list taking the herbal supplement Echinacea and cite "boosting the immune system" as the reason for taking it [1, 3, 4]. However, there are reports that Echinacea may also be performance-enhancing as well [5, 6]. We will discuss the literature on Echinacea later in this chapter.

While many studies do not report anabolic steroid (AS) use, Congeni and Miller [7] found female adolescent steroid usage to be up to 2.5% [7]. Other researchers have found that 5.1% of middle school female students have already reported steroid use by the age of 12 [8]. In a 2009 report from the National Collegiate Athletic Association (NCAA), the use of anabolic steroids increased from 2005 to 2009 in the following women's sports: lacrosse (0–0.2%), swimming (0.3–0.4%), and track (0.1–0.2%) [9]. Frequency of use in other women's sports such as basketball, field hockey, golf, soccer, and volleyball either remained the same or the prevalence of steroid usage actually decreased [9].

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23.2.2 Protein Needs in Female Athletes

Systematic reviews including meta-analysis studies [10, 11] support the notion that physically active people including athletes require greater daily protein consumption than the current RDA recommendation of 0.8 g/kg of body mass (BM)/day (d) [12]. As the level of physical activity increases, the role of dietary protein becomes increasingly relevant in providing amino acids for supporting efficient protein metabolism throughout the body, including skeletal muscle remodeling and growth [13]. Although a minimum daily protein intake of 1.6 or as high as 2.2 g/kg BM/d appears to be a highly influential factor in supporting exercise adaptation and outcomes for both men and women [14], only a small to modest, nonstatistical significant, improvement can be obtained by adding protein supplementation [11, 14]. From a practical point of view, a potentially, albeit slightly, superior result obtained by a higher protein ingestion will be of relevance in athletes [15]. This becomes important as competitions are won or lost by fractions of a second or 0.5 kg lifted.

In females, the reported estrogen protein-sparing effect [13] peaks later in the follicular phase and again during the luteal phase, antagonizing the overall progesterone-induced catabolic effect that predominates over the entire luteal phase [16]. These hormonal fluctuations may lead to slight variations in protein metabolism which affect dietary needs across the menstrual cycle [17]. Currently, no meaningful variations in protein requirement have been observed in female athletes across the menstrual cycle [18].

Recent studies suggested a daily protein intake of 1.7–1.9 g/kg BM/d for team sport [18] and resistance [16] trained female athletes, respectively. Although these figures are lower than the recommended amount (~2.1 g/kg BM/d) for similar male athletic populations [19, 20], they are still within the range of recommendation (i.e., 1.2–2.0 g/kg BM/d) of the American College of Sports Medicine (ACSM) Position Stand for active populations based primarily on research conducted in males [12]. Presently, there is no biologically relevant evidence that reflects a sex-based difference in protein requirements for humans [11].

Even though the current literature is still unable to accurately analyze the contribution of protein-based supplements to the daily protein intake, it could be appropriate to discuss the convenience of adding high-quality protein supplements into the diet to help athletes achieve the required daily amount of protein. In turn, this would facilitate the ingestion of protein under special circumstances where the access to more traditional forms of foods (steak, chicken, eggs, etc.) becomes more difficult (e.g., before, during, or after training). Within this context, female athletes tend to take protein and amino-acid supplements in the form of powders, bars, tablets or as meal replacements [1]. When asked why they take protein supplements, females responded: '*for enhanced recovery, just like the taste, provide more energy, to meet nutritional needs, enhanced performance, greater muscle strength, and don't know*'. When these same athletes were asked if they had questions about protein supplement usage, there were several questions or concerns: increasing lean body mass and losing body weight, adverse effects on the kidneys, positive vs. negative effects, how much to consume, and whey vs. soy protein [1].

During the last 30 years, studies have investigated the effects of protein obtained from animal- and plant-based sources, as well as techniques or methodology used to manufacture the protein product to formulate recommendations for their ingestion. The following sections describe the main characteristics of the most popular protein and amino acids supplements currently commercialized, their recommended doses, and estimated acute or chronic effects.

23.2.3 Protein Supplements Sources

Protein supplements are currently obtained from animals (milk, produced from whey and casein subtraction, bovine colostrum, beef, etc.) and vegetables sources (legumes such as soy or pea, wheat, rice, quinoa, hemp, etc.). The quality of the supplement may vary depending on the type and quality of the manufacturing process [21]. In this section we will summarize and discuss the characteristics of some currently commercialized animal (e.g., whey, casein bovine colostrum, beef, and insect) and plant (e.g., soy, pea, and rice) forms of protein supplements. As you read through these sections, it is important to keep in mind that protein sources vary in their amino acid content. Two proteins that are "complete" may have differing amounts of essential amino acids (EAAs). This concept will be discussed in more depth as various protein sources and recommendations for amino acid intake are covered.

23.2.3.1 Animal Protein Sources (Milk, Bovine Colostrum, Beef, and Insect)

Milk Protein Supplements (Whey and Casein)

Whole milk is composed of approximately 87% water, with the remaining 13% being solids. The solid proportion is composed of 30% fat, 37% lactose, 27% protein, and 6% minerals. Of the 27% of milk which is protein, 20% is whey and 80% casein protein [22]. During the process of making cheese, reducing the pH to 4.6 at 30 °C, about 80% of the whole milk proteins will clot and separate. This group of proteins is called caseins. The remaining 20% consists of several protein liquid fractions that are collectively known as whey proteins [23]. Milk protein concentrate, produced by ultrafiltration of skimmed milk, contains both casein and whey proteins in similar proportions to whole milk, but the total amount of protein, lactose, and mineral content may

vary between different formulations [21]. The casein fraction comprises α_1-casein (~37%), α_2-casein (10%), β-casein (35%), and κ-casein (12%) [24], while whey contains multiple globular proteins including β-lactoglobulin (~50 to ~55%), α-lactalbumin (~20 to ~25%), bovine serum albumin (~5 to ~10%), lactoferrin (~1 to 2%) immunoglobulins (~10 to ~15%), lactoperoxidase enzymes (~0.5%), glycomacropeptides (~10 to ~15%), and other minor proteins such as β-microglobulin, lysozyme, insulin-like growth factors, and γ-globulins [21, 25]. Of the listed whey sub-fractions, β-lactoglobulin is the major source of branched chain amino acids (BCAAs): leucine, isoleucine, and valine. β-lactoglobulin has been proposed as the most influential whey protein fraction for stimulating muscle protein synthesis (MPS) [23] through activation of the Mechanistic Target of Rapamycin (mTOR) signaling pathway [26].

Whey Protein Supplements

There are several types of whey protein supplements on the market. The most common are (1) whey protein concentrate, (2) whey protein isolate, and (3) whey protein hydrolysate. These products contain all the Essential Amino Acids (EAAs) (see Table 23.1), and compared to other protein sources, provide a higher concentration of cysteine, which may elevate the antioxidant glutathione activity, and BCAAs [22]. Whey is also a reliable source of bioactive peptides, which are short chains of amino acids with immune-enhancing effects [28]. However, considering athletic needs and adaptation to exercise, the amino acid profile of whey could be further improved by the addition of di- and tripeptides of L-glutamine, L-arginine, and taurine [29]. These amino acids have important physiological functions affecting muscle remodeling and growth [27, 30].

The positive effects of ingesting one or two servings of ~250 mg/kg BM of whey protein under resting condition or up to 400–500 mg/kg BM postexercise have been shown to maximize training outcomes while favoring body composition changes (gaining muscle mass and/or reducing body fat) in endurance [31, 32] and strength and power [15] athletes.

Table 23.1 Essential and nonessential amino acids. (Modified from Reeds PJ. Dispensable and indispensable amino acids for humans. J Nutr. 2000:130:1835S–1840S [27])

Essential	Non-essential
Isoleucine[a]	Alanine
Leucine[a]	Arginine[b]
Valine[a]	Asparaginim
Lysine	Aspartic acid
Methionine	Cysteine
Phenylalanine	Glutamic acid
Threonine	Glutamine
Tryptophan	Glycine
Histidine	Proline
	Serine
	Tyrosine

[a] Branched chain amino acids (BCAAs)
[b] Not considered essential as most humans synthesize agrinine

Casein Protein Supplements

Casein is responsible for the white color of milk. It is the protein source of cheese and forms curds during processing because it exists as a micelle in milk [29]. Because native casein has low solubility and forms clumps or curds, casein used in nutritional supplements is made into rennet casein or caseinates, an acid form that is usually combined with sodium, calcium, or potassium. Compared to the whey protein forms that remain soluble in the stomach and thus are emptied rapidly, casein is converted into a solid clot, thus slowing gastric emptying [33].

A single dose of casein ingestion does not lead to large increases in circulating levels of amino acids as was observed with an equivalent single dose of whey protein [34]. These differences in digestive properties likely contribute to the variation in the pattern of amino acid concentrations that have been observed after ingestion of whey or casein protein. Casein has been termed a "slow" protein, and whey protein has been named a "fast" protein [35]. The slowly absorbed casein protein promotes more sustained and prolonged postprandial protein deposition via inhibition of protein breakdown without an excessive increase in amino acid concentration. By contrast, a fast whey protein stimulates protein synthesis and oxidation. The impact of amino acid absorption speed on protein metabolism is true when proteins are given in isolation; however, this effect might be blunted in more complex meals that could affect gastric emptying (lipids) and/or insulin response (carbohydrates) [35]. While whey seems to be a more convenient choice to optimally stimulate muscle protein synthesis at post-workout time [36], the more prolonged anabolic effects of casein seem to be most effective when consumed under resting condition [34]. Overall, it would appear that casein protein with its slow absorption rate leads to a greater positive net whole-body protein state and better leucine balance than single feedings of whey protein or amino acids at rest. Research suggests that ingesting ≥250–400 mg/kg BM, 30 min prior to sleep and 2 h after the last meal (dinner) from slow absorption protein sources (e.g., casein), could be an effective and recommendable strategy to optimize training outcomes, favoring a more anabolic environment or to maintain overnight lipolysis and fat oxidation during the sleeping time [37].

Bovine Colostrum Supplements

Bovine colostrum is the first milk produced by the mammary glands of the mother cow during the final days of pregnancy and the first 3–4 days postpartum. It is rich in carbohydrates, proteins, fats, and micronutrients (minerals, trace elements) containing higher amounts of oligosaccha-

rides, growth factors, antimicrobial agents, and immunoregulatory compounds compared to the regular milk [38]. Factors contained in bovine colostrum may aid the absorption of active components (growth and immune factors) by preventing their breakdown and digestion in the gastrointestinal tract [39]. Supplementation with 20 to 60 g/d has been shown to optimize changes in body composition [40], while lower doses of ~3.2 g/d attenuate post-exercise muscle damage and hasten recovery [41] in males and females. Furthermore, 60 g of bovine colostrum/d paired with an 8-week resistance training program was beneficial for maximizing strength gains and attenuating bone loss in older men and women [42]. This may be of importance to the female master athlete.

Beef and Insect Protein Supplements

Beef is a high-quality protein source rich in micronutrients (vitamins and minerals), with a very similar amino acid profile to the human skeletal muscle. High quality hydrolyzed beef protein powder-supplements (e.g., 100% All beef) can provide about 82% of high-quality protein, including more than 40% of EAAs, 6.6 g of leucine per 100 g of product, essential fatty acids, heme-iron, zinc, potassium, and vitamins B12 and D [43]. Supplementation with 20 g/d of a beef protein supplement over 8 weeks improved immunological responses [44] in young active men and women. Additionally, the ingestion of a post-workout beverage providing 20 g/d of hydrolyzed beef protein with no carbohydrate for 10 weeks, maintained lower limb muscle mass and improved iron profiles in masters (>60 years old) female triathletes [45].

In addition to beef, other complete insect-based protein supplements have been recently commercialized. While insect protein is new to the market, it is easily obtainable; insects are being "farmed" for production, and insect protein powder has even made the radar of popular body building websites. In terms of their amino-acid content, insects included in the following orders: Coleoptera (beetle), Hymenoptera (ants and wasps), Lepidoptera (caterpillars), and Orthoptera (locusts, grasshoppers, and crickets) on average meet or even exceed EAA requirements for a typical sedentary adult person. However, the edible protein and digestible amino-acid profile is quite variable, due to different developmental (feeding) or manufacturing processes [46]. Although the ingestion of 25 g of insect protein supplement (from the lesser mealworm) promoted a similar blood amino acid response compared to the ingestion of the same amount of soy, the observed changes in the aminoacidemia were still lower than those elicited by ingestion of 25 g of whey protein [47]. Insect protein, although representing a complete protein source, in general tends to be a lower quality source compared to milk and beef [48].

23.2.3.2 Plant-Based Protein Supplements

The increased interest in plant-based protein sources by clinical and sports nutrition industries is mainly based on the reduced costs and lesser environmental burden compared to animal-derived products [49]. However, plant-based protein has lower digestibility and greater splanchnic extraction and subsequent urea synthesis [49]. To achieve a high-quality complete EAA profile using plant-based proteins, it may be necessary to combine different vegetable sources. Vegetable sources may be higher or lower in certain amino acids such as methionine, lysine, or leucine which are relevant amino acids for supporting adaptations to training. Some of the current commonly available commercialized vegetable proteins supplements are soy, rice, and pea.

Soy Protein Supplements

Soy is a complete vegetable protein that, when compared to other plant-protein sources contains a superior amino acid complex with a higher proportion of BCAA's, plus arginine and glutamine. However, the amino acid complex of soy is still slightly inferior compared to that observed in animal sources such as milk [50]. Although foods such as tofu, miso, and soymilk are well-commercialized, these products possess a considerable amount of carbohydrates. Recall that most research on digestion and availability has been conduction with protein isolated. Therefore, the use of soy protein supplements containing >55% up to 92% of proteins (e.g., isolated soy protein, soy protein concentrate, soy flour, and textured vegetable) has been extensively used by athletes and analyzed in different scientific studies to avoid confounding results due to nutrients that may alter digestion (e.g., carbohydrates) [51]. Despite the longer splanchnic digestion time assumed for vegetable proteins sources, when ingested as a supplement, soy isolate showed faster absorption rates than casein but still slower than whey. After ingesting a standardized dose of soy isolate, plasma amino acid levels peaked at 150 min, as opposed to 75 min if a comparable dose of whey is consumed. Thus, it seems that soy isolate is more of an "intermediate" protein in terms of digestion rate based on peak plasma amino acid concentrations [52].

One criticism of soy protein for supporting strength or muscle mass gains in athletic population is that the isoflavones naturally present in the soybean will inhibit the mTOR signaling pathway favoring catabolism and cell autophagy [37]. Multiple studies demonstrate the isoflavone-induced inhibition of soy on the mTOR pathway conducted in rodents [53], which possess an accelerated isoflavone metabolism compared to humans [54]. It is accepted that, at least in untrained men and women, supplementation with soy protein containing isoflavones could similarly optimize resistance training outcomes as do animal sources such as whey [51].

Soy protein is associated with a number of advantages over animal protein, such as improved plasma lipid profiles,

increasing LDL-cholesterol oxidation, and decreasing blood pressure [55]. These health-related benefits have been attributed to the amount of isoflavones which are naturally active nutrients contained in soy protein. Isoflavones' molecular structure is similar to natural body estrogens (phytoestrogen). The following foods contain anywhere from 1 to more than 5 mg/g of isoflavones: tofu, green soybeans, mature or roasted soybeans, and soy flour [56].

Rice and Pea Protein Supplements

Rice and pea protein isolates and concentrates are complete protein sources containing up to ~40% of the total protein as EAAs. The amino acid concentrations of the various isolates and concentrates all differ from the amino acid profile of their respective source materials, (e.g., raw brown rice). Typically, concentrations of lysine and glutamate decrease, but those of methionine, tyrosine, and cystine increase in some brown rice protein isolates [57]. When equivalent amounts of EAAs from plant protein-based supplements (e.g., rice or pea) are compared to whey, a similar anabolic response has been observed [37]. In this context, animal protein sources providing higher amount of EAAs, including leucine, seem to be more efficient than plant protein supplements (pea, rice, or soy) on a gram per gram basis [22]. When plant-based sources with lower proportions of EAAs are ingested, larger amount of proteins with a concomitant increased nitrogen, energy intake, longer digestion time, oxidation, and ureagenesis [34, 58] may be needed to compensate for the less efficient anabolic stimulus [59].

23.2.4 Nutritional Profile of Different Animals and Plant-Based Protein Supplements

Based on the digestible nutritionally essential or indispensable amino acid (DIAAS) methodology [60], animal protein, including whey, casein, egg, or beef, contains a higher amount and proportion of EAAs compared to vegetable protein sources such as soy, legume, cereals, or wheat [60]. Moreover, certain plant-based proteins (e.g., cereals) are limited in EAAs such as lysine, threonine, and tryptophan, whereas others (e.g., legumes) are poor sources of cysteine and methionine. Whereas the DIAAS for milk, eggs, and beef are well above the estimated optimum (100%) for covering humans' basic needs (maintaining body mass), plant-derived proteins generally score well below 80% [48]. Some protein extracts obtained from soy [61], rice [62], or pea [63] have demonstrated scores closer to or above the optimum 100% for satisfying the needs of a typical sedentary person [50]. Figure 23.1 compared the amount of EAAs ingested

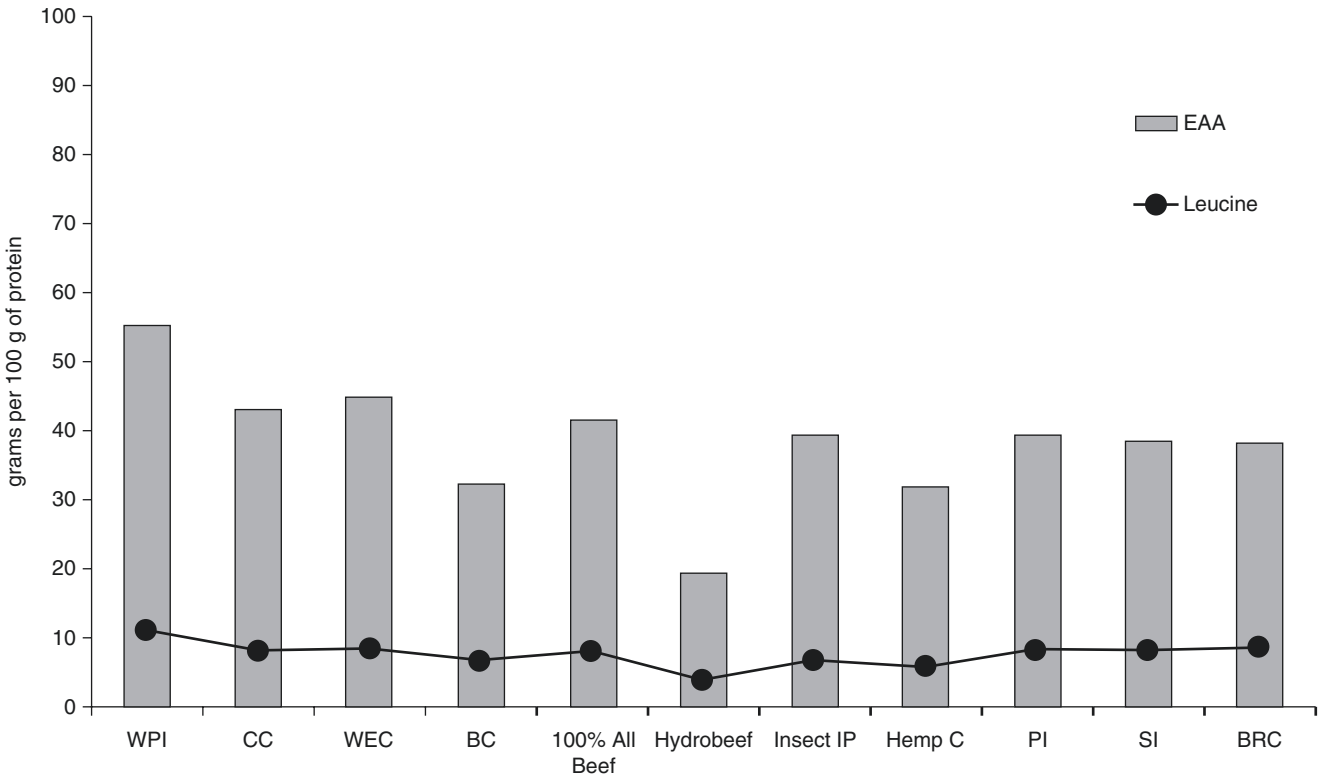

Fig. 23.1 Amino acid profile of different protein sources describing the proportion of indispensable (IAA) or essential amino acids (EAA) and leucine in different animals and plant protein sources. *WPI* whey protein isolate from the raw matter Optipep, *CC* calcium caseinate, *WEC* whole egg concentrate, *BC* bovine colostrum, *100% All Beef* Hydrolyzed Beef Protein from Crown Sport Nutrition (Spain), *Hydrobeef* Hydrolyzed Meat Protein from the raw matter, *Insect IP* insect isolate, *Hemp C* hemp protein concentrate, *PI* pea isolate protein, *SI* soy isolate protein, BRC brow rice concentrate (Modified from Phillips SM [64]; Naclerio F, Seijo-Bujia M, Larumbe-Zabala E, Earnest CP [65]; Churchward-Venne TA, Pinckaers PJM, van Loon JJA, van Loon LJC [46])

from different protein sources when the same amount of protein is consumed. Whey isolate provides more EAAs, including leucine, compared with other animal (casein, egg, beef, insect, or bovine colostrum) and plant (hemp, pea, brown rice) protein-based supplements [46, 48, 65].

With the DIAAS, protein quality is determined based on the ideal minimum amino acid requirement pattern and the true ideal digestibility of each EAA [60]. The scoring pattern for protein quality is obtained by calculating the ratio of each EAA established requirement to the protein need and expressed as mg of amino acid provided per g of the analyzed protein [60]. Overall, a good quality protein source for sedentary adults is the one that meets at least 100% of all EAA requirements if 0.66 g/kg BM/day of this protein source is ingested [60]. Considering leucine as the key trigger EAA for initiating MPS [66], the amount of leucine is an important aspect to consider in determining the potential effect of a given protein rich food for covering the demands of training and avoiding limitation in exercise adaptations and training outcomes in athletes. When the amino acid profile of the ideal protein source is used to calculate the DIAAS, it is possible to establish the amino acid reference ratio (AARR)—defined as the digestible content of a given EAA in the protein source, compared to a hypothetical best protein that provides the necessary amount of all EAAs [48]. Milk protein concentrates and whey isolate extracts seem to produce the highest AARR (>100%) in all the EAAs [50]. Furthermore, the AARR of leucine was higher in milk (1.77) and whey (isolate, 2.57 and concentrate, 1.93) when compared to two sources of soy protein isolate (1.13 and 1.29), pea protein isolate (1.37), and rice protein concentrate (1.11) [50]. In certain circumstances, such as regular exercise training, some protein sources may be more appropriate to satisfy physiological demands. For example, an increased consumption of whey protein containing foods providing higher levels of leucine, compared to those suggested by the DIAAS, may be useful to optimize training adaptation in athletes [64].

Despite the aforementioned differences, it is worth considering that each protein source has unique attributes that may convey specific nutritional advantages when compared to the others. These benefits include boosting general health, body weight management, increased lean body mass, enhanced muscle recovery after exercise,, and an ability to stimulate skeletal muscle protein synthesis.

23.2.5 Acute Dose-Response Effects of Ingesting Different Types of Protein Supplements

The effective dose of ingested amino acids/protein for stimulating a maximal resting postprandial anabolic response has been well-documented, [64, 67] and established as ~0.24 g/kg BM per serving in young men and women [68] achieving a minimum daily intake of ~0.8 g/kg BM/d of protein to potentially maintain muscle mass in resting conditions [58]. During exercise conditions, mainly for trained individuals, a higher single dose of high-quality protein (e.g., whey) ~0.40 g/kg BM [69] along with a minimum daily protein intake of >1.6 (2) to ~2.0 g/kg BM/d [37] has been recently suggested as the optimal amount for post-workout intakes [37]. Regardless of sex and body size, factors related to the training configuration (volume and the amount of exercised muscle mass) are much more influential on the determination of the effective optimal protein dose to maximize recovery in athletes [22].

Even though rapidly digested proteins such as whey, may optimally stimulate MPS over 1–3 h post-exercise, the associated high amino acid oxidation rates that could be produced after a large single dose can negatively affect protein retention over time [34]. This finding, together with the difficulty in ingesting several frequent smaller portions of whey protein over the day, has led sports nutrition manufacturers to design blends of proteins involving varying protein sources as the best strategy to obtain a timed-release of amino acids into circulation. The difference in digestion rates provided by the combination of different protein sources (e.g., whey, soy, bovine colostrum, or beef) will prolong the post-prandial aminoacidemia resulting in greater muscle amino acid uptake, and consequently maximizing the post-exercise anabolic response [70]. Blending whey, casein, and soy protein supplements stimulates a more balanced amino acid profile, specifically the BCAAs, glutamine, arginine, and lysine. This may confer an advantage by providing a wider range of benefits for exercise adaptation and health-related effects compared to a single protein source rich in only 1 or 2 of these key amino acids. Although different studies have tested the effectiveness of different post-workout protein-carbohydrate recovery drinks differentiated by the proportion of whey, casein, or beef protein [71, 72], the exact ratio of protein sources to accomplish this task still needs to be elucidated. To our knowledge, no specific recommendations have been made for active women or female athletes.

Collectively, the above analysis indicates that achieving competitive advantages while optimizing recovery and gains are the most important variables to most athletes and active individuals. Considering the intake of only one type of protein source (whey, casein, soy, or beef), it would appear that casein leads to the optimal total body protein state at rest. Following exercise, it would appear that ingestion of a whey source, or a combination of whey with other protein sources and carbohydrates would be appropriate.

23.2.6 Long-Term Effects of Protein Supplementation

Although there is no conclusive evidence demonstrating specific needs and differentiated responses between female and

male athletes to regular protein supplementation, meta-analyses of randomized controlled trials [11, 15] and narratives reviews [28, 73] support the benefits of protein supplementation for maximizing exercise-induced adaptation in athletic or active individuals. Including protein concentrates or isolates as a part of the habitual diet is an effective nutritional strategy for maximizing training outcomes in athletes after ~6 weeks or longer periods of training [22]. These maximizing effects are most effective when the total daily protein intake achieves a minimum of 1.6 g/kg BM/d [11]. The current literature is still unable to accurately analyze the contribution of this supplement to the daily protein intake. Future studies need to analyze the convenience of using high-quality protein supplements integrated into the habitual diet to help athletes achieve the required daily amount of protein, thereby facilitating the ingestion of protein under special circumstances where the access to more traditional forms of foods (steak, chicken, eggs, or fish) becomes more difficult (e.g., before, during, or after training).

23.2.7 The Use of Amino Acids as Nutritional Supplements

Regardless of sex, when resistance exercise is followed by an increase in amino acid availability, the rate of MPS is increased beyond that of exercise or amino acids alone [74]. Under exercising conditions, protein requirements increase, and although the minimal effective dose of ~60 mg/kg BM of EAAs can still be effective in enhancing post-exercise MPS compared to baseline, the post-workout anabolic response can be further improved with the ingestion of higher amounts of EAAs. Doses between 200 and 250 mg/kg BM providing ~40 mg/kg BM of EAAs and >10 mg of leucine, respectively, are currently being considered to optimize post-exercise recovery after demanding exercise sessions [22, 73]. Thus, when considering dietary strategies to maximize postexercise recovery and optimize training outcomes, protein sources with a higher proportion of EAAs and leucine will be the best choice [73].

Strong scientific evidence supports the efficacy of combining EAA supplementation with resistance exercise for maximizing muscle mass gain. However, their impact for optimizing performance-related outcomes (e.g., increase strength) is still unclear [75]. Research indicates that ingesting 3–6 g (>45 mg to 86–95 mg/kg BM) prior to and/or following exercise can significantly stimulate MPS [76]. In sedentary or slightly active healthy older men and women, twice-daily between-meal ingestion of 7.5 g/d (~100 to 125 mg/kg BM/d) of EAAs (15 g/d or >200 mg/kg BM/d in total) for 3 months has been shown to effectively retard the loss of muscle mass associated with aging [77]. This regimen may stimulate MPS in the period between meals when blood amino acid concentration tends to decline.

Compared to younger individuals, older men and women could show a blunted muscle protein synthesis response known as an "anabolic resistance" condition [78]. In older adults (>65 years old), this impaired adaptational response has been associated with a sedentary lifestyle and inadequate nutritional intake [69] particularly essential amino acids [78]. Consequently, the minimum effective dose of EAAs proven to increase MPS in young individuals (3 g or 45 mg/kg BM) may not be enough for an older population, where a dose of ~6 g (≥120 mg/kg BM) has been proposed as the minimum threshold-dose for stimulating MPS [79]. In summary, at rest and during the early postexercise recovery period, ~60 to 120 mg/kg BM of EAAs including ~10 to 20 mg/kg BM of leucine represents an appropriate dose to reduce catabolism and favor anabolism in young individuals [22], while higher, ~ double the dosage may be necessary for older persons [79]. This recommendation is important to keep in mind when working with female masters athletes.

23.2.8 Branched Chain Amino Acids (BCAAs)

The EAAs leucine, isoleucine, and valine forms are collectively referred to as BCAAs. BCAAs comprise about one-third of the total muscle protein pool [80] and act as a primary nitrogen source for Glutamine and Alanine synthesis in muscle [80]. Unlike most free form AAs, BCAAs are not degraded in the liver. Twenty to thirty percent of ingested BCAAs from food or supplements are metabolized by the intestine, the rest are rapidly absorbed in plasma. Muscle tissue BCAAs uptake primarily occurs from plasma BCAAs [81].

BCAAs promote protein synthesis, aid in glycogen resynthesis, delay the onset of fatigue, help maintain mental function with aerobic-based exercise, and enhance mitochondrial biogenesis in cardiac and skeletal muscle [82]. Many studies agreed that supplementation with BCAAs conveys an anabolic stimulus both in resting and exercise conditions. However, there are still controversies regarding the effectiveness of BCAA supplementation in promoting muscle accretion and maximizing performance improvements in athletes [75].

In order to promote anabolism and facilitate recovery, 100 up to 200 mg/kg BM of BCAAs added to a sports drink with 6–8% of carbohydrate concentration administered before or during exercise may be an acceptable nutritional strategy [82]. Furthermore, to improve glycogen recovery and stimulate MPS after exercise, the addition of BCAAs to a carbohydrate-rich beverage with a BCAAs:CHO ratio of 1:4 or even higher has been recommended [83].

One of the proposed effects of BCAA supplementation relates to a phenomenon known as central fatigue, which sig-

nifies that mental fatigue in the brain can adversely affect physical performance in endurance events. The central fatigue hypothesis suggests that low blood levels of BCAAs may accelerate the production of the brain neurotransmitter serotonin, or 5-hydroxytryptamine (5-HTP), and prematurely lead to fatigue [84]. Tryptophan, an EAA, is a precursor of serotonin, which can be more easily transported into the brain (to increase serotonin levels) when BCAA plasma concentrations decrease due to prolonged exercise sessions (endurance training) when the intake of BCAAs is increased by the working muscles [84]. The increased release of fatty acids into the blood during endurance exercise displaces tryptophan from its place on albumin and facilitates the transport of tryptophan into the brain for conversion to serotonin. Thus, the combination of reduced BCAAs and elevated fatty acids in the blood causes more tryptophan to enter the brain and more serotonin to be produced, leading to central fatigue [85]. Due to these metabolic processes, it has been hypothesized that BCAA supplementation can help delay central fatigue and maintain mental performance in long-duration exercises [86]. Literature has also shown that combining BCAAs with L-Arginine [87] and L-Citrulline [88] was effective to alleviate the exercise-induced central fatigue symptoms.

The positive effects of BCAAs in reducing fatigue in exercise may also be due to its possible influence on other biochemical events in the brain, where BCAAs may be involved as precursors for the synthesis of several neurotransmitters. In this model, leucine, or its metabolic by products, would act as neurotransmitters, playing a possible role to counteract fatigue [85]. Other documented effects of BCAA supplementation include the ability to attenuate delayed-onset muscle soreness (DOMS) and suppress the decrease of muscle strength after an unaccustomed high-volume resistance training workout in untrained women [89]. These effects have been shown to be more pronounced in women as compared to men when BCAAs were ingested at 77 mg/kg (males) or 92–100 mg/kg BM (females) before exercising [90]. More recent reviews have confirmed that the role of BCAA supplementation to attenuate delayed onset muscle soreness (DOMS) plays a slight to moderate effect, as well as to hasten the rate of recovery after hard workout sessions [82, 91]. Evidence of BCAA supplementation showing reduction in postexercise-induced muscle damage is less clear [92].

23.2.9 β-Hydroxy ß-methylbutyrate (HMB)

β-hydroxy β-methylbutyrate (HMB) is a metabolite resulting from the metabolism of leucine. In the sarcoplasm and mitochondria of skeletal muscle, leucine is transaminated to a metabolic intermediary α-ketoisocaproate (α-KIC), and despite most α-KIC being transported to the liver, about 5% is metabolized in the cytosol toward HMB. Nearly 60 g of leucine is required to produce 3 g of HMB, thus supplementing with HMB appears to be a more practical and efficient method of increasing HMB concentrations in skeletal muscle [93]. Even though there is strong scientific information endorsing the effect of combining HMB supplementation with resistance exercise for maximizing muscle mass gain, there is still limited evidence to support additional performance increases (ergogenic) resulting from the ingestion of HMB [75].

The current established minimal effective dose of HMB is 1.5 g/d, with 3 g/d offering additional benefits on muscle mass gain and to attenuate loss in lean body mass when following energy-restricted diets. During non-training days, it is recommended to take three doses of 1 g (with breakfast, lunch, and bedtime) [75], while on training days a single dose of 3 g before workout has been recommended [94]. There are no apparent side effects due to HMB supplementation. Furthermore, no difference between men and women has been reported regarding its potential benefits in supporting muscle mass accretion and attenuation of muscle damage [95].

23.2.10 L-Glutamine

Glutamine is the most abundant free amino acid in plasma and skeletal muscles, accounting for 60% of the total free amino acids in skeletal muscles without considering taurine, and 20% of plasma amino acids [96]. Plasma glutamine levels can decline due to reduced production or decrease in the release of glutamine by muscles. L-glutamine operates as a nitrogen shuttle, an immunosuppressor, and a powerful anticatabolic agent which contributes to the production of other amino acids, glucose, nucleotides, protein, and glutathione [97]. All together, these relevant physiological functions of glutamine provide a strong rationale to propose L-glutamine as a nutritional supplement for athletes. There is no compelling evidence to support glutamine supplementation in terms of increasing lean mass, enhancing exercise performance [75] or to attenuate immunosuppression caused by hard endurance exercise sessions in male or female athletes [97]. However, some studies have observed potential benefits of L-Glutamine or derivatives such as alanyl-glutamine to favor cell hydration [98] and maintain gastrointestinal integrity which in turn facilitates nutrients absorption during long duration exercise [99].

In conclusion, despite the lack of convincing evidence regarding the ergogenic effects of glutamine in athletes, it still can be considered a useful nutrient for maintaining optimal nutrition, aiding in the absorption of co-ingested nutrients (e.g., carbohydrates and proteins), favoring hydration, and promoting a better cell anabolic environment under exercise conditions.

In both male and female athletes, a dose of L-glutamine or alanyl-glutamine of 200–500 mg/kg BM ingested 1–2 h prior to training promoted hydration and attenuated exercise-induced catabolism in athletes [98, 99].

23.2.11 L–Arginine and L-Citrulline

Arginine is conditionally or functionally an EAA [30] synthesized from ornithine and citrulline. Arginine is involved in numerous areas of human biochemistry, including ammonia detoxification, hormone secretion, immune modulation, synthesis of creatine, phosphate or polyamines, and promoting fertility in both men and women [30]. L-arginine is the main physiological precursor of nitric oxide (NO), which plays an important regulatory role by increasing blood flow to the muscles and modulating muscle contraction, along with glucose and amino acid uptake by skeletal muscles [100, 101] Supplementation with L-arginine is thought to increase vasodilatation by increasing NO production in the active muscle during exercise, improving muscular strength, power, and recovery through increased substrate utilization and metabolite removal, such as proteins and ammonia .

Although long-term arginine supplementation showed some ergogenic benefits [102, 103], its effects on performance improvements are still inconsistent [75]. There is no evidence that supplementation with L-Arginine can elicit a somatotropic effect to increase NO levels [97]. Regarding females, Fricke et al. observed no significant difference in maximal isometric grip force (N) and jump performance variables after 6 months of L-arginine supplementation (18 g) in postmenopausal women [104].

Although safety is still a concern [75], oral L-arginine supplementation appears to be well-tolerated when used between 3 and 15 g in healthy individuals [97]. Notably, orally ingested L-Arginine is largely metabolized by the splanchnic area, leading to a decrease in its peripheral bioavailability [97]. In general, it has been proposed for athletes to ingest 3–5 g/d before training or competition as a possible effective strategy to improve performance.

Alternatively, the use of oral L-citrulline has been shown to be more effective in increasing arginine due to limited intestinal catabolism and a greater absorption into the systemic circulation. Based on citrulline metabolism, it was hypothesized that instead of L-Arginine, supplementing with L-citrulline could be more effective to stimulate NO production while maximizing muscle blood flow and oxygen delivery during exercise [97]. However, research regarding L-Citrulline's effect on exercise performance is still limited [75, 97].

Research does not support the use of oral L-Arginine supplementation for health and athletic performance [75, 97]. Alternatively, there is no clear evidence to clarify whether supplementing with oral citrulline can be effective to improve performance or support exercise adaptations [75, 97].

23.2.12 β-Alanine

β-alanine is an endogenously produced nonessential amino acid with the relevant role as a rate-limiting precursor to carnosine synthesis in skeletal muscle [105]. Carnosine is a dipeptide comprised of the amino acids, histidine and *β*-alanine, that naturally occur in large amounts in skeletal muscles. Although men have higher levels of carnosine than women, increasing intramuscular carnosine improves buffering capacity, metal-ion chelation, and antioxidant scavenging regardless of sex [106]. Although β-alanine can be obtained through the diet (poultry and meat), supplementation has been shown to increase levels of carnosine in human skeletal muscles by improving performance in high-intensity exercises with significant increases of muscle acidosis [97]. Increased buffering capacity may enhance tolerance to exercise primarily in high intensity glycolytic events lasting between 1 and 4 min. However, events of intermittent or long lasting activities including a relatively high activation of the glycolytic energy pathway may also benefit [107]. Further favorable effects of *β*-alanine are related to attenuation of neuromuscular fatigue, particularly in older subjects [105].

β-alanine supplementation is safe in healthy populations with doses from ~1.2 to 6.4 g/d [105] up to 12 g/d [108] with the only reported side effect as paresthesia (tingling). Paresthesia can be avoided by the use of sustained-release formulas. Despite the available strong evidence supporting the ergogenic effect of *β*-alanine supplementation in both men and women [75, 97], a high interindividual variability has been observed [107].

To summarize, *β*-alanine supplementation seems to be safe and beneficial for athletes performing highly glycolytic events. The optimal protocol is still unknown for *β*-alanine supplementation despite a 4-week loading phase involving 4 doses of 1.6 g/kg BM/d followed by a maintenance period using 4 daily doses of 0.8 g has been successfully been used [105]. Individual doses based on body mass [~16 to 22 mg/kg BM 4Xs daily, spaced out in 3 h intervals (65–88 mg/kg BM/d)] would represent a more practical, individualized approach.

23.2.13 Integrating Supplementation and Diet

Co-ingesting protein and amino acids with other macronutrients such as carbohydrates has been shown to be a useful strategy for optimizing exercise adaptation. Mixing high-quality protein supplements with carbohydrates resulted in enhanced cellular hydration, glycogen resynthesis, and promoted pro-

tein balances [109], when compared to the ingestion of only protein or amino acids. These beneficial effects are, in part, related to higher insulin anabolic-related stimuli caused by the addition of carbohydrates to protein extracts including higher concentration of EAAs [59, 110]. Since insulin initiates a suppression of muscle protein breakdown via the ubiquitous proteasome pathway [111], the co-ingestion of carbohydrates acts as an optimizing, permissive nutrient for achieving a more favorable net muscle protein balance. In the absence of sufficient blood amino acid availability, the carbohydrate-induced insulin concentration rise will likely target a suppression of muscle protein breakdown with no additional stimulation of MPS [112].

The available evidence supports the benefits of multinutrient supplementation including carbohydrates, creatine monohydrate, and high-quality protein isolates (whey, casein, beef, or vegetable blends) for maximizing training outcomes in athletes. The additional benefits of adding amino acids or derivatives (e.g., HMB) remain unclear and may be limited by the total daily protein intake and the relative amount (g/kg BM) of EAAs and leucine ingested in each singular intake [22].

Even though muscles remain sensitized to nutrient ingestion for at least 24 h following exercises [113], from a practical viewpoint some athletes may still struggle, particularly those with high body mass, to consume enough foods to meet their requirement for optimizing recovery between training sessions. Therefore, the pragmatic recommendation is for an athlete to consume some nutrients prior to and during workout, and then ingest an appropriate nutrient-rich meal post-workout. If an athlete chooses not to feed during exercise, not only will the athlete not benefit regarding exercise adaptation, this choice may also interfere with subsequent training sessions [37]. Taking this into consideration, during a workout, it is advisable to drink a beverage containing 0.4 g/kg BM of carbohydrates (CHO) mixed with 50–60 mg/kg BM of EAAs, or approximately 100–120 mg of a high-quality protein dissolved in 0.750–1 L of water. This beverage will provide a nutrient concentration of around 8% CHO to promote gastric emptying. An optimal post-workout meal should provide between >0.45 and ~1 to 1.2 g/kg BM of high glycemic load carbohydrates with >0.20 to ~0.4 mg/kg BM of high-quality protein (e.g., whey) [22, 72]. In order to elevate MPS and favor a positive muscle protein balance, it is advisable to distribute the daily protein ingestion equally across four to six meals [37, 114]. For example, in addition to the protein included in a typical meal (dairy, meat, egg, etc.), the consumption of 15–30 g (~250 to 320 mg/kg BM) of high-quality protein in the form of a powder or protein bar supplement could be an adequate between-meal snack. The typical American and some European diets distribute protein intake unequally in such a manner that lower amounts of protein are consumed with breakfast (>10 to 14 g of protein) when compared to dinner (>15 g). The use of protein powder or bar supplements can help to maintain an equal distribution of protein ingestion throughout the day. This strategy has been shown to be more effective for maintaining muscle mass when compared to an unequal distribution of protein contained within the daily meals.

23.2.14 Creatine

Creatine is traditionally taken by men more than women [1, 2]. However, a large enough percentage of women are taking this supplement to make creatine worthy of discussion. Recently, more studies have been published examining the effects of creatine on female participants.

Creatine is composed of two non-EAAs (arginine and glycine) and one EAA (methionine) [86]. The average daily requirement is 2 g/d [7, 115]. The body makes 1–2 g/d via the liver, kidneys, and pancreas. Meat and fish also contain creatine. Vegetarian athletes have lower muscle creatine than omnivores [116].

Creatine is an important part of the adenosine triphosphate phosphocreatine (ATP-PC) energy system. Phosphocreatine (PC) is used to phosphorylate adenosine diphosphate (ADP) to ATP during high-intensity maximal muscle contractions, resulting in ATP and free creatine. Creatine is rephosphorylated during periods of rest (mitochondrial creatine kinase). Generally speaking, an average person has enough PC stores to supply ATP for anaerobic activities up to 10–15 s [7, 115]. Since the ATP-PC system is short-lived, glycolysis becomes the dominant energy system as PC stores are depleted and ADP builds up. Rest periods required to regenerate PC are typically 1–3 min depending on the intensity/duration of the exercise [7].

Creatine supplementation increases muscle creatine stores in subjects who do not already have maximal stores. Some athletes who consume high quantities of meat or fish are thought to have maximal or near-maximal stores already while vegetarian/vegan athletes may not [115]. Increased muscle creatine stores may lead to more PC to regenerate ATP, a faster recovery time to rephosphorylate free creatine, and in some cases buffer lactic acid [7, 115–117]. While many studies show improvement of anaerobic performance, some researchers have reported no ergogenic effect on anaerobic exercise [34, 118, 119]. Authors have speculated this could be due to sex differences or nonresponders [119]. Furthermore, aerobic endurance-type activities and submaximal efforts will not show any improvement with creatine supplementation [7, 120].

Fukuda, Smith, Kendall, et al. [121] examined the effects of 5 g creatine citrate, 4 Xs/d, for 5 days in recreationally active men (n = 26) and women (n = 24) on anaerobic running capacity (ARC). Men exhibited an increase in ARC (23%), while the women did not. It is difficult to determine if this lack of effect in the female group was a sex or a nonresponder issue. While the statistical analysis did not find the mean change to be significant, 67% of women in the creatine group increased their ARC.

In a similar study, Eckerson et al. [122] examined the effects of a 2 day and 5 day creatine loading protocol on anaerobic work capacity (AWC). Ten physically active women consumed 5 g creatine citrate 4Xs/d for 5 days. A critical power test was administered on days 2 and 5 to determine AWC. There was a 22.1% increase in AWC with 5 days of creatine loading. This is similar to the percent increase Fukuda et al. [121] observed in the male participants. In contrast, using a similar 5 day loading protocol, Ledford and Branch [123] found no difference in peak power output in multiple Wingate tests in physically active women. The authors speculate, based on previous literature [124], that women may not be as receptive to creatine supplementation as it has been reported that women have a relatively higher total muscle creatine concentration than men [123, 124].

Oral creatine supplementation has also been reported to be effective in maximizing brain creatine saturation. Even though, when compared to skeletal muscle, only a small percentage of total body creatine is in the brain (i.e., <5%), its role is essential for energy production in the brain including buffering energy supply, improving mitochondrial efficiency, directly acting as an antioxidant and a neuroprotectant [125]. Recent studies conducted in men and women, suggest a dosage of >20 g/d for at least 7d of creatine monohydrate could increase total brain creatine stores by 6–10%. This dose improved cognitive capacity and attenuated mental fatigue while performing a complex task lasting for more than 90 min [126].

Creatine is usually taken in the form of creatine monohydrate (there are other formulations) with a loading phase (5 g/d, 4 Xs/d) up to 7 days. A maintenance phase of 2 g/d is recommended for 3 months. This protocol has shown increases of muscle creatine 10–25% [115, 127]. However, most creatine data are based on male data. Consumption of creatine with a carbohydrate enhances absorption while caffeine will inhibit absorption [128].

It was previously thought that creatine supplementation could result in dehydration or heat cramps due to an intracellular fluid shift [115]. However, more recent research suggests this is not the case and creatine supplementation may actually reduce the risk for dehydration and heat-associated muscle cramps.

23.3 Common Ingredients in Energy Drinks and Pre-workouts

23.3.1 Carnitine

Carnitine is synthesized from lysine and methionine, which are the amino acids that soy protein is deficient compared to animal protein [129]. Mammals synthesize carnitine and most healthy humans can synthesize it even with a diet lacking in animal protein. In times of low dietary consumption, daily losses through excretion are lowered to compensate for this reduction [130].

When marketed as L-carnitine, an isomer of carnitine, it has been touted as a fat burner. As such, athletes have taken it for weight loss, increased muscle mass, and enhanced β-oxidation. While L-carnitine is involved in transportation of fatty acid chains across the membrane, studies have generally shown it to be an effective weight-loss agent for obese subjects and inconclusive for healthy non-obese subjects [130].

Athletes may also take L-carnitine to enhance recovery after high-intensity exercise. Research findings include decreased creatine kinase, production of purine, reduced free radical formation, and have reported less DOMS symptoms [130].

L-carnitine is available as a supplement and also as a prescription. Recommendations for daily supplementation are 2–3.5 g/d. Amounts in excess of 4 g/d may cause gastrointestinal distress. A lethal dose (LD) of 630 g/d in humans has been extrapolated from studies using rats [130].

23.3.2 Caffeine

Caffeine is widely used by athletes and nonathletes for various reasons. Varsity females listed enhanced performance, more energy, alertness, and taste as reasons why they consume caffeine. Athletes generally consume their caffeine via beverages such as coffee, tea, or soda. It is also consumed in caffeine tablets, energy bars, and even chocolate [1]. Many energy drinks and gels contain caffeine. Caffeine is allowed up to a certain quantity by the NCAA and WADA. You should advise your athlete to read the current guidelines regarding the amount of caffeine allowed by these agencies and the amount of caffeine in the products they ingest. As with most supplement studies, the majority of research has been conducted on men. However, it has been suggested that men and women respond to caffeine in a similar manner [131].

Caffeine's main mode of action is due to its structure. The chemical structure resembles adenosine and will bind to adenosine receptors. Caffeine also stimulates the release of epinephrine [132]. Caffeine has also been reported to

enhance fat oxidation and spare muscle glycogen. It also exerts a thermogenic effect, which is why it is an ingredient in most energy drinks and pre-workouts. Caffeine is widely consumed, although it is not necessary for metabolic functions. People who consume caffeine regularly may become habituated to it and the physiological effects will be blunted. These subjects would also be classified as nonresponders [133].

One question asked by athletes is how does caffeine tablet ingestion differ from drinking coffee [1]. While coffee does contain caffeine, it also contains many other compounds which form more metabolites in the body [134, 135]. Coffee has also shown some ergogenic effects, just not to the same magnitude as ingesting caffeine alone [134]. Coffee would have to be consumed in large amounts to equal the caffeine typically found in tablets. When answering the athletes' question of coffee or tablets, coffee would most likely result in less of an ergogenic effect unless the subject was naïve to caffeine.

23.3.2.1 Dosage

For an ergogenic effect on exercise, 3–6 mg/kg of caffeine is sufficient to produce an ergogenic effect. Since many beverages are variable in the amount of caffeine they contain, tablets are probably the most convenient way to get the dosage required to get an ergogenic effect [136]. Drinks containing caffeine vary on amounts so the amount needed on a mg/kg BM basis must be calculated. This may result in the athlete consuming a large volume of fluid (and other ingredients) if the beverage has a low caffeine content. Sport gels are also available with caffeine added, usually in a low amount. Athletes should read the packaging to know if they are buying a sport gel with or without caffeine prior to ingesting these products.

23.3.2.2 Adverse Effects

It is often suggested that caffeine usage will result in dehydration. Caffeine is a mild to moderate diuretic. Its effect is seen mainly at rest. Studies have found no effects of caffeine and dehydration after prolonged exercise so long as athletes are replacing fluids adequately [135, 136]. During prolonged exercise, epinephrine-induced renal vasoconstriction causes blood flow to be diverted from the kidneys to the exercising muscle [136]. The diuretic effect of caffeine is minimized during exercise [133].

Other side effects of caffeine include tachycardia with exercise, increased blood pressure, gastrointestinal distress, and habituation/addiction to caffeine [135, 136]. There are also side effects associated with discontinuing caffeine usage. Headache, fatigue, and possible flu-like symptoms may occur [135, 136]. Caffeine also inhibits the ergogenic effect of creatine [115, 128, 135].

23.3.2.3 High-Intensity Exercise

During high-intensity exercise, caffeine could lower rate of perceived exertion (RPE) and increase glycolytic activity performance. Conversely, caffeine is also associated with an increase in blood lactate [137]. However, not all anaerobic studies are in agreement. Greer, McLean, and Graham [138] found no ergogenic effect or increase in blood lactate of subjects studied when performing the Wingate test.

In a female-specific study, female volleyball players consumed a low dose of caffeine in a sports gel (1.39 mg/kg BM). No improvements were observed for vertical jump, agility (3 cone drill), and sprint performance (30 m sprint) in collegiate volleyball players [139]. This dose may have been too low to elicit an ergogenic effect. Typically, 3 mg/kg BM seems to be ergogenic without many adverse effects.

23.3.2.4 Strength

The effect of caffeine on strength activities is not conclusive. Previous studies have suggested caffeine may have a direct mode of action on muscle function. This proposed mode of action suggests that caffeine causes the sarcoplasmic reticulum to release more calcium, allowing the muscle to sustain force production for a longer period [135, 136, 138].

Goldstein, Jacobs, Whitehurst, et al. [140] examined the effects of 6 mg/kg BM versus placebo on 15 resistance trained women. Subjects performed 1 RM bench press and a muscular endurance bench press test to failure (60% 1 RM). Although it is a small increase, the caffeine trial demonstrated a higher 1 RM (52.9 ± 11.1 vs 52.1 ± 11.7 kg, $P < 0.05$). No change was observed for muscular endurance, heart rate (HR), or diastolic blood pressure. Systolic blood pressure was elevated in the caffeine group immediately post-exercise, but not during or 60 min post-exercise [140].

23.3.2.5 Endurance

Endurance exercise and caffeine have been studied extensively. The main concept is that caffeine causes fatty acid mobilization and glycogen sparing [135, 136]. Many of the studies investigating glycogen sparing were not designed to cause sufficient glycogen depletion with or without caffeine. It is unlikely that the ergogenic effects of caffeine on endurance exercise are due to glycogen sparing [135, 136]. Likewise, research has not supported the theory of caffeine-enhanced fatty acid oxidation during exercise. While many studies report no decrease in respiratory exchange ratio (RER) with caffeine and exercise, caffeine does promote lipolysis at rest [135]. It is clear that caffeine does prolong endurance exercise. The mechanism behind that is not clear. Graham [135] suggests more future research to explore alternative hypotheses.

In a study examining the effect of caffeine on endurance exercise, 27 male and female endurance trained cyclists per-

formed time trials to exhaustion with and without caffeine. The caffeine dose was 3 mg/kg BM. Mean time trial improvement was 169 s in the caffeine trial. Additionally, no difference in caffeine's performance-enhancing effect was observed between male and female participants [131]. This would suggest that men and women have the same response to caffeine if not habituated.

23.3.3 Ginseng

Ginseng is a widely used herbal supplement in many fat burners and energy drinks. It is reported to improve mood, performance, alertness, and increase fat utilization. There are two prevalent types of ginseng used: Chinese (also called Korean or Asian) ginseng (*Panax ginseng*) or Siberian ginseng (*Eleutherococcus ginseng*). Other less commonly used ginseng plants include Japanese ginseng (*P. japonica*), Tienchi ginseng (*P. notoginseng* or *P. pseudoginseng*), Dong Quai (*Angelica sinensis*), or American ginseng (*P. quinquefolius*) [132].

Chinese ginseng is an herbal supplement that has been evaluated in human performance studies and was reported to exhibit promising effects to improve strength and aerobic capacity [132, 141]. However, other studies have shown no improvements in maximal oxygen consumption (VO_{2max}), strength performance, or postexercise recovery [132, 141, 142]. This could be due to varying populations, different dosages, types of ginseng, or various durations of the studies [142–144]. The general dosage guidelines for Chinese ginseng are 1–2 g/d. This may vary based on type of preparation (powder vs. root extract). Chinese ginseng is usually supplemented for a certain duration in combination with athletic training [132]. The majority of research suggests that Chinese ginseng is not ergogenic.

Eight weeks of supplementation with Panax ginseng in 24 healthy active women did not result in improvements of supramaximal exercise testing or recovery values [145]. Participants consumed 400 mg of Panax ginseng for 8 weeks or consumed their normal diet. Prior to the treatment period and at the end of treatment, participants performed a Wingate cycle ergometer test. There were no significant differences for mean power output, peak power output, rate of fatigue, or recovery HR [145]. Caldwell et al. [146] examined the effect of Korean ginseng under the product GINST1510 in 10 active women and 9 men. Participants consumed a high dose (960 mg/day), low dose (160 mg/day), or placebo. Participants performed 5 sets of 12 reps at 70% 1 RM on leg press. No sex differences were observed. There were no differences in reaction time or peak power generated from a ballistic jump between pre-, post-, and 24 h post-acute resistance exercise. The authors suggest that the lack of positive effects may be due to responders and nonresponders. Ginseng supplementation did, however, reduce perceived soreness in the high-dose group immediately post- and 24 h post-exercise [146].

There have been some adverse effects reported with Chinese ginseng use. As ginseng is a stimulant, it may cause sleeplessness or nervousness. Since many supplements contain ginseng plus caffeine, this side effect may not be due entirely to ginseng. Hypertension, dermatological problems, morning diarrhea, and euphoria have also been reported with ginseng use [132, 141].

Siberian ginseng is in the same plant family as Chinese ginseng. However, the two herbs are distantly related. It does contain saponins, but they are different than the ones found in Chinese ginseng. Many of the early studies involving Siberian ginseng did not give experimental design details or data, nor were they peer-reviewed. Subsequent studies have failed to show an ergogenic effect [132, 141, 147]. Dowling et al. [147] examined the effects of Siberian ginseng on submaximal and maximal exercise tests in 20 trained distance runners. After 8 weeks of supplementations, no differences existed between placebo and treatment groups for VO_2, ventilation (VE), respiratory exchange ratio (RER), HR, or rating of perceived exertion (RPE) in both the submaximal runs at 10 k race pace or maximal treadmill tests. There were also no differences in lactate and time to exhaustion during the maximal testing [147]. Without further research demonstrating an effect, it would be difficult to recommend supplements containing Siberian ginseng for athletic activity.

23.3.4 Energy Drinks

Most energy drinks contain sugar, caffeine (derived from guarana), taurine, and ginseng. Some energy drinks may also contain B vitamins. Energy drinks contain a unique combination of these ingredients and may contain other substances as well. It is important that athletes consult the allied health professionals with the drink they chose to consume. The allied health professional should inform the athlete about the ingredients in the beverage and the effect of energy drinks on sports performance. Currently, there are not many well-controlled studies examining the effects of energy drinks on performance. It is difficult to perform studies using all different brands of energy drinks since the market keeps growing. However, there are a few well-controlled studies examining the effects of a representative major brand energy drink on exercise endurance and sprint performance.

23.3.4.1 The Effects of Energy Drinks on Sprint Performance and High-Intensity Exercise

Astorino et al. [148] examined the effects of acute consumption of the energy drink Red Bull on sprint performance in

female collegiate soccer players. Soccer players were asked to drink either one can of Red Bull or the equivalent amount of the placebo beverage 1 h before performing multiple *t*-tests. These *t*-tests were performed as all-out sprints in three bouts of 8 *t*-tests. Heart rate was monitored with a chest strap HR monitor. There were no differences between the placebo and Red Bull in regard to RPE, HR, or sprint times. These researchers concluded that a single serving of a Red Bull does not provide the female athlete with any ergogenic benefit [148].

Similar results were found when sugar-free Red Bull was given to physically active male and female college students (Mean VO_{2max} 45.41 ± 6.3 mL/kg/min) before performing a run to exhaustion test [149]. Participants consumed either a placebo beverage or a sugar-free Red Bull 60 min prior to a run to exhaustion treadmill test at 80% VO_{2max}. Run time to exhaustion was not significantly different between either group nor was RPE. Blood lactate levels were significantly elevated postexercise in both trials, but there were no significant differences between groups. The consumption of sugar-free Red Bull did not influence substrate utilization during this high-intensity run to exhaustion in physically active college-aged males and females [149].

In recreationally active men (n = 11) and women (n = 4) consuming Red Bull, no differences were found for any variable in Wingate performance. Participants also performed submaximal bench press to fatigue (70% 1 RM). The total number of repetitions performed for all 3 sets were higher in the Red Bull trial compared to the placebo (34 ± 9 RB; 32 ± 8 PL, P = 0.031, respectively). There were no significant differences for number of repetitions in any one set [150]. The dose of caffeine in Red Bull used in the study was 2.0 mg/kg BM. This may account for the lack of effects as this is lower than the range of caffeine dose that seems to be ergogenic.

In a double-blind, randomized, repeated measures study, 13 trained female volleyball players consumed either a caffeine-containing energy drink designed to yield 3 mg caffeine/kg body weight or a placebo drink identical except lacking in caffeine. Both drinks contained the same amounts of taurine, sodium bicarbonate, and L-carnitine. Sixty minutes after consumption of the energy drink, the athletes performed both a standing and jumping spike, maximal spike jump, squat, counter movement, and block jumps, maximal grip strength, and a *t*-test. Following the laboratory tests, the players participated in a 3-set simulated game. The caffeine trial resulted in increased hand grip strength in both hands (R: P = 0.004, L: P = 0.019), standing (P = 0.023) and jumping (P = 0.038) spike ball velocity, jump height for all jumps, and reduced time for the *t*-test (P = 0.036). During the simulated game, the caffeine trial yielded a higher maximal and average heart rate, positive game actions were increased while actions causing errors were decreased. These participants reported having increased nervousness in the hours after completion of testing [151].

In a similar study, 18 female soccer players ingested either a caffeine-containing energy drink designed to yield 3 mg caffeine/kg BM or a placebo drink identical except lacking in caffeine. Both drinks contained the same amounts of taurine, sodium bicarbonate, and L-carnitine. Sixty minutes after consumption of the energy drink, the athletes performed counter movement jumps, a 7 × 30 m maximal running speed test, and a simulated soccer game during which various data points and heart rate were obtained. The caffeine trial yielded an increase in mean jump height (P = 0.05), increased average peak and maximal speed ($p < 0.05$) in the 7 × 30 m test, and an increase in distance covered during the simulated game ($p < 0.05$). Average and maximal heart rate was not statistically different between trials during the simulated game. No adverse effects were reported [152]. The results indicate that caffeine may be the most important ergogenic aid in this energy drink regarding performance since the placebo was identical in all other ingredients.

23.3.4.2 The Effects of Energy Drinks on Endurance Performance

The effect of an energy drink on endurance performance was examined by Ivy et al. [153]. Participants were male and female competitive cyclists (VO_{2max} 54.9 ± 2.3 mL/kg/min). The dosage for the energy drink was determined by the amount of caffeine needed to elicit an ergogenic effect. Participants consumed the equivalent of two cans of Red Bull (500 mL) or placebo 40 min prior to exercise. This represented a dose of 2.35 mg/kg BM caffeine in the Red Bull trial. A time trial was performed on the cycle at 70%-watt max, 90 rpm for approximately 1 h. On average, participants improved their performance 4.7% in the treatment group ($P < 0.01$). By 50 min of exercise, HR was elevated above the placebo group (173 ± 4.0 to 166.5 ± 5.8 bpm, respectively) and remained elevated at completion of the exercise session (172.2 ± 4.3 to 170.5 ± 5.7 bpm, respectively). Epinephrine was elevated above the placebo group at 30 min (461.0 ± 122.5 to 195.6 ± 43.8 pg/mL, respectively), 50 min (470.8 ± 96.9 to 219.5 ± 293.9 pg/mL, respectively), and after completion of exercise (1011.8 ± 295.1 to 287.1 ± 69.7, respectively). Norepinephrine, cortisol, and B-endorphin were not different between the two treatment groups. There was also no difference in RPE. Blood lactate levels in the treatment group were elevated pre-exercise and remained elevated over the treatment group for the duration of the exercise. Except for the immediate period before exercise, blood glucose levels did not differ between groups. Glucose levels were significantly higher in the energy drink group prior to exercise ($p < 0.05$). Insulin levels were also elevated pre-exercise and also at 10 min into the exercise session in the energy drink group. Blood glycerol levels increased with longer exercise duration in both groups. Glycerol levels were significantly

higher in the placebo group at 10 min ($p < 0.05$). No other time points were significantly different for glycerol values. Free fatty acids were significantly increased from 10 to 50 min of exercising in the placebo group ($p < 0.05$). After completion of exercise, there was no difference between either group in terms of free fatty acids. Substrate utilization, as determined from VO_2 and RER data, did not differ between the two groups. In general, carbohydrate usage declined with larger exercise duration and fat usage increased. The researchers demonstrated a nonsignificant trend ($p < 0.09$) where carbohydrate usage in the energy drink group was higher than the placebo group from 30 to 50 min of exercising. The main finding of this study is that 500 mL of an energy drink containing a combination of caffeine, carbohydrates, taurine, and B vitamins can improve cycling performance in a 1 h time trial. The amount of caffeine in this study was towards the lower end of the range where caffeine has been shown to be effective (2.35 mg/kg BM); therefore, the researchers speculate that the effects are due to the combination of ingredients in the energy drink. Increased epinephrine levels were likely elevated in response to the caffeine and could have spared muscle glycogen levels and allow for the increasing trend ($p < 0.09$) of carbohydrate utilization during the second half of the exercise [153]. It should be noted that participants consumed energy drink before exercise and consumed water during exercise in a climate-controlled laboratory. Athletes should be aware that results of the same energy drink could be different in outdoor race conditions when climate and nourishment can also affect exercise. Athletes should also be cautioned about the increased HR that consumption of an energy drink may cause and the dangers of cardiac drift in a hot and humid climate.

23.3.4.3 Conclusion: Are Energy Drinks Ergogenic?

In summary, studies examining the effects of high-intensity exercise and sprint performance have not shown an ergogenic effect from energy drinks with doses of caffeine <3 mg/kg BM. When studies administered doses of 3 mg/kg BM, research has shown a favorable improvement in performance. Lara et al. [152] suggest that the ergogenic effect in a taurine containing energy drink may be due to the caffeine in the energy drinks as a placebo containing identical ingredients (minus caffeine) did not yield improvements in performance. Endurance exercise may yield ergogenic effects with a dose of caffeine slightly less than 3 mg/kg BM, as seen in the results of Ivy et al. [153].

An important feature of this research is that all of the studies had the participants consume the beverage 40–60 min prior to exercise, but did not consume the beverage during exercise. Most studies had athletes consume a certain volume of beverage to attain a specific dose of caffeine per kg BM. As with utilizing caffeine to obtain an ergogenic effect, it seems that the most common method to administer an energy drink is to calculate the amount of fluid consumed to contain at least 3 mg/kg BM of caffeine. This would be appropriate for either high intensity/sprint exercise or endurance. The dose of 3 mg caffeine/kg BM seems to be well-tolerated without adverse side effects while still yielding beneficial effects.

The evidence regarding ergogenic effects of energy drinks is still an emerging field. The allied health professional should routinely scan the literature for new research on this front and also look on retail shelves to see what new drinks are being marketed; become familiar with the ingredients and the amounts of the ingredients; and know the target audience they are marketed to. With regard to safety of energy drinks, there have been reports of cardiac events and/or death with consumption of energy drinks and exercise. However, there are also reports of exercise without elevated HR, BP, EKG abnormalities and showed improved performance.

23.3.5 Pre-workouts

An emerging market in sports supplements is the "Pre-workout." While the idea of a pre-workout supplement is not novel, products on store shelves labelled as such are becoming more prevalent and popular. In a review by Eudy et al. [154], it is thought that up to 89% of college athletes consume pre-workouts. Pre-workouts are available at specialty performance/nutrition stores and other large drugstores, which makes them widely accessible. Common ingredients are a cocktail of stimulants, EAAs, BCAAS, L-arginine, L-citrulline, β-alanine, taurine, B-vitamins, creatine, and sometimes herbal supplements. Typically, claims for the effects of the product will be backed up by studies on individual ingredients. Many of these multiple ingredients studied as single ingredients have been combined into a cocktail with product claims such as: enhanced "muscle pump", increased blood flow, and/or increased exercise performance. Some products will list "proprietary blend" without specifying amounts or formulations. Pre-workouts may come as powders or premixed drinks marketed in a variety of palatable flavors with names that evoke a sense of a powerful workout. An issue in the literature is the lack of well-designed studies examining the effects of specific pre-workout products. In the last few years, companies have been marketing pre-workouts specific for females.

Martinez et al. [155] examined the effects of acute ingestion of a pre-workout on power and strength performance in 13 recreationally active males. Participants ingested the pre-workout or placebo as directed, 20 min prior to completing a medicine ball put, vertical jump, 1 RM bench press, and a Wingate test. The pre-workout was commercially available and contained: vitamins and minerals, "ATP Amplifier",

Cellular Transport & Insulin Activator', "Athlete performance blend", "Energy & Neuro igniter", and "Hydration system". Some ingredients of the proprietary blends: beta-alanine, taurine, BCAAs, caffeine, taurine, an aqueous extract of cinnamon, coconut water power, and beet extract. There were no significant differences for the medicine ball put, vertical jump, and 1 RM bench press. Peak power ($P = 0.003$) and mean power ($P = 0.006$) were significantly higher in the pre-workout trial; however, there were no differences in the fatigue index.

In a study utilizing a pre-workout product targeted at females, 15 recreationally active female consumed the pre-workout as directed or the placebo. Ingredients in the proprietary "FitMiss Ignite Blend" were: carnosyn, beta alanine, choline, bitartrate, L-tyrosine, L-glycine, Taurine, L-carnitine, beet root extract, hawthorn berry, caffeine, agmatine sulfate, and huperzine A 1%. The study does not mention a specific time of ingestion to exercise; however, 20–30 min is a standard time frame. Resting energy expenditure was elevated over the placebo trial ($P = 0.043$). Participants performed a counter movement vertical jump, muscular endurance back squat and bench press tests (85% of 5RM), and a 25 s sprint test on a treadmill. Heart rate and systolic blood pressure were not different between trials. At rest, diastolic blood pressure was elevated in the pre-workout trial compared to placebo (84 ± 1.1, PL 64.8 ± 1.3 mmHg, $P = 0.011$, respectively). No differences were found for the vertical jump and back squat. There was a significant difference between trials for number of reps completed for bench press, albeit a small increase (~12 reps pre-workout, ~11 reps placebo, $p < 0.05$). Total work completed in the 25 s treadmill sprint was higher in the pre-workout trial ($p = 0.039$) [156].

23.4 Echinacea as an Ergogenic Aid

Multiple studies have reported that female athletes commonly use Echinacea in order to boost their immune system [1, 3, 4]. In fact, Echinacea supplementation is commonly listed in the top 5 supplements which female athletes consume. However, research suggests that supplementation with various Echinacea species or preparations does not prevent or shorten the duration of a cold [157–159].

Turner et al. [158] treated 50 participants with 900 mg/d Echinacea and 42 participants with placebo and found no significant difference between rhinovirus infection (44% and 57%, respectively) and clinical colds (50% and 59%, respectively). The duration of the treatment period in this study was 2 weeks [158].

Turner et al. [159] also examined the dosage of 900 mg/d in three different preparations of *Echinacea angustifolia,* one of the varieties of Echinacea recommended to treat a cold [159]. Participants were assigned to receive the treatment either as a prevention of or treatment for a cold. After a week of supplementation, participants in the prevention group were given a nasal spray containing a rhinovirus. There was no positive treatment effect of Echinacea with regard to infection prevention. Treatment of infected participants did not result in any significant effects on alleviating rhinovirus symptoms [159].

In agreement with Turner and colleagues, Barrett et al. [157] found that supplementation with an Echinacea supplement made of *Echinacea purpurea* (675 mg) and *Echinacea angustifolia* (600 mg) did not reduce the duration or ease symptoms of a cold. Participants in the treatment group consumed 2 tablets, 4 times/d the first day and 1 tablet/d for the next 4 days. Symptoms were tracked for 2 weeks. There were no significant differences in cold duration or relief of symptoms in any group studied [157].

23.4.1 Echinacea and Erythropoietin

It has been suggested that Echinacea could be an ergogenic aid, not used to treat cold symptoms, but to increase Erythropoietin (EPO) and subsequently increase VO_{2max} [5, 6]. The literature is inconsistent regarding the effectiveness of Echinacea for increasing EPO.

A 2007 study examined the effects of 8000 mg/d (most over the counter [OTC] Echinacea supplement doses are far less than this, thus requiring ingestion of multiple pills/capsule to get to this amount) of *Echinacea purpurea* on EPO production in recreationally active males for 28 days. Blood samples were taken baseline, 7 days, 14 days, 21 days, and 28 days and analyzed for red blood cell (RBC) count, hemoglobin (Hb), hematocrit (Hct), mean corpuscular volume (MCV), mean corpuscular hemoglobin content (MCHC), ferritin, and EPO. Erythropoietic growth factors were also measured: interleukin-3 (IL-3), granulocyte-macrophage-colony-stimulating factor (GM-CSF), and prostaglandin E_2 (PGE_2). There were no significant effects at any time point between groups for RBC, Hb, Hct, MCV, or MCHC. EPO in the treatment group was elevated 44% above baseline at day 7, 63% at day 14, and 36% at day 21. At day 28, EPO was no longer elevated above baseline. EPO was elevated compared to the placebo group at days 7, 14, and 21. The only erythropoietic growth factor that was significantly elevated compared to the placebo group was IL-3 at days 14 and 21. While not significant from baseline, both groups exhibited a decrease in serum ferritin over time. The authors speculate that IL-3 may be involved in the EPO stimulus and the time frame for Echinacea to yield similar results to hypoxia may require a longer supplementation period than hypoxia stimulus at altitude [6].

In a similar study, Whitehead et al. [5] administered 8000 mg/d *Echinacea purpurea* to 24 healthy male college

students for 4 weeks to examine the effect on running economy and VO_{2max}. Blood samples were taken baseline, 7 days, 14 days, 21 days, and 28 days. After day 7, EPO values were increased over baseline as compared to the placebo group. However, while at day 21 even though EPO values were still significantly elevated, they had started to decline. By day 28, EPO values were no longer significantly elevated over baseline or different from the placebo group. Red blood cell (RBC) count was not different between groups or within groups. At day 28, a maximal exercise test was administered. Submaximal VO_2 was ~1.5% lower from pre-study values during the first 3 stages of the maximal exercise test in the Echinacea group. VO_{2max} was ~1.5% higher in the Echinacea group [5]. From the results of this study, it appears that high doses of Echinacea may slightly increase VO_{2max}, while allowing an endurance athlete to perform the same amount of work at a lower submaximal VO_2. It also appears that Echinacea may increase EPO up to 2 weeks and then wane.

The same group of researchers examined the effects of Echinacea in trained male athletes (VO_{2max} 52.9 ± 0.9 mL/kg/min). Participants ingested 8000 mg/d of *Echinacea purpurea* for 6 weeks. Blood samples were taken at baseline, 14 days, 28 days, and 42 days, and analyzed for RBC, Hb, Hct, MCV, MCHC, and EPO. In contrast to the previous data, there were no significant differences from baseline or between groups for any variable measured. The authors suggest that while Echinacea supplementation may enhance EPO production in recreational participants of average fitness, it does not stimulate EPO production in trained athletes [160]. In an additional paper, the authors speculated that increased EPO could enhance nitric oxide (NO) production and presented evidence in this same cohort that 8000 mg/d did not result in increased NO production [161].

In a larger scale study, which included women, 45 endurance trained athletes (30 men, VO_{2max} 61.0 ± 1.4 mL/kg/min; 15 women, VO_{2max} 51.7 ± 1.7 mL/kg/min) consumed either 8000 mg/d or 16,000 mg/d of *Echinacea purpurea* and a mixture of vitamins, minerals, and plant extracts or the placebo for 35 days. Participants performed a graded exercise test to establish baseline VO_{2max} and again at the end of the study. Blood samples were taken at baseline, 14 days, and day 35. Samples were analyzed for RBC, Hb, Hct, EPO, and ferritin. No significant changes were observed in any of the blood variables or VO_{2max} [162]. Baumann et al. [163] also examined the effect of *Echinacea purpurea* in trained distance athletes. Sixteen male endurance trained runners (VO_{2max} 65.17 ± 6.60 mL/kg/min) consumed 8000 mg/d of Echinacea or placebo for 6 weeks. No significant changes were observed for VO_{2max}, Hb, or Hct [163].

Not all studies on recreationally active males show improvements. In a study examining the effects of *Echinacea purpurea* in recreationally active males (VO_{2max} 51.7 ± 7.0), Bellar et al. 2014 found supplementation of 8000 mg of Echinacea, along with herbal supplements, vitamins, and minerals for 30 days to not be effective to increase VO_{2max} [164].

With the addition of new studies looking at the effects of *Echinacea purpurea,* it would seem the literature suggests that an aerobic ergogenic benefit may be conferred to untrained males but not trained males. In the one study examining trained females, no effect was found. To date, studies on this supplement have largely utilized male participants. Future research concerning whether there is an ergogenic effect for untrained or recreational female athletes is warranted.

23.5 Multivitamins

When surveyed, multivitamins were in the top 5 of dietary supplements taken by female athletes [1–3]. The reasons females gave for using multivitamins were as follows: *"recommended by family, friends, coaches or trainers, to meet nutritional needs, boost the immune system and prevent disease, boost energy, alertness, and habit from childhood*" [1, 2, 165]. While both male and female athletes report taking multivitamins with minerals, female athletes are more likely to take iron and calcium supplements than their male counterparts [165].

However, not all multivitamins are just that—a multivitamin. Several multivitamins contain herbal extracts (phytoextracts), soy proteins, BCAAs, ginseng, and Ginkgo biloba, to name a few. These are usually marketed as multivitamins labeled for performance and are widely available on drugstore shelves or nutrition stores.

It is important to remember that multivitamins fall under the dietary supplement category and are not subject to FDA regulation. Allied health professions who work with athletes and coaches should be aware of the brand their athletes are taking and be able to counsel them to make informed purchases and encourage them to read labels. As an alternative, there are several prescription vitamins which are subject to FDA regulations that could be prescribed by the team physician. Information on specific recommendations for vitamin and mineral requirements can be found in chapters in this text addressing requirements for various female populations.

23.6 Iron

From dietary analysis, male and female athletes appear to approach or meet the recommended daily allowance (RDA) for iron [166–168]. However, mean intakes may not be as useful when working with individual athletes. Beals [167] examined iron intake in volleyball players and found 67% of

athletes did not meet the RDA, even though the mean suggested the cohort met the RDA [167]. This is in agreement with a study of Koehler et al. [168] who reported mean iron intake for males to meet the RDA for iron with 19% not meeting the RDA and mean female values meeting the RDA, while 63% did not on an individual basis [168].

High dose of OTC iron supplements can cause gastrointestinal distress or constipation, both of which would prove to be ergolytic to athletic performance [169]. When considering iron supplementation, there is a slow release of OTC formulation that can minimize the side effects. It is best to consult with a physician prior to recommending iron supplementation. Regarding supplementation and performance, studies of iron supplementation in non-anemic athletes have not shown improvement in performance [170].

23.6.1 Does Correcting Iron Insufficiency or Deficiency Improve Performance?

Female marathon runners ($n = 85$) were recruited to discern the effects of iron or folate supplementation on exercise performance in female runners who are either iron- or folate-deficient but not anemic. Participants were divided into groups based on serum ferritin level or folate levels and a subset of participants were selected for the study. The low serum iron group ($n = 19$) was supplemented with 500 mg of amino acid chelate iron (50 mg elemental iron). The low serum folate group ($n = 23$) was supplemented with 5 mg of folic acid. The control group ($n = 10$) was a subset of the initial recruiting pool with high serum ferritin levels who were given a lactose placebo. Participants consumed the supplement for a period of 11 weeks. Blood samples and VO_{2max} tests were performed at baseline, 1 week, and 11 weeks. At baseline, 16% of the participants had low serum ferritin levels, 2% were classified as iron-deficient anemia (IDA), and 33% had low serum folate levels (13% of which had macrocytic anemia). After 1 week of treatment, serum ferritin levels rose significantly from 29.7 ± 10.0 ng/mL to 78.2 ± 66.3 ($P < 0.05$), and by 11 weeks, levels were still elevated above baseline, 59.8 ± 69.5 ng/mL. In the high ferritin group, serum ferritin continually fell over the 11 weeks; however, at week 11, levels were still elevated above baseline. Percent saturation of ferritin was significantly elevated from baseline at week 1 in both the low ferritin group and the high ferritin group. Serum folate levels followed the same trend as ferritin. There was no difference in VO_{2max}, maximal HR, submaximal and peak lactate levels, treadmill speed, or lactate inflection point for any group at any of the three time points tests or between groups. The authors conclude that serum ferritin levels beyond the normal range do not enhance exercise performance. Levels of ferritin or folate below the normal range did not affect exercise performance as there were no improvements in parameters after 11 weeks of supplementation in the low ferritin/folate groups despite a rise in serum levels [171].

Klingshirn et al. [172] investigated the effects of 8 weeks of 160 mg ferrous sulfate (equaling 50 mg elemental iron) supplementation twice per day in 19 ID non-anemic female runners. A VO_{2max} treadmill test and a test to exhaustion (10 k) was performed pre-and post-study along with hematological variables. Serum ferritin increased in both placebo (12.0 ± 3.21 to 15.77 ± 10.45 ng/mL) and supplement (11.6 ± 3.14 to 23.44 ± 6.65 ng/mL) groups with the largest increase in serum ferritin in the supplement group. No differences were found pre- and post-study or between groups for Hb, Hct, serum iron, or saturation of transferrin. No differences were found pre- and post-study or between groups in VO_{2max}, blood lactate at any time point, or HR response. Increased time to exhaustion was observed in both groups with no difference between groups. No difference was found pre- to post-study or between groups for submaximal VO_2, blood lactate, RER, RPE, or HR. The authors explained the increased time to exhaustion in both groups as a learned effect since most participants had never completed a run to exhaustion test on a treadmill before. The authors concluded that iron supplementation improved serum ferritin levels, but had no effect on improvement of endurance exercise capacity [172].

23.7 Contemporary Understanding of the Issues

Female athletes are consuming supplements for a variety of reasons:

- Health
- Inadequate diet
- Body composition
- Improved performance
- Increased "energy"

When choosing protein supplements, the athlete needs to understand the properties of protein sources: animal vs plant-based. Whey is absorbed at the fastest rate followed by soy and then casein. The quick absorption rate yields a rapid but transient increase in MPS, while a slower rate tends to mediate protein catabolism. A protein supplement utilizing a mixture of sources would be preferred. It should be noted that both whey and casein are animal-derived protein sources. If you work with a vegetarian athlete, they should be made aware of the importance of complete proteins and EAAs as some plant sources may be complete (i.e., soy), yet contain differing amount of EAAs compared to animal sources.

While there is a suggested range of caffeine (3–6 mg/kg BM) ingestion to elicit an ergogenic effect, there are no guidelines for many of the other components in energy drinks or pre-workouts. A caffeine dose of 3 mg/kg BM seems to provide ergogenic benefits without side effects. Further, most pre-workouts contain a "proprietary blend" of ingredients that do not detail specific amounts. Creatine may be a component of pre-workouts. Creatine may be less effective when consumed with caffeine; and in women, may not be as effective for increasing anaerobic power.

Echinacea is a popular supplement for boosting the immune system. Overall, it does not seem that Echinacea can prevent or shorten a cold. Echinacea supplementation has also been proposed to improve VO_{2max} through increased EPO independent of an increase in RBC count. Research suggests this may be the case in untrained male athletes, but not in trained male and female athletes. Currently, there is no data to suggest Echinacea would increase EPO or improve performance in trained female athletes.

Female athletes commonly report supplementing with multivitamins or single vitamins/minerals, such as iron. In general, supplementing individual vitamins or minerals may correct a deficiency or insufficiency, but may not confer performance benefits once the issue has been corrected. Athletes and allied health professionals should be aware that many multivitamin products on the market contain additional ingredients beyond just vitamins and minerals.

23.8 Future Directions

Historically, studies examining ergogenic aids or nutritional supplements have been conducted on males. Studies that did include both men and women typically examined untrained or recreationally trained populations. Although a growing number of studies are including women, there are still some recommendations based on male populations that need to be confirmed in females. Additionally, evidence of different patterns of response between sex needs still has yet to be demonstrated.

It has only been relatively recent (~within the last 10 years) that studies examining protein supplementation have specifically aimed at the effects on female participants. Currently, the literature suggests that the amount of protein (g/kg BM) necessary to optimize MPS is almost identical, with negligible differences between sexes. The same could be said for creatine, when considering the dose-response effect in relative value to BM or fat-free mass. Future research should continue to focus on the female population to confirm current recommendations and support any potential sex differences.

Regarding caffeine, one study suggested men and women respond similarly to caffeine. While there is a suggested range of caffeine to elicit an ergogenic effect, there are no specific guidelines for many of the other components in energy drinks or pre-workouts. Further, most pre-workouts contain a "proprietary blend" of ingredients that do not detail specific amounts. Manufacturers of supplements are increasingly producing pre-workouts geared towards females.

Future research regarding ergogenic/nutritional supplements should focus on the female population, particularly active/athletic populations as this is a gray area in research. Making decisions on doses for females based on male data may not be ideal for the female athlete to maximize athletic gains, due to fluctuations in sex hormones in different phases of the menstrual cycle. For an in-depth understanding of how to take menstrual cycle fluctuations into consideration for research on female subjects, we direct the reader to a recent review by Janse De Jonge et al. [173].

23.9 Concluding Remarks

It is of the utmost importance that allied health professionals and coaches who work with female athletes be familiar with the ergogenic aids female athletes are likely to use and the products that may contain them. Athletes will be more inclined to discuss supplements and seek your advice if you address them with an open mind and explain the pros and cons. Many athletes list family and other athletes as major sources of information on supplements [2]. Herbold et al. [3] reported that family was the first source athletes went to regarding supplements (53%). Other sources of information included friends (24.6%), physicians (18.7%), coaches (10.5%), and nutritionist (8.2%) [3].

When surveyed, athletes indicated they do not use a certain supplement and usually list a product containing it under the "other" category [2]. This demonstrates that athletes lack knowledge about supplements, regulations, and how to read labels.

Finally, a supplement may be legal for OTC sales but illegal in certain competitions, or a supplement may be contaminated with substances not listed on the label. It is also important that the athletes know they are responsible for what they put in their bodies whether or not it is on the label and could result in a failed drug test.

A systematic review regarding supplement contamination from studies between 2000 and 2017 found reports of contamination rates to be between 12 and 58% for the supplements tested. The most common category of banned substances reported were prohormones/anabolic steroids/stimulants. In some instances, researchers reported testing urine samples after consumption of contaminated products yielding high enough levels of banned substances to result in a positive drug test by WADA guidelines [174].

An independent lab tested 67 common supplements on store shelves in Australia. Roughly 1 in 5 products (19%) tested positive for banned substances with anabolic steroids (AS) and stimulants being the most common categories observed. Powders and capsules were the most prevalent form of products testing positive. Weight management and prework products comprise the most common functional category to test positive [175].

Contamination has been found in products from many different countries. This may be due to lack of cleaning on the production line between manufacturing prohormones and nutritional supplements (i.e., vitamins, minerals, proteins, creatine). It may also be due to cross-contamination from shipping containers of raw materials. Some supplements available are "faked" supplements (steroids not listed on the label or given fake names) intentionally produced with high amounts of AS normally available by prescription. The same manufacturers of "faked" supplements may also manufacture other nutritional supplements again leading to contamination. Anabolic steroids present in contaminated substances have been found to contain metandienone, stanozolol, boldenone, oxandrolone, dehydrochloromethyltestosterone, and clenbuterol. Even some supplements marketed for weight loss have been found to contain clenbuterol. In as little as 3 h after ingestion of a clenbuterol-contaminated weight-loss product, clenbuterol was detectable in the urine (2 ng/mL) [176].

Aside from the risk of testing positive for AS from unintentional ingestion, the female athlete should also be aware of female-specific physiological changes a woman may experience from steroid use. The most notable effects of AS on women are the virilizing effects: hirsutism, voice deepening, male-pattern baldness, and enlargement of the clitoris. Females may also experience menstrual irregularities and reduced breast size [7, 177]. Some of these adverse effects are irreversible.

The cardiovascular system is also adversely affected by steroid use. Blood pressure increases have been associated with AS usage [115, 177]. Left ventricular hypertrophy (LVH) has also been indicated as a side effect [115]. Decreased high-density lipoprotein (HDL) is also associated with steroid usage, although not all studies have reported decreased HDL [7, 115, 117, 177]. Other adverse effects include hepatic abnormalities, dermatological problems, and psychological effects such as aggressive behavior and mood swings [7, 115, 117, 177].

This is not to say all supplements are contaminated or all manufacturers are involved in cross-contaminating production. It is meant to bring attention to the fact that supplements are not subject to the same labeling rules as prescriptions and that one should do considerable research when deciding if a supplement is necessary and, if so, what manufacturer makes a product that one can feel comfortable that what the label says are the ingredients that are actually present. An IOC consensus statement with two decision trees regarding supplementation decisions may be of assistance to address these issues [178]. For complete information from the decision trees, the reader is directed to review the IOC consensus statement. Some important questions to address regarding whether to use a supplement are as follows:

Is it to correct a nutritional deficiency or insufficiency?

- Has a deficiency or insufficiency been identified by an RD or MD?
- Could this be corrected by a diet modification?
- Is there published evidence from quality research to suggest a supplement would correct the issue?
- Did the supplement correct the issue? If so, can I quit taking it? If not, should I continue taking it?

Is it to enhance performance?

- Has my training reached a level where supplementation would provide enhanced performance?
- Is there published evidence from quality research to suggest the supplement would improve performance in my event?
- Are there adverse effects that would outweigh the benefits of performance enhancement?
- Is there a reliable source for this supplement to minimize contamination?
- Is it possible this supplement could yield a positive drug test?

The allied health team should be aware of the regulations regarding banned substances for the governing body of athletes such as International Olympic Committee (IOC), WADA, and/or the NCAA. The list of banned substances from each organization is updated every year and as such, amounts or substances may change with each update. It is imperative for the athletes to understand that they are responsible for what they ingest and where to find the list of banned substances for their organization. The team may also want to access http://www.naturaldatabase.com [179]. The Natural Medicines Comprehensive Database is a good resource for evidence-based information on nutritional supplements that is not biased from advertising sponsorship.

Chapter Review Questions

1. What is the currently recommended daily range, in g/kg of body mass, for protein intake in female athletes?
   (a) 0.1–0.8 g
   (b) 1.2–2.0 g
   (c) 5 g
   (d) 1 g

2. Which of the following protein supplements is more effective to stimulate protein synthesis under exercise conditions?
   (a) Whey
   (b) Caesin
   (c) Soy
   (d) They are all equal in protein synthesis rate during exercise
3. What is an appropriate amount of high-quality protein for the post-workout intake
   (a) No protein intake is recommended post-workout
   (b) Less than 100 mg/kg
   (c) Between 240 and ~400 mg/kg
4. The central fatigue hypothesis states that low blood concentrations of BCAAs:
   (a) Increase glycogen restoration
   (b) Increase production of 5-HTP
   (c) Reduce production of 6-HTP
   (d) Decrease the amount of tryptophan entering the brain
5. Arginine is a conditional EAA synthesized from:
   (a) Ornithine
   (b) Citruline
   (c) Glutamine
   (d) Both A and B
6. The recommended dosage of L-carnitine per day is:
   (a) >4 g/day
   (b) 630 g/day
   (c) 2–3.5 g/day
   (d) 15 g/day
7. Which of the following statements is true about Ginseng?
   (a) All forms have been equally as effective improving performance
   (b) 8 weeks of supplementation with Chinese ginseng improved Wingate performance
   (c) Siberian ginseng is more effective at improving VO_{2max}
   (d) Results are equivocal regarding ginseng performance improvements
8. Echinacea has been reported to:
   (a) Improve immune system function
   (b) Enhance protein synthesis at rest
   (c) Enhance VO_{2max}
   (d) Both A and C
9. Supplementation of Iron in iron deficient, non-anemic female athletes resulted in:
   (a) Correction of the deficiency
   (b) Improved performance
   (c) Both A and B
   (d) None of the above
10. Adverse effects of anabolic steroid use may include:
   (a) Decreased HDL
   (b) Enlargement of the clitoris
   (c) Muscle hypertrophy
   (d) Both A and B

Answers

1. b
2. a
3. c
4. b
5. d
6. c
7. d
8. c
9. a
10. d

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Part V

Exercise Guidelines and Precautions for Active Females Throughout the Lifespan

Screening for Safe Exercise Participation and Exercise Guidelines for Health-Related Fitness

24

Audra R. Day and Jacalyn J. Robert-McComb

Learning Objectives
After completing this chapter, you should understand:

- The physical activity objectives for health from Health People 2020.
- The current standards for completing a pre-exercise screen including indications for referral to a health care professional prior to initiating exercise.
- The recommendations for health-related fitness from leading health organizations for cardiorespiratory fitness, muscular fitness, healthy body composition, and flexibility.
- Methods used to determine exercise intensity.
- The FITT principle (frequency, intensity, time, type) for exercise programming to maximize health-related fitness in apparently healthy females across the lifespan.

24.1 Introduction

Why is physical activity important? Since the late 1990s, national government agencies have collected data and made recommendations regarding the benefits of physical activity beginning with the initial Surgeon General's Report (SGR) on Physical Activity and Health [1]. It was apparent with these early studies that there was a correlation between physical activity and decreased disease and death rates among all persons. Additionally, these reports showed that generally women were less active than men and this difference became more pronounced after 75 years of age. Recent studies demonstrate that although the national average for adults being active has improved somewhat, women remain 1.4 times less active than their male counterparts across the lifespan [2]. This same study showed obesity rates for adult women to be 4% higher than adult men and major depressive disorders in adolescent females is 13% higher than adolescent males [2]. So, although much attention has been focused on the importance of physical activity, women remain less likely to become active which can result in profound loss of physical and mental wellbeing.

These new data beg the question why are women less active than men, but more importantly how can exercise professionals and health care providers improve this disparity? First, it is essential to remove barriers to begin exercise while simultaneously guarding against unsafe exercise practices. Second, it is necessary to provide sound guidelines for cardiorespiratory (aerobic) training, strength training, and flexibility exercise to transmit the necessary physiological benefits. Lastly, we must work through appropriate goal setting to maintain motivation and sustain exercise so that it improves health-related fitness for all women.

24.2 Current Research Findings and Objectives

What evidence exists to support the positive effects of exercise? In 2018, the U.S. Department of Health and Human Services (HHS) in collaboration with the Centers for Disease Control (CDC) and Prevention, the National Institutes of Health (NIH), and the President's Council on Sports, Fitness & Nutrition released a second edition of Physical Activity Guidelines (PAG) in 2018 based on a systematic review of the scientific literature on physical activity and health [3]. This in-depth review provided continued evidence supporting the disease prevention benefits of exercise, stating that these positive effects are almost immediate and long lasting. Furthermore, there were multiple studies supporting improved quality of life, sleep, and cognitive function with increased physical activity. One major change included in this edition is that very short duration (<10 min) activity elicits positive health benefits including improved insulin sensitivity and decreased blood pressure.

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Table 24.1 Selected Healthy People 2020 physical activity objectives: a verbatim sample from Healthy People 2020. Sample from Healthy People 2020. For a complete list of objectives see Healthy People 2020, US Department of Health and Human Services, Office of Disease Prevention and Health Promotion, https://www.healthypeople.gov/2020/topics-objectives/topic/physical-activity/objectives [4]

• Reduce the proportion of adults who engage in no leisure-time physical activity
• Increase the proportion of adults who engage in aerobic physical activity of at least moderate intensity for at least 150 min·week^{-1}, or 75 min·week^{-1} of vigorous intensity, or an equivalent combination
• Increase the proportion of adults who engage in aerobic physical activity of at least moderate intensity for more than 300 min·week^{-1}, or more than 150 min·week^{-1} of vigorous intensity, or an equivalent combination
• Increase the proportion of adults who perform muscle-strengthening activities on 2 or more d of the week
• Increase the proportion of adolescents who meet current Federal physical activity guidelines for aerobic physical activity and for muscle-strengthening activity
• Increase the proportion of children and adolescents who do not exceed recommended limits for screen time
• Increase the proportion of the Nation's public and private schools that require daily physical education for all students
• Increase the number of States with licensing regulations for physical activity provided in childcare
• Increase the number of States with licensing regulations for physical activity in childcare that require children to engage in vigorous or moderate physical activity
• Increase the proportion of trips made by walking
• Increase the proportion of trips made by bicycling
• Increase the proportion of office visits made by patients with a diagnosis of cardiovascular disease, diabetes, or hyperlipidemia that include counseling or education related to exercise
• Increase the proportion of physician visits made by all child and adult patients that include counseling about exercise
• Increase the proportion of employed adults who have access to and participate in employer-based exercise facilities and exercise programs

The initiatives by leading governing agencies to increase the level of physical activity in all Americans reflect the importance of being physically active for long-term good health for all ages and both sexes, *especially young girls and women*. Healthy People 2020 [4] defines physical activity as "participation in moderate and vigorous physical activities and muscle-strengthening activities." Like the CDC and NIH, Healthy People 2020 provides multiple studies supporting the positive benefits of well-designed exercise programming on adults (healthy and those with chronic disease), children, and adolescents. This agency validates the ability of exercise to lower the incidence of premature death, coronary artery disease, hypertension, type 2 diabetes, and cancer (breast and colon). Healthy People 2020 also describes studies where physical activity improved bone health, symptoms of depression, cardiorespiratory, and muscular fitness. Based on the wealth of research evidence supporting the benefits of exercise, Health People 2020 developed several physical activity objectives (See Table 24.1).

24.3 Physical Activity Recommendations for Health-Related Fitness from Leading Health Organizations

What are the general recommendations for physical activity? The Physical Activity Guidelines for Americans (PAG) 2nd edition [5] provided seven key focus areas related to physical activity: preschool-aged children; children and adolescents; adults; older adults; women during pregnancy and the postpartum period; adults with chronic health conditions and disabilities; and safe physical activity. Regardless of the age range, health, or disability because women remain substantially less active than men, it is imperative for exercise and health care professionals to target this population and encourage all females to become more physically active (Table 24.2).

24.3.1 Review of Current Standards

Prior to 2014, the primary mechanism used to identify individuals in need of medical clearance before beginning an exercise program or administration of an exercise test

Table 24.2 Physical activity guidelines for Americans 2nd edition summary [5–7]

Target population	Summary of activity recommendations for health-related benefits
Preschool-aged children (3–5 y)	Physically active throughout the d
Children and adolescents (6–17 y)	60 min/d of moderate-vigorous intensity (should include aerobic, muscle-strengthening, and bone-strengthening activities)
Adults	150–300 min/week of moderate intensity or 75–150 min/week vigorous intensity physical activity including aerobic activities spread throughout the week and muscle-strengthening activities 2 d/week
Older adults	Same as for adults. Include balance training. Effort should be relative to fitness level
Women during pregnancy and postpartum	150 min/week of moderate intensity aerobic activity spread throughout the week
Adults with chronic health conditions and/or disabilities	Same as for adults or according to their disease limitations but avoid inactivity
All individuals	Reduce the risk of injury and adverse events during exercise

Note: The American Heart Association (AHA) recommends 150 min/week of moderate or 75 min/week of vigorous intensity exercise to improve overall cardiovascular health and for lowering blood pressure; 40 min of moderate—vigorous intensity activities 3–4 times/week [6]. Importantly, like the PAG, the AHA encourages starting small and that any physical activity is better than nothing at all. Finally, the American College of Obstetrics and Gynecology (ACOG) recommends for pregnant and postpartum women to participate in at least 150 min/week of moderate intensity aerobic exercise adjusted as medically indicated [7]

centered on a complex risk stratification process. This system was based on the presence of cardiovascular disease (CVD) risk factors, signs or symptoms of diseases (cardiovascular/pulmonary/metabolic), and diagnoses related to these same disease categories. In the past, it was postulated that this method effectively selected persons who were at greatest risk of death due to a sudden cardiac event or death during exercise. Although risk stratification had a sound purpose, recent reports [8] identified weaknesses that needed to be addressed including: excessive medical referrals in the elderly (≥60 years), "high risk" individuals did not receive uniform recommendations for exercise testing, lack of evidence supporting that exercise testing in asymptomatic adults reduced risk of morbidity and mortality, and data did not substantiate that the presence of pulmonary disease increased cardiovascular complications after exercise. Due to these issues, the current exercise preparticipation screening system eliminates the consideration of CVD risk factors and known pulmonary diseases as a flag for individuals who need a medical referral prior to exercising. Additionally, it functions to simplify the exercise preparticipation screening process while reducing the emphasis on medical evaluations for healthy individuals and simultaneously identifying persons with known high-risk diagnoses or symptomatology.

An additional important change to note is the inclusion of High Intensity Interval Training (HITT) as an alternative to the traditional 30-min of moderate intensity aerobic exercise as defined 40–59% of heart rate reserve (HRR). HIIT is defined as interval training that consists of alternating short periods of maximal-effort exercise with less intense active recovery periods. It is typically done with a 2:1 work to rest ratio. Healthy adult subjects who participated in HITT showed improved insulin sensitivity, blood pressure, and body composition. Additionally, adults with overweight or obesity and type 2 diabetes had greater gains in these areas when doing HIIT compared to normal-weight or healthy adults [9]. This training regime will be revisited and discussed more thoroughly later in this chapter.

In the past, much focus has been placed on the 30-min time goal per session for aerobic exercise. For individuals who have never participated in physical activity and lead a completely sedentary lifestyle, that standard could be seen for some as unobtainable. So, a new viewpoint has developed regarding the aerobic exercise time requirement and is embodied in the phrase "anything is better than nothing". This idea targets sedentary individuals and allows them to develop attainable short-term goals with aerobic exercise bouts even less than 10 min [10]. It has been well-documented that a significant reduction in all-cause mortality is attained with moderate (40–59% of HRR) to vigorous intensity (60–89% of HRR) activity lasting 10 min. However, it has been validated that beginning the process of physical activity is more important to initiate lifestyle modifications and target disease reduction. Research shows that short duration exercise times, less than 10 min, improve resting blood pressure, blood lipids, C-reactive protein, and fasting blood glucose [10]. These results underpin the importance of designing exercise programs that will decrease CVD risks while simultaneously improving adherence to aerobic exercise.

Due to the increasing prevalence of obesity in young children, prevention practices have become an important public health priority in economically developed nations [11]. A recent systematic review found that there is strong evidence that higher amounts of physical activity are associated with better weight- and adiposity-related outcomes in 3- to 5-year old children [12]. In the past, only limited information concerning this age group has been available. The specifics of the recommendations for preschool age children emphasize they should be physically active throughout the day and minimize prolonged sitting. Caregivers should encourage activities including tricycle or bicycle riding and games that include catching, throwing, or kicking [4].

24.4 Safe and Effective Exercise for Health-Related Benefits

Based on the general exercise recommendations from multiple health organizations and the well-established relationship to improved health and fitness, the following sections will provide practical details regarding developing quality exercise programs for women. These key elements include: (1) how to screen for high-risk individuals; (2) determining moderate versus vigorous intensity exercise; (3) aerobic, muscle strengthening, and flexibility exercises; and (4) exercise programming for health benefits.

24.4.1 The Pre-exercise Screening Process

What can be done to remove barriers for safe exercise participation while minimizing adverse effects? No evidence is available to indicate that people who consult with their health care provider receive more benefits and suffer fewer adverse events than people who do not. People without diagnosed chronic conditions and who do not have symptoms of cardiovascular, musculoskeletal, or metabolic diseases most likely do not need to consult with a health care provider about physical activity. However, those individuals with chronic conditions and symptoms can consult a health care professional or physical activity specialist about the types and amounts of activity appropriate for them.

So how can these individuals be identified? In 2014, The American College of Sports Medicine (ACSM) developed a new screening algorithm (Fig. 24.1) to identify individuals who are at the highest risk for experiencing an acute

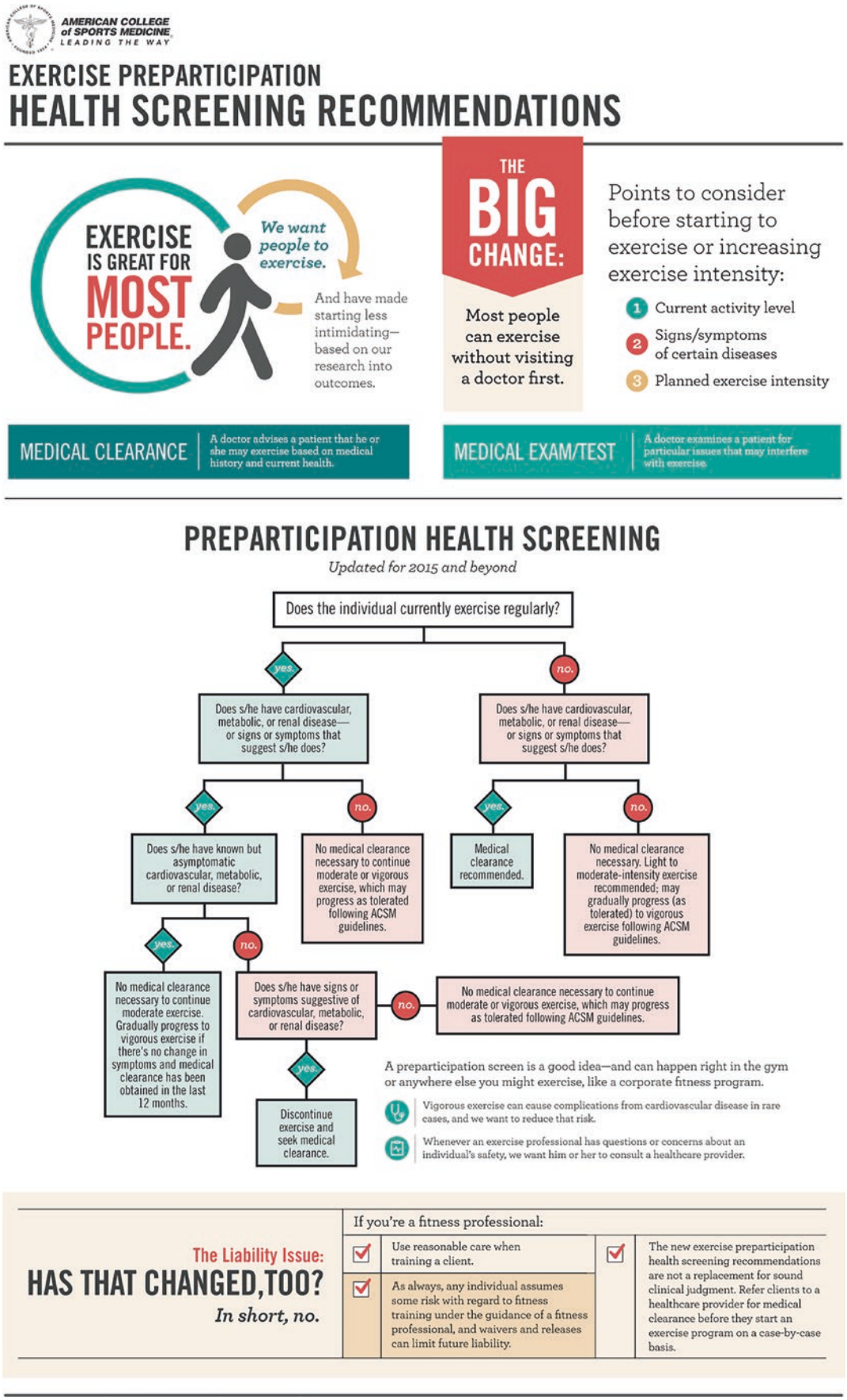

Fig. 24.1 American College of Sports Medicine Exercise Preparticipation Screening Algorithm Infographic [13]. (Reprinted with permission from The American College of Sports Medicine)

myocardial infarction or sudden cardiac death during exercise while minimizing the barriers for beginning an exercise program [13]. This exercise preparticipation screening revision excludes the use of cardiovascular risk factors as the primary source for physician referrals and exercise testing, but continues to use them for education concerning lifestyle modification. Additionally, the ACSM adopted a revised version of the PAR-Q+, a self-administered preparticipation questionnaire to help identify individuals that may warrant further medical evaluation [14, 15]. The 2021 PAR-Q+ can be found in Appendix 1 and can be downloaded at www.eparmedx.com free of charge [16].

The algorithm or the PAR-Q+ can be used to identify high-risk individuals who should not participate in exercise or have limits on their exercise intensity until evaluated by health-care provider who can provide detailed medical clearance.

The ACSM algorithm uses current activity level; physical symptoms associated with cardiovascular, metabolic, or renal diseases; known medical conditions; and desired exercise intensity to determine readiness for safe exercise. While the PAR-Q+ does not use current activity level, the tool screens for any medical conditions would suggest that you seek medical advice before beginning an exercise program: Both screening methods have found to be effective and time efficient. According to the ACSM algorithm, non-exercising healthy individuals lacking signs/symptoms of disease can immediately begin light-moderate exercise program without medical clearance. Non-exercising individuals with diagnosed cardiovascular, metabolic, or renal disease but who are asymptomatic should obtain medical clearance prior to beginning an exercise program. Non-exercising individuals with symptoms of CVD should seek medical clearance regardless of prior disease history. Regular exercisers with no history, signs, or symptoms of disease can continue to exercise and progress exercise. Regular exercisers with known cardiac metabolic or renal medical conditions who have no "new" symptoms may continue moderate intensity exercise, but should obtain clearance prior to progression to vigorous intensity exercise. Regular exercisers with no known medical conditions but with physical symptoms of CVD should stop exercising and immediately obtain medical clearance. In summary, this method of screening focuses on identifying sedentary individuals with diagnosed disease or symptoms of disease, which place them at very high risk for life-threating events during a single session of vigorous intensity exercise.

After completing a basic health questionnaire or preparticipation interview, it is essential to measure resting blood pressure. Once obtained, the values should be compared to American Heart Association (AHA) standards [17]. Those individuals whose systolic pressure is above 130 mmHg or diastolic pressure above 80 mmHg should be referred to their health care provider for further evaluation and treatment, but can begin exercise. However, if the systolic pressure is above 180 mmHg and/or diastolic pressure is above 120 mmHg, the individual should seek medical attention immediately prior to exercising (Table 24.3).

Table 24.3 Blood pressure categories based on systolic and/or diastolic pressures [17]

Current standard blood pressure categories (2017)			
Category	Systolic (mmHg)	and/or	Diastolic (mmHg)
Normal	Below 120	and	Below 80
Elevated	120–129	and	80 or below
Hypertension stage 1	130–139	or	80–89
Hypertension stage 2	140 or higher	or	90 or higher
Hypertension stage 3	180 or higher	and/or	120 or higher

Once it is determined that it is safe to move forward with exercise, *what are the parameters that should be considered to improve health and wellness*?

24.4.2 The Difference Between Moderate Physical Activity, Vigorous Physical Activity, Exercise and Physical Activity, Health-Related Physical Fitness, and Sports-Related Fitness

According to Ainsworth and colleagues, moderate-intensity physical activity refers to any activity that burns 3.5–7 kilocalorie per min (kcal/min) [18] or 3.5–5 metabolic equivalent of task (MET) [19]. One MET is the oxygen cost of an individual at rest or MET = 1 kcal/kg/h. METs are used because it is an easy way to represent energy expenditure. If someone is working at a 5 MET level, they are working five times above their resting state. The ACSM defines moderate exercise intensity as 40–59% of oxygen uptake reserve (VO_2R) or heart rate reserve (HHR) [13]. In the 1996 Surgeon General's Report [1], moderate exercise was defined as some increase in breathing or heart rate (HR) or a "perceived exertion" of 12–14 on the Borg Rate of Perceived Exertion (RPE) scale [20, 21]. These levels are equal to the effort a healthy individual might burn while walking at a 3–4.5 miles per hour (mph) pace on a level surface, playing golf, gardening and yard work, swimming for recreation, or bicycling [13]. METs corresponding to moderate and vigorous activity can be found in Table 24.4. Since the methods to prescribe intensity (HRR, VO_2R, and HR_{max}) are a little more complicated, these methods are presented in the section, The American College of Sports Medicine's Exercise Recommendations for Cardiorespiratory Fitness, in this chapter.

Ainsworth et al. defined vigorous-intensity physical activity as any activity that burns more than 7 kcal/min kcal/min [18] or equal to 6 METs [19]. The ACSM [13] refers to vigorous exercise as 60–89% of VO_2 R or HHR. In the 1996

Table 24.4 Metabolic equivalents of task (MET) values for physical activity levels [22]

Physical activity intensity	MET
Light intensity activities	<3
Sleeping	0.9
Watching television	1.0
Writing, desk work, typing	1.8
Walking, 1.7 mph (2.7 km/h), level ground, strolling, very slow	2.3
Walking, 2.5 mph (4 km/h)	2.9
Moderate intensity activities	3–6
Bicycling, stationary, 50 W, very light effort	3.0
Walking 3.0 mph (4.8 km/h)	3.3
Calisthenics, home exercise, light or moderate effort, general	3.5
Walking 3.4 mph (5.5 km/h)	3.6
Bicycling, <10 mph (16 km/h), leisure, to work or for pleasure	4.0
Bicycling, stationary, 100 W, light effort	5.5
Vigorous intensity activities	>6
Jogging, general	7.0
Calisthenics (e.g., push-ups, sit-ups, pull-ups, jumping jacks), heavy, vigorous effort	8.0
Running jogging, in place	8.0
Rope jumping	10.0

Note: 1 MET = 1 kcal kg^{-1} h^{-1} or 1 MET = 3.5 mL kg^{-1} min^{-1} of O_2

Surgeon General's Report [1], vigorous exercise was defined as a large increase in breathing or HR (conversation is difficult or "broken") or a "perceived exertion" of 15 or greater on the Borg RPE scale. These levels are equal to the effort a healthy individual might burn race walking or walking at a 5-mph pace, engaging in heavy yard work, participating in high-impact aerobic dancing, swimming continuous laps, scuba diving, or bicycling uphill [13]. Additional examples of general physical activities that meet the guidelines established by the Centers for Disease Control and Prevention (CDC) and the ACSM for moderate activity (3.0–5.9 METs or 3.5–7 kcal/min) and vigorous activity (more than 6.0 METs or greater than 7 kcal/min) can also be found at the CDC via: http://www.cdc.gov/nccdphp/dnpa/physical/recommendations/adults.htm [22] or The Compendium of Physical Activities via: https://sites.google.com/site/compendiumofphysicalactivities/home [23].

A useful subjective measure of exercise intensity, described above, can be obtained by the client rating their perception of exertion during physical activity or exercise. This feeling should reflect how heavy and strenuous the exercise feels to them, combining all sensations and feelings of physical stress, effort, and fatigue. They should not concern themselves with any one factor such as leg pain or shortness of breath, but they should try to focus on their total feeling of exertion. They should choose the number that best describes their level of exertion. This will give them a good idea of the intensity level of their activity. *Moderate exercise* is defined as a "perceived exertion" of **12–14**. *Vigorous exercise* is defined as a "perceived exertion" of **15 or greater**. The *average RPE* range associated with *physiologic adaptation* is **12–16**. However, there is significant interindividual variability; **9** corresponds to "very light" exercise, for a healthy person, it is like walking slowly at his or her own pace; **13** on the scale is "somewhat hard" exercise, but it still feels okay to continue; **17** "very hard" is very strenuous, a healthy person really has to push himself or herself and will probably feel very tired; **19** on the scale is an extremely strenuous exercise level; for most people, this is the most strenuous exercise they have ever experienced [20, 21]. The Borg scale can be found in Fig. 24.2 [20]. The scale and full instruction can be obtained through BorgPerception www.borgperception.se [20]. More information about this scale and discussion about the meaning of the scale can be found at the Centers of Disease Control and Prevention at https://www.cdc.gov/physicalactivity/basics/measuring/exertion.htm [21].

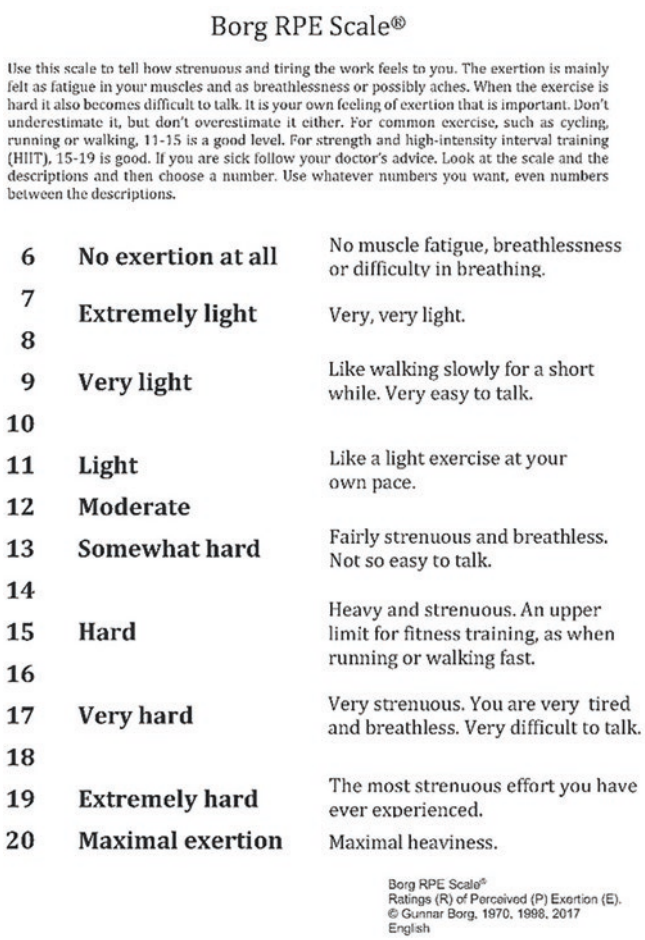

Fig. 24.2 Determining Moderate and Vigorous Exercise Intensity Using The Borg RPE scale (R). The Borg RPE scale (R) ((C) Gunnar Borg, 1970, 1998, 2017). Scale printed with permission from Borg. The scale and full instruction can be obtained through BorgPerception www.borgperception.se [20]

Table 24.4 highlights the MET cost of general activities from the compendium of physical activities. These MET examples refer to adults primarily, although METS can be used to describe intensity for children also.

What is the difference between *physical activity* and *exercise*? The United States Department of Health and Human Services refers to *physical activity* as bodily movement that is produced by the contraction of skeletal muscle that substantially increases energy expenditure [1], whereas *exercise* is a type of physical activity that represents structured, planned activities, and repetitive bodily movement, designed to maintain or enhance overall physical fitness [13].

Both physical activity and exercise contribute to increases in physical fitness. *Physical fitness* is a multidimensional concept that has been defined as a set of attributes that people possess or achieve that relates to the ability to perform physical activity [13]. There are skill-related components of physical fitness (also known as sports-related forms of physical fitness) and health-related components of physical fitness. *Skill-related components of physical fitness* include balance, agility, coordination, speed, power, and reaction time. These components are associated mostly with sport performance. *Health-related components of physical fitness* include cardiovascular endurance, muscular strength and endurance, flexibility, and body composition. The focus of this chapter is on the health-related components of physical fitness.

24.4.3 The American College of Sports Medicine's Exercise Recommendations for Cardiorespiratory Fitness

24.4.3.1 Adults

Aerobic fitness, or CR fitness refers "to the ability to perform large muscle, dynamic, moderate-to-high intensity exercise for prolonged periods." The terms, CR fitness, VO_{2max}, aerobic capacity, and aerobic fitness, are used synonymously. CR fitness is defined as the ability of the body to engage in physical activity in which oxygen consumption is relied on as the primary energy source [13]. These terms refer to the maximal capacity to produce energy aerobically and are usually expressed in METs or mL $O_2 \cdot kg^{-1} \cdot min^{-1}$. One MET (metabolic equivalent unit) is equal to approximately 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$. Improvements in the ability of the heart to deliver oxygen to the working muscles and in the muscle's ability to generate energy aerobically result in increased CR fitness [13].

Exercise recommendations must consider the fitness level of the individual. Individuals with low level of fitness generally demonstrate the greatest improvements in CR fitness, whereas modest increases occur in healthy individuals and in those with high initial fitness levels [13]. Exercise recommendations to improve CR fitness include four components, frequency, intensity, time, and type, also known as the FITT (frequency, intensity, time, and type) principles. The format for an exercise session should include a warm-up period (approximately 5–10 min), a stimulus or conditioning phase (20–60 min), and a cool-down period (5–10 min). Table 24.5 demonstrates the recommendations for continuous exercise proposed by the ACSM to improve and maintain CR fitness

Table 24.5 American College of Sports Medicine's training guidelines for cardiorespiratory fitness [13]

Frequency
3–5 days·week^{-1}
Intensity
Method 1
Determining intensity using the HRmax method
(Moderate intensity = 64–76%; vigorous intensity = 77–95% of maximum heart rate)
Moderate intensity: 64–76% of maximum heart rate (HR_{max}) for a 20-y-old
HR_{max} = 207 − (0.7 × age in y) = _____bpm
Target heart rate = HR_{max} (64–76%)
i.e., HR_{max} = 207 − (0.7 × 20) = 193
HR_{max} = 193
Target heart rate = 193 × (0.64–0.76)
Target heart rate may range from **124 to 148 beats min^{-1}**
Vigorous intensity: 77–95% of maximum heart rate (HR_{max}) for a 20-year-old
HR_{max} = 207 − (0.7 × age in y) = _____bpm
Target heart rate = HR_{max} (77–95%)
i.e., HR_{max} = 207 − (0.7 × 20) = 193
HR_{max} = 193
Target heart rate = 193 × (0.77–0.95)
Target heart rate may range from **149 to 183 beats min^{-1}**
Method 2
Determining intensity using the HRR method
(Moderate intensity = 40–59%; vigorous intensity = 60–89% of heart rate reserve)
Moderate intensity: 40–59% of heart rate reserve (HRR) for a 40-year-old with a resting HR of 60 beats min^{-1}
HRR = HR_{max} [207 − (0.7 × age in y)] − resting heart rate
Target heart rate = [(HRR) (exercise intensity)] + resting heart rate
i.e., target heart rate
=HR_{max} = 207 − (0.7 × 40) = 179
=HRR = 179 − 60 = 119
=[(HRR) (exercise intensity)] + resting heart rate
=[(119 × (0.40 × 0.59)] + 60
=108–130 beats min^{-1} is your training heart rate range
Vigorous intensity: 60–89% of heart rate reserve (HRR) for a 40-y-old with a resting HR of 60 beats min^{-1}
HRR = HR_{max} [207 − (0.7 × age in y)] − resting heart rate
Target heart rate = [(HRR) (exercise intensity)] + resting heart rate
i.e., Target heart rate
=HR_{max} = 207 − (0.7 × 40) = 179
=HRR = 179 − 60 = 119
=[(HRR) (exercise intensity)] + resting heart rate
=[(119 × (0.60 − 0.89)] + 60
=131–166 beats min^{-1} is your training heart rate range

(continued)

Table 24.5 (continued)

Method 3 Determining intensity using the VO2R method **(Moderate intensity = 40–59%; vigorous intensity = 60–89% of oxygen uptake reserve)**
$VO_2R = VO_{2max} - VO_{2rest}$ (VO_{2max} $mL \cdot kg^{-1} \cdot min^{-1} - 3.5\ mL \cdot kg^{-1} \cdot min^{-1}$)
Target VO_2 $mL \cdot kg^{-1} \cdot min^{-1} = [(VO_2R)$ (exercise intensity)$] + VO_{2rest}$
i.e., Target VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$ for a person with VO_{2max} of 40 $mL \cdot kg^{-1} \cdot min^{-1}$
Moderate intensity 40–59% of oxygen uptake reserve (VO_2R)
$=[(40\ mL \cdot kg^{-1} \cdot min^{-1} - 3.5\ mL \cdot kg^{-1} \cdot min^{-1})$ (40–59%)$] + 3.5\ mL \cdot kg^{-1} \cdot min^{-1}$
$=[(36.5\ mL \cdot kg^{-1} \cdot min^{-1})$ (40%)$] + 3.5\ mL \cdot kg^{-1} \cdot min^{-1}$ (example)
$=18.1\ mL \cdot kg^{-1} \cdot min^{-1}$ $=[(36.5\ mL \cdot kg^{-1} \cdot min^{-1})$ (59%)$] + 3.5\ mL \cdot kg^{-1} \cdot min^{-1}$ (example) $=25\ mL \cdot kg^{-1} \cdot min^{-1}$ Target VO_2R for moderate exercise = 18.1–25 $mL \cdot kg^{-1} \cdot min^{-1}$
Vigorous intensity 60% to 89% of oxygen uptake reserve (VO_2R)
$=[(40\ mL \cdot kg^{-1} \cdot min^{-1} - 3.5\ mL \cdot kg^{-1} \cdot min^{-1})$ (60–89%)$] + 3.5\ mL \cdot kg^{-1} \cdot min^{-1}$
$=[(36.5\ mL \cdot kg^{-1} \cdot min^{-1})$ (60%)$] + 3.5\ mL \cdot kg^{-1} \cdot min^{-1}$ (example) $=25.4\ mL \cdot kg^{-1} \cdot min^{-1}$ $=[(36.5\ mL \cdot kg^{-1} \cdot min^{-1})$ (89%)$] + 3.5\ mL \cdot kg^{-1} \cdot min^{-1}$ (example) $=35.9\ mL \cdot kg^{-1} \cdot min^{-1}$ Target VO_2R for vigorous exercise = 25.4–35.9 $mL \cdot kg^{-1} \cdot min^{-1}$
Time 20–60 min of continuous aerobic activity. Duration is dependent on the intensity of the activity: thus, lower intensity should be conducted over a longer period of time **Type** Rhythmic and repetitive activity that uses large muscles

Note: For individuals with VO_2max below 40 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$, a minimal intensity of 30% VO2R or HRR can elicit improvements in VO_2max. In contrast, individuals with greater cardiorespiratory (CR) fitness (>40 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) require a minimal threshold of 45% VO_2R or HRR. For most individuals, intensities within the range of 60–80% of VO_2R or HRR or 70–90% HRmax are sufficient to achieve improvements in CR fitness with the appropriate duration and frequency of training

for adults using three different methods to prescribe intensity. The recommendations for intensity differ depending on the method used. The three different methods to determine intensity are: (1) *the Heart Rate maximum (HR_{max} method)*; (2) *HRR method*; and (3) *VO_2R method.* The recommendation range is broad because of the heterogeneity in a response to an exercise stimulus. The required recommendation for percentage of intensity to improve CR fitness is in parenthesis behind each method.

A training strategy mentioned earlier in this chapter that deserves more attention is High-intensity interval training (HIIT) or Sprint interval training (SIT): This type of training is also called high-intensity intermittent exercise (HIIE) by some. This is a cardiovascular exercise strategy alternating short periods of intense exercise with brief rest periods in between the intense exercise [13]. Although there is no universal HIIT session duration, these intense workouts typically last under 30 min, with times varying based on a participant's current fitness level. The intensity of HIIT also depends on the duration of the session. However, HIIT, SIT, or HIIE is not limited to only aerobic-based exercises; resistance-based interval training can also be implemented via a combination of plyometrics, resistance training, and body weight exercises. It is characterized by near maximal efforts with an intensity close to ≥80–100% peak HR [13].

Examples of protocols include: (1) a 4 × 4 protocol (4 intervals at 4 min each at 90–95% peak HR with a 3 min rest between intervals; (2) a 3 × 20 protocol consists of 3 intervals at 20 seconds (s), 90–100% peak HR with a 2 min rest between intervals; (3) resistance-based interval training includes 5 repetitions of the following 5 exercises performed back to back: alternating hammer curls; bent-over row; tricep extensions; front squat; lunge, rest 2 min and repeat as many intervals as is appropriate for the client, not to exceed 30 min. The client should choose the weight that allows them to complete the interval with a HR between 80 and100% HR. Another example of HIIT training using a spin cycle and Tabata training music is explained next. Tabata training consists of eight sets of fast-paced exercises, each performed for 20 s interspersed with a brief rest of 10 s. This 4 min training interval is then followed by a 1 min recovery period so the total time for each set is 5 min. These sets can be continued for as long as is appropriate for the population that is being trained. In a college environment with spin rooms, a typical HIIT protocol using a spin cycle and Tabata music would look like this: 10 min warm-up; 7 sets of 4 min interval training (20:10) with a 1 min recovery period in each set so the total time for each set is 5 min (7 sets × 5 min per set = 35 total min); 5 min cool-down; 10 min stretch using the bike as a prop. Total duration of the exercise session is 60 min. The authors have found interval training to be extremely popular and can be used with multiple mediums, water, land, and bike. An example of HITT training using a spin bicycle and Tabata music can be found in Table 24.6.

24.4.3.2 Children and Adolescents

Children and adolescents are defined as individuals aged 6–19 years and are also referred to as youth. For children, the emphasis is on play rather than structured exercises, yet adolescents normally engage in some type of structured activities or sports. The 2018 Physical Activity Guidelines for Americans recommends that children and adolescents should engage in at least 60 $min \cdot day^{-1}$ of moderate-to-vigorous

Table 24.6 High-intensity interval training protocol using a spin cycle and Tabata music for a 20-year-old

Time	Intensity	Revolutions per min (RPM)	Resistance	% of HRmax
10 min warm-up	Comfortable for the person	50–80 RPM	None	Not the goal during the warm up
Total time for set 1 is 5 min				
20:10 (20 s high intensity 10 s recovery)	>80–100% HR max during the 20 s decrease resistance or RPM during the recovery period	80–100 RPM	0.5–1.5 kp	[207 − (0.7 × 20)] × 0.80 − 1.0 = 154–193 bpm
Repeat 8 times total	>80–100% HR max during the 20 s decrease resistance or RPM during the recovery period	80–100 RPM	0.5–1.5 kp	[207 − (0.7 × 20)] × 0.80 − 1.0 = 154–193 bpm
1 min rest while pedaling comfortably	Comfortable for the person	50–80 RPM	None	Goal is to buffer the hydrogen ion accumulation (plasma acidity)
Total time for set 2 is 5 min				
20:10 (20 s high intensity 10 s recovery)	>80–100% HR max during the 20 s decrease resistance or RPM during the recovery period	Standing up, bottom-end off cycle seat 50–70 RPM for 20 s, sit on the cycle seat during recovery for 10 s	Have clients increase resistance so that they can maintain desired RPM and elicit desired HR	[207 − (0.7 × 20)] × 0.80–1.0 = 154–193 bpm
Repeat 8 times total	>80–100% HR max during the 20 s decrease resistance or RPM during the recovery period	Standing up, bottom-end off cycle seat 50–70 RPM for 20 s, sit on the cycle seat during recovery for 10 s	Have clients increase resistance so that they can maintain desired RPM and elicit desired HR	[207 − (0.7 × 20)] × 0.80 − 1.0 = 154–193 bpm
1 min rest while pedaling comfortably	Comfortable for the person	50–80 RPM	None	Goal is to buffer the hydrogen ions or to decrease the acidity
These 5 min sets can be continued for as long as the clients wants to work, it is recommended not to exceed 30 min max or 6 cycles	>80–100% HR max during the 20 s decrease resistance or RPM during the recovery period	80–100 RPM for sitting 50–70 RPM for standing	Client-specific increase or decrease to elicit the desired HR	
10 min Cool-down and stretch	Comfortable for the person	50–80 RPM	None	Not the goal during the warm up

Some recommend a cadence between 80 and 110 RPM for flat roads and 60 and 80 RPM for simulated hills. One common aim for outdoor cyclists is 90 RPM

Table 24.7 Society of Health and Physical Educators (SHAPE) national standards for physical activity for children. https://www.shapeamerica.org/standards/guidelines/pa-children-5-12.aspx [24]

Guideline 1: Children should accumulate at least 60 min, and up to several h, of age-appropriate physical activity on all, or most d of the week. This daily accumulation should include moderate and vigorous physical activity with the majority of the time being spent in activity that is intermittent in nature
Guideline 2: Children should participate in several bouts of physical activity lasting 15 min or more each d
Guideline 3: Children should participate each day in a variety of age-appropriate physical activities designed to achieve optimal health, wellness, fitness, and performance benefits
Guideline 4: Extended periods (periods of 2 h or more) of inactivity are discouraged for children, especially during the daytime h

intensity physical activity. Resistance exercise and bone loading activities are also recommended for at least 3 day·week^{-1} and count toward the 60 min·day^{-1} total [5]. Tables 24.7 and 24.8 highlight recommendations from the Society of Health and Physical Educators (SHAPE) [24] organizations for children and from the ACSM [13]. Although MET-based intensities for physical activity specific to youth are available [25, 26], the *2018 Physical Activity Guidelines for Americans* recommend estimating youth physical activity intensity using a perceived effort scale from 0 (sitting) to 10 (highest effort possible), with moderate intensity at a 5 or 6, and vigorous intensity starting at a 7 or 8 [5]. These guide-

Table 24.8 Physical activity recommendations for children and adolescents [5, 13]

	Frequency	Intensity	Time	Type
Aerobic	Daily *Note: At least 3 d per week at vigorous intensity*	Moderate (*noticeable increase in heart and breathing rates*) to vigorous (*considerable increase in heart and breathing rates*)	Most of the 60 min per d	Developmentally suitable activities *Moderate intensity*: Walking, skipping, bicycle or tricycle riding, throwing/catching activities (baseball or softball), house/yard work, (sweeping, raking, pushing a lawn mower) *Vigorous intensity*: Running, bicycle or tricycle riding (higher speeds), sport/game activities (tag, jump rope, gymnastics, swimming, tennis, football, soccer), vigorous dancing
Muscle strengthening	At least 3 d each week	Body weighted 1–2 sets 8–15 repetitions to the point of moderate fatigue	As part of the 60 min each d	Climbing (playground equipment, trees, ropes) gymnastics, resistance exercises[a] (body weight, resistance bands, weight machines, handheld weights)
Bone strengthening	At least 3 d each week	Forces that trigger impact with the ground resulting in bone loading	As part of the 60 min each d	Hopping, skipping, jumping, running, sports that require rapid change in direction (soccer, tennis, basketball)

[a] Resistance exercises using equipment should only be utilized in adolescents

lines can be downloaded as a PDF at no cost at, https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf [5].

24.4.4 The American College of Sports Medicine's Exercise Recommendations for Muscular Fitness

Improving muscular functioning through a resistance-training program may provide physiological benefits for girls and women of all ages. Research has clearly indicated that strength can be effectively increased with training in girls before the age of puberty [27]. For middle aged, older adult, and postmenopausal women, a reduction in the risk of osteoporosis, low-back pain, hypertension, and diabetes have been associated with resistance training programs [28, 29]. Appendix 2 displays resistance training exercises that can be performed by the mature woman.

Unlike cardiovascular activity, intensity for resistance exercise is not easily determined. Miriam E. Nelson, author of Strong Women Stay Young, suggests that women beginning a resistance-training program should use a scale similar to the RPE scale (see Fig. 24.2) to determine the amount of weight that they should incorporate into their resistance-training program [30]. For strength gains to continue to accrue, there must be a gradual increase in the stress or load placed on the body throughout the resistance-training program. The *overload principle* refers to placing greater demands on the body than what it is accustomed to, and the *principle of progression* refers to the constant application of the overload principle throughout the resistance-training program. Hence, the term *progressive overload* has been coined. The RPE scale has become a popular method to assess *progressive overload*. Nelson suggests that during the first week, individuals should focus on form and that the effort involved in lifting should be easy or moderate. When learning the exercises, an intensity of 9 (very light) to 11 (light) on the RPE scale would be appropriate. According to Nelson [30], the goal should be for the exercise set (eight repetitions) to become difficult after six or seven repetitions. Faigenbaum and the ACSM recommend an initial goal of 12–13 (somewhat hard) and a final goal of 15–16 (hard, heavy) on the RPE scale for submaximal training [13, 31]. A target of 19–20 (extremely hard, maximal exertion) on the RPE scale is synonymous with high-intensity strength stimuli for healthy populations [31]. However, for people with high cardiovascular risk or those with chronic disease, the exercise should be terminated if the lifting portion of the exercise becomes difficult corresponding to an RPE of 15–16 [13] or if there are any warning signs such as dizziness, unusual shortness of breath, anginal discomfort, or dysrhythmias [13, 32]. Therefore, a more modest level of exertion should be chosen. Table 24.9 provides resistance guidelines as outlined by the American College of Sports Medicine for healthy adults [13].

Table 24.10 outlines the ACSM Position Stand on Progression Models in Resistance Training for Healthy Adults [33]. Although it is common to estimate intensity on repetition maximum (RM), this should only be used as a general guideline since RM differs between muscle groups [34]. These guidelines are appropriate for healthy adult women who desire goal-oriented guidelines for athletic performance enhancement, rather than simply health benefits. In order to more fully understand the guidelines as outlined in Table 24.10, the following terms are defined [35, 36]. Definition of terms needed to understand the resistance guidelines proposed by ACSM.

Table 24.9 American College of Sports Medicine's resistance training guidelines for healthy adults [13]

Frequency
For novice trainers, each major muscle group should be trained at least 2 d ·week^{-1}
For experienced individuals, exercise frequency is secondary to training volume, thus individuals can choose a weekly frequency based on personal preference and muscle group
Intensity
40–50% 1-RM (very light-to-light) for older individuals and sedentary individuals just beginning a program
60–70% 1-RM (moderate-to-vigorous intensity) for strength improvement in novice and intermediate trainers
80% or less 1-RM (vigorous-to-very vigorous) for strength improvement in experienced trainers OR experienced trainers can choose a wide range of intensities and repetitions dependent on specific muscular fitness goals
Type
Should involve each major muscle group (chest, shoulders, upper and lower back, abdomen, hips, and legs)
Multijoint exercises affecting more than one muscle group are recommended targeting agonist and antagonist muscle groups
Single-joint and core exercises may also be included
A variety of exercise equipment and/or body weight can be used
Repetitions
8–12 repetitions for strength and power improvements
10–15 repetitions for middle-aged and older individuals beginning exercise to improve strength
15–20 repetitions for muscular endurance improvements
Sets
2–4 sets are recommended to improve strength and power
1 set is effective for older and novice exercisers
2 or more sets are effective for muscular endurance improvements
Pattern
2–3 min rest intervals between each set are effective
Rest at least 48 h between sessions for any single muscle group
Progression
Gradual progression of greater resistance, and/or more repetitions or sets, and/or more frequency is recommended

Table 24.10 Overview of American College of Sports Medicine's position stand on progression models in resistance training for healthy adults [33]

Concentric, eccentric, and isometric actions must all be included for all training levels
Unilateral and bilateral and multiple-joint exercises should be included
Sequence of exercise should be multiple-joint before single-joint, higher-intensity exercises before lower-intensity, rotation of upper and lower body or opposing exercises
Novice individuals should train the entire body 2–3 d ·week^{-1}
Intermediate individuals should train 3 d ·week^{-1} total body or 4 d with a lower/upper body split
Advanced lifters should train 4–6 d ·week^{-1}
Strength training
1–3 sets of 8–12 repetitions using an intensity of ~60–70% 1RM are recommended for novice and intermediate individuals
Cycling loads of ~80–100% 1RM are recommended for advanced individuals
Rest period of at least 3 min for core exercises
Muscle hypertrophy
For novice and beginning individuals, an intensity range of 70–85% 1RM should be used for 1–3 sets of 8–12 repetitions with 1–2 min rest between sets
For advanced individuals, working at an intensity of 70–100% 1RM for 1–12 repetitions in 3–6 sets with a 2–3 min rest time in core exercises
Local muscular endurance
Novice and intermediate training should include a relatively light load with a moderate to high volume (10–15 repetitions with about 1 min rest)
Advanced training should use various loading with high repetitions (15–25 repetitions or more with a min or less rest)
When circuit training, rest intervals should be the time it takes to get from one exercise to the next
Older adults
Use a slow-to-moderate lifting velocity for 1–3 sets of 8–12 repetitions using 60–80% 1RM with 1–3 min rest
Should train 2–3 days·week^{-1}

- *Concentric* (*shortening*): Concentric muscle actions occur when the total tension developed in all the cross-bridges of a muscle is sufficient to overcome any resistance to shortening.
- *Eccentric* (*lengthening*): Eccentric muscle actions occur when the tension developed in the cross-bridge is less than the external resistance, and the muscle lengthens despite contact between the myosin cross-bridge heads and the actin filament.
- *Hypertrophy*: The muscular enlargement that results from resistance is called hypertrophy and is primarily a result of an increase in the cross-sectional area of the existing fibers.
- *Multi-Joint exercise*: multi-joint exercises involve two or more primary joints (i.e., front or back squat, bench press, shoulder press).
- *Periodization*: Effective program design involves the use of periodization, which is the varying or cycling of training specificity, intensity, and volume to achieve peak levels of conditioning.
- *Power*: Power is precisely defined as the "time rate of doing work" [20] where work is the product of the force exerted on an object and the distance the object moves in the direction in which the force is exerted (power = work/time).
- *Repetitions*: Repeating an identical movement for a specific number of times. To improve strength, you must do enough repetitions of each exercise to fatigue your muscles. The number of repetitions needed to cause fatigue depends on the amount of resistance. In general, a heavy weight and a low number of repetitions (1–5) build strength, a lightweight and high number of repetitions (15–20) build endurance, for general fitness purposes, 8–12 repetitions are usually recommended.
- *Repetition maximum*: The maximum amount of resistance a person can move a specific number of times is referred

to as a repetition maximum (RM). The RM indicates that the muscle has reached a point of fatigue in which the force generating capacity falls below the required force to shorten the muscle against the imposed resistance [7]. One RM is the maximum amount of resistance that can be lifted one time, 5 RM is the maximum amount of weight that can be lifted five times.

- *Set*: A set refers to a group of repetitions of an exercise followed by a rest period.
- *Single joint exercise*: Single joint exercise involves only one primary joint (i.e., bicep curl).

Even though guidelines for children and adolescents are similar to those for adults, there are specific guidelines for resistance training in this population. Guidelines for children and adolescents can be found in Table 24.11 from Essentials of Strength Training and Conditioning [37].

For more specific information on developing effective resistance training programs for specific goals, it is recommended that you access on-line resources at: (1) National Strength and Conditioning Association (NSCA) at http://www.nsca-lift.org/Home/ [38]; (2) the American College of Sports Medicine at www.acsm.org [39]; or Exercise Prescription on the Net (ExRx.net) http://www.exrx.net/index.html [40]. These resources will also provide recommendations for texts and videos. In addition, workout templates and live video clips of the proper form for performing resistance exercise can be found at Exercise Prescription on the Net. ExRx.net has been a recommended internet resource for the ACSM Resource Manual for Guidelines for Exercise Testing and Prescription [41]. ExRx.net is also a NSCA authorized Continuing Education Unit (CEU) provider.

Table 24.11 National Strength and Conditioning Association (NSCA) guidelines for resistance training with children [37] (Adapted from Travis Triplett. Essentials of Strength Training and Conditioning. Fourth edition. Champaign, IL: Human Kinetics, 2016)

- Children should be supervised by a qualified instructor when performing exercises
- Equipment should be appropriate for the size and skill level of the child
- Begin with relatively light loads and always focus on the correct exercise technique
- Perform 1–3 sets of 6–15 repetitions on a variety of upper and lower body *strength* exercise
- Increase the resistance gradually (5–10%) as strength improves
- Begin resistance training two to three times per week on nonconsecutive days
- Perform 1–3 sets of 3–6 repetitions on a variety of upper and lower body *power* exercises
- Optimize performance and recovery with healthy nutrition, proper hydration, and adequate sleep

Table 24.12 Recommendations for body fat percentages for women [42]

Category			Recommended percentage		
Essential			8–12%		
Minimal			10–12%		
Athletic			12–22%		
Recommended body fat percentage levels for adults and children					
Age (y)	NR	Low	Mid	High	Obese
6–17	<12	12–15	16–30	31–36	>36
18–34	<20	20	28	35	>35
18–34 PA		16	23	28	
35–55	<25	25	32	38	>38
35–55 PA		20	27	33	
55+	<25	25	30	35	>35
55+ PA		20	27	33	

NR not recommended, *PA* physically active

24.4.5 The American College of Sports Medicine's Exercise Recommendations for Healthy Body Composition

Although national standards have been developed and accepted for body mass index and waist circumference, there are no national standards for body fat percentage. Lohman et al. [42] proposed a set of standards for women using data from the National Health and Nutrition Examination Survey. Table 24.12 lists Lohman's et al. body fat percentage recommendations for women.

Exercise programs to optimize lean body mass (LBM) should include both cardiovascular and muscular fitness exercise components. In accordance with the United States Department of Health and Human Services, the ACSM recommends a target of 1000 kcal (or range of 5400–7900 steps each day) of physical activity and/or exercise a week for energy expenditure [13]. Reports indicate that at the very least >150 min a week may be necessary for weight loss [43]. Wearable technologies (See Fig. 24.3) allowing for improved tracking of physical activity, a walking pattern, or cadence of at least 100 steps • min^{-1} in adults appear to meet the minimum threshold for moderate intensity physical activity [45].

The goal of 10,000 steps·day^{-1} is often cited as a target; however, a daily step count of 7000–8000 steps·day^{-1}, with at least 3000 steps·day^{-1} at a brisk pace (3 METs/>100 steps·min^{-1}), is a reasonable minimum daily threshold associated with health benefits [46]. Greater amounts of physical activity (>250 min·$week^{-1}$) may be needed to promote long-term weight control [13]. Physical activity and/or exercise expenditure in excess of 2000 kcal·$week^{-1}$ (8000–12,000 steps per day) have been successful for both short- and long-term weight control [13, 47].

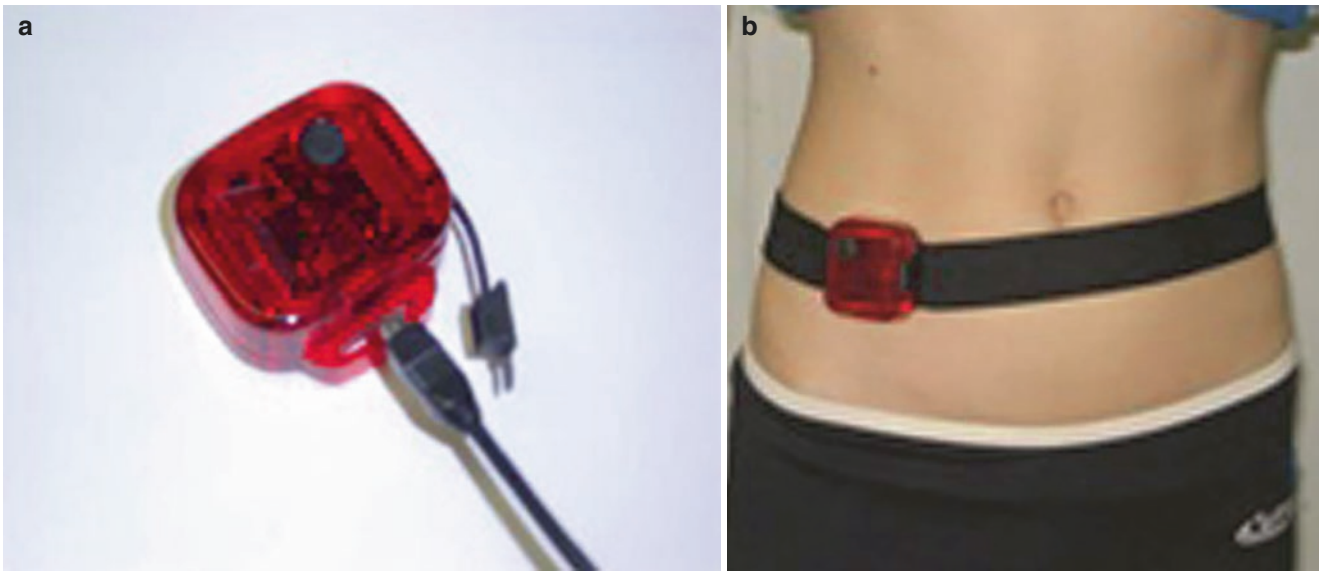

Fig. 24.3 (**a**, **b**) Physical Activity Tracker [44]. (Reprinted with permission from Springer Nature, The Active Female: Health Issues Throughout the Lifespan, 2e, Robert-McComb JJ, Norman RL, Zumwalt M, Editors, Chapter 25, Screening Tools for Excessive Exercise in the Active Female, Fernandez-del-Valle M, pgs 373–388, © 2014)

24.4.6 The American College of Sports Medicine's Exercise Recommendations for Flexibility

Since flexibility is believed to be transient, it is recommended that flexibility exercises should be performed a minimum of 2–3 days a week [13]. The greatest change in flexibility has been shown to be in the first 15 s of the stretch with no significant improvements after 30 s [48]. Therefore, ACSM recommends that each stretch be held for 15–30 s. The optimal number of stretches per muscle group is two to four since no significant improvement in muscle elongation is seen in repeated stretching of 5–10 repetitions [49]. ACSM recommends a total of 90 s of discontinuous flexibility exercise per joint [13]. Table 24.13 lists general exercise guidelines for achieving and maintaining flexibility [13, 50, 51]. The American Academy of Orthopaedic Surgeons provides examples of flexibility exercises for the young athlete as well as for older individuals, See http://orthoinfo.aaos.org/main.cfm [52].

Table 24.13 General exercise prescription for achieving and maintaining flexibility [13]

• Precede stretching with light aerobic activity or by external methods (ex: hot bath, moist heat packs) to warm up body
• Perform a minimum of 2–3 d week^{-1}, 7 days·week^{-1} is most effective
• Stretch to the end of the range of motion to a point of tightness or slight discomfort
• Hold each stretch for 10–30 s
• For older adults, holding each stretch for 30–60 s may show more benefits
• For proprioceptive neuromuscular facilitation (PNF) stretching, a 3–6 s light-to-moderate contraction (i.e., 20–70% of maximum voluntary contraction) followed by a 10–30 s assisted stretch is desirable
• Perform 90 s of total stretching time for each exercise for the major muscle tendon groups
• Static flexibility (i.e., active or passive), dynamic flexibility, ballistic flexibility, and PNF are each effective

24.5 Concluding Remarks

Despite the documented benefits of regular physical activity, most children, adolescents, and adult women are not engaged in physical activity consistent with public health recommendations. At one end of the continuum, we have young girls and female athletes who are not taking in enough calories to meet their energy needs associated with exercise, and at the other end of the continuum, we have most children, adolescents, and adult women who do not get enough physical activity.

There are many resources on the Web to assist with activity and exercise recommendations to achieve optimum health and fitness. The Department of Health and Human Resources Centers for Disease Control and Prevention offers a Web site that provides information to assist in healthy physical activity program planning and evaluation as well as ideas for healthy physical activity promotion (See http://www.cdc.gov/physicalactivity/index.html [53].

Appendix 1 2021 PAR-Q+

This document can be downloaded free at http://eparmedx.com/ [14–16]. Reprinted with permission from the PAR-Q+ Collaboration (www.eparmedx.com) and the authors of the PAR-Q+ (Dr. Darren Warburton, Dr. Norman Gledhill, Dr. Veronica Jamnik, Dr. Roy Shephard, and Dr. Shannon Bredin). Warburton D, Jamnik V, Bredin S, Shephard R, Gledhill N. The 2019 Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and electronic Physical Activity Readiness Medical Examination (ePARmed-X+). *Health & Fitness Journal of Canada* 2018;11(4):80–83. https://hfjc.library.ubc.ca/index.php/HFJC/article/view/270 and Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, Shephard RJ, on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and electronic Physical Activity Readiness Medical Examination (ePARmed-X+): Summary of consensus panel recommendations. *Health & Fitness Journal of Canada* 2011;4:26–37.

2021 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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2021 PAR-Q+

If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

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Appendix 2 Determining Exercise Intensity Using the Heart Rate Reserve Method (HRR) [13]

STEP 1

Take your resting heart rate. For this to be most accurate, it is suggested that you count the number of beats per minute three mornings in a row before arising and average the three readings.

Reading 1_____bpm Reading 2_____bpm Reading 3_____bpm Average bpm_____

Resting heart rate = _____ (i.e., *resting heart rate = 72)*

STEP 2

Determine your maximum heart rate (MHR) 207 − (0.7 × age in years) = _____bpm

i.e., *207 − (0.7 × 35) = 182.5 = 183 bpm*

Moderate Exercise Intensity

STEP 3

Target Heart Rate = [(MHR-resting heart rate) (40–59%)] + resting heart rate

i.e., [(183–72) (0.40–0.59)] + 72 = 116–138 bpm

Vigorous Exercise Intensity

STEP 3

Target Heart Rate = [(MHR-resting heart rate) (60–89%)] + resting heart rate

i.e., [(183–72) (0.60–0.89)] + 72 = 139–171 bpm

Note: The intensity range to increase and maintain cardiorespiratory fitness (CR) is broad. For individuals with low levels of CR fitness, the lower range will result in improvements in CR fitness. For individuals who are already fit, exercise intensities at the high end of the continuum (60–<90% HRR) may be needed to improve and maintain CR fitness or High Intensity Interval Training.

Sample Exercise Resistance Program for Postmenopausal Women: 4, 6, 8, and 12-Week Programs

A safe and effective training load for postmenopausal women is from 50 to 80% of a 1 RM. This level is enough to allow for the development of strength, but light enough to reduce the risk of injury. Progress gradually by starting off with 50% 1 RM using 2 sets of 6 repetitions for the first 2 weeks. During weeks 3 and 4, increase the lower body intensity by 10% and the upper body intensity by 5% as well as increasing the reps to 2 sets of 7 repetitions. When reaching weeks 5 and 6, make similar increases in upper and lower body intensity by increasing intensity by 5% and 10%, respectively, as well as increasing the repetitions in each set to 8. Weeks 7 and 8 have increasing intensity, but the repetitions are not increased. Finally, for those who have completed the eighth week, the following weeks have an increased intensity to 70–80% of the 1RM for all exercises as well as an additional set of repetitions. The 4-week program is intended for an introduction to resistance training that can then progress to the 6, 8, and 12 week programs for beginners, intermediates, and advanced exercisers, respectively. All programs are performed 3 times per week.

Introduction part I: weeks 1 and 2

Exercise	1 RM (lbs)	% 1 RM	Weight (lbs)	Set 1	Set 2
Wall squats	10	50	5	6	6
Machine bench press	20	50	10	6	6
Leg press	100	50	50	6	6
Low rows	40	50	20	6	6
Lat pulldown	40	50	20	6	6
Back extension	60	50	30	6	6

Introduction part II: weeks 3 and 4

Exercise	1 RM (lbs)	% 1 RM	Weight (lbs)	Set 1	Set 2
Wall squats	10	60	6	7	7
Machine bench press	20	55	12	7	7
Leg press	100	60	60	7	7
Low rows	40	55	22.5	7	7
Lat pulldown	40	55	22.5	7	7
Back extension	60	55	32.5	7	7

Beginner: weeks 5 and 6

Exercise	1 RM (lbs)	% 1 RM	Weight (lbs)	Set 1	Set 2
Wall squats	10	70	7	8	8
Machine bench press	20	60	12.5	8	8
Leg press	100	70	70	8	8
Low rows	40	60	25	8	8
Lat pulldown	40	60	25	8	8
Back extension	60	60	35	8	8

Intermediate: weeks 7 and 8

Exercise	1 RM (lbs)	% 1 RM	Weight (lbs)	Set 1	Set 2
Wall squats	10	80	8	8	8
Machine bench press	20	70	15	8	8
Leg press	100	80	80	8	8
Low rows	40	65	27.5	8	8
Lat pulldown	40	65	27.5	8	8
Arm curl	20	70	15	8	8
Arm extension	40	70	27.5	8	8
Back extension	60	65	40	8	8

Advanced: weeks 9, 10, 11, and 12

Exercise	1 RM (lbs)	% 1 RM	Weight (lbs)	Set 1	Set 2	Set 3
Wall squats	10	80	8	8	8	8
Machine bench press	20	70	14	8	8	8
Leg press	100	80	80	8	8	8
Low rows	40	70	28	8	8	8
Lat pulldown	40	70	28	8	8	8
Arm curl	20	75	15	8	8	8
Arm extension	40	75	30	8	8	8
Back extension	60	70	42	8	8	8

Sample resistance exercises for women (Springer has pictures-also copied below)

Wall squats

Start position	End position

Wall squats with ball

Start position (front view)	End position (front view)
Start position (side view)	End position (side view)

Machine chest press

Start position	End position

Dumbbell arm curl

Start position	End position

Machine arm curl

Start position	End position

Arm extension

Start position	End position

Lat pulldown

Start position	End position

Back extension

Start position	End position

Leg press

Start position	End position

Low row

Start position	End position

Sample Resistance Exercises for Women

Wall squats

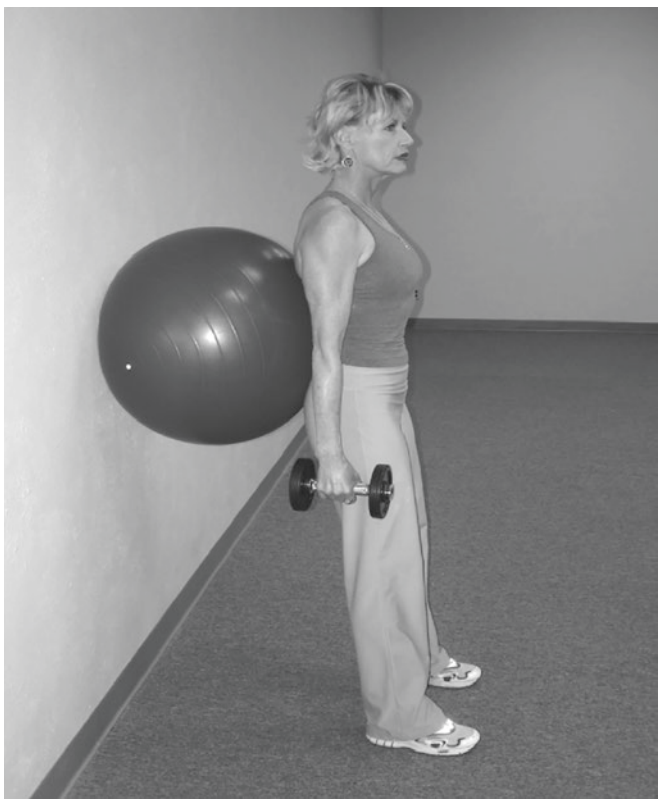
Start position (App fig 1a)

End position (App fig 1b)

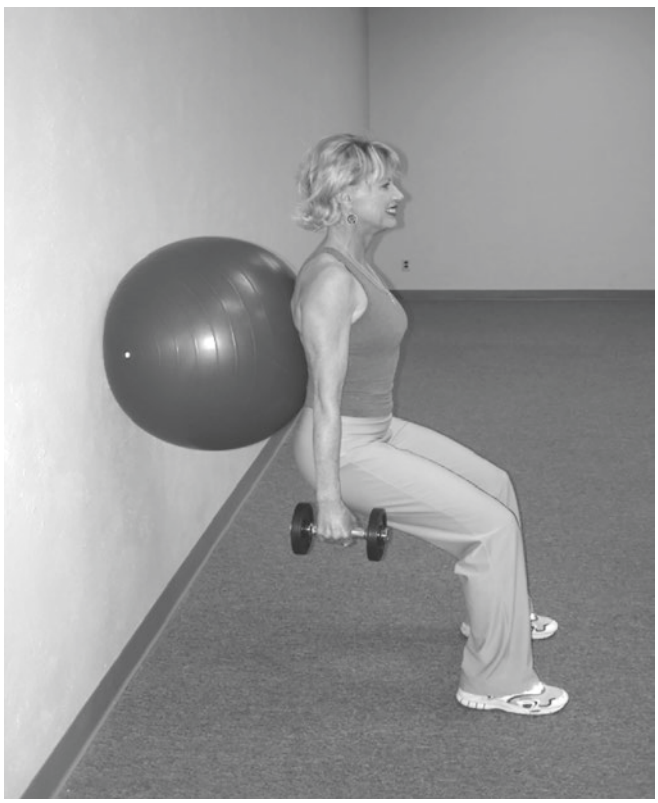
Wall squats with Ball

Start position (front view) (App fig 1c)

End position (front view) (App fig 1d)



Start position (side view) (App fig 1e)



End position (side view) (App fig 1f)

Machine chest press

Start position (App fig 1g)

End position (App fig 1h)

Dumbbell arm curl

Start position (App fig 1i)

End position (App fig 1j)

Machine arm curl

Start position (App fig 1k)

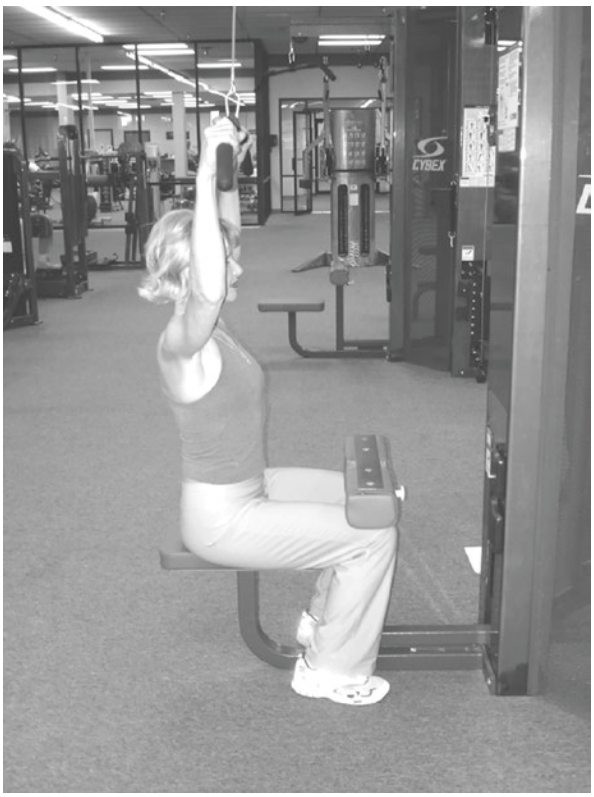
End position (App fig 1l)

Arm extension

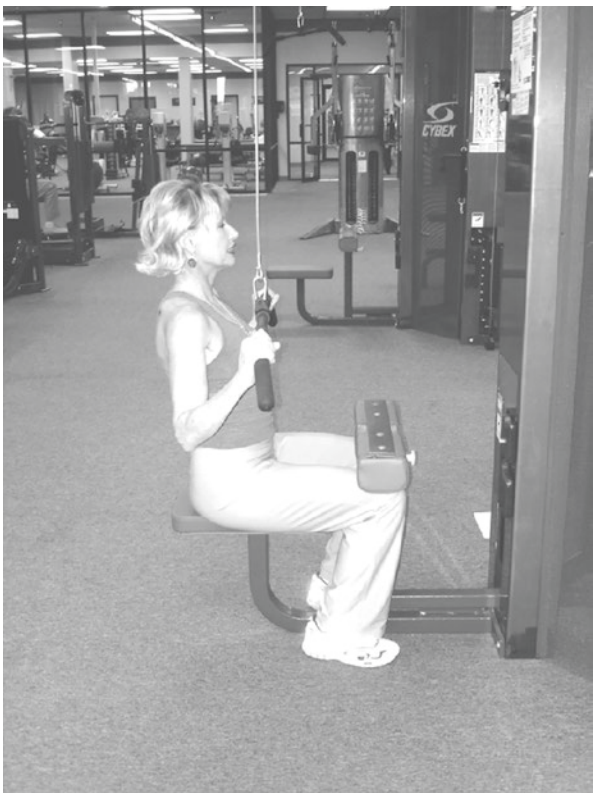
Start position (App fig 1b)

End position (App fig 1n)

Lat pulldown



Start position (App fig 1o)



End position (App fig 1p)

Back extension

Start position (App fig 1q)

End position (App fig 1r)

Leg press

Start position (App fig 1s)

End position (App fig 1t)

Low row

Start position (App fig 1u)

End position (App fig 1v)

Appendix 3 Determining Moderate and Vigorous Exercise Intensity Using the Borg Rating of Perceived Exertion (RPE) Scale [13, 22]

	13 Somewhat hard
6 No exertion at all	**14**
7	**15 Hard (heavy)**
Extremely light (7.5)	
8	**16**
9 Very light	**17 Very hard**
10	**18**
11 Light	**19 Extremely hard**
12	**20 Maximal exertion**

Instructions: While doing physical activity, rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion. Choose the number that best describes your level of exertion. This will give you a good idea of the intensity level of your activity. *Moderate exercise* is defined as a "perceived exertion" of **12–13**. *Vigorous exercise* is defined as a "perceived exertion" of **14–17**. The average RPE range associated with physiologic adaptation is **12–16**. However, there is significant interindividual variability.

9 corresponds to "very light" exercise; for a healthy person, it is like walking slowly at his or her own pace

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

17 "very hard" is very strenuous, a healthy person really has to push himself or herself and you will probably feel very tired

19 on the scale is an extremely strenuous exercise level; for most people, this is the most strenuous exercise they have ever experienced.

Chapter Review Questions

1. What is the recommended *time per day* for children and adolescents to be physically active?
   (a) 30 min
   (b) 60 min
   (c) 20 min
   (d) 10 min
2. What is the recommended *time per week* for women during pregnancy and postpartum to be physically active?
   (a) 150 min
   (b) 60 min
   (c) 120 min
   (d) 45 min
3. Which of these is important in identifying the need for medical clearance prior to beginning exercise?
   (a) History of cardiovascular, renal, or metabolic disease(s)
   (b) Signs and symptoms suggestive of cardiovascular, renal, or metabolic disease(s)
   (c) Exercise history
   (d) All of these
4. Non-exercising individuals with diagnosed cardiovascular, metabolic, or renal disease but are asymptomatic should:
   (a) Begin light-moderate intensity exercise immediately
   (b) Seek medical clearance by a qualified clinician to determine exercise limitations
   (c) Never exercise due to risk of disease progression
   (d) Only exercise while being observed by a clinician or exercise professional
5. Which metabolic equivalent of task (MET) corresponds to vigorous intensity exercise?
   (a) 8.8
   (b) 3.3
   (c) 6.2
   (d) 4.9
6. Which rating of perceived exertion (RPE) from the Borg 6–10 scale corresponds to light intensity exercise?
   (a) 9
   (b) 12
   (c) 15
   (d) 18
7. You are cycling to work at a speed of less than 10 mph. This corresponds to what exercise intensity?
   (a) Very light
   (b) Light
   (c) Moderate
   (d) Vigorous
8. It is recommended that novice healthy women should participate in resistance training
   (a) 1 day per week
   (b) 2 nonconsecutive days per week
   (c) 2 consecutive days per week
   (d) Never since they are more prone to joint injuries
9. It is recommended that healthy women should participate in flexibility training a minimum of:
   (a) 5 days per week
   (b) 7 days per week
   (c) 2–3 days per week
   (d) 1 day per week
10. Which of these physical activities would be appropriate for bone strengthening in an adolescent female?
   (a) Jumping rope
   (b) Sweeping the house
   (c) Riding a bicycle
   (d) Swimming

Answers

1. b
2. a
3. d
4. b
5. c
6. a
7. c
8. b
9. c
10. a

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25 Cardiovascular Exercise Guidelines for Optimal Performance of Active Females Throughout the Lifespan Including Children, Adolescents, and the Aging Female

Melissa Mae R. Iñigo-Vollmer and Maria Fernandez-del-Valle

Learning Objectives
After completing this chapter, you should have an understanding of:

- Cardiovascular exercise guidelines for children, adolescents, healthy adults, and older adults
- How to approach exercise with children and adolescents
- Unique characteristics of children, adolescents, adult women, and postmenopausal women
- Training principles and methods for optimal performance

25.1 Introduction

Cardiovascular exercise is essential for optimal performance in an activity and for gaining health benefits. Through regular physical activity/exercise and training, muscular adaptations and enhancements in motor skill performance occur. Exercise also improves health and quality of daily life as the body adapts to training. Many positive cardiovascular and metabolic adaptations occur that lead to risk reduction for chronic diseases such as Coronary Heart Disease, Metabolic Syndrome, Type 2 Diabetes, and even cancer [1, 2]. Notably, the health benefits are evident even in the absence of weight loss [1, 3]. Exercise also improves bone health, mental health, self-esteem and socialization [1, 4–6]. In simple terms, cardiorespiratory or cardiovascular fitness refers to the body's ability to sustain physical activity without feeling tired or fatigue. Greater cardiovascular fitness allows greater exercise performance for a longer period of time. Common cardiovascular exercises that improve cardiovascular fitness include but are not limited to brisk walking, running/jogging, cycling, swimming, and dancing. Any sport that incorporates these activities or movements such as basketball, soccer, tennis, gymnastics, triathlon, water polo, etc. also improves cardiovascular fitness.

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25.2 Research Findings

25.2.1 General Cardiovascular Exercise Guidelines for Children and Adolescents

Current Physical Activity Guidelines for Americans (2018) included guidelines for children and adolescents [7]. The recommended exercise duration, intensity, and frequency are to exercise:

- at least 60 minutes (min) per day at a moderate to high intensity for at least 3 days a week.

Running, cycling, swimming, and other moderate-to-high intense activities are recommended in order to achieve the overall health benefits of physical activity and to improve motor performance skills of children. Exercises may either be continuous (60 min) or composed of intermittent bouts [10, 20, or 30 min each]. However, this depends on the goals of the individual as well. A child or an adolescent who is training for a particular organized sport or dance needs a well-designed program that is specific to improving performance for that activity. Otherwise, the effectiveness of the program may not be optimal and may also promote injury. Other important guidelines are that exercise intensity and recovery period should be age-appropriate. The exercises

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should also be safe and well-supervised by an expert trainer or coach. Finally, the activities should be those that children and adolescents enjoy, and outside play with peers should be encouraged.

25.2.1.1 Children's and Adolescents' Unique Characteristics

Youth physical activity programs, including dynamic sports (swimming, gymnastics, rhythmic gymnastics, soccer, judo, etc.), have long been recognized to improve overall health and performance measures such as sprint speed, long jump, vertical jump, flexibility, agility, kicking distance, etc. [8–12]. While children are grossly seen as young, underdeveloped adults, some physiological traits that aid children during exercise are not so obvious. Several exercise-related characteristics differ between children and adults, which is eloquently summarized in a review by Armstrong et al. [13] Briefly, children preferentially utilize aerobic metabolism over anaerobic metabolism during exercise compared to adults [13]. Factors that contribute to enhanced aerobic metabolism include the preferential oxidation of lipids and ingested carbohydrates (aerobic glycolysis) as well as the sparing of stored glycogen in skeletal muscle of children [13]. In boys, this may be due to the greater percentage of Type 1 (slow twitch, oxidative) muscle fibers and lower glycogen stores [13]. Regardless of gender, skeletal muscle of children also exhibits greater activity of oxidative enzymes than adults [13]. The apparent high level of aerobic fitness can also be observed by the quantifiable measure of aerobic capacity, peak or maximum rate of oxygen consumed during exercise (VO_2peak or VO_2max). Data from the National Health and Nutrition Examination Survey (NHANES) in 1999–2002 revealed that in boys and girls aged 12–19 years, VO_2max is estimated to be approximately 46 mL/kg/min and 39 mL/kg/min, respectively [14]. In general, boys have greater VO_2max than girls, and this sex difference remains in adults [13–15]. However, caution must be taken when VO_2max or VO_2peak is normalized to body mass then compared between children and adults. Many researchers argue that boys and girls continue to increase VO_2peak as they age and transition into adults, which can be observed more accurately if VO_2peak is not normalized to body mass [13, 16]. Since muscle mass substantially and disproportionately increases compared to VO_2peak as children age and mature into adulthood, normalization to body mass will invariably result in adults having lower apparent VO_2peak compared to children, which is a misinterpretation of the data. Nonetheless, the VO_2peak of girls plateau at an earlier age [~12–14 years old] than boys [13, 14]. This can be attributed to a decrease in physical activity during their adolescent years [17, 18]. Peak work rate, also referred to as power or the force applied times displacement per unit of time, increases as children age and mature as well. Peak work rate is higher in girls that mature earlier than age-matched boys; however, as boys mature, peak work rate of boys becomes increasingly greater compared to girls [13, 19]. The increase in muscle size, improved neuromuscular control, and factors mentioned above such as changes in muscle fiber type and muscle metabolism all contribute to the increased peak work rate upon maturation [13]. Remarkably, children have fast heart rate recovery after an exercise bout [13, 20, 21]. Thus, they can recover quicker from intense exercise bouts and are more resistant to fatigue compared to adolescent and adult counterparts. Notable factors promoting rapid recovery likely include the children's greater oxidative capacity in skeletal muscle and lower peak work rate as described above, as well as lower lactate production and faster phosphocreatine resynthesis in skeletal muscle [13, 21]. Enhanced oxidative capacity suggests greater muscle endurance. Lower peak work rate is thought to lessen the need to recover from such power output. High lactate concentrations in blood and muscle have long been associated with lower exercise capacity. Lower lactate production lowers lactate accumulation that is associated with the ability to recover faster from fatigue while lactate clearance is not a contributing factor. The direct link between lactate and fatigue is, however, still incompletely understood. Finally, phosphocreatine is used to regenerate adenosine triphosphate (ATP), the energy currency of the cell required for muscle contraction. Faster phosphocreatine resynthesis increases ATP availability for exercise. Interestingly, ventilatory efficiency during exercise is inherently different between children and adults. Children have a high minute ventilation in response to the rate of carbon dioxide production (VE/VCO_2 slope) during exercise and more specifically, a high alveolar ventilation/VCO_2 slope because of maturational issues in the control of ventilation

Table 25.1 General cardiovascular exercise guidelines throughout the lifespan from the American College of Sports Medicine [26] and the Physical Activity Guidelines for Americans by the U.S. Department of Health and Human Services [7]

	Intensity	Duration	Frequency
Children and adolescents	Moderate-to-vigorous	≥60 min/d	≥3 d/week
Healthy adults	Moderate intensity	≥30 min/d	≥5 d/week (150–300 min/week)
	Or		
	Vigorous intensity	≥20 min/d	≥3 d/week (75–150 min/week)
Older adults	Moderate intensity	30–60 min/d	≥5 d/week (150–300 min/week)
	Or		
	Vigorous intensity	≥20 min/d	≥3 d/week (75–150 min/week)

[a]Additional benefits can be gained from exercising at frequencies that are greater than the recommended guidelines

Table 25.2 Common approaches of determining training intensity [26]

	Description	Moderate intensity[a]	Vigorous intensity[a]
MET	MET—metabolic equivalent, 1 MET = resting energy expenditure at 3.5 mL O_2/kg of body weight (BW)/min or 1 MET = 1 kcal/kg/h	4–6 METs, e.g., bicycling <10 mph	>6 METs, e.g., jogging, running
Percent of VO_2max	VO_2max—maximal oxygen consumption rate, a marker of cardiovascular fitness, accurately measured by a metabolic cart, or estimated by validated protocols	46–53% VO_2max	64–90% VO_2max
Percent of VO_2R	VO_2R—maximal oxygen uptake reserve	40–59% VO_2R	60–89% VO_2R
Percent of HRmax	HRmax—maximum heart rate, accurately measured by an electrocardiogram or predicted by validated formulas, the simplest formula: HRmax = 220 − age	64–76% HRmax	77–95% HRmax
Percent of HRR	HRR—heart rate reserve HRR = (HRmax-HRrest) + HRrest	40–59% HRR	60–89% HRR
RPE scale	RPE—rate of perceived exertion Borg RPE Scale = a scale from 6 to 20, where 6 = no exertion at all and 20 = maximal exertion	12–13	14–17

[a]Training intensities from the ACSM Position Stand: Quantity and Quality of Exercise for Developing and Maintaining Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise (2011) [26]; however, defining whether an intensity is moderate or vigorous can depend on the individual's level of cardiovascular fitness (see Principle of Individuality)

[22]. In simple terms, children relatively hyperventilate. The VE/VCO_2 slope decreases and normalizes to adult values as children get older. These physiological characteristics that are unique to children as well as the sex differences that occur as they age must be taken into consideration when developing age-appropriate exercise programs. With the rise in development of more sophisticated tools for research, future studies may uncover more novel exercise-related characteristics specific to children and adolescents. However, more research is required to determine how we can optimally utilize the current scientific knowledge to tailor exercise programs for children and adolescents, and in turn, accelerate improvements in performance and maximize the health benefits of exercise.

25.2.1.2 How to Approach Exercise with Children and Adolescents

Establishing good health habits during the earlier stages of life may drive children and adolescents to continue to have an active lifestyle during adulthood. Indeed, researchers see a decline in physical activity participation rates even prior to adolescence, and it continues to decline as individuals get older [18]. This cultural trend can be combated if the promotion of a healthy lifestyle begins during childhood and adolescence because many habits are formed during this critical time. Much of the activities that young children engage in should have an emphasis in enjoyment, peer-to-peer interaction, safety, age-appropriateness, and effectiveness. Being active should be enjoyable and something the children look forward to, for at their age, the fun factor promotes exercise adherence [23]. Children and adolescents also enjoy the social interaction during training sessions, games, and competitions, which is another important factor that encourages physical activity participation [23]. Training programs for children must also be safe and guided by an expert so that under- or overtraining does not occur, and injuries can be prevented. Finally, exposing children to multiple physical activities and sports is far more beneficial in encouraging exercise and sport adherence [24, 25]. Specializing in one sport at such an early age (<15 years) may result in overtraining, burnout, and a less positive psychosocial development. Thus, for example, cross training during the active recovery period (1–3 weeks after the in-season) is recommended. (See Tables 25.1 and 25.2).

25.2.2 General Cardiovascular Exercise Guidelines for Healthy Adults

In 2011, the American College of Sports Medicine (ACSM) Position Stand presented updated exercise guidelines for improving health and cardiovascular fitness of healthy adults [26]. Current exercise guidelines are for both men and women. Based on the evidence from randomized and non-randomized control trials, ACSM recommends cardiovascular exercise training for:

- ≥30 min per day, ≥5 days per week (≥150 min per week) at moderate intensity or
- ≥20 min per day, ≥3 days per week (≥75 min per week) at vigorous intensity or
- a combination of moderate and vigorous exercise to expend 500–1000 MET-min per week

in order to improve or maintain health and cardiovascular fitness. Exercises can be carried out over multiple ≥10 min sessions per day to complete the recommended exercise duration per day if time constraints prevent the ability to achieve this in 1 session. One metabolic equivalent (MET) refers to one's resting energy expenditure at approximately 3.5 mL O_2/kg of BW/min. Moderate intensity refers to expending 4–6 times the energy expended when at rest. Vigorous intensity refers to expending >6 times the energy expended when at

rest. To achieve 500–1000 MET-min per week, one can simply calculate that moderate intensity (~4–6 METs) × 30 min × 5 days = 600–900 MET-min/week and vigorous intensity (>6 METs) × 20–30 min × 3 day = >360–540 MET-min/week. What constitutes a moderate or vigorous activity depends on the individual (see Principle of Individuality below). Brisk walking may be a light activity for a trained athlete, but may be a moderate activity for an older deconditioned adult. Importantly, ACSM also emphasizes that a combination of moderate and vigorous intensity training or even exercise training that is less than the recommended guidelines will still elicit health benefits, although to a lesser extent. Thus, the take home message is to continue exercise training, even though exercise targets for a particular day or week may not have been met. The World Health Organization (WHO) [27] and the U.S. Department of Health and Human Services, Office of Disease Prevention and Health Promotion (DHHS) [7] have similar recommendations.

25.2.2.1 Adult Women's Unique Characteristics

Substrate metabolism during cardiovascular exercise differs between women and men. Eumenorrheic women (i.e., women with normal or regular menstruation) are capable of relying more on fat as a fuel source during cardiovascular exercise than men, indicating less reliance on carbohydrates [28]. Studies also showed that women utilize ~25–50% less muscle glycogen (the storage form of glucose) than men during prolonged submaximal running [29] and specifically in Type 1 (slow twitch fibers) during cycling at high-intensity [30 second (s) sprint] [30]. Interestingly, in this high-intensity cycling study, the women were only tested either during day 12 to the last day of their menstrual cycle phase, implying they were either in the late follicular or the luteal phase, when estrogen levels are high [30].

To better understand the following section, we provide here an overall picture of hormonal fluctuations during the menstrual cycle (MC). The MC (typically 28 days ±7 long) is mainly divided into the follicular phase and luteal phase, which are separated by ovulation (day 14). Based on the varying levels of estradiol (the most common form of estrogen) and progesterone, follicular and luteal phases can be further subdivided into early and late stages. Early follicular phase (days 1–7) is characterized by low estrogen and progesterone levels. Then, the body transitions to the late follicular phase (days 8–13), where estrogen levels increase and peak while progesterone levels remain low. Ovulation, the ovary release of an egg, occurs soon thereafter. Following ovulation, the body transitions to the early luteal phase (days 14–21), where circulating estrogens remain high, but slightly lower than the levels observed during the late follicular phase. Importantly, progesterone levels significantly increase above estrogen levels and peak at the end of the early luteal phase. Finally, the transition to the late luteal phase (days 21–28) occurs, characterized by the decreased levels of both progesterone and estrogen.

Differences in exercise metabolism may occur between MC phases. Women were observed to use less glycogen during the mid-luteal phase of the MC (high estrogen and progesterone levels) than the early follicular phase (lowest levels of progesterone and estrogen) [31]. Another study showed that in fasted endurance-trained young women, total percent contribution of carbohydrate was lower and total percent contribution of fat was higher during the mid-luteal phase compared to the early follicular phase in a 2-hour (h) cycling exercise test at 70% VO_2max [32]. These data suggest that women may have a higher reliance on aerobic pathways than glycolysis during the mid-luteal phase [31, 32], albeit not all studies strongly observed these findings [33].

Since aerobic metabolism is essential for endurance exercise, endurance performance may also differ between MC phases. Indeed, endurance capacity, measured by time to exhaustion at submaximal intensity, appears to be greater in the mid-luteal phase compared to the mid-follicular phase (low estrogen and progesterone levels) [34]. This difference between MC phases was observed to be greater in women with higher estrogen/progesterone (E/P) ratio in their mid-luteal phase than women with a lower E/P ratio in the same MC phase [34].

Overall, increased estrogen and progesterone levels during the mid-luteal phase may have a positive effect on endurance performance. However, the E/P ratio may play a critical role such that the metabolic benefits of estrogen may be incrementally blunted as progesterone concentrations rise during the mid-luteal phase [34]. More research studies that include the late follicular phase (peak of estrogen alone) are necessary to fully understand the effects of high and low E/P ratios on exercise performance and metabolism. Nonetheless, it is possible that synchronizing cardiovascular training to the MC phases in order to take advantage of women's hormonal status may be a novel strategy to attain the greatest and/or fastest improvements in exercise performance and health.

25.2.3 General Cardiovascular Exercise Guidelines for Older Adults

The ACSM and DHHS also released exercise guidelines for older adults in 2009 and 2018, respectively [7, 35]. Exercise can delay functional and mental decline, improve metabolic health, and restore functional capacity in deconditioned older adults. Regular exercise is important for reducing the risk for chronic cardiovascular and metabolic diseases as

mentioned above. Similar to the guidelines for healthy adults, older adults should aim to exercise for:

- 30–60 min per day at moderate intensity for a total of 150–300 min per week or
- 20–30 min per day at vigorous intensity for a total of 75–150 min per week

To meet the recommended exercise duration, exercise can be continuous or in 10–20 min sessions. Performance gains are greater when exercising at high intensities and greater frequency and duration; however, health benefits, independent from weight loss, can still be gained from less intense exercise programs.

25.2.3.1 Postmenopausal Women's Unique Characteristics

Natural menopause, which refers to the natural and permanent cessation of menstrual cycle phases in older women (~50 years old), accelerates declines in bone health, metabolism, and muscle strength. Cardiovascular exercise is important for postmenopausal women, especially for those who are not on estrogen therapy. Earlier exercise studies on postmenopausal women focused on preventing osteoporosis, a disease characterized by a decrease in bone density that increases the risk for fractures [36, 37]. Researchers also recognized that low levels of circulating estrogens in postmenopausal women were associated with excess body fat and insulin resistance [38]. Indeed, the prevalence of the Metabolic Syndrome is higher in men than premenopausal women, but is surprisingly higher in postmenopausal women than men of the same age [39]. In a postmenopausal monozygotic twin study, where the twins were discordant for hormone (estrogen) therapy (HT), the absence of HT appeared to promote the development of the Metabolic Syndrome [40]. The non-HT users displayed higher blood glucose and glycated hemoglobin as well as higher body fat compared to their HT using twin [40]. In animal studies, a reduction in estrogen levels by ovariectomy results in the development of insulin resistance and the obese phenotype [41–43]. Low estrogen levels in postmenopausal women are also associated with a moderate decrease in muscle force generation affecting overall strength [38]. Data from ovariectomized animal models suggest that the reduction in estrogen levels directly impacts contractile proteins in skeletal muscle, thus decreasing muscle quality [38].

The benefits of regular cardiovascular exercise for postmenopausal women are evident in the literature. Although resistance training may be most beneficial for maintaining bone health [44], moderately intense aerobic dancing, walking, and jogging for ~30 min on most days of the week can delay decreases in bone mineral content of postmenopausal women [37, 45]. However, such aerobic activities more likely prevent osteoporosis when combined with strengthening/resistance exercises [44]. In order to obtain sufficient adaptations in cardiovascular fitness and body composition, the minimum dose for postmenopausal women appears to be at least a moderately intense walking program on most days of the week [46]. For instance, healthy postmenopausal women who walked for ~40–60 min, 5 days/week at 45–55% VO_2max improved their VO_2max and lowered body fat percentage after 24 weeks [46]. Another study showed that walking 30–45 min, 5 days/week at 50% of VO_2 reserve (VO_2R) for 12 weeks also resulted in greater VO_2max, lower body fat percentage, and an improved lipoprotein profile (i.e., higher HDL-c) in combined lean and overweight postmenopausal women [47]. VO_2R refers to the difference between one's peak VO_2 and VO_2 at rest, and defining a certain percentage of VO_2R is another approach of setting training intensity. Longer exercise durations yield more positive changes in metabolic health, including improvements in insulin sensitivity and adipokine profiles (i.e., leptin, adiponectin levels) [47, 48]. When comparing exercise duration and intensities to achieve a certain amount of energy expenditure per week, exercise duration appears to be more important than training intensity in improving insulin sensitivity in obese/overweight postmenopausal women [49]. Although low volume/high intensity training, including sprint training 2×/week [50] improves glucose control and aerobic fitness in postmenopausal women, the greatest adaptations in insulin sensitivity have been observed in longer exercise durations of >170 min/week, regardless of whether intensity was moderate or vigorous [49]. Thus, longer cardiovascular exercise sessions with exercises that promote increases in bone mineral density and muscle strength may be most beneficial for postmenopausal women.

25.2.4 Training Principles and Methods

25.2.4.1 Principles of Training

Exercise training programs generally follow the Principles of Training. Briefly, the 7 principles are as follows:

Principle of Individuality

Exercise prescription must be individualized. One's exercise program must be based on a multitude of factors including but not limited to prior level of cardiovascular fitness, experience, rate of progression throughout the training program, sex, age, body composition, and health status.

Principle of Specificity

An exercise program must specifically train the muscles involved in the activity or sport for optimal performance. For example, training for a marathon will involve running a lot of miles each day. Cycling or swimming will be less beneficial to runner's performance. Furthermore, training for a shorter 800 meter (m) or 1500 m race will involve running shorter distances at higher speeds repeatedly. Both running events require significant cardiovascular fitness, but the training volumes and intensities will differ from each other.

Principle of Overload

In general, the exercise program must continually increase in intensity, volume, or frequency over time to keep gaining physiological adaptations. When the body becomes accustomed to the current exercise program, performance plateaus due to the absence of training adaptations from the lack of resistance or load that the body has to work against.

Principle of Progression

Progression refers to the transition from an easier to a harder exercise program (see Principle of Overload). The rate of progression will depend on the individual (see Principle of Individuality). Some individuals will be able to progress at a faster rate than others. If the progression is too fast or too difficult, this can lead to musculoskeletal injuries or diminished exercise adherence. If the progression is too slow or too easy, then the lack of overload can lead to a plateau in exercise performance.

Principle of Diminishing Returns

The performance gain or the change in performance within a time frame is greater for a beginner than an advanced or elite athlete. For example, a beginner in swimming will improve his/her personal best in any event by seconds or even tens of seconds after 1 year of training, whereas an elite athlete will only improve by milliseconds (ms) or seconds (s).

Principle of Reversibility

Reversibility refers to the loss and reversal of performance gains when one stops training regularly. The acquired training adaptations over time can be lost due to several reasons including reductions in muscle mass, maximal oxygen consumption rate (VO_2max), and flexibility.

Principle of Recovery

A good exercise program incorporates a rest period. During the training session, rest periods allow the body to replenish substrates needed for the muscle to perform adequately. When looking at an exercise program as a whole, whether it be a month- or 6 month- or a year-long program, rest periods of 1–2 days per week are critical to prevent injuries and chronic fatigue. An individual, who trains everyday but does not improve in performance, may be experiencing chronic fatigue.

25.2.4.2 Examples of Training Load and Specificity for Optimal Performance

To become a successful advanced or elite athlete, one must commit and dedicate a significant amount of time for training for the specific event. For instance, a recent study showed that elite British swimmers, who have participated in the World Championships, Commonwealth Games, and Olympic Games, typically have 9–10 swimming sessions per week and 3–4 strength and conditioning sessions per week (for 4–5 h per week) [51]. Elite long distance swimmers swim significantly more distance than sprinters [58 vs. 43 kilometers (km) per week] [51]. Long distance swimmers also have greater "Threshold" swimming sessions than middle distance and sprinters [51]. "Threshold" was described as training at an intensity where one could maintain heart rate at 20–30 beats below maximal heart rate. Sprinters have greater "Pure speed" swimming sessions compared to long distance and middle distance swimmers [51]. "Pure speed" was swimming short (15–25 m efforts) at or above race pace. Middle distance swimmers have greater "Tolerance" training sessions compared to sprinters [51]. "Tolerance" training referred to high intensity sessions with medium rest to improve anaerobic capacity and speed endurance at the same time.

Indeed, exercise training at the appropriate training intensity is critical for achieving maximal performance gains within a given period of time. Setting the training intensity is also often based on VO_2max. Training at 40–50% VO_2max may be sufficient for improving cardiovascular fitness of the untrained individual, while training at 70–80% VO_2max for the moderately trained athlete and 95–100% VO_2max for the well-trained athlete may be necessary [52]. Training intensity must also be specific for the physical demands of the sport or event. In a study that documented the training program of elite female Norwegian cross country skiers, percent of maximum heart rate (% HRmax) was used to set training intensity [53]. Low intensity endurance training sessions (<81% HRmax) were performed ~90% of the time during the preparation period of the year, which consisted of varied exercises including 50–60% skiing and roller skiing and 40% running [53]. Moderate intensity training (81–88% HRmax) was performed 4–5% of the time, and high intensity sessions (>88% HRmax) were performed 4–6% of time, both of which focused on skiing-specific exercises. However, the number of training hours separates the world class from the national class skiers. World class skiers trained for 920 h/year, 2 h/session, while national class skiers trained for 709 h/year, 1.7 h/

session [53]. World class skiers also performed 26% more high intensity training sessions than national class skiers. The benefits of greater training loads were evident, where world class skiers exhibited higher peak oxygen consumption rates (VO_2peak) than national class skiers (double poling: 65 mL/min/kg vs. 58.8 mL/min/kg; diagonal stride: 70.9 mL/min/kg vs. 65 mL/min/kg) and displayed greater cycle rates of double poling and greater overall speed [53].

25.2.4.3 Training Program Designs

The general exercise guidelines mentioned above can be manipulated in a more creative manner and still achieve the goals of a training program (e.g., improve cardiovascular fitness and improve metabolic health). Below are a few training program designs that have been studied and popular for many years. These short-term and long-term program designs were developed to provide alternative methods and to potentially maximize performance and health gains.

Continuous Training vs. HIIT

Continuous training refers to performing an exercise or activity at a specified exercise intensity for a specific amount of time. Classic examples are walking or jogging for 30 minutes at a moderate intensity, maintaining the same pace from start to end. High intensity interval training (HIIT) refers to programs where several sets of an exercise are performed at high intensity for a short amount of time with short rest periods in between sets. An example of a HIIT session is 10 sets of a fast-paced 3-min run with a 2-min rest between each set. As you can see, this HIIT example also sums up to a 30-min run and a HIIT session can be designed in an unlimited number of ways. HIIT programs that have been studied typically set the target intensity at 80–100% HRmax or aerobic capacity for an exercise lasting ~10 s to 5 min. The rest period is typically ~30 s to 4 min long, depending on the duration of the intense exercise bout and the participants' level of fitness. HIIT studies are usually ~20–45 min long at ~3 days/week for ~10–12 weeks. HIIT significantly improves cardiovascular fitness in untrained and trained adolescents and adults [54–56], although not superior to continuous training for adolescent athletes [54]. Recent systematic reviews and meta-analyses showed that when continuous training and HIIT were matched for energy expenditure and workload, both programs modestly reduced body fat percentage and fat mass to a similar degree in healthy and overweight/obese men and women [57, 58]. Shorter HIIT sessions compared to continuous training were effective in lowering body fat in overweight/obese adults, but not in healthy adults [57, 58]. Furthermore, running HIIT sessions were more superior in lowering body fat than cycling HIIT sessions in overweight/obese adults [58]. Overall, HIIT can be a good alternative to continuous training provided that it is appropriately designed to fit the individual's goals, level of fitness, age, and health constraints. Comprehensive reviews on HIIT program designs will be found in the references cited above.

Periodization

Periodization refers to a systematic way of designing a training program in a manner that unifies short-term and long-term programs and incorporates the Principles of Training to maximize performance and health gains. Periodization is typically used in sports for athletes to achieve peak performance during desired competitions such as the Olympics or World Cup. Thus, a periodized program is designed to be specific to achieving one's goals within a specified amount of time, the demands of the activity/sport, the individual's level of fitness, the number of competitions per season, and the amount of recovery needed after competitions. This approach is traditionally structured into:

- Macrocycles—long, ~6-month to 1-year programs
- Mesocycles—medium, ~1-month programs
- Microcycles—short, ~7-day training programs

Within a macrocycle are mesocycles, and within a mesocycle are microcycles. Training load (volume*intensity) is designed to increase progressively during the early phase of the season, applying the Principles of Overload and Progression to attain physiological adaptations. For instance, one's training load may slightly increase from one microcycle to the next microcycle. As the competition date approaches, training load and the type of exercises become more specific to the activity/sport. Training volume typically decreases and specificity in the exercise type and intensity increases when close to the competition date. Finally, after the competition or season is over (i.e., the end of a macrocycle or mesocycle), a rest/recovery period is typically included in the periodized program to recover from injuries and fatigue before the new/upcoming season. In the study on elite swimmers cited in Sect. 25.2.4.2, training load peaked on specific months (i.e., October, February, and June) possibly due to the dates of competitions that the swimmers had anticipated to participate in [51]. Training load decreased for weeks after reaching the peak, then gradually increased again for the next subsequent peak [51]. Notably, designing a periodized program is more challenging for team sports, which involve competing in multiple games during the in-season before reaching the championship. Studies have shown that in professional and elite team sports, their periodized programs employ short-term training cycles with high training loads during the early preseason, lower and tapered training loads during the late preseason, and moderate training loads in between games during the in-season [59]. Comprehensive reviews and alternative periodization

structures with similar features are discussed elsewhere [59]. Importantly, a periodized cardiovascular exercise program can also be utilized by the non-elite. This approach has been shown to improve cardiovascular fitness and reduce body mass index as well as body fat percentage in inactive adults [60].

Cardiovascular Exercise Alone vs. Combined Cardiovascular and Resistance Training

Endurance performance, exercise economy, and maximal speed are among the major benefits of incorporating resistance training to endurance sport training programs [61]. In healthy and overweight/obese inactive populations, combined cardiovascular and resistance training, including periodized programs, has also been shown to lower body mass, fat mass, and body mass index and improve lipoprotein profiles [62–64]. Although some studies show that this approach may not be superior to cardiovascular exercise alone [62], combined training can increase fat free mass to a greater extent [63], implying this approach provides additional beneficial skeletal muscle adaptations in inactive individuals. Indeed, the ACSM Position Stand (2011) and Physical Activity Guidelines for America (2018) recommend including resistance training 2–3 days per week into a cardiovascular exercise program. Resistance training will be extensively discussed in Chap. 26.

25.3 Contemporary Understanding of the Issues

When exposing children and adolescents to physical activity, their unique exercise characteristics are important to consider for safety reasons. The key point here is that the exercise program should not be as physically and mentally demanding as that in trained adults. This also increases the likelihood of children and adolescents adhering to exercise throughout their lifespan. For adult women, taking into account hormonal status (i.e., premenopausal, menopausal) and sex hormone fluctuations (i.e., MC, use of contraceptives, etc.) may be the key to optimized training. Furthermore, regular cardiovascular exercise on most days of the week, with an emphasis on long exercise durations, is beneficial for attenuating the negative effects of menopause in women. Short-term and long-term training programs must be designed in a manner that follows the Principles of Training to obtain the greatest gains. Program designs should be well-rounded [26] and flexible rather than rigid [59], like combining a cardiovascular and resistance training program. Finally, regular cardiovascular exercise on most days of the week, or in other terms, having an active lifestyle throughout your life improves health even in the absence of weight loss.

25.4 Future Directions

Continuing research on exercise is paramount in understanding how the body works and in developing a means to maximize health benefits and exercise performance. Indeed, more research for the development of specific recommendations is still needed, especially for children, adolescents, and women. Currently, women have no guidelines of their own, despite their differences from males. Women experience an earlier onset of adolescent changes; therefore, it might be beneficial to develop different cardiovascular training guidelines to adjust for those changes during the adolescent period. Recommendations should also be further developed for premenopausal women during adulthood to maximize the female's greater reliance on fats as a fuel source and the differences detected in exercise performance between menstrual phases. Furthermore, postmenopausal women are at risk for accelerated declines in bone health, lipid and glycemic control, as well as skeletal muscle strength parameters that can be maintained or improved with an appropriate long-term exercise program. More research is also warranted for optimizing multiple component training programs beyond combined cardiovascular and resistance training, such as the inclusion of functional exercises (strengthening the deep musculature of the trunk) for further improving cardiovascular fitness, exercise performance, prevention of injuries, and exercise adherence.

25.5 Concluding Remarks

In this day and age, the importance of maintaining a healthy and active lifestyle and starting from an early age cannot be stressed enough. The physical, health, and psychosocial benefits of regular exercise are plentiful. Staying physically active throughout the lifespan may be more likely if one starts participation and adheres to physical activity during childhood. Health risks are greater in women after menopause, and exercise can reduce such risks. Exercise programs should be individualized based on one's goals and fitness level. Finally, minimal amounts of exercise are better than none; however, following the general recommended guidelines and Principles of Training will provide greater improvements in performance and health.

Chapter Review Questions

1. Which among the following is a general cardiovascular exercise guideline for healthy and older adults?
   (a) ≥20 min per day, 2–3 days per week at moderate intensity
   (b) ≥30 min per day, 5 days per week at moderate intensity

(c) <10 min per day on most days of the week at low intensity
(d) >60 min 1–2 days per week at low intensity

2. What is the general cardiovascular exercise guideline for children?
   (a) As little exercise as possible to keep them safe
   (b) 15–20 min per day for at least 1–2 days per week
   (c) ≥60 min per day at moderate to high intensity at least 3 days per week
   (d) ≥60 min per day at vigorous intensity 6–7 days per week
3. Which of the following statements is true?
   (a) A short recovery period between consecutive competition seasons is important to recover from injuries and prevent potential development of chronic fatigue
   (b) Recovery periods are not important
   (c) Recovery periods are only important for kids
   (d) Rest and recovery for 8 months to a year will not affect exercise performance
4. What does the Principle of Overload refer to?
   (a) The progressive increase in exercise intensity, volume, or frequency over time so the body continues to physiologically adapt to the increase in load, which further improves performance
   (b) The overproduction of ATP that occurs with consistent training at vigorous intensity over a long period of time
   (c) The rate of progression of a training program
   (d) The Principle of Overload does not exist
5. Which among the following is the most validated and appropriate marker that can be used to set training intensity when designing a training program?
   (a) How much you sweat at a particular pace
   (b) Absolute time it takes for you to complete an exercise
   (c) Your maximum HR
   (d) Your BW
6. The simplest validated formula for determining maximum heart rate is
   (a) HRmax = 200 − age
   (b) HRmax = 220 − age
   (c) HRmax = 210 − age
   (d) HRmax = 225 − age
7. Which of the following statements is true?
   (a) The only benefit of regular cardiovascular exercise training is weight loss.
   (b) There are no sex differences in substrate metabolism during exercise.
   (c) Cardiovascular exercise is not important for postmenopausal women.
   (d) Cardiovascular exercise can improve metabolic health, independent of weight loss.
8. Which of the following most likely describes a healthy inactive older adult exercising at vigorous intensity?
   (a) Bicycling at 60% VO_2R
   (b) Bicycling at 30% VO_2max
   (c) Bicycling at RPE = 8
   (d) Bicycling at 50% HRmax
9. A well-rounded cardiovascular exercise program includes
   (a) Vigorous intensity exercise 5 days per week
   (b) Cardiovascular and resistance exercise at the same intensity and volume for 2 years
   (c) Resistance training 2–3 days per week
   (d) Running because running is always the best type of cardiovascular exercise
10. Which among the following statements is false?
    (a) HIIT is not always superior to moderate intensity continuous training, but is nonetheless a good alternative
    (b) Performance and health gains are optimized by well-designed programs that follow the Principles of Training
    (c) Previously inactive adults who have begun to regularly exercise but below the recommended guidelines will not gain any beneficial physiological adaptations
    (d) 10-min exercise bouts for at least 30 minutes per day at moderate intensity can maintain cardiovascular fitness

Answers

1. b
2. c
3. a
4. a
5. c
6. b
7. d
8. a
9. c
10. c

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Resistance Training Guidelines for Active Females Throughout the Lifespan, from Childhood to Elderly

26

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Learning Objectives

After completing this chapter, you should have an understanding of:

- The role of strength as a neuromuscular essential conditional capacity for humans.
- Effects of Resistance training in the Muscular-Skeletal tissue through lifespan.
- The relevance of resistance training as an essential component to attenuate the incidence of injury and promote health at all ages from childhood to elderly.
- How to approach resistance training programs for children, and adolescents.
- To properly design and conduct resistance training programs for adults and elderly.
- Understand the influence of hormonal status on the expected resistance training outcomes in women.

26.1 Introduction

Humans need to generate force to support the body weight and lift and carry against the pull of gravity on Earth. Strength is the neuromotor ability to generate force [1] that has an essential role in supporting athletic performance. Nevertheless, appropriate strength levels are also required to support health and well-being across ages [2, 3]. Within this context, the development of muscular strength by the implementation of resistance-based training is essential for muscle fitness and function.

Resistance training (RT) configures a specialized method of training that involves the progressive use of a wide range of resistive load, different rates of muscle activation or movement velocities, and a variety of training modalities. These modalities include weight machines; free weights (barbells and dumbbells); medicine balls; elastic bands; an individual's own body mass; weight vests; or more sophisticated devices. From this point of view, RT is a more complete term that should be distinguished from the competitive sports of weightlifting and powerlifting [4].

RT is currently considered essential in the athletic preparation and a key component for optimizing growth and maturation in children [2], promoting health and quality of life in the elderly [5] and attenuating the incidence of injuries in a physically active populations [6]. Qualified professionals are necessary to design effective RT programs across all ages and disciplines. They must consider specific needs and make the necessary adaptations to meet performance outcomes for athletes as well as for the nonathlete. For that purpose, strength and conditioning coaches need a science background and a basic understanding of how the process of growth and development occurs across sex and all ages. It is important for them to understand how an active or sedentary lifestyle impacts the health and quality of life in all humans so that they can impart this attitude to those they meet and coach.

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26.2 Research Findings and Contemporary Understanding of the Issues

26.2.1 Skeletal Muscle as an Essential Organ for Health

Skeletal muscle is a tissue able to metabolize fats and carbohydrates (up to 80%) and synthesize and release a wide range of proteins with local and systemic effects [7] in

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both exercising and resting conditions. Therefore, muscle is considered an organ in itself [8]. Skeletal muscle is the primary site of glucose placement and the largest reservoir of human body protein. Diminished muscle mass results in an impaired glucose metabolism—related to increased risk in the genesis of chronic diseases [9]. Indeed, a healthy skeletal muscle mass (SMM) represents the major energy consumer and contributor to maintain an elevated metabolic rate at rest and during exercise [10]. An active lifestyle across ages aimed to maintain the appropriate muscle amount and function must be a priority for promoting health and attenuate the deleterious effects of aging [11, 12]. Loss of muscle mass is an index of undernutrition, mortality, and physical disability [13]. However, despite the known importance of muscle mass and function, general measures such as total body mass and body mass index (BMI) are used to assess and predict health status, dependence, longevity, mortality, and risk of diseases [14, 15]. Total body mass and BMI do not distinguish the proportion of muscle mass and fat and could be misleading, especially for athletes.

26.2.2 The Importance of Muscle Growth and Its Relationship with Bone Health

Muscle and bone structures are related to the quantity and quality of loads they have to endure [16]. Muscular contractions represent the most important physiological stimulus to strengthen the skeletal system [17] and are a determinant factor in the improvement and preservation of muscular function and bone health across all ages. Childhood and adolescence are the most crucial and sensitive periods for accelerating the growth in bone mass [18]. Research has shown a 40–60% increase in bone density in girls who exercise before pubertal growth compared to girls who exercise 2 years after menarche (+10 to 20% in bone density) as well as for women who exercise only after the age of 18 (+5% in bone density) [19]. An adolescent progresses and continues in a linear positive path in bone density and formation until their twenties. However, up to 90% of peak bone mass is acquired by age 18 in girls and by age 20 in boys, which makes youth the best time to "invest" in one's muscle and bone health. The amount of bone tissue in the skeleton, known as bone mass, can keep growing until the late twenties. At that point, bones have reached their maximum strength and density, known as peak bone mass. Women tend to experience minimal change in total bone mass between age 30 and menopause. But in the first few years after menopause, women's bone density losses a range from 0.5 to 1% per year and becomes more evident in women during menopause and postmenopause [20]. It is, therefore, important to highlight the importance of childhood and adolescence periods for conducting supervised RT programs that will maximize peak bone mineral content [21, 22].

Skeletal muscle mass (SMM) is the largest component of lean body mass (LBM) in humans [40–50% of total body mass (BM)], with more than 650 muscles allowing every movement and posture for the human body [23]. SMM changes with age, gender, ethnicity, and environmental influences. At birth, SMM is between 23 and 25% of total BM and continues growing by increasing the number of muscle cells (hyperplasia) for a short time after birth. Thereafter, SMM acquisition occurs mainly due to the increase of muscle cell thickness (hypertrophy) [24]. As in bone mineral density, SMM diminishes with aging, being evident after 30 years old in sedentary population [25]. Indeed, in early adulthood, a concomitant and progressive increase of fat mass that "replaces" SMM has been reported [26]. Losses result on 10% average between mid-20s and 50s probably caused by significant reduction in physical activity (PA). In sedentary population, after 30 years, the rate of SMM loss is 3–8% per decade and is associated with a concomitant reduction of muscle strength. This rate of decline will be higher after 60 years of age [27]. Nonetheless, individuals who maintain good habits—ingesting appropriate amount of proteins [~1.6 grams/kilogram (g/kg) of BW per day] [28] combined with regular resistance exercise—demonstrate a significant attenuation of SSM loss compared to sedentary counterparts with poor dietary habits. In nonphysically active elderly individuals, the loss of SMM is about 50% with respect to the level achieved during early adulthood [25]. Women's SMM corresponds to 45% of their BM compared to 54% made by males [24]. Such differences seem to be due to a trend to maintain higher levels of PA in males at any range of age [29–31], making females more susceptible to injury, poor physical condition, or lower bone mineral content [32].

For several years, research has focused more on the bones and joints' consequences of the aging process than on muscle mass and functioning [33]. However, a decrease in SMM is a consequence of aging process with serious impairments on muscle function [33, 34]. Sarcopenia is a progressive and generalized skeletal muscle disorder associated with increased likelihood of falls, fractures, physical disability, and mortality [35]. Low muscle strength is the primary parameter associated to sarcopenia which increases physical frailty and is partly responsible for hospitalization and loss of independence in many older people [36]. Although sarcopenia is common among older adults, it can also occur earlier in life. The prevention of age-related loss in muscle mass and strength is essential for preserving independent living and quality of life with aging [37]. Epidemiologic research has reported values of sarcopenia

from 5 to 13% in elder between 60 and 70 years, and up to 50% for those 80 years or above [34]. Interestingly, there is a higher incidence of sarcopenia in women (8.5%) compared to men (4.1%) in 65–74 years old elder [38]. The primary factors affecting the degree of muscle mass loss and poor muscular functionality are dietary protein intake and physical activity habits [39, 40]. In fact, physically active individuals significantly attenuate muscle loss during aging [41]. The shift of muscle fiber distribution (fast to slow muscle fiber type) with aging is influenced by two events: (1) disuse (immobilization), and (2) denervation. Low levels of physical activity induced fast motor units denervation contributing to an increased proportion of slow type fibers [42, 43]. Note that the aforementioned changes are drastically influenced by the level of physical activity rather than the aging [26]. Indeed, the progressive reduction of fast motor units is associated with a loss in power output necessary for quick movements (stand up, sit down, climbing stairs) and postural adjustments. The reduced capacity to apply force quickly impacts negatively their ability to control body position and maintain balance and avoid fatal falls [44]. Moreover, this loss is accompanied by an increase in the placement of lipids in adipocytes within and outside cells [26].

As muscle is lost, the mechanical stimulus to bone tissue and bone metabolism is decreased affecting bone turnover [45]. With a higher prevalence of osteopenia (women: 49%, men: 34%) and osteoporosis (women: 18%, men: 5%) in women compared to men [46, 47] and a lower SMM compared with non-osteoporotic matched controls [48], women may be more susceptible to benefit from resistance exercise prescription. The prevalence of sarcopenia in premenopausal women with osteoporosis is 12.5%. Similarly, 75% of women suffering from osteopenia and osteoporosis—including pre- and postmenopausal women—have associated sarcopenia. On this note, individuals with reduced SMM and bone mineral density and increased risk of osteoporosis show a considerably low incidence in physically active persons [49]. Bone-related diseases such as osteoporosis and osteopenia are unusual in young healthy and active population such as children, adolescents, or young adults. Those conditions early in life are influenced by chronic diseases (i.e., eating disorders, cystic fibrosis, liver disease, renal disease, diabetes, or cancer among other) or prolonged low energy availability or malnutrition.

Although an active lifestyle, without engaging in regular physical training, has shown to be enough to maintain about 80–90% of the mechanical properties of ligaments, exercise exposure is necessary to further increase the remaining 10–20% of strength and stability of ligaments in sedentary women [50]. In this sense, a well-designed exercise program (including resistance exercise) helps maintaining or increasing strength and protecting tendons and ligaments from injuries across ages, including elderly [51].

26.3 Determining Strength Expression During Resistance Exercise Training

An effective training stimulus can be only elicited by forcing the organism to adapt to a relatively new situation (e.g., higher physiological demands, strength, endurance, etc.). In the case of RT, overload is provided by performing exercise using resistances which goes beyond normal levels of performance. From a practical point of view, a strength and conditioning coach can design RT session using different exercise performing several repetitions with external resistance by adding weight, bands, or other methods specifically designed for applied overload to human movements (i.e., air or hydraulic system) [52].

The intent is to stress the body at a higher level than previously stressed. However, in order to avoid overtraining, coaches must consider the appropriate way to manipulate the following training variables:

1. Physiological and neurological-related variables: Intensity, volume, rest interval between sets and exercises, frequency, and duration of workouts.
2. Biomechanical-related variables: selection and order of the execution of the exercises included in the workout session, devises used to perform the exercises: e.g., free weights, weight, air pressure or hydraulic machines, elastic bands, medicine ball, vibratory stimulus, etc.

26.3.1 Physiological and Neurological Variables

26.3.1.1 Training Intensity and Volume (Sets and Repetitions)

In RT, the intensity has been typically referred to the relative amount of weight (percentage of the maximum load mobilized in one singular maximal repetition, 1RM) lifted for each exercise, whereas the volume generally refers to the total amount of work performed in a training session [53].

Training intensity is the key component for conducting an optimal RT design [54]. Intensity of exercise has been defined as the degree stress or resistance to the stressor (overload) expressed by the human body when performing a given task. In resistance exercises, the intensity is determined by the magnitude of force and the time over which the force is applied [52]. Within this context, the intensity results by the combination of two main factors, the relative load and the

movement velocity [52]. This consideration is particularly important when using submaximal loads (e.g., ~30 to ~85% of the 1RM) that can be intentionally lifted at maximal (fast) or submaximal (controlled or slow) movement velocities, or when as a result of fatigue, the velocity drops below certain thresholds. For instance, a 10% drop of the maximal movement velocity determines that the athletes perform exercises at ~90% of the maximal possible velocity achieved when exercising without fatigue (i.e., first repetitions of a set performed at the beginning of the workouts) [54, 55]. According to these criteria, the relative load (%1RM) and movement velocity (% of maximum) achievable when exercising with no fatigue allow the identification of the following 5 loading or strength training zones [52].

1. Maximum Strength: The resistance is maximal >85% of the estimated 1RM in dynamic exercise. The magnitude of the resistance impedes modulating the movement velocity [52].
2. Impulsive Strength using light loads: Refers to the capacity to apply the maximal possible force to light to moderate resistances (up to ~60% of the estimated maximum). In dynamic exercises, this strength expression is generated during maximal velocity movements using light loads, as occurring during ballistic actions, e.g., jumping or throwing [56].
3. Impulsive Strength heavy loads: Refers to the capacity to apply the maximal possible force to moderate or heavy resistances (up to >60 to ~85% of the estimated maximum). In dynamic exercises, this strength expression is generated during maximal velocity actions using heavy loads as occurring during weightlifting [56].
4. Endurance Strength light loads: In dynamic exercises , resistances are between ~30 and ~60% 1RM of the estimated 1RM. The movement velocity is submaximal, below 90% of the maximal possible movement velocity achieved with no fatigue (impulsive action) [56].
5. Endurance Strength heavy loads: In dynamic exercises, resistances are between >60 and ~85% of the estimated 1RM. The movement velocity is submaximal, below 90% of the maximal achievable with no fatigue (impulsive action) [56].

As previously indicated, the volume of RT estimates the total work performed considering the applied force and the distance or range of motion, completed in each repetition of every exercise. Nonetheless, given the interindividual variabilities of body size and anthropometric dimensions, calculating the work across different persons and exercises, although possible, is still a complex task. Therefore, a more practical approach for RT sessions is to estimate the volume of the entire workout, by the product of the total number of repetition and sets performed per exercise multiplied by the actual resistance (load) used in each set or repetition [56]. A set is a group of repetitions sequentially performed before the athlete stops to rest. A representative value of the volume can be obtained by multiplying a total number of repetitions by the amount of resistance used (kg).

26.3.1.2 Rest Between Sets

Rest between sets refers to the time allocated to recovery between sets and exercises. The length of rest periods is dictated by the aim of the RT zone trained in each workout (strength, impulsive or endurance), but also by athlete's training status [52]. High-performance athletes recover faster than novice or low-performance practitioners [57]. Additional considerations are that age and state of maturation stage can also influence recovery between sets. Children and adolescents, despite being less strong and less powerful than adults, tend to recover faster [58]. In overall lengths of rest period for strength, impulsive oriented workout are longer (>2 to 3 min) than when training for muscle endurance (~1 to 2 min) or focused in gaining muscle mass (~2 min) [52].

26.3.1.3 Frequency of Training

Refers to the number of workouts conducted in a given period of time usually a week or microcycle [59]. The optimal training frequency is highly influenced by the training status, the volume of each singular workout and the sport discipline by which the RT component needs to be integrated with other exercise modalities. With respect to training-induced muscular hypertrophy for fitness or body building, the frequency of training is often associated to the number of times a given muscle group is trained, and it is generally associated with a 1-week training duration [60].

26.3.1.4 Duration of Session and the Available Time per Session

The duration of workouts refers to the time each session requires to be completed. Although this variable has been closely associated with the volume which quantifies the total work and is estimated by the number of sets, the duration is related only with the time needed to compete the volume and obviously needs to include the rest period between sets.

26.3.2 Biomechanical Variables

26.3.2.1 Exercises Selection and Order of Execution

The selection of the exercise depends on the body area to be target in each workout. In overall resistance, exercise has been classified as either core or assistance. Core exercises recruiting large muscle areas (i.e., chest, shoulder, back, hip,

or thigh), involving two or more primary joints (multi-joint exercises), for example, squat, cleans, or lunges, are usually prioritized and consequently performed at the bringing of the training session [61].

Assistance exercises in overall recruit smaller muscle areas (i.e., upper arm, abdominals, calf, neck, lower back, anterior or posterior thigh, etc.). These groups of exercises generally involve only one primary joint (single-joint exercises), having less impact on athletic performance but still be useful to prevent muscle imbalance or local muscle weakness or as a part of injury prevention programs [62]. An example of using stability exercises to support multi-joint activities could be activation of the trunk musculature (abdominal and lumbar) assisting in stabilizing the spine and improving hip and knee stabilization. This is of relevance to prevent the incidence of anterior cruciate ligament injury [63]. In any case, the order of exercise execution should be dictated by the goals of the session. For instance, multi-joint impulsive exercises demanding a highest level of skill and concentration, such as weightlifting and derivatives, need to be performed with no fatigue and therefore included at the beginning of the session [64]. Athletes who become fatigued are prone to using poor technique and consequently are at higher risk of injury.

26.3.2.2 Training Device

The type of device or resistance will impact on the way muscles are activated and consequently influence on the induced training outcomes [65]. Although a detailed description of the type of resistance used in strength training is beyond the scope of this chapter based on the nature of the acting forces on the musculoskeletal system, five groups of resistances can be identified:

1. Constant, iso-inertial-resistance: Free-weight or any other gravitational-based implement or equipment (medicine ball, smith machines) or progressive loading system as chains or more sophisticated machines [56].
2. Variable gravitational-based resistance: Lever-arm-based systems or CAMs [56].
3. Accommodating resistance: including two technologies systems (1) Isokinetic in which the movement velocity is controlled while the applied force changes over the range of motion at a relatively constant velocity [65] and (2) Isotonic that controls the force and measures changes in movement velocity over a range of motion at a constant force.
4. Nongravitational resistance: vibration machines [66] and rotary inertial machines (flywheel-based equipment) [67].
5. Combining different mode of resistances: (1) hydraulic and pneumatic-based equipment which combines non-gravity with accommodating resistance [65] (2) simple pieces of equipment such as bands, springs that combine non-gravity with progressive resistance [68] or chains that use gravity while is applied progressively [69].

26.4 Resistance Training for Children and Adolescents

The term 'children' refers to boys and girls approximately up to age 11 in girls and 13 in boys. This period of life has been identified as preadolescence. The term 'adolescence' refers to the phase occurring between childhood and adulthood and includes girls aged ~12 to ~18 years and boys aged ~14 to ~18 years. Recent studies have focused on the SMM benefits of children participating in sports, jump-based training, and RT [70]. Research supports that regular physical activity including lifting and jumping exercises during childhood and adolescence results in greater bone mineral density than when training starts during adulthood. Active children showed 5 to 8% higher bone density compared to sedentary counterparts. Resistance and jumping training both improve muscular strength and mechanical power; although there are no meaningful increases in muscle mass. Such muscular changes occur due to neurological adaptations in lieu of the lack of testosterone in children [4]. Muscles attach to growth plates in the bone. Regular and intermittent increased levels of muscle activation as occurring during physical activity stimulate proper bone growth [24]. BMD, bone mineral content, and growth hormone activity also increase with neuromuscular-based training such as lifting, jumping, or gymnastic [71]. Zanker et al. reported that high impact exercise before 7 years old seems to be beneficial for bone mass acquisition. In prepubertal stages, some authors have shown gains from 2 to 4% in bone mass related with different exercise programs; moreover, strength-related exercises and high impact exercises such as jumps reported longer benefits [72]. Junior Olympic powerlifting and gymnasts reported greater bone mineral density values compared with general population. In addition, preadolescents shown also higher bone mineral density and strength after high-impact (jump-based) and RT [73].

Current evidence shows that preadolescent girls have similar strength to boys [74]. Sex-based differences are noticed during the adolescence period: boys become taller, with higher muscularity, and lesser body fat than females [75], and girls go through adolescence earlier than boys [76]. This may suggest that physiological adaptations may be different between sexes during the late preadolescent stage and that exercise guidelines must be distinct for preadolescent girls. Unfortunately, studies on the physiological responses to exercise of young female athletes are scarce due to limitations of noninvasive experiments [75]. Thus, at present, there

are no differences in RT guidelines for boys and girls or during the adolescence.

26.4.1 How to Approach Strength Training with Children and Adolescents

In the past, RT was avoided for children due to unfounded beliefs of potentially deleterious effects on growth and maturation. This fear was in reference to children's growth plates closing prematurely with the stresses of resistance exercise placed on the plates. The theory originated from research on animal models and from monitoring the effects of the intense exercise regimen maintained by gymnasts, who seemed to have a corresponding decrease in growth. RT was also dismissed under the belief that children could not receive the benefit of increased strength due to their lack of androgenic hormones [24]. However, current evidence-based reports have found that carefully prescribed and supervised PA programs including resistance exercises can be safe and effective for children and adolescents [76, 77]. RT should be approached in a manner that will encourage a positive attitude towards active lifestyles, which might lessen the incidence of sedentary behaviors during adolescence and adulthood.

Resistance training programs need to be carefully designed based on physiological events. Training intervention exceeding a youngster's capacity not only increases the risk of overtraining, injury, and burnout, but may undermine enjoyment of the training experience [78]. Since the age of ~6 years could be an appropriate time to start with regular sport activities, including resistance exercise, in children. For instance, playground equipment, such as jungle gyms, monkey bars, and rock walls, can encourage children to climb and pull themselves up [79]. These types of activities resemble load bearing and body weight RT. The Centers for Disease Control and Prevention, or CDC, has made several recommendations on how to get and keep children active. They include but are not limited to, leading by example, going to parks or community recreational centers, encourage children, and again, making the activities fun [80].

Even though there are several organizations and studies that have suggested their own guidelines for RT programs with children and adolescents, in overall the following variables should be considered when designing strength-based trainings for children and adolescents: (1) choice and order of exercise; (2) workout configuration including the integration intensity and volume; (3) repetition number and recommendation about the execution velocity; (4) rest intervals between sets and exercises; and (5) training frequency.

26.4.1.1 Type of Exercise and Order of Execution for Children

The American College of Sports Medicine (ACSM) recommends both multi- and single-joint exercises [3] targeting multiple muscles and major muscle groups, respectively, for multi- and single-joint exercises. This allows the child to perform the more difficult and tiring exercises without fatigue. The chosen exercises should promote muscle balance across joints and between opposing muscle groups. It is reasonable to start with relatively simple movements (e.g., squat with no external resistance, leg press, knee supported push-ups, or slight 1–2 kg medicine ball throw) and gradually progress to more advanced exercises as confidence and competence improve. A progressive strategy to introduce children with proper execution of weightlifting exercises is highly advanced, provided a qualified coaching is available [81].

26.4.1.2 Workout Configuration (Intensity and Volume) for Children

For beginners, 1 or 2 sets of 8–12 repetitions with a moderate load (<60% 1RM) and between 6 and 10 exercises per session could be a reasonable approach [4]. Thereafter, gradually progress depending on the acquired skills will be implemented [2]. For multi-joint complex exercises (e.g., back squat or weightlifting techniques), it is recommended to perform fewer repetitions (e.g., <6), while providing real-time feedback after every repetition to guarantee and preserve proper movement patterns. As participants progress, demonstrating higher skills and control of the movements, a 5–10% increase (about 1–5 kg) is appropriate for most exercises in order to maintain a desired training stimulus.

Regarding the volume, overall, a gradual progress to 2-or 4-sets of 5–8 up to 12 repetitions with a moderate (~60% 1RM) to heavy (<80% 1RM) but no maximal (>80% 1RM) load is advised [2]. Overall, the total number of repetitions per exercise should be up to 25: E.g., 4 sets of 8 with heavy loads or 2 sets of 12 with light, moderate loads [82].

26.4.1.3 Rest Intervals Between Sets for Children

While a rest interval of 2–3 min for primary, multi-joint exercises is typically recommended for adults, this recommendation may not match the needs and abilities of children and adolescents who have demonstrated faster recovery process compared to adults [83]. Shorter rest interval (1 min for children and up to 2 min in adolescents) between sets could be appropriate. Nonetheless, young athletes performing complex exercise demanding high level of strength and mechanical power may require longer rest intervals to fully recover between sets.

26.4.1.4 Repetitions and Movement Velocity for Strength Training for Children

The number of repetitions per set and the velocity of execution will dictate the intensity and therefore the strength expressed (maximal, endurance, or impulsive). Since beginners need to learn how to perform exercises correctly as they enhance their RT competency, it is recommended to start with light to moderate load in a controlled manner, initiating with low to moderate velocity, and only progress to a faster impulsive action when a complete mastery of the exercise technique is demonstrated [12]. Over time, based on the type of strength that needs to be trained, different number of repetitions and movement velocities may be prescribed.

26.4.1.5 Frequency of Strength Training for Children

A training frequency of two to three times per week on non-consecutive days is recommended for most children and adolescents [84]. This frequency with 48–72 hours (h) between sessions will allow for adequate recovery favoring optimal training effects. Nonetheless, lower frequency (~1 workout per week) whether integrated with other physical activities could successfully maintain training gains [70]. The main recommendations on how to design RT workout for children and adolescents are summarized in Table 26.1.

26.4.1.6 Specific Program Design Considerations and Progression Strategies for Children and Adolescents

In order to establish a habit of regular exercise that will carry over to the adult years, participants should have a positive experience. Strength and conditioning coaches need to be aware that poor experiences, related to excessive training overload, and frustrations due to unrealistic expectations are typically associated with diminished levels of participation [85].

Progression in terms of increasing overload or exercise complexity is essential to maximize fitness improvements and maintain motivation with training-related activities. According to Stricker et al. [82], the following considerations should be followed to guarantee safety and optimal training outcomes in children and adolescents: (1) Exercises should be performed initially with very light load until proper technique has been mastered; (2) Incremental loads may then be added by using either more complex exercise execution, including body weight, or other forms of resistance as long as proper technique is maintained; (3) Occasional, strength assessments (including 1RM test) may be appropriate to develop an individualized RT program and monitor progress; (4) Exercise selection should prioritise all major muscle groups with emphasise in core using multi-joint exercises, such as squats and weightlifting techniques; and (5) constantly evaluate any symptom of illness or sign of injury or overuse from RT or sport participation and decide to change the program demands whether it is necessary to protect children's health. Table 26.2 summarizes the guidelines to implement strength and conditioning training in children and adolescents.

Table 26.1 Workout configuration for children and adolescents. Adapted from Faigenbaum AD, Naclerio F (2016), Paediatric strength and conditioning. In: Jeffreys I, Moody J (Eds.) Strength and Conditioning for Sports Performance, 1st ed. Routledge, New York, NY, pp 484–505 [4]

Strength (weightlifting)	Repetitions per set, 1–5 with >60 to ≤80%
	Total repetitions per exercise ~15 to 25
	Well-trained youth can occasionally perform a few repetitions using higher loads (>80%)
Impulsive strength (jump- or throwing-based exercise)	Repetitions per set 1–5 and up to 10 when there is a short inter-rep rest (~5 s)
	Total repetitions per exercise 15–30
Muscular endurance (starting training zone)	Repetitions per set 5–8 up to 12 with ≤60%
	Total repetitions per exercise ~20–25
Rest period for children 30 s to 1 min and for adolescents up to 2 min	
Training frequency 2–3 per week	

26.4.2 Resistance Training as a Preventive Factor from Injuries and Healthy Posture Later in Life

RT is one of the most effective strategies to attenuate acute and overuse injuries related to sports [6]. In female athletes, RT combined with proper instructions on exercise executions implemented throughout a multifaceted program integrated by different kinds of exercises (jumps, running, changes of direction, concentric and eccentric contraction modalities) proved to be effective in decreased anterior cruciate ligament (ACL) injuries [86]. However, one area of concern is the appropriate dosage of RT and its combination with other physical activities. Excessive volume, as usually conducted during preseason phases, could be the cause of overloading, leading to overuse injury in athletes, despite the inclusion of injury prevention programs [70].

Faigenbaum and Schram looked at five studies dealing with RT and incidences of sport injury [87]. The participants of the studies analyzed by these authors were divided into an exercise and a group, ranged in ages from 13 to 19 years old or listed as high school students and included both males and

Table 26.2 General strength and conditioning guidelines for children and adolescents. Adapted from Faigenbaum AD, Naclerio F (2016), Paediatric strength and conditioning. In: Jeffreys I, Moody J (Eds) Strength and Conditioning for Sports Performance, 1st Ed. Routledge, New York, NY, pp 484–505 [4]

Qualified Sports Science Professional should be able to provide appropriate instruction focused on developing and preserving proper exercise technique (this aspect represents an essential priority). Avoiding excess overloading is essential to avoid overtraining and reduce to a minimal the risk of injury and dropouts
Carefully monitor individual responses and progression over the program
A starting phase including about 10 min-based dynamic-exercise warm-up to motivate and engage children and adolescents with the task is highly advisable
Perform 1–3 sets of 6–12 repetitions in a variety of strength exercises
Perform 1–3 sets of 3–6 repetitions in a variety of more complex, weightlifting-based exercises
Include core multi-joint exercises aimed to strengthen the abdominal, hip, and lower back region
Progress from simple movements to more advanced exercises as resistance training skill competency improves
Rest period between sets is shorter in children (~1 min) and progressively longer in adolescents (~2 min)
Progression by increasing volume (number of sets, rep, or adding exercise) and load should be gradual and carefully monitored
Cool down with less intense calisthenics exercise before ending the session
The recommended weekly frequency of resistance exercise-based workout is between two to three times on nonconsecutive days
Systematically vary the training program to optimize adaptations and maintain interest
Integrate resistance training programs with other sport-games-based activities that can include or not competitions

females. Participants were also involved in a variety of team sports. The training time lasted anywhere from 5 to 6 weeks up to around one year. The training offered was a multicomponent program that included RT with other forms of training such as cardiovascular, flexibility, and speed and agility drills. RT included weight training, plyometrics, and proprioceptive training. No study made use of all forms of training. One study looked at only RT in the form of proprioceptive and jump-based training. All investigations reported a decrease in injuries, ranging from knee injuries to acute and overuse injuries, as compared to the control group [87].

Posture is a relevant component for health in which RT demonstrated to be beneficial. Corbin et al. list two issues concerning the muscles involving in posture: muscle weakness and muscle rigidity [88]. When muscles on either side of a joint are weaker or lacking flexibility compared to the opposite across the joint, poor posture will follow. Stretching, which should also be a part of PA, should remedy muscle inflexibility. Exercises that work on strengthening the core muscles are recommended for development of a healthy posture [89]. A proper RT program will strengthen the muscles favoring proper posture.

26.5 Resistance Training for Adults and the Elderly Population, with Emphasis for Females

Chronic exercisers present higher functional capacity and quality of life throughout lifespan as age increases [26]. It is known that protein synthesis rates decrease with age. However, research reported that progressive RT can increase protein synthesis rates in only 2 weeks. Those findings have shown protein synthesis rate increases up to 182% following 2 weeks of supervised RT program (78–84 year old) [90] and following 2 weeks of RT in 63–66 years old elder [91] and increases by approximately 50% after 3 months of supervised progressive RT in 76–92 years old elder [92]. Such findings suggest that RT in old men and women increases the rate of muscle protein synthesis in response to RT [93].

The ability to retain muscle mass and strength has been demonstrated in regularly active people, therefore "chronic-exercise is prophylactic against age-related functional decline" [26]. Nevertheless, increases greater than 50% in lower body strength can be obtained by performing short-term [94] and long-term [95] training interventions in older adults. Indeed, master athletes performing 4–5 workout per week showed less proportion of body fat compared to untrained counterpart along with similar body composition as young trained individuals [96].

26.5.1 Resistance Training Guidelines for Adults

RT involves a wide variety of exercises that target specific muscle groups. If performed correctly and consistently in a progressively effective manner, RT will change the muscle's appearance and improve the functional capacity. Current recommendations assume that active adult women respond to RT similar to men [3]. Although this is true in terms of how training adaptations occur, research involving sex hormones showed that hormonal status may impact the magnitude of the gains and the recovery needed between sessions [97–99]. The present section describes (1) the general RT guidelines for adults (which are common for male and females), (2) the research describing sex-hormonal status, and (3) the RT recommendations for elderly.

26.5.2 General Guidelines for Adults

As all training adaptations are specific stimulus applied [3], appropriate RT designs are necessary to specifically target the desired strength loading zone (maximal strength, impulsive strength, or muscle endurance) and obtain expected muscle function or body composition-related outcomes.

Once decided about the loading training, coaches can configure the workout structure by the manipulation and integration of the mechanical (exercises, order and type of resistance) and physiological (intensity, volume, rest periods, frequency and duration) variables. One of the most popular criteria to assign the load and repetitions per set is the Repetition Maximum (RM) continuum [100] (see Fig. 26.1).

1. The RM-continuum is a relatively simple and practical method to design RT particularly for general fitness purposes [52]. Most studies have recommended this methodology to prescribe and assess the effects of strength training in different populations [3, 52]. However, when the RM-continuum is associated with the relative load (% of 1RM) and the movement velocity, the following workout-design recommendations need to be considered *To improve maximal strength*: Novice intermediate individuals should perform between 4–6 sets per muscle group using loads of ~60–70% of 1RM for ~8–12 repetitions [3, 52] and 1–3 sets per exercise. Movement velocity is controlled in order to assure good exercise technique. Advanced athletes can perform 4–5 sets (moderate volume) up to 9–10 sets per exercise (high volume) [101] with loads ~85–100% of 1RM or even supramaximal loads using eccentric spotted-based methods [52]. Repetitions per set are between 1–5, based on the magnitude of the load. Rest periods between sets/exercises should allow for full recovery between sets (>2 to ~5 min based on individuals responses) [102].
2. *To improve muscle endurance and induce hypertrophy:* Novice and intermediate individuals should perform one to three sets per exercise using light to moderate loading (>30 to 60% of 1RM) for ≥ 12 repetitions per set [100]. Advanced athletes can perform 3–4 sets per exercise (low volume), 5–9 (moderate volume) or ≥10 sets per muscle group performing ≥15 repetitions with light to moderate (>30 to 60% 1RM) loads or ~6 to 12 repetitions with heavy (>60 to ~85% 1RM) loads [52]. When training for hypertrophy, although relative loads >60% 1RM have been recommended [103] using light loading zones (30 to <60% 1RM) performed close or until the muscular failure, to increase metabolic stress is also effective [104]. Rest periods between sets/exercises should allow to maintain the relative load and the prescribed number of repetitions. Although a full neuromuscular recovery is not necessary, ≥1 min to ~2 to 3 min have been recommended to maintain optimal hypertrophy stimulus [102].
3. *To improve impulsive strength and enhance mechanical power output*: This performance outcome is highly specific to the sports discipline. Overall, several sets per exercise using light to moderate (~15 to 30–60% of 1RM) or heavy (>60 to 85% of 1RM) loading performed with the maximal possible velocity, avoiding drops of more than 10%, is recommended [54, 104, 105]. Although

Fig. 26.1 RM-Continuum describing the association between the RM ranges and resistance training outcomes [4]. Figure courtesy of Eloi Badia-Rovira, BSc in Exercise Science, University of Lleida, Spain. *RM* repetition maximum; *M* muscular. The darkest background in each goal depicts the principal outcome achieved by selecting that RM range. *For improving mechanical power output, the number of repetitions per set should be around half of those assigned for the RM continuum range. **While the existing repetition range for hypertrophy appears most efficacious, there is emerging evidence that exercising near to the muscular failure will elicit similar levels of hypertrophy regardless of the loading range

when using velocity control devices such as accelerometers or transducers, sets can be interrupted based on velocity thresholds (e.g., 10% velocity loss); in overall, to improve power mechanical output within the impulsive training zones, ~6 to ~8 repetitions can be performed with light loads (≤60% of 1RM) and ~3 to ~5 with heavy (>60 to <85% of 1RM). Rest periods between sets/exercise should allow for full neuromuscular recovery (>2 min with light loads and >3 min to ~5 min with heavy loads) [56]. Table 26.3 summarizes the recommendations for designing RT sessions in adults.

26.5.2.1 Training Volume

Optimum volume allows functional and structural adaptations according to the objectives. Therefore, training out of the optimal stimulus will promote the risk of injuries or will not produce the expected results. Altering the number of exercises, training frequency, intensity, number of repetitions, number of sets, or rest periods will alter the training volume [3]. Due to the interindividual differences in the adaptation response and expected outcomes (i.e., increase or maintain functional capacities or muscle mass) to RT, low, moderate, high, and maximal volumes have been proposed [101]. Table 26.4 summarizes the recommended sets per muscle group and workout associated with the expected outcomes.

26.5.2.2 Types of Exercise/Exercise Selection

In adults, RT exercise includes both single- and multi-joint, unilateral, and bilateral exercises. Single-joint exercises are useful to recruit specific muscles while multi-joint exercises are capable of recruiting major muscle groups which require greater coordination and muscular balance. Multi-joint exercises have been reported as more effective to promote strength gains because more weight can be lifted [106]. It is recommended that novice, intermediate, and advanced individuals perform dynamic repetitions with concentric (CON: muscle shortening) and eccentric (ECC: muscle lengthening) muscle actions as well as isometric contractions (ISOM: no changes in muscle length) to stabilize core strength and specific isometric exercises [3]. Additionally, functional core-based exercises are recommended to enhance muscular balance in joints, core, and pelvic and scapular girdle [107].

For general fitness purpose in novice and intermediate individuals, a typical RT program may include 4 upper body, 4 lower body, and 2 core/abdominal exercises. For advanced fitness training (RT >3 days/week), it is recommended that a split routine be used (e.g., 1st and 3rd day: upper body; 2nd and 4th day: lower body). The recommendation for sequencing during a RT session is to begin the workout with multi-joint exercise recruiting larger muscle mass and end the session with single joint exercise involving less amounts of muscles.

26.5.2.3 Frequency

RT frequency recommendations in novice individuals are lower 2–3 days/week and focused on entire body. The pro-

Table 26.4 Resistance training volume per session and the associated outcomes

Workout volume	Aim(s)
Maximal >10 sets per muscle group (including all the exercise/s acting on the same muscle group). >30 total sets per workout (including all exercises).	Increase functional performance Improve body composition (hypertrophy) Sessions can be performed once a week
High 9–10 sets per muscle group (including all the exercise/s acting on the same muscle group) ~27–30 total sets per workout (including all exercises)	Increase functional performance Improve body composition (hypertrophy) Sessions can be performed up to twice per week
Moderate 6–8 sets per muscle group (including all the exercise/s acting on the same muscle group) ~18–26 total sets per workout (including all exercises)	Increase functional performance Improve body composition (hypertrophy) Sessions can be performed up to three times per week
Low 3–5 sets per muscle group (including all the exercise/s acting on the same muscle group) ~12–17 total sets per workout (including all exercises)	Higher frequencies (>3 times per week) can be performed for increasing functional or body composition outcomes Lower frequencies (one to two times per week) are applied for maintaining previously achieved outcomes

Table 26.3 General recommendations to design resistance training workouts in adults-athletic population. Adapted from Naclerio F, Moody J. Resistance Training. In: Rieger T, Naclerio F, Jimenez A, Moody J, editors. Europe's Active Foundations for Exercise Professionals. first ed. Human Kinetics; 2015. p. 67–96 [52]

		Endurance strength		Impulsive strength	
Variables	Maximum strength	Heavy loading	Light-moderate loading	Heavy loading	Light-moderate loading
Estimated load as percent of 1RM	≥85%	>60 to 85%	≤60%	>60 to 80%	>30 ≤60%
Reps/set	1–5	12–6	≥12	1–3 up to 5	6–8
Rest between exercises/sets	2–5 min	≥1 min to ~2–3 min		>3 to 5 min	~2 min

gression from novice to intermediate RT depends upon other variables such as volume and intensity more than frequency. Therefore, it is recommended that an intermediate individual progress to 3–4 training days (e.g., from total-body workout using 3 days to split body routines using 4 days). Frequency to progress toward an advanced training may vary depending on the objectives, recovery between sessions, nutrition strategies, and sport discipline. For example: football players obtain better results if they train 4–5 days/week, while weightlifters and bodybuilders use high-frequency training programs double splitting routines to 8–12 training sessions per week. Training 2–3 days/week for novices, 2–4 days/week for intermediate, and 4–6 days/week for advanced is recommended. The rest days for recovery are essential to prevent the negative effects of overtraining.

26.5.2.4 Special Considerations for Women

Even though current RT guidelines do not discuss possible differences between men and women, there is hard science behind the importance of having women's specific guidelines. The rationale behind this proposal is based on the observed hormonal make-up difference between sexes. Females with a normal (28 ± 7 days) menstrual cycle (MC) go through hormonal fluctuations that start with menstruation (day 1). Throughout the cycle estrogen, especially estradiol (E_2) and progesterone hormones change. These changes can be arranged in four phases [108] as shown in Fig. 26.2: (1) *Early follicular phase* or Early-FP (days 1–7): Starts with menstruation (days 1–5). Early-FP is characterized by slightly increase of estrogen and relatively stable progesterone levels; (2) *Late follicular phase* or Late-FP (days 8–14): Estrogen levels rise and peak while progesterone levels remain low. It is important to note that testosterone levels also tend to be higher during this phase [109]; (3) *Early luteal phase* or Early-LP (days 15–21): Progesterone levels rise and peak and estrogen levels start rising again but remain lower than progesterone; and (4) *Late luteal phase* or Late-LP (days 22–28): levels of progesterone and estrogen decline as Late-LP phase progresses. Note that ovulation occurs somewhere between Late-FP and Early-LP (around days 12–17).

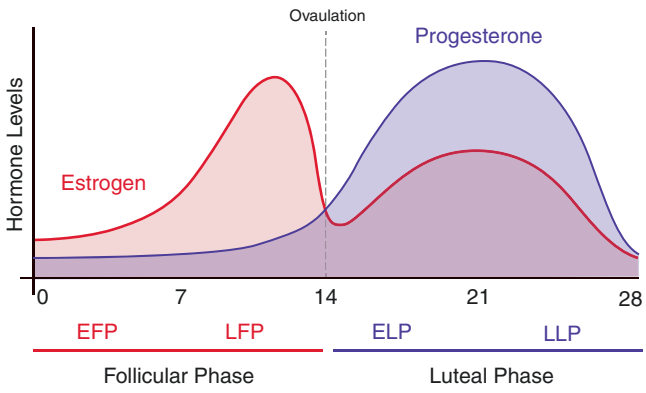

Fig. 26.2 Estrogen and progesterone concentrations over a single menstrual cycle in women. Figure courtesy of Eloi Badia-Rovira, BSc in Exercise Science, University of Lleida, Spain. Note: *EFP* early follicular phase; *LFP* late follicular phase; *ELP* early luteal phase; *LLP* late luteal phase

The aforementioned hormonal fluctuations do not apply to all women as the use of contraceptives, ingested by about 60% of women, alters 60% the cycle [110]. Contraceptives eliminate MC variability suppressing the natural production of estrogen and progesterone. Contraceptives utilize synthetic hormones (i.e., ethinyl-estradiol and one type of progestin or only progestogens) which are distributed in different hormone-variation patterns (i.e., monophasic, triphasic, etc.) and regimes (i.e., 21/7, 24/4, months, etc.) depending on the type of contraceptive utilized. Monophasic contraceptives on a 21/7 day regime—one of the most common types—utilize synthetic hormones that are constantly elevated for 3 weeks (21 days) followed by a week off (7 days). Another common contraceptive pattern is triphasic on a 21/7 regime which includes three hormonal phases (1 week each) with different hormonal concentrations followed by a week off (1 week), mimicking the natural menstrual cycle. Based on the physiological differences caused by fluctuating hormones, females with either normal MC or on triphasic contraceptives could benefit from exercise periodization [96–98, 110]. However, when female ingest monophasic contraceptives, the benefit of integration training with MC phases disappears [97].

Effects of Hormones on Muscular Fitness

Several studies reported meaningful strength peaks during ovulation (days 12–17) [112–117] which coincides with the end of Late-FP and beginning of Early-LP. Additionally, lower levels of fatigue and improved recovery time have been also reported [111, 112]. On average strength fluctuates 10–20% throughout the cycle [113], impacting on female performance and willingness to train at higher exercise intensities whether they are in phases of the MC.

Periodization Strategies and Their Integration with Resistance Training in Women

Periodization refers to methodical planning and structuring of training process conducted over logical and systematic sequencing of the training variables (intensity, volume, rest periods, frequency, exercises selections, and type of resistance) in an integrative fashion aimed to optimize specific performance outcomes at predetermined time points [118], while minimizing potential for overtraining [119]. Periodized RT plans are proposed to be superior to nonperiodized training programs for enhancing RT outcomes [120] mainly when conducted for long period of time [119].

Different from the concept of programming which refers to the manipulation of the previously defined mechanical and

physiological variables for designing workouts, periodization refers to the strategy used to integrate the aforementioned variables across the training process [119]. Based on the level of performance, sports discipline, individual needs, and stages of athletic preparation, several periodization strategies have been proposed. In competitive sports, the length and numbers of competitive period serve as a foundation to determine the basic structure of the annual plan [118]. An annual training plan, consisting of a hierarchy of time periods or phases, is coherently connected. Although the terms used to categorize these phases may slightly differ among authors, an annual training can contain one of more macrocycles composed by one preparatory and one competition period (in team sports such as football, one annual plan contains only one macrocycle, but in other disciplines such as track and field or swimming, two or more macrocycles can be included within the same annual plan). Furthermore, every period can be divided in mesocycles (middle-length cycle) which are composed by microcycles (short-length cycle) which include the training units or workouts [120].

The periodization approach uses a sequential method to transition from the a general preparation to a more sport-specific-oriented training as the athlete increases the level of performance [121].

The original traditional model of periodization based on the Matveyev proposal advocates to start with the application of high-volume and low-intensity training during the initial preparatory period and gradually shifts to low-volume, high-intensity training by the end of the cycle when the athletes approach competitions. Due to this gradual increase in intensity and reduction in volume, this model has been named as linear periodization to reflect a progressive gradual increase or decrease of intensity and volume, respectively [120]. Alternatively to this model, a nonlinear or undulating periodization strategy was proposed in RT [122]. The undulated methodology is characterized by frequent variations in volume and intensity, mainly by changing to the relative loading zone, that occur between microcycles (in some cases weeks), simple undulation or changing the loading zone between workouts sessions within the same microcycle or training week [123]. Although several studies have suggested that periodized approaches are more effective than nonperiodized designs in the development of muscular strength [53], there are still arguments against the effectiveness of periodized strategies [119]. The role of periodization to maximize RT outcomes still need to be better analyzed using more realistic scenarios commonly observed during the athletic preparation. Indeed, athletic training integrates different activities not only for increasing strength or gain muscle mass, but also for improving performance within a more complex sport scenario [118]. For instance, some well-designed interventions, conducted in laboratories, where the impact of RT is assessed under a controlled environment with no integration with other activities and circumstances, might not be the best training scheme to compare periodized vs non periodized strategies. Furthermore, it seems that using periodized approach in RT could have a moderate advantage and only when conducted over long period of times (several months) [119] or even could be not necessary, provided appropriate scientific-based designed programs are conducted [124].

Resistance Training and Hormonal Status in Adult Women

The need to integrate MC as one of the variables to design training programs in premenopausal women has been largely discussed [111, 125] and implemented to some extent by exercise professionals [126, 127]. However, due to the difficulties associated to hormonal assessment, research focusing on the study of menstrual cycle-based periodization is scarce. To our knowledge, four studies [97–99, 111] have investigated the impact of MC phases on RT outcomes.

1. Reis et al. [99] used a cross-over design study to compare the effect of two different models of altering frequency of RT in 7 young, regular ovulatory, females. The participants performed a leg extension-based program where one leg was trained with a regular training program involving a constant training frequency every third day (9 sessions), independent of MC, while the other leg was trained using a MC-based program consisting of exercising every second day (7 sessions) during the FP and about once a week during the LF (2 sessions). After completing the first MC, the participants were tested and switched the leg-allocated condition to the opposite used in the first cycle. Regardless of the conditions, all the participants completed 9 sessions per leg over an entire MC. The participants performed 2 sets of 12 maximal repetitions of leg press (~70% 1RM) with a velocity of 0.4 m/s during extension and 2 m/s during flexion. Significant greater improvements in maximal strength were observed for the leg trained with MC-based program (+32.6%) compared to the one exercised with the regular (+13.1%) intervention. Additionally, the pattern of relative intensity sustained by the participants on the MC-based program showed an initial decrease during menstruation followed by an increase during Late-FP, and another decrement during Early-LP followed by an increase during Late-LP which was more noticeable at the second MC.
2. More recently, Sung et al. [98] used a very similar cross-over design to analyze the effects of a FP- and LP-based training programs on muscular structure and function over three consecutive MC (~3 months). The FP-based training program comprised 8 sessions during FP (4 sessions/week) and 2 sessions during LP (1 sessions/week). The LP-based training program utilized an opposite design. For all exercise sessions, participants performed 3

sets of 8–10 maximal repetitions of single leg press until exhaustion (~80% 1RM) with 3–5 min of rest between sets. Maximal strength increased in both treatments. However, compared to the LP-based intervention, the FP-based program showed greater improvement (+28.9% vs. +21.3%). The pattern of response on the FP-based program was similar to the previously reported study by Reis et al. [99]. Biopsy analysis demonstrated significant larger muscle diameter of rectus femoris, vastus intermedius, and vastus lateralis in both treatments. Nonetheless, the FP-based program induced greater increases compared to LP-based program. Lastly, fiber type distribution remained the same after both training programs (40% type I and 60% type II), but fiber diameter increased in type II fibers and nuclei-to-fiber ratio increased significantly only following FP-based training.

3. Wikström-Frisen et al. [97] used a parallel group design study with females who were randomized into the following three groups (1) FP-based program (n = 19, 11 using contraceptive), trained 5 days per week during the FP and only once per week during the LP phase; (2) LP-based program (n = 19, 10 using contraceptive), trained 5 days per week during the LP and only once per week during the FP; or (3) A control group (n = 21, 11 using contraceptive) performed a 3 time per week training program. All the participants performed a lower limb exercise program (leg press and leg curl), involving 3 sets of 8–12 RM (~70–80% 1RM) per exercise with 1–2 min rest between sets. The contraceptives included monophasic and triphasic forms. Interestingly, the FP-based program included mainly females on triphasic contraceptives, while regular training program included a mix of both types. After training for 2 MC, the FP-program group (pooling both MC and contraceptives) significantly increased strength (hamstrings: +10.42% right leg, and +6.6% left leg), mechanical power output (squat jump +5% and countermovement jump +5.8%), and lower body lean mass (+1.3% LBM_{legs}) compared to LP-based group. Additionally, the control group showed higher improvement of strength (hamstrings: +6.6% left leg) and mechanical power output (squat jump +4.34% and countermovement jump +4.7%) than the observed for the LP-based group. When considering the use or not of contraceptives, all the participants included in the FP-based group, regardless of the use of contraceptive, increased strength, mechanical power output, and lower body lean mass. The observed response suggests that women on triphasic contraceptives treatment might also benefit from MC-based training. However, only females with normal MC presented superior strength values to participants in the LP-based program. Interestingly, the LP-based program caused only one significant change in strength, which was a reduction in the quadriceps strength of normal menstruating females. This result might indicate that excessive overload in LP could be detrimental for muscular performance.
4. Lastly, Sakamaki-Sunaga et al. [111], compared the effects of a FP-based and a LP-based program on upper body function and muscle mass over 3 MCs. The FP-based program included 3 weekly training sessions program during the FP (6 days total), and one weekly workout during the LP (2 days total). The training protocol involved 3 sets of 8–15 maximal repetitions (~75–80% 1RM) with 2 min rest between sets of the standing arm curl. Both FP-based and LP-based groups, respectively, improved the cross-sectional area (CSA) of the brachial and biceps brachii muscles (+6.2 and +7.8%), maximal voluntary contraction (MVC, 16.7% and 14.9%), and 1RM (36.4% and 31.8%). No significant differences were reported between interventions; however, the pattern of response observed for the FP-based program was similar to that previously reported in the studies of Reis et al. [99] or Sung et al. [98]. Opposite to the other studies, Sakamaki-Sunaga et al. [111] used an upper-body single-joint exercise protocol with a lower weekly training frequency (3 vs. 5) during the FP.

Taken together, results from the previously analyzed four studies highlight the relevance of designing training program integrating the MC hormonal fluctuation as well the ingestion of triphasic contraceptives. Studies with the most significant results were those employing ≥4 training-days per week during FP for the same muscular group and used multi-joint and larger muscle groups combined with a low-frequency one-weekly training session during LP. Interestingly, a frequency of 5 workout per week during LP showed to be detrimental for muscular strength and LBM gains, especially for females with natural MC and on triphasic contraceptives treatment. Table 26.5 describes the main characteristics of the four previously analyzed studies.

26.5.3 Specific Recommendations for the Elderly

The development of sarcopenia and osteoporosis is multifaceted and many of the causative factors are uncontrollable. RT has been shown to be a powerful intervention in the prevention and treatment of sarcopenia [32], as well as positively influence the neuromuscular system, hormone concentrations, and protein synthesis rates. The American College of Sports Medicine, published in 2009 in the "American College of Sports Medicine Position Stand. Exercise and Physical Activity for Older Adults" [51], recommends that older adults should regularly engage in a 2-weekly RT program. Muscle protein synthesis increases after one bout of hard RT and peaks approximately 24-h post-work-

Table 26.5 Main characteristics of the studies investigating the impact of menstrual cycle on adaptations to resistance training

Training Programs Focused on Lower Body (LEGS)								
Authors/year	Group	Cycles	Frequency	Intensity	Sets	Reps	Rest	Results
Reis et al. 1995 [99]	FP-based program	2	**FP**: 7 sessions (~3.5 days/week) **LP**: 2 sessions (1 day/week) 18 sessions total	~70% 1RM	2	12	Not reported	Strength +32.6%
	Regular training	2	~3 sessions/week 18 sessions total	~70% 1RM	2	12	Not reported	Strength +13.1%
Sung et al. 2014 [98]	FP-based program	3	**FP**: 8 sessions (4 days/week) **LP**: 2 sessions (1 day/week) 30 sessions total	~80% 1RM	3	8–10	3–5 min	Strength +28.9%* $Muscle_{diam}$ ↑ Fiber Type-II_{diam} ↑ Nuclei-to-fiber ratio ↑
	LP-based program	3	**FP**: 2 sessions (1 day/week) **LP**: 8 sessions (4 days/week) 30 sessions total	~80% 1RM	3	8–10	3–5 min	Strength +21.3%*
Wikström-Frisen et al. 2016 [97]	FP-based program	4	**FP**: 10 sessions (5 days/week) ***LP***: 2 sessions (1 day/week) 48 sessions total	~70–80% 1RM	3	8–12	1–2 min	Strength +6.6 to 10.42%* Power +5 to 5.8%* LBM_{legs} + 1.3%*
	LP-based program	4	**FP**: 2 sessions (1 day/week) **LP**: 10 sessions (5 days/week) 48 sessions total	~70–80% 1RM	3	8–12	1-2 min	Strength: +6.6%* Power: +4.34 to 4.7%*
	Regular training	4	3 sessions/week 48 sessions total	~70–80% 1RM	3	8–12	1–2 min	Strength: −10%*
Training Programs Focused on Upper Body (ARMS)								
Sakamaki-Sunaga et al. 2015 [111]	FP-based program	3	**FP**: 6 sessions (3 days/week) **LP**: 2 sessions (1 day/week) 24 sessions total	~75 to 80% 1RM	3	8–15	2 min	Strength +36.4% MVC +16.7% CSA +6.2%
	LP-based program	3	**FP**: 2 sessions (1 day/week) **LP**: 6 sessions (3 days/week) 24 sessions total	~75 to 80% 1RM	3	8–15	2 min	Strength +31.8% MVC +14.9% CSA +7.8%

FP follicular phase; *LP* luteal phase; *1RM* one repetition maximum; *$Muscle_{diam}$* muscle diameter; *Fiber Type-II_{diam}* fiber type II diameter; *LBM_{legs}* legs' lean body mass; *MVC* maximal voluntary contraction; *CSA* muscle cross-sectional area

out. Moreover, the anabolic effect of the strength training is maintained 36–48 h before losses start [128]. For that reason, the training frequency should be prescribed based on the population characteristics [initial physical activity (PA), body composition status, nutrition, disability level, disease, etc.] owing to the value of the SMM as an essential index for independence, longevity, absence of disease, and quality of life.

26.5.3.1 Designing and Supervising Resistance Training in Older Adults: Key Points

Aging adults have to perform exercises with correct technique in controlled manner "pain-free". This means that individuals with arthritis and joint and bone disorders have to avoid RT during pain and inflammation periods. Further, the breathing patterns during RT exercises have to be taught to prevent apnea during the practice [84]. RT can be progressively introduced to individuals with cardiovascular, metabolic, pulmonary, renal, psychiatric-related, and other diseases. Moreover, individuals on uncontrolled conditions (e.g., hypertension, chest pain, metabolic disturbances) need medical assessment and clearance before RT practice [129].

For general fitness purpose, provided the exercise execution is correct, older adults can use free-weight, machine or band single, and multi-joint exercises performed with a slow

to moderate movement velocity [51]. RT can be accomplished despite not having access to a facility with the use of therapy bands, stability balls, and other equipment as well as self-body weight.

In elderly population, the ACSM recommends using light easy to use resistances for 8 weeks to allow the joints and connective tissues (e.g., ligaments, tendons, etc.) to adjust while the neuromuscular system learns the correct exercises techniques [3]. After a period of absence of training is recommended, restart the RT with loads 50% or less than previous intensity. For muscular strength, 1–3 sets with loads from 60 to 80% of 1RM are recommended. The rest periods are 1–3 min if volume is 2–3 days/week. When the objective is to improve the capacity to apply force quickly, 1–3 sets of 6–10 repetitions per exercise using light to moderate (≤60% of 1RM) loads emphasizing high velocity movement are recommended. Moreover, to improve local muscular endurance does not differ from the guidelines presented for young adults where sets of 10–15 reps with low to moderate loads (40–70% of 1RM) have been suggested [3]. Furthermore, to enhance stability, muscle proprioception, and coordination functional exercise in a standing position to emphasize the activation of core musculature is highly recommended [130]. The manipulation of the training variables, to maintain an effective training stimulus, will depend on the observed individual responses, as well as the health status, strength level, and goals.

26.6 Future Directions

There are still some areas requiring further clarification. The proper manipulation and integration of the physiological and mechanical variables to design RT programs across ages is still debatable. For instance, the use of velocity as one of the key components for designing training programs is currently the focus of several investigations. Indeed, there is a lack of consensus on how to integrate the movement velocity with other variables such as load and number of repetitions per set to target different training outcomes. Additionally, the appropriate methodology on how to control and design RT for children and adolescents preparing for competitions in different sports (weightlifting, impulsive-based sports, contact-team or fighting sports, etc.) needs to be better and specifically defined. Future studies should clarify on how to progress toward optimal workout configuration (dose-response) and using realistic designs to properly integrate RT with sports-specific activities (teams or fighting sports, sprints, powerful oriented, or endurance disciplines).

An area deserving special attention is integration of RT with the MC fluctuations. As previously highlighted, an increased training frequency and load during the FP followed by a concomitant reduction during the LP should be advised. Future studies using diverse populations (i.e., natural MC, monophasic contraceptives, triphasic contraceptives, etc.) considering enough cycle time points—e.g., four phases if triphasic or natural MC—quantifying hormonal changes should be conducted. Also, other studies investigating the effects of hormonal fluctuations in women's performance should include interventions with more than two exercises per muscle group and/or focus on whole body or comparing upper and lower body adaptations (i.e., changes in strength or muscle mass) in response to RT rather than only one muscular group.

26.7 Concluding Remarks

RT configures a specialized method of training that involves the progressive use of a wide range of resistive load, different rate of muscle activation or movement velocities, and a variety of training modalities. Therefore, RT is a more complete term that should be distinguished from the competitive sports of weightlifting and powerlifting. RT is currently considered essential in the athletic preparation and a key component for optimizing growth and maturation in children, promoting health and quality of life in elderly or to attenuate the incidence of injuries in physically active populations. However, qualified professionals are necessary to design RT programs across ages, considering specific needs and necessary adaptation and performance outcomes in athletes from different disciplines. For that purpose, strength and conditioning coaches need scientific basic understanding of how the process of growth and development is conducted across ages and how an active or sedentary lifestyle impacts on health and quality of life in humans.

An effective training stimulus can be only elicited by forcing the organism to adapt to a relatively new situation (e.g., higher physiological demands, strength, endurance, etc.). In the case of RT, overload is provided by performing exercise using resistances which goes beyond normal levels of performance. However, in order to avoid overtraining, coaches must consider the appropriate way to manipulate physiological and neurological-related variables (i.e., Intensity, volume, rest interval between sets and exercises, frequency, and duration of workouts), and biomechanical-related variables (i.e., selection and order of the execution of the exercises included in the workout session, devises used to perform the exercises: e.g., free weights, weight, air pressure or hydraulic machines, elastic bands, medicine ball, vibratory stimulus, etc.).

Even though current RT guidelines do not discuss possible differences between men and women, there is hard science behind the importance of having women's specific guidelines. However, due to the difficulties associated to hormonal assessment, research focusing on the study of men-

strual cycle-based periodization is scarce. Taken together, results highlight that designing training programs integrating the MC hormonal fluctuation or the ingestion of triphasic contraceptives might be of relevance to optimize performance in premenopausal women.

Chapter Review Questions

1. Muscular contractions are a determinant factor for a healthy skeletal system, and _____ is/are the most crucial and sensitive periods for accelerating growth in bone mass
   (a) Childhood and adolescence
   (b) Adolescence and early adulthood
   (c) Adulthood
   (d) None of them
2. Skeletal muscle mass (SMM) accounts for what percentage of body weight at birth?
   (a) 23–25%
   (b) 30–35%
   (c) 42–46%
   (d) 28–30%
3. What has been defined as the SMM loss associated with physical frailty partly responsible for hospitalization and loss of independence?
   (a) Osteopenia
   (b) Hypertrophy
   (c) Sarcopenia
   (d) Osteoporosis
4. Resistance training was avoided in the past for children because of which of the following?
   (a) Damage to growth plates
   (b) Not able to receive benefits
   (c) Both a and b
   (d) None of the above
5. Intensity is the key component of conducting an optimal resistance training design, and it is the result of combining two main factors
   (a) relative load and the resting periods
   (b) number of exercises and the movement velocity
   (c) relative load and frequency of training
   (d) relative load and the movement velocity
6. Impulsive strength using heavy loads refers to the capacity to apply maximal force to moderate or heavy resistances.
   (a) up to ~60% of the estimated maximum
   (b) up to ~70% of the estimated maximum
   (c) up to >60% to ~85% of the estimated maximum
   (d) between ~30 and ~60% 1RM of the estimated maximum.
7. Current evidence shows that preadolescent girls have _____strength to boys
   (a) higher
   (b) similar
   (c) lower
   (d) none of the above
8. A workout volume >30 total sets (including all exercises) once a week in adults aims
   (a) Hypertrophy
   (b) Power
   (c) Muscular strength
   (d) Muscular endurance
9. Research highlights the relevance of designing training programs integrating the menstrual cycle hormonal fluctuations. Most optimal results were attained when training
   (a) ≥4 days/week during Follicular Phase (same muscular group, multi-joint and larger muscle groups) combined with 1 day/week training session during Luteal Phase
   (b) 3 days/week during Follicular Phase (same muscular group, multi-joint and larger muscle groups) combined with ≥4 days/week training sessions during Luteal Phase
   (c) 1 day/week during Follicular Phase (same muscular group, multi-joint and larger muscle groups) combined with 3 days/week training sessions during Luteal Phase
   (d) 1 day/week during Follicular Phase (same muscular group, multi-joint and larger muscle groups) combined with ≥4 days/week training sessions during Luteal Phase
10. In elderly, after a period of absence of training is recommended restart the resistance training with loads ____ or less than previous intensity.
    (a) 20%
    (b) 30%
    (c) 40%
    (d) 50%

Answers

1. a
2. a
3. c
4. c
5. d
6. c
7. b
8. a
9. a
10. d

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Exercise Guidelines During Pregnancy

27

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Learning Objectives

After completing this chapter, you should have an understanding of:

- Acute and chronic adaptations to physical activity and/or exercise training during pregnancy
- Benefits of regular physical activity for pregnant women and fetus
- How to avoid risks for fetus and mother associated with exercise training
- Recommendations and guidelines to prescribe exercise during pregnancy and the postpartum period

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27.1 Introduction

Despite previous controversy surrounding the benefits vs. consequences of exercise during pregnancy, there is an accumulating body of evidence that supports the benefits of exercise and provides recommendations for reducing risk to both the mother and fetus. Physical activity (PA) and exercise training provide several benefits for both the mother and the fetus: blood pressure control, blood glucose regulation, healthy birth weight, prevention of obesity, and maintenance of pre-gravid physical fitness. Nevertheless, there are potential risks (hyperthermia, hypoglycemia, chronic fatigue, abortion, etc.) associated with excessive and poorly planned exercise regimens. These conditions primarily occur when environmental conditions, volume and intensity thresholds, and contraindications are not respected. National associations of obstetricians and gynecologists from several countries have collected scientific knowledge to develop useful guidelines to design safe and effective PA and exercise training programs. However, due to the lack of research in the field of exercise prescription during pregnancy, these guidelines must not be considered specific, and some rules are adapted from recommendations for healthy people.

27.2 Research Findings

27.2.1 Physiology of Pregnancy

Pregnancy is a period of a female's vital cycle lasting 40 weeks to carry and gestate a new human person. Parturition is the formal term for birth, and labor is the sequence of events that occur leading up to birth. Classical pregnancy is divided into trimesters, and each is characterized by milestones. Weeks are also used to quantify gestational age at delivery, anatomical and physiological development of the fetus or assessment agenda (ultrasound or blood samples). In order to support the life growing inside her body, pregnant women undergo several organic morphologic and functional

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changes, affecting multiple organ systems, and may affect physical performance (Table 27.1) [1, 2].

27.2.1.1 Cardiovascular Function

The most striking changes operate at the level of cardiovascular system. Increased weight-bearing elicits increased heart load which promotes myocardial hypertrophy, either volumetric or wall thickness [49]. By the end of the first trimester, the diaphragm has raised resulting in a progressive increase in resting cardiac output that continues throughout pregnancy, peaking around the 20th week (40% more than in the non-pregnant state), and remaining steady during the final 3 months. Increased cardiac output induces several hemodynamic changes during the resting state

Table 27.1 Physiological changes during pregnancy

System	Function	Mechanism
Cardiovascular	(a) Higher peripheral oxygen demands (from 50 mL/min to 500 mL/min) [3, 4] (b) Cardiac output increases by 40%: heart rate (HR) increases at the beginning up to 10–15 bpm and systolic volume by 10–12% [4–6] (c) Peripheral resistance decreases from week 12 to week 24, becoming normal later [7–9]	(a) Oxygen uptake increases from 15 to 20% during the second half of pregnancy. This is caused by increased oxygen uptake from the uterus, placenta, and fetus [3, 4] (b) Resting HR increases due to increase in gonadotropin hormone, reduced parasympathetic system activity, and reduced concentration of blood catecholamines [4, 5] (c) Caused by vasodilatation produced by hormones (i.e., estrogen, relaxin, etc.) [7, 8, 10]
Blood	(a) Plasma volume increases gradually until 32 weeks (30–60%) [14, 15] (b) Red blood cells number and size increase [15, 16] (c) Veins increase capacity and peripheral vascular resistance decreases [14]	(a) Causes hemodilution of the blood causing physiological anemia of pregnancy [14, 15] (b) Produced by increased renal erythropoietin [15, 16] (c) Produced by effect of progesterone [14]
Respiratory	(a) Resting hyperventilation to compensate alkalosis (increased ventilation from 6 L/min to 9 L/min) (b) Decreased AV-O_2 difference (blood returning to the heart is more oxygenated) [9, 10] (c) Resting respiratory rate is reduced, while vital capacity is preserved [17–20]	(a) Due to increased tidal volume, which removes more CO_2 from blood, thus raising pH. In addition, enhanced chemoreceptor sensitivity to CO_2 prevents fetal ischemia and acidosis [18–21] (b) Minute volume increases more than oxygen uptake [7, 8, 10] (c) This is caused by a slight increase in inspiratory capacity [11–13]
Renal and urinary	(a) Dilated ureters and renal pelvis producing an increase of the dead space and delay [22] urine elimination [23, 24] (b) Increased kidney length [24] (c) Diastolic blood pressure decreases 5 to 10 mmHg [25, 26] (d) Increased renal plasma flow, in the first quarter (600 mL/min to 836 mL/min) [25, 26]	(a) Caused by increased aldosterone and estrogen release, which balance progesterone (b) Caused by increased kidney vascular and interstitial volume, compressive mechanical forces and may be due to increased progesterone concentrations [24] (c) Increased renin secretion and activation of the renin–angiotensin–aldosterone axis [25, 26] (d) Due to increased glomerular filtration, which later decreases [25, 26]
Gastro-intestinal	(a) Nausea, vomiting [27] (b) Predisposition to tooth decay and gum hyperemia [28] (c) Delay in time for gastric evacuation producing constipation [29] (d) Pyrosis [28]	(a) Associated with hormone secretion (gonadotropins and estrogens) [27, 30] (b) Related to hormone concentration in saliva [28] (c) Due to increased uterus size, displaced bowel and stomach and hormonal influence (d) Cardiac sphincter relaxation causes the hydrochloric acid in the stomach to reflux into the esophagus [28]
Metabolic	(a) Diabetogenic effect of pregnancy [31] (b) Change in blood lipid profile [32, 33] (c) Increased resting metabolic rate [32, 34]	(a) Due to hormones such as cortisol, estrogens and lactogen from placenta which can inhibit the effects of insulin (insulin resistance). Pancreas can naturally produce more insulin, leading to gestational diabetes (b) Lipids increase from 600 to 900 mg/mL. Produced by the influence of estrogens and cortisol [33] (c) Caused by increased absolute metabolic demand from gestational state [32, 34]
Water metabolism	Increased total body water [33, 35]	– Increased hydrostatic pressure in vessels – Increased lower limb blood flow return – Increased capillary permeability – Increased sodium retention

Table 27.1 (continued)

System	Function	Mechanism
Dermatological	(a) Increased pigmentation [36] (b) Striae gravidarum or stretch marks [36–38] (c) Increased sweat secretion [36, 38]	(a) Caused by increased estrogen and progesterone concentrations [36] (b) Caused by distension of tissues, increased adrenocortical and estrogenic activities, or excessive weight of babies and mothers [36] (c) Increased eccrine sweat gland activity due to elevated hormonal secretion (i.e., estrogen, progesterone) [36]
Skeletal system	(a) Ligaments become more relaxed (sacroiliacus, sacrococcygeal, and pubic joints) [39, 40] (b) Increased lumbar dorsal curvature (lordosis) [41, 42] (c) Pain in zones around peripheral innervation [41, 43] (d) Frequent muscle cramps in the third trimester, especially in legs [37, 44]	(a) Caused by relaxin [39, 40] (b) Produced by the displacement of the center of mass [41, 42] (c) Produced by liquid retention and relaxation of ligaments due to increased relaxin [41, 43] (d) Related to sodium depletion [37, 44]
Hormonal changes	(a) Increased human chorionic gonadotropin [44] (b) Increased estrogens [44, 45] (c) Increased progesterone [44, 45]	(a) Human chorionic gonadotropin develops the placenta (b) Estrogens increase the size of the uterus [44, 45] and prepare milk ducts for breastfeeding (c) Progesterone retains pregnancy and develops the lobules of the breast [44, 45]
Body weight	Increase between 9 and 12 kg [46–48]	Due to fetus growth; increased maternal fat mass, increased plasma volume, uterus blood volume, amniotic fluid, and placenta and breast tissue [46–48]

which begin at 5 weeks [4]. The changes may be a result of vasodilation occurring in the maternal systemic vasculature and renal system [26]. There is also a notable reduction in peripheral vascular resistance (35–40%) beginning in the first trimester and subsequent plateau during the remainder of pregnancy [14, 50].

Systolic blood pressure during pregnancy is completely stable, while the diastolic blood pressure falls from 5 to 10 mm Hg, consequentially due to the reduction in peripheral resistance and development of circulation in the uterus and placenta up to 22 weeks. Diastolic pressure tends to drop more than systolic pressure resulting in a widened pulse pressure [11, 50–52].

Blood volume increases up to 40%, peaking in weeks 32–34 of pregnancy. The increase in plasma volume begins at 6–8 weeks and continues through to 28–30 weeks and associated with activation of renin–angiotensin–aldosterone system [53]. Plasma volume increases more than increased production red blood cells, resulting in hemodilution, reduced blood viscosity, reduced circulation time, and physiological anemia [53].

Hemodynamic changes during pregnancy are accompanied by changes in oxygen uptake. Although, the oxygen content of arterial and mixed venous blood (a-V O_2 difference) decreases during the first few months, oxygen uptake (VO_2) increases between 15 and 20% at the second half of pregnancy, thus resulting in increased a-V O_2 difference. This increase is primarily due to increased oxygen consumption by the uterus, placenta, and growing fetus [51]. Subsequently, the a-V O_2 difference returns to previous levels (normal) in the third trimester. Partial pressure of carbon dioxide ($PaCO_2$) decreases to 32–34 mm Hg during pregnancy during first trimester as a consequence of the hyperventilation (see next section), which might enhance the CO_2 output from fetal tissues [51, 53].

27.2.1.2 Pulmonary Function

During pregnancy, ventilation (VE, L/min) is increased at rest and during incremental exercise compared to nonpregnant women [20, 54–56]. Residual respiratory capacity is reduced, while vital capacity is not altered, due to the slight increase in inspiratory capacity noted during pregnancy. Tidal volume increases, even though the respiratory rate is held constant, leading to an increased volume about 40% [20, 56]. Maternal hyperventilation leads to a compensated respiratory alkalosis, which decreases the concentration of carbon dioxide in the blood and increases pH slightly [12]. Adaptations in pulmonary volumes and capacities are necessary to meet the increased metabolic demands of the fetus, uterus, and maternal organs. VO_2, carbon dioxide production (VCO_2), and basal metabolic rate are increased by 20–30% at term [20, 56]. In addition, there is increased edema and hyperemia of upper airway mucosa which can cause nasal congestion and contribute to difficult endotracheal intubations in pregnant women.

27.2.1.3 Endocrine System

The endocrine system of a pregnant woman undergoes significant changes driven primarily by placental hormone production (prolactin and growth hormone, steroid hormones, and neuropeptides) [57]. For example, human chorionic gonadotropin (hCG), which is released by the placenta, is

responsible for decreasing thyrotropin-stimulating hormone secretion in early pregnancy when the thyroid function is partially taken over by the placenta. hCG is also the main trigger to increase T4-binding globulin, the main factor contributing to an elevation of T4 concentration [1]. Thyroid function is relatively stable during pregnancy; although the concentrations of T3 and T4 in plasma are increased [58], their molar ratio is stable [58].

Regulation of glucose homeostasis is a main concern during pregnancy. The pancreatic beta cells increase in volume due to hypertrophy and hyperplasia of the islets of Langerhans [59]. This morphological adaptation increases insulin secretion and creates an imbalance between hormones from the endocrine pancreas (glucagon and insulin), which antagonizes diabetogenic hormones of placenta (human lactogen/estrogens/progesterone). Both placental release and excess insulin secretion would contribute to insulin insensitivity, commonly diagnosed during pregnancy. Peak concentrations of glucose and insulin become progressively higher, and up to a 50–60% reduction in insulin sensitivity occurs in both normal pregnancy and in pregnancies with gestational diabetes [59]. This significant reduction in insulin sensitivity indicates insulin resistance during the late phase of pregnancy. However, PA can promote positive acute and chronic effects on insulin resistance, making pregnant women an important population to consider for these benefits [60–62].

In addition to endocrine pancreatic secretions, lipid metabolism is also under strong hormonal control. Adrenal cortex hormones, such as cortisol and adrenaline, regulate lipid oxidation which is necessary to compensate excessive lipid influx. Under resting conditions, plasma adrenaline levels remain the same as before pregnancy [63]. Stimulation of the pituitary adrenal axis increases the production of adrenocorticotrophic hormone, which results in increased total and free cortisol [63]. Often, a threefold increase in the production of plasma triglycerides is considered normal. Relatedly, during late pregnancy, concentrations of free fatty acids typically increase by 2–4 times above normal [32]. Increased triglycerides occur due increased maternal storage of carbohydrate and increased fat oxidation in order to preserve placental, fetal, and uteral energy demands. The increase in cortisol and decreased insulin sensitivity help meet the glucose needs of the growing fetus [59, 63]. As a consequence, in the third trimester, increased plasma acetone and decreased fasting plasma glucose induce a metabolic state characterized by hypoglycemia, hypoinsulinemia, and hyperketonemia [59, 61].

27.2.1.4 Metabolism, Energy Expenditure, and Weight Control

Weight gain is inevitable during pregnancy and supports the growth of the fetus throughout pregnancy. An increase in body fat between 3.5 and 5 kg (mainly from 10th to 30th week) can be expected. Although weight gain can be expected for all pregnant women, the health normal range of weight gain varies based on the body mass index (BMI) of the female prior to pregnancy (Table 27.2). A proportional increase in energy intake from a balanced diet must be ensured to support the nutritional needs of the fetus. During pregnancy, an additional daily caloric intake of approximately 300 kcal is required to maintain metabolic homeostasis. All pregnant women should eat a diet well-balanced in macronutrients [64] and micronutrients [65] and should not restrict calories [64].

Basal metabolic rate is elevated during all trimesters of pregnancy (first trimester: ~30 kcal/day; second and third trimester ~390 kcal/day), which is associated with body weight gain, increased cardiac output and respiratory work, fetal activity, and metabolic rate of fetal tissues observed during pregnancy [66]. Furthermore, the growth of the placenta, uterus, and fetus during the second part of pregnancy [67] also contributes to increased total daily energy expenditure described in women during gestation [68]. However, the amount of energy expenditure adjusted per kg of fat free mass during the pregnancy is relatively constant [69]; therefore, the energy needs to maintain a healthy weight gain which is proportional to the gains in fat free mass (FFM).

27.2.1.5 Musculoskeletal System

Several adaptations during pregnancy and labor promote changes in musculoskeletal tissues. The action of the hormone relaxin (produced by placenta) progressively leads to a softening of the ligaments, particularly at the region of the pubic symphysis and sacroiliac joints. The process of ligament softening reaches its peak at the beginning of the third trimester. Together, the effects of relaxin and the increased uterus size induce a great pressure against the lumbar spine, which increases lordosis, joint angle changes, and joint

Table 27.2 Recommended weight gain during pregnancy, as related to the pregravid body mass index (BMI). Adapted with permission from Gunderson EP, Nutrition during pregnancy for the physically active woman, Clinical Obstetrics and Gynecology, Vol. 46/Issue 2, pgs. 390–402, https://journals.lww.com/clinicalobgyn/Citation/2003/06000/Nutrition_During_Pregnancy_for_the_Physically.18.aspx© 2003 [64]

Pregravid BMI groups	Recommended total weight gain (kg)	Recommended rate of weight gain (kg/month)[a]
Underweight (<19.8 kg/m^2)	12.5–18	2.3
Normal weight (19.8–26.0 kg/m^2)	11.5–16	1.8
Overweight (>26.0–29.0 kg/m^2)	7–11.5	1.2
Obese (>29.0 kg/m^2)	7.0 maximum	2.0–0.9

BMI body mass index

[a] Rate of gain applies to gain during the second and third trimesters

relaxation which often leads to lumbar pain [39]. In addition, the relaxed pubic symphysis can move a few millimeters which can cause pain when walking or standing [2]. All these adaptations are important concerns when selecting activity to prescribe exercise during pregnancy [70].

27.3 Contemporary Understanding of the Issues

27.3.1 Benefits of Exercise in Pregnant Women

Since engagement in PA and exercise has positive effects on the health of non-pregnant women, these outcomes could be expected during pregnancy (Table 27.2). However, a decrease in daily PA has been widely reported among pregnant women [71, 72], although PA participation has increased since 1999–2002 [71]. Misperceptions about exercise risks during pregnancy may be one of the most important reasons explaining this behavior [73, 74]. Available evidence shows that pregnant women spent more than 50% of their time being sedentary [71, 72].

Despite historical beliefs about the harmful consequences of exercise in pregnancy, there is mounting evidence indicating positive health outcomes of exercise for both mother and fetus [75, 76]. Furthermore, current understanding of the risks associated with exercise training during pregnancy are well-known and easily managed [75, 77]. Moreover, PA can be incorporated safely into the lives of pregnant women even if they were not previously active [78]. In this section, we will summarize benefits associated with regular PA or exercise training during gestation (Table 27.3).

The American College of Sports Medicine suggests that pregnant women should accumulate at least 150 min of moderate-intensity aerobic exercise every week [79, 80]. Available data from 2007 to 2014 underscore the lack of exercise engagement for pregnant females, with 23.4% of pregnant women in the USA meeting the minimum recommendation [78]. Despite the low rate of activity engagement, pregnant women who participated in regular activity had a lower probability of cesarean delivery [81, 82]. For pregnant women, regular activity has also been associated with a reduction in gestational diabetes mellitus (38%), preeclampsia (41%), gestational hypertension (39%), prenatal depression (67%), and macrosomia (39%), a term that describes a baby who is born much larger than average for their gestational age [83, 84].

27.3.1.1 Cardiorespiratory Health

The hormonal and physiological changes that occur during pregnancy impact the cardiorespiratory system during exercise [9, 50]. Cross-sectional data indicate a general reduction in VO_{2max} in women who are not regular exercisers during pregnancy. However, VO_{2max}, and thus overall aerobic fitness is maintained in women who are able to remain active throughout pregnancy [85]. Currently, the role of power output and aerobic and anaerobic threshold HR in maintaining VO_{2max} during pregnancy is unclear [86]. As a general rule, VO_{2max} will not be reduced during pregnancy if women maintain exercise training, at least when expressed in absolute units (L/min) [87, 88]. However, if VO_{2max} is normalized to body weight (ml/kg/min), a slight reduction of 9% is observed during the first weeks of postpartum. For female athletes, this reduction seems to recover around 4 months after delivery [88].

Although adjusted aerobic fitness (VO_{2max} by kg of body weight) does not improve in pregnant women, aerobic training may result in other positive effects, such as reduced insulin resistance [89, 90]. In addition, resting HR is lower in trained vs. sedentary pregnant women, as a result of greater cardiac reserve in trained women [87]. It is important to note that even moderate levels of PA can have a positive impact on overall health in pregnant women. Thus, engaging in exercise for at least 30 min per day even in the last trimester of pregnancy can benefit general health [82].

Table 27.3 Possible benefits of exercise training during pregnancy

Cardiovascular effects	– Reduces HR [76, 126] – Improves circulation [76, 126] – Prevents varicosities [86] – Improves blood pressure regulation [86, 127]
Improvement of muscle fitness	– Increases muscle tone [70, 128] – Reduces muscle cramps [70, 128] – Improves posture [70, 129] – Reduces prevalence of back pain [95, 129]
Prevention of excessive weight gain	– Prevents excessive weight gain [130] – Reduces fluid retention [129]
Digestive system regulation	– Reduces digestive discomfort [131] – Reduces constipation [131]
Psychological well-being enhanced	– Reduces: fatigue [124], postpartum depression and insomnia [117, 122, 125] – Reduces anxiety [123, 132] – Reduces stress [123, 132] – Creates healthy lifestyle habits [75]
Prevention of gestational diabetes	– Regulates glucose and insulin [104, 133] – Prevents excessive weight gain [130]
Enhancement of postpartum recovery	– Reduces hospitalization time [81, 82] – Reduces the risks of pregnancy [70] and helps labor [84, 134] – Reduces cesarean section risk [81, 82, 135–137] – Helps restore physical appearance [70, 136, 138]

27.3.1.2 Decreased Lumbar Pain

At least 50% of pregnant women suffer from lumbar pain [91–93]. Although meta-analysis indicates that there is lim-

ited high-quality evidence that exercise itself completely prevents low back pain during pregnancy [94, 95], there are some studies showing exercise-associated pain reduction. Exercise used to enhance spine flexibility during the second half of pregnancy has been related to reduction in the intensity of back pain. In addition, muscle strengthening exercises have been found beneficial to overall prevention in pain that may occur during pregnancy and postpartum [93]. Fortunately, a significant decrease in the intensity of low back pain is commonly noted around 8 weeks after childbirth [70].

A second factor impacting lumbar pain is maternal weight gain and the related loss of pelvic girdle stability. The pelvic girdle can lose stability as a result of interplay between weight gain and hormonal changes, which concentrate the weight in the abdominal region. Specifically, lumbo-pelvic stabilization can be improved with posture training strategies and should be included within the exercise prescription. A study in 2005 reported reductions in the intensity of lumbar pain and improved mobility of the spine, in spite of no changes in lordosis (angle of inward curve of the lumbar spine) [92]. Thus, it appears that internal mechanisms more than lordosis angle are responsible for low back and pelvic pain [92, 94]. Overall, exercise treatment to address low back pain has important implications for health-related quality of life in pregnant women.

27.3.1.3 Weight Control

Excessive weight gain is associated with gestational diabetes, pre-eclampsia, and postpartum weight retention [37]. In 2020, the American College of Obstetricians and Gynecologists (ACOG) endorsed the Institute of Medicine's weight gain goals during pregnancy based on a woman's BMI at her first prenatal visit (Table 27.2). Exercise can help prevent excessive weight gain during pregnancy. For example, women who attended 24 supervised exercise sessions during a 12-week program stayed within the Institute of Medicine's weight gain guidelines compared with 62% of the control group [96]. In addition, preventing an increase in body weight >10% of pre-pregnancy mass has been shown to reduce the risk of diabetes or pre-eclampsia, and the probability to deliver a macrosomic baby [78]. Specific activities which have beneficially impacted maternal weight gain were aqua-aerobics 1–2 days per week; supervised walking/biking at 60% of VO_{2max}; walking 3–4 days per week at 30% of HR reserve; or resistance training with a personal coach [78]. Taken together, prenatal PA is associated with reduced risk for excessive gestational weight gain [96].

27.3.1.4 Prevention of Gestational Diabetes

Gestational diabetes is a result of the interaction between insulin and placental hormones. Together, these factors lead to insulin resistance and can result in macrosomia [57, 60]. In addition, a lack of PA and overweight or obesity can aggravate the risk of gestational diabetes [97].

Fortunately, both pre-pregnancy exercise [98] and prenatal exercise [99, 100] can reduce the risk of developing gestational diabetes. Notably, results from a large meta-analysis indicate that any pre-pregnancy PA or early pregnancy PA was associated with 31% and 24% reduced risk of gestational diabetes, respectively [100, 101]. In addition, prenatal exercise can help in mitigating the onset of gestational diabetes and can improve glucose control once diagnosed [61]. Most studies using exercise as an intervention to treat gestational diabetes were successful to control the negative consequences of the diabetes [102].

Physically active pregnant women have shown significantly lower glucose levels after an oral glucose tolerance test between the 24 and 28 weeks of pregnancy [102, 103]. For example, women involved in 30 min per day of moderate PA during pregnancy reduced the risk of gestational diabetes by 50–75% compared to women who remained sedentary [83, 103]. Among pregnant women who are overweight or obese with gestational diabetes, a simple exercise program (25 min 3–4 days per week and increments of 2 min per week until 40 min per sessions is reached) can improve glucose regulation and insulin action [83]. In addition, pregnant women had significantly decreased fasting insulin levels after exercise training [104].

The results of randomized control trials examining the effects of exercise training during pregnancy on measures of insulin sensitivity are variable. There are exercise interventions showing no improvement in insulin sensitivity [105], fasting glucose, or insulin levels [106], while other studies show reduced incidence of gestational diabetes, improved glucose tolerance, reduced insulin resistance [83], and/or decreased fasting glucose and insulin levels [104, 107] in pregnant women [61]. The contrasting outcomes of these studies are likely attributed to a number of variables, including exercise frequency, duration, type, intensity, level of exercise supervision, and study population (healthy vs. overweight, obese, or at risk for gestational diabetes). In addition, the benefits exercise training during pregnancy appear to carry over to the postpartum period, as exercised pregnant women exhibit lower insulin levels and markers of insulin resistance compared to those who did not exercise during pregnancy [107].

Furthermore, in women already diagnosed with gestational diabetes, exercise training is an effective method for maintaining normoglycemia and improving maternal and fetal outcomes [61, 62]. For example, a home cycling program (2 days/week, 25–30 min sessions, moderate intensity with high intensity intervals) was effective at reducing mean daily postprandial glucose levels compared to non-exercising women with gestational diabetes [108]. In addition, exercise training can reduce the need for insulin in women gestational

diabetes. This is especially important, since insulin use during pregnancy is associated with an increase in hypertensive disorders [109]. As indicated by de Barros et al., females diagnosed with gestational diabetes at 24–34 weeks of pregnancy who performed resistance exercise were less likely to require insulin during the remainder of their pregnancy as compared with women with gestational diabetes in non-exercise control group [109].

Conclusively, studies suggest that exercise interventions improve several markers of insulin resistance and gestational diabetes; nevertheless, there is large individual variability in response to exercise treatment.

27.3.1.5 Hypertension and Preeclampsia

There are several disorders related to high blood pressure during gestation, the most prevalent are preeclampsia/eclampsia, gestational hypertension, and chronic hypertension [52]. Preeclampsia is a disorder related to hypertension, which occurs in 3–9% of pregnancies and is associated with glucose intolerance, hypertriglyceridemia, systemic chronic inflammation, and endothelial dysfunction [52, 78]. Furthermore, preeclampsia has been associated with perinatal complications and it is one of the main risk factors for maternal mortality during pregnancy [110]. The risk of preeclampsia appears to be reduced by about 30% in mothers who are physically active before and during gestation [111, 112]. However, there is no consensus on the effect of PA/exercise training on preeclampsia as some research studies have demonstrated benefit [112, 113], while others show no effect [78].

Pregnant women who experience anxiety or depression are at three times greater risk of preeclampsia. Given the benefits of activity on both mental health outcomes and preeclampsia, exercise benefits health via many avenues for these individuals [112, 114]. Several studies have shown the positive effect of PA on blood pressure regulation during pregnancy. However, research should be interpreted with caution as several confounding variables may account for some the exercise benefits. In fact, a review on the influence of PA on hypertensive disorders concluded that leisure time PA seems to protect against preeclampsia [111]. More randomized control trials in all forms of pregnancy hypertensive disorders are needed to confirm these findings. Despite these outcomes, the effect of exercise and diet on preeclampsia was reviewed and concluded that there is no difference in the development of preeclampsia when comparing women who exercised with those who did not [78]. The limitations of these studies highlight that exercise dose may be an important factor impacting the effects of exercise on preeclampsia. Data from large cohort studies suggest that >25 bouts of PA per month or 270–419 min per week of leisure PA can help expecting females to reduce the likelihood of suffering preeclampsia [78].

Although there is mixed-quality evidence about the relationship between exercise and a decreased risk of hypertensive disorders of pregnancy [78], epidemiological data seem to support that PA during pregnancy reduces the risk of hypertensive complications during pregnancy, such as preeclampsia [111]. In addition, gestational hypertensive complications may be less common in women who are physically active not only during but also before pregnancy [113].

27.3.1.6 Psychological Benefits

Pregnancy and childbirth are physically and psychologically stressful events. Not only do changes occur to one's physical health, but the mother's mental health can also be impacted, both positively and negatively, during this time. During pregnancy and the postpartum period, dramatic fluctuations in steroid hormones (progesterone, estrogen, and cortisol) are thought to contribute to antenatal and postpartum depression [115]. Importantly, estrogen has extensive interactions with the central serotonergic systems and low estrogen levels may decrease serotonergic activity and contribute to depressed mood during the postpartum period [115]. Furthermore, chronic sleep deprivation, while caring for a newborn can contribute to depressive symptoms [116]. Importantly, it is well-established that exercise increases serotonin levels [117] and is comparable to medication use for treating symptoms of anxiety and depression [118]. Untreated depression during pregnancy is associated negative birth outcomes and child development [119]. In addition, postpartum depression has negative effects on maternal–fetal bonding [120]. Furthermore, antidepressant medication use is associated with small, but increased risk of negative birth outcomes including miscarriage, cardiac malformations, preterm birth, and few antidepressant medications are safe for use during breastfeeding. Thus, the psychological benefits of exercise during pregnancy and the postpartum period are just important as the physiological benefits for both mother and the baby.

Indeed, pregnant women who engage in exercise exhibit improved body image [121], reduced depression symptoms [122], increased self-esteem [122] and reduced psychological stress [96, 123] during pregnancy. Furthermore, exercise during postpartum period has also been shown to reduce symptoms of depression [119], reduce fatigue [124] and is associated with lower odds of very poor sleep quality, short sleep duration, and better self-reported sleep quality [117, 125].

Regarding female athletes who are able to train during pregnancy, additional psychological benefits ensue as they are able to maintain their identity and return to competition sooner with more confidence and motivation [119]. On the other hand, improved performances observed after having children have been attributed either physiological or psychological reasons [122] (see Table 27.3).

27.3.1.7 Benefits for the Fetus

Improved Labor and Birth Outcomes

The seminal research conducted by Clapp et al. in 1984 showed that women who maintained at or near preconception levels of endurance training during pregnancy until the third trimester of the gestation period, gained less weight, gave birth faster and had lighter weight babies compared to women stopped exercising before 28 weeks of gestation [139]. Since then, this group and others have conducted studies [82, 134, 140–142] reporting numerous positive effects of exercise training on fetus weight/body composition and placental adaptations. However, this beneficial relationship has not always been confirmed by others [134]. Other studies concluded that exercise engagement can decrease the duration of the active stage of labor and diminish the incidence of obstetric difficulties during labor [138, 141]. Moreover, a meta-analysis found no difference between mothers who did exercise vs. control in duration of labor, birth weight, or APGAR score (standardized scoring system that rates infant color, HR, reflexes, muscle tone, and respiration) [77].

The human placenta is not excluded from the adaptations of exercise training. A study showed increased fetoplacental growth (greater functional volume, nonfunctional volume, villous volume, and terminal villi) and birth weight after a walking exercise program [140, 141]. In addition, newborns of exercising women are leaner and have lower body fat percentage compared to newborns of non-exercising women [141]. Nonetheless, it is difficult to isolate the effects of exercise on the characteristics of the fetus at birth, given the immense influence by many other factors, such as genetics, nutrition, socio-economic elements, or environmental factors [33].

More Active Children

Engagement in activity starting at a young age contributes to the healthy long-term development in children. This is not limited to exercise in childhood and can include the benefits of maternal exercise during fetal development [142]. For example, one study which assessed the impact of maternal exercise on motor and intellectual capacities of children (between 1 and 5 years) showed that at 1 year of age, children whose mothers exercised during pregnancy had improved motor skills, but mental abilities and morphological characteristics identical to non-active mothers. When 5-year-old children were assessed, children of exercising mothers have much better levels of intelligence than the latter, mainly in oral skills. The consequences of these data on future life remain to be elucidated [138]. A relationship of causality between PA during pregnancy and children's PA, psychomotor development, and morphology is appealing; however, there is not strong evidence supporting it.

27.3.2 Risks of Exercise in Pregnant Women

Despite the numerous benefits of activity on the pregnant body, there are some risks associated with exercise during pregnancy. There are many ways in which sport and PA during pregnancy may induce risk to the mother and fetus such as during strenuous PA when medical conditions appear throughout the pregnancy. The ACOG has classified relative and absolute risks and identified warning signs during exercise in order to guide pregnant women and PA professionals to prevent risks associated with exercise and PA practice (Fig. 27.1).

Although there is epidemiological evidence supporting a lack of association between PA practice and hospitalization [82], complications related to poorly planned exercise are still plausible and reported. For example, severe *hypoglycemia* can occur in pregnant women after intense exercise, which, if repeated chronically, can prompt malnutrition and low birth weight in the fetus [76]. *Chronic fatigue* is another common symptom associated with erroneous exercise prescriptions; this must be a main concern when planning PA for pregnant women, because physiological characteristics of pregnancy can induce early fatigue. Increased body size and weight during gestation induces fatigue, even at lower workloads. Likewise, increased hCG together with hemodynamic changes and lower parasympathetic activity results in higher maternal HR by approximately 15 beats per minute [5]. Consequentially, all strenuous activities performed during the third trimester of pregnancy can lead to chronic fatigue; thus, special care must be taken in prescribing weight-bearing activities.

Musculoskeletal injury is associated with the increased body mass (15–30%) during pregnancy. This increased risk is associated with biomechanical modifications occurring in the pelvic/abdominal region, leading to greater elasticity of the ligaments and changes in the musculature (abdominal diastasis) and thus inefficiency of movement [94, 95]. Further risks are associated with increased relaxin (promotes joint laxity and mobility), while the expanding uterus coupled with unfamiliar weight gain leads to axial shifts in forces that create additional pressures on the spine, pelvis, and joints [39, 43]. Together, these factors augment the risk of suffering from a musculoskeletal injury while performing basic movements, such as moderate intensity or long duration walking [42].

27.3.3 Risks of Exercise During Pregnancy for the Fetus

Similar to the mother, if caution is not taken when engaging in PA, risk could ensue for the unborn fetus. This section

describes the most common events affecting the fetus as consequence of unhealthful maternal exercise.

27.3.3.1 Acute Hypoxia

It has been hypothesized that the fetus may experience acute hypoxia (rapid reduction in oxygen levels) during aerobic exercise due to the redistribution of blood flow to working muscle and away from the uterus [143]. However, although reduced oxygen delivery to the placenta may result in a slight reduction in fetal oxygen saturation, this effect stimulates a fetal sympathetic response that maintains fetal perfusion and fetal oxygen uptake [140]. In addition, evidence indicates that uterine blood flow is not changed during moderate (40–59% of HR reserve) or vigorous intensity exercise (60–84% of HR reserve) in regular exercisers and non-exercising pregnant women [144]. This is further supported by a meta-analysis of 91 studies showing no significant changes in umbilical or uterine blood flow during or after acute exercise sessions [145]. Furthermore, chronic exercise training results in increased maternal (and possibly fetal) plasma volume, intervillous space blood volume, cardiac output, and placental function. a-V O_2 difference also determines O_2 delivery, which is improved in the active mother [10]. These beneficial effects buffer acute reductions in oxygen and nutrient delivery during exercise [140].

HR responses in the fetus can reflect tissue oxygenation. The fetal HR, which reflects cardiac output, ranges between 120 and 160 beats per minute (bpm). Exercise engagement inducing fetal HR elevations above 160 bpm for ≥10 min is designated as tachycardia, and lower than 120 bpm is considered bradycardia. Parer et al. report that an increase of 10–30 bpm in the fetus during maternal exercise is not dangerous [146]. Furthermore, a review on fetal HR response to maternal exercise concludes that current ACOG guidelines for exercise in pregnancy are consistent with fetal HR response to exercise and submaximal exercise (not in the supine position) is well-tolerated by the fetus if the pregnancy is uncomplicated [147].

27.3.3.2 Acute Hyperthermia

Fetal temperature is approximately 0.5 °C higher than the mother and excessive elevation of maternal body temperature during the first weeks of pregnancy may increase risk for developmental defects and fetal death [21, 148]. However, the pregnant woman has thermoregulatory mechanisms that increase the circulation to the skin to lose heat, so the increase in temperature of the fetus is tightly regulated to prevent fetal hyperthermia. Regardless, it is not advised for women to perform exercise in high environmental temperatures (above 40 °C). Hydration and avoiding dehydration can reduce internal warming and thus close attention must be paid to ensure that enough water is consumed throughout training [33, 128].

27.3.3.3 Low Glucose Availability

The use of carbohydrates by skeletal muscle in pregnant women increases significantly during strenuous exercise [140]. This may limit the ability to extend vigorous exercise and predispose pregnant women to hypoglycemia [126]. This effect may be the result of the insulin resistance that develops in the latter half of pregnancy [59]. However, a drop in blood glucose levels, which can limit glucose consumption by the fetus, may be a consequence more probable of long-term nutritional short comings than exercise engagement [33]. Nonetheless, frequent hypoglycemia may lead to low birth weight or alterations in the growth of fetal organs and tissues [149], so carbohydrate intake after exercise training should be considered, primarily for those training longer than 60 min.

27.3.3.4 Spontaneous Abortion in the First Trimester

Beliefs about PA as a promoter of abortion have not been supported in the literature [73, 150]. The risk of spontaneous abortion was not found to be higher in athletes than in healthy controls [151]. Furthermore, there are no significant differences in early miscarriage rates between recreational runners, aerobic-training participants, and physically active-fit controls [152]. Nonetheless, very vigorous exercise in the first trimester can lead to early abortion, so avoiding strenuous PA is of the great importance to prevent other risk factors, such as hyperthermia [21].

27.3.3.5 Risk of Preterm Delivery

It has been purported that acute exercise may induce premature birth, because it increases the secretion of catecholamines, especially norepinephrine, which causes uterine contractions after exercise [73]. This hypothesis was refuted by a study that included more than 7000 women and showed that standing 8 h per day increased the risk of preterm delivery. However, exercising 4 h per day was not associated with preterm delivery. Similarly, there were no significant differences in the rates of premature births compared to women who did sedentary or physically active jobs [153]. Moreover, there were no significant differences in birth outcomes (preterm births and birth weight) in women exceeding ACOG recommendations, while participating in 3–9 vigorous continuous exercise sessions per week (ranging from 16 to 40 min) compared to those who exercised within the guidelines [82]. Indeed, guidelines point out that moderate-intensity activity in healthy women during pregnancy does not increase the risk of preterm labor.

27.3.3.6 Reduced Birth Weight

There appears to be a dose–response relationship between days per week/weekly energy expenditure of training and low birth weight of babies among pregnant athletes. As a

suggestion, exercise energy expenditure, less than 2000 kcals per week or intense exercise 1 h a day performed 5–7 days per week, must be avoided in order to reduce the probability of delivering a low weight baby, mainly after 28th week of gestation [88]. Conversely, recreational exercisers or those who meet the ACOG guidelines (see next section) gave birth to babies within a healthy weight range, even while continuing to perform vigorous intensity activities [152, 154]. In addition, children of high-performance female athletes (and ex-participants in the Olympic Games) have been of normal weight [155].

However, it has been shown that exercising beyond preconception levels could limit fetal growth. Specifically, regular running and/or an aerobic exercise program at 50% or above the preconception levels in the last 5 months of pregnancy explained 40% of the variability in birth weight over an 1100 g birth weight range [142]. Since there seems to be lower (>120 min per week) and upper (see sentences above) thresholds of safe levels of exercise [77, 152], it seems rational that individual exercise programs and nutritional prescriptions should be followed to ensure that a baby with a healthy birth weight is born when exercising at high-performance level [76].

27.3.4 Recommendations for Exercise During Pregnancy

27.3.4.1 General Recommendations for Programming Exercise

As pointed out in the previous sections, PA and/or exercise has many positive effects in both pregnant women and fetus; however, risks can ensue. As a result, supervision during activity is encouraged, both to mitigate risk as well to facilitate benefits [77, 78]. Furthermore, gestational physiology and possible complications as a consequence of excessive workload highlight that the extra care required in designing exercise protocols for pregnant women. The core of a training program is determined by the appropriate interaction of its major components: intensity, duration, frequency, and type of exercise [86, 89, 156]. It is important to note that non-programmed, spontaneously undertaken PA in pregnancy, even though still safe for the mother and fetus, does not always result in an easier childbirth [150] and weight management during pregnancy [157].

Load (duration and intensity), mode (contraction pattern and metabolic pathway), type (activities), periodization, nutrition, and environment have been the variables most commonly studied in order to define specific guidelines by the representative professional/academic associations of pregnancy or exercise [21, 86, 89, 156, 158, 159]. These recommendations have been updated during the last decade and are summarized in Table 27.4. Further details can be found in the ACOG guidelines [159] and the PA readiness examination (PARmed-X for pregnancy) [160].

Before starting any exercise program, considerations should be made regarding the overall health status of the pregnant woman. It is therefore necessary to consider the contraindications to exercise that may arise in pregnancy. In addition, several physical signs outlined in Fig. 27.1 must be considered in order to stop the exercise and proceed with an emergency protocol if necessary (Fig. 27.1). Daily PA during pregnancy can be encouraged if no contraindications arise. As a general recommendation, pregnant women can accumulate at least 150 min of moderate intensity PA each week to achieve clinically meaningful health benefits and reductions in pregnancy complications (including previously inactive and/or overweight and obese women) [136]. However, it is important to note that these guidelines have not been experimentally designed for pregnant women and are an adaptation from healthy adult guidelines. Pregnant women can incorporate a variety of aerobic and resistance training activities while complimenting these activities with yoga and/or gentle stretching [75].

The intensity of exercise is considered by many to be one of the most important aspects of an exercise prescription. HR control is a classic parameter used to quantify the intensity of continuous aerobic activities. While HR may be a good indicator for exercise prescription in the general population, maximum HR decreases during pregnancy [77] as a result of an attenuated sympathetic response to exercise. Thus, in order to accurately recommend exercise intensity in pregnant women, fitness level, BMI prior to pregnancy and age must all be taken into consideration [161]. To safely prescribe exercise, one must first set an upper limit of HR. A meta-analysis examining HR and pregnancy found that engaging in training up to 80% of HR_{max} (144 beats in women around 26 years), 43 min per session, up to 3 days/week did not harm the mother or growing fetus [77]. As mentioned, HR is only one consideration for safe exercise prescription during pregnancy. Consideration of underlying fitness and previous sporting level intensities is important. Indeed, although pregnant athletes are able to train during pregnancy; their previous regime may not be well-suited to pregnancy and training at lower intensities is recommended [88, 156, 159, 162]. For that reason, the ACOG recommends the use of rate of perceived exertion (RPE) to monitor exercise intensity [86, 150, 159, 163, 164]. According to the ACOG [159], women who were regular exercisers before pregnancy and who have uncomplicated healthy pregnancies should be able to engage in high-intensity exercise programs (while avoiding maximal levels of exertion), such as jogging and aerobics, with no adverse effects [151]. Nonetheless, elite athletes who continue to train during pregnancy are advised to seek supervision from an obstetric care provider with knowledge of the impact of vigorous-intensity PA on maternal, fetal, and

Table 27.4 Recommendations for exercise prescription during pregnancy

Exercise prescription variables	Level of performance/practice			
	General	Sedentary	Recreational	Elite/athlete
Bout volume	At least 15 min	– 30 min – Strength: Low repetitions (8–10 repetitions ×1 set)	– 30–60 min – Strength: Low repetitions (12–15 repetitions x 2–3 sets)	– 60–90 min – Strength: high repetitions (2–3 sets)
Bout Intensity	– 140–160 bpm (safe for walking and cycling) – %HR_{max}: 70% (cycling and aerobics) – %VO_{2max}: 70% (swimming and water exercises), lower HR than biking – "Talk Test" * High intensity	– RPE: 12–13 (6–20 scale) moderately hard – %HR_{max}: 65–75% – Strength: Submaximal, moderate fatigue	– RPE: 14–17 (6–20 scale) moderately hard to hard – %HR_{max}: 65–80% – Strength: Submaximal, moderate fatigue	– RPE: hard – %HR_{max}: 75–80% – Strength: Light weights
Frequency	3 days/week	3 days/week Strength: 1 day/week	3–5 days/week Strength: 2 days/week	3–5 days/week Strength: 2–3 days/week
Mode	– Low impact * Extensive isometric contractions, anaerobic exercises – Strength training without Valsalva maneuver	– Low impact – Flexibility	– Low and moderate impact – Flexibility	– Low and moderate impact * Maximum and isometric strength exercises * Exercise in supine position first quarter – Flexibility
Type (Activities)	– Childbirth preparation (minimum) – Start with no weight-bearing exercises (cycling, swimming, etc.) – Walking and brisk walking – Aerobics – Water exercises are recommended to relieve back pain. They make easier the blood mobilization and reduction of edema – Pilates under individual supervision	– Walking, cycling, swimming and water aerobics – Resistances machines and body weight exercises – Flexibility exercises	– Low impact, and progress to moderate as jogging/running, tennis – Resistances machines, body weight exercises – Flexibility exercises	– Jogging/running, tennis and similar, progress to racing activities – Change races by elliptical device – Resistances machines, body weight exercise and free weights – Water exercises to prevent back pain – Flexibility exercises
Avoid (*) or Proceed with Care	* Participating in competitions, contact sports or risk of trauma * Exercises that could overload the lower back * Exercise at moderate altitude (2500 m over the sea) * Frequently shallow diving (never deep) * Sport contacts (team sports or martial arts) * Horse riding, skating, skiing, climbing and others, which increase fall risk			* Train with infection, fever or fatigue * Competition events * Contact sports * Quick changes of direction (ligamentous laxity) * Anaerobic exercises * Stop training with symptoms, such as pain, bleeding, etc.
Environment	* Avoid high temperatures			
Nutrition and Supplementation	Adequate nutrition and hydration			* Dehydration
Periodization	* Supine position during the first quarter; start the training program first quarter	– Begin with 15 min and progress to 30 min – From 3 days/week to 5 days/week		– 3 days/week in the first and third quarter – 5 days/week in the second quarter

Abbreviations: *, this symbol indicate practices must be avoided; *HR_{max}* maximal heart rate; *VO_{2max}* maximal oxygen uptake; *RPE* rate of perceived exertion; *bpm* beats per minute (heart rate). Created from Paisley, et al., 2003, Wolfe & Davies, 2003 and Liguori 2018 [80, 86, 156]

neonatal outcomes [151, 156, 163]. That being said, more research examining HR ranges for specific modalities of exercise, and sport are needed to understand training limits [88, 150].

Estimation and exercise prescription using metabolic/energy expenditure data require VO_{2max} assessment, which is unpractical during pregnancy. Several methods exist to estimate VO_{2max} in simple testing and are traditionally useful in

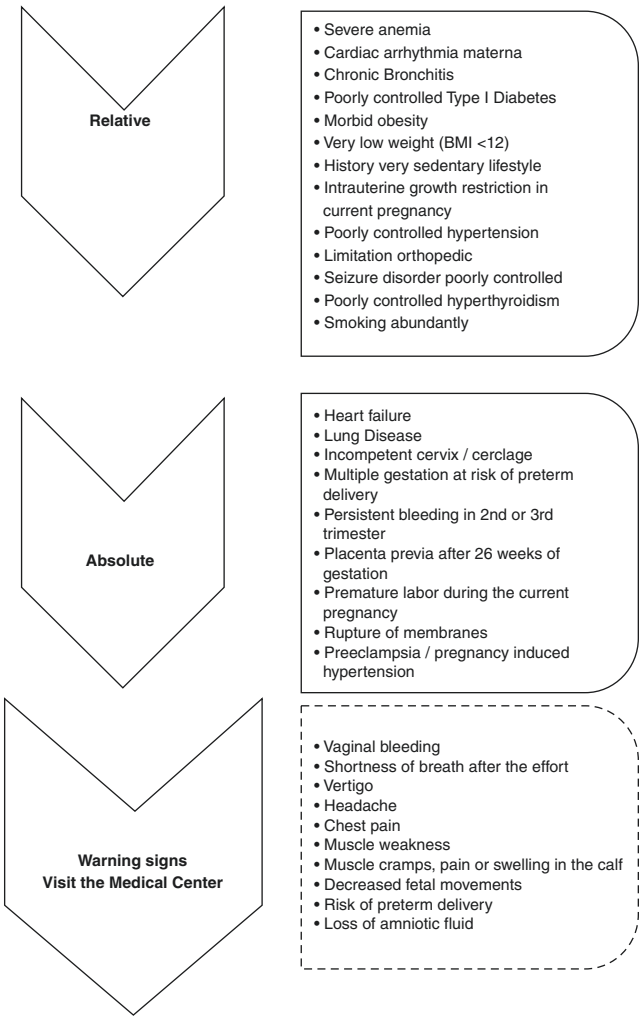


Fig. 27.1 Absolute and relative contraindications for and during practice exercise. (Adapted from Artal & O'Toole, 2003) [13]

clinical and field settings to avoid time consuming and expensive laboratory tests. Bike tests using external load and the Astrand nomogram are widely applied by exercise physiologists, clinicians, and coaches [80, 165]. However, the Astrand nomogram has been shown to overestimate the VO_{2max} by about 9% in pregnant women. Other methods using linear regression from the relationship between VO_2 and HR during submaximal loads overestimate the value around 6%. There are few well-validated methods of estimating VO_{2max} during pregnancy; one of the successful protocols utilized a single constant workload (SCW). The SCW measures HR after 6 min of constant, steady-state exercise on a bike. Afterward, Eqs. (27.1) and (27.2) are used to estimate VO_{2max} [166]:

$$\%\mathbf{VO}_{\mathbf{2max}} = \left(\mathbf{0.634 \bullet HR}\right) - \mathbf{30} \qquad (27.1)$$

$$\mathbf{VO}_{\mathbf{2max}} = \mathbf{VO}_{\mathbf{2}} / \%\mathbf{VO}_{\mathbf{2max}} \bullet \mathbf{100} \qquad (27.2)$$

Another key element of prescribing exercise during pregnancy is the mode or modality of the activities. There are many aspects to consider in selecting safe exercise; these are summarized in Table 27.4. A basic training circuit is illustrated in Panel 27.1.

27.3.4.2 Post-delivery

Following childbirth, the re-establishment of muscle fitness, the quality of breastfeeding, and mother's return to pre-pregnancy body weight can all be important factors in postpartum recovery. The initial and primary recovery goal is *strengthening of perineal muscles and abdominal* region. During the first 4 weeks of recovery, several physiological changes continue at the cardiorespiratory level, prompting several specific temporal guidelines to be suggested [13, 159, 167]:

- Within a few hours of delivery, pelvic floor exercises may be initiated.
- The first aim is to perform exercise focused on recovering strength of perineal muscles.
- During the first 3 weeks, isometric exercises to recover abdominal wall *tonus* should be performed. Limit aerobic exercise training.
- Moderate aerobic activities outdoors, jumping or running must be delayed until after 8–12 weeks after birth (risk of trauma for the pelvic floor).
- Hypotension is common. Avoid sudden changes of position.
- Restart strenuous or competition activity only 8 weeks after delivery and begin gradually.

Regarding weight control, *excessive weight gain* during gestation is the strongest predictor of postpartum weight retention. Adherence to recommended guidelines for weight gain during pregnancy can reduce postpartum weight retention [157, 165]. In addition, it has been reported that weight retention after delivery and low PA may also contribute to obesity [157]. It has recently been suggested that individualized diet and exercise training plans are need in order to manage a healthy weight loss [157]. However, more important than weight loss is an enhanced body composition profile, since exercise training preserves fat free mass, while dieting alone reduces fat mass and fat free mass, the best results are ensured when both strategies are used.

Excessive PA and poor energy intake may impoverish milk production and quality, which may prevent adequate weight gain in the breastfed infant. Thus, it is important to balance exercise energy expenditure and energy intake in order to ensure adequate quality and quantity of breastmilk. General guidelines encourage mothers to intake fluid and nutrients to meet increased energy requirements as conse-

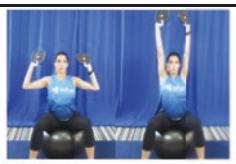
1 WARM UP

			
BACK MOBILIZATION (CAT-COW OVER FITBALL)	TRUNK LATERAL MOVEMENT, HIP STABILIZATION	HIP LATERAL MOVEMENT TRUNK STABILIZATION	VERTICAL AXIS TWIST
3 x 8 to 10 reps	**3 x 8 to 10 reps**	**3 x 8 to 10 reps**	**3 x 8 to 10 reps**

2 CORE TRAINING

			
SCAPULAE ADDUCTION	HAMSTRING BRIDGE	BRIDGE OVER FITBALL	GLUT BACK KICK
2 to 3 sets x 8 to 10 reps	**2 to 3 sets x 8 to 10 reps**	**2 to 3 sets x 8 to 10 reps**	**2 to 3 sets x 8 to 10 reps**

3 STRENGTH TRAINING

			
CHAIR SQUAT	KETTLEBELL ROW	SUMO LIFT	SINGLE ARM TRICEPS
1 to 3 sets x 8 to 10 reps	**1 to 3 sets x 8 to 10 reps**	**1 to 3 sets x 8 to 10 reps**	**1 to 3 sets x 8 to 10 reps**
			
HIP EXTENSION PLUS STABILIZATION	CHEST PRESS	SHOULDER PRESS	DOUBLE ARM TRICEPS
1 to 3 sets x 8 to 10 reps	**1 to 3 sets x 8 to 10 reps**	**1 to 3 sets x 8 to 10 reps**	**1 to 3 sets x 8 to 10 reps**

4 STRETCHING

			
SPINE TWIST PLUS SHOULDER STRETCH	UPPER BACK STRETCH	LEG ADDUCTORS PLUS BACK STRECTH	HAMSTRING PLUS LOWER BACK STRETCH
2 x 15 sec	**2 x 15 sec**	**2 x 15 sec**	**2 x 15 sec**

Panel 27.1 Example of a training circuit during pregnancy

quence of PA [13]. In addition, nursing women are advised to feed babies before exercise in order to diminish the discomfort of engorged breasts [13] and to prevent increaed acidity of milk due to lactic acid accumulation [89]. Reduction of postpartum depression symptoms is an additional benefit of exercise, which has been widely reported and reviewed above.

27.4 Future Directions

Although the knowledge of exercise during pregnancy has been improved widely during the last few decades, several concerns remain to be investigated. The effects of exercise training on the future physiological function and body composition of children are not completely elucidated; thus, longitudinal studies need to be designed in order to investigate this relationship. In addition, data on the dose–response relationship between exercise training load and health outcomes have not been extensively studied. Finally, improved methods to assess maternal physical fitness and body composition need to be developed in order to improve exercise prescriptions in field settings.

27.5 Concluding Remarks

PA and exercise training provide several health benefits for both mother and fetus, including improved blood pressure control, blood glucose regulation, healthy birth weight, prevention of excessive maternal weight gain, and maintenance of physical fitness. Nevertheless, there appears to be some risks (hyperthermia, hypoglycemia, chronic fatigue, hypertensive responses, etc.) associated with excessive or unhealthful exercise as well as exercising in extreme environmental conditions. Globally, obstetricians and gynecologists have come to a consensus and developed guidelines to facilitate safe exercise training recommendations for pregnant women. Following delivery, exercise prescription must consider the physiological changes and demands of pregnancy and delivery in order to ensure a full physiological and psychological recovery.

The information presented in this chapter should only be used as guidelines. Pregnant woman should be monitored closely to adjust training load as a function of body mass, blood markers, and fetal development. Individual prescription should be based on energy requirements, individual exercise experience, and health. Communication should be established between gynecologist, nutritionist, and exercise physiologist in order to maximize benefits to both the fetus and the mother. The first aim of the exercise program must be to guarantee the safety of the mother and the fetus more than performance or esthetic outcomes during pregnancy and after delivery. Hence, a checklist of risks along with relative and absolute contraindications must be kept in mind when planning PA goals and prescribing training loads.

Pregnant women should maintain a precise exercise record including recall of volume, intensity, and type of exercise in addition to physical and clinical assessment outcomes to monitor and modify PA programs. This will allow professionals to understand the individual dose–response relationship in each specific case and the need for individualized exercise prescription in order to maximize the health benefits for both the mother and the fetus.

Chapter Review Questions

1. During pregnancy, peripheral vascular resistance decreases by approximately 35–50%. A consequence of reduced peripheral vascular resistance that occurs during pregnancy is:
   (a) Increased plasma volume
   (b) Decreased diastolic blood pressure
   (c) Hemodilution
   (d) Increased HR
2. Maternal hyperventilation results in which of the following:
   (a) Decreased CO_2 in blood
   (b) Increased pH
   (c) Respiratory alkalosis
   (d) All of the above
3. Increased _____ is the main factor causing increased release of T4 during pregnancy?
   (a) Increased weight gain
   (b) Estrogen
   (c) Progesterone
   (d) HCG
4. Which of the following are true regarding pregnancy?
   (a) Plasma triglycerides increase by threefold
   (b) Pancreatic insulin secretion is reduced
   (c) Cortisol is reduced
   (d) All of the above
5. Recommended total weight gain for a woman who is in the normal weight BMI category before pregnancy is _____ while recommended total weight gain for a woman who is in the overweight BMI category is _____.
   (a) 12.5–18 kg, 7 kg
   (b) 11.5–16 kg, 7–11.5 kg
   (c) 11.5–16 kg, ≤7 kg
   (d) 12.5–18 kg for both
6. It is recommended that a pregnant woman increase caloric intake by _____ kcals per day during pregnancy.
   (a) 100
   (b) 300

(c) 500
(d) 650

7. Which of the following are true regarding the benefits of exercise in pregnant women?
   (a) VO_{2max} can be maintained during pregnancy in exercising women
   (b) Pre-pregnancy exercise can lower the risk of gestational diabetes
   (c) Exercise during pregnancy can lower the risk of gestational diabetes
   (d) All of the above
8. What amount of PA is suggested for reduction of risk for preeclampsia?
   (a) >100 bouts per month
   (b) >50 bouts per month
   (c) >25 bouts per month
   (d) >10 bouts per month
9. Which of the following are effects of exercise during pregnancy?
   (a) Increases resting HR
   (b) Increases constipation
   (c) Increases insulin sensitivity
   (d) Increases risk for cesarean section
10. Which of the following are true regarding the effects of exercise on pregnancy or labor and delivery?
   (a) Increased placental volume
   (b) Decreased birth weight
   (c) Lower APGAR score
   (d) Lower infant HR
11. Which of the following is an absolute contraindication to exercise in pregnant women?
   (a) Severe anemia
   (b) Poorly controlled seizure disorder
   (c) Placenta previa (after 26 weeks gestation)
   (d) All of the above
12. Which of the following are true regarding exercise during pregnancy?
   (a) Pregnant women should avoid exercising in the heat
   (b) Pregnant women should accumulate at least 150 min of moderate exercise per week
   (c) Excessive exercise can cause low birth weight
   (d) All of the above

Answers

1. b
2. d
3. d
4. a
5. b
6. b
7. d
8. c
9. c
10. a
11. c
12. d

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Exercise and Immunity: Beliefs and Facts

28

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Learning Objectives
After completing this chapter, you should be able to:

- Understand the J-shaped curve and open window hypothesis and their controversial aspects in light of current knowledge.
- Describe the effects of moderate and intense exercise on immune system.
- Understand the possible mechanisms of exercise-induced immunosurveillance.
- Distinguish the most important sex differences in the immune system.
- Describe the effects of some dietary supplements on the immune system function.
- Realize the limitations in this research field.
- Know the expertise recommendations to perform exercise training during and after upper respiratory tract infection (URTI).
- To know the effect of exercise-induced immune changes in the context of contemporary topics, such as microbiome, immunometabolism, or immunosencesce.

28.1 Introduction

Exercise immunology is a sub-discipline within exercise physiology that explores physiological and molecular mechanisms underlying the immune function and its regulation during exercise, as well as their implications for health and performance in sport [1]. Although first studies were published more than a century ago, exercise immunology has experienced an exponential growth in the last three decades, with more than 90% of the related research published from 1990 onward [2].

Studies in exercise immunology cut across multiple conditions related to the issues of today, including acute vs chronic changes and pro- vs anti-inflammatory effects, thus providing relevant knowledge for the prevention or modulation of aging and disease (including infection, cancer, metabolic, or inflammatory mediated disorders) through exercise in general population or for improvement of sport performance in athletes. The key discoveries in exercise immunology can be briefly summarize into several time periods supported by the availability of different assessment methods and changes in the paradigm, as presented in the most recent and comprehensive review by Nieman et al. [3]. The first studies in exercise immunology (1900–1979) were based on the analysis of basic immune cell counts and function [4]. Thus, the analysis of leukocyte count in young healthy men runners after the Boston marathon displayed increased leukocyte cell numbers after the event, and the authors concluded that such exercise have a negative effect on the immune responses. In 1980s, the availability of flow cytometers in research centers involved a growing number of scientific papers addressing cellular and humoral aspects of exercise immunology. In this period, some publications associated intense exercise with transient immune dysfunction,

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characterized by elevated pro-inflammatory markers [i.e., diminished salivary immunoglobulin A (IgA), decreased natural killer (NK) cell activity, impaired phagocytosis, and reduced function of T- and B-cells] and increased risk of upper-respiratory tract infections (URTI), usually described as the common cold (main causal agents: influenza, rhinovirus, and coronaviruses) [5–14]. A deeper investigation into the relationship between susceptibility to infection and exercise was conducted in this period. The quantification of blood leukocyte subtypes (i.e., lymphocytes) by number and function (i.e., NK cell activity) may not reflect the immunocompetence as a whole. In addition, the host immune system is sensitive to many factors, such as age, gender, nutrition state, and stress; consequently, it is difficult to predict the overall effects of small-to-moderate changes on immune parameters on host resistance to disease. For this reason, the incidence of URTI was considered the most useful outcome from a clinical point of view [15]. Thus, some researchers analyzed infection incidence in elite and recreational athletes following long-distance running events through self-reported symptoms. Findings suggested a two to sixfold greater risk for URTI after heavy training) or longer distance events, such as marathons, compared with shorter distance events (i.e., half-marathon, and 5 and 10 km) [14]. Such evidence motivated David C. Nieman in the 1990s to formulate the controversial "J-shaped curve" explaining the relationship between an acute bout of prolonged vigorous exercise and susceptibility to infections (i.e., URTI) (Fig. 28.1) [15, 16]. These observations led to the creation of the "open-window" hypothesis which states that the immune system is compromised after high-intensity exercise, making individuals more susceptible to infections [17–20]. Then (1990s–2009), exercise immunology research was focused in the effect of nutrition, aging, and inflammatory cytokines [21–23].

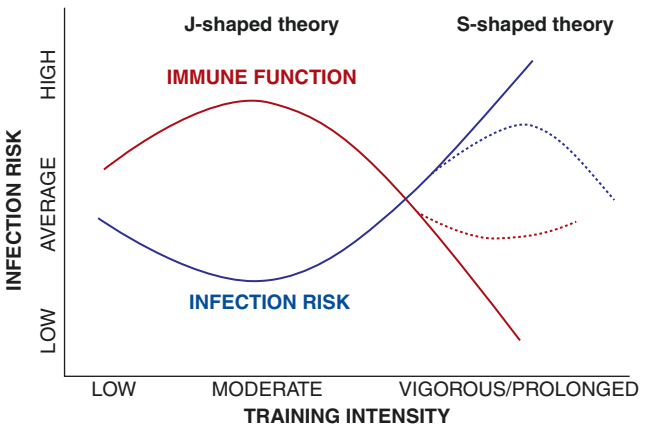

Fig. 28.1 "J"- vs "S"-shaped models of relationship between varying amount of exercise and infection risk. J-shaped theory suggests that moderate exercise may enhance immune function, thus reducing the risk of infection, while excessive exercise amounts may increase the risk; interestingly, the S-shaped model proposes that the immune system from elite athletes could be trained to adapt and attenuate responses to greater workloads than the general public extending the "J"-shaped into a "S"-shaped curve (explained in text)

Since then, numerous studies have demonstrated the profound impact that exercise can have on the immune system [18, 19]. Nowadays, it is well-known the beneficial effects provided by regular moderate exercise on the immune response to pathogenic antigens, thus reducing the risk of contracting infectious diseases [24]; indeed, regular bouts of moderate intensity exercise have been associated with a lower chronic low-grade inflammation that prevent the development of diseases, including cancer, cardiovascular disease, and other chronic inflammatory disorders [25, 26]. Conversely, a central dogma of exercise immunology has persisted that strenuous exercise bouts or periods of intensified training suppress the immune function and have been associated with increased symptoms of URTI, latent viral reactivation, and impaired immune responses to vaccine [17, 27, 28]. For almost three decades, the J-curve and open-window hypothesis have provided the theoretical framework to explain how exercise can apparently exert both enhancing and suppressive effects on the immune system and alter susceptibility to disease [18, 29]. However, contemporary evidence has recently challenged the idea that any form of exercise can be considered "immunosuppressive" [30]. In fact, current research interests are focused into the understanding of how exercise-induced immune changes are able to reduce risk for common chronic diseases. To this end, the introduction of *-omics* approaches (metabolomics, proteomics, lipidomics, and metagenomics) are providing new insights on the interactions between exercise and immunity [31, 32].

In this chapter, we deep into the previous literature addressing the "immunity-exercise axis" in order to critically review the basis of the J-shaped curve and open window hypothesis to understand the role of exercise in the risk of infection. In addition, an overview of the components of the immune system and how are affected by exercise considering the gender dimension will help us to unravel the key role of regular physical activity in the prevention and treatment of disease.

28.2 Exercise and Risk of Infection: Challenging the J-Shaped Curve

28.2.1 Extrenous Exercise and Risk of Infection

The relationship between exercise and infection susceptibility was an active area of research at the end of the twentieth century [33]. Early epidemiological studies suggested that athletes engaged in strenuous exercise (i.e., a marathon and

ultramarathon race) and/or intense training period, such as near a competition, suffer a short period of immunodepression (commonly lasts 3–72 h) and physiological stress that heightens the risk of opportunistic infections [34]. One of the most relevant studies in that time was performed by Nieman et al., who conducted an epidemiologic survey-based research of Los Angeles Marathon (LAM) participants to investigate the relationship between self-reported infectious episodes, previous training performed, and the intensity at which the race was run. Results showed that runners under heavy training (defined as more than 96 km/week) may be at double risk of infectious episodes compared with those who trained less than 32 km/week. In addition, runners who participated in the LAM race experienced a greater incidence of URTI compared to runners who did not run in the race [35]. These data suggested that other than exercise intensity, such as cumulative training or mental stress, increases URTI risk [33, 36]. However, these studies of the J-curve present methodological limitations which make evident that more anecdotal than evidence-based the role of exercise in the incidence of URTI [18]. Thus, the "J" curve hypothesis was built based on a combination of observational results and case series surveys [15]; self-reported infections were not clinically confirmed by laboratory analyses (i.e., molecular or microbiological techniques, such as polymerase chain reaction or bacterial cultures). Anyhow, there are no a gold standard for assessing URTI episodes, since 20–40% of people with classic symptoms cannot detect the causing pathogens by laboratory methods; indeed, viral infection can be asymptomatic at the time of testing in 25–35% of people [37, 38]. Herein lies the controversy of this hypothesis. In this sense, diverse studies comparing self-reported URTI with laboratory analyses have concluded that the incidence of URTI is not substantially different to the general population. Particularly, a study concluded that only the 30% of illness symptoms reported by athletes were clinically diagnosed by laboratory methods that confirmed a viral rather than bacterial etiology [39], which is in line with the typical infections at general population [40]. These observations open the possibility that many of the reported URTI were a symptom of other non-infectious causes, including allergy and asthma or non-specific mucosal inflammation [41]. In addition, the 7–10% of athletes competing in the Olympic Games report symptoms of illness during the competition weeks, whereas 24% of adult general population in the USA experienced a cold during a 4-week period, which is a similar timeframe to many international sporting competitions [42, 43].

It is interesting to consider that other underlying factors likely play a role in infection risk than exercise participation *per se*. Thus, attendance at any mass-participation event is likely to increase the risk of URTI infection, as supported by studies demonstrating the greater risk of infection among people exposed to crowds [44]. In addition, illness symptoms in athletes have been linked to air travel and exacerbated by long-haul flights crossing multiple time zones [45].

On the other hand, studies conducted on elite athletes should be considered separately. A longitudinal analysis of illness records (3–16-year follow-up) of elite endurance athletes showed that the total number of training hours per year was inversely correlated with the sickness days reported [46]. Likewise, swimmers monitored for 4 years found that athletes at national level had higher incidence of infections than elite international athletes [47]. In addition, immune function seems to be enhanced in elite athletes, as supported by a cross-sectional study in female rowers that showed a significantly higher mitogen-induced lymphocyte proliferation and NK cytotoxic activity in elite rowers compared to the non-athletic group in spite of the numbers of days with URTI symptoms did not differ between both groups [48]. Interestingly, marathon and ultra-marathon runners, who undertake the largest volume of exercise among athletes, reported 1.5 and 2.8 sick days in a year, respectively, while general population reports an average of 4.4 illness days each year [49, 50]. Nevertheless, the performing of an integrative -omics approach in female athletes undertaking prolonged periods of intense training coupled with low-energy availability revealed an state of immunosuppression characterized by loss of immune cell proliferation and reduced antibody and chemokine secretion [51], thus revealing the role of other factors, such as diet modifications, in the exercise-induced immune changes. Remarkably, such dysregulated immune function was reversed during an 18-week weight regain period.

All in all, these observations highlight a lower incidence of illness in athletes undertaking the biggest training loads despite the presence of immune changes, suggesting that elite athletes are better adapted to the demands of their training and by extending the "J-shaped curve" into an "S-shaped curve" (Fig. 28.1). Thus, immune system from elite athletes could be trained to adapt and attenuate responses to greater workloads than the general public.

28.2.2 Moderate Exercise and Risk of Infection

Most epidemiological studies support the notion that moderate levels of physical activity reduce URTI incidence in 20–30% [52], although research in this field is scarce compared to the evidence documented regarding heavy exercise and risk of infection [15]. Activity in this field emerged in response to an increasing interest to find factors that may lessen the incidence and severity of influenza and/or improve the efficacy of influenza's vaccine [53]. A study performed in mice by Lowder et al. showed a protective effect of moderate treadmill exercise at 65–70% of their maximal oxygen uptake (VO_{2max}) in mice who exercised 3 days after influenza

virus inoculation yet before the onset of flu symptoms. Meanwhile, prolonged exercise (2.5 h) led to increased morbidity and moderate exercise significantly increased survival rates (83%) even when compared with sedentary controls (43%) [53]. Such beneficial effects of moderate exercise on susceptibility to respiratory infections seems to be mediated by lung macrophages playing a role in immunosurveillance, whereas alveolar macrophage antiviral resistance is suppressed in mice that exercised to the point of fatigue [54–59]. Data from animal studies have been difficult to apply to human participants, but, in general, are consistent with the idea that heavy exercise bouts after virus inoculation may lead to higher morbidity and mortality rates [53, 60–62], whereas moderate intensity exercise may be safe during virus infection. In a well-designed control intervention study performed in moderate fit young adults, no differences were reported in severity and duration of virus infection between exercise group trained 10 days at 70% of heart rate reserve during 40 min sessions, beginning the first day of virus inoculation, and sedentary control groups [63].

The American Colleague of Sport Medicine's physical activity guidelines for healthy adults recommend that most adults should engage in moderate-intensity cardiorespiratory exercise training for at least 30 min/day on 5 day/week for a total of no less than 150 min/week. The effects of a moderate bout of 30 min brisk walking on the immune system function were investigated by Nieman et al., in healthy non-obese women [64]. Results showed that walking between 60 and 65% of VO_{2max} compared with the same participant sitting as a non-exercise control-induced discrete and short-lived increases primarily in NK cells and neutrophils. In addition, mitogen-induced leukocyte proliferation has been observed immediately after walking due to an increase in circulating T cells. Furthermore, Interleukin-6 (IL-6) IL-6 cytokine showed a small yet significant increase, while cortisol levels, salivary IgA or plasma IL-1ra concentration, remained unchanged. Interestingly, prolonged and intensive exertion produces that large increases in leukocyte counts, plasma cortisol, IL-6 and IL-1ra concentration, and extensive post-exercise decline in IgA secretion rate, NK count and activity, and mitogen-induced lymphocyte proliferation [64, 65]. In addition, several case–control studies regarding the chronic effect of exercise training performed in elderly participants revealed a greater risk of developing URTIs in sedentary subjects compared to active ones [15].

In sum, findings suggest that exercise-induced changes in immune functions are not always associated with a higher infection susceptibility [66, 67], and other underlying factors seem to play a role in infection risk, such as travel, pathogen exposure, sleep disruption, stress and altered diet that can increase the risk independently of the exercise per se [18, 19]. Importantly, these 'factors' are rarely controlled in exercise studies. In this line, advances in measurement technologies and bioinformatics analysis will improve our capacity to understand the effect of exercise intensity and co-dependent factors on the immune function and the subsequent influence in risk of illness and infections in individuals.

28.3 Effect of Exercise on the Immune System

Both cross-sectional and longitudinal studies have demonstrated the profound impact that exercise has on the immune system. While physical fitness and moderate exercise training have shown to improve immune responses to vaccination, low-grade inflammation, and various markers in diseases (i.e., HIV, cancer, diabetes, or obesity), extraneous bouts of exercise have been linked to either suppressed immunity and increased URTI symptoms, or improved immune function. The following subsections summarize the influence of acute vs chronic exercise on the components of the immune system and briefly discuss their potential health and clinical implications.

28.3.1 Overview of the Immune System

The immune system is a complex network of cells and molecules working together to prevent the host from infection and disease [68]. Immune cells or leukocytes are derived from hematopoietic cells placed in the bone marrow, which migrate to peripheral lymphoid organs to complete their maturation and acquire the capacity to recognize non-self-components. Although all these components often work synergistically in the overall immune response, the immune system can be divided into two lines of defense: the innate and the acquired immunity.

The first line of defense against infections is mediated by effector cells of the innate immune system: monocytes/macrophages, dendritic cells (DCs), granulocytes (neutrophils, eosinophils and basophils) and NK cells. These cells mediate the inflammatory response or neutralize pathogens through phagocytosis or receptor-mediated endocytosis, intracellular digestion by granular cytolytic enzymes (degranulation) or reactive oxygen species (oxidative bursts) (monocytes, macrophages, and granulocytes), antigen presentation (DCs, macrophages), or by directly lysing the pathogen or infected/tumoral cells (NK cells).

– Monocytes/macrophages make up around 10–15% of leukocytes, and their main function is to capture and kill pathogens. Human circulating monocytes constitute a heterogeneous group, being the "classical" monocytes ($CD14^+CD16^-$) the major subset, whereas $CD14^+CD16^+$ populations represent the 10–20% of all circulating

monocytes and are considered more mature cells associated with various disease states [69].
– NK cells are a heterogeneous subpopulation of lymphoid cells whose main function is to destroy infected and tumoral cells. Two main NK cell subtypes have been described: $CD56^{bright}$ and $CD56^{dim}$. $CD56^{dim}$ NK cells are the most cytotoxic subtype, whereas $CD56^{bright}$ NK cells produce high levels of cytokine production.

In addition, innate cells, such as monocytes/macrophages or DCs, play an important role as antigen-presenting cells (APCs) in mediating the acquired immune response. Basically, APCs are responsible for displaying fragments of the phagocyted pathogens (antigens) through molecules of the major histocompatibility complex on their membrane that could be specifically recognized by T-lymphocytes. Therefore, APCs play an important role in coordinating the action between the innate and adaptive arms of the immune system [70].

On the other hand, the adaptive immune response constitutes the second line of defense and is mediated by T and B lymphocytes able to recognize specific antigens of pathogens to create memory cells for generating long-term immunity. B-cells secrete different antibody or immunoglobulin (Ig) classes to neutralize extracellular pathogens. T-cells can be divided into two functional groups: cytotoxic T cells with CD8 co-receptor ($CD8^+$) are able to directly kill infected cells or tumoral cells, whereas T helper cells express the CD4 co-receptor ($CD4^+$) and their function is to collaborate with other immune cells that mainly produce cytokines to magnify the immune response.

Communication among immune cells is mediated by cytokines, proteins produced by numerous cellular subsets. As a result, a complex cytokine network of pro-inflammatory and immunosuppressant molecules regulates the immune responses [25]. The main pro-inflammatory–cytokines participating in a pathogenic immune response are TNF-α, IL-1β, and IL-6, and they are responsible of the movement of leukocytes (leukocytosis) to the inflamed tissue [71]. In the inflammatory conditions, immunosuppressive cytokines such as IL-10, IL-4, and IL-1 receptor antagonist (IL-1ra) are released into the circulation to suppress the pro-inflammatory cytokine production [72] and re-establish basal conditions.

28.3.2 Exercise Influence on Immune Cell Count

Although leukocyte count in the peripheral bloodstream has been traditionally used to diagnose acute immune alterations associated with disease, the analysis of its frequency and functional capacity in response to a single bout of exercise is common in the literature [73]. Typically, an acute bout of exercise results in increased leukocyte levels in the blood or leukocytosis with a characteristic bi-phasic response (Fig. 28.2). During vigorous exercise (lasting at least 45–60 min), it is commonly observed an immediate increase of lymphocytes, neutrophils, and monocytes that is followed by a delayed response of additional neutrophils 2-h post-exercise, suggesting that exercise "stimulates" the immune system (first phase). The predominant cells mobilized with exercise are neutrophils and lymphoid cells, with a smaller contribution made from monocytes [74]. Exercise-induced cells tend to have cytotoxic functions, such as NK-cells or $CD8^+$-T cells, and also present a mature phenotype, such as $CD16^{pos}$ monocytes and $CD16^{neg}$ neutrophils; in contrast, those subtypes with early maturation profiles and/or limited cytotoxic/effector functions such as $CD4^+$ T-cells, B-cells, and classical monocytes ($CD16^{neg}$) are redeployed in relatively fewer numbers [75–77]. Then, during the early stages of exercise recovery (within less than 60 min of exercise cessation), a rapid reduction in the blood lymphocyte count below pre-exercise levels occurs (1–2 h) concomitantly with a sustained neutrophilia (elevated blood neutrophil count) (second phase) [65, 78]; finally, leukocyte counts usually return to baseline within 24 h [79–81].

The transient leukocytosis and posterior decline of immune cells of this classic bi-phasic response to exercise depend on the type, intensity and duration of the exertion, and could also be attenuated by exercise training [18, 20, 65, 81, 82]. Brief exercise (up to 30 min) leads to a two to three-fold increased leukocyte cell count which returns to baseline levels within 10–30 min after cessation of exercise, whereas longer aerobic exercise (i.e., marathon and ultra-marathon) increases significantly leukocyte counts in a dose-dependent manner (increase up to five- or tenfold) and requires longer time periods for leukocytes to return to baseline [18, 83].

28.3.2.1 Factors Responsible for Exercise-Induced Leukocytosis

Several mechanisms are responsible for the redeployment of leukocytes in exercise. Originally, the increase in leukocyte numbers was attributed to hemoconcentration, but this theory was rejected, because the fluid loss from plasma during exercise does not fully explain the large increase in peripheral blood leukocytes, which may be more than double at maximal aerobic exercise [41]. Then, the mobilization of leukocytes from marginal pools has been proposed to explain this sharp increase that occurs in the first phase of immune response to exercise. At least two factors have been postulated to be responsible for this mobilization: (1) leukocyte demargination; shear stress within capillaries coupled with increased in hemodynamics during exercise (blood pressure, cardiac output, and vasodilatation) induce a greater mechanical force on the endothelium causing the adherence of leukocytes to blood vessels walls (demargination) [84];

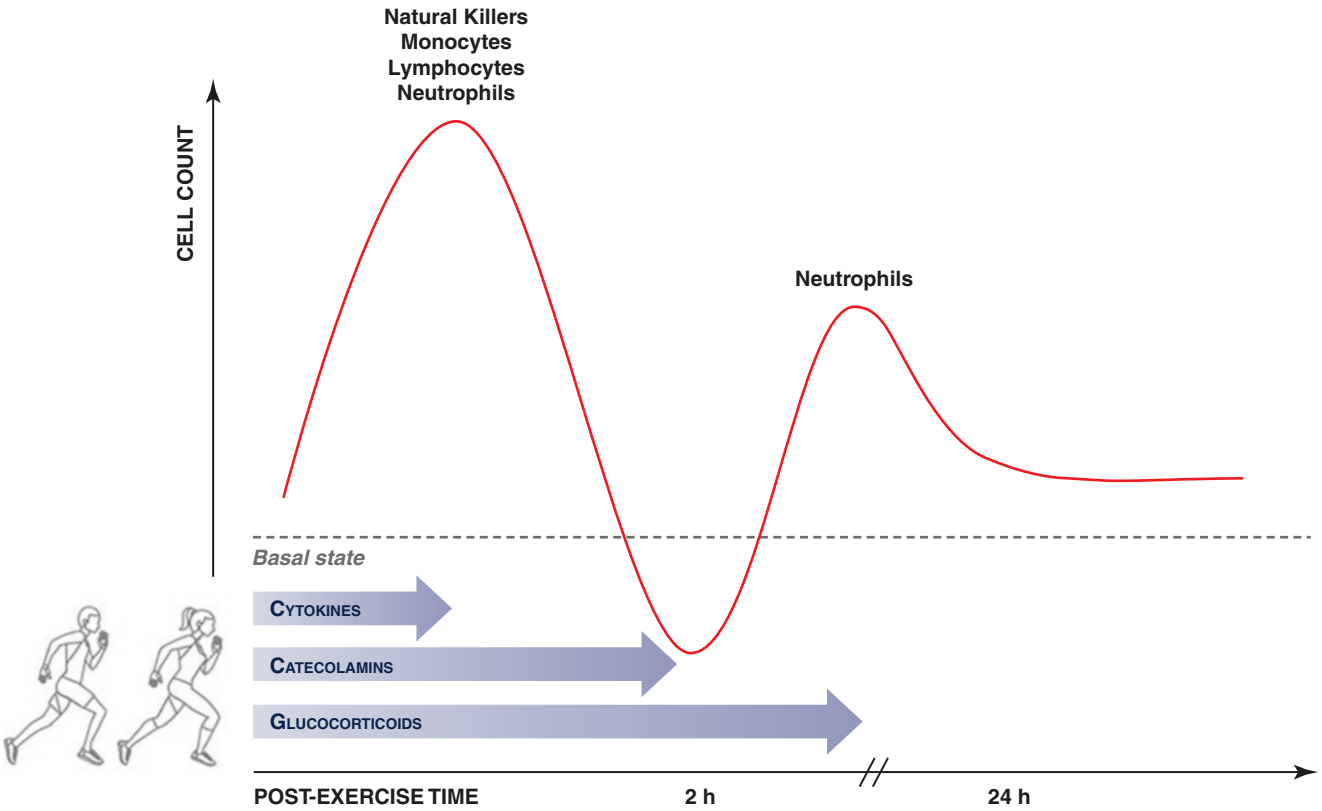

Fig. 28.2 Circulating leukocyte count after a single bout of exercise. Vigorous exercise typically induces an immediate increase of blood leukocytes that is followed by a delayed response of additional neutrophils 2-h post-exercise (first phase). Then, a rapid reduction in blood lymphocyte count below pre-exercise levels occurs (1–2 h) concomitantly with a sustained neutrophilia (elevated blood neutrophil count) (second phase); finally, leukocyte count returns to baseline (usually, 24-h post-exercise). The leukocyte mobilization to exercise is affected by the release of catecholamines and glucocorticoids, and also cytokines are playing a role (extended in the next section)

in addition to the dislodging of leukocytes from the endothelium, many other organs (liver, lung, spleen, bone marrow, thymus, intestines, and skeletal muscle) are likely to be major sources of the leukocytes mobilized into the circulation with exercise [85]. In addition, increased lymphatic flow with exercise is also likely to contribute to this leukocytosis as lymph nodes are emptied into the blood via the thoracic duct. In fact, the origin and destination of the mobilized leukocytes seem to vary depending on the cellular type. Thus, since exercise-mobilized cells tend to have a more mature profile, the lymphoid organs are unlikely to contribute greatly to the initial exercise-induced leukocytosis. However, the bone marrow likely contributes to the sustained neutrophilia during the recovery phase after prolonged exercise, while the lymph organs may be responsible for the restoration of the blood lymphocyte count following the transient lymphopenia. (2) Effect of stress hormones; increased sympathetic nervous system activity and the resulting secretion of catecholamines (i.e., the hormone epinephrine and the neurotransmitter norepinephrine), as well as the hypothalamic–pituitary–adrenal (HPA) axis activation, releasing cortisol during exercise, stimulate beta-2 adrenoreceptors and glucocorticoid receptors on the surface of lymphocytes, modifying endothelial cells adherence capacity and their subsequent trafficking and egress from the blood compartment [86, 87]. Interestingly, the release of catecholamines and glucocorticoids affects the kinetics of the leukocyte response to exercise, since catecholamines evokes a profound lymphocytosis within minutes of dynamic exercise, whereas the cortisol release peak values of neutrophils a few hours after exercise cessation [88].

28.3.2.2 Enhanced Immunosurveillance After Acute Exercise

Coinciding with changes in cell counts, alterations to cell function have been parallelly observed, leading to perceive that exercise induces a short-term immune suppression during exercise recovery that provides an "open-window" for opportunistic infections [89]. However, a more contemporary viewpoint is that this transient reduction in the frequency of immune cells after exercise is due to a preferential mobilization of cells to tissues and organs (i.e., mucosal surfaces). Cell function in peripheral blood is directly dependent on the amount of cells present at sampling; as a consequence, results of studies exploring the effects of exercise on cell function must be interpreted with caution and taking into

consideration if the samples have been collected immediately after exercise or in the following hours.

The mentioned cellular mobilization represents a beneficial state of immunosurveillance, since redistributed immune cells are thought to identify and eliminate infected cells with pathogens, or those that have become damaged or malignant [90]. The usage of fluorescent cell tracking in rodents revealed that immune cells are redeployed in large peripheral tissues, where pathogens are likely placed during and after exercise, such as lungs or gut [91]. In humans, those leukocyte subtypes that are preferentially redeployed with exercise tend to exhibit phenotypes associated with tissue migration potential like high expression of integrins, adhesion molecules and chemokine receptors for activated endothelium [92]. Specifically, exercise selectively mobilizes into blood circulation mature NK cells ($CD56^{dim}$) and memory $CD8^{+}$ T lymphocytes with a phenotypic propensity for homing to peripheral tissues and potent cytotoxic capabilities to facilitate the detection and elimination of neoplastic, damaged or infected cells [76, 93, 94].

Over time, transitory exercise-induced increases in effector immune cells enhance immunosurveillance and, consequently, and state of lower inflammation that may be of particular clinical value for diseased individuals. Accordingly, the rapid mobilization of NK cells has been associated with improved immune function and reduced risk of virus infection [70]. In addition, inhibition of tumor onset and disease progression associated with NK cell infiltration has been observed in active rodents [95]. In addition, in humans, NK cells with a mature phenotype are preferentially redistributed after exercise and present augmented anti-tumoral capacity in vitro [93, 94].

28.3.3 Effect of Exercise on the Immune Function

The majority of studies in the field of exercise immunology supported the viewpoint that theimmune system reflects the magnitude of physiological stress induced by the exercise. Several changes in the components of the immune system are altered for several hours to days during recovery from prolonged and intensive endurance exercise [17]. This section takes a tour of the main biomarkers of immune function that have been analyzed in relation to exercise, such as NK cell and neutrophil function, various measures of T- and B-lymphocyte activity, salivary IgA output, skin delayed-type hypersensitivity (DTH) response or vaccination.

28.3.3.1 Innate Immune Responses to Exercise

The innate arm of the immune system incorporates both soluble factors and cells that are attracted to sites of infection or inflammation via chemotaxis (migration to tissues guided by chemical signals).

Among the cells of the innate immune system, NKs are the most responsive leukocyte to exercise intensity (more than duration) due to their catecholamine sensitivity [96]. Moderate regular exercise has been found to increase NK cell function in both sedentary individuals and obese or cancer patients [97–100]. A recent meta-analysis provides solid evidence for elevated NK cytotoxic activity through performing sports activities, especially in the case of endurance training, independently of the modification in NK-cell number [101, 102]. However, other factors seem to influence the effect of exercise on the NK cell activity. Thus, gender dimension seems to play a role, since males tend to be more sensitive to NK cell activity elevation after physical exercise, probably due to sex differences in the number of NK cells (higher in males) and hormonal differences. In addition, age is an individual factor affecting NK cell activity and positive effects of exercise seem to be more evident among younger people which could be explained by a decreased immune response in aged individuals or immunosenescence [103].

Research evidence has demonstrated that counts of neutrophils (and monocytes) circulating in blood may increase by about 90% after an intensive bout of exercise [78]. In addition, neutrophils functions can be affected by the characteristics of the exercise. Thus, a single bout of moderate intensity exercise has been reported to enhance neutrophil phagocytic activity, degranulation (digestion of microbes by releasing granular lytic enzymes), oxidative burst activity (digestion of microorganism by reactive oxygen species), and neutrophil extracellular traps (NETs)-associated cellular death (NETosis) [18, 20, 65, 104–106]. Therefore, an improved response of neutrophils to stimulation following exercise of moderate intensity could mean an improved resistance to infection. Nevertheless, neutrophils' respiratory burst activity seems to be influenced by the intensity and duration of the exercise. Exhaustive or long duration exercise attenuates the production of reactive oxidants, indeed during exercise recovery [77, 107]. According to this, competitive athletes undertaking regular exhaustive intense exercise may be at greater risk of picking common infections, but not serious illness, by such temporary immune dysfunction.

On the other hand, monocyte phagocytosis may increase after prolonged moderate but not maximal intensity exercise. Actually, after a long bout of intense exercise, the expression of some Toll-like receptors, such as TLR-2 and TLR-4 [108, 109] (TLR; innate immunity receptors for broadly shared patterns from pathogens) on monocytes decreases, and it could be related to a reduced IL-6, IL-1α, and TNF-α production [18]. Instead, studies analyzing the impact of chronic exercise on the distribution of monocyte subsets have described no alterations in total counts or subpopulations [110]. However, endurance exercise training increased the proportion of classical $CD16^{neg}$ monocytes and reduced the inflammatory $CD16^{pos}$ cellular subsets [111, 112]. Interestingly, Timmerman et al. reported higher baseline

Table 28.1 Effect of acute vs chronic exercise on functions of innate immune cells

	Cellular function	Acute moderate exercise	Acute exhaustive exercise	Chronic exercise at rest
Neutrophils	Chemotaxis	↑	↔	↓ ↔
	Phagocytosis	↑	↓	↓
	Degranulation	↑	↓	↓ ↔
	Oxidative burst activity	↑	↓ ↔	↓ ↔
	NETosis	↑		↓
NK cells	Cytolytic activity	↑	↑	↔ ↓
Monocytes	Chemotaxis	↑	↑	↓ ↔
	Phagocytosis	↑	↑↔	
	Oxidative burst activity	↑	↑	
	Antigen presentation	↑		↓

Data reviewed from Gleeson et al. [20]; Walsh et al. [18]; Pedersen and Hoffman-Goetz [65], and Valeria Oliveira de Sousa et al. [105]
Increase, ↓; decrease, ↑; no change ↔
ROS reactive oxygen species; *NETs* neutrophil extracellular traps

$CD16^+$ counts in physically inactive subjects, with normalization after completion of exercise training program [113]. Of note, reductions of inflammatory monocytes do not seem to be indicative of increased tissue infiltration as murine studies have reported reduced leukocyte infiltration after exercise training [114]. Table 28.1 shows a summary of the effect of exercise on functions of innate cells.

28.3.3.2 Adaptive Immune Responses to Exercise

The T- and B-lymphocytes are part of the acquired immune system and play an important role in the control of microbial infection. Lymphocytes are activated by the recognition of an specific antigen that induces their proliferation to form multiple effector cell clones able to recognize the antigen that caused the initial response and destroy any infected cell that displays such antigen on its surface. T lymphocyte's function is typically modeled in vitro using a mitogen (i.e., phytohemagglutinin, PHA).

Lymphocytosis was observed during and immediately after an acute bout of exercise followed by decreased below resting levels during early stages of recovery, largely observable in T lymphocytes, especially Th1 subtype, while B lymphocyte showed a lesser effect. Several studies have reported that T-cell proliferation decreases both during and after exercise [18]. This depression is usually short-lived and will resolve within 24 h unless insufficient recoveries between exercise sessions cause chronic depression of acquire immunity [18]. Moreover, reductions in the migratory and homing properties of T-cells have been reported during the recovery phase of prolonged exercise [115]. In spite of this fact suggest that acute exercise compromises T-cell function, many researchers arguing the usage of mitogens in in vitro tests of proliferation elicit a very general T-cell response and are not indicative of the antigen-specific properties of memory T-cells. Accordingly, T-cells stimulated with common viral antigens such as cytomegalovirus (CMV) and Epstein–Barr virus (EBV) are specifically activated after 30 min of steady-state exercise [116].

To overcome limitations associated with the in vitro experiments to study T-cell function after exercise, several studies have examined the effects of exercise on immune responses to antigen challenge in vivo. Trained triathletes were intradermically inoculated with several recall antigens (tetanus, diphtheria and streptococcus) following a half-ironman race [28]. The diameter of the resulting edema (skinfold thickness) and erythema (redness) at the inoculation site was measured 48 h later as an indicator of the DTH response, revealing a significantly lower DTH response in the triathletes compared to both non-exercising triathletes and moderately trained healthy men; these results indicates that single bouts of prolonged endurance exercise may inhibit memory T-cell responses. Nevertheless, prolonged endurance exercise was observed to inhibit immune responses to topically applied novel antigens able to stimulate T lymphocytes and DCs, such as diphenylcyclopropenone (DPCP). Particularly, studies in young adults receiving a primary DPCP exposure 20 min after 2 h (but not after 30 min) of moderate-intensity running and a recall challenge 4 weeks later showed impairs both the induction of T cell immunity and the memory response [27, 117].

On the other hand, acute moderate intensity exercise mostly enhances immune responses against constituent antigens contained within the vaccine administered (influenza, tetanus toxoid, diphtheria, pneumococcal, and meningococcal vaccines) in subjects different ages [118]. Interestingly, antibody responses in women were significantly improved when moderate-intensity aerobic exercise was performed immediately prior to vaccination, whereas no beneficial effects were found in men [119]. However, the response to certain vaccine strains may differ between males and females. For example, no benefits on the immune response to influenza and pneumococcal vaccination were observed after a single 45-min bout of moderate-intensity walking exercise in women [120]. In addition, other factors than sex, like aging, can limit the immunostimulatory effects of exercise [121]. However, exhaustive prolonged exercise has been observed to increase or not modified antibody titers after vaccination. Chiefly, athletes vaccinated with tetanus toxoid 30 min after a marathon, a timepoint characterized by reduced blood lymphocyte frequency and function, presented high antibody titers 15 days later compared to those from a control group who did not compete in the race [122]. However, the administering of diphtheria and tetanus toxoid and a pneumococcal

polysaccharide vaccine to athletes 30 min after a triathlon produced antibody titers similar to the observed in vaccinated control individuals without prior exercise [28]. In brief, acute exercise could constitute an adjuvant method to enhance antibody-specific response to vaccinations, specifically in vulnerable populations, such as the elderly.

The effect of acute exercise on mucosal immunity, responsible for protecting the epithelial surfaces of the respiratory, genitourinary, and gastrointestinal tracts, has been widely studied over the last three decades. Mucosal secretions contain high levels of IgA which main role is the inhibition of invading pathogens [123]. As a consequence, changes in the secretion of salivary IgA (SIgA) following exercise have been quantified in order to analyze its effect on adaptive B-cell immunity [123]. Some studies found reduced salivary IgA levels after exercise, but returned to normal levels within 24 h [124]. Although the correction of SIgA levels considering the saliva flow rate supported these findings, many other studies of similar design reported analogous findings [125]. Conversely, a study exploring the effects of moderate intensity exercise to exhaustion found that although saliva flow rate decreased, IgA secretion rate increased in response to both exercise intensities [126]. Other studies have also reported that exercise does not diminish IgA secretion rates [127, 128]. However, a number of factors seem to be responsible of discordant findings, including training status, intensity and duration of the exercise, the method of saliva collection, sleep patterns, psychological stress, diet, oral health, and circadian rhythms [129]. Even so, SIgA levels are also affected by factors, such as sex differences [130]. As a result, the use of salivary IgA as a measure of immune competency after exercise should be interpreted with caution. At systemic level, it has never been demonstrated that exercise suppresses immunoglobulin production by plasmatic cells, probably due to the high concentration of immunoglobulins with high half-life in blood, which may mask any subtle change of circulating levels.

In summation, it appears that acute exercise is capable of both augmenting and inhibiting adaptive immune responses in vivo depending on the intensity and duration of exercise mainly, contradicting the "open-window" hypothesis.

28.3.3.3 Cytokine Induction

The detection of exercise-induced changes in cytokine levels has been challenging by the existence of some confounding factors. First, cytokines present a short half-life act, working in low concentrations, and the cellular response often depends on the presence of other stimulant molecules or circulating inhibitors [131]. In addition, the in vitro production of cytokines by mitogen-stimulated cells has not always mirrored the changes observed in vivo. Furthermore, cytokines are released after exercise or muscle damage and the cytokine profile depends on the intensity and duration of exercise or the fitness level [65].

Dr. Bente Pedersen et al. described how in vivo cytokines were secreted as a cascade, where one cytokine elicits secretion of the next element in the chain. During exercise, the cytokine release differs from the typical cytokine profile of an pathogenic inflammatory response; thus, IL-6 released to blood from the muscle is the most responsive cytokine to exercise (increased up to 100-fold) and presents anti-inflammatory properties through the induction of anti-inflammatory cytokines IL-1ra and IL-10, in addition to inhibiting TNF-α release [132]. On the other hand, acute exercise has been described to reduce cytokine production and may contribute to immunosuppression and increased risk of infection, as observed in endurance-trained athletes [133]. However, rather than a handicap, suppressed cytokine production seems to reduce the risk of chronic disease, thus constituting a key link between exercise and health.

28.3.4 Possible Factors Underlying Immune Suppression Through Intensive Exercise

The role that intense exercise plays in the risk of infection has multiple potential explanations. As previously discussed, there is evidence that high-volume exercise training can depress certain aspects of immune function that may leave athletes susceptible to opportunistic infections.

28.3.4.1 Immune Cell Frequency and Function

Commonly, a temporary drop in the number of circulating immune cells after a vigorous exercise bout is known to allow easier access to pathogens and is commonly known as "open window, which generally lasts for several hours. In fact, leukocyte counts in athletes are similar to those from healthy age-matched controls, although endurance athletes tend to present lower resting leukocyte, monocyte and neutrophil counts [134]. In addition, athletes undertaking prolonged periods of intensive training can present sustained altered counts of NK and $CD8^+$ T-cells [135] as well as impairments in innate (reduced neutrophil respiratory burst and NK-cell activity) [136, 137] and adaptive immune function (reduced T-cell proliferation, Th1 differentiation, and stimulated antibody synthesis) [135]. However, maybe, the most relevant finding from a clinical point of view is the observation of significantly reduced naïve T-cells due to a decreased thymic output in elite that could impair adaptive immune responses to novel pathogens. Functional declines in adaptive immunity due to prolonged periods of intensive exercise training appear to be related to alterations in the cytokine pro- and anti-inflammatory balance and elevated plasma levels of cortisol.

28.3.4.2 Reactivation of Latent Virus

As previously discussed, exercise has the potential to transiently alter immune protection, but in the case of elite athletes, such immunosuppression can occur during prolonged periods of training [138]. Some studies suggested that this immunosuppressive state may result in reactivation of latent herpes viruses, such as EBV or CMV [139], likely due to an exercise-induced decline in cytotoxic T-cells [138] and altered cytokine responses [140]. In this line, viral reactivation of EBV is a common finding in athletes experiencing recurrent URTI [139], and expression of EBV DNA in saliva was associated with a reduction in salivary IgA levels prior to the symptoms [141, 142]. Moreover, the best predictive use of salivary IgA is monitoring immune status in individual athletes with a history of URTI; particularly, low levels of salivary IgA and/or secretion rates over a training period and failure to recover to pre-training resting levels are associated with an increased risk of URTI in elite athletes [141, 143]. What is more, herpes viruses can reactivate in response to adrenergic activity, reactive oxygen species, and inflammatory cytokines [144], all of them increased during exercise, and independently of the state of the immune system. Anyway, a study in individuals previously infected with EBV and/or CMV exhibited a lower incidence of illness symptoms than individuals not latently infected [145], thus contradicting previous findings.

28.4 Clinical Implications of Regular Moderate Intensity Exercise

Regular exercise of a moderate intensity is accepted to exert beneficial effects on immune function (Fig. 28.3). Thus, it has been proposed that each session of moderate physical activity promotes a temporary immunosurveillance that, if regularly repeated, confers multiple health benefits including decreased disease [61]. Epidemiologic studies consistently show reduced URTI incidence in subjects engaging in regular training (at least 20 min; ≥5 days/week; 12 weeks) [146]. Interestingly, findings persisted after adjustment for confounders, such as age, gender, body mass index (BMI), and perceived mental stress. In addition, inflammatory biomarkers are reduced in fit adults. For example, the values of BMI has been directly associated with levels of the inflammatory marker C-reactive protein (CRP), female gender, exercise frequency, age, and smoking status [147]. In addition, cardiorespiratory fitness was inversely associated with CRP, IL-6, IL-18, and abdominal obesity [148]. Moreover, exercise training improves vaccine response and seroprotection to influenza both in elderly and non-diseased people [149]. However, controlled trials failed to demonstrate that exercise training decrease inflammation in the absence of weight loss [150], probably due to low activity levels and short duration of the interventions.

In addition, frequent exercise training seems to enhance the antibody response to vaccination in older adults physically active [151]. Although studies in rodents support the protective effect of vaccines from infection [152], it is unknown whether increased immunity for training is finally traduced into protection from infections in humans.

In relation to studies performed in ill subjects, training studies in cancer or obesity have reported positive effects of exercise on the immune system [153]. There are several immunoenhancing factors induced by exercise that could explain its positive effect in a disease context, all of them addressed to the reduction of inflammation. Systemic low-grade inflammation is an underlying factor of multiple disorders, including obesity, cardiovascular disease, metabolic

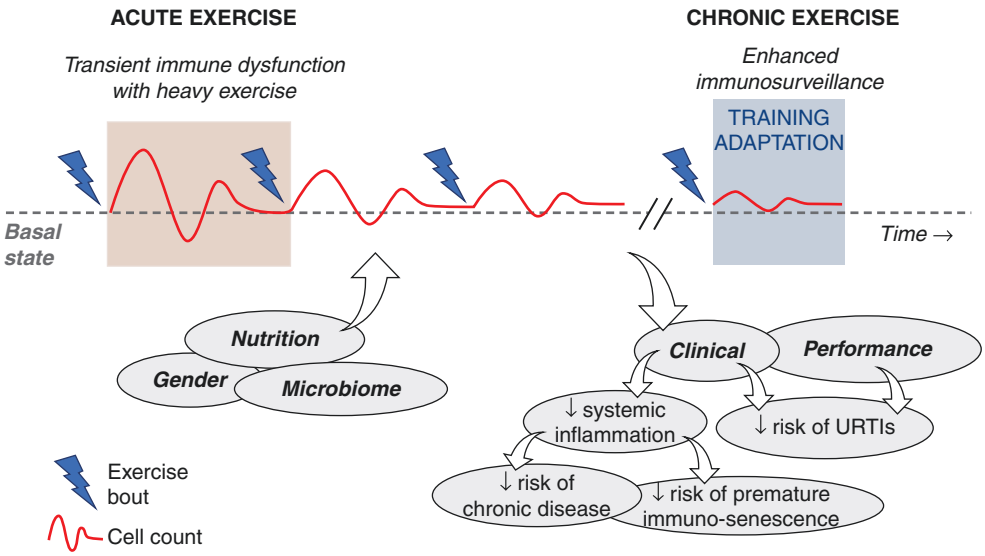

Fig. 28.3 Summary of the clinical effects of acute and chronic exercise on the immune system. It is proposed that individual bout of moderate physical exercise promotes a temporary immunosurveillance derived from leukocyte mobilization that, if regularly repeated (chronic exercise), confers multiple health benefits resulting in decreased disease risk and improved sport performance. In addition, several factors can affect this process, such as nutrition, gender, microbiota, among others (extended in the next section)

syndrome, dementia, or cancer [154]. Hence, the anti-inflammatory effects of regular exercise have a summation effect over time that may reduce the risk of disease. Among the multiple pathways of exercise contributing to reduce low-grade systemic inflammation, it is worth mention the release of muscle myokines (IL-6) that stimulate production of anti-inflammatory cytokines, such as IL-10 and IL-1ra (plasma IL-1ra inhibits IL-1b signaling, a proinflammatory cytokine usually involved in disease pathogenesis); the decrease of visceral fat mass, a variable associated with elevated production of pro-inflammatory adipokines; the secretion of hormones with anti-inflammatory properties, like cortisol and adrenaline; inhibition of expression of TLRs, thus reducing innate immune responses; augmenting of antioxidant defenses (enzymes, such as catalase, superoxide dismutase and glutathione peroxidase; and non-enzymatic antioxidants including glutathione) [153, 155].

28.5 Contemporary Understanding of the Issues

28.5.1 Methodological Limitations

Abundant anecdotal and survey data exist supporting the J-shaped curve hypothesis [61]. The limitations in this research field come from many factors that include the following: the use of self-report data, non-clinically diagnosed URTI, poorly defined exercise intensity, and lack of control over other underlying co-variables playing a role in infection susceptibility [62].

- The reliability of the self-reported symptoms of URTI collected from survey-based epidemiology studies may have been influenced by several variables of the experimental design: the participants may have been aware of the objective of the survey and consequently altered their responses; in addition, recall information over a long period of time may have produced potential error due to participant's boredom [20].
- A common bias in this field of research is that most of the studies did not clinically confirm URTI infections. Therefore, a sore throat reported as a URTI symptom would be the consequence of a non-infectious airways inflammation due to drying of the mucosal surfaces and or/inhalation of pollutant or dry air [15, 18, 20].
- Most human studies in the exercise immunology field are limited to immune measures derived from the blood, and immunosurveillance is not fully represented by serum measures. Therefore, it is difficult to determine the impact of changes on the human immune system's ability to fight against infections [18].
- Studies with athletes or those who describe the effect of acute bouts of exercise-induced change in the immune system rarely report an objective measure of exercise intensity (e.g., intensity assessed by heart rate, lactate or VO_{2max} percentage) [15]. This makes the comparison of result among studies much more difficult.
- Control of other important variables such as nutrition status, overall level of stress, and the use of nutritional supplement among others were rarely performed [15, 62].
- Protocols of exercise training in controlled trials to test the inflammatory response present low activity levels and/or short duration of interventions.

28.5.2 Role of Nutrition in Exercise-Induced Immune Changes

A healthy and balanced diet may supply all the required nutrients for non-athletes engaging in moderate physical activity. However, athletes might benefit from immunonutritional support to enhance immunity during heavy training periods. Several publications have highlighted the role of nutritional support to counteract the exercise-induced immune dysfunction, inflammation, and oxidative stress [156, 157]. It is widely accepted that inadequate water or nutrient intake during heavy training periods is involved in exercise-induced immunosuppression. In particular, many immune cells present high-energy requirements, and low substrate availability, such as decreased blood glucose levels, can increment the stress response to exercise, increasing the cortisol levels, which it is translated into direct immunosuppressive effects.

Considering the most effective nutritional strategies recommended for athletes, the intake of carbohydrates (CHO) and polyphenols have been extensively analyzed. On one hand, CHO constitutes the primary energy source in the human body, and it can modulate the immune system properties as studied in exercise. Thus, CHO have been consistently linked to a strong attenuated post-exercise inflammation (about 30–40%) [158]. CHO ingestion during prolonged endurance exercise is associated with higher plasma glucose and insulin levels, lower circulating stress hormones (epinephrine and cortisol), diminished oxidation, and both cellular and molecular mediators of inflammation (blood neutrophil and monocyte cell counts, cytokines, such as IL-6, IL-1ra, and IL-10, and granulocyte phagocytosis) [3, 17]. Furthermore, CHO-rich diet augments the activity of NK cells [159]. However, CHO supplementation does not present effectiveness to recover from URTI during strenuous exercise [160] and CHO intake after exercise reduces the T-cell functionality in vitro [17]. On the other hand, in addition to the known beneficial health effects of dietary poly-

phenols (plant-derived substances, such as quercetin), more recent studies have revealed their value as modulators of the immune system [156, 157]. A high proportion of ingested polyphenols from fruits and vegetables reach the colon, where bacterial degradation produces smaller phenolics. The gut-derived phenolics circulate throughout the body exerting a range of bioactive effects (anti-inflammatory, anti-viral, anti-oxidative, and anti-carcinogenic) [161]. Initial studies analyzing the effect of polyphenols in exercise were performed in trained male cyclists receiving quercetin (1000 mg/day) or placebo before, during, and for 2 weeks after a 3-day period in which subjects cycled for 3 h/day at approximately 57% watts max. Although quercetin ingestion did not alter exercise-induced changes immune function, it significantly reduced URTI incidence in cyclists during the 2-week period following intensive exercise compared to placebo group [162]. In addition, the daily consumption of non-alcoholic beer containing polyphenols for 3 weeks before and 2 weeks after a marathon decreases the URTI incidence, IL-6, and leucocytes blood levels [163]. Thus, polyphenols seem to provide immunity against the risk of URTI, although the mechanisms underlying this immunomodulatory role are unknown. Most recent research using *-omics* approaches analyzing ingestion of bananas during prolonged and intensive cycling have shown large-fold increases in at least 18 banana-related metabolites in plasma with anti-inflammatory effects that may enhance metabolic recovery [164]. Echinacea is another herbal supplement commonly used to treat respiratory infections. Particularly, Echinacea has been observed to reduce the common cold incidence and duration [165]. Thus, the supplementation with Echinacea purpurea for 28 days has been observed to improve the mucosal immune functions probably due to both innate and adaptive immunomodulatory functions attributed to several bioactive components, such as glycoproteins, caffeic acid, phenolic compounds, and flavonoids [166–168]. Scientific evidence supporting the use of other supplements apart from CHO and polyphenols for the prevention of immune alterations after exercise training is scarce. Vitamins C (ascorbic acid) and E have been described as antioxidants responsible for mediating, in part, free radicals neutralization in a process called free radical scavenging or quenching [169, 170]. Intense exercise generates free radicals that are the primary reason for muscle injury, fatigue, and poor performance. In addition, it is known that free radicals cause inhibition of chemotaxis, phagocytosis, proliferation of T and B lymphocytes, and cytotoxic activity of NK cells [171]. Some studies have investigated the efficacy of vitamin C supplementation in decreasing the risk of URTI [21, 172]. In this sense, the consumption of high doses of vitamin C supplement (water-soluble vitamin considered safe and non-toxic) for 3 weeks before an ultra marathon race enhanced runners' resistance to URTI infections [173]. The ratio of URTI infections after vitamin C supplementation alone, or in combination with Vitamin E or beta-carotene, was almost halved [21, 172]. In addition, reduction in oxidative stress has been described after combined consumption of vitamins C and E [174]. In this sense, some studies revealed us that combinations of vitamins and mineral supplements have been observed to be more effective than single nutrients improving individuals' immune functions and immune status [175].

Dairy-derived supplements have also been analyzed in the context of the immune response induced by exercise. Available evidence to date supports the benefits of consuming bovine colostrum (natural milk nutrient-rich produced by cows during the first days after birth) by boosting immunity and rendering resistance to infection to normal healthy subjects or athletes doing intensive exercise [176]. The supplementation with colostrum avoids body fat loss and muscle healing after strenuous exercise in athletes [177]. In addition, resistance training and bovine colostrum uptake for 8 weeks decrease the bone resorption in male and female individuals [178, 179]. Supplementation of bovine colostrum (20 g/day, 4 weeks) in male subjects acts as an immune booster in exercise-induced stress through significant increase in the neutrophil function [180]. On the other hand, probiotics are living microorganisms provided as food supplements that reach the intestine in sufficient numbers to benefit the host's health, and particularly, enhancing immunity. Since only certain strains are valuable to provide immunity when appropriately consumed, dose and the specific microbial strain of probiotics should be considered as stated prior to treatment [181]. Hence, probiotics are also helpful in reducing RTI incidence and duration [182] by increasing T helper and cytotoxic lymphocytes (CD4+ and CD8+, respectively) [183].

28.5.3 Sex Differences in Immune Response and Exercise

Notable differences have been documented regarding immune response in males and females. Sex differences in the immune system can arise from sex chromosomes and levels of sex hormones [184]. The human X chromosome contains many genes and microRNAs with main roles in the regulation of immune function. In females, X-inactivation takes place to ensure the expression of a single set of X chromosome genes; however, it has been estimated that 15% of genes escape to human X-inactivation, thus resulting in a higher gene expression in females compared to males that support the a differential immune response in males and females. On the other hand, sex hormones have various immunomodulating functions through sex hormone receptors or response elements in promoter regions present on numerous immune cells. Besides, sex hormones influence

glucocorticoid concentrations by modulating the HPA axis, which in turn can regulate immune responses.

At rest, females generally mount stronger immune response compared with males. In relation to cytokine regulation, women present a higher in vitro Th2 cytokine production characterized by increased release of IL-4 and IL-10, responsible of increased secretion of antibodies, whereas men displayed a greater Th1 profile (IFN-γ and IL-2) [185]; females also have a greater T-cell proportion from total lymphocytes [186] as well as a higher percentage of activate neutrophils and macrophages [187, 188]. At large, the estrogen levels stimulate both humoral and cellular immunity [189]. These differences might explain why females have a lower mortality rate than males for cancer and infections, but higher rates of autoimmune diseases [82, 190]. Thus, initial studies in this area employed the inoculation of animals with viruses as a model to study the whole immune response revealing an equal susceptibility to infection but a lower mortality of female mice after intranasal inoculation with herpes simplex virus 1 (HSV-1) at rest and after exercise than males [191], which could be explained by a increased macrophage function dependent of female hormones different to estrogens [59].

In relation to cytokine regulation, studies comparing the cytokine response to exercise not display noticeably differences between sexes, and only a potential increase in IL-6, the most responsive cytokine to exercise, may exist after maximal exercise in females [192]. Thus, no differences were reported in serum IL-10, IL-1ra, IL-6, and IL-8 between men and women after completing a marathon, or in the in vitro production of IL-1, IFN-γ, and IL-4 from cultured whole blood in response to continuous incremental cycling at 55%, 70%, and 85% VO_{2max} [193, 194]. The augmented IL-6 response in women could be due to their greater fat content, since adipose tissue released this cytokine [195]. IL-6 has a potent anti-inflammatory effect due to the up-regulation of IL-1ra and IL-10 at the same time as avoid TNF-α release. Nevertheless, methodological differences could explain disparity in the research regarding IL-6, since its production is directly correlated with the duration, intensity of exercise, and the number of muscle fibers recruited but inversely related to the fitness level of subjects (attenuated response) [196]. In addition, a few studies were controlled for either menstrual phase or oral contraception. Therefore, women in the luteal phase were prone to a pro-inflammatory profile after exercise compared to women in the follicular phase or men. Particularly, up-regulation of inflammation at the transcriptional level (129 genes up-regulated vs 143 genes down-regulated) was described in the luteal phase after exercise [197]. Remarkably, post-exercise IL-6 mRNA was down-regulated in the luteal phase, while up-regulated in the follicular phase after exercise. Accordingly, IL-6 trend to be increased in women who took oral contraceptives (OC) exercising in the follicular phase [198], probably due to a higher carbohydrate (CHO) depletion by oxidation in this menstrual stage [82, 199]. Indeed, female showed sustained IL-6 values after exercise compared to men. It has been suggested that the pro-inflammatory condition in the luteal phase could be a "mechanism designed to end a very early pregnancy under influence of stress". Other research in recreationally active women analyzed the combined effect of heat and exercise on immune response comparing OC and normally menstruating women. The authors found elevated (threefold) resting CRP in OC vs women in early follicular phase. However, both groups women exhibited similar immunoendocrine at rest, after exercise, and under hot environment [200]. Along these lines, a study investigating the association between the use of OC, and CRP, immune cell and circulating pro- and anti-inflammatory cytokine concentrations in Olympic female athletes did not find immunoendocrine differences, except IL-6 that was increased in normally menstruating women [201].

On the other hand, sex differences in cell counts have been also described in relation to exercise. Moderate aerobic exercise results in a temporal increase of cell subsets of the innate (monocytes, macrophages, neutrophils, and NK cells) and acquired (B and T lymphocytes) immune system. As previously explained in this chapter, exercise-induced leukocytosis through demargination from vascular pools and immune organs depends on epinephrine release and cardiac output associated with exercise. Interestingly, epinephrine release in response to sub-maximal exercise has been increased in males compared to mid-follicular females [202, 203]. Most of research studies pointed out to no post-exercise sex differences in leukocytes, lymphocytes, NK cells, monocytes, or neutrophils [193, 204], yet these studies did not control for menstrual cycle phase, OC consumption, or fitness level. In this line, women taking OC (especially in the high progesterone phase, during days taking the pill) displayed increase in lymphocytes and neutrophils post-moderate exercise compared to men and non-OC [198].

At rest, men and women have similar NK cell numbers, but higher NK cell activity is lower in women, specifically in those using OC [205]. In response to exercise, research supports the notion that there are no sex differences in NK cell number or activity [204], but as usually, most of studies were not controlled for menstrual phase or OC use. Thus, girls (non-OC) cycling (60 min at 70% VO_{2max}) tested in the mid-follicular phase had a greater increase in NK cell count than boys [206].

Studies from animals suggest a role of estrogens in limiting neutrophil infiltration to repair inflamed tissue after acute exercise [207]. Although data are inconsistent, generally female rats use to present less neutrophils infiltrating skeletal muscles post-exercise [208, 209]. Data from human cohorts reveal higher numbers of circulating neutrophils at rest and after cycle ergometry in women taking OC compared to men and non-users, specifically in luteal phase when lowest levels of estradiol are unable to inhibit the inflammatory response

to exercise [198]. The post-exercise leukocytosis and neutrophilia in women taking OC could be related to their higher growth hormone and cortisol levels [210, 211], whereas female lymphocytosis during exercise may be due to their greater density of β2-adrenergic receptors in these cells [212]. Since estradiol supplementing in men had no effect on resting or post-exercise cortisol, IL-6, or neutrophil counts [213], estrogens alone are not responsible for immune sex differences, and other factors such as the differential expression of estrogen receptors on cells throughout the body could be playing a role.

In brief, males and females show differences in immune cell counts and function as well as cytokine alterations in response to exercise when studies consider the menstrual phase and OC usage [82, 198, 200], but estrogens do not seem to be the primary factor responsible for many of the observed sex differences in research.

28.5.4 Recommendation to Exercise During and After a URTI

Acute URTI is the most common medical condition affecting athletes at international competition, with higher proportions for females and those engaging in endurance events [214]. Heavy training work-load can increase the duration and severity of the infection, and although rarely, myocarditis could be developed with life-threatening consequences [20]. In this picture, several athletic organizations including the International Olympic Committee and the International Association of Athletics Federation analyzed underlying risk factors to improve illness prevention for an proper immunity of athletes and treatment strategies to reduce interruption in training [215, 216]. Tables below show practical guidelines for medical staff, athletes, and coaches to prevent and treat infections [18, 19] (Tables 28.2, 28.3, and 28.4).

28.5.5 Exercise, Immune Function and Microbiome

Human beings have groups of bacteria (the microbiota) in different parts of the body, such as the skin, mouth, gut, lungs, vagina, and all surfaces exposed to the external medium. The interest in the microbiome has grown in last decades, because its central role in vital functions such as the development and maturation of the immune system, protection against pathogens, and production of metabolites [219] needed for fermentation of indigestible food components in the large intestine (nutrient activity). The human gastrointestinal tract is a very complex ecosystem, whose microbiota is composed of more than 100 trillions of microorganisms,

Table 28.2 Guidelines for illness prevention in athletes

Recommendations
• *Monitoring for early signs and symptoms of illness and over-training: usage of* sensitive tools for subclinical signs of illness, such as non-specific signs particularly during alterations in training load, travel and competitions
• *Behavioral, lifestyle and medical strategies* – Minimize pathogen exposure by avoiding contact with infected people, crowded areas. Not to share drinking bottles, towels, etc., with other people – Avoid exercise sessions in poorly ventilated facilities. The medical staff should isolate infected athletes – Wash hands regularly and effectively and limit hand-to-face contact to avoid self-inoculation and contagious to others (i.e., sneezing and coughing into the crook of the elbow, using of antimicrobial foam/cream or alcohol-based hand washing gel) – Follow other hygienic practices to limit all types of infections including safe sex, wearing open footwear when using public facilities to limit skin infections, using insect repellents, and covering the arms and legs with clothing at dawn or dusk – Maintain vaccines needed for home and foreign travel, with a focus on annual influenza vaccination – Follow strategies that facilitate regular, high-quality sleep – Avoid excessive alcohol intake – Consume a well-balanced diet with sufficient energy to maintain a healthy weight, with a focus on grains, fruits, and vegetables to provide sufficient carbohydrate and polyphenols that reduce exercise-induced inflammation and improve viral protection. Consider ingesting probiotic such as *Lactobacillus* probiotics on a daily basis. Pay attention to potential individual deficiencies of essential micronutrients
• Training and competition load management – Develop a detailed individualized training and competition plan, including postevent recovery measures (encompassing nutrition and hydration, sleep, and psychological recovery) – Use small increments when changing the training load (ideally weekly increments should be <10%) – Develop a competition event calendar that is based on the health of the athlete: schedule adequate recovery, particularly after intensive training periods, competitions and travel, including nutrition and hydration, sleep and rest, active rest, relaxation strategies and emotional support
• Psychological load management – Follow stress management techniques to help minimize the effects of stress and reduce the likelihood of illness – Develop coping strategies that minimize the internalized impact of negative life events and emotions – Periodically monitor psychological stresses using available instruments [217, 218]

Adapted from Walsh NP et al. [19]

Table 28.3 Guidelines for exercise during episodes of URTI in athletes

Day of illness	Recommendations
First	No strenuous exercise or competitions when experiencing URTI symptoms like sore throat, coughing, runny or congested nose (which can make the illness more severe and prolonged) No exercise when experiencing symptoms like muscle/joint pain and headache, fever, generalized feeling of malaise, diarrhea or vomiting Drink plenty of fluids, keep from getting wet and cold, and minimize life-stress Consider use of topical therapy with nasal drainage, decongestants and analgesics if feverish Consider zinc lozenges (>75 mg zinc/day; high ionic zinc content) at the onset of upper respiratory symptoms, as there is some evidence that the number of days with illness symptoms can be reduced Report illness to team physician or health care personnel and keep away from other athletes if you are part of a team training or travelling together
Second	If fever is >37.5–38 °C, or coughing increases as well as diarrhea or vomiting: *no training* If no fever or malaise and no worsening of "above the neck" symptoms: *light exercise (pulse < 120 bpm)* for 30–45 min, indoor during winter and by yourself
Third	If fever and URTI or gastrointestinal infections (GI) symptoms are still present: consult your physician. Quinolones should be avoided whenever possible because of an increased risk of tendinopathy If no fever or malaise and no worsening of initial symptoms: *moderate exercise (<150 bpm)* for 45–60 min, preferably indoor and by yourself
Fourth	If no symptom relief: do not to exercise but make an office visit to your doctor If first day of improved condition, follow the guideline below

Adapted from Walsh NP et al. [19]

Table 28.4 Guidelines for return to exercise after infections

Recommendations
• Wait 1 day without fever and with improvement of URTI symptoms before returning to exercise
• Stop physical exercise and consult your physician if a new episode with fever or worsening the initial symptoms or persistent coughing and exercise-induced breathing problems occur
• Use the same numbers of days to step up to normal training as spent off regular training because of illness
• Observe closely your tolerance to increased exercise intensity and take extra day off if recovery is incomplete
• Use proper outdoor clothing and specific cold air protection for airways when exercising in temperatures below −10 °C the first week after URTI

Adapted from Walsh NP et al. [19]

with more than three million genes (150 times more than human genes). Gut microbiota is mainly composed by two bacterial phylotypes that represent the 90% of the intestinal bacteria: *Firmicutes* (Gram-positive bacteria) y *Bacteriodetes* (Gram-negative) with low proportions of Actinobacteria, Proteobacteria, and Verrucomicrobia. In physiological conditions, one-third of the adult gut microbiota is similar between most individuals, while two-thirds are specific to each one of us and diversity is associated with a healthier status. The gut microbiota composition and diversity present plasticity as it can be influenced by diverse factors, including exercise habits, sex, age, genetics, and antibiotics [220]. Since microbiome and derived metabolites have been shown to influence immune function both locally and systematically [221], alteration of gut microbiota composition, dysbiosis, can led to inflammatory disease. In fact, alterations in gut microbiome has been associated with different disease states, including autoimmunity, allergy, or viral infections [222–224], so the modulation of the gut microbiota to promote health or prevent disease represents a field of therapeutic interest.

Although research in this area is emerging, recent studies indicate that exercise enhances richness of beneficial microbial communities and improves immune function both in athletes and physically fit individuals [225, 226]. Moreover, diet and exercise are known drivers of biodiversity in the gut [227], being diet proposed to be the primary cause by which the microbiota may be more diverse in athletes [220].

28.5.6 Exercise and Immunometabolism

During the last years, studies examining the metabolic needs of immune cells have increased exponentially [228]. Although research in this file is limited, the regulation of immune cells by metabolism presents some common characteristics. Thus, pro-inflammatory responses are mainly activated by an enhanced glycolysis to support a rapid energy demand during immune activation [229–231], whereas induction of oxidative phosphorylation use supports anti-inflammatory responses [232, 233]. In this picture, it is not surprising that alterations in immunometabolism have been associated with pro-inflammatory responses underlying disease states, such as obesity and cardiovascular conditions [234], cancer [235], or autoimmune disease [236]. Amusingly, exercise could be used as a modulator of the immune system. Thus, in response to an acute exercise stress, immune cells are activated and require a metabolic reprogramming to generate the energy to proliferate and produce molecules, such as cytokines or other molecular mediators [237]. Thus, metabolomics-based investigations indicate that prolonged and intensive exercise produces a extensive increase in numerous metabolites [238, 239] that could be still apparent in endurance athletes after 14 h of recovery [240]. As a consequence, data suggest that immune cell metabolic capacity is transitory decreased during recovery from intensive exercise, but it can be counter by the intake of carbohydrate and polyphenols [32, 34]. However, several stud-

ies have revealed exercise training as an anti-inflammatory treatment mediated by the polarization of immune cells toward more oxidative phenotypes [241, 242]. Thus, it has been suggested that metabolic pathways in immune cells could be specifically targeted to enhance or suppress the immune response as appropriate, so more studies unravelling the effect of exercise in the crosstalk between immune system and metabolism are needed.

28.5.7 Exercise and Immunosenescence

Immunosenescence is defined as immune dysregulation related to aging process characterized by increased susceptibility to infections, autoimmunity, cancer, metabolic diseases, and neurologic disorders. Among other variables, exercise has been proposed to reverse cell immunosenescence as a result of a selective apoptosis of senescent T cells ($CD4^{+}CD28^{null}$) and by promoting the development of new naïve T cells (T cells before specific antigenic contact) [103]. Actually, high fitness levels have been associated with higher levels of naïve T cells and lower senescent T lymphocytes in healthy men [243]. Furthermore, exercise is able to induce the plasmatic release of IL-7 from contracting skeletal muscle, a cytokine known to increase thymic mass and activity [244]. In addition, frequent exercise has been associated with diverse regulatory activities of the immunosenescence process, such as: enhanced vaccination responses; increased T-cell proliferation, neutrophil phagocytosis and NK cytotoxicity, low levels of inflammatory cytokines, and longer leukocyte telomere lengths [238, 245].

28.6 Future Directions

There is increasing evidence that moderate exercise might have the capability to improve immunosurveillance against infection and disease. Nowadays, the use of multi-*omic* techniques and immunometabolism-based studies is essential to further our understanding of the immunomodulating effects of exercise and their clinical implication in the susceptibility to disease. Likewise, if athletes are more susceptible to illness than the general population continues to be debated, so more longitudinal studies using laboratory-confirmed infections to determine the susceptibility are needed. In this line, multifactorial investigations testing for confounding variables (i.e., nutrition, sleep, hygiene, history of infections/vaccinations) are needed to determine the effect of extraneous and/or prolonged exercise in the global immune competency, thus leading to the evidence-based measures to face enhance immune state during training and competition. Yet, the analysis of the sex dimension in exercise immunology is critical for optimizing sports performance and health promotion or prevention. Overall, the performance of multiparametric approaches will reshape our understanding of the underlying mechanisms of the exercise influence on the immune function. In addition, other new laboratory technologies such as single-cell RNA sequencing or mass cytometry are revolutionizing the analysis of phenotypic profiling of cells and it will be applied to the analysis of exercise-induced cellular immune alterations in a close future.

28.7 Concluding Remarks

The concluding remarks that the authors feel are most noteworthy have been bulleted.

- Current experimental evidences and methodological limitations challenge the "J-shaped curve" hypothesis. Thus, exercise per se does not heighten the risk of opportunistic infections.
- Infection susceptibility has a multifactorial underpinning; factors such as stress, sleep, fitness condition, nutritional status, and infection/vaccination history could directly contribute to the immunity function and infection risk.
- Strenuous exercise produces quick leukocytosis that mainly is mediated by neutrophils and lymphocytes demargination from others pools. In addition, delayed neutrophilia released from the bone marrow was observed.
- Exercise leukocytosis has a bi-phasic response regarding numbers of circulating immune cells with an increase in the number of cells occurring during exercise as well as a decrease in cell quantity after exercise. The degree of this change is intensity and duration dependent.
- Leukopenia after exercise reflects a transitory redistribution of immune cells from the blood to the tissues. Although immune responses to single exercise bouts are temporary, effects seem cumulate over time and form the immunological adaptations to chronic exercise training.
- *The effects of exercise on immune function can depend on exercise intensity.* Regular bouts of moderate intensity exercise are beneficial for the normal functioning of the immune system and reduced risk of infection/illness. Conversely, high exercise workloads and competitions are linked with transient immune dysfunction and illness risk.
- Cessation or reduction in the amount and intensity of exercise may improve the time of recovery from a URTI infection. However, athletic competition or training maintained at high intensity levels may increase the severity and duration of the disease.
- Estrogens alone are not responsible for immune sex differences in exercise-induced immune system changes.

More research is needed to clarify the role of variables, such as menstrual cycle, OC use, fitness level, and exercise intensity in the sex differences.

- Nutritional strategies recommended for athletes includes the intake of carbohydrates and polyphenols by their capacity to modulate post-exercise inflammation.
- The microbiome diversity, associated with a healthier status, is enhanced by exercise.
- Regular exercise might limit or delay the onset of immunological aging through a regulatory effect of the immune system.

Chapter Review Questions

1. Diverse studies comparing self-reported URTI with laboratory methods have concluded that the incidence of URTI is _____ in athletes compared to general population
   (a) higher
   (b) similar
   (c) lower
   (d) none of the above
2. The J curve was first proposed based on
   (a) Studies with moderate exercise intensity
   (b) Studies in nonathletic population
   (c) Studies in athletic population that performed high-intensity exercise
   (d) Studies in rats
3. After moderate exercises, studies have showed to _____ immune responses to vaccination, low-grade inflammation and various markers in diseases (i.e., HIV, cancer, diabetes or obesity)
   (a) Improve
   (b) Worsen
   (c) Not affect
   (d) Randomly change
4. During prolonged aerobic exercise
   (a) Only a sharp increase of leukocyte is observed
   (b) A biphasic increase in leukocyte is observed
   (c) A decrease in leukocyte is observed
   (d) No changes in leukocytes are observed
5. Which is the most responsive cell to exercise stimulus?
   (a) Neutrophils
   (b) Lymphocyte T
   (c) Lymphocyte B
   (d) NK cells
6. What causes NK cells increase their cell number immediately after exercise?
   (a) Increased catecholamine production
   (b) Decreased plasma volume
   (c) Increased Th2 lymphocyte numbers
   (d) Increased T lymphocytes
7. A transient reduction in the frequency of immune cells after exercise is due to
   (a) negative changes in cell count
   (b) negative changes in cell function
   (c) preferential mobilization of cells to tissues and organs
   (d) preferential mobilization of cells to the bloodstream
8. Which supplementation reduces URTI incidence following intensive exercise?
   (a) Vitamin C
   (b) Vitamin D
   (c) Quercetin
   (d) Glutamine
9. Females with normal menstrual cycles show _____ in immune cell counts and function as well as cytokine alterations in response to exercise compared to males.
   (a) Similar
   (b) Different
   (c) Higher
   (d) Lower
10. During URTI episodes, the guidelines for exercise recommend do not exercise if we have
    (a) Runny nose
    (b) Fever
    (c) Sore throat
    (d) Cough

Answers

1. b
2. c
3. a
4. b
5. d
6. a
7. c
8. c
9. b
10. b

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Exercise Recommendations for Females Affected by Cancer Throughout the Lifespan

29

Cayla E. Clark and Carolina Chamorro-Viña

Learning Objectives
After completing this chapter, you should be able to:

- Understand the definition of cancer, types of treatment, and common side effects.
- Identify the most prevalent cancers in women and children.
- Describe the benefits of physical activity, recommended exercise programs, and precautions to exercise for woman and children with cancer.
- Discuss the ACSM and American Cancer Society (ACS) stands on exercise prescription for cancer patients and survivors.

29.1 Introduction

Cancer is a genetic disease caused by changes to genes that control the way our cells function, particularly how they grow and divide. It is also considered a chronic disease, because it requires extended medical attention. There are over 200 types of cancers known, beginning in any tissue, such as the skin, organs, muscle, bone, fat, immune system, and blood vessels [1, 2]. Cancer is characterized by the growth of abnormal cells that divide uncontrollably without stopping, ignore the signals of apoptosis (programmed cell death as a part of normal cellular function), and have the potential to invade healthy body cells and tissues. In the body, cells grow, die, and replace each other through a process called mitosis. Cancerous cells begin dividing rapidly with abnormal cellular characteristics, leading to a buildup of the new foreign cells. When a buildup of cancer cells occurs, a tumor arises. Tumors can either be benign or malignant. Benign tumors grow only in one place and they cannot invade other parts of your body. Even so, they can be dangerous if they press on vital organs, such as your brain. Malignant means that the cells are cancerous. Cancerous cells are not limited to tumors. Cancers of the blood, such as leukemias, generally do not form solid tumors. Cancer can travel through the body via the bloodstream or lymphatic system and invade several tissues. The spreading of cancer from its original invading site to another location in the body is known as metastasis. When metastasis occurs, the cancer has already progressed to a serious state. Cancer can also be classified in stages. Stage I is the earliest stage with the highest probability of successful treatment, while stage IV is the most advance stage in which usually the cancer is spread in distant tissues, requiring aggressive treatment. The best way to combat cancer is through early diagnosis and treatment.

Cancer is the second leading cause of death among adults in the United States, following heart disease. However, the death rate for cancer has dropped by around 30% in the past three decades due to lifestyle changes (i.e., less people smoking cigarettes) paired with early detection and treatment [3]. The National Cancer Institute predicts 1.8 million cases of cancer in the United States in 2020, with female breast cancer as the largest subcategory at 276,000 new cases. In other words, it is estimated that 15% of the new cancer cases in 2020 will be breast cancer [4]. Furthermore, the American Cancer Society (ACS) estimates that 39 out of 100 women will develop cancer in their lifetime, but this number could vary based on individual lifestyle, environmental factors, and genetic history [3]. The most common types of cancer in women are breast, colorectal, lung, endometrial, cervical, skin, and ovarian cancers.

Cancer is most prevalent in older populations, but that does not mean children and adolescents are not at risk for developing cancer as well. Pediatric cancer is rare, accounting for about 1% of all cancers, yet it is the second cause of death in children after accidents. The ACS predicts that there

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will be about 10,500 children in the United States under the age of 15 diagnosed with cancer in 2021. 89,500 new cancer cases and 9270 cancer deaths in adolescents and young adults ages 15–39 years in the United States in 2020 [3]. It is important to differentiate children and young adults from older populations when identifying cancer trends, because there are differences between cancer development, treatment, and survival between these populations. In children and adolescents (under 20 years), the most common types of cancer are acute lymphoblastic leukemia (ALL), brain and spinal cord cancers, and lymphomas.

When cancer is detected, there are several different treatments to fight the cancer, and the best treatments are dependent upon the type of cancer and how advanced the cancer is. Although the same treatments are used often to fight cancers of similar origin and severity, not all people respond the same to treatment. More and more researchers are recognizing distinctions that create the differing responses to cancer treatments between individuals [5]. Not only do the success rates of treatments vary between individuals, but the side effects of the treatments too. Chemotherapy, surgery and radiotherapy are the most common standard treatments.

Chemotherapy slows the growth of cancer cells by reducing the cells' ability to divide and grow. Chemotherapy can be given several different ways, such as orally, intravenously, through an injection, or topically. It is seen as an effective treatment to either reverse or delay the growth of cancer and is oftentimes combined with other treatment methods. Chemotherapy is a systemic treatment, because the drugs travel throughout the body and can kill cancer cells that have spread (metastasized) to parts of the body far away from the original (primary) tumor. It cannot distinguish between healthy and cancer cells, meaning it not only attacks cancerous cells, but also healthy cells as well. For example, chemo can attack the cells lining your mouth and esophagus, creating difficulty eating [1]. It can also cause hair loss, severe nausea, and fatigue. This is due to chemotherapy often attacks cells that reproduce fast as cancer cells does.

Surgery aims to remove the cancerous cells or tumors. Surgeons can either remove part of a tumor or the entire tumor(s), depending on severity, metastasis, and percent of positive or negative predictable outcome. Removing part of a tumor could help decrease a patient's symptoms, especially in brain tumors that because of location cannot be safely removed. Surgery could be very successful in cancer treatment, but there are high risks, such as increased pain, infection, rejection by the body, and death.

Radiation therapy can be used to shrink tumors and kill cancer cells. Radiation therapy takes time, and usually requires several treatments before the cancer begins to shrink. Side effects can vary with the type and location of radiation therapy. The most common side effect is fatigue and shows up weeks after initiation. In breast cancer specifically, radiation therapy can cause fatigue, hair loss, skin changes, and tenderness. In the pelvic region, radiation therapy could lead to fertility problems [6]. In children, similar side effects occur, but children can additionally face inhibited bone growth affecting their stature, joints, and future skeletal development. Radiotherapy of the brain also has negative outcomes in children, because their brains are not fully developed. As a late effect which can occur years after end of treatment hormonal deficiencies, secondary to radiation such as hypopituitarism and hyperprolactinemia can occur [7]. Other cancer treatments include hormone therapy, immunotherapy, and stem cell treatment.

Cancer is a complex disease, but research is guiding us toward new discoveries of successful treatments, preventions, and cures. The focus of this chapter is exercise as medicine for women and children with cancer. Studies have shown that exercise cannot only prevent the development of cancer [6], but could also serve as a therapy for reducing harmful side effects during cancer treatments and during survivorship once the cancer is gone [5, 8–10]. The benefits from regular exercise as medicine for cancer range from the physical benefits of enhanced strength and endurance [11] to improvements in psychological health [10, 12], which all greatly promote advancement in a cancer patient's quality of life. Now that we have discussed various types of cancer treatments and side effects, we will take a further look at the benefits of exercise for women and children.

29.2 Research Findings and Contemporary Understanding of the Issues in Women

29.2.1 Cancer in Females

29.2.1.1 Most Common Types of Cancer in Women

The most common types of cancer in women are breast, lung, colorectal, uterine, thyroid, and skin (Fig. 29.1) [3]. Women should regularly monitor their bodies in order to quickly identify any abnormal growths or symptoms. With any form of cancer, the earlier it is detected, the more likely it can be managed or cured. A variety of change is inevitable with a cancer diagnosis, including physical and psychological symptoms. For example, women and children who undergo cancer treatment are susceptible to fertility complications, especially if they were irradiated in the pelvic area, were exposed to chemotherapy that caused the ovaries to stop releasing eggs or ceased menstruation or underwent surgery to remove cancerous reproductive organs [6]. In young adult women, this can be a devastating development and affects emotional health. Cancer bears heavy weight on the patient and loved ones of those diagnosed, but this section

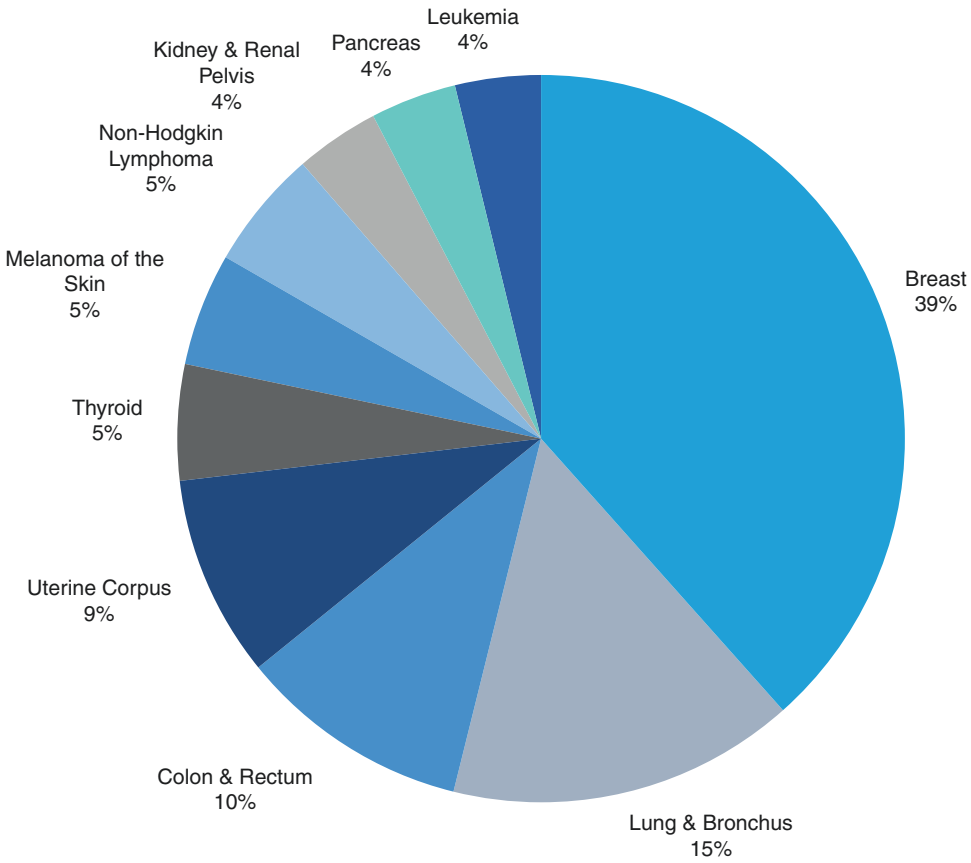

Fig. 29.1 2020 estimated new cases of cancer in women [3]

will focus on exercise interventions that could improve symptom, survival, and relapse outcomes.

29.2.1.2 Benefits of Physical Activity on Common Cancer Symptoms in Women

There is ever growing research in the area of cancer treatment, prevention, and cure, but there is no way to feasibly predict how cancer will affect any individual person. Nonetheless, research has shown that there are ways to slow the spread of cancer and prevent future diagnoses through medical treatment and lifestyle changes. Research in exercise and cancer is growing, with clear benefits of physical activity or exercise to cancer patients. Physical activity refers to any type of physical movement that results in a person moving around, such as walking or activities of daily living. Exercise occurs from structured programs with intentional body movements to illicit physiological changes in the body. For the purposes of this chapter, physical activity and exercise will be used as synonymous terms to describe movement as an aid in cancer therapy. Some of the benefits of physical activity include fewer side effects during treatment, such as chemotherapy, improved daily functions, and improved psychological health [8]. The American College of Sports Medicine (ACSM) states that lower amounts of exercise can help with cancer treatment-related symptoms, including fatigue, physical function, anxiety, depression, bone health, and quality of life [5, 13]. The aim for any cancer patient is survival, and more physicians and oncologists are beginning to advocate exercise in conjunction with common cancer treatments in order to improve the quality of life of their patients. Exercise physiologists and other healthcare professionals have a clear understanding of how to develop safe and effective exercise programs for cancer patients. It is important to keep in mind the effects that medications and treatments have on the physical and psychological health of cancer patients, in addition to knowing how to avoid injury or prevent further pain or discomfort depending on the site or type of cancer a patient may have.

The following sections will highlight the benefits of physical activity for women with cancer. However, before we discuss the benefits of exercise, we must first interpret the pathophysiology of cancer and the symptoms it produces.

29.3 Pathophysiology of Cancer and Symptoms Produced

29.3.1 Cancer-Related Fatigue

The national comprehensive cancer network defines fatigue as a distressing, persistent, subjective sense of physical,

emotional, and/or cognitive tiredness or exhaustion related to cancer and/or cancer treatment that is not proportional to recent activity, and significantly interferes with usual functioning [14, 15]. Fatigue is one of the most common and persistent symptoms in cancer patients. Cancer-related fatigue (CRF) can result from the cancer and/or the treatment [3, 15] and is experience mainly during treatment, but can also persist month or years after treatment. The pathogenesis of CRF is not fully understood and is complex. It is cause by multifactorial, involving the interaction of cognitive, emotional, psychosocial, and somatic factors [14]. Despite the lack in evidence, there are many factors that can contribute to the development of CRF. One of these symptoms is anemia. Anemia, or abnormally low levels of red blood cells in the body, is a common comorbidity with cancer, especially for people undergoing cancer treatments, such as chemotherapy or radiation therapy. Erythrocytes, or red blood cells, are responsible for transporting oxygenated blood from the lungs to the rest of the body's tissues while also carrying back carbon dioxide to the lungs for expulsion. When the body is not making enough erythrocytes or when they are being destroyed due to the cancerous cells or therapies, anemia occurs and thus can bolster CRF. One of the reasons anemia that can occur in female cancer patients is due to metastasis to the bone marrow, the location, where erythrocytes are formed. In breast cancer patients specifically, bone marrow metastasis is common, especially when the breast cancer is more advanced [16–18]. In addition, women are more likely to develop anemia than men, especially during their childbearing and menstruating years, with or without a cancer diagnosis. Because of this, women with cancer, especially breast cancer, can succumb to CRF due to low red blood cell count. In a pooled analysis of 4703 patients with stage I–III breast cancer, micrometastasis of the bone marrow was detected in 30.6% of the patients [16]. The most cases occurred in the later stages of breast cancer compared to the earlier or smaller stages. Other causes of CRF often relate to cancer treatments. These could include increased inflammation, increased cellular waste for the body to expel from chemotherapy, and increased toxicity in the body and brain.

Research evidence is growing in regard to the benefits of exercise on CRF. Various forms of exercise, including aerobic activities, resistance training, and stretching, have shown improvements in CRF [19]. Regarding fatigue in relation to anemia, a study showed that moderate intensity aerobic exercise-maintained erythrocyte levels in the cancer patients compared to the declined levels in non-active individuals [20]. Exercise can promote improved homeostasis of the body, which is the body's way of maintaining balance across the bodily systems. Increasing a person's physical activity promotes their cardiovascular system to do more work. When a person exercises, the heart pumps more blood throughout the body to promote faster oxygen delivery to working muscles. Simultaneously, the need to expel carbon dioxide (waste) increases as well resulting in faster respiration. In addition, the more physically active someone is, the more energy they will have at rest through increased metabolic functions. For someone with cancer, this is important in combating CRF. Cardiovascular fitness activities, strength training, stretching, and relaxation therapies can all decrease fatigue in cancer patients. It is important to note that health care professionals who are working with cancer patients should always make safety their top priority when prescribing exercise programs to cancer patients. The goal is to increase the intensity and/or duration of the activity to promote higher levels of energy, but this should not compromise the patient's physical abilities or safety.

29.3.2 Physical Function

Reduced physical function, closely related to fatigue, is another common symptom of cancer. As described above, fatigue is defined as physical, emotional, and/or cognitive tiredness or exhaustion related to cancer or cancer treatment that is not proportional to recent activity and interferes with functioning [16]. Conditions that result from cancer treatments can enhance fatigue-related physical dysfunction, such as anemia, hypothyroidism, insomnia, pain, and hypopituitarism [14, 15]. Other cancer symptoms such as nausea can cause a reduction in energy levels, furthering the decline in physical function for women with cancer. Low energy levels can also lead to low bone density in women, in addition to cancer-related declines in bone health [21]. Osteoporosis, a disease that affects the density and makeup of bone tissue, is a common disease seen in post-menopausal women or women with menstrual dysfunctions. Most of the reported cancer cases in females occur in women over 55, which is typically when women no longer produce menses, leading to a greater chance of developing low bone mineral density. The inter-relationship between low energy availability, menstrual dysfunction, and low bone mineral density in female athletes, referred to as the female athlete triad, is a heavily studied topic in exercise physiology. As we have discussed, one condition can result in another, and cancer symptoms can expedite these common issues in women's health.

There is substantial evidence that physical activity can improve overall physical function and strength in cancer patients. Ideally, cancer patients should aim to increase their lean body mass. Women with gynecological cancer reported improvements in physical function as well as increased BMI from multifocal exercise programs compared to sedentary control groups [22]. Exercise itself results in improved energy levels, bone composition, muscular tone, endurance, and strength, range of motion, and BMI. Regardless of the

type of exercise, the message to take away is that physical activity of any type can improve a woman's physical function while living with cancer.

29.3.3 Lymphedema

A common symptom found in cancer patients is lymphedema, the build-up of fluid in some or all limbs usually caused by the removal of or damage to lymph nodes. Primary lymphedema is a chronic condition caused by abnormal development of the lymphatic system. Secondary lymphedema results from damage to the lymph system, such as after cancer treatments [4]. Examples of cancer treatments that cause lymphedema are radiation therapy and surgery. These procedures damage the lymph nodes in hopes to remove or reduce cancerous growths. There can also be blockage of the lymph resulting from build-up of scar tissue around the nodes. People who suffer with lymphedema can have significantly decreased physical function and quality of life due to limited mobility, discomfort, and pain.

Women with breast cancer are among the highest populations at risk for developing lymphedema following cancer treatment. One-in-five breast cancer survivors are at risk for developing lymphedema [22]. Research is scarce on specific exercise programs and the corresponding effectiveness on lymphedema prevention and treatment, but it is becoming more apparent that exercise is better than sedentary behavior for people with lymphedema. Research is beginning to show that careful exercise programs can help ease some of the complications attributed to lymphedema [22]. The best improvements exercise can contribute are reduced swelling or the cessation of further swelling, improved range of motion at affected joints, decreased pain, and improved confidence. Exercise can also promote the flow of fluids throughout the body, important for the management of lymphedema [23]. Exercise may not always be an available option depending on the severity of symptoms, but it should be considered and discussed by the patient along with her doctor. If a woman's physician or health care professional determines that exercise is a safe course of treatment, consider supervised exercise with a professional. Lymphedema can be a very painful and mentally tolling condition, so the support of a trained professional is the safest approach [23].

29.3.4 Anxiety, Depression, and Quality of Life

Another effect cancer on women is an increased number of patients who report anxiety or depression. Due to the increased symptoms that arise with cancer and cancer treatment, overall quality of life can quickly decrease for people with cancer. There are no significant differences between the reports of men and women with declined quality of life in cancer, but it is important to note some changes that could significantly change the life of a woman. For example, women can face several complications with fertility and sexual function after a cancer diagnosis [6, 24]. Surgery, such as a hysterectomy (removal of the uterus) or oophorectomy (removal of the ovaries), will leave a woman infertile. Most cancer treatments can cause infertility as well. Other changes, such as a mastectomy (removal of the breast tissue), can also lead to psychological problems, making a woman feel less feminine. Without help, women can lose the desire to heal and fight their diagnosis.

Motivation is one of the key factors for improving a person's psychological trauma and quality of life with cancer. Exercise can decrease a patient's anxiety and improve overall quality of life, especially for women with breast cancer [25–29]. For cancer patients as a whole, aerobic exercise improves anxiety, depression, and quality of life [5, 28]. Resistance training improves quality of life and is a safe form of exercise for cancer patients who have completed their first round of treatments [30–32], while combined aerobic and resistance training improved patients' endurance by raising their steps per day by 7000 steps despite undergoing radiation treatment [28]. It is clear that exercise improves the patient's mental state, but to further support women who are undergoing cancer treatment, it is best to have a clinician or caregiver accompany them during their workouts. If a clinician is not available, then women should be sent to motivational counselors and clinical exercise professionals who can guide them through a program they can complete independently [33]. However, research has shown that the greatest benefit on mental health and quality of life for people with cancer is through supervised exercise programs [28, 31].

29.3.5 Peripheral Neuropathy

Peripheral neuropathy is a condition resulted from peripheral nerve damage, commonly affecting the hands and feet the most. People with peripheral neuropathy can experience acute sensations, or chronic pain and irreversible nerve damaging [34]. Cancer patients can develop peripheral neuropathy after undergoing chemotherapy, depending on the type of drug administered, known as chemotherapy-induced peripheral neuropathy (CIPN). Unfortunately, this chronic symptom could last beyond the cancer diagnosis, so it is important to discuss the possible benefits that increased physical activity could have on CIPN. It is important to remember the importance of individualized programs when working with cancer patients, because the exercises should target improvements in their specific symptoms. With CIPN, there is an evident need to improve neurological function. One way that physical activity helps the brain and the muscles work

together is through improved neuromuscular connection. Neuromuscular connection is the phenomenon when the brain sends a signal to the skeletal muscles causing a muscular contraction. Improved neuromuscular connections increase several physical abilities, including muscle strength, tone, coordination, and balance while also exercising the peripheral nerves affected by CIPN.

Peripheral neuropathy could be caused through decreased blood flow to the extremities. When blood flow is decreased through inflammation or other vascular disorders, nerve cells are deprived of oxygen causing neural damage or even nerve cell death. This can lead to the symptoms of pain and paresthesia (tingling sensations, commonly called "pins and needles") that patients with peripheral neuropathy experience. Exercise can ease these symptoms through improvements in circulation. Aerobic and resistance exercise produces increased blood flow in the body as the demand for oxygen consumption increases throughout bodily cells. The diameters of the blood vessels grow in response to the demands for more blood to pump through the circulatory system.

In regard to cancer patients, there is evidence that exercise improves symptoms of CIPN. Chronic exercise promotes greater vascular remodeling, but acute exercise can be beneficial as well. Women with breast cancer reported improved quality of life in relation to living with peripheral neuropathy following 10 weeks of home-based exercises [35]. A systematic review on cancer patients with CIPN undergoing treatments found that longer interventions produced greater improvements in CIPN symptoms compared to shorter exercise programs, but there were still improvements in symptoms and self-reported quality of life [36]. They also found that the specific type of exercise was not necessarily important, but emphasized greater improvements with programs focused on specific goals to improve symptoms, such as balance and sensorimotor training.

29.3.6 Body Composition

Besides aiding cancer-related symptoms, exercise can improve other physiological factors in the body. It is no surprise that exercise improves resting metabolism, lowers body fat composition, and improves muscular tone and cardiovascular health. For cancer patients, these improvements can prove far more beneficial than what they seem on the surface. Obesity is a risk factor for developing cancer, but the reason for this is not greatly understood. Likely, it is the result of metabolic and endocrine changes resultant of obesity [37]. Excess fat, or adipose tissue, results in increased estrogen and insulin production. These hormones promote cell growth and reproduction, encouraging the growth of cancerous cells (i.e., rapid tumor growth). Furthermore, adipose tissue provides a suitable environment for cancerous cells to thrive [38]. Breast cancer is one of the most common cancers linked to obesity. Post-menopausal breast cancer is more attributable to obesity than pre-menopausal breast cancer [37, 38]. It is important for women with breast cancer to understand the dangers of excess body fat on their cancer's improvement and survival. Exercise can help lower body fat percentage and thus decrease the viable environment for cancer cells. For cancer prevention and treatment, seen more evidently in research on women with breast cancer, exercise is an important lifestyle intervention. The following section will explain details over exercise prescriptions for women with cancer and cancer survivors.

29.3.7 Other Symptoms

Limited research has been found over the effects of exercise on nausea and pain unless they are subcategorized under treatments, such as chemo. One study observed the effects of supervised strength training on survivors of head and neck cancer with upper extremity pain, finding that pain was reduced following the 12-week intervention [39]. However, far more research is needed to identify improvements in nausea and pain cancer-related outcomes from exercise interventions. Another symptom with limited research in regard to cancer and exercise is immunosuppression. Immunosuppression occurs when the body's immune system is not functioning. Cancer directly affects the body's immune system and is bolstered with the addition of cancer treatments. Regular physical activity can improve the body's immune response through promoting the production of blood cells (hematopoiesis). Regardless of the limited research, it is clear that exercise can bolster immune function and thus could serve as a beneficial interventional treatment for cancer patients and survivors.

29.4 Physical Activity Recommendations

29.4.1 Current Standings on Physical Activity for Women with Cancer

With cancer patients, physiologists and qualified exercise professionals must have the quality of adaptability when prescribing exercise protocols. The best type of exercise for cancer patients is dependable upon the individual. When working with someone who has cancer, it is important to know the type of cancer, how far the cancer has progressed, other comorbidities that could be involved, medication taken, and the individual's symptoms. Other important factors to consider when developing programs for cancer patients and survivors are the patient's current and previous fitness status as well as personal goals. Research suggests that the type of exercise does not matter for physical improvements, but cancer patients could have a greater benefit with supervised pro-

grams verses home-based or independent exercise. Supervised exercise also plays a key role in women's mental health through the journey of diagnosis and treatment, as we will discuss later. When considering exercise as a method to improve strength, resistance training takes the focus in healthy populations, but there is not explicit evidence that strength programs show any greater benefits than aerobic or combined exercise prescriptions. The ACSM assembled a group of experts in the fields of cancer and exercise in 2010 to develop exercise guidelines for cancer survivors [13]. This committee set out to find the best exercise prescriptions for persons recovering from cancer. Table 29.1 summarizes the updated roundtable findings for aerobic, resistance, and a combination of both for specific cancer-related outcomes following a cancer diagnosis [13]. Overall, the goal when working with a patient is to avoid inactivity and improve her health status.

These outcomes were discussed earlier in the chapter, and now that we have an understanding of the benefits of exercise for women with cancer, we can identify specific exercise rec-

Table 29.1 Summary of ACSM FITT prescriptions for cancer-related health outcomes. Reprinted from Campbell KL, Winters-Stone KM, Wiskemann J, May AM, Schwartz AL, Courneya KS, et al., Exercise Guidelines for Cancer Survivors, Medicine and Science in Sports and Medicine, Vol. 51/Issue 11, pages 2375–2390, © 2019, with permission from Wolters Kluwer Health [13]

Outcome	Type	Frequency (sessions per week)	Intensity	Time (Duration in min or reps)
Anxiety	Aerobic	3	60–80% HRmax RPE 13–15	30–60
	Resistance	NA	60–80% HRmax RPE 13–15 65–85% 1-RM	NA
	Aerobic (A) + Resistance (R)	A: 2–3 R: 2–3	A: 60–80% HRmax RPE 13–15 R: 65–85% 1-RM RPE 13–15	A: 20–40 R: 2 sets 8–12 reps
Depressive Symptoms	Aerobic	3	60–80% HRmax RPE 13–15	30–60
	Resistance	NA	60–80% HRmax RPE 13–15 65–85% 1-RM	NA
	Aerobic + Resistance	A: 3 R: 2–3	A: 60–80% HRmax RPE 13–15 R: 65–85% 1-RM RPE 13–15	A: 20–40 R: 2 sets 8–12 reps
Fatigue	Aerobic	3	65% HRmax RPE 12	30
	Resistance	2	60% 1-RM RPE 12	2 sets 12–15 reps
	Aerobic + Resistance	A: 3 R: 2	A: 65% HRmax RPE 12 R: 60% 1-RM RPE 12	A: 30 R: 2 sets 8–12 reps
Health-related Quality of Life	Aerobic	2–3	60–80% HRmax RPE 11–13	30
	Resistance	2–3	60–75% 1-RM RPE 13–15	2–3 sets 8–15 reps
	Aerobic + Resistance	A: 2–3 R: 2–3	A: 60–80% HRmax RPE 11–13 R: 60–80% 1-RM RPE 12–14	A: 20–30 R: 2 sets 8–15 reps
Breast-cancer-related lymphedema	Aerobic	NA	NA	NA
	Resistance	2–3	60–70% 1-RM RPE 15	1–3 sets 8–15 reps
	Aerobic + Resistance	NA	NA	NA
Physical function	Aerobic	3	60–85% HRmax RPE 12–13	30–60
	Resistance	2–3	60–75% 1-RM RPE 13–15	2 sets 8–12 reps
	Aerobic + Resistance	A: 3 R: 2–3	A: 60–85% HRmax RPE 12–13 R: 60–75% 1-RM RPE 13–15	A: 20–40 R: 2 sets 8–12 reps

ommendations for each symptom. This summary follows the current recommended physical guidelines for health: 150 min of aerobic activity per week with strength training twice a week. Specifically, effective exercise prescription for cancer survivors is at least 30 min of moderate-intensity aerobic training at least three times per week for at least 8–12 weeks [5, 13]. Furthermore, at least 2 days a week of resistance training added in addition to aerobic training, using at least two sets of 8–15 repetitions and at a minimum of 60% of her one repetition maximum (1-RM), could show similar benefits to aerobic activity alone [5]. Following the same protocol, the ACSM suggests that 8–12 weeks of aerobic, resistance, or combined training for 3–5 days a week improves a survivor's self-reports of physical function and strength as well [13, 40]. It is not known whether a specific type of exercise is superior to another in the treatment of cancer. Evidence suggests that any physical activity promotes progress when aiming to combat CRF in breast cancer [5, 26, 31]. For women with breast, colorectal, lung, and gynecological cancers, research has shown the greatest benefits arise within training protocols under supervised programs compared to unsupervised [8, 28]. Pairing supervised programs with aerobic and resistance training, women should expect a significant increase in health-related quality of life, CRF, lymphedema, physical function, and mental health.

For people living with cancer, the exercise recommendations look different than those described previously. Persons who have already finished cancer treatment likely have less physical limitations to exercise than people actively fighting cancer, but the same principle of maintaining safety and individuality when developing exercise programs for both groups remains the same. Cancer patients have exacerbated symptoms, meaning that the CRF, weakness, lymphedema, and mental health problems can be intensified. Regarding women, these issues can be bolstered with poor self-image resultant from a greater prevalence of insecurities and poorer body composition associated with women's most common cancers (refer to Fig. 29.1 for the most common cancer sites in women). It is important to take a gradual approach, understanding that women with cancer may start at much lower intensities than healthy populations and progress at a slower rate and more breaks might be needed. The ACSM advises that the goal for cancer patients is 30 min of aerobic activity 3 days a week for improved cancer symptoms [8]. If the patient cannot complete 30 min of an activity, begin with 5 or 10 min three times a week, then increase the volume (amount) and intensity (resistance) gradually. For resistance training, low-intensity exercises for 10–15 reps and 2–4 sets would be a good starting point for cancer patients, aiming for two times a week. Once the patient becomes comfortable with this intensity and volume, she can transition to higher weight and shorter reps [8].

In addition, flexibility and stability training are important for cancer patients as well, especially if they are experiencing symptoms of fatigue, lymphedema, physical weakness, anxiety, or depression. Stretching, alongside all forms of physical activity, improves the body's neuromuscular connection. This can help cancer patients limit physical limitations, such as falling or weakness. Flexibility programs also improve range of motion at the joints. Cancer patients can be sedentary for extended periods of time while undergoing treatments, recovery, and fighting physically ill symptoms. This sedentary behavior can negatively impact the bones, muscles, and joints. Regular stretching can help fight this stiffness and improve safety when beginning and throughout the course of exercise programs. Working on flexibility three to four times a week in addition to aerobic training and strength training is a good goal for people with cancer.

There are still benefits to independent physical activity programs for women with cancer, but the most effective programs involve professional help. The ACSM states that the ideal intervention would be a multidisciplinary approach, where the exercise prescription is fully integrated into clinical pathways [8]. This would ensure the quickest start to the exercise program, while treatments are occurring, but there are not currently resources or funding to offer this approach. Nevertheless, the clinician should identify motivational behaviors in the patients to promote a change in the patient's behavior. This could include recommending activities until they choose one they could enjoy, encouraging them in their physical appearance to feel confident in their ability to exercise, and seeking support from their caregivers. ACSM's driving point is that exercise is medicine, and clinicians need to educate themselves on how to provide this medicine to millions of people affected by cancer each year. If the clinician assesses the physical state of the patient, motivates a behavior change, and makes referrals, they are following the ACSM's recommended considerations for their patient [8].

29.4.2 Considerations to Exercise

Although we have been discussing all the benefits of physical activity for women with cancer, there are several precautions that clinicians should take when working with cancer patients. First, it is important to understand that not every patient or survivor is the same. A healthcare or wellness professional working with cancer patients should work on building up their patient to this recommended level of fitness if it is not appropriate to perform at the time. Clinicians should know all the past medical history of their clients, including the dates of each of their past and future treatments since the cancer diagnosis. Clinicians should also clearly understand the symptoms that the cancer patient is facing. The goal is for exercise to alleviate or improve these symptoms, but there must be special care in place for the patient. For example, consider a patient with colorectal cancer who has a colonoscopy bag. A doctor's approval for her to exercise, especially after recent surgery, is imperative. It is also important to monitor any pain or discom-

fort at the incision site, even after it is healed. Finally, it could serve as beneficial to use a belt or strap to secure the bag in place, while she is lifting weights or involved in a moderate-to-high intensity cardiovascular activity to prevent leakage or discomfort, because it is very probable the patients will already be self-conscious that it is there.

There are special implications for patients who have recently undergone surgery that require modifications for physical activity. Ideally, the surgeon, primary physician, exercise professional, and patient should work together to ensure that the patient is healing properly following her operation. The patient should not engage in any physical activity until the surgeon provides consent, which could take several weeks or even months. Once the patient is cleared, there are still precautions to take in regard to physical activity. Low intensity and low volume exercises should be the starting point, with slow, gradual increases in volume and intensity over time. The goal is to improve health, so rushing through progressions could cause more harm than good for a post-surgical client.

Professionals could not only risk injury or worsened conditions through carelessness and neglect, but they could also negatively impact the patient's desire to improve. If the patient does not want to progress, she will not. This is especially important when training women: women are more self-conscience regarding exercise than men, so any negative association with the program will likely lead to immediate abandonment of the program that is supposed to help them improve their quality of life. Certain cancer treatments that have large effects on the body, such as surgery or chemotherapy, can lead to negative feelings of altered body image. In addition, major surgeries such as amputations could result in the patient completely learning how to function with a new normal. There would be greater adaptations to the exercises programs in extreme cases as these. The exercise prescriber should understand that patience is highly important for someone with cancer. Whether the patient is going through treatment or recovering from it, she will likely begin and progress at a much lower rate than other populations. It is safe for women with cancer to exercise, but all qualified exercise professionals, clinicians, exercise physiologists, nurses, and other professionals should consider these precautions when developing the exercise program. The goal is always to improve the patient, not to harm her any further. However, professionals should clearly discuss potential hazards from exercise with their clients and have them sign a waiver before beginning the program. The failure to do this could create a serious liability problem for the health professional. They should do so in a clear, but encouraging way, in order to thoroughly explain the precautions and risks exercise involves.

Taking precautions when developing exercise programs should be one of the top priorities for qualified exercise professionals working with cancer patients. However, as the ACSM has stated, any physical activity is better than no physical activity. The goal should be to improve cancer patient's and survivor's overall health outcomes through adaptable exercise programs. Table 29.2 provides a concise summary of our discussion on the specific exercise programs that help improve cancer-related outcomes [13].

Table 29.2 Summary of ACSM exercise programs to improve health-related outcomes in those with cancer. Adapted from the 2019 ACSM Exercise Guidelines for Cancer Survivors: Consensus Statement from International Multidisciplinary Roundtable [13]

Outcome	Aerobic	Resistance	Aerobic and resistance
Cancer-related fatigue	30 min of moderate intensity 3/week	2 sets of 12–15 reps at moderate intensity 2/week, targeting major muscle groups	30 min 3× a week of moderate aerobic activity plus 2 sets of 12–15 reps moderate strength training 2× a week
Health-related quality of life	30–60 min of moderate to vigorous intensity 2–3/a week	2 sets of 8–15 reps 2/week at moderate to vigorous	20–30 min 2–3× a week of moderate aerobic activity plus 2 sets of 8–15 reps moderate to vigorous strength training 2× a week
Physical function	30–60 min 3/week at moderate to vigorous	2 sets of 8–12 reps 2–3/week at moderate to vigorous	20–40 min 3× a week moderate to vigorous aerobic plus 2 sets of 8–12 reps 2–3× a week of moderate to vigorous strength training
Anxiety	30–60 min 3/week at moderate to vigorous	Insufficient evidence	20–40 min 2–3× a week of moderate to vigorous aerobic plus 2 sets of 8–12 reps 2/week of moderate to vigorous strength training
Depression	30–60 min 3/week at moderate to vigorous	Insufficient evidence	20–40 min 2–3/week of moderate to vigorous aerobic plus 2 sets of 8–12 reps 2/week of moderate to vigorous strength training
Lymphedema	Insufficient evidence	2–3/week of supervised, increasing training that does not worsen lymphedema	Insufficient evidence
Bone health	Insufficient evidence	2–3/week of moderate to vigorous strength training with high impact training for at least 12 months	Insufficient evidence
Sleep	30–40 min 3–4/week of moderate	Insufficient evidence	Insufficient evidence

29.5 Research Findings and Contemporary Understanding of the Issues in Children and Adolescents

29.5.1 Prevalence of Cancer in Children and Adolescents

In children and adolescents, the most common types of cancer are ALL, brain and spinal cord cancers, and lymphomas [4] (Fig. 29.2). The most common cancers in children and adolescents can vary by age group, but there is a trend of common cancers overall (Table 29.3).

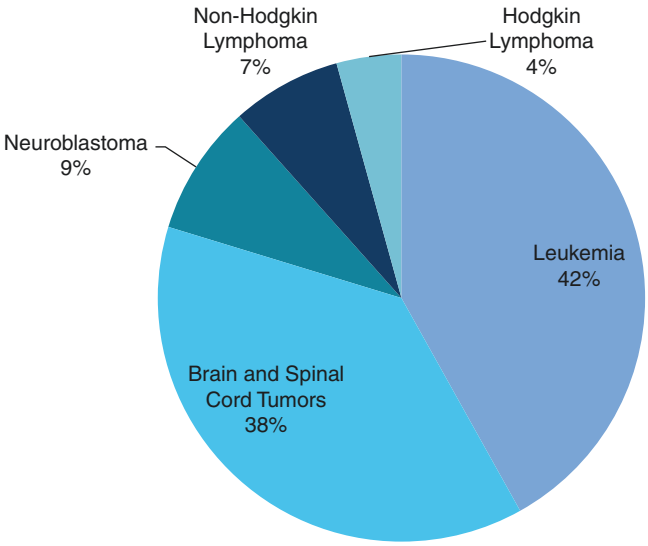

Fig. 29.2 Most common types of childhood cancer [4]. Adapted from information in Common Cancer Sites—Cancer Stat Facts [Internet]. Available from: https://seer.cancer.gov/statfacts/html/common.html

Table 29.3 Common childhood cancers

Cancer type	Description
ALL	A type of leukemia (blood cancer) and cancer of bone marrow that affects the child's white blood cells (immunity)
Brain	Cancerous growth in the tissue of the brain, could be benign or malignant (both require treatment)
Spinal cord	Cancer developed in the spinal cord, could be benign or malignant
Lymphomas	Cancer Childhood cancers: that develops in the lymphatic system (i.e., lymph nodes)

29.6 Physical Activity Recommendations for Children with Cancer

29.6.1 Exercise and Childhood Cancer Evolution

Fortunately, pediatric cancer is a rare disease among children with only ~1% of all cancer patients being pediatric. The large adult population affected by cancer facilitates the recruitment of larger population that aid researchers in the production of stronger evidence and better designs around cancer and exercise compared with the evidence generate in children. Other limitations in pediatric cancer and exercise research are low quality design. Most research was conducted in children affected with leukemia, because it is the most common pediatric cancer. Finally, in pediatric populations, there is no evidence regarding that the different effects of exercise in boys or girls are all consider children. For all these reasons, evidence in adults with cancer is much stronger than in pediatric population. In addition, the field of pediatric cancer and exercise is a relatively new field. The first studies showing an association between cancer treatment and impaired exercise performance with abnormalities in cardiac function in children with cancer were published in 1990 [41]. In current literature, it is well-known that pediatric cancer and its treatments are associated with pain, limitation of range of motion, balance and gait impairment, body composition alteration, decreased strength and aerobic capacity [41], osteoporosis, avascular necrosis, and decreased cognitive function and quality of life [42]. A study published in 2006 by Oeffinger et al., with a population of more than 10,000 adult survivors of pediatric cancer showed that at a median age of 26 years, 62% of survivors of childhood cancer had at least one chronic condition and 27.5% had a severe or life-threatening condition [43]. Among this population, the following severe life-threatening conditions were described: major joint replacement, congestive heart failure, second malignant neoplasm, cerebrovascular accident, and renal failure.

In 1999, Keats et al. published a study in adolescents with cancer showing the positive relationship between time expended in physical activity as leisure time and improvement in psychosocial well-being [41, 44]. From that study, many studies were performed in pediatric cancer and exercise studying the benefit of physical activity during and after cancer treatment with highly promising outcomes.

29.6.2 Benefits of Physical Activity in Pediatric Cancer

Regular physical activity has been shown to have beneficial effects on improving strength, cardiovascular capacity, and fitness while decreasing the impact of late effects and the risk to developed future treatment-related morbidity in children with cancer [43]. Most of the physical activity intervention done in pediatric oncology are a combination of moderate intensity endurance training, strength conditioning of major muscle groups, and flexibility. There are also some yoga interventions done. The intervention period lasts between 1 week and 6 months, but usually lasts for about 8–12 weeks [45]. The frequency is anywhere between one time per week to five times per week, with most reporting two or three times per week. Descriptive information about the interventions done can be found in many published scientific reviews articles [42, 46–48].

As was describe early in this chapter, children experience many of the same benefits women experience from physical activity. Positive effects were found on fatigue, strength, quality of life, promising evidence boosting the immune system, body composition, sleep, activity levels, improvement of cognitive tests, and various aspects of physical functioning [48, 49].

The evidence regarding the effects of exercise in pediatric cancer patients has increased substantially in the last few years; however, questions remain regarding the dose and type of exercise that would be more beneficial that has not been asked yet [48, 50]. However, we know that tailored physical activity is safe during and after cancer treatment. A recent study performed in Germany concluded that supervised exercise interventions for pediatric cancer patients and survivors seem to be safe and only a few adverse events were encountered compared with exercise in healthy populations. Most of the adverse events reported were symptoms, such as muscle soreness, which is an indicator of intense exercise and might be a common response of training [51]. Regular physical activity and sports are associated with improved general health and disease prevention in any healthy children and adolescence [52]; thus, it is even more important to do regular physical activity in children with cancer and any other chronic condition, because they already are at a higher risk than healthy populations to develop other non-communicable diseases and secondary cancers [53].

Research showed the importance of regular physical activity not only in pediatric cancer patients but also in children with chronic health conditions, such as diabetes, epilepsy, and asthma [54]. A recent review published by Moving Medicine for Children working Group conclude that "… While further research is required to investigate benefits of physical activity on specific aspects of long-term conditions in children, in general this group should be advised to increase participation in sports and exercise as a means of improving long-term physical and mental health" [54].

29.6.2.1 Physical Activity Guidelines

As described earlier in this chapter, a consensus statement from an international group of cancer and exercise specialist was published describing exercise recommendations to improve certain outcomes (anxiety, fatigue, health-related QOL, and lymphedema), where enough quality evidence existed to generate FITT recommendations.

In pediatric oncology research, due to limitations already described, we are not there yet. However, we need to start reassuring that the evidence we already have is more than enough to affirm that physical activity including exercise is safe, beneficial, and recommended for all children and adolescents affected by cancer [55]. To develop the statement, an international group of professionals in pediatric oncology and exercise (n = 131) got together and synthetized the best available evidence [48], collected input for stakeholders, and completed four surveys using Delphi technique that asked closed and open-ended questions informed by literature synthesis and an in-person meeting. The result of this process was the publication of the International Pediatric Oncology Exercise Guidelines (iPOEG) [55]. These guidelines emphasize the fact that it is time for children and adolescent affected by cancer to MOVE MORE. The iPOEG guidelines are the first international consensus guidelines, and due to the evidence available in pediatric oncology, the guideline and recommendations statements are generic as work need to still be done in this field. It is an important first step to provide families, health care providers, and stakeholders with a clear message about the importance of move more during pediatric oncology treatment or survivorship and reassure that is safe. To be up-to-date, learn more about iPOEG, or download the free toolkit to promote physical activity in pediatric oncology, please see: https://kinesiology.ucalgary.ca/labs/health-and-wellness/research/research-studies/pediatric-oncology-research/international-pediatric [55].

Another great resource to know more about exercise prescription and pediatric oncology is the pediatric oncology exercise manual (POEM). POEM was published in 2015 also by the Health and Wellness Lab at the University of Calgary. The POEM was developed by a team of international experts. It consolidates evidence-based information and contains resources to promote an active lifestyle among children and adolescents affected by cancer. This exercise manual synthetizes the benefit of exercise in pediatric oncology while providing a great overview about the best evidence and interventions done in children affected by leukemia, solid tumors, brain tumors, palliative care, and children that received hematopoietic stem cell transplant. This manual

contains detailed information about recommendations and contraindications to exercise in presence of common childhood cancer side effects, such as CIPN, osteoporosis, avascular necrosis, and pancytopenia. This manual can be downloaded free at https://kinesiology.ucalgary.ca/labs/health-and-wellness/research/research-studies/pediatric-oncology-research/pediatric-oncology [56, 57].

It is also important to mention that parents are the goalkeepers of the children. Thus, it is extremely important to educate parents and increase their awareness about the benefits of regular physical activity to have children affected by cancer moving more. The literature mentioned that overprotection and lack of awareness about exercise benefits from caregivers are important barriers to exercise in pediatric cancer. The family version of the POEM manual and infographics are excellent resources to educate parents increasing awareness of physical activity during and after cancer treatment to improve recovery and avoid deconditioning.

29.6.3 Considerations to Exercise

It is important to educate families and health care providers in the benefit of exercise during and after cancer treatment. Research shows that most commonly, enablers of physical activity included perceiving that physical activity improves their health and strength while also being fun and enjoyable [58]. Thus, enjoyment and fun are key elements to promote an active lifestyle and behavior change in pediatric oncology. To prescribe exercise in childhood cancer, we also need to be aware of child age and developmental stage to be able to promote the right activity and empower physical literacy [59]. Going back to iPOEG guidelines, there are a few considerations that are key factors and were clearly recommended when prescribing exercise in pediatric oncology (see Table 29.4).

Research shows that specific exercise programs created for children with cancer might be beneficial to improve quality of life, participant self-confidence to practice physical activities, increase healthy levels of fitness, and decrease fatigue in a safe environment [60]. An environmental scan published in 2019 provides guidance for those seeking to develop/implement physical activity program for pediatric oncology population.

Finally, in children and adolescents affected by cancer, it is important to rebuild their self-confidence and enjoyment to practice a myriad of physical activity in exercise programs created specific for cancer patients. Furthermore, it is also important to expose them to physical activities offered in the community and help them find their way back to those to keep them active for life. Empowering them and improving physical illiteracy are key components to decrease sedentary behavior and empower an active lifestyle [59].

Table 29.4 iPOEG—summary of main guidelines statements and recommendations. Adapted from Wurz A, McLaughlin E, Lategan C, Chamorro Viña C, Grimshaw SL, Hamari L, et al., The International Pediatric Oncology Exercise Guidelines (iPOEG), Translational Behavioral Medicine, Vol. 11/Issue 10, pages 1915–1922, © 2021, with permission from Oxford University Press and Society of Behavioral Medicine [48]

1	Choose to move. Do what you can. Do it when you can
2	Movement is possible and important for every child and adolescent with cancer across all ages, diagnoses, and stages of treatment
3	Evidence shows that movement and exercise are safe and may provide benefits
4	When prescribing exercise, and exercise professional with appropriate knowledge on pediatric cancer and exercise is recommended. Standardized training in pediatric oncology and exercise is not available yet and thus certifications might vary among countries
5	Factors to consider when exercise is prescribed by an exercise professional: • age • diagnose and date • treatment (s) planned, current and previous • other medical issues and symptoms that might impact exercise • physical restrictions • setting (hospital/home) • participations preferences and barriers • current fitness condition
6	Communication between exercise professionals and health care team is important to promote exercise among children and adolescent with cancer
7	Movement is encouraged and safe for all pediatric oncology patients and survivors. However, might be some cases in which an exercise professional might be necessary to support initial movement goals as well. This woul be up the discretion of family and healthcare team

29.7 Future Directions

As the benefits to physical activity for cancer patients and survivors become more pressing and evident, perhaps there can be programs developed in the future by fitness professionals specifically trained for the art of exercise and cancer. For example, there is clear research over the benefits of exercise for women with breast cancer. One study observed the effects of combined exercise training on obese women with breast cancer. They found that BMI, waist circumference, waist/hip ratio, and estimated VO_2 max following the intervention significantly improved in the cancer patients compared to the controls [39]. Ideally, exercise physiologists, CETs, or other healthcare professionals who are able to create exercise programs for cancer patients should work directly with clinicians to combine exercise with medical treatments [8]. However, this is not yet available due to a lack of economic resources.

There is now an ACSM/ACS Certified Cancer Exercise Trainer (CET) certification offered that teaches fitness professionals how to develop programs specific to a person's

diagnosis, treatment, and recovery status [61]. The reason this program is set apart from others is because it is derived from evidence-based medicine, incorporating the research and skill of cancer professionals and scientists in the field [29, 61]. A pediatric oncology module was also developed by the Health and Wellness Lab at the University of Calgary. ACSM explains that research has shown an effective exercise prescription for cancer survivors, as we discussed earlier. Cancer survivors should aim for moderate-intensity exercise, getting 30 min of exercise in at least 3 days a week [13]. Even though a majority of the research on exercise programs for cancer patients emphasizes cancer survivors and women with breast cancer, there are significant benefits from increased physical activity for any type of cancer. As the ACSM recommends, any activity is better than sedentary lifestyles to improve the overall quality of life for cancer patients and survivors.

29.8 Concluding Remarks

Exercise puts people at an advantage when it comes to cancer prevention, treatment, and survival. Exercise can reduce the growth of tumors (such as lower the stage of cancer) and delay the onset of cancer for years. It is never too late to begin making lifestyle changes to better a person living with the disease. Cancer is an intense illness that takes physical and mental rigor for a person to fight the disease, as well as for caretakers who encourage their patients or loved ones to continuing fighting. However, with the growing research on the benefits of exercise as medicine for cancer, there is hope for a stronger fight for persons facing this disease. There is still plenty of research that still needs to be done, but the bottom line to understand is that any activity is better than inactivity in children, adolescents, and women. For cancer, exercise is medicine and the goal for any patient and healthcare professional is survival. The greatest way to reach that goal is to make a plan to get active with the desire to fight the disease. The key is getting patients to move, and the benefits of any physical activity far outweigh the risks of no activity at all.

Chapter Review Questions

1. What is the *best* way to describe cancer cells?
   (a) Progressive cells in a specific tissue
   (b) Foreign cells with abnormal characteristics
   (c) Benign tumor cells
   (d) Modified cells with advanced qualities
2. Tumors that are cancerous and have the potential to invade neighboring tissues are
   (a) Malignant
   (b) Benign
   (c) Metastatic
   (d) Non-invasive
3. What is a concern of radiation therapy in women with cancer?
   (a) Impaired cognitive function
   (b) Loss of sense of taste or smell
   (c) Infertility
   (d) All above
4. What are the most common types of cancer in children?
   (a) Colorectal and breast
   (b) Breast and prostate
   (c) Leukemias, brain and other central nervous system tumors, and lymphomas
   (d) Brain and lung
5. What is cancer-related fatigue?
   (a) Fatigue in cancer patients induced by the cancer or the cancer treatments
   (b) Fatigue that results from exercise programs for cancer patients
   (c) Anxiety-driven fatigue from the diagnosis of cancer
   (d) The same as non-cancer-related fatigue
6. What resistance training exercise protocol does the ACSM recommend for cancer survivors?
   (a) 30 min of moderate intensity activity three times a week for 12 weeks
   (b) 2 or 3 sets of 10–15 reps of low intensity activity three times a week for 8 weeks
   (c) 30 min of 10–15 reps at 40% of the individual's one repetition maximum at least twice a week for 8–12 weeks
   (d) 2 or 3 sets of 8–15 reps at 60% of the individual's one repetition maximum at least twice a week for 8–12 weeks
7. When creating an exercise program for women with cancer:
   (a) Healthcare professionals should aim to improve the individual and modify programs to meet her safety needs and personal goals
   (b) Healthcare professionals must strictly follow the recommended protocols, since research shows it is the only effective form of exercise
   (c) Healthcare professionals should let the patient exercise on her own at home, since it can be overwhelming to exercise in front of a professional
   (d) Healthcare professionals should let the patient create her own program and follow-up with her after 12 weeks of activity
8. Exercise for children with cancer can lead to improvements in:
   (a) Muscle and bone mass
   (b) Cognitive function

(c) Cardiovascular fitness
(d) All of the above

9. Movement is possible in pediatric oncology:
   (a) After treatment ends
   (b) From diagnose to survivorship
   (c) It is not safe and not possible if patients have mobility issues
10. For cancer patients, exercise is _____.
   (a) Optional
   (b) Concerning
   (c) Medicine
   (d) Scary

Answers

1. b
2. a
3. d
4. c
5. a
6. d
7. a
8. d
9. b
10. c

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Part VI

The Obese Active Female

Not So Normal Unhealthy Lean

30

Nadeeja N. Wijayatunga and María Fernandez-del-Valle

Learning Objectives
After completing this chapter, you should be able to

- Understand that body mass index underdiagnoses unhealthy normal weight individuals
- Understand the different classifications for unhealthy lean including metabolically unhealthy normal weight (MUNW), normal weight central obesity (NWCO), normal weight obesity (NWO)
- Discuss factors associated with unhealthy lean
- Discuss pathophysiology and health risks associated with unhealthy lean
- Discuss possible interventions for unhealthy lean

30.1 Introduction

Body mass index (BMI) is the most commonly used index to screen for disease risks and it is calculated as the person's weight (in kilograms) divided by the height square. However, BMI is unable to determine body fat distribution, or the proportions of muscle mass, lean body mass, and fat mass [1]. BMI has poor sensitivity and specificity body fat, and often underestimates body fat in older adults while overestimates body fat in athletes and physically active individuals [2]. In addition, women tend to have a lower BMI compared to men despite the presence of higher fat percent [1]. Hence, BMI is not the most accurate method to determine body fat content.

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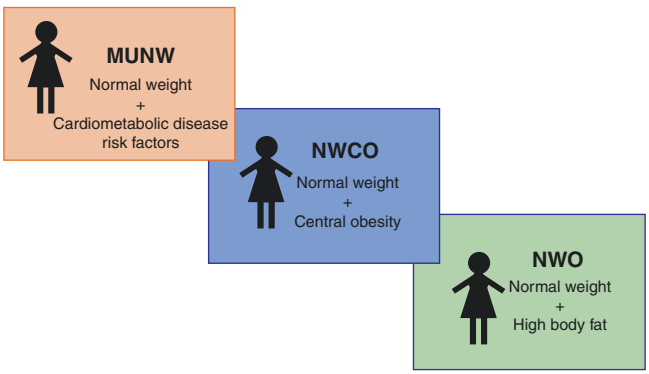

Fig. 30.1 Unhealthy lean phenotypes and their main diagnostic features. Abbreviations: *MUNW* metabolically unhealthy normal weight; *NWCO* normal weight with central obesity; *NWO* normal weight obesity

Normal BMI values, also known as "*normal weight*", range from 18.5 to 24.9 kilogram/meter squared (kg/m^2) and individuals with a normal BMI are often considered to be "healthy". However, some *normal weight* adults have cardiometabolic abnormalities, central obesity, and excess body fat [3–6]. These contradictions have led to the emergence of the concept "unhealthy lean" (the lay term is "skinny fat"). Different phenotypes of unhealthy lean have been described in the literature and these are summarized in Fig. 30.1. These phenotypes include metabolically obese normal weight (MUNW), normal weight with central obesity (NWCO), and normal weight obesity (NWO) [3–5, 7]. In this chapter, the definitions, prevalence of healthy lean phenotypes, predisposing factors, associated health risks, and interventions for unhealthy lean will be discussed. See Table 30.1 for definitions for these phenotypes.

30.1.1 Metabolically Unhealthy Normal Weight (MUNW)

Individuals with MUNW show cardiometabolic abnormalities despite having a normal BMI [4, 7]. This condition is also known as "metabolically obese normal weight", or as

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Table 30.1 Definitions of unhealthy lean phenotypes in women

	Common criteria	Specific criteria
1. Metabolically unhealthy normal weight (MUNW)	Normal BMI	(a) At least one/two or more/three or more NCEP–ATP-III factors [4, 8–13], or (b) At least two of the following criteria: high sensitivity CRP >90th percentile, HOMA-IR >90th percentile and four NECP–ATP-III factors except for high WC [14, 15], or (c) At least two of the IDF criteria for metabolic syndrome, or (d) Other criteria, such as ↑ TyG index [16] or ↑ IR [17]
2. Normal weight with central obesity (NWCO)	Normal BMI	Central obesity defined as: (a) WC ≥88 cm and ≥80 cm, based on NCEP–ATP-III and IDF, respectively, for Caucasian women [18, 19], or (b) WtH >0.85 [19], or (c) WHtR ≥0.5 [5] Note: ethnic-specific WC cutoffs in Tables 30.2 and 30.3
3. Normal weight obesity (NWO)	Normal BMI	Excess %BF defined as, (a) >33.3% for women in the United States (US) [20], or (b) >35% by AACE and ACE [21], or (c) >30% diagnose NWO [22]

Abbreviations: ↑ elevated; *%BF* percent body fat; *AACE* and *ACE* American Association of Clinical Endocrinology and the American College of Endocrinology; *ATP* adenosine triphosphate *BMI* body mass index; *cm* centimeter; *CRP* C-reactive protein; *HOMAR-IR* homeostasis model assessment of insulin resistance; *IDF* international diabetes federation; *IR* insulin resistance; *MUNW* metabolically unhealthy normal weight; *NWCO* normal weight central obesity; *NCEP–ATP-III* national cholesterol education program adult treatment panel III; *NWO* normal weight obesity; *TyG* triglyceride glucose index; *WC* waist circumference; *WtH* waist-to-hip ratio; *WHtR* waist-to-height ratio

"metabolically abnormal normal weight". Several definitions have been used to determine MUNW: normal weight with the presence of at least one, two or more, or three or more of the five metabolic risk factors listed in the National Cholesterol Education Program Adult Treatment Panel III (NCEP–ATP-III) [4, 8–13]. The NCEP–ATP-III components are listed in Table 30.2 [13]. Furthermore, Stephan et al. [14] and Wildman et al. [15] considered MUNW as those with a normal BMI and having two or more out of the following criteria; elevated high sensitivity C-reactive protein (CRP) levels, insulins resistance, and four components of the ATP III with the exception of waist circumference. Others have defined MUNW using the International Diabetes Federation (IDF) criteria for metabolic syndrome listed in Table 30.3 [23] or other criteria, such as triglyceride glucose index [16], and insulin resistance based on homeostasis model assessment of insulin resistance [HOMA-IR] [8, 17]. Hence, there is a lack of consensus for the definition of MUNW.

Table 30.2 National cholesterol education program adult treatment panel III (NCEP–ATP-III) components to determine metabolic syndrome [13]

Components
1. Central obesity with high waist circumference: in males ≥102 cm (>40 inches); in females ≥88 cm (>35 inches)[a]
2. High triglycerides: ≥150 mg/dL (1.7 mmol/L) or on medication for high triglyceride
3. Low HDL-C: in men <40 mg/dL (1.03 mmol/L); in women <50 mg/dL (129 mmol/L) or on medication for low HDL-C
4. High blood pressure: systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥85 mmHg or on medication for high blood pressure
5. High fasting glucose: ≥100 mg/dL or on medication for diabetes

Abbreviations: *HDL-C* high-density lipoprotein cholesterol; *mmol/L* millimole per Liter; *mg/dL* milligrams per decilLiiter; *mmHg* millimeters of mercury

[a] Waist circumference thresholds for Asians are ≥90 cm (35 inches) and ≥80 cm (31 inches) for men and women, respectively

Table 30.3 International diabetes federation (IDF) criteria to determine metabolic syndrome [19]

Components
1. Central obesity with a high waist circumference (ethnic-specific cutoffs[a])—this is a compulsory criterion[b]
Plus two of the following criteria:
2. High triglycerides: ≥150 mg/dL (1.7 mmol/L) or on drug treatment for high triglyceride
3. Low HDL-C: in men <40 mg/dL (1.03 mmol/L); in women <50 mg/dL (129 mmol/L) or on medication for low HDL-C
4. High blood pressure: systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥85 mmHg or on medication for high blood pressure
5. High fasting glucose: ≥100 mg/dL (≥5.6 mmol/L), diagnosed with type 2 diabetes

Abbreviations: *HDL-C* high-density lipoprotein cholesterol; *mmol/L* millimole per Liter; *mg/dL* milligrams per decilLiiter; *mmHg* millimeters of mercury

[a] Ethnic specific cutoffs: for Europeans, Eastern Mediterranean, Middle East, and Sub-Saharan Africans, ≥94 cm and ≥80 cm for men and women, respectively; for South Asians and Chinese, ≥90 cm and ≥80 cm for men and women, respectively; for Japanese, ≥85 cm and ≥90 cm for men and women, respectively [19]

[b] Central obesity is assumed to be present if the body mass index is more than 30 kg/m^2

30.1.2 Normal Weight with Central Obesity (NWCO)

NWCO is defined as the presence of central or abdominal obesity with a normal BMI [5]. However, different methods have been used and there is a lack of consensus regarding the cutoff thresholds. For example, waist circumference thresholds for Caucasian women are ≥88 cm and ≥80 cm, based on NCEP–ATP-III (see Table 30.2) and IDF criteria (see Table 30.3), respectively [18, 19]. At the same time, there are population-specific waist circumference threshold values for Asians [19, 24, 25]. Likewise, in women, waist-to-hip ratio and waist-to-height ratio have been used to define abdominal obesity with the cutoff thresholds of >0.85 [19] and ≥0.5 [5],

respectively. In addition, dual-energy X-ray absorptiometry and ultrasound methods have also been used to determine abdominal obesity through android–gynecoid percent fat ratio, visceral adipose tissue (VAT) mass and/or volume, and abdominal subcutaneous adipose tissue (SAT) thickness/mass or volume in individuals with NWCO [12, 26].

30.1.3 Normal Weight Obesity (NWO)

NWO is defined as the presence of excess body fat percent with a normal BMI [3, 27]. However, NWO body fat percent cutoffs to define excess adiposity vary [22] with some studies using the same body fat percent cutoff for males and females, sex-specific values or both sex- and age-specific cutoffs [28–31]. The American Association of Clinical Endocrinology and the American College of Endocrinology suggested body fat cutoffs of >35% and >25% for women and men, respectively [21]. Body fat percent cutoffs used in the past studies to determine NWO range from 19 to 32.6% for men, and 29.2 to 44.4% for women., but many studies used the body fat percent cutoff of 30% to diagnose NWO in females [22]. However, Romero-Corral et al. identified body fat percent cutoff as >33.3% for women and >23.1% for men in the US using the tertile method [20]. Hence, there is a lack of consensus regarding the definition of NWO, since different methods are used to measure body fat percent and to determine body fat percent cutoffs to define excess body fat.

30.1.4 Overlap Between Different Unhealthy Lean Phenotypes

Even though the unhealthy lean phenotypes have different definitions, there is ambiguity in the usage of the terms for unhealthy lean in a few publications. For example, Zhang et al. defined individuals with normal BMI and metabolic syndrome as NWO instead of using the term MUNW [32], while Liu et al. defined individuals with a normal BMI and high waist-to-height ratio as NWO instead of using the term NWCO [33]. Some defined MUNW as the presence of visceral fat adiposity ≥100 cm^2 with a normal BMI instead of NWCO [34, 35]. Thus, there is a need for consensus on unhealthy lean phenotype definitions.

30.2 Research Findings

30.2.1 Prevalence of Unhealthy Normal Weight Phenotypes

30.2.1.1 Prevalence of Metabolically Unhealthy Normal Weight (MUNW)

The prevalence of MUNW among adults is about 23.5% in the US [15] and about 20% in the world [36]. The prevalence of MUNW differs depending on age, sex, race/ethnicity, region, smoking, and alcohol intake, and according to study design factors including sample size and criteria used to define MUNW [36, 37].

30.2.1.2 Prevalence of Normal Weight Central Obesity (NWCO)

The prevalence of NWCO differs depending on the method used to determine central obesity [24, 26, 38]. For example, the prevalence of NWCO in non-diabetic normal weight young adults [≥20 years] was 33.7% when the waist-to-hip ratio was applied, while a 7.6% prevalence was reported when waist circumference was used [38]. Irrespective of the method used to define central obesity, there is a clear increase in the prevalence of NWCO among adults in the US over the years [38]. In addition, about 9% of normal weight children in the US have NWCO based on waist-to-height ratio ≥0.5 [39].

30.2.1.3 Prevalence of Normal Weight Obesity (NWO)

The prevalence of NWO among adults varies from 4.5% to about 22% [40, 41], and about 29–46% normal weight adults have NWO [42, 43]. Romero-Corral et al. estimated that about 30 million Americans have NWO phenotype [20]. NWO has been described in children and adolescents as well [44–48]. About one in every ten children aged 3–6 years seems to have NWO [47]. Furthermore, about one in every two (42–46%) normal weight youth aged 9–18 years could have NWO [44, 48]. However, the variability in body fat percent cutoffs makes comparisons between studies challenging [22].

Considering the above prevalence rates, it is clear that a significant proportion of normal weight women may belong to one or more of the unhealthy lean phenotypes. However, these unhealthy lean women may not be identified in the routine health screening with BMI.

30.2.2 Pathophysiology of Unhealthy Normal Weight Phenotypes

30.2.2.1 The Role of Adipose Tissue

Adipose tissue can be classified into two functionally different tissues: white adipose tissue (WAT) and brown adipose tissue. In addition to being the main energy storage in the body, WAT functions as an endocrine organ by contributing to the regulation of energy balance, maintaining insulin sensitivity, and inflammation among others [49]. WAT is composed of VAT and SAT. VAT is found around central organs of the body (intra- and retroperitoneal depots), while SAT, which is more than 80% of total body fat in a healthy population, is present under the skin [50, 51]. Abdominal and gluteofemoral (lower body) are the two main SAT depots in the body [50].

Table 30.4 Differences in body fat between unhealthy lean phenotypes

	MUNW	NWCO	NWO
Excess total body fat percent	↑ in some	↑ in some	↑ in all
Central obesity	↑ in majority	↑ in all	↑ in some

Abbreviations: ↑ indicates higher in unhealthy lean compared to healthy lean

Compared to healthy lean, individuals with MUNW have larger adipocytes (hypertrophy) in VAT [7]. An increase in total body fat percent and central obesity is associated with increased odds for MUNW [12]. Central obesity with a high amount of VAT is often observed in MUNW [12, 52]. Furthermore, higher amounts of body fat percent and abdominal SAT and lesser amounts of SAT in the lower extremities are observed in MUNW compared to healthy lean [7, 14, 50]. Individuals with NWO have a higher total body fat percent, and are more likely to have central obesity compared to normal weight lean [42, 44, 53, 54] with ~43% of NWO presenting with central obesity [55]. The similarities and differences in adipose tissue between unhealthy phenotypes are summarized in Table 30.4.

Excessive accumulation of VAT is known to cause inflammation, increase oxidative stress, and increase insulin resistance and cardiovascular risk [7, 56]. Similar to sarcopenic obesity, increased visceral fat contributes to the increased secretion of pro-inflammatory cytokines that promote muscle mass loss (catabolism) and a decline in muscle function [57]. Similarly, excess abdominal SAT is associated with increased cardiometabolic risk [58]. In contrast, gluteofemoral (lower body) SAT stores excess fat that is being redistributed and thereby prevents unwanted fat deposition in metabolic organs, such as the liver and muscle. Thus, healthy storage of fat at gluteofemoral and leg SAT is likely to associate with lower cardiometabolic risk [50, 58]. Thus, having excess VAT and abdominal SAT with less SAT in the lower extremities may increase cardiometabolic abnormalities in unhealthy lean.

30.2.2.2 Increased Inflammation and Oxidative Stress

Past literature suggests the presence of increased inflammation in unhealthy lean compared to healthy lean [7, 59, 60]. More macrophages infiltrate the SAT in MUNW compared to healthy lean suggesting increased inflammation in MUNW [61]. Cells in the body secrete proteins called "cytokines" which are needed for communications between cells and may have pro- or anti-inflammatory effects [62]. Circulatory levels of proinflammatory leptin, tumor necrosis factor-alpha (TNFα), and interleukin 6 (IL-6) are higher, while anti-inflammatory adiponectin is lower in MUNW compared to healthy lean [7, 52, 63]. Similarly, proinflammatory Interleukin (IL): IL-1α, IL-1 beta (IL-1β), IL-6, IL-8 and IL-15, leptin, and TNFα are higher in NWO compared to normal weight lean [60, 64–67]. In addition, CRP is higher in unhealthy lean adults compared to their healthy counterparts [6, 7, 28, 52, 59, 68–71]. Complement 3 (C3), another marker of inflammation in plasma, is elevated in NWO compared to normal weight lean [69, 72]. In contrast, some studies did not find any significant differences between NWO and normal weight lean women for plasma adiponectin, CRP, leptin, and visfatin [66, 73]. These discrepancies in findings between studies could be due to the different body fat percent cut-offs used to define unhealthy lean.

Accumulation of reactive oxygen (ROS) and nitrogen species is known as "oxidative stress" [74]. Proinflammatory processes and immune cells release ROS causing oxidative stress which in turn increases inflammation. Furthermore, oxidative stress impairs insulin secretion and glucose transport, causes hypertension, atherosclerosis, and fat deposition in the liver, and increases the risk for cardiometabolic diseases [75]. Oxidative stress is higher in unhealthy lean individuals compared to healthy lean [65] increasing cardiometabolic disease risk in unhealthy lean.

30.2.2.3 The Role of Skeletal Muscle

The skeletal muscle is the primary site of glucose metabolism regulation and the main organ for energy consumption. It is critical for metabolic control as it has autocrine, paracrine, and endocrine activity. Muscle-released cytokines—known as myokines—are implicated in the regulation of autocrine metabolism, and paracrine and endocrine regulation of other tissues including metabolic reactions in cardiovascular, adipose, liver, or brain tissues [76, 77]. Myokine release is modulated by both exercise and muscle disease resulting in various physiological adaptations [77]. Myokines are synthesized and released by muscle cells during muscular contractions and play a crucial role in adipose tissue and skeletal muscle crosstalk. The most characterized myokines include myostatin, IL-6, IL-15, or adiponectin, which have been recognized as beneficial modulators of different diseases [76–78]. Myostatin is a negative regulator of muscle growth, therefore, resulting in a decreased muscle mass, strength, and glucose control. IL-6 is a pleiotropic cytokine with anti- and pro-inflammatory effects depending on the context of the secretion. When anti-inflammatory (exercise-mediated), IL-6 is able to increase non-insulin-dependent glucose metabolism and enhance insulin action. However, when pro-inflammatory (disease-related) IL-6 is associated with obesity and insulin resistance and reduces skeletal muscle health [76]. Likewise, IL-15 is accumulated in the skeletal muscle in response to exercise, attenuating protein breakdown, improving glucose metabolism, and enhancing muscle growth and strength in the general population. However, IL-15 acts differently under pathological conditions [76]. Adiponectin, which is expressed in muscle and

adipose tissue, helps improving glucose and lipid metabolism through insulin-dependent and non-insulin-dependent mechanisms [79] and plays a key role in muscle regeneration, suppression of proteolysis, and attenuation of inflammatory signaling [80]. Despite the importance of the muscle tissue, it has been mainly quantified through the assessment of lean mass—which includes the weight of bones, ligaments, muscles, and organs—rather than the muscle mass alone.

Physical inactivity results in a reduced myokine synthesis and secretion that leads to muscle atrophy and increases inflammation short term. Furthermore, the release of pro-inflammatory factors by the adipose tissue correlates with sedentary lifestyle, muscle atrophy, and both visceral and subcutaneous fat accumulation [77]. However, consistent engagement in physical activity results in the release of anti-inflammatory myokines that help modulate the inflammation-anti-inflammation axis and protect against the development of cardiometabolic conditions and other pathologies [77, 78]. This brings up the question: "*Is sedentary lifestyle a risk factor for MUNW, NWCO, and NWO?*"

Individuals who are MUNW have a decreased cardiorespiratory fitness, lean mass, mid-thigh muscle area, and muscle strength compared to metabolically healthy lean [4, 8, 11]. In the case of NWO, lean mass, fat-free mass, and appendicular skeletal muscle mass are shown to be lower compared to normal weight lean [27, 29, 81]. Even in NWO children between 9 and 12 years of age, estimated muscle area is lower in both upper and lower extremities compared to normal weight lean [45]. It is known that decreased muscle mass is a risk factor for metabolic syndrome and cardiometabolic disease in older adults with a normal BMI [82] and together with decreased muscle function (i.e., strength) indicates probable sarcopenia [83]. In addition to having reduced skeletal muscle mass, intramuscular fat is increased in girls aged 11–18 years with NWO compared to normal weight lean [84]. In addition, older women with NWO have an increased risk of physical impairment compared to normal weight lean probably due to reduced lean mass and muscle quality [85]. Still, more research is needed to reveal the impact of low muscle mass and decreased strength in unhealthy lean and their relationship with sedentary lifestyle and physical activity.

30.2.2.4 Changes in Bones

Strong and robust bones are important to be able to withstand repetitive loads (stress). The most important period of bone development is around 11–15 years for girls and 13–17 years for boys; and by 18 years of age, approximately 90% of peak bone mass has been accrued [86, 87]. Peak mass is achieved by the third decade [88]. Skeletal robustness of the lower limbs is poorer in children aged 9–12 years with NWO compared to normal weight lean [45]. Therefore, early intervention is important to improve bone health in children with NWO. In a cross-sectional study performed in 18-year-old young adults with NWO, there was no significant difference in bone density compared to normal weight lean [44]. Nevertheless, according to another population study, young and middle-aged women with MUNW had lower forearm bone mineral density compared to metabolically healthy lean [89]. More large-scale and longitudinal studies are needed to determine the skeletal changes associated with unhealthy lean phenotypes.

30.2.3 Factors Associated with Unhealthy Lean

Factors associated with unhealthy lean are summarized in Fig. 30.2.

30.2.3.1 Early Life Factors

Low birth weight was also associated with MUNW in children [90] and excess body fat in childhood is associated with MUNW later in life [9, 46]. Increased BMI from childhood to adulthood due to excess weight gain is the strongest predictor of MUNW in adults [23]. According to a 2-year follow-up study with normal weight children aged 8–19 years having a parental history of obesity, those with gain body fat percent while maintaining a normal weight had an increased risk of developing MUNW [9]. It has also been observed that pre-pubertal girls with NWO continue to have excess body fat with an increased risk for cardiometabolic diseases in adulthood [46].

The presence of high levels of low-density lipoprotein cholesterol (LDLc) and low levels of high-density lipoprotein cholesterol (HDLc) in childhood are predictors for developing MUNW during adulthood [23]. Furthermore, childhood psychosocial adversity is associated with the increased risk of being metabolically unhealthy during adulthood in both normal weight and overweight/obese [91].

Maternal factors including parity, maternal education, and smoking as well as factors related to birth including gestational age at birth, type of delivery, and birth weight were not associated with NWO in young adults according to one study done in Brazil [53]. However, more large-scale studies in different populations are needed for a comprehensive understanding of early life factors associated with unhealthy lean phenotypes.

30.2.3.2 Age and Sex

Aging is associated with all types of unhealthy lean (MUNW, NWO, and NWCO) [24, 41, 81, 92, 93]. The prevalence of NWO increases with age in women with a normal BMI [94, 95]. According to the Nurses' Health Study, about 68% of healthy lean women aged 30–55 years became MUNW

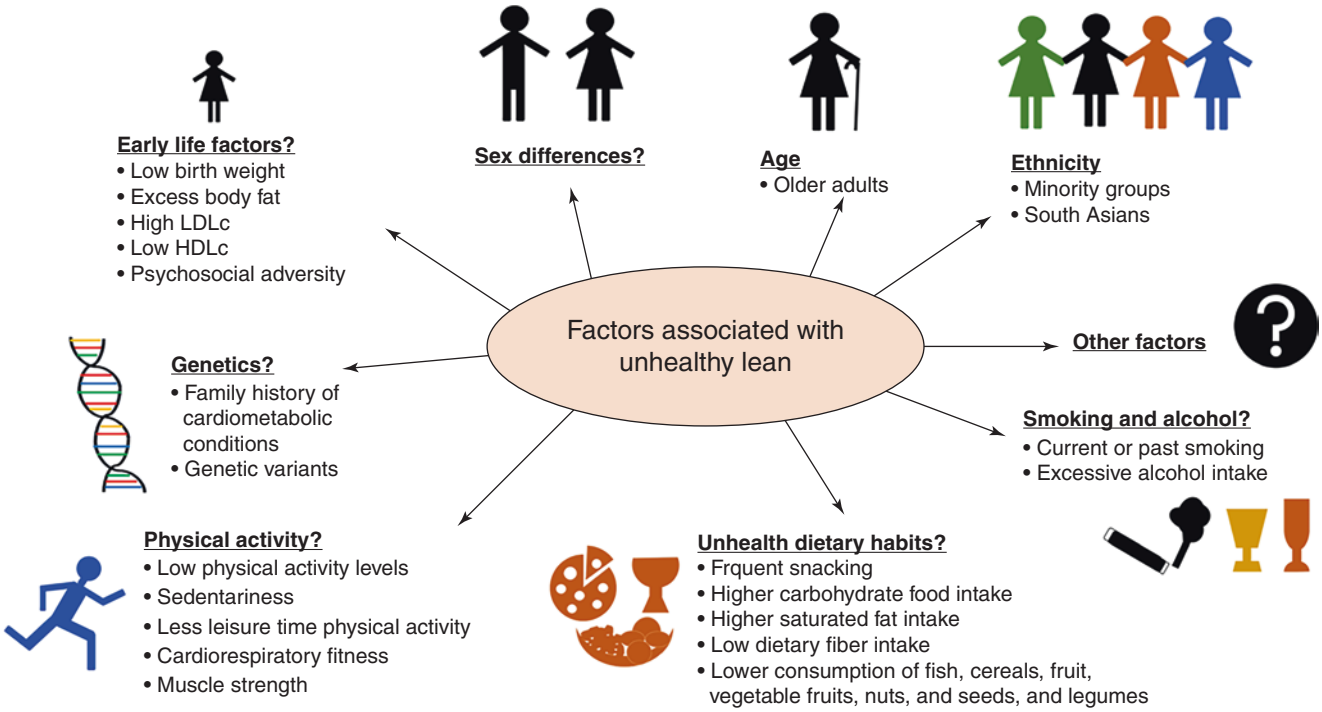

Fig. 30.2 Factors associated with unhealthy lean phenotypes. Abbreviations: *HDLc* high-density lipoprotein cholesterol; *LDLc* low-density lipoprotein cholesterol

20 years later [96]. With aging, body fat and central obesity increase, lean mass decreases, and the body fat is redistributed centrally and infiltrates to visceral organs and muscle, while BMI tends to remain stable [94, 97].

In general, males have a higher risk of MUNW than females [4, 23, 36, 52, 92], while women are more likely to have NWCO than men [24–26, 93]. Following menopause, women have an increased risk for MUNW [98]. In Chinese adults aged <45 years, the prevalence of MUNW was higher in men than in women. However, in the same study, women had a higher prevalence of MUNW than men among adults ≥50 years [98]. NWO has been observed mainly in women [31, 66, 85, 99, 100], but a few studies have reported that the prevalence of NWO is higher in men [30, 44, 101]. Overall, it is challenging to compare the sex-related differences in NWO prevalence due to the lack of consensus on the definition of unhealthy lean and the scarce research conducted in males.

30.2.3.3 Ethnicity

The prevalence of MUNW differs depending on ethnicity [7]. The prevalence rates of MUNW among US adults with normal weight are about 21%, 32%, 31%, 39%, and 44% for whites, Chinese Americans, African Americans, Hispanics, and South Asians, respectively [37]. Urban South Asian adults with a normal BMI have higher odds of having abnormal blood glucose and lipid levels compared to white [102]. Thus, one needs to be cautious when assessing health risks in normal weight individuals of different racial/ethnic groups.

30.2.3.4 Genetics

Genetic variants in several genes related to inflammation (*IL-6* promoter, IL-15 receptor alpha [*IL15-Rα*], *IL-1Ra* TNF-promoter *G/A-308*), tumor suppression (*p53*), and folate metabolism (MTHFR) have been associated with NWO [64, 103–107]. In contrast, some genetic variants (in *CDKAL1* gene) are associated with reduced risk for MUNW [90], Family history of diabetes, hypertension, and cardiovascular disease increases the risk of developing MUNW [98]. In addition, children with NWCO are more likely to have a parental history of type 2 diabetes compared to those who are normal weight without central obesity [39]. Since only a few research studies have explored the genetic associations for unhealthy lean, more studies are needed to increase our understanding of the genetic predisposition for unhealthy lean phenotypes.

30.2.3.5 Physical Activity and Physical Fitness

Physical activity is defined as "*any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase in caloric requirements over resting energy expenditure*" including but not limited to exercise [108]. Several studies have reported that self-reported physical activity is lower in unhealthy lean (MUNW, NWCO, and

NWO) compared to their healthy counterparts. Engagement in sports reduces the risk of developing type 2 diabetes in normal weight adults [52]. Self-reported leisure-time physical activity is lower and time watching television is higher in women with MUNW compared to healthy women [109]. Furthermore, young women (18–35 years) with MUNW seem to have lower physical activity energy expenditure calculated based on measurements of total energy expenditure (measured using double-labeled water) and resting energy expenditure (measured using indirect calorimetry), compared to healthy lean [110]. In children with MUNW, self-reported moderate-to-vigorous physical activity was lower compared to health lean [90]. However, other studies utilizing self-reported physical activity assessment showed no significant differences in leisure activities in adults with MUNW [111] and no differences in physical activities in men with MUNW [112] compared to healthy lean. Furthermore, in a study carried out with healthy non-obese participants using accelerometry, women with MUNW (n = 12) did not show significantly different daily energy expenditure [109]. In adults with NWCO, self-reported physical activity level is lower than those with normal weight and normal waist [113]. Similarly, self-reported physical activity level is lower in adults with NWO compared to normal weight lean [43]. More specifically, adults with NWO are less likely to exercise regularly for more than 20 min, more than three times a week [81], and similarly, adolescents with NWO are less physically active compared to normal weight lean [44]. Adults with NWO are more likely to spend less leisure-time physical activity compared to normal weight lean based on self-reported measures [31]. However, some studies did not find a clear association [8, 54]. These differences between studies could be due to the inherent limitations of the self-reported measures for physical activity [114] and due to variability of definitions used for unhealthy lean. The role of physical activity in unhealthy lean needs a more in-depth examination.

Periods of sedentary behavior (i.e., sitting time) are associated with harmful health consequences (i.e., greater risk for all-cause mortality, cardiovascular disease incidence, and mortality, cancer incidence and mortality, diabetes type two, etc.) independent of physical activity. Interestingly, these sedentary time-associated risks decrease in those individuals with higher levels of physical activity compared to those with low levels [115]. The prevalence of NWO is higher among sedentary normal weight young adults compared to those who are active [53].

These findings should be examined carefully, since the majority used self-reported physical activity assessment. Therefore, the above-mentioned discrepancies could be due to over-or under-estimations inherent to self-reported measures used for data collection [116]. In addition, there could be discrepancies associated with the lack of consensus in definitions and cutoffs for unhealthy lean phenotypes as discussed in previous sections.

Physical fitness is defined as "*the ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and meet unforeseen emergencies*" and includes five health-related components: (a) cardiorespiratory fitness (or endurance), (b) muscular strength, (c) muscular endurance, (d) body composition, and d) flexibility [108]. From all the physical health-related components, cardiorespiratory fitness, upper extremity muscle strength (i.e., hand grip), and fat content (body composition) are the most studied in unhealthy lean. Cardiovascular fitness—maximal oxygen consumption (VO_2max)—is often decreased in unhealthy lean (MUNW and NWO) compared to healthy lean [8, 44, 48, 99, 117, 118]. MUNW have decreased cardiorespiratory fitness, lean mass, mid-thigh muscle area, and strength compared to metabolically healthy lean [4, 8, 11, 109]. Lower physical fitness observed in NWO—including cardiorespiratory fitness and muscular endurance—has been partially explained by reduced lean muscle mass [99]. Similarly, muscle strength is reduced in unhealthy lean compared to healthy lean [10, 48]. According to past research in MUNW examining muscle fitness, handgrip strength is reduced in older MUNW females compared to healthy lean [10]. Muscle strength is also reduced in children, adolescents, and adults with NWO compared to normal weight lean [42, 45, 48]. However, there is no research examining the effects of unhealthy lean on muscular endurance or flexibility. Overall, poor cardiorespiratory fitness and muscular fitness—including muscle strength and endurance, and muscle content—has been shown to increase morbidity and mortality in the general population [119–121]. Therefore, there is a strong need for more exhaustive research in the health-related components in unhealthy lean and the development of interventions to increase cardiovascular function and improve muscular components of physical fitness. This will aid in the development of specific exercise guidelines and recommendations for unhealthy lean individuals.

30.2.3.6 Dietary Factors

Several unhealthy dietary habits including frequent snacking, higher consumption of carbohydrate-rich snacks and saturated fat, lower dietary fiber, and lower polyunsaturated fatty acids to saturated fatty acids ratio have been associated with MUNW [34, 122]. In addition, a higher intake of fast foods, sodium, potatoes, organ meats, processed meats, and vegetable fats increases the risk of developing MUNW [123]. Choi et al. reported that an adequate intake of proteins and reduced intake of carbohydrate-rich diet and snacks lower the risk for MUNW in women [122] The majority of MUNW (~69%) are likely to have vitamin D deficiency with 25-hydroxy vitamin D levels less than 50 nmol/L [124]. This

is of great importance, as vitamin D deficiency has been recently associated with skeletal muscle weakness and fatigue [125]. In addition, a higher intake of vitamin A and calcium lowers the risk for MUNW [123]. Consumption of a balanced diet, high in vegetarian food, flavonoids, and carotenoids, may help lower the risk for MUNW [98, 126]. A higher intake of fruits, dairy, tea/coffee, and magnesium reduces the risk of developing metabolic abnormalities irrespective of the BMI [123]. In premenopausal women in the US (<45 years), adherence to the Dietary Approaches to Stop Hypertension (DASH) style diet or Mediterranean diet are associated with reduced the risk for MUNW [127]. However, the association of MUNW with major food groups (refined grains, sugar-sweetened beverages, dairy, meat, fish fruits, and vegetables, etc.) is not clear [8]. Hence, different dietary interventions need to be assessed in the future for the effectiveness as a trial in unhealthy lean.

Unhealthy dietary habits have also been observed in NWO individuals. Lower consumption of fish, cereals, fruit, vegetable fruits, nuts, and seeds, root vegetables, and legumes, higher consumption of fat and sugar, and skipping breakfast is associated with NWO compared to the normal weight lean [31, 44, 53, 128]. However, some studies did not observe differences in energy, macronutrient, and food type intake between NWO and normal weight lean [44, 54], while others have reported contradictory findings, an association of healthy dietary patterns, such as lower consumption of meat, and less soft drink intake in NWO than normal weight lean [31].

Considering the available literature, there are many gaps to be filled to understand the role of diet causing lean individuals to be unhealthy. The discrepancies between the past studies could be attributed to the use of different definitions to define each unhealthy lean phenotype and/or due to the inaccuracy of self-reported dietary assessment methods [8]. Furthermore, the majority of the studies were cross-sectional which limits the ability to discuss causation.

30.2.3.7 Alcohol Consumption and Smoking

Smoking and being a former smoker are associated with being unhealthy lean [31, 36, 41, 52]. The prevalence of MUNW is higher in normal weight individuals who consume alcohol [36]. In addition, daily excessive consumption of alcohol increases the odds of having NWCO in normal weight individuals [25]. Similarly, higher alcohol consumption per occasion is associated with NWO, but alcohol consumption frequency is not [41].

Contradictory findings were reported in Chinese adults by Song et al. who observed no association between smoking and alcohol consumption with NWCO [24], while Zheng et al. observed that regular alcohol intake is associated with a lower risk for MUNW [98]. Even though the associations between unhealthy lean phenotypes, smoking, and alcohol intake are not clear, it is important to provide preventative advice to normal weight individuals regarding alcohol consumption and smoking.

30.2.3.8 Other Sociodemographic Factors

Higher education attainment has been reported to be associated with a lower risk for unhealthy lean compared to healthy counterparts [24, 25, 41, 98]. However, the association between socioeconomic status and NWCO is mixed [24, 25]. Urban residence increases the risk of NWCO when defined based on waist circumference and waist-to-hip ratio, while it decreases the risk of NWCO by when assessed using the waist-to-height ratio in the same population of Chinese adults [24]. Being married is positively associated with NWCO by waist circumference in Chinese adults [24]. In contrast, Ohlsson et al. reposted that marital status is not associated with NWO [41]. Hence, the definition of unhealthy lean may affect its associations.

30.3 Contemporary Understanding of the Issue

30.3.1 Health Risks Associated with Unhealthy Lean

Health risks in unhealthy lean phenotypes are summarized in Fig. 30.3.

30.3.1.1 Increased Cardiovascular Disease Risk

MUNW are more likely to have a higher cardiometabolic risk profile [7, 129]. A study that followed up women aged 30–55 years for a median of 24 years observed that the risk of developing cardiovascular disease is 2.4 times higher in MUNW women compared to healthy lean [96]. Furthermore, the prevalence of stroke is higher in women with MUNW compared to metabolically healthy obesity [130]. Similarly, both adults and children with NWCO have a higher risk for cardiovascular disease compared to those with a normal weight without central obesity [33, 39, 131]. Accumulation of central fat has a higher increased risk for metabolic conditions compared to the accumulation of total body fat, particularly in women according to a study conducted in Chinese adults with a normal weight [132]. NWO is also associated with higher cardiovascular disease risk [42, 43, 101], and the prevalence of metabolic syndrome is four times higher in US adults with NWO compared to normal weight lean [20]. In addition, NWO adolescents and adults have a higher prevalence of metabolic syndrome compared to normal weight lean [44, 53, 101] and normal weight girls with NWO have a higher cardiometabolic risk in adulthood [46]. The presence of less leg fat mass which suggests impaired expansion is the strongest predictor of metabolic health in normal weight

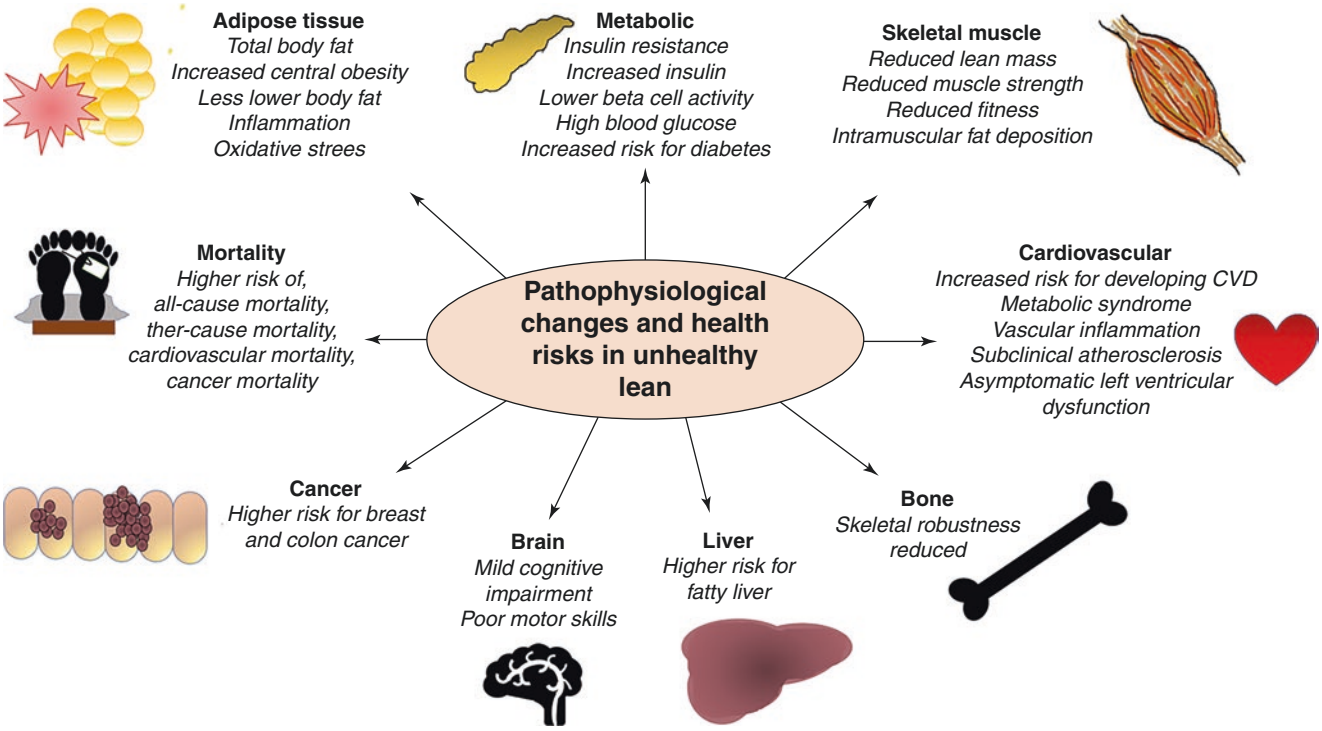

Fig. 30.3 Health risks in unhealthy lean phenotypes. In comparison to healthy lean. Abbreviations: *CVD* cardiovascular disease

adults but not in those with obesity. The next main predictor of metabolic health in normal weight adults is liver fat [14].

Multiple cardiovascular changes have been observed in unhealthy lean individuals. Vascular inflammation, carotid intima–media thickness (a measure of subclinical atherosclerosis), arterial stiffness, aortic artery aneurysms, and carotid atherosclerosis are higher in MUNW compared to the healthy lean [92, 133, 134]. Similarly, carotid intima–media thickness is higher in individuals with NWCO compared to normal weight individuals without central obesity [68, 135], and the prevalence of subclinical vascular inflammation, subclinical atherosclerosis with soft plaques, and asymptomatic left ventricular systolic and diastolic function impairment [59, 71, 136] are higher in NWO compared to normal weight lean.

Even though the cardiovascular risk is high in unhealthy lean individuals, those may be missed in normal weight individuals due to the use of BMI classification. Furthermore, these subclinical cardiovascular changes in unhealthy lean are likely to be missed during a routine health assessment.

30.3.1.2 Increased Risk for Hyperlipidemia and Hypertension

Compared to healthy lean counterparts, individuals with MUNW and NWCO have higher levels of total cholesterol, triglycerides, and LDLc, and lower levels of HDLc [7, 39, 52, 68, 93, 135, 137]. Similarly, women with NWO have 2.5 times higher odds of having hypertriglyceridemia than normal weight lean women [54]. While several studies reported that the serum triglyceride, LDLc, apolipoprotein B, and the apolipoprotein B/A–I ratio are higher, and HDLc is lower in NWO adults compared to normal weight lean [28, 42, 53, 66, 81], a few studies conducted in adolescents in Iceland and Trinidad and Tobago did not observe significant differences in triglycerides, HDLc, and LDLc between NWO than normal weight lean [30, 44]. This may be because the metabolic abnormalities are subclinical in the younger age groups with NWO or could be due to the use of different definitions to define NWO.

Higher blood pressure has been observed in MUNW, NWCO, and NWO compared to their unhealthy lean counterparts [28, 42, 54, 66, 70, 135, 137]. Furthermore, the prevalence of hypertension is higher in adults with NWCO than in normal weight adults without central obesity [135] and blood pressure is higher in children and young adults (20–44 years) with NWCO than those with normal weight but without central obesity [68, 138]. However, blood pressure was not significantly higher in young adults with NWO in one study [30] and this could be due to subclinical disease in young individuals with NWO.

30.3.1.3 Increased Risk for Diabetes

Compared to healthy lean, the unhealthy lean adults have a higher risk of developing diabetes [129] and may have higher glycated hemoglobin (HbA1C) [7, 14, 52, 69, 135], higher fasting plasma glucose [3, 6], and 2-h postprandial glucose

[135]. Postmenopausal older women aged 50–79 years with MUNW have twice the risk of developing type 2 diabetes over time (after about 16 years) compared to healthy lean [139]. NWCO and NWO are also associated with a higher prevalence of type 2 diabetes compared to their healthy counterparts [93, 101, 135].

Insulin resistance and hyperinsulinemia (increased plasma insulin) are commonly seen in unhealthy lean [3, 5, 8, 53, 140, 141], and increased plasma insulin could be due to insulin resistance [3]. When there is insulin resistance, carbohydrates will be used for lipogenesis in the liver instead of being taken up by the muscle, and this causes an elevation of plasma triglycerides [142] and ectopic fat accumulation in the liver [143]. Reduced beta-cell function with reduced insulin secretion from the pancreas may also be seen in some instances in unhealthy lean compared to healthy lean [14, 29] and this can also cause hyperglycemia. Hence, screening for insulin resistance and hyperglycemia is important in normal weight individuals.

30.3.1.4 Increased Risk for Mild Cognitive Impairment

A few of the studies have suggested that unhealthy lean may have an increased risk for mild cognitive impairment compared to healthy lean [32, 47, 144]. Older adults with amnestic mild cognitive impairment have higher odds of having MUNW compared to those without cognitive impairment. Thus, MUNW may be a risk factor for amnestic mild cognitive impairment in later life [32]. Similarly, NWO is associated with poorer cognitive function in young and middle-aged normal weight adults in the US, and cognitive performance declines as total body fat percent increases [144]. Even preschoolers with NWO are more likely to have severe motor deficits and poorer fundamental motor skills than normal weight lean [47]. However, more studies are needed to confirm this association.

30.3.1.5 Increased Risk for Cancer

Only a few studies have explored the association between unhealthy lean phenotypes and cancer risk. Postmenopausal unhealthy lean women have a higher risk for breast cancer than their healthy lean counterparts [145, 146]. In addition, MUNW women have a higher risk for colorectal cancer than metabolically healthy lean [147, 148]. Further research is needed to understand the association of unhealthy lean and other types of cancer and the mechanisms to develop interventions for prevention.

30.3.1.6 Increased Mortality Risk

Similar to unhealthy overweight and obese phenotype, MUNW also has higher all-cause and cardiovascular mortality risks compared to healthy lean [149]. All-cause, cardiovascular, and cancer mortality risks are also higher in postmenopausal women with NWCO, similar to those with obese BMI and central obesity, compared with lean without central obesity [150]. In addition, older women with NWO have higher short-term cardiovascular mortality, while older men with NWO have higher long-term cardiovascular mortality [29]. Screening for unhealthy lean is important, since they have a higher mortality risk compared to healthy lean.

30.3.2 Interventions to Improve the Health of Unhealthy Lean

30.3.2.1 Normal Weight Status May Be a Barrier to Healthy Behavior

It has been postulated that the "Normal weight" status may be a barrier for healthy behavior in unhealthy lean women, because it may cause the individual to underestimate the importance and decrease motivation to engage in healthy behaviors [151]. In a population study carried out by Zhang and collaborators, 73% of NWCO adults self-rated themselves as "sub-normal" or "normal weight", and only about 13% tried to lose weight [93]. In another study in normal weight Korean adults, the majority (~54%) of women with NWCO were unaware of their excess fat and only about 36% tried to lose weight [25]. Further examination of this hypothesis is needed.

30.3.2.2 Dietary Interventions

Studies testing supplements and dietary interventions in unhealthy lean are sparse, and well-designed studies of longer duration are needed. Even though weight loss is beneficial to obesity, a large amount of weight loss is less likely to be possible in unhealthy lean [8]. However, calorie restriction of about 25% seems to be safe and well-tolerated in non-obese subjects while monitoring for bone loss and anemia according to a study conducted over 2 years [152]. Weight loss is likely to be beneficial to unhealthy lean according to a small study with 11 MUNW Asian adults ($n = 5$ women). In this study, diet-induced a weight loss of ~5% and caused a reduction of total body fat percent, VAT, SAT, and intrahepatic fat (9%, 11%, 17%, and 50%, respectively) along with improved lipid profile and insulin sensitivity [153]. To validate these findings, large-scale randomized studies are needed.

A few studies have explored the role of a few supplements in unhealthy lean. According to a small-scale case–control study, twice a daily oral alpha-Lipoic acid (600 mg) supplementation for 4 weeks resulted in a reduction of fasting glucose, and improved insulin sensitivity in lean patients with diabetes [154]. Hypomagnesemia is also associated with MUNW [155]. In a randomized double-blind, placebo-controlled trial, blood pressure, fasting glucose, TG, and

insulin resistance improved in the intervention group who received a daily dose of 382 mg of magnesium for 4 months compared to the control group [156]. De Lorenzo et al. investigated the effectiveness of probiotic supplements on eating behavior, body composition, and psychological status in Italian women with NWO, overweight, and obesity. Body composition, eating behavior, gastrointestinal symptoms, and psychological status improved following probiotic supplementation for 3 weeks in women with either NWO and obesity compared to normal weight lean [157]. Di Renzo et al. studied the role of dark chocolate (containing 70% cocoa) in NWO Caucasian women in a nonrandomized pilot study. In this study, the participants consumed a standard Italian Mediterranean diet for 7 days, and during the next 7 days, they consumed 100 g of dark chocolate per day in addition to the standard Italian Mediterranean diet. Following the dark chocolate consumption period, HDLc increased and IL-1Rα decreased, suggesting reduced inflammation [158]. However, these findings are confounded by the effects of the Mediterranean diet, and randomized-controlled studies with a cross-over design are needed to validate these findings. Haghighat et al. conducted a randomized controlled trial to determine the effectiveness of 12 weeks of high protein supplementation (25% of daily calories from proteins) on body composition and appetite in 50 NWO women. Compared to the control group who consumed a standard protein amount (15% of daily calories from proteins, but same calorie intake), the high protein group did not lose weight, but the body composition improved in the high protein group [159].

30.3.2.3 Exercise Interventions

It is well-known that exercise is capable of reducing systemic inflammation in both healthy individuals and those with pathologies associated with chronic inflammation [160, 161]. Adipose tissue and skeletal muscle are significantly affected by exercise. One of the adaptations to exercise is the secretion of molecules capable of modulating not only local but also systemic metabolism and inflammation. These secreted molecules can act in an endocrine manner to facilitate tissues crosstalk and work together to improve overall health [162]. There is a dose–response relationship between exercise and benefits for health defined mainly by intensity, duration, and frequency [163]. Therefore, the intensity of exercise must be appropriate to optimize anti-inflammatory and metabolic effects, with higher intensities having a greater impact on overall inflammatory and metabolic balance [164], and central fat and visceral fat content [165]. More importantly, insufficient intensity will not induce biochemical adaptations that will lead to health improvements. The duration of the exercise interventions is crucial, being necessary at least 9 weeks to achieve significant anti-inflammatory adaptations [166]. In addition, exercise in the form of circuits or intervals will mimic best real-life physical activity patterns, which favors anti-inflammatory responses, and improve body composition and metabolic health in both the general population and chronic conditions, where inflammation affects prognosis [167–172]. This emphasizes the importance of individualized and well-planned nutritionally supported exercise programs—therapeutic exercise programs—designed with a specific purpose (i.e., increase the anti-inflammatory responses, increase muscle mass, or reduce visceral fat), and supervised by specialized exercise professionals.

There are many gaps in the literature regarding the role of exercise in unhealthy lean women. Jung and collaborators examined the impact of three different exercise intensities in a small sample of nine NWO Korean female college students [173]. Each participant performed three exercise sessions on the ergometer with similar energy expenditure on separate days: (a) 30 min continuous exercise at 60% of VO_2max; (b) 26 min interval exercise including 2 min warm-up, and three sets of 1 min at 40% of VO_2 max followed by 3 min at 80% VO_2max; and (c) three short-duration (10 min) exercise bouts at 60% VO_2max separated by intervals of 1 h. There was no difference in VO_2 during exercise; however, both interval exercise routines (b and c) resulted in significantly higher excess post-exercise oxygen consumption or "*after burn*" [173]. "*After burn*" is the elevated VO_2 (higher than resting VO_2) that persists for some time after exercise and results in temporary increase of fat oxidation [174]. Thus, the authors postulated that interval exercise may help reducing body fat in NWO [173]. However, long-term interventions are needed to confirm this hypothesis.

Resistance exercise leads to muscle mass gain, reduction of VAT and percent body fat, and weight control, regulates inflammation and glucose metabolism, and reduces cardiometabolic risk and mortality [165, 175]. Ferreira et al. studied the impact of a 10-week intervention in NWO women [176], where the intervention consisted of three sets (one warm-up set) of a circuit resistance training program—including six whole-body exercises and three single-joint exercises—three times a week at an intensity of 60–80% of their maximum. After the intervention, body fat percent was reduced by ~26%, the lean mass increased by ~5 kg, and fasting glucose decreased significantly in the exercise group compared to controls who did not exercise. In addition, cardiovascular fitness, muscle strength, and endurance increased significantly and ~50% of the women in the exercise group were no longer classified as NWO [176].

A meta-analysis on the effect of aerobic versus resistance exercise on visceral fat by Ismail and collaborators concluded that aerobic exercise is superior at reducing VAT [177]. However, the total number of resistance exercise and combined aerobic and resistance exercise studies, sample heterogeneity (i.e., older/frail, diabetics, pre- and postmenopausal, sedentary, obese, overweight, females, males,

Table 30.5 Example of estimation equations for resistance exercise-derived energy expenditure [178, 179]

net Kcals = 0.874 (height, cm) − 0.596 (age, years) − 1.016 (FM, kg) + 1.638 (lean mass, kg) + 2.461 (TV × 10) − 110.742 TV = sets × reps × weight lifted
net Kcals = 36.379 × (sex) + 2.2999 × (FFM, kg) + 0.000524 × (counts*) − 74.671 Sex: 1 female; 2 male

Abbreviations: *FM* fat mass; *FFM* fat-free mass; *TV* total exercise volume; * accelerometer worn at the waist

etc.), lack of adjustment by energy expenditure, or the inclusion of nutritional intervention in some studies, make comparisons unrealistic and difficult to support this conclusion [177].

The ability to accurately assess energy expenditure is critical in the design of exercise clinical trials that are reproducible and comparable (i.e., same exercise-derived energy expenditure) with other interventions and, therefore, necessary to develop successful exercise recommendations. The problem relies on the difficulty of measuring resistance exercise-related energy expenditure. This assessment can be expensive (i.e., portable metabolic cart, respiratory closed chamber, and doubly labeled water) and uncomfortable especially to those participants that are not used to resistance training protocols. Few researchers have worked on the development of resistance exercise-derived energy expenditure predicting equations (see Table 30.5): Lytle and collaborations developed the equation using VO_2 measurement with a portable metabolic cart in a group of healthy 18–58-year-old men and women [178], and Rawson and collaborators developed an equation based on the quantification of physical activity with accelerometers in a group of healthy 18–30-year-old men and women [179]. Nevertheless, more research is needed in this area for optimal quantification of resistance exercise-derived energy expenditure.

Overall, the prescription of interval exercise [173] in the form of circuit resistance training [176] seem to be a key strategy for VAT reduction [176, 177] and increase of muscle mass [176] in NWO. However, more short- and long-term intervention studies including energy expenditure-matched aerobic exercise and resistance training alone or in combination [175] are needed for (1) realistic comparisons in both the general population and unhealthy lean [177] and (2) development of exercise prescription recommendations specific for unhealthy lean.

30.3.2.4 Combined Lifestyle Interventions

A 2-month lifestyle intervention that combined diet, exercise, and behavioral modification was conducted by Kelishadi et al. in Iranian adolescents with normal-weight BMI and obese BMI [180]. This intervention consisted of aerobic exercise intervention (40 min/day, three times a week), nutrition education, and behavioral modification that were supervised by a physical therapist, a registered dietitian, and a psychologist, respectively. They observed a significant reduction in body weight, central obesity, and body fat amounts in the MUNW group following the intervention. Furthermore, inflammation and dyslipidemia decreased in MUNW adolescents following this combined intervention [180]. However, this was not a randomized trial and did not include resistance training. Hence, well-designed randomized trials including diet, behavioral, and different exercise approaches (i.e., aerobic alone, resistance training alone, or combined) are needed to test the effectiveness of lifestyle interventions.

30.4 Future Directions

30.4.1 Consensus on Definitions is Needed

The current understanding of unhealthy lean types is rudimentary. Most of the past studies are cross-sectional studies that limit the understanding of causality and there are many gaps in the literature to be addressed. Most importantly, there is an urgent need for consensus on the definitions for different types of unhealthy lean phenotypes by the scientific and medical communities.

30.4.2 Screening for Unhealthy Lean

Raising awareness regarding unhealthy lean phenotypes is important for early detection. To diagnose unhealthy lean a more comprehensive health assessment beyond BMI is required and an agreement on the criteria is required. Additional screening could include assessment of body composition including body fat percent and muscle mass (not just lean mass), and central obesity.

NWO and NWCO are associated with a higher risk for metabolic disease compared to healthy lean but only a subset of NWO and NWCO have metabolic impairments [12]. Thus, a combination of screening measures with a stepwise screening approach may be useful to determine the health status of normal weight individuals and these should be explored in future research studies.

30.4.3 Future Research on Interventions for Unhealthy Lean

There are many gaps in the literature on unhealthy lean and the majority of the past literature on interventions in unhealthy lean were small-scale studies and some were not randomized trials. Thus, well-designed cross-sectional and longitudinal larger scale randomized controlled trials are

needed to explore the role of dietary, exercise, behavioral, and pharmacological interventions for unhealthy lean.

30.5 Conclusions

A significant proportion of individuals with a "normal" range BMI who are usually assumed to be healthy could be unhealthy with metabolic abnormalities, central obesity, and excess body fat. The three main types of unhealthy lean include MUNW, NWCO, and now, but there is a lack of consensus on the definitions used for unhealthy lean. Few studies have explored the possible etiology, pathophysiology, health outcomes, and interventions related to unhealthy lean, so there are many gaps in the literature. Finally, most of these normal weight individuals are unaware of their increased health risks; therefore, better screening is needed for unhealthy lean.

Chapter Review Questions

1. If a person has a normal BMI (normal weight) it,
   (a) Indicates good health always
   (b) Indicates no cardiovascular risk
   (c) Indicates no central obesity
   (d) Does not indicate good health always
2. Which of the following is a characteristic feature of metabolically unhealthy normal weight (MUNW)?
   (a) Normal weight
   (b) Cardiometabolic risk factors
   (c) Overweight
   (d) Both a and b
3. Which of the following are characteristic features of normal weight obesity (NWO)? Mark all correct answers.
   (a) Normal weight
   (b) Cardiometabolic risk factors
   (c) Increased body fat percent
   (d) Obese BMI
4. Which of the following are characteristic features of normal weight central obesity (NWCO)? Mark all correct answers.
   (a) Low waist to hip ratio
   (b) High waist circumference
   (c) Normal weight
   (d) Increased visceral fat
5. Which of the following may be associated with increased risk of unhealthy lean?
   (a) Aging
   (b) Ethnicity
   (c) Low physical activity
   (d) All of the above

Answers

1. d
2. d
3. a, c
4. b, c, d
5. d

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Maternal Obesity and Its Epigenetic Effects

31

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Learning Objectives

After completion of this chapter, readers should understand the following:

- Definition, prevalence, and health consequences of maternal obesity
- Epigenetic mechanisms involved in maternal obesity
- Human studies of maternal obesity
- Animal models of maternal obesity
- Effects of over nutrition and exercise in obesity and its influence on offspring

31.1 Introduction

Obesity is a complex disease, defined as having excess body fat leading to adverse health outcomes. It is caused by a variety of lifestyle factors including diet and physical inactivity [1]. Other elements that influence obesity are heritable/genetic and environmental factors, metabolic conditions such as insulin resistance, chronic diseases, or medicinal drugs that may impact weight gain [2]. Heritability has a greater impact on obesity than other chronic diseases [3]. A specific population of concern is women in reproductive age (18–44 years) when their body mass index is greater than 30 kilograms per meter squared (kg/m^2), given its impact both on mother and offspring [4].

Current rate of obesity in the United States for women is 40.4%, with another 26.5% being overweight [5]. Globally, 39% of women were overweight, with an additional 15% suffering from obesity as of 2016 (Global Health Observatory Data). This is in line with obesity in women of childbearing age around the globe, which was at 30% in 2018 [6]. Moreover, non-Hispanic black and Hispanic women have the greatest risks of maternal co-morbidities compared to Caucasian women [7]. Thus, there is urgency to address obesity in general, but more specifically obesity before and during pregnancy with special emphasis on ethnic/racial disparities.

Obesity can impair fertility in women. Furthermore, consequences of maternal obesity are deleterious due to its adverse health effects on the pregnant mother as well as on child health pre- and postnatally [8]. Women with pre-pregnancy overweight have a higher risk for cesarean delivery, gestational diabetes, preeclampsia, obstructive sleep apnea in pregnancy, congenital anomalies, perinatal death and birthing children who are larger sized for their gestation age at delivery, and increased risk of shoulder dystocia at time of delivery [9–11]. Additionally, there is up to 25% increased risk of still birth with increasing rates of obesity, especially during later weeks of gestation [12, 13].

When the mother suffers from obesity, the fetus is exposed to metabolic alterations due to excess maternal adiposity and fatty acids [8]. This in turn triggers metabolic abnormities in the fetus, thereby increasing the risk of early development of chronic diseases such as type 2 diabetes (T2D) and non-alcoholic fatty liver disease (NAFLD) [14]. Interestingly, several studies have demonstrated that serum triglyceride levels and pre-pregnancy weight are better predictors of excess fetal growth and incidence of metabolic syndrome in the offspring [15, 16]. This is in line with a prospective study

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that demonstrated that maternal body mass index (BMI) and percentage body fat are the strongest perinatal predictors of children becoming overweight, even when measured at 8 years of age [17]. Hence, research suggests that factors associated with obesity such as inflammation and hypertriglyceridemia contribute to both maternal and childhood obesity. This highlights the importance of overweight or obesity in women of reproductive age and suggests that routine screening before pregnancy is necessary.

Out of many factors which contribute to obesity, epigenetic modifications have received considerable attention during the past decade due to its involvement in altering metabolic homeostasis. Epigenetics is defined as study of heritable changes that involve DNA alterations without changes to sequence that could be passed to the offspring [18]. Epidemiological studies identified that the relationship between nutritional status during pregnancy and the development of adult diseases in the offspring are attributable to epigenetic changes (discussed later in the chapter) [12]. In this chapter, we will discuss the different epigenetic modulations, followed by clinical and animal models used in studying epigenetics in maternal obesity research.

31.2 Overview of Epigenetic Reprogramming Mechanisms

The word "Epigenetics" was coined in 1941 by Conrad Waddington to define "the branch of biology that studies the causal interactions between genes and their products which bring the phenotype into being" [19]. Its current definition deals with heritable changes in gene expression that arises during development. These modifications are necessary for development and cell proliferation. However, certain environmental, dietary, or genetic factors alter these modifications, leading to abnormal phenotypes that have lifelong impact which include neurological disorders and certain cancers [20, 21]. The currently known epigenetic alterations include DNA methylation (deoxyribonucleic acid methylation), histone modifications, and alterations of non-coding Ribonucleic acid (RNA) or microRNAs (Fig. 31.1).

31.2.1 DNA Methylation

DNA methylation is a heritable epigenetic mechanism which is critical for normal development and genomic imprinting. It has a key role in epigenetic programming and is long being studied in the field. Its mode of action is by binding to a transcription factor and changing its chromatin structure, thereby preventing its access to the promoter. In a typical human, there are ~29 million CpGs (CpGs are regions in the DNA where a cytosine nucleotide is followed by a guanine nucleotide in the 5′ → 3′ direction) [22]. Out of this, 7% are located in CpG islands [~1000 base pair (bp) long] which are regions of high cytosine-guanine (CG) density [23]. In vertebrates, DNA methylation is specifically restricted to cytosines in CpG sites which typically occurs immediately after fertilization and during early implantation of the zygote [24].

Addition of methyl groups is regulated by several steps which are carried out by a family of enzymes called DNA methyltransferases (DNMT) [25]. Three DNMTS (DNMT1, DNMT2, and DNMT3, which include DNMT3A, DNMT3B, and DNMT3L) are found in vertebrates [26], whereas others including DNMT4, 5, and 6 are found in algae and fungi [27]. The importance of DNA methyltransferases was revealed through a series of experiments using mouse models where these genes were knocked down. DNMT1 and DNMT3 deficiency is lethal to mice indicating their importance in development [28]. DNMT1 is essential for regular maintenance of already established patterns of DNA methylation [29]. DNMT3s are known to mediate de novo synthesis of new methylation patterns. However, research in the

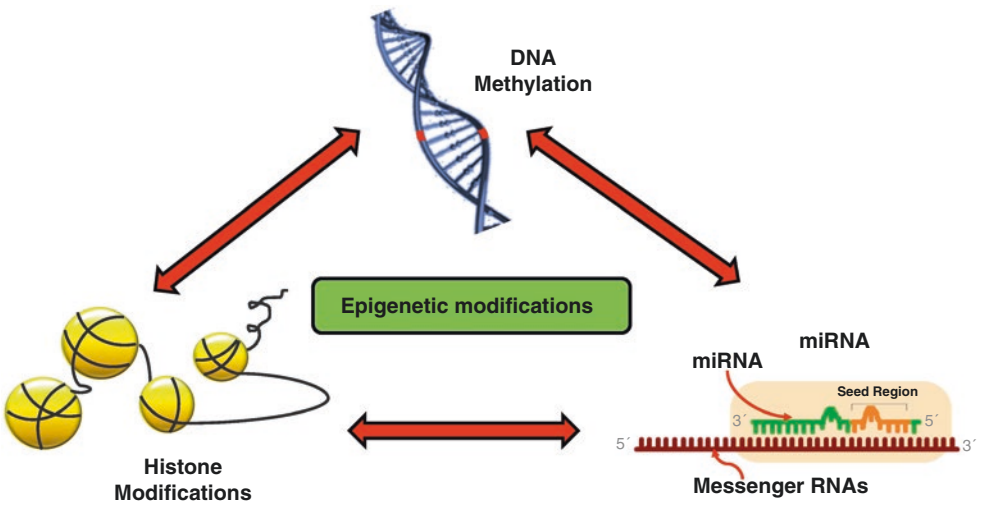

Fig. 31.1 Epigenetic mechanisms. Epigenetic modifications occur through various mechanisms including DNA methylation, histone modifications, and microRNAs (miRNAs), all of which are interrelated

past decade has shown that DNMT1 can also synthesize new methylation patterns, and DNMT3 could aid in synthesizing established patterns of methylation [30]. Specifically, DNMT1 is responsible for copying the DNA methylation pattern to the daughter strands during replication [31]. DNMT1 preferably methylates hemimethylated DNA [32], while DNMT3B does not distinguish between hemi- or unmethylated DNA. DNMT2 and DNMT3L are non-canonical as they do not possess catalytic activity. DNMT2 traditionally methylates RNA and is known as tRNA methyltransferase. In general, hypermethylation by DNMT leads to transcriptional repression, while hypomethylation leads to transcriptional activation traditionally, but few instances of the opposite occurring is also possible [33].

31.2.2 Histone Modifications

Histones are alkaline proteins which are core components of chromatin. They mainly package DNA and alter the chromatin structure involved in DNA replication by recruiting histone modifiers. Histone modifications include acetylation, methylation, ubiquitination, phosphorylation, and sumoylation, which modulate DNA replication and repair [34]. The major enzymes involved in different histone modifications include acetyl transferases, deacetylases, methylases, and demethylases. The other enzymes include threonine kinases, phosphatases, ubiquitin ligases, sumolyases, and desumolyases. The histone modifications catalyzed by above enzymes act predominantly at the N terminal chain involving amino acids such as lysine, arginine, or threonine [35]. Among all histone modifications, DNA acetylation and methylation have gained major attention for modulating gene regulation in the last decade and will be discussed below.

31.2.3 Histone Acetylation

This is a dynamic reversible process which is regulated by histone acetyl transferases (HATs) and histone deacetylases (HDACs). HATs are responsible for enzymatic addition of an acetyl group from acetyl coenzyme A to target lysine residue in histone tails. This leads to removal of positive charge on the histone, thereby weakening interaction between histone and DNA increasing accessibility of chromatin to transcriptional machinery.

HDACs hydrolyze and remove the acetyl group, thus reducing DNA accessibility. Four classes of HDACs have been identified with each class consisting of few members: Class I (includes HDAC 1, 2, 3, and 8), Class II (comprises HDAC 4, 5, 6, 7, 9, and 10), Class III (includes sirtuins from 1 to 7), and Class IV (includes only HDAC 11) [35]. HDAC classes could be zinc or NAD^+ dependent for its functional activity; Classes I, II, and IV are Zn dependent and catalyze removal of acetyl groups from lysine residues in histone and cellular proteins [36]. Class III HDAC requires nicotinamide adenine dinucleotide (NAD) as a co-factor for its activity and is inhibited by nicotinamide [37]. It is important to remember that histone proteins are not the only substrates for HDACs, because other non-histone proteins exist which include transcription factors and signal transduction molecules to name a few [38].

HDACs are critical since abnormalities in expression or function of HDACs place a critical role in cancers, neurological disorders [39, 40], endocrine disorders, and inflammatory diseases [41]. HDAC inhibitors are known to elevate acetylation at more global and loci specific levels. Additionally, targeting HDAC inhibitors leads to both up- and downregulation of genes, which indicates that HDAC targets co-factors which then regulate the genes [42]. HDAC inhibitors have profound effects since some of the acetylation also occurs on non-histone proteins. Hence, a complete understanding of acetylation at both cellular and total systemic level is required in the future. Furthermore, targeting HDAC for lifestyle and pharmacological interventions is beneficial and few inhibitors are currently in phase I and II of clinical trials.

31.2.4 Histone Methylation

Histone methylation involves transfer of 1–3 methyl groups from s-adenosyl-L-methionine to lysine or arginine of histone proteins by histone methyltransferases [43]. They control DNA methylation through chromatin-dependent transcriptional repression or activation. Histone methylation is mainly regulated by histone methyltransferase (HMT), lysine methyl transferase and arginine methyl transferase and histone demethylation by histone demethylases (HDMs). There is very limited research conducted on other histone modifications, which will not be discussed here.

31.2.5 MicroRNAs (miRNAs) in Epigenetic Regulation

MicroRNAs (miRNAs) are evolutionarily conserved RNA molecules which were recently recognized as a key regulatory gene family. They are approximately 22 nucleotides long and are involved in regulating genes post transcriptionally [44]. miRNAs exert their functions via binding to complementary site at 3′ untranslated region (UTR) of messenger RNA (mRNA) where they regulate metabolic functions by silencing mRNA expression [45]. A single miRNA could target hundreds of mRNAs. Also, a single mRNA could be

regulated by several miRNAs due to their complementary base-pair interactions. miRNA mediated mRNA silencing consists of (1) cleavage of mRNA molecules (abundantly exists in plants), or (2) mRNA decay (poly(A) tail shortening, or (3) inhibition of translation of proteins. miRNAs are found in almost every mammalian cell confirming their potential importance in cellular functions. For instance, several lines of evidence demonstrate that the involvement of miRNAs is not limited to cellular development, cell differentiation, proliferation, metabolism, and disease progression [46, 47] but also extends to epigenetic regulation [48].

31.2.6 Interrelationships Between Epigenetic Modifications

31.2.6.1 Link Between DNA Methylation and Histone Modifications

DNA methylation and histone modification cooperate to regulate gene activities. DNA methylation provides a base frame for histone modifications after replication, while histone modifications aid in directing DNA methylation patterns [49]. Microarray profiling performed in mice after HDAC3 inhibition has shown that DNA methylation is also altered, suggesting that these two modifications are intertwined [50]. Moreover, DNMT regulates specific set of genes involved with histone deacetylases, and DNMT3A/DNMT3B recruit other epigenetic repressors including histone deacetylases and H3K9 methyltransferases for de novo methylation [51]. The main take-home message here is that identifying epigenetic alterations is important but identifying gene regulators that are altered by epigenetic regulators is even more critical as they are transferred across multiple generations.

31.2.6.2 Cross Talk between miRNA, DNA Methylation, and Histone Modifications

miRNAs are involved in cross talk with DNA methylation and histone modifications by targeting enzymes and proteins directly or indirectly [48, 52, 53]. They directly target histone methyltransferases, HDACs, and DNMTs [53, 54] and indirectly target inhibitors of these epigenetic enzymes [55].

DNA methylation also participates in regulation of miRNA expression [48]. When CpG islands (in promoter region) of a miRNA are hypermethylated, it represses miRNA synthesis, resulting in overactivation of target genes [56]. For example, hypermethylation of CpG islands of miR-424 promoter significantly reduces its expression and apoptotic function [57]. Therefore, aforementioned epigenetic modification in miRNA expression could be beneficial in healthy cells, yet it would be detrimental in tumor cells as reduced miR-424 expression is directly involved in invasion and migration of cancer cells [57]. On the contrary, evidence from both in vivo and in vitro studies shows that miR-29b (in early porcine embryonic development), miR-101 (in lung cancer cell line A549), and miR-377 (in human skin fibroblasts) target DNMTs influencing DNA methylation affecting vital cellular processes including early embryo development, apoptosis, and skin senescence [58–60].

Similar to DNA methylation, histone modifications also regulate miRNA expression [48]. Histone deacetylation promotes compact chromatin state causing reduced miRNA gene transcription and suppresses miRNA expression. A study conducted using HDAC inhibitors has demonstrated that decreased histone deacetylation substantially induces miR-124 expression resulting in downregulation of miR-124 target genes such as CDK4 and CDK6 [61]. In addition, numerous miRNAs regulate histone modifications targeting HDACs. miR-34a bind at complementary site in the 3'UTR of HDAC1 mRNA to regulate gene expression in foam cells [62], whereas miR-138 regulates histone demethylase, lysine demethylase 5B (KDM5B) in breast cancer cells [63].

Taken together a reciprocal relationship exists between the epigenetic modifications. Hence, proper knowledge of these epigenetic cross talks is crucial to better understand how these could be used to lessen the progression of chronic conditions including maternal obesity. However, practical applications of epigenetic cross talk in therapeutics are still under research stage. Therefore, additional research is warranted before recommending epigenetic cross talks for clinical diagnosis and applications.

31.3 Maternal Obesity and Its Epigenetic Effects in Humans

As discussed earlier in this chapter, maternal lifestyle factors in humans such as diet and physical activity can have a profound effect on the health and subsequent risk for noncommunicable diseases like T2D, hypertension, and neurological disorders in the offspring [64]. This concept is called the "Developmental Origins of Health and Disease (DOHD)." These changes are mostly attributed to epigenetics. Recent evidence also suggests that the time immediately prior to and after conception (periconceptional period) is also important to these epigenetic modifications [64]. The earliest evidence for the DOHD theory originated from the "Dutch Famine Studies." During the winter of 1944–1945, during the Second World War, widespread starvation occurred in Western Netherlands. Infants conceived during this famine, had low birthweight, and subsequently were at a higher risk of being obese and dysglycemic. These changes were later attributed to DNA methylation [65] suggesting the epigenetic origins of these diseases. Other studies have also confirmed that maternal undernutrition is associated with metabolic diseases of the offspring.

31.3.1 Maternal Obesity and Its Effects on the Offspring

Numerous observation studies in humans show that maternal overweight and obesity increases the risk of the offspring subsequently developing obesity. A meta-analysis of 45 studies showed that pre-pregnancy overweight/obesity increased the risk of the offspring having a higher birth weight by 53%. The same study showed that these children have a 95% increased chance of subsequently developing obesity or being overweight [66]. These risks are enhanced with increasing rate of obesity. A study conducted in Washington State, USA, with over 700,000 women demonstrated a significant increase in rate of maternal mortality and morbidity with increasing rates of maternal obesity [67]. Early studies conducted in United Kingdom have also found a strong risk association between maternal obesity and cardiovascular disorders in women at later ages (after 50 years of age) [68].

Maternal BMI also can impact the cardiovascular disease risk of the offspring [69]. In the Generation R study, a prospective cohort study of more than 4000 mothers, fathers, and their children, higher maternal BMI was associated with higher blood pressure, insulin resistance, and adverse lipid profiles of the offspring, indicating a higher risk for cardiovascular diseases [70]. There is evidence that this relationship between maternal BMI and the offspring body composition and metabolic markers is mediated via epigenetic changes in the fetus. Since it is difficult to obtain fetal DNA during pregnancy, investigators have used placental DNA to study these epigenetic changes. In one such study, placental DNA from obese mothers was found to have altered levels of DNA methylation in leptin and adiponectin promoters, two adipokines important for determining fat mass of the offspring [71].

31.3.2 Maternal Dietary Factors and Epigenetic Changes of the Offspring

In addition to weight status, maternal diet itself is important for the subsequent health of the offspring. Emerging evidence suggests that the dietary glycemic index [72] and dietary inflammatory index [73] are associated with DNA methylation changes in the newborns and thus important for health of the offspring. Additionally, specific nutrients such as Vitamin B12, [74] folate [75] and Vitamin D [76] are known to impact the methylation of the offspring DNA and further studies are needed to understand their long-term impact.

It is known knowledge that ~400 micrograms of folic acid is recommended for pregnant women or those planning pregnancy as it is donor for methionine and aids in methylation [77]. This was confirmed in a human study where pregnant women supplemented with folic acid showed methylation of insulin like growth factor-2 (IGF-2) in children, compared to children whose mothers were not supplemented with folic acid during pregnancy [78]. IGF-2 is a critical player in growth and development. Interestingly, IGF-2 methylation levels were lower in siblings who were exposed to the Dutch famine in comparison to those not exposed [79]. In line with this, Swedish population with T2D had increased DNA methylation of insulin like growth factor for isomer one [80]. Another recent systemic review, not specifically related to obesity, reported an inverse association between folate supplementation during pregnancy and autism development in children, suggesting the importance of methionine supplemented diet in pregnancy [81].

DNA methylation levels were also related to obesity and BMI grade. A recent systemic study using the Methyl Epigenome Network Association (MENA) project showed that DNA methylation is associated with HOMA-IR, which is a measure of insulin resistance suggesting that obesity and DNA methylation are associated [82]. Using the MENA project, they associated ~670 CpG islands to waist circumference, a strong indicator for abdominal obesity. Of these, ~375 CpGs were found to be differentially regulated between women suffering from obesity and healthy women. But, only 95 CpG islands were differentially regulated between obese and normal men. It is worth noting that some of the CpG islands were related to inflammatory pathways, key features of obesity-associated immune dysfunctions. Consistent with this, a sequencing study with more than 10,000 subjects in a high-risk population for metabolic abnormalities identified 187 CpG islands that were hypermethylated that may be linked to obesity [83]. Of these, 120 CpG sites had direct association with BMI in both blood and adipose tissue. Additionally, they compared methylation in adipose tissue, liver, and muscle and indicated that methylation patterns in blood correlate with methylations in the above tissues. In line with this, a study showed an increase in DNA methylation of hypoxia inducible factor 3 subunit alpha in adipose tissue, which was associated with obesity [84]. Another study performed in human adipose tissue also showed an association between BMI and global methylation both in blood and adipose tissue [85].

Apart from adipose tissue, increased global methylation was also evaluated in blood leukocytes of diabetic retinopathy patients in comparison to non-retinopathy patients [86]. Also, methylation was assessed in a cluster of differentiation 4 ($CD4^+$) immune cells, where eight sites associated with BMI and genes related to lipid oxidation, such as carnitine palmitoyl tansferase-1 was identified [87]. These studies suggest that there is increased DNA methylation with obesity and T2D. However, some of the studies demonstrated

higher variation because of heterogenicity in these diseases. Lastly, similar results were also validated in human studies where DNA methylation was responsive to calorie restriction in post-menopausal women after 6 months of calorie restriction [88]. These examples indicate that nutrients in maternal environment can alter the genome.

A recent study conducted by Zamanillo et al. revealed that maternal obesity considerably affects miRNA levels available in breast milk during lactation. miRNAs such as miR-222, -103, -200b, -17, -let7c, and -146b were significantly downregulated in lactating women who suffered from obesity. Alterations of these miRNAs directly modulate expression of their respective target genes causing deficiencies in infant growth and brain development [89]. Furthermore, clinical trials conducted using obese pregnant women have revealed that miR-155, miR-221, and miR-181a are differentially expressed in infants born to mothers suffering from obesity compared to infants born to normal weight mothers. They further indicated that these changes in miRNA expression may be directly linked to epigenetic alterations in early fetus development and could lead to metabolic disorders in children further confirming the importance of proper regulation of both epigenetic modifications and miRNAs during pregnancy [90].

Potential cross talk between epigenetic modifications and miRNA expression during maternal obesity was examined in a recent study completed using 72 pregnant women-infant pairs [91]. The study indicated chromosome 19 microRNA cluster (C19MC) which is responsible for transcription of 56 mature miRNAs, is differentially methylated during pregnancy [91, 92]. DNA methylation of C19MC regulates the expression of miRNAs and pregnant women with higher body weight showed a reduced placental C19MC methylation. Interestingly, reduced methylation of C19MC in mothers correlated with increased body size of children [91]. Several other research groups have also demonstrated a potential involvement of maternal obesity in affecting epigenetic modifications and miRNA profiling among individuals.

Bioactives, especially, omega-3 fatty acids of marine origin when supplemented to the maternal diet are known to provide beneficial effects for the offspring. However, to date, data from human studies have not provided conclusive evidence whether supplementing the maternal diet with omega-3 fatty acids will improve the body composition of the offspring and provide them with metabolic benefits. A recent meta-analysis of 11 randomized controlled trials concluded that maternal supplementation of omega-3 fatty acids during pregnancy does not prevent obesity in the offspring [93]. However, since there was a heterogeneity of study design, further studies using a larger sample and higher omega-3 doses are needed to confirm whether omega-3 fatty acids will influence the body composition in the offspring via epigenetic mechanisms in humans.

31.3.3 Maternal Physical Activity and Epigenetic Changes

Regular physical activity during pregnancy is associated with lower pregnancy complications and improved fetal growth. A meta-analysis of randomized controlled trials shows that supervised prenatal exercise reduces the odds of having a large baby by 31% [94]. Emerging evidence suggests that maternal physical activity potentially leads to epigenetic changes of the fetus, which could be at least in part responsible for improved fetal growth [95]. Therefore, being physically active during pregnancy is important for better maternal health as well as the long-term health of the offspring.

31.3.4 Lifestyle Interventions to Reduce Gestational Weight Gain in Overweight and Obese Women

As discussed earlier in this chapter, maternal obesity significantly increases the risk of maternal mortality and morbidity and subsequent development of metabolic disorders in the offspring. Emerging evidence suggests that lifestyle modification, comprising healthy eating and increased physical activity, is effective in reducing gestational weight gain in overweight or obese women. A meta-analysis of 23 randomized trials concluded that regular physical activity was effective in reducing gestational weight gain in overweight/obese women [96]. In a recent randomized trial of 400 overweight or obese pregnant women, the women who followed a telehealth lifestyle intervention had lower weekly gestational weight gain compared to controls [97]. Further clinical studies using different ethnic groups are needed to identify the efficacy of different lifestyle interventions to prevent excessive gestational weight gain in overweight/obese women.

31.4 Animal Models of Maternal Obesity

The above sections have discussed epigenetic modulations and its influence on obesity and insulin resistance. Epigenetic modulations are altered by excess nutrient intake that contributes to alterations in genes associated with obesity and its co-morbidities. The effects of excess nutrient intake during pregnancy are passed to the offspring, which is studied using animal models of maternal obesity followed by investigating their offspring.

For in-depth mechanistic studies of maternal obesity, animal models are needed as they provide a controlled environment to tests influence of genetics and early development as well as subsequent influence of early life perturbations. Additionally, lower life span, cheaper cost, and higher num-

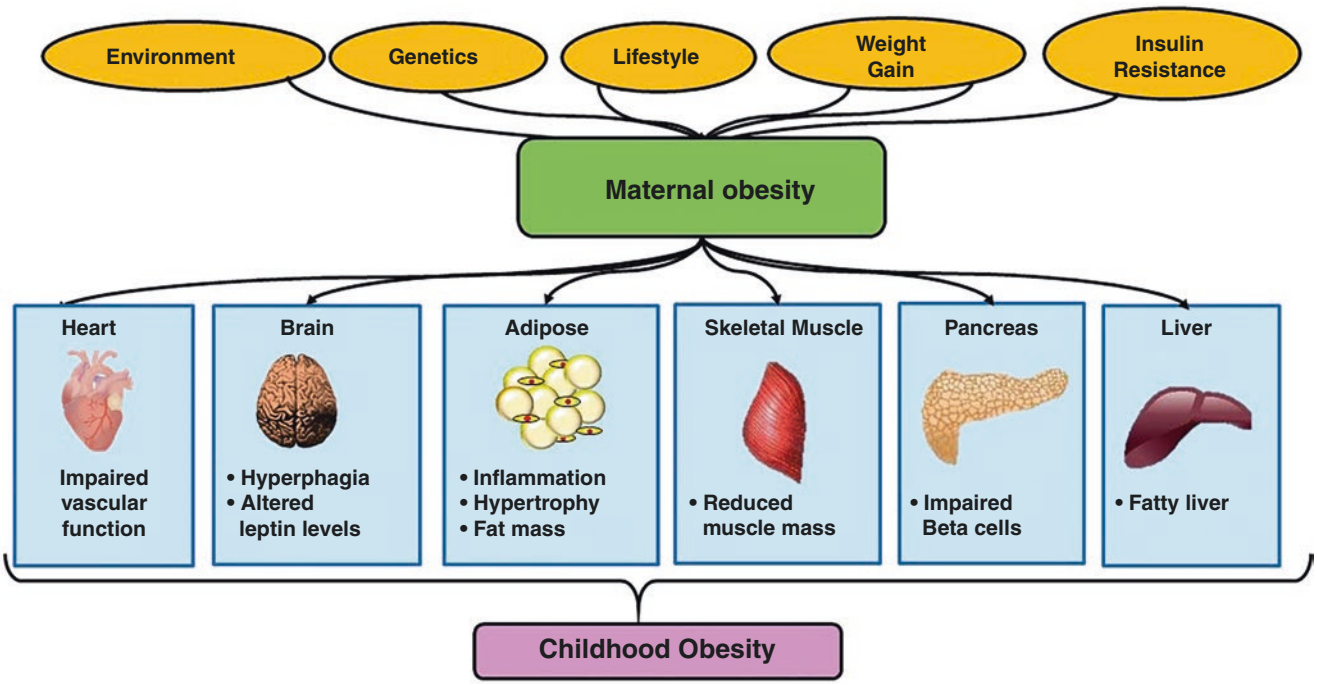

Fig. 31.2 Tissue-specific effects of early life programming, associated with maternal obesity. Various factors such as environmental, genetic and lifestyle factors, weight gain and insulin resistance influence maternal obesity, which in turn affect body organs. In the heart, impaired vascular function could occur in the offspring, if the mother suffers from maternal obesity. In the brain, possible complications include hyperphagia and altered leptin signaling. In adipose tissue, increased inflammation and fat mass or adiposity occur in the offspring as a result of maternal obesity. Reduced muscle mass, beta cell dysfunction, and fatty liver in the offspring may also result from mother's obesity. Heart: "Heart" by Injurymap is licensed with CC BY 2.0. Brain: Modified from "File:Rainbow brain, Aug 2014.png" by en:User:Muffinator is marked with CC0 1.0. Liver, pancreas, and muscle: Modified from "File:The master circadian clock in the human brain.jpg" by Ian B Hickie, Sharon L Naismith, Rébecca Robillard, Elizabeth M Scott, and Daniel F Hermens is licensed under CC BY 3.0

bers of subjects could be studied simultaneously. Furthermore, it helps us to better understand molecular mechanisms behind maternal obesity. A plethora of animal studies have been conducted in different animal models starting from rodents to non-human primates to study the role of maternal over nutrition and have been extensively reviewed [98]. Some of the differences in animal models in comparison with human beings are that while singleton pregnancies are a norm in human beings, multiple pups are born in rodents. Moreover, brain and peripheral systems are more mature in humans than rodents at time of birth. Within animal models, gestation time is vastly different between species. Ovine models have ~150 days gestation period and usually have singleton or double pregnancies compared to rodents [99]. Additionally, organs in non-primate animal models are more mature compared to rodents.

An interesting meta analyses of high fat diet (HFD) exposure in animal models indicated increased body weight at birth and weaning in both males and females [100]. Additionally, influence of maternal obesity is studied in offspring metabolic organs which include adipose, skeletal muscle, and liver but only few mechanistic studies exist in these tissues (Fig. 31.2).

Specifically, the offspring has increased adiposity and dyslipidemia [101] when exposed to high fat intrauterine environment due to mothers being on a HFD [102]. The increase in adiposity could lead to increased pro-inflammatory cytokines such as tumor necrosis factor alpha and interleukin 1β. Apart from increased adiposity, fatty liver with impaired glucose tolerance and insulin resistance is observed in offspring born to HFD fed pregnant dams [103, 104]. Fatty liver associated with maternal obesity is linked to activation of Jun kinase (JNK), consistent with the development of NAFLD [105]. The other factors/mechanisms that contribute to obesity in the offspring include reduced fatty acid oxidation measured by markers such as carnitine palmitoyltransferase-1 (*Cpt-1*) and *Pparα* [106, 107]. Moreover, HFD induces abnormalities in pancreas, including reduced beta cell volume which in turn reduces insulin secretion [108]. Lower insulin secretion and insulin resistance are associated with alteration in levels of glucose transporters and markers of insulin signaling pathway in pancreatic islets [108].

In rodent models, maternal obesity is initiated in dams through feeding either 45 or 60% of total calories as fat for 4–6 weeks before pregnancy to create obesogenic effects [98]. The duration of experimental diets and amount/percentage of fat, in addition to the genetic strain, determine the phenotype of offspring. Additionally, the type of fat also makes a difference in the metabolic phenotype of offspring. In consensus with current knowledge, offspring of pregnant mice fed diets with excess saturated fats or diets deficient of polyunsaturated fatty acids have shown to develop metabolic disorders and hypertension [109]. However, the underlying mechanisms are not clearly defined in terms of maternal obesity.

Some studies mimic human consumption, where the diet has ~33% sugar of total calories. Mice on high sugar show similar phenotype to those on HFD [102]. Additionally, studies have demonstrated that differences in type of carbohydrate could also contribute for this altered metabolic phenotype in offspring. A diet with 68% sucrose caused deleterious effects such as elevated triglycerides and plasma glucose compared to a diet with lower amount of sucrose [110]. Moreover, fructose was responsible for even more severe effects compared to sucrose [111]. Most of studies with high fat and high sugar show deleterious effects in the offspring; however, to date, only few dietary interventions for maternal studies are available and more studies are warranted.

31.4.1 Dietary Regulation in Animal Models

31.4.1.1 Dietary Effects on DNA Methylation

Nutrient deprivation in terms of reduced protein or fat intake during pregnancy lowers methylation in animals [112]. Feeding rats with protein restricted diets reduces DNMT1 expression and leads to hypomethylation, while supplementing the same diet with folic acid prevents hypomethylation, and in turn prevents dyslipidemia in their pups [113].

The enzymes involved in DNA methylation use s-adenosyl methionine (SAM) as a source of methyl donor, which is synthesized in the methionine cycle by different precursors such as B6 [114], B12 vitamins [115], folate [116], choline [117], and betaine [118]. These dietary components specifically alter one carbon metabolism. In terms of folate [116], limiting its intake, lowers DNA methylation by affecting DNMT activity. Rats fed a diet deficient in choline showed hypomethylation in liver [119]. Similarly, rats fed a diet deficient in vitamin B12 demonstrated hypomethylation of cystathionine beta synthase promoter in liver but were rescued with dietary methionine [120]. Corroborating with this, extra folate supplementation (~7 times higher than recommended human dose of 400 mcg) rescued liver methylation indicating the importance of folate in epigenetic regulations [121]. Though the doses were higher, these studies show evidence of how maternal nutrition alters DNA methylation.

31.4.1.2 Histone Modification by Dietary Modulation

Various bioactives have the potential to affect histone modification by altering the expression of HDACs. One such example is resveratrol which activates sirtuins. Another bioactive theophylline, found in both black and green tea, increases activation of HDAC and suppresses anti-inflammatory genes in epithelial cells and macrophages at lower doses [122, 123]. Similarly, epigallocatechin-3-gallate (EGCG), also found in green tea inhibits histone acetyl transferases (HAT) activity [124].

The beneficial effects of HDAC inhibitors have being analyzed using animal models. Overexpression of Class I HDAC blockers increases beta adrenergic activation, which in turn activates brown adipose tissue (BAT) thermogenesis in mice, suggesting that blockage of HDAC is beneficial for BAT [125, 126]. Similarly, in liver, an HDAC3 inhibitor improved glycemia by blocking hepatic lipid accumulation and indicated beneficial effects in metabolic syndrome [127]. Additionally, inhibiting HDAC11 improved glucose clearance, oxygen consumption and reduced cholesterol levels [128]. Another important member of HDAC family is HDAC9 which has a role in adipocyte differentiation. Elevated levels of HDAC9 repressed adipogenic proliferation, while inhibiting HDAC9 increased adipogenic potential [129]. Also, valproic acid, which is an HDAC inhibitor increased adiponectin expression and its transcription factor, C/EBP alpha at mRNA levels in both adipocytes and in vivo [130]. Similar to DNA methylation, HFD is also known to alter histone acetylation by altering levels of specific genes such as of sodium glucose transporter 1 [131]. Lastly, methionine deficient diets alter histone methylation like DNA methylation, but tissue specific effects are observed in different tissues, hence regulation of histone methylation by methionine diets is more complex than DNA regulation.

31.4.1.3 Diet-Mediated Alterations of miRNAs

Involvement of miRNAs in obesity has been extensively studied during past few years. Studies have demonstrated that adipogenic markers such as peroxisome proliferator-activated receptor gamma (PPARγ) and cytosine-cytosine-adenosine-adenosine-thymidine (CCAAT)/Enhancer Binding Protein (C/EBP) are regulated by miRNAs where abnormalities of these miRNAs lead to chronic disease progression. A study conducted in mice indicated that miR-27a directly regulates PPARγ expression and adipose differentiation. They further showed, significant reduction of miR-27a level in obese mice compared to lean mice suggesting a potential involvement of miR-27a in adipose tissue dysregulation during obesity [132]. Additionally, miR-143, miR-519d, miR-210, miR-21, and miR-30 family members (miR-30c, miR-30a/d), are shown to

Table 31.1 Epigenetic alterations in different tissues of maternal obese animal models [143–150]

Model	Type	Diet of dam and offspring	Offspring			Reference
			Tissue	Time	Main effect	
Rats	DNA methylation	Choline deficient	Brain and liver	E-17	DNA methylation of the *G9a* and *Suv39h1* genes was up-regulated by choline deficiency	[144]
Rats	DNA methylation	Diets deficient of Vit B12 and Folate	Liver	21 days	Mitochondrion metabolism and phospholipid homeostasis was reduced	[145]
Mice	DNA methylation	60% fat	Brain	18–24 week	Global and gene-specific (DAT, MOR, and PENK) promoter DNA hypomethylation in the brains of offspring from dams that consumed the HFD.	[146]
Mice	DNA methylation	45% fat	Liver	8 weeks	Maternal overnutrition programs long-term epigenetic modifications, namely, *Irs2* and *Map2k4* gene methylation in the offspring liver	[147]
Rats	Histone methylation	45% fat	Liver	5 weeks	Hepatic mRNA expression of circadian (*CLOCK, BMAL1, REV-ERBα, CRY, PER*) and metabolic (PPARα, SIRT1) gene	[148]
Mice	DNA methylation	45% fat	Liver	14 weeks	key genes in tissue development and metabolism (*Fgf21*, *Ppargc1β*) with maternal HFD and in cell adhesion and communication (*VWF*, *Ephb2*)	[149]
Rats	DNA methylation	45% fat	Liver	12 weeks	*Map3k5* and *Igf1r* were confirmed to be differentially expressed.	[150]
Ewes	miRNA	150% NRC rec	Muscle	150 days	Reduced expression of miRNA let-7 g and increased intramuscular adipogenesis	[143]

increase adipogenesis [133–137] while miRNAs such as miR-27, miR-130, Let-7, miR-448, miR-155, and miR-145 are responsible for downregulating adipogenesis by targeting genes peroxisome proliferator-activated receptors (PPARγ), High-mobility group AT-hook 2 (HMGA2), Kruppel-like factor 5 (KLF5), C/EBPß, cyclic amp-response element binding protein; (CREB), and insulin receptor substrate 1 (IRS1), respectively [138–142].

An interesting study conducted in ewes demonstrated how maternal obesity affects miRNA let-7 g expression and enhances intramuscular adipogenesis in muscle development in fetus [143]. Moreover, miRNA let-7 g level was significantly reduced in obese ewes (received an obesogenic diet) compared to ewes fed a control diet. Furthermore, PPARγ and CCAAT-C/EBPα which are let-7 g targets were significantly upregulated in obese ewes [143]. More studies can be seen in Table 31.1 [143–150].

31.4.2 Physical Activity in Animal Models

Maternal exercise in humans has beneficial outcomes for mom [151] and the offspring based on few epidemiological studies [152]. Animal models are a necessity to study the effects of maternal exercise in offspring, as it is harder to follow up children until adulthood.

Different parameters are considered while evaluating physical activity in rodents which include type, duration, and intensity of exercise. Studies performed in rodents traditionally involve voluntary wheels placed in cages. An alternative to this modality is forced training exercises which includes treadmill or swimming regimen [153], which have beneficial effects on the offspring based on the intensity of the exercises. Maternal exercise performed in rodents ranges from few weeks before gestation, continuing during gestation and couple of studies conducted exercise regimen even during lactation period [154, 155]. Additionally, different studies tested effects of exercise under diet induced obese conditions where the fat percentage of diet ranged from 20 to 60%. Refer additional studies in Table 31.2 [153–163].

A study performed by Stanford et al. compared different durations of maternal exercise in female dams which ranged from having access to voluntary exercise either only during pre-gestation, or only duration gestation and then a combination of both pre and during gestation, which were compared to sedentary moms [156]. The effect of exercise was evaluated in the offspring at different time points up to 52 weeks. They identified that exercise both during pre- gestation and gestation had greatest beneficial effects in the male offspring when tested at 52 weeks in terms of glucose tolerance and body fat percentage compared to groups that had access to physical activity either only during pre-gestation or gestation. Additionally, they found that exercise only during pre-gestation had no advantageous effects and exercise only during gestation had beneficial effects at early time points but was diminished by 52 weeks [156]. In line with this, another study demonstrated similar beneficial effects in terms of glucose tolerance in male and female offspring, when dams had access to voluntary physical activity from pre-gestation through lactation [154, 155]. Few studies evaluated beneficial effects of exercise even during lactation and found beneficial effects in the offspring in terms of glucose tolerance [164]. These studies indicate that intervention during the right time point is needed and beneficial effects are observed in both sexes with a pronounced effect in male offspring.

The effect of exercise during pregnancy was evaluated in the offspring mostly by measuring metabolic phenotype and

Table 31.2 Exercise intervention in animal models

	Dam			Offspring					
Rodent	Training duration	Training type	Diet	Sex	Diet	Tissue	D	Major effect	
Mice	2 weeks PG and G	Wheels	HFD; 60% fat	M	Chow	Pancreatic islets	52	Improved beta cell phenotype	[157]
Mice	1 week PG, G and L	Wheels	Chow; 16.4%	M	Chow; 18% fat		80	Improved glucose clearance and insulin sensitivity	[154]
Mice	2 week PG, G and L (14 days)	Wheels	Chow; 16.4%	F	Chow; 18% fat	Muscle	80	Improved glucose homeostasis and higher glucose uptake in muscle	[154]
Mice	2 weeks PG and G	Wheels	HFD; 60% fat	F	Chow; 14% fat	Liver	52	Exercise improved glucose clearance, reduced adiposity and hepatic glucose production	[163]
Mice	2 weeks PG and G	Wheels	21% fat	F	Chow; 14% fat	Liver	52	Lower adiposity, no effect on glucose clearance or glucose infusion rate.	[163]
Mice	2 weeks PG and G	Swim daily	standard diet	M	HFD; 45% fat	Muscle	28	Increased adiponectin, lower leptin levels in skeletal muscle	[158]
Mice	G and L	Wheels	Chow; 4% fat	M	Chow; 4% fat	NA	23	Male offspring ran more but no difference in physical activity	[159]
Mice	G and L	Wheels	Chow; 4% fat	F	Chow; 4% fat	NA	8	Higher reduction in adiposity and more physical activity in females	[159]
Mice	2 weeks PG and G	Wheels	HFD; 60% fat	M	Chow; 14% fat	Muscle	52	Exercise during PG and G improved glucose clearance and reduced percent fat mass. No difference in insulin stimulated glucose clearance.	[156]
Mice	2 weeks PG and G	Wheels	21% fat	M	Chow; 14% fat	Muscle	52	Exercise during PG and G improved glucose clearance and reduced percent fat mass no difference in insulin stimulated glucose clearance	[156]
Rats	2 week PG, G and L (12 days)	Wheels	Chow; 16.7% fat	F	Chow; 18% fat	NA	73	Improved glucose disposal and infusion rate	[155]
Rats	4 weeks PG and G	Wheels	Chow; 14% fat	M	HFD; 45% fat	Liver	34	Reduced susceptibility to HFD-induced hepatic steatosis in adult male offspring.	[160]
Rats	4 weeks PG and G	Wheels	Chow; 14% fat	F	HFD; 45% fat	Liver	34	Reduced susceptibility to HFD-induced hepatic steatosis in adult male offspring	[160]
Rats	4 weeks PG and G	TM 5 days/ week	Chow; 13% fat	M	Chow; 16% fat	Pancreas	30	No difference in pancreas weight, blood or glucose levels	[161]
Rats	G and L	Wheels	Chow, 4.5% fat	M	Chow; 4.5% fat		8	Improved object recognition memory in adult male offspring	[162]
Rats	4 weeks PG and 18 days G	TM 5 days/ week	Chow; 5.1% fat	M	HFD; 36% fat	Muscle/ liver	10	No improvements in glucose clearance but improved Pakt stimulation with insulin with exercise	[153]
Rats	4 weeks PG and18 days G	TM 5 days/ week	Chow; 5.1% fat	M	Chow; 5.1% fat	Muscle/ liver	10	No improvements in glucose clearance but improved Pakt stimulation with insulin with exercise	[153]

D duration in weeks; *G* gestation; *HFD* high fat diet; *PG* pre-gestation; *L* lactation; *M* male; *F* female; *TM* treadmill

glucose clearance [154]. However, several studies have evaluated the effects of maternal exercise at tissue levels in the offspring. In the case of pancreas, pancreatic adaptation was increased due to increase in beta cell mass by exercise, measured by the insulin secretory capacity in pancreas [157]. In the liver, hepatosteatosis caused by HFD in male offspring at 8 months of age was reversed with no differences in body weight, when the dam had access to physical activity [160]. In brain, exercise improved object recognition memory in adult offspring. Additionally, higher muscle insulin sensitivity [165], and improved cardiovascular outcome were seen in muscle and heart of offspring when the dam had access to physical activity [166]. To validate the metabolic effects, hyperinsulinemic euglycemic clamps were performed in mice and rats. Studies in rat dams show that maternal exercise improved glucose turnover and reduced glucose production in female offspring [155]. However, studies in mice have reported no beneficial effects of exercise under euglycemic hyperinsulinemic conditions in female offspring [163]. Interestingly, this study found higher expression of genes involved in mitochondrial oxidation and fatty acid oxidation in isolated hepatocytes in offspring of exercised dams. The difference in the two studies is that the rat dams were fed a chow diet while the mice dams were an HFD and different rodent models could respond differently to diets.

Most of the studies have found beneficial effects of maternal exercise except in case of trained exercise at sub maximal intensity in pregnant dams. High intensity trained exercise in dams had beneficial effects on the offspring at a younger age (~4 weeks) but the effects were negative in offspring at a

later time point (~7 months) in pancreas, which could be probably be due to added stress of higher intensity exercise in the pregnant females [161].

All these studies raise the question whether offspring of moms who had access to maternal exercise increased physical activity in offspring. This was answered by an interesting study that found that when moms had access to voluntary maternal exercise, their offspring when exposed to voluntary wheels in the cages, performed more physical activity compared to offspring born to sedentary dams [159].

One thing that remains to be tested is, if the intensity of exercise has different influence on metabolic effects in the offspring. A study which compares different modalities of maternal exercise would be beneficial to ascertain the best type of exercise in pregnancy and would be useful for translational purposes. Only a couple of studies have investigated the effects of epigenetics alterations due to physical activity with one study indicating that the hypermethylation of pgc1 alpha in skeletal muscle was reversed in presence of physical activity [167]. This is one area which warrants future investigation in understanding the role of physical activity and epigenetics.

31.5 Conclusion and Future Studies

Maternal lifestyle factors including dietary habits, overnutrition, undernutrition, and physical activity can impact the metabolic wellbeing of the child. Current evidence indicates that epigenetics at least in part are responsible for these changes. Especially, maternal obesity can increase the risk of obesity, T2D, and cardiovascular diseases in the offspring. Limited evidence suggests that lifestyle modification comprising healthy eating and physical activity can prevent excessive gestational weight gain in overweight or obese mothers.

Current and ongoing research clearly indicates that we are in an epigenetic era where research is focused on understanding how to improve offspring health through diet-mediated epigenetic modifications. Most epigenetic research has focused on cancer prevention. Few HDAC inhibitors are already being tested in cancer clinical trials. A few other HDAC inhibitors are being evaluated in in vitro experiments and animal models for their tissue-specific metabolic effects. One example is HDAC7, which is known to improve insulin secretion in pancreatic islets isolated from T2D patients, a potential target for future clinical study [168]. However, when designing epigenetic regulators or inhibitors, it needs to be noted that they could modulate multiple genes/organs simultaneously.

Epigenetic regulators have tissue specific effects, which require further investigation and specific experimentation on tissue biopsies. This might take several years as these are harder to be accomplished, especially in human subjects. Additionally, epigenetic clinical studies require larger cohorts with collaboration across different research teams. Epigenome sequencing is still at its infancy stages with only 1.5% of the total CpG islands (regions of DNA where a cytosine nucleotide is followed by a guanine nucleotide in the linear sequence of bases along its 5' → 3' direction) sequenced until now. Hence, as more advanced sensitive tools are developed, more epigenetic modulators will be uncovered, including tissue specific epigenetic regulators. With the progress in sequencing and bioinformatics tools, individualized epigenome sequencing may help identify risk of certain diseases in the offspring. Moreover, the dynamic relationship between histone modification, DNA methylation, and miRNAs has not been completely understood and more research is warranted in this area.

Lastly, maternal obesity in addition to affecting the first generational offspring affects further generations also known as transgenerational effects [169]. A study by Pentinat et al. showed that maternal overfeeding affected F2 generation with a moderate phenotype compared to F1 phenotype where they observed greater changes in hyperglycemia and insulin resistance [170]. The mechanisms involving transgenerational effects are less understood, and this is one of the areas where more research is needed. Because epigenetics alterations modulated by diet are reversible, dietary interventions during this critical early period are valuable to study.

Chapter Review Questions

1. The percentage of women in the reproductive age suffering from obesity in United States is:
   (a) 39%
   (b) 50%
   (c) 10%
   (d) 70%
2. The strongest predictor for children to be overweight depends on these factors of the mother:
   (a) Maternal body mass index
   (b) Percentage body fat
   (c) Maternal behavior
   (d) Both a and b
3. Epigenetics is defined as:
   (a) Heritable changes that involve DNA alterations
   (b) Changes in the maternal DNA sequence during pregnancy
   (c) Changes in RNA of the mother
   (d) Epidemiological studies on genetics of mothers
4. DNA methylation is carried out by a family of enzymes called:
   (a) DNA methyltransferase
   (b) Histone methyltransferase
   (c) DNA acetylase
   (d) DNA sumolase

5. All these nutrients contribute to one carbon metabolism required for DNA methylation *except*:
   (a) Vitamin B6
   (b) Fish oil
   (c) Folic acid
   (d) Choline
6. With obesity and type 2 diabetes, there is ___ in DNA methylation:
   (a) A decrease
   (b) An increase
   (c) No change
   (d) An increase or decrease
7. Physical activity is performed in rodent models using:
   (a) Voluntary wheels
   (b) Treadmill
   (c) Swimming
   (d) All of the above

Answers

1. a
2. d
3. a
4. a
5. b
6. b
7. d

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Exercise and Nutritional Guidelines for Weight Loss and Weight Maintenance in the Obese Female

32

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Learning Objectives

- To explain the definition of overweight and obesity in terms of body mass index (BMI).
- To differentiate the differences between the three types of macromolecules: carbohydrates, fats, and proteins.
- To understand the importance of pre-testing and meeting with health specialist regarding dieting and exercising.
- To compare and contrast the most common diets and understand their benefits, limitations, and potential side effects.
- To describe the basis of bariatric surgery.
- To explain the fundamentals of health-related components of physical fitness: energy balance, body composition, aerobic training, resistance training, and flexibility training.
- To evaluate literature findings' implications on different modalities of exercise.

Table 32.1 Definitions of overweight and obesity using the body mass index (BMI) in kg/m^2 [1–3]

Class	BMI (kg/m^2)
Overweight	25.0–29.9
Obesity	–
Class 1	30.0–34.9
Class 2	35.0–39.9
Class 3	≥40.0

Table 32.2 Percentage of United States adults with overweight and obesity [5]

Weight classification	All (men and women)	Men	Women
Overweight or obesity	70.2%	73.7%	66.9%
Overweight	32.5%	38.7%	26.5%
Obesity (including extreme obesity)	37.7%	35%	40.4%
Extreme obesity	7.7%	5.5%	9.9%

32.1 Introduction

Much of our discussion in the previous chapters has been in consideration of females who are a "normal" or "healthy" weight. The focus of this chapter will be on nutritional and exercise guidelines for overweight/obese females. Table 32.1 lists the definitions for overweight and obesity using the BMI in kilograms per meter squared (kg/m^2)

Obesity has been linked to numerous health problems including type II diabetes, hypertension, heart disease, strokes, and certain types of cancer [4]. Table 32.2 provides data from the Centers of Disease Control and Prevention (CDC) regarding the percentage of overweight or obese adults in the United States, it also illustrates that a higher percentage of U.S. men are overweight as compared to women, although more women are classified as obese or extremely obese [5].

Although there are many factors (family history and genes, socioeconomic status, race, ethnicity, age, eating and physical activity habits, and medical conditions) that have been linked to obesity, it remains unclear as to exactly why there is a higher percentage of obese women than men [6]. Considering that a 5–15% weight loss may greatly reduce the health problems associated with obesity, weight loss is one of the primary treatments for obesity. Since diet and exercise are the preferred methods for weight loss, the remainder of this chapter will be dedicated to showing how nutrition and exercise can assist with weight loss for obese females. In addition, we will briefly

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describe how surgery can be utilized to enhance the process of weight reduction [7].

32.2 Nutrition Guidelines for Weight Management

32.2.1 Background

As has been stated previously, diet and exercise are the two primary strategies for weight loss. For a diet to be effective, caloric expenditure, comprising resting metabolic rate and physical activity, must exceed caloric intake. Optimal weight loss occurs at a rate of 1–2 pounds (lb)/week or 0.45–0.91 kilograms (kg)/week. It is recommended that overweight and obese individuals should set an initial weight loss goal of up to 10% of body weight (3–5% if cardiovascular risk factors* present). It is also important to recognize that although most diets have good short-term effects (patients typically lose 5% of body weight (BW) over the first 6 months), many patients return to initial weight after just 1–2 years [8].

**Cardiovascular disease risk factors include "smoking, high LDL cholesterol, low HDL cholesterol, uncontrolled hypertension, physical inactivity, obesity, uncontrolled diabetes, and uncontrolled stress"* [9].

Several types of dietary changes are correlated with weight loss and reduced BMI. These dietary strategies generally consist of increasing intake of nutrient dense foods such as fruits, vegetables, and whole grains, and decreasing consumption of sugary foods. In addition, successful weight loss has been noted as patients replace sugar-sweetened drinks with increased water intake [8].

32.2.2 Understanding Macronutrients (CHO, Protein, and Fats)

A major component of dieting effectively is understanding how food is used and stored as energy. The purpose of this section is to describe the basics of how carbohydrates, fats, and proteins are used as energy sources.

Carbohydrates: There is a wide variety of sources of carbohydrates. Carbohydrates that are unprocessed/minimally processed (i.e., whole grains, fruits, and vegetables) tend to be healthier, whereas heavily processed foods (i.e., white bread, breaded goods, and sodas) are less healthy [10]. Carbohydrates provide 4 calories (kcal)/gram (g) of energy. The body breaks down carbohydrates into glucose, a form of sugar that through several biopathways yields adenosine triphosphate (ATP). ATP is the body's predominate form of energy. If the body has excess glucose or plenty of ATP, glucose can be stored in the liver and muscles in the form of glycogen.

Fats: It is important to understand that there are both "good" and "bad" fats. "Good," or unsaturated fats carry lower disease risk and come from foods like vegetable oils, nuts, seeds, and fish. "Bad" or artificial trans fats increase disease risk and have been banned in the United States. Saturated fats are not as harmful as trans fats, but negatively impact health in comparison to unsaturated fats. Foods high in saturated fats such as read meat, butter, and cheese should not be eaten in excess [11].

Fats have 9 kcal/g of energy. Fats are metabolized by the body into fatty acids and glycerols and are essential for the production of hormones. Fatty acids and glycerols can be run through various biopathways to yield ATP or can be stored as triglycerides and cholesterol for later usage [12].

Proteins: Proteins come primarily in the diet from meat, dairy products, nuts, and beans. Proteins, like carbohydrates, provide 4 kcal/g of energy. Proteins are made up of molecules called amino acids, which are necessary for tissue maintenance and growth. These amino acids may also be used by the body for energy if the intake of carbohydrates and/or fats is insufficient [12].

32.2.3 Pre-testing and Meeting with Health Specialists

Before we discuss the different types of diets that are available to choose from, we feel it necessary to advise those seeking to lose weight that all steps be taken in a medically safe way, preferably under the supervision of a physician. We also recommend that patients obtain a health screening that includes lab work to evaluate their blood sugar and lipid levels, and have their vital signs, such as blood pressure and heart rate measured before beginning a diet regiment. A patient's lab work and vital signs should also be checked periodically throughout the course of the dieting process. Taking this initiative serves several purposes. First, obtaining lab work and vitals gives the patient a "baseline," so that over the course of their diet, they can track and recognize progress. Second, a physician may find and diagnose certain conditions that can impact a patient's ability to diet and lose weight. For example, a patient with diabetes needs to take greater care to ensure that their blood sugar levels are well balanced in order to avoid adverse side effects as they diet [13]. Third, the results of a health screening may help patients to select the diet that will best help them to lose weight and improve other risk factors like cholesterol levels and hypertension. Patients should direct questions and concerns to their physicians and utilize weight loss methods that are proven to be safe and effective by valid research methods.

32.2.4 Diets

In this section, we will discuss several of the most common/popular dieting techniques, giving the description, benefits, limitations, and potential side effects of each diet.

Atkins Diet: a high protein diet that restricts carbohydrates to 20 g/day for at least 2 weeks. The Atkins diet claims that the overconsumption of refined carbs is responsible for much of the obesity, blood sugar imbalances, and cardiovascular problems observed in America today. It comprises four phases: Induction, Balancing, Pre-maintenance, and Lifetime maintenance.

- Induction: 20–25 g/day of carbohydrates or CHO [carbon (C), Hydrogen (H) and Oxygen (O)], diet consists mainly of vegetables, proteins, healthy fats, cheese, nuts, and seeds.
- Balancing: 50 g/day of CHO, same foods as the induction phase with the addition of berries, Greek yogurt and cottage cheese, and legumes.
- Pre-maintenance: 50–80 g/day of CHO, same foods as the induction and balancing phases, plus the addition of starchy vegetables and whole grains.
- Lifetime maintenance: as many CHO/day as a patient's body can tolerate, although the Atkins diet recommends approximately 80–100 g/day of CHO. All the above foods listed in the induction, balancing, and pre-maintenance phases are permitted [14, 15].

The Atkins diet induces weight loss primarily by reducing total caloric intake by restricting carbohydrate consumption [14]. This caloric restriction results in an increase of breakdown of fat and protein to meet the body's energy demands. It also induces the body to begin two bioprocesses called gluconeogenesis and ketosis. Gluconeogenesis is a metabolic pathway that generates glucose from pyruvate and lactate (the end products of glycolysis), glycerol and odd chain fatty acids from the breakdown of triglycerides, and glucogenic amino acids from the catabolism of protein. The process of gluconeogenesis takes place primarily in the liver but is performed in the kidneys and the small intestine as well [16, 17]. This process is illustrated by Fig. 32.1.

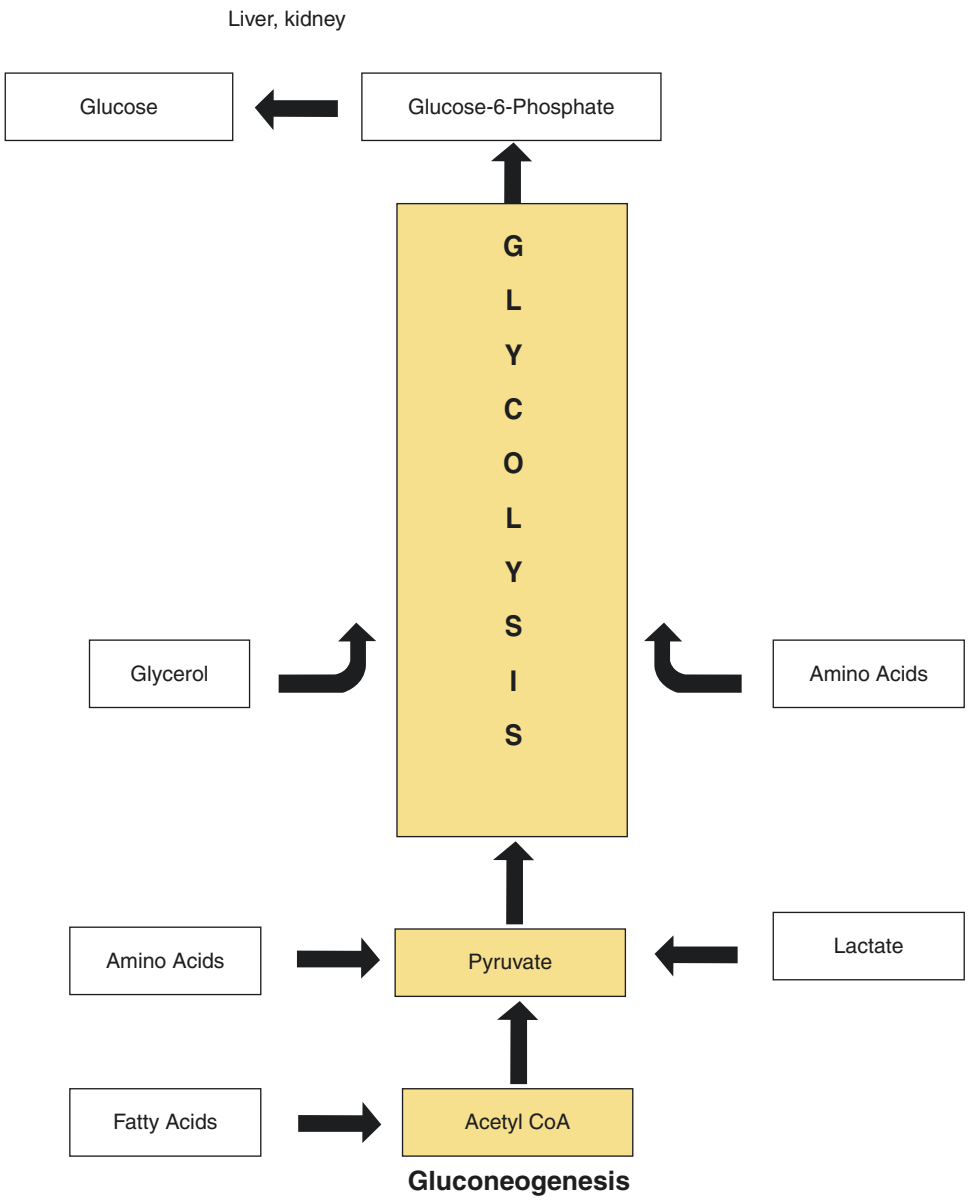

Fig. 32.1 Simple Schematic of Gluconeogenesis. Gluconeogenesis takes place primarily in the liver and is one way that the body produces glucose for energy during times of fasting. Fatty acids, amino acids, lactate, and glycerol are used as precursors for this process, which entails going in the "reverse" of glycolysis

Ketosis is a normal physiological process that occurs when the body is low on glucose, such as would occur during low carbohydrate diets like the Atkins diet. During ketosis, ketone bodies are synthesized from the break down products of fatty acid oxidation. These ketone bodies or "ketones" can be used for energy in the brain in place of glucose [18]. It is important to note that ketosis is not ketoacidosis. Ketosis is merely an elevation in blood ketone body levels, whereas ketoacidosis is a pathologic state where ketones become excessive and make the blood acidic and toxic [19]. Ketoacidosis most often results from a lack of insulin in patients with type I diabetes but may occur in late-stage type II diabetes as well. Ketone levels will be significantly elevated in ketoacidosis [i.e., blood concentration > 10 mM (millimoles) per Liter (L)] in comparison to physiologic ketosis (0.5–3.0 mM/L) [20].

One of the benefits of the Atkins diet is weight loss, which has been associated with improved outcomes for patients struggling with chronic health conditions such as hypertension and diabetes [14]. Also, the increased protein consumption may cause people to feel full longer [14, 21].

Although the Atkins diet helps with weight loss, it does have some limitations. It reduces fruit and grain intake, can be restrictive, hard to maintain, and requires counting carbs. It is recommended that patients consult with their physician before starting the diet if they are taking medications to treat hypertension or diabetes. Experts have also warned that the high protein and saturated fat content associated with Atkins diet may negatively impact patients' health [22]. A study conducted in Finland found higher total protein intake (especially protein coming from animal sources) to be associated with mortality among patients with underlying health conditions such as diabetes or cardiovascular disease. In fact, the study results showed that men who consumed the highest amount of protein had a 33% higher risk of heart failure in comparison to men who consumed the lowest amounts [23]. High-protein (HP) diets may also exacerbate complications related to kidney dysfunction, leading to diuresis, acceleration of chronic kidney disease (CKD), and blood pressure changes [24, 25].

During the early phases of the Atkins diet, restriction of carbohydrates can result in a normal physiological process called ketosis. Some of the potential side effects of ketosis are nausea, headache, mental fatigue, and bad breath. These symptoms are also sometimes referred to as the "keto flu" [14].

Ketogenic: The ketogenic diet is a high fat, low carbohydrate, adequate protein diet, with a typical ratio of 3:1 or 4:1 of fats to carbohydrates and protein [26]. This diet helps to shift the body's metabolism from glycolysis to fatty acid oxidation. The metabolites from fatty acid oxidation are used to generate ketone bodies. These ketone bodies or "ketones" can be used in place of glucose to provide energy for the brain.

The ketogenic diet has been shown to assist with weight loss, decreased diastolic blood pressure, and reduced hunger [21, 27]. Weight loss from the keto diet, similar to the Atkins diet, helps patients to manage conditions like diabetes, high blood pressure, and cardiovascular disease. In addition, several studies have shown an association between the keto diet and a reduction in seizures in patients with epilepsy [28, 29]. In contrast to these benefits, some patients may consider the keto diet restrictive as it requires reducing carbs, fruits, and the intake of some vegetables (potatoes and carrots) from the diet. There are only a few rare conditions in which the keto diet is absolutely contraindicated [30].

Some of the early onset adverse effects of the keto diet include hypoglycemia, gastrointestinal distress, lethargy, and difficulty focusing, also known as the "keto flu." However, many of these symptoms are considered transient and easy to manage [26]. Case studies have also observed rapid ketosis/acidosis, a condition where the body's blood becomes abnormally acidic due to excessive numbers of ketone bodies [31]. The keto diet has also been associated with a trace element deficiency of vitamins. Accordingly, a sugar-free multivitamin is recommended with commencement of the keto diet [30]. A comparison of the Atkins and Keto diets can be found in Fig. 32.2.

Wheat Belly: The Wheat Belly diet started with cardiologist William Davis, MD [32]. Believing that increased wheat consumption leads to increased adipose tissue, inflammation, and blood insulin levels. Davis began an experiment where he asked his overweight, diabetes-prone patients to give up all wheat products, such as bread, pasta, baked goods, cereals, etc., and gluten from their diet. Gluten, which in Latin means, *glue*, is a mixture of two proteins that gives the dough in wheat, barley, and rye, an elastic texture [33]. Davis claimed that his patients lost significant amounts of weight and that those with "abnormal glucose tolerance and type 2 diabetes were cured" [34].

Some of the major benefits of the wheat belly diet is weight loss and better control of diabetes, but these benefits are attributed to a reduction in calories, not necessarily due to eliminating wheat products [34]. Dr. Davis' patients also claim that his Wheat Belly diet can cure or effectively treat other conditions like asthma, acid reflux, irritable bowel syndrome, rashes, ulcerative colitis, joint pain, and poor sleep [32]. Although weight loss may play a role in treating these conditions, each of these claims are anecdotal and lack sufficient evidence to support them [34].

As a word of caution to patients who are considering the Wheat Belly diet, those with high cholesterol or heart disease should avoid the high-fat dairy and red meat that are major components of this diet [9]. In addition, patients should be aware that the Wheat Belly diet claims removing wheat from the diet may cause withdrawal symptoms. However, human research on withdrawal effects from

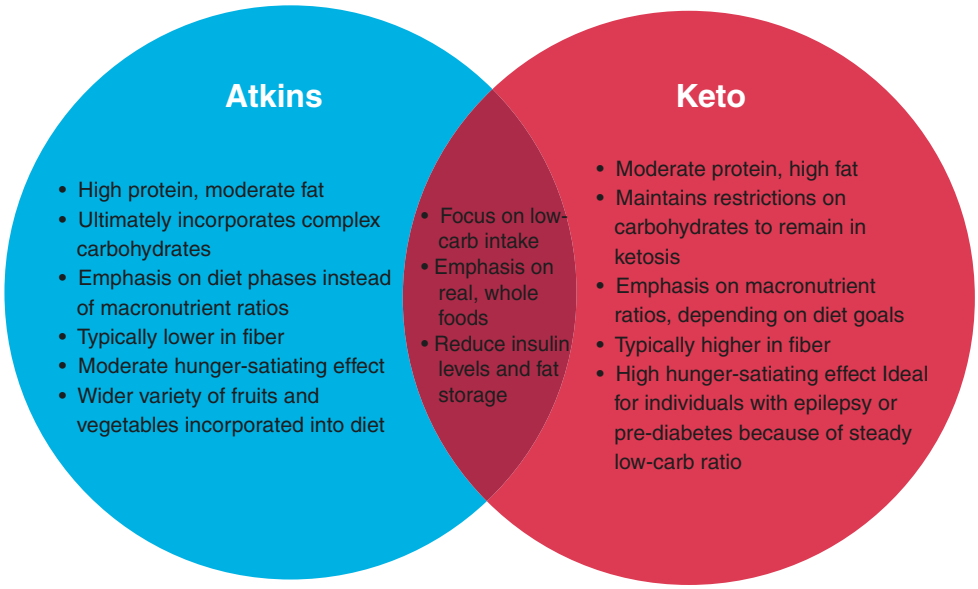

Fig. 32.2 Atkins vs. Keto diet [14, 27]. The Atkins and Keto diets have some components that are the same, and several aspects that make them each unique. Components unique to the Atkins diet can be found in the blue shaded circle on the left. Features that are specific to the Keto diet can found in the red shaded circle on the right. Shared characteristics of both diets are located in the darkly shaded circle at the center of the image

Table 32.3 Intake of energy sources: Western Diet vs estimated Paleolithic Diet [36]

Energy source	Current Western diet (% of daily energy)	Paleolithic diet (% of daily energy)	Comments
Carbohydrates	45–65%	35–40%	High intake of total fiber, fruits, and vegetables, and low intake of added sugar
Fat	20–35%	30–40%	High intake of omega-3 fats
Saturated fat	<7%	7.5–12%	None
Protein	10–35%	25–35%	Moderate intake

food are limited and lack the evidence to substantiate this claim [34].

Paleo Diet: also known as the "caveman" diet focuses on foods that would have been consumed during the Paleolithic era tens of thousands of years ago. The diet's reasoning is based upon the discordance hypothesis, or the idea that the human body is "genetically mismatched" to the modern dietary staples of dairy, grains, and legumes that emerged with farming practices. According to the hypothesis, this change in diet has outpaced the body's ability to adapt, leading to obesity, diabetes, and heart disease [35]. The Paleo diet only allows unprocessed meat/game, fish, eggs, nuts, fruits, and vegetables, whereas dairy, grains, legumes, and extra sugar are excluded [8]. It also emphasizes daily physical activity (150–490 kcal/d). Table 32.3 compares the dietary recommendations between the current Western Diet and the Paleo Diet [36].

Several case studies have compared the Paleo diet to control diets and observed benefits such as reduced Low-density lipoprotein (LDL) cholesterol, triglycerides, fasting insulin, and blood pressure, as well as weight loss [37]. Before beginning the Paleo diet, there are two items that should be taken into consideration [35]. The first is that the exclusion of whole grains and legumes reduces fiber and other vitamins from the diet. In addition, removing dairy products from the diet eliminates good sources of protein and calcium.

As the Paleo diet is high in protein, it may have adverse effects on kidney function, but the benefits from weight loss are believed to outweigh these effects [38]. There are also cautions and limitations in these specific populations [38].

- Advise patients taking diuretics to switch slowly to Paleolithic diet to avoid significant decrease in blood pressure.
- Patients with type 2 diabetes taking sulphonylurea drugs (such as glipizide, glibenclamide, and glimepiride) are at increased risk for low blood sugar.
- Patients taking warfarin should consult physician or nurse while transitioning to Paleolithic diet.
- Counsel patients who are at increased risk of osteoporosis (i.e., elderly, postmenopausal women) about the need for sufficient calcium intake/supplementation while on the Paleo diet [39].

Mediterranean: The Mediterranean diet refers to a dietary pattern modeled after foods consumed in several countries in the Mediterranean basin includes abundant whole grains, vegetables, fruits, nuts, olive oil, fish/seafood; moderate poultry and dairy products; and minimal meats and sweets. From a macronutrient perspective, the Mediterranean diet is approximately 43% carbohydrates, 37% fat, and 15% protein [40]. Moderate wine consumption (1–2 glasses/day for men, 1 glass/day for women) is also considered an optional part of the Mediterranean

diet. As for lifestyle, the Mediterranean diet encourages daily physical activity and eating meals in the company of family friends to provide a sense of community [41].

Studies have indicated that patients who follow the Mediterranean Diet experience increased weight loss and reduced risk of coronary heart disease, cardiovascular events, mortality after heart attack, as well as improvements in LDL, High-density lipoprotein (HDL), and triglyceride levels. Cardiovascular events include heart attack, pulmonary embolism, stroke, etc. [42].

Despite these numerous benefits, the Mediterranean diet and lower meat consumption may lead to lower iron stores [43]. In addition, patients on the Mediterranean diet may not be meeting their calcium needs. The amount of calcium provided by the Mediterranean diet is estimated to be between 700 and 820 mg/day, which is below the National Institutes of Health (NIH) recommendation of 1000 milligram (mg)/day for adults in the United States. However, a study conducted in Australia found that patients could increase their servings of dairy to provide more calcium while on the Mediterranean diet and still merit the benefits of reduced cardiovascular disease risk [44].

Intermittent Fasting: Humans generally eat at least three times daily, with overconsumption at these meals leading to conditions such as obesity, type II diabetes, and heart disease. However, food was not as always readily available as it is today. It is believed that much of human evolution took place during times of food scarcity. During this evolutionary period, the human body adapted in order to "function at a high level, both physically and cognitively, when in a food-deprived/fasted state" [45]. Intermittent fasting (IF) takes advantage of these adaptations to induce weight loss and improve overall health. The idea here is not as much a restriction of what people eat, but rather a modification of how often people eat. There are several different strategies that are considered a form of intermittent fasting, as described in Table 32.4.

Although relatively short in duration and limited in participants, the few studies that have been conducted on IF in human subjects have shown numerous benefits such as weight loss, reduced LDL cholesterol and blood triglycerides, reduced insulin resistance in diabetic patients, and decreased markers of oxidative stress and inflammation [8, 46]. Accompanying these benefits are the potential side effects of hunger, mental fogginess, weakness, and nausea.

One potential concern with IF is adherence to the diet, even more so than traditional diets. One study showed a 38% drop out rate for participants on an IF diet as opposed to 29% for a calorie restricted group and 26% for a control group [47]. These results may indicate that patients in the real world may struggle with this diet as well. In addition, little is known about how well patients can tolerate IF when combined with exercise, and there is greater need for research in this topic [48]. Two other limitations of IF have been described by Dr. Hu, chair of the department of nutrition at the Harvard T.H. Chan School of Public Health. Dr. Hu stated that, "There is a danger of indulging in unhealthy dietary habits on non-fasting days," meaning that patients may overeat on non-fasting days and fail to lose weight. Dr. Hu also warns that we, "live in a toxic obesogenic food environment" and that patients will "need a strong social support network to endure very low-calorie days" [49].

Patients, especially females, should consult with a doctor and be aware of contraindications for IF. Studies in rats have indicated that IF in female rats led to hormone irregularities resulting in emaciation, masculinization, and infertility [50, 51]. Although these results came from studying rats, female patients should ease into IF and immediately discontinue the diet if they experience amenorrhea. IF is also contraindicated in patients who are underweight, have a history of eating disorders, struggle with infertility, or who are currently pregnant or breastfeeding. Patients with other conditions such as diabetes, heart disease, or low blood pressure should not begin IF without consulting a doctor first.

Table 32.4 Common strategies used in intermittent fasting [8]

Terminology	• Definition of terms
Alternate day fasting	• Comprises a 2-d cycle • D 1—Patient consumes 25% of baseline energy needs at lunch • D 2—Patient consumes 125% of baseline energy needs, split between three meals
Whole day fasting	• Patient fasts for 24 hours (h) at a time • 1–2 d a week
The 5:2 Diet	• Patient consumes 500–600 kcal on 2 non-consecutive d of the week • Patient eats normally the other 5 d
Time restricted feeding	• Patient restricts their daily eating period to 8 h (e.g., 1–9 PM) • Patient fasts for the 16 h in between

32.2.5 Summary of Diets

We have discussed several different diets and described the benefits, limitations, and potential side effects of each diet. The Atkins and Keto diets are both low-carbohydrate diets, but the Atkins diet encourages higher protein consumption, whereas the keto diet encourages higher fat consumption. The Atkins diet allows for the reintroduction of carbohydrates to the extent that one's body can tolerate; this is different from the Keto diet which remains strictly low carb. The American Heart Association advises against the Atkins diet due to concerns that the high protein intake may negatively impact heart health and could harm patients with kidney dysfunction. The Wheat Belly diet restricts all wheat and gluten products from the diet, and although it has the potential to help with weight loss, many of its claimed ben-

efits are strictly anecdotal and lack scientific backing. The Paleo diet emphasizes eating the foods available to our prehistoric ancestors, like unprocessed meat/game, fish, eggs, vegetables, fruits, and nuts. It excludes dairy products, grains, legumes, and extra sugar. The Paleo diet has been shown to help with weight loss and other cardiometabolic measures of health, but as a high protein diet, patients with kidney dysfunction should consult a physician before starting it. The Mediterranean diet includes abundant whole foods and emphasizes daily physical activity and eating with friends and family. Studies have shown that the Mediterranean diet can help with weight loss and improve heart health, but patients should also ensure that they are getting adequate iron and calcium in their diet. IF uses various forms of short-term fasts to aid in weight loss. Rather than emphasizing what patients should or should not eat, it focuses on portion control and meal schedule. IF has been shown to be an effective weight loss tool for those who can adhere to the diet, but not more so than a traditional caloric restriction diet. IF is safe in patients who are well nourished and healthy, but there are many concerns with it, especially with patients who have diabetes or for female patients with a history of menstrual cycle dysfunction or infertility. In conclusion, dieting is a vital aspect of helping obese females to lose weight and live a healthier lifestyle. Patients should consult with their doctor before beginning a diet and periodically over the course of a diet.

32.2.6 Weight Loss Programs

Considering that Commercial Weight Loss Diets may be more effective than standard care, and that WW: Weight Watchers reimagined (formerly called Weight Watchers), Jenny Craig, and Nutrisystem might be among the more efficacious commercial weight loss programs, we evaluate these three programs here [8]. Much of the description of these programs comes from each company's respective website [52–54].

WW: Weight Watchers reimagined: (formerly known as Weight Watchers) helps subscribers to lose weight based on portion control to elicit a moderate caloric deficit. WW uses the *myWW program*, which is based on a system of a "SmartPoints" budget and "ZeroPoint" foods. The SmartPoints budget is essentially your allotted calories for the day and is based on a patient's age, height, weight, and sex. Different foods and drinks are assigned a SmartPoints value, which subscribers can plan into their meals for the day. ZeroPoint foods are just what they sound like, they count as zero points towards one's SmartPoints budget. People in the *myWW program* can eat as many of these foods, which are usually fruits and vegetables, as they would like. WW users can then select from different plans that balance the SmartPoints budget and options for ZeroPoints to help them lose weight.

WW also emphasizes exercise where members can earn "FitPoints" for physical activity. Members earn FitPoints for any physical activity but the most points come from resistance training and more demanding exercise. Members can also receive support through in person workshops, members-only social networks, and WW coaches, as well as a host of online resources on dieting, exercise, cooking, and lifestyle on the company's website.

WW has been researched extensively and has been shown to an effective weight loss program, in fact, the *U.S. News & World Report* ranked WW first for both "Best Weight Loss Diet" and "Best Commercial Diet Plan" in 2019. Several studies have confirmed that WW helps patients to lose weight better than those who tried their own dietary plans [55–57]. WW has also been shown to improve glycemic control in diabetic patients [58]. Another positive aspect of WW is its emphasis on lifestyle changes, rather than simply dieting. Research has shown that comprehensive treatment programs that include diet, physical activity, and behavior therapy are more successful than programs with a single intervention [8]. WW aligns well with these findings by integrating nutrition, physical activity, social support, cooking, and coaching into its program. Based on its positive reviews within the scientific community, the authors of this chapter also recommend WW as an effective weight loss tool.

Jenny Craig: The Jenny Craig diet helps members to lose weight by providing prepackaged low-calorie meals, a health coach to offer support, and help with tracking meals and exercise. Along with prepackaged meals, members of Jenny Craig are encouraged to eat fruits, vegetables, and low-fat dairy products. Towards the beginning of the program, users are restricted to Jenny Craig meals, but once they reach the halfway point to their weight loss goal, they may begin eating homemade meals occasionally. When a subscriber reaches their weight loss goal, they will spend about a month transitioning into home cooked meals. Members are also invited to attend in-person meetings and encouraged to get 30+ minutes (min) of moderate intensity exercise 5 or more days per week.

The Jenny Craig diet has been shown to help overweight and obese adults to lose weight, and like WW may be more effective than standard care [8]. One of the advantages of Jenny Craig over WW is the prepackaged meals are easy to prepare and may require less effort than using the WW app. However, the prepackaged meals are also a drawback in the sense that members may struggle to transition from ready-made meals to planning out, shopping for, and preparing their own meals. In addition, although Jenny Craig's meals are low in fat and salt, they often include meat and dairy products, which would not work well for those who are vegetarian or vegan.

Nutrisystem: Nutrisystem, like Jenny Craig, helps dieters to limit calories by sending them food directly from the company. Nutrisystem generally covers breakfast, lunch, dinner, and dessert for a 28-day period. On Nutrisystem, one can expect about 25% of their daily caloric intake to come from fat. In addition, the 50% of the diet that comes from carbohydrates focuses on whole grains and limits foods with a high glycemic index (i.e., white bread, white rice, certain fruits). Like Jenny Craig, on Nutrisystem subscribers can personally buy and add in additional fruits and vegetables to their diet. Nutrisystem also recommends getting daily physical activity for at least 30 min.

Like WW and Jenny Craig, Nutrisystem has been shown to help overweight and obese adults lose weight [59]. Similar to Jenny Craig, Nutrisystem's packaged foods and meals will simplify dieting and meal planning for subscribers. However, the prepackaged meals restrict people's food options. In addition, various dietary restrictions (vegetarian, vegan, allergies) may not make Nutrisystem a practical option. It should also be noted that Nutrisystem is primarily a single intervention program, as it emphasizes dieting while offering limited instruction on physical activity or behavioral therapy.

32.3 Weight Loss Procedures

Bariatric surgical procedures can induce "weight loss by restricting the amount of food the stomach can hold, causing malabsorption of nutrients, or by a combination of both gastric restriction and malabsorption" [60]. Bariatric surgeries are part of a continuum of treatments for patients with severe obesity but are not a replacement for diet, physical activity, or behavioral changes [61]. Bariatric surgery in severely obese patients has been associated with reduced mortality, better long-term weight loss, and higher reductions in comorbidities such as diabetes, hyperlipidemia, and hypertension, as well as improved fertility in women [7].

32.4 Exercise Guidelines for Weight Management

32.4.1 Background

Dieting by itself is not sufficient enough to induce and maintain weight loss. Fat-free mass (FFM) loss during dieting reduces the body's ability to burn fat leading to issues with weight loss maintenance [62]. Successful periods of weight loss can be followed by the gradual or quick onset of weight regain with an approximate average of 33–50% weight regain within 1 year [62]. Obese and overweight individuals must combine their diets with physical activity to efficiently target weight loss and avoid weight regain. The Center for Disease Control and Prevention (CDC) and American College of Sports Medicine (ACSM) recommend an average of 30 min per day or 150 min per week of physical activity to prevent this weight regain [62]. These recommendations only exist as approximations as studies have not been able to identify a clear-cut answer; it's believed the quality and quantity of physical activity varies depending on each individual's body type. Still, the combination of both a caloric reduction with physical activity will maximize weight loss.

In this next section, we will be discussing the appropriate steps an obese and overweight individual should take in tackling obesity from a fitness perspective. This includes understanding the importance of meeting with health specialist, breaking down the components of energy balance and body composition, and exploring the fundamentals and implications of the most common and important forms of exercise: cardiovascular, resistance, and flexibility training.

32.4.2 Pre-testing and Meeting with Health Specialists

Prior to beginning any form of physical activity, all overweight and obese people should meet with a health/bariatric specialist. According to the University of Rochester Medical Center [63], healthcare providers can:

- "Take a medical history. This includes your history of nutrition, exercise, and weight loss.
- Do a physical exam, including BMI, waist circumference, and blood pressure.
- Look at your health problems related to obesity.
- Look for other medical problems that might cause weight gain.
- Look at how ready you are to start an exercise program.
- Find out if you need tests.
- Help you make realistic weight loss goals.
- Give you a nutrition plan.
- Tell you to keep a food diary.
- Find out if you need a weight-loss medicine.

In addition, your bariatric healthcare provider should also give you information about:

- Healthy eating habits
- Healthy exercise habits
- How to change health behaviors
- How mental health affects obesity
- Complications of obesity
- Benefits and risks of medicines"

Tackling obesity by itself can be a difficult road to travel alone as there will be many unexpected and difficult obstacles to cross. For example, physical activity increases energy expenditure, which the body responds to with various hormones such as ghrelin to satisfy its BMR and set weight point [64]. The hypothalamus of the brain will increase hormonal hunger signals and decrease satiety, the state of feeling fulfilled, in an attempt to avoid fat loss [64]. Many will overeat or binge eat and find themselves adding more weight to the scale. Health/bariatrics specialist can help you differentiate this psychological hunger as a result of bad habits and prescribe the proper nutritional diet to increase satiety.

In addition, many studies have associated excessive weight with an increase in physical injuries. The Obesity Medicine Association suggests the amount of excessive weight and form of physical activity can cause injury due to "increase torque on weight-bearing joints, especially the knees and ankles" [64]. These types of injuries can be devastating to an individual's confidence and discourage them from performing any form of physical exercise. Many health specialists advise the slow progression into physical activity starting with low intensity exercises such as chair exercises, water aerobics, and bike riding [64]. These activities place less stress on the joints while effectively reducing weight until more intense exercises can be performed.

These examples only highlight a few of the many more factors that can and will play a role in your ability to successfully tackle weight loss. Health/bariatric specialists have the knowledge to provide you with an appropriate health assessment that tailors weight loss treatments to your specific needs.

32.4.3 Health-Related Components of Physical Fitness

Energy Balance: The rudimentary goal of fitness is to increase physical activity related caloric output. We place our body in a strenuous state to increases our total energy expenditure (TEE) in hope of putting our body in a caloric deficit. The three components for determining TEE are basal metabolic rate (BMR), thermic effect of food, and physical activity expenditure [65]. BMR, Table 32.5, is defined as the body's resting caloric rate necessary to maintain homeostatic activities such as breathing, detoxification, and circadian rhythm [67]. Many uncontrollable factors determine the fate of our BMR such as genetics, age, and gender, however, we still have the ability to control our BMR through our lean muscle mass, such as skeletal muscle [65].

Thermic effect of food (TEE), another component of TEE, consists of the energy expenditure used in the act of eating and digesting foods. Finally, physical activity expenditure, the most lifestyle influential factor of our metabolism, is determined by daily activity levels. Overall, total energy expenditure can be broken down into 60–70% BMR, 10% thermic effect of food, and 20–30% physical activity expenditure. A high TEE increases the likelihood our daily caloric intake falls short of meeting out metabolic caloric needs, inducing a fuel burning state of carbohydrates and fats called oxidation. To calculate an individual's TEE, you must first predict their BMR using the predictive equations from Table 32.5 and multiply it by their physical activity factor. Physical activity levels can be stratified into five categories each with their own common activity factor: sedentary (1.2), light activity (1.375), moderate activity (1.55), very active (1.725), and exceedingly active (1.9) [66].

Table 32.5 Common resting energy expenditure [(kcal day^{-1}) predictive equations for adults [65]. Reprinted with permission from Wolters Kluwer Health Inc., Magyari P, Lite R, Kilpatrick M, Schoffstall J, ACSMs Resources for the Exercise Physiologist, Wolters Kluwer Health, Inc., American College of Sports Medicine, Philadelphia, PA, 2018

	Men	Women
Harris-Benedict (for adults)	66.47 + 13.75 (weight in kg) + 5 (height in cm) − 6.8 (age in year)	665 + 9.6 (weight in kg) + 1.8 (height in cm) − 4.7 (age in year)
Mifflin-St. Jeor (for obese adults)	10 (weight in kg) + 6.3 (height in cm) − 5 × age + 5	10 (weight in kg) + 6.3 (height in cm) − 5 × age − 161

For an example case, a 55-year-old obese woman, who is 5 ft 7 in [170.18 centimeters (cm)], weighs 220 lb (99.8 kg), and works a desk job asks you to calculate her total energy expenditure in desire of starting a weight loss program. To calculate her TEE, you would first calculate her BMR using the Mifflin-St. Jeor equation and then multiply it by the common factor of 1.2 since she reported a sedentary lifestyle.

$$\text{TTE} = \text{BMR} \cdot \text{Common Activity Factor}$$

Example Calculation:

$$BMR = 10(99.8\text{kg}) + 6.3(170.18\text{cm}) - 5 \times (55\,yo) - 161$$
$$= 1634\,\text{kcal} \cdot \text{day}^{-1}$$

$$\text{TTE} = 1634\,\text{kcal} \cdot 1.2 = 1961\,\text{kcal}$$

The predictive formula indicates the patient must consume 1961 kcal a day if she wants to maintain her weight. If she wants to lose weight, then she must put herself in a caloric deficit by consuming less than her predicted TEE. The ACSM Guideline recommends not eating less than 1200 calories a day unless medically indicated since an extremely low-caloric diet can be detrimental to basic nutritional needs [65]. If the patient decides to lose 1 lb of weight per week, then she must put herself in a total negative caloric deficit of 3500 kcal over the whole week; each 3500 kcal above or below TEE transforms into 1 pound of weight gain or loss. To do so, the patient must consume

3500 kcal ÷ 7 days = 500 kcal less than her TEE which is equivalent to 1961 kcal −500 kcal = 1461 kcal a day. This will force the body to compensate for its overall negative caloric intake of 500 kcal a day by breaking down fuel storages such as fats and carbohydrates.

Body Composition: Our body composition provides us with the basis of our health implications. We can break down body composition into two categories: fat mass and fat-free mass. Fat mass is found under our skin (subcutaneous fat), around our muscles, and all over a majority of our organs (visceral fat) [68]. Although associated with a negative connotation, fat mass plays a vital role in our overall health by protecting our internal organs, storing fuel, and regulating important hormones [68]. Still, excess fat beyond those necessary are non-essential and can become detrimental to our health. Fat-free mass is every other component of our body such as our bones, muscles, and organs [68]. It is often associated as our "lean mass" since these types of tissues are metabolically active and play a role in our body's BMR [68].

Many methods exist for approximating body size, specifically anthropometric methods which are noninvasive, quantitative techniques that use general body dimensions such as height, weight, and circumference [65]. They are commonly utilized tools since they provide important information regarding the relationship between obesity and health. BMI, as mentioned earlier in the chapter, is one of the most popular anthropometric techniques used for determining obesity as it examines weight relative to height. It should be noted that BMI fails to distinguish fat from muscle mass or bone and should be avoided using on individuals with obvious, large amounts of muscle mass; still, it is accepted that individuals with a BMI >30 kg · m^{-2} have excess body fat [65].

$$\begin{aligned}\text{BMI} &= \text{weight}\left(\text{kg}\right) \div \text{height}\left(\text{m}^2\right) \\ &= \left(\text{weight}\left[\text{lb}\right] \div \text{height}\left[\text{in}^2\right]\right) \times 704.5\end{aligned}$$

Another common anthropometric method is circumference measures which help determine body fat distribution using a "flexible yet inelastic tape measure with a spring-loaded handle" [65]. This traditionally simple method determines waist-to-hip ratio (WHR) by dividing waist circumference by hip circumference and identifies individuals with a higher amount of abdominal fat; health risks predictors increase in correlation with an increase in WHR. Table 32.6 illustrates WHR ranges for different age groups and their corresponding risk category. Table 32.7 demonstrates risk categories solely based off waist circumference. Waist circumference alone can be used to predict central obesity health risks as well since abdominal obesity is primarily linked to health risks. According to ACSM's Resource for the Exercise Physiologist [65]. central obesity (known as abdominal or android obesity) is "associated with higher risk of hypertension, metabolic syndrome, Type 2 diabetes mellitus, dyslipidemia, cardiovascular disease, and premature death compared with gynoid obesity, which is characterized by a greater proportion of fat distributed on hips and thighs" [65].

Table 32.6 Waist-to-hip ratio norms for men and women [69]

Age	Low risk	Moderate risk	High risk
Men (year)			
20–29	<0.71	0.71–0.77	>0.77
30–39	<0.72	0.72–0.78	>0.78
40–49	<0.73	0.73–0.79	>0.79
50–59	<0.74	0.74–0.81	>0.81
60–69	<0.76	0.76–0.83	>0.83
Women (year)			
20–29	<0.71	0.71–0.77	>0.77
30–39	<0.72	0.72–0.78	>0.78
40–49	<0.73	0.73–0.79	>0.79
50–59	<0.74	0.74–0.81	>0.81
60–69	<0.76	0.76–0.83	>0.83

Table 32.7 Risk criteria for waist circumference in adults [70]. Republished with permission from American Society for Nutrition, American Journal of Clinical Nutrition, Don't Throw the Baby Out With the Bath Water, Bray GA, Vol. 79/Issue 3, pgs 347–349, © 2004

Waist circumference		
Risk category	Females	Males
Very low	<70 cm (<2.75 in)	<80 cm (31.5 in)
Low	70–89 cm (27.5–35.0 in)	80–99 cm (31.5–29.0 in)
High	90–110 cm (35.5–43.0 in)	100–120 cm (39.5–47.0)
Very high	>110 cm (> 43.5)	>120 cm (> 47.0)

Anthropometric measurements can only serve as a useful tool up to a certain extent since they fail to indicate exact estimates of body fat percent. Precise body composition measurement techniques help identify specific health risks related to different levels of body fat percent, create reasonable weight management programs, and assess patient progress throughout intervention programs [65]. There are many different techniques for determining body composition with varying accuracy, accessibility, cost, and complexity. The ACSM's Resource for the Exercise Physiologist [65] specifically mentions those "used in health/fitness settings include skinfolds and bioelectrical impedance. Laboratory measures include underwater weighing, plethysmography, and dual-energy X-ray absorptiometry (DEXA)." Of those mentioned, bioelectrical impedance is the most accessible method since it is a rapid, noninvasive assessment tool that can be found in many health clinics and gyms. Specifically, the tool passes a harmless electrical current throughout the body and measures current impedance; a good conductor would be fat-free mass (lean tissue) which is composed of water and electrolyte and a poor conductor would be fat which contains little water [65]. The bioelectrical impedance estimates total body water composition and estimates body fat, producing an accuracy of ±2.7% and 6.3% [65].

Table 32.8 Modes of aerobic (cardiorespiratory endurance) exercises to improve physical fitness [71]. Reprinted with permission from Wolters Kluwer Health Inc., *American College of Sports Medicine, Liguori G. ACSM's Guidelines for Exercise Testing and Prescription. Philadelphia, PA:* Wolters Kluwer Health Inc., *Lippincott Williams & Wilkins, 2020*

Exercise group	Exercise description	Recommended for	Examples
A	Endurance activities requiring minimal skill or physical fitness to perform	All adults	Walking, leisurely cycling, aqua-aerobics, slow dancing
B	Vigorous intensity endurance activities requiring minimal skill	Adults (as per the preparticipation screening guidelines in Chap. 2) who are habitually physically active and/or at least average physical fitness	Jogging, running, rowing, aerobics, spinning, elliptical exercise, stepping exercise, fast dancing
C	Endurance activities requiring skill to perform	Adults with acquired skill and/or at least average physical fitness levels	Swimming, cross-country skiing, skating
D	Recreational sports	Adults with a regular exercise program and at least average physical fitness	Racquet sports, basketball, soccer, downhill skiing, hiking

Note: Can be measured in inches (in) or centimeters (cm) just be consistent

Aerobic Training: Physical activity can be clumped it into two general categories: aerobic and anaerobic exercise. Aerobic exercises commonly known as endurance exercises consist of long periods of cardiovascular conditioning such as walking, jogging, and swimming. The goal of the exercise is to "perform large muscle, dynamic, moderate-to-vigorous intensity for prolonged periods of time [71]; a combination of the respiratory, cardiovascular, and musculoskeletal systems determines the performance ability for different modes of aerobic exercises, illustrated in Table 32.8. The goal of these exercises is to increase maximal volume of oxygen consumed per unit time (VO_{2max}) to induce oxidation in the body. The presence of oxygen (aerobic) allows our bodies to fully break down carbohydrates and fats for energy in the mitochondria of a cell.

The ACSM's Resources for the Exercise Physiologist [65] recommends implementing the Frequency, Intensity, Time, Type, total Volume, and Progression (FITT-VP) principle for patients starting a physical activity routine; the FITT principle can be adjusted according to their BMI and level of experience with exercising. Table 32.9 elaborates on the different components of the FITT principle based off evidence rooted research. In addition, they recommend minimizing sedentary behaviors such as watching tv, sitting at a desk, and lying down to increase total energy expenditure (TEE).

Table 32.9 Aerobic (cardiovascular endurance) exercise evidence-based recommendations [72]. Reprinted with permission from Wolters Kluwer Health Inc., Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, et al., Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and Neuromotor fitness in apparently healthy adults. Medicine & Science in Sports & Exercise, Vol. 43/Issue 7, pgs. 1334–1359, © 2011; https://journals.lww.com/acsm-msse/Fulltext/2011/07000/Quantity_and_Quality_of_Exercise_for_Developing.26.aspx. https://doi.org/10.1249/mss.0b013e318213fefb

FITT-VP	Evidence-based recommendations
Frequency	• ≥5 d · week^{-1} of moderate exercise, or ≥3 d · week^{-1} of vigorous exercise, or a combination of moderate and vigorous exercise on ≥3–5 d · week^{-1} is recommended
Intensity	• Moderate and/or vigorous intensity is recommended for most adults • Light-to-moderate intensity exercise may be beneficial in deconditioned individuals
Time	• 30–60 min · d^{-1} of purposeful moderate exercise, or 20–60 min · d^{-1} of vigorous exercise, or a combination of moderate and vigorous exercise per d is recommended for most adults • <20 min of exercise per day can be beneficial, especially in previously sedentary individuals
Type	• Regular, purposeful exercise that involves major muscle groups and is continuous and rhythmic in nature is recommended
Volume	• A target volume of ≥500–1000 MET-min · week^{-1} is recommended • Increasing pedometer step counts by ≥2000 steps · d^{-1} to reach a daily step count of ≥7000 steps · d^{-1} steps is beneficial • Exercising below these volumes may still be beneficial for individuals unable or unwilling to reach this amount of exercise
Pattern	• Exercise may be performed in one continuous session, in one interval session, or in multiple sessions of ≥10 min to accumulate the desired duration and volume of exercise per day • Exercise bouts of <10 min may yield favorable adaptations in very deconditioned individuals
Progression	• A gradual progression of exercise volume by adjusting exercise duration, frequency, and/or intensity is reasonable until the desired exercise goal (maintenance) is attained • This approach of "star low and go slow" may enhance adherence and reduce risks of musculoskeletal injury and adverse cardiac events

For many, assessing their intensity through VO_2 rate, the product of maximal cardiac output and arterial-venous oxygen difference, can be difficult [71]. Dr. Nelson and Dr. Wernick [73], the authors of "*Strong Women Stay Young*," emphasize using a 5-point exercise intensity scale instead as shown in Table 32.10. The scale is subjective compared to other intensity measurements; however, it allows participants to evaluate their own Rate of Perceived Exertion (RPE). They recommend participants to aim for an exercise intensity Level 4 during their physical activity. Level 3 or even Level 2 intensity is normal during the first couple of exercise

sessions since your body has to adapt and learn correct form. Level 5 can be risky because a high exertion rate can lead to improper form which might result in an injury.

Resistance Training: Anaerobic exercises, the latter commonly known as resistance training or muscular fitness, involves short bursts of strenuous activity such as weightlifting and sprinting. The difference in the wording might be subtle, but the switch from oxygen usage to none tremendously shifts our body's metabolic pathways and energy expenditure. The absence of oxygen (anaerobic) prevents fat metabolism and prematurely stops carbohydrate metabolism in the cytoplasm of a cell to produce lactate and less energy per molecule. It should be noted that our aerobic and anaerobic pathway are not our only energy source but constitute our major pathways for energy formation. Our body has an initial pool of ATP and creatine phosphate (phosphagen) it utilizes within seconds (s) to initiate exercise. Following, our body will switch to anaerobic glycolysis as long as supply matches energy expenditure. This can be associated with the "burning" sensation you feel from lactic acid build up when you perform intense exercise. If energy expenditure exceeds production, then our body must switch to aerobic glycolysis and rely on oxygen consumption for energy maintenance [74]. Figure 32.3 titled "3 Primary Energy Systems in The Body" provides a general overview of our body's energy expenditure as a variable of time [75].

Muscular fitness provides a variety of benefits including improving or maintaining the following health-related fitness characteristics according to the ACSM's Guidelines for

Table 32.10 Exercise intensity scale [73]. "Illustrations," 1997 by Wendy Wray; from STRONG WOMEN STAY YOUNG by Miriam Nelson. Used by permission of Bantam Books, an imprint of Random House, a division of Penguin Random House LLC. All rights reserved

Exercise intensity level	Description of effort
1	Very easy: Too easy to be noticed, like lifting a pencil
2	Easy: Can be felt, but isn't fatiguing, like carrying a book
3	Moderate: Fatiguing only if prolonged, like carrying a full handbag that seems heavier as the day goes on
4	Hard: More than moderate at first and becomes difficult by the time you complete six or seven repetitions. You can make the effort eight times in good form but need to rest afterward
5	Extremely hard: Requires all your strength, like lifting a piece of heavy furniture that you can raise only once, if at all

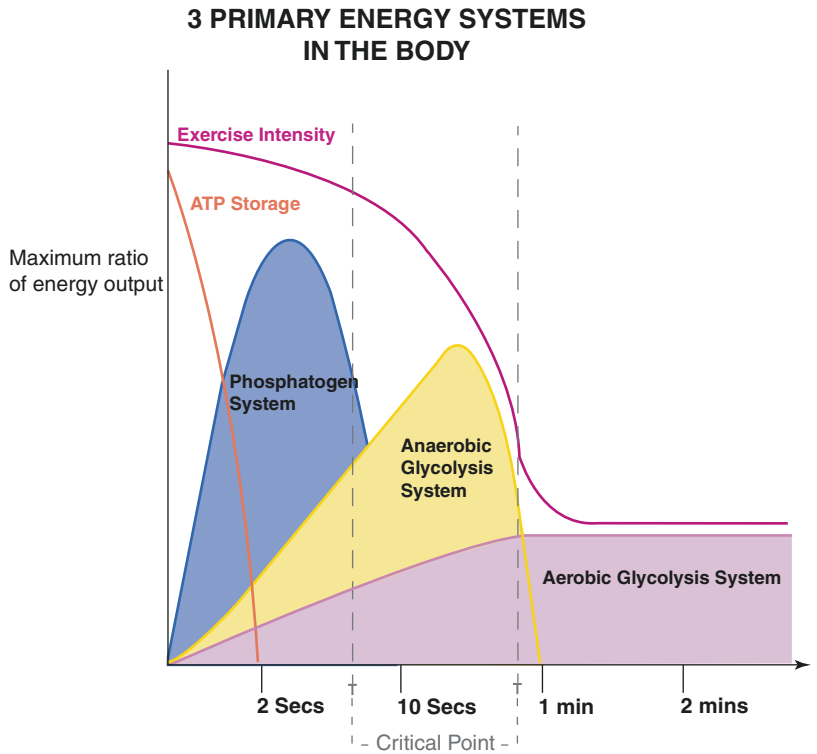

Fig. 32.3 Primary energy sources in the body [65]. Energy expenditure as a variable of time can be divided into three main components: stored energy, anaerobic glycolysis, and aerobic glycolysis. For our initial burst of energy, our body consumes stored ATP and phosphagen to facilitate movement. The body quickly switches over to anaerobic glycolysis as energy expenditure depletes energy reserves. As exercise continues, aerobic glycolysis takes over to produce a constant energy level. Figure adapted by Amber McCord, Texas Tech University, from American College of Sports Medicine, Swain DP, Brawner CA; American College of Sports Medicine. ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription (7th edition.). Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins, 896 pgs, ©2014 [75]

Exercise Testing and Prescription [71]: bone mass, muscle mass, glucose tolerance, musculotendinous integrity, ability to perform daily functions, and weight management in terms of free-fat mass and BMR. Table 32.11 elaborates on these specific components for resistance training off the FITT principle using evidence-based research.

Table 32.11 Resistance Exercise Evidence-Based Recommendations [72]. Reprinted with permission from Wolters Kluwer Health Inc., Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, et al., Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and Neuromotor fitness in apparently healthy adults. Medicine & Science in Sports & Exercise, Vol. 43/Issue 7, pgs. 1334–1359, © 2011; https://journals.lww.com/acsm-msse/Fulltext/2011/07000/Quantity_and_Quality_of_Exercise_for_Developing.26.aspx. https://doi.org/10.1249/mss.0b013e318213fefb

FITT-VP	Evidence-based recommendations
Frequency	• Each major muscle group should be trained on 2–3 d · week^{-1}
Intensity	• 60–70% 1-RM (moderate-to-vigorous intensity) for novice to intermediate exercises to improve strength • Experienced strength trainers can gradually increase to ≥80% 1-RM (vigorous-to-very vigorous intensity) to improve strength • 40–50% 1-RM (very light-to-light intensity) for older individuals beginning exercise to improve strength • 40–50% 1-RM (very light-to-light intensity) may be beneficial for improving strength in sedentary individuals beginning a resistance training program • < 50% 1-RM (light-to-moderate intensity) to improve muscular endurance • 20–50% 1-RM in older adults to improve power
Time	• No specific duration of training has been identified for effectiveness
Type	• Resistance exercises involving each major muscle group are recommended • Multi-joint exercises affecting more than one muscle group and targeting agonist and antagonist muscle groups are recommended for all adults • Single-joint exercises targeting major muscle groups may also be included in a resistance training program, typically after performing multi-joint exercise(s) for that particular muscle group • A variety of exercise equipment and/or body weight can be used to perform these exercises
Repetitions	• 8–12 repetitions are recommended to improve strength and power in most adults • 10–15 repetitions are effective in improving strength in middle-aged and older individuals starting exercise • 15–25 repetitions are recommended to improve muscular endurance
Sets	• 2–4 sets are recommended for most adults to improve strength and power • A single set of resistance exercise can be effective especially among older and novice exercisers • ≤2 sets are effective in improving muscular endurance
Pattern	• Rest intervals of 2–3v min between each set of repetitions are effective • A rest of ≥48 h between sessions for any single muscle group is recommended
Progression	• A gradual progression of greater resistance, and/or more repetitions per set, and/or increasing frequency is recommended

Note: Resistance Maximum (RM)

Flexibility Training: All aspects of our lives, especially everyday functions like walking, bending, and lifting rely on our flexibility. Flexibility is characterized as a joint's capability with its surrounding muscle to move through its full range of movement without any pain or hindrance. Flexibility training, also known as stretching, activates and lengthens muscles by releasing tension and promoting relaxation. Imagine bending down to tie your shoes and feeling tightness in your back as you reach for your shoelaces—a lack of stretching combined with a buildup of tension probably led to this agitating sensation.

The gradual onset of tightness throughout the body is primarily linked to tissue elasticity loss. Overtime our body loses its natural "resilience" due to physical inactivity which causes muscles to become less supple and our joints to stiffen, leading to bad posture and making the body more prone to tears, aches, and pain. In addition, physical activity that requires movement unaccustomed to the body puts your body at a higher risk of injury due to the lengthening of inactive muscle with little to no elasticity. The specific mechanism is unknown, but a mixture of the type, volume, and intensity of the exercise-induced muscle damage leads to this injury potential [76]. These symptoms are commonly seen as the delayed onset of muscle soreness, muscular swelling, and decreased range of motion and muscular strength [76].

There are six flexibility techniques you can implement into your stretching routine. The ballistic method ("bouncing") stretches exerts body impulse to recoil from side to side to create a stretch. The dynamic (slow) movement method involves a gradual transition from one body position to another while progressively increasing your range of motion across each set. The static stretch applies a gradual tension to your muscle(s) while holding specific body positions (e.g., extending your right arm across your left shoulder) across multiple sets while progressively increasing your range of motion. The active static stretch involves constant tension with the help of your agonist muscles to maintain a specific body position, commonly seen in yoga. The passive static uses the assistance of an external force to maintain a body position, like yoga bars or elastic bands. Finally, the proprioceptive neuromuscular facilitation (PNF) applies an isometric contraction followed by a static stretch. Overall, these six techniques emphasize the necessity to relax and increase muscle mobility for optimal and safe use [72].

Table 32.12 provides a summary of evidence-based recommendations on how to successfully implement stretching into your daily routine.

According to Adrian [77] and ACE Fitness [78], the benefits seen from stretching 5–10 min per day, especially before and after exercise includes:

Table 32.12 Flexibility exercise evidence-based recommendations [72]. Reprinted with permission from Wolters Kluwer Health Inc., Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, et al., Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and Neuromotor fitness in apparently healthy adults. Medicine & Science in Sports & Exercise, Vol. 43/Issue 7, pgs. 1334–1359, © 2011; https://journals.lww.com/acsm-msse/Fulltext/2011/07000/Quantity_and_Quality_of_Exercise_for_Developing.26.aspx. https://doi.org/10.1249/mss.0b013e318213fefb

FITT-VP	Evidence-based recommendations
Frequency	• ≥2 to 3 d · week^{-1} with daily being most effective
Intensity	• Stretch to the point of feeling tightness or slight discomfort
Time	• Holding a static stretch for 10–30 s is recommended for most adults • In older individuals, holding a stretch for 30–60 s may confer greater benefit • For proprioceptive neuromuscular facilitation (PNF) stretching, a 3–6 s light-to-moderate contraction (e.g., 20–75% of maximum voluntary contraction) followed by 10- to 30-s assisted stretch is desirable
Type	• A series of flexibility exercises for each of the major muscle-tendon units is recommended • Static flexibility (i.e., active or passive), dynamic flexibility, ballistic flexibility, and PNF are each effective
Volume	• A reasonable target is to perform 60 s of total stretching time for each flexibility exercise
Pattern	• Repetition of each flexibility exercise two to four times is recommended • Flexibility exercise is most effective when the muscle is warmed through light-to-moderate aerobic activity or passively through external methods such as moist heat packs or hot baths
Progression	• Methods for optimal progression are unknown

- Decreased muscle stiffness related to muscle degeneration and increased range of motion.
- Increased contraction strength of our muscles, the active element involved in body motion. This places less emphasis on our body's passive elements such as bones, ligaments, and tendons.
- Increased tissue elasticity by activating muscular groups that tend to shorten and tighten over time.
- Increased body temperature followed by blood flow allowing for maximal nutrient circulation. Joint degeneration is avoided which helps maintains range of motion necessary for good posture and balance.
- Prevention of body straining, improving physical performance and decreasing the risk of injury by preparing the body for exercise stress.
- Relieved post-exercise aches related to stiffening and shortening of muscle groups.
- Improved posture by keeping back in alignment.
- Increased mechanical efficiency and functionality by decreasing energy demands necessary to create movement.
- Reduced overall mental stress by relieving tension held throughout the body.

32.4.4 Research and Contemporary Findings

Many worry that physical activity will lead to injuries. Researchers Janney and Jakicic [79] attempted to study physical activity related injuries in overweight and obese individuals. Sedentary adults with a BMI between 25 and 40 were assigned to walking exercises that differed in duration (150, 200, or 300 min/week or control group). Following 18 months of longitudinal study, 32% of the individuals attributed an injury due to exercise with lower-body musculoskeletal injuries (21%) being the most common; 9% of injuries were attributed to solely exercise with 59% being attributed to other causes. The researchers found that "BMI (p </= 0.01) but not exercise (p >/= 0.41) was significantly associated with time to first injury and injuries over time. Participants with higher BMIs were injured earlier or had increased odds of injury over time than participants with lower BMIs" [79]. There were no differences in injury rates between those prescribed physical activity and those in the control group, illustrating moderate physical activity does not cause injuries. Instead, constant weight gain will make you more prone to injuries.

To understand the differences between aerobic and anaerobic exercises better, Zeng et al. [80] compared commonly utilized workouts, specifically aerobic training (AT), high intensity intermittent training (HIIT), and resistance training (RT) on the body composition of obese women. Fifty-four young obese women with an average body fat composition of >30% were randomly assigned to one of the three exercise interventions, requiring three 45-min-long sessions per week for 12 weeks. The results revealed that all three-exercise methods proved to be effective in significantly reducing body fat rate (BF %) and body fat mass (FM) with a greater reduction in weight loss seen at the initial 0–6-week period compared to the 7–12-week period. Amongst the different types of exercises, HIIT led to the greatest decrease in BF% and FM compared to aerobic training and resistance training (HIIT: −40.18% and −44.97% vs. AT: −24.59% and −28.09% vs. RT: −22.84% and −29.32%, all $P < 0.05$). Resistance training showed the greatest increase in muscle mass (RT: 27.14% vs. HIIT: 23.15% and FATmax: 24.26%, both $P < 0.05$).

The different outcomes amongst the aerobic and anaerobic exercises (AT vs. HIIT and RT) and the two anaerobic exercises (HIIT vs RT) suggest each physical activity affects our metabolic pathways differently. HIIT reduced BF% and FM the most, outdoing AT and RT by roughly 16% each, despite being an anaerobic exercise that uses carbohydrates instead of fats as its main energy source. Zeng et al. [80] credits this to HIIT playing "a positive role in the mobilization, transportation, and utilization of glycolipid metabolism." The methodology behind HIIT exercises is repeating short, intense periods of high activity where 90% VO_{2max}

intensity is reached with short intermission periods with little-to-no activity until fatigue is reached. This pushes the body into a state of low oxygen, creating a state of excessive oxygen consumption post-exercise. Elevated levels of oxygen in the body post-exercise induces fat metabolism via the aerobic pathway for hours after the workout, suggesting intensity plays a critical role in fat metabolism. Intensity increases the total amount of excessive oxygen consumption which increases the time during which fat storages must be broken down for energy post-exercise.

The effects of aerobic training and resistance training should not be disregarded though. Aerobic training still effectively reduced BF% and FM in the woman. The effects might not match those of HIIT over a 24-h period, but the results are still significant in relation to the initial BF% and FM of each participant. The methodology behind aerobic training is maintaining a low-intensity pace for a long-duration to induce oxygen consumption for the metabolization of carbohydrates and fats. Likewise, resistance training proved to be successful in significantly decreasing BF% and FM similar to aerobic training. In addition, resistance training showed the most significant increase in muscle mass, outdoing HIIT and AT by roughly 4%. Prior studies have linked a positive correlation between muscle mass and resting BMR, providing another beneficial factor for tackling weight. Resistance training's methodology can be attributed to its strain technique "that maintains a constant movement speed, which is an indispensable part of overall physical exercise by imposing certain load on the muscles to achieve muscle growth and strength increases. It has long been used as an effective way to increase muscle strength, volume, endurance, and maintain fat-free weight" [80].

Now, the psychological effects of aerobic versus anaerobic training must be examined to understand their application better. Many factors play a role in the sustainability of an exercise from its difficulty and practicality to the motivation and mood of the individual. For example, many might find aerobic training difficult due to its constant movement for a long duration of time while others might enjoy it due to its convenience. On the other hand, many might find resistance training unattractive due to its gym membership prerequisite while others might find it enjoyable for its static workouts. Goldfield et al. [81] decided to investigate these differences in obese youth between the ages of 14–18 with a BMI in the 95th percentile of their age and sex. Individuals were divided into three groups: aerobic training, resistance training, or combined training, and performed four exercise sessions per week for 45 min. Following 26 weeks, there appeared to be no significant difference amongst the three exercise groups in regards to adherence nor attrition. Participants who withdrew from the study reported a lack of interest or time as their reason. The "median exercise training adherence was 62% (interquartile range [IQR], 36–81%) in aerobic, 56% (IQR, 37–75%) in resistance, and 64% (IQR, 39–75%) in combined, with no significant differences between groups. Seventy-five participants (25%) withdrew between randomization and 6 months: 18 (24%) from aerobic, 21 (28%) from resistance, 17 (23%) from combined, and 19 (25%) from control" [81].

Goldfield et al. [81] furthered their findings and investigated the effects of aerobic training, resistance training, and combined training on mood, body image, and self-esteem. Mood, body image, and self-esteem were measured using the Brunel Mood Scale, Multiple Body Self-Relations Questionnaire, and Harter Physical Self-Perceptions Questionnaire-accordingly. The results revealed overall body fat reduction, regardless of the exercise, exhibited the greatest improvement on psychological health factors such as enhanced body image and self-esteem. No group differences emerged in regards to body image reflection; however, perception significantly increased as a variable of effect over time. Resistance training showed a significant increase "in global self-esteem, some indicators of mood and perceived strength, while combined training produced greater changes than controls in physical self-perceptions in adolescents with overweight or obesity" [81]. In fact, resistance training and combined training adherence positively correlated with improved body image, physical self-perception, and global self-esteem while aerobic training adherence showed no association with any physiological factor. Adherence to an exercise is, if not, one of the most integral factors in exercising. An exercise cannot produce the anticipated results in an individual, especially if overweight or obese, if they struggle to stay consistent.

Nevertheless, many of these studies fail to account for differences between sexes in regards to standing position exercise for overweight and obese individuals—current physical activity guidelines misrepresent females. Researchers Caudwell et al. [82] investigated these possible differences in their literature review "Exercise and Weight Loss: No Sex Differences in Body Weight in Response to Weight," designed to search through published articles on physical activity and/or body composition. Despite the name of the article, their literature review identified multiple studies where males lost more weight compared to female or showed no differences at all; however, none of the studies revealed a greater significant weight loss in females compared to their male counterparts. Their final study included 21 studies with 14 being carried out on overweight and obese individuals and seven on normal-weight individuals; the studies varied in duration and were classified as a short-term, medium-term, or long-term exercise interventions. The short-term exercise intervention group consisted of two studies with normal-weight individuals which showed no statistical differences between sexes in weight loss. The medium-term

exercise intervention group consisted of nine studies in which three studies demonstrated a significantly greater weight loss reduction in men compared to women [82]. A good example of this is seen by Irving et al. [83] with a 16-week supervised exercise program in which energy expenditure was fixed at 400 kcal per session; obese men significantly lost more weight during low-intensity exercise compared to obese females (−4.4 vs −2.1 kg), suggesting that women possibly have a greater compensational response to increasing energy expenditure due to their complex hormonal makeup. Finally, the long-term exercise intervention group consisted of 11 studies with six studies revealing a greater weight reduction in men than women [82]. Another great example of these differences was seen under the Midwest Exercise Trials with Donnelly et al. [84] where men lost 5.2 kg of BW and 4.9 kg of FM while females maintained their body weight and FM after 16 months of supervised training. In general, it is evident conflicting information exists regarding differences in weight loss between sexes as a result of physical activity which can lead to misguided and ineffective guidelines for overweight and obese females engaging in physical activity. More studies must investigate these implications while accounting for confounding variables such as energy expenditure, intensity, etc.

Overall, many factors play a role in an exercise's effectiveness in treating overweight and obesity. An exercise must be able to significantly reduce both BF% and FM while maintaining a high adherence rate. Of the exercises observed, HIIT proved to be the most effective in significantly reducing body weight while resistance training or combined training proved most effective in maintaining consistency in an individual. It should be noted that HIIT adherence was not investigated in the Goldfield et al. study. An overweight and obese individual should use a mixture of resistance training in consistency with HIIT to maximize their weight loss. They will see the most significant decrease in weight loss, an increase in muscle mass, an increase in BMR and TEE, a higher probability they will adhere to their exercises as time gradually goes on, and overall increase psychological well-being. It should be noted, HIIT increases the likelihood of injury due to its high intensity so obese individuals should gradually incorporate themselves into these types of activities once they decrease their excessive weight to a safe level according to their health specialist and feel comfortable with moderate exercise. Finally, it should be made known many studies have identified differences in weight loss between males and females despite following the same exercise intervention program—more studies must investigate these differences, so guidelines become more applicable toward each sex rather overall. Table 32.13 summarizes the FITT recommendations for aerobic, resistance, and flexibility training.

Table 32.13 FITT recommendations for individuals with overweight and obesity [71]. Reprinted with permission from Wolters Kluwer Health Inc., Reprinted with permission from Wolters Kluwer Health Inc., *American College of Sports Medicine, Liguori G. ACSM's Guidelines for Exercise Testing and Prescription. Philadelphia, PA:* Wolters Kluwer Health Inc., *Lippincott Williams & Wilkins, 2020*

	Aerobic	Resistance	Flexibility
Frequency	≥5 d · week^{-1}	2–3 d · week^{-1}	≥2–3 d · week^{-1}
Intensity	Initial intensity should be moderate (40–59% VO_2R or HRR); progress to vigorous (≥60% VO_2R or HRR) for greater health benefits	60–70% of 1-RM; gradually increase to enhance strength and muscle mass	Stretch to the point of feeling tightness or slight discomfort
Time	30 min · d^{-1} (150 min · week^{-1}); increase to 60 min · d^{-1} or more (250–300 min · week^{-1})	2–4 sets of 8–12 repetitions for each of the major muscle groups	Hold static stretch for 10–30 s; 2–4 repetitions of each exercise
Type	Prolonged, rhythmic activities using large muscle groups (e.g., walking, cycling, swimming)	Resistance machines and/or free weights	Static dynamic, and/or PNF

32.5 Future Directions and Concluding Remarks

At the beginning of this chapter, we explained that weight loss is one of the primary treatments for overweight or obese females [7]. We also described how diet and exercise in conjunction are more effective than a single intervention on its own [8]. The primary goals of dieting are to help with the reduction of BF% and FM and improve nutrition. We have discussed how there are numerous diets that fulfill this objective, although the Mediterranean diet does appear to be both effective and have less limitations or potential side effects than the other diets described in Sect. 32.2.4. Commercial weight loss programs have also been shown to be effective weight loss tools as seen in Sect. 32.2.6, with WW being the program that we would recommend. The main purpose of exercise is to reduce BF% and FM, while also preserving or increasing lean body mass. We explained in Sect. 32.4.4 how HIIT training may lead to a greater reduction in BF% and FM than AT and RT, whereas RT is associated with the greatest gains in lean body mass. From these findings, we can conclude that diet and physical activity can greatly improve overweight or obese patient's health, but the real question is *how* to best integrate these two modalities.

A study by Parr, Heilbronn, and Hawley sought to evaluate the comparative and potential complementary effects of diet

and exercise. They conducted a study based upon the body's circadian rhythm, or "sleep/wake" cycle, which they theorized could be "matched" by Time-Restricted Eating (TRE) and exercise to improve metabolic health. Time-Restricted Eating (TRE) is a form dieting where energy intake is limited to a "window" of less than 10 h/day (i.e., 7 am to 5 pm). TRE is similar to Intermittent Fasting, although Intermittent Fasting has various strategies and caloric allotments [82]. Their research found that TRE in itself led to weight loss, improved glycemic control, and better overnight fasting glucose levels. They also evaluated exercise patterns based on time of day but found little difference in outcomes in subjects who exercised in the morning vs the evening. In the future, the goal is to take things one step further and compare exercise training with a TRE dietary regimen vs TRE alone [85]. We anticipate that the findings from this study, along with other future studies will bring more insight into how different dietary strategies and exercise can be integrated to give the best outcomes possible for our patients.

Chapter Review Questions

1. Which of the following properties is true of both the Atkins and the Keto Diet?
   (a) High protein
   (b) High fat
   (c) Low carb
   (d) Dietary phases
2. Which of the following is shown by research to be the most effective way to lose weight?
   (a) Diet only
   (b) Exercise only
   (c) Diet and exercise
   (d) Diet, exercise, and behavioral therapy
3. You are meeting with an obese patient who is considering various diets to help her lose weight. She would like to begin the Atkins Diet. Her past medical history indicates eczema, hypertension, and chronic kidney disease. Based on these findings, you recommend that she
   (a) Begins the Atkins diet because it will help her to lose weight
   (b) Starts the Atkins diet to help her treat her eczema and hypertension
   (c) Avoids the Atkins diet because it may accelerate her kidney dysfunction
   (d) Not do the Atkins diet as it may induce ketosis
4. Which of the following is NOT a contraindication for Intermittent Fasting
   (a) Infertility
   (b) Nausea
   (c) Amenorrhea
   (d) Bulimia nervosa
5. A 54-year-old female comes to your clinic seeking dietary advice. She has a blood pressure (BP) of 131/89, heart rate (HR) of 78, a respiratory rate (RR) of 16, and a BMI of 36 kg/m^2. She has been diagnosed on previous visits with hypercholesterolemia and type II diabetes. There is also a history of chronic heart disease in her family. Based on this information which diet would you recommend for her?
   (a) Mediterranean
   (b) Intermittent fasting
   (c) Paleo
   (d) Atkins
6. A 44-year-old obese woman, who is 5 ft 1in (154.9 cm), weighs 182 lb (82.6 kg), and lives a sedentary lifestyle comes into the clinic complaining about her weight. Her sister's wedding is approaching in May, and she wants to lose 20 lbs by then. We set a weight loss goal of 1 lb per week. What should her total caloric intake be per day?
   (a) 1705 kcal/day
   (b) 1205 kcal/day
   (c) 921 kcal/day
   (d) 500 kcal/day
7. Which of the following is proven to increase basal metabolic rate (BMR)?
   (a) Fat mass
   (b) Fat-free mass
   (c) Aerobic training
   (d) Flexibility training
8. A 27-year-old fit woman complaining about severe back pain is seeking medical attention after straining her back during a HIIT session. She has a blood pressure (BP) of 124/78, heart rate (HR) of 105, a respiratory rate (RR) of 20, and a BMI of 20 kg/m^2. At which of the following levels of Rate of Perceived Exertion (RPE) did her injury most likely occur at?
   (a) Level 1
   (b) Level 2
   (c) Level 3
   (d) Level 4
   (e) Level 5
9. Which of the following forms of exercise will most likely achieve a VO_{2max} intensity of 90%?
   (a) Jogging
   (b) Weight-lifting
   (c) High-intensity-interval training
   (d) Swimming
   (e) Speed walking
10. A 33-year-old obese woman began to feel a burning sensation in her arms during a workout session requiring intense upper body movement. She has a blood pressure (BP) of 138/88, heart rate (HR) of 98, a respiratory rate (RR) of 17, and a BMI of 32 kg/m^2. Which of the follow-

ing energy systems in the body can the burning sensation be attributed to?

(a) ATP storage
(b) Creatine storage
(c) Aerobic glycolysis
(d) Anaerobic glycolysis

Answers

1. c
2. d
3. c
4. b
5. a
6. b
7. b
8. e
9. c
10. d

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