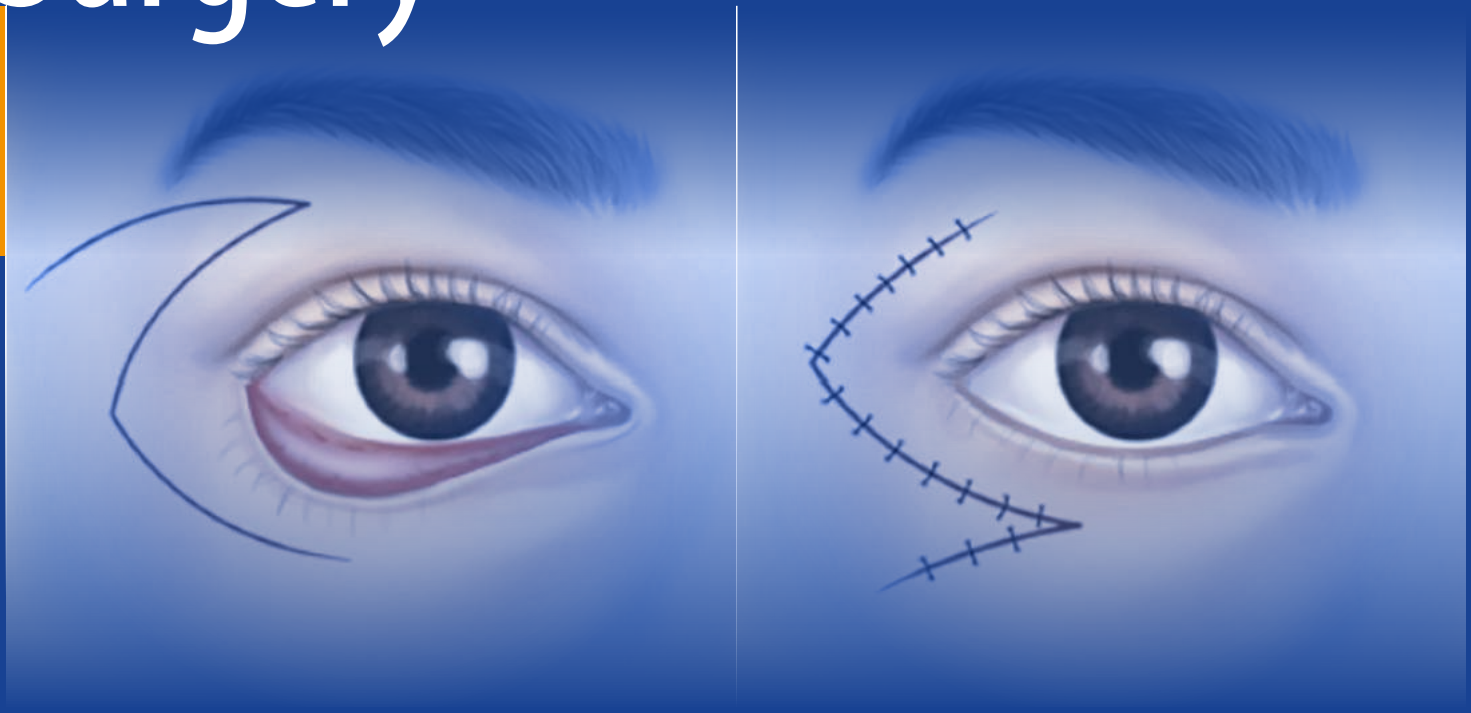
Rei Ogawa · Dennis P. Orgill
Luc Téot · Hiko Hyakusoku
Julian J. Pribaz *Editors*

Color Atlas of Burn Reconstructive Surgery



Second Edition

MOREMEDIA

Springer

Color Atlas of Burn Reconstructive Surgery

Rei Ogawa • Dennis P. Orgill • Luc Téot
Hiko Hyakusoku • Julian J. Pribaz
Editors

Color Atlas of Burn Reconstructive Surgery

Second Edition

Springer

Editors
Rei Ogawa
Department of Plastic Reconstructive and Aesthetic Surgery
Nippon Medical School
Tokyo, Japan

Dennis P. Orgill
Director of the Wound Care Center, Brigham and Women's Hospital
Harvard Medical School
Boston, MA, USA

Luc Téot
Department of Surgery Pôle EMMBRUN Wound Healing Unit
Montpellier University Hospital
Montpellier, France

Hiko Hyakusoku
Department of Plastic Reconstructive and Aesthetic Surgery
Nippon Medical School
Tokyo, Japan

Julian J. Pribaz
Department of Plastic Surgery, Morsani College of Medicine
University of South Florida
Tampa, FL, USA

ISBN 978-3-031-88352-1 ISBN 978-3-031-88353-8 (eBook)
https://doi.org/10.1007/978-3-031-88353-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface to the First Edition

Reconstructive surgery of burns, especially of extensive burns, is a topic that requires the ideas and inspiration of plastic surgeons. Traditionally, it is considered that almost all burn wounds can be reconstructed using simple skin grafting. However, sophisticated reconstructive surgery based on knowledge of various surgical methods is needed to accomplish both functionally and cosmetically acceptable long-term results. The contents of this book represent ideal guidelines for burn reconstructive surgery and were provided by authors from 14 different countries. In other words, this book is the grand sum of the newest surgical technologies and strategies proposed by plastic surgeons.

I have been involved in reconstruction surgery for extensive burns since I became a plastic surgeon. I have developed many reconstructive procedures and have been able to apply these methods clinically. Burn reconstruction has brought many thoughts to develop flap surgical methods to me. Moreover, I have realized that burn reconstruction should be accomplished via an all-out mobilization of knowledge on flap surgery and that this is an area that requires continual development of surgical methods. However, I have met many plastic surgeons who are performing novel and innovative methods. This book is a collection of these worldwide experiences. I hope that this book will provide great benefits for burn patients worldwide.

Damage to skin from thermal, electrical or chemical injury has devastating effects on aesthetic and functional outcomes of burn victims. The stigmata of burn patients remains one of the most devastating injuries that man can survive. Fortunately, over the last 30 years, there have been simultaneous advances in scar biology, materials science and knowledge of microanatomy, surgical techniques, transplantation and cell culture. As a result there are now many treatment options available that give greater hope to our patients restoring function and improving their societal interactions.

In this atlas, Dr. Ogawa has brought together the world's experts to review the important topics of super-thin flaps, prefabricated flaps, dermal and epidermal replacements as well as vacuum-assisted closure technologies. This atlas will be an important resource for practicing plastic surgeons as well as students and residents in training. Examples in the atlas will also be valuable for patient education of these varied techniques.

Burns represent a pathology remaining among the hardest to heal wounds. Even if important progresses in resuscitation allowed life-threatening body surfaces to regress during the last 50 years, force is to recognize that restoring the original function after extensive and deep burns re-quires a long period of fight against contractures, hypertrophy and tissue shortening. A multi-disciplinarity approach is mandatory to obtain a return to the social and working life, but skin has changed for the rest of the life of the patient.

The development of microsurgery in the 80s, followed by an intense activity in anatomical studies, could evidence the angiosomes and the skin, muscle, tendon and bone vascular cartographies. From this era, all types of flaps were proposed, including prefabricated and perforator flaps, a founding melting pot and a source of intense activity for the new plastic and reconstructive surgery. This atlas details how to use them in burn reconstructive surgery.

During the last decade, the surgical possibilities of dermal replacement becomes more and more efficient. The recent development of tissue engineering, leading to added biological

similarities with the normal skin, opens a new space for reflexion and trials, based on cell-extracellular matrix interactions via cytokines and growth factors.

The need for repairing the cosmetic outcome of facial burns remains a social challenge and will certainly be a long-term contract for the new generation of burns specialists and plastic surgeons.

Every reconstructive surgeon thinks that evidence-based burn reconstruction is an ideal method; however, it is yet to be established. The reason for this may be that every single wound or scar is unique. Moreover, the color, texture, thickness and hardness of the skin vary according to human race, age, sex and body site. Thus, we are forced to select treatment methods on a case-by-case basis according to the limited experience of each surgeon.

Meanwhile, during the finishing stage of reconstruction, large parts of the surgical procedure should include elements of aesthetic surgery. In this stage, it may not be an exaggeration to state that evidence-based surgery is not beneficial. Treatment methods should be selected and performed based on the aesthetic sense and cultivated sensitivity of each surgeon. Evidence-based surgery and artistic reconstruction represent a big dilemma that is posed to every burn reconstructive surgeon.

I believe this book, which is entitled Color Atlas of Burn Reconstructive Surgery, provides an answer for this particular dilemma. This answer may be the fusion of evidence-based surgery and artistic reconstruction. After reading this book, the surgeon will recognize what part of the reconstruction should be carried out using evidence-based surgery and what part should be performed artistically. We should not give up on the generation of evidence-based standardized protocols for patient safety or on the education of younger-generation surgeons. In addition, we should not neglect artistic reconstruction at any time.

In this book, international authors who have wide perspectives in burn reconstructive surgery shared their own valuable experiences and concepts about the characteristics and indications of their methods. The contents include wound management, classification and evaluation of wounds/scars, various artistic and geometric methods and future treatment strategies from a regenerative medicine standpoint. I hope that this book will enhance the work of burn reconstructive surgeons and confer tremendous benefits to burn patients.

Finally, I thank all authors and coeditors who have taken time from their busy schedules to assemble this book. In addition, I appreciate the tremendous help of Ms. Ellen Blasig at Springer in Germany. Her contribution was essential for the accomplishment of this project. Moreover, I thank the illustrator Kazuyuki Sugiu from Studio Sugis for preparing the figures.

Tokyo, Japan — Hiko Hyakusoku
Tampa, FL, USA — Julian J. Pribaz
Boston, MA, USA — Dennis P. Orgill
Montpellier, France — Luc Téot
Tokyo, Japan — Rei Ogawa

Preface to the Second Edition

I am delighted to announce the publication of the second edition of the *Color Atlas of Burn Reconstructive Surgery*, which was first published in 2010. Nearly 15 years have passed since the first edition, and the world has seen remarkable changes during this time. Advances in science and technology, such as artificial intelligence (AI) and virtual reality (VR), have been particularly striking. Similarly, medicine has undergone significant transformations. For example, molecularly targeted therapies have become commonplace for conditions such as cancer and other internal diseases.

Globally, the number of burn victims has been decreasing. However, in certain regions, accidents and fires remain prevalent, resulting in many burn patients who require care. Encouragingly, there have been major advancements in burn treatment as well. New technologies have greatly improved the quality of initial care, and techniques for secondary reconstructive surgery have also advanced significantly.

For this second edition, we invited specialists deeply experienced in burn care to share their expertise and insights. The book includes not only practical techniques that go beyond what can be learned from academic papers but also comprehensive overviews and detailed methodologies. I hope that this edition will help readers update their knowledge and contribute to saving the lives of countless burn patients.

Finally, I would like to express my heartfelt gratitude to Lee Klein, who played an indispensable role from planning to editing, and to the entire team at Springer for their dedication and support.

Tokyo, Japan — Rei Ogawa

Contents

Part VII Free Flap and Perforator Flap

Part VIII Facial Allotransplantation

Contributors

Satoshi Akaishi Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan

Sadanori Akita Fukushima Medical University, Fukushima, Japan, Tamaki Aozora Hospital, Tokushima, Japan

Abbas Albayati Department of Plastic, Reconstructive and Aesthetic Surgery, Baskent University Faculty of Medicine, Ankara, Turkey

Ziyad Alharbi Plastic Surgery and Burn Unit, Fakeeh Care & Fakeeh College of Medical Sciences, Jeddah, Saudi Arabia

Mieke Anthonissen OSCARE, Antwerp, Belgium

KU Leuven, Department of Rehabilitation Sciences, Leuven, Belgium

Kohei Aoki Department of Plastic and Reconstructive Surgery, Tokyo Medical University, Tokyo, Japan

Rintaro Asahi Nippon Medical School, Tokyo, Japan

Matthias Aust Privatklinik Aust Ästhetik, Landsberg am Lech, Germany

Branko Bojovic Department of Plastic, Reconstructive, and Laser Surgery, Shriners Children's, Division of Plastic and Reconstructive Surgery, Massachusetts General Hospital, Harvard, Boston, MA, USA

Sam Boroumand, MD Department of Surgery, Division of Plastic and Reconstructive Surgery, Yale School of Medicine, New Haven, CT, USA

Martin Buta Department of Plastic, Reconstructive, and Laser Surgery, Shriners Children's, Division of Plastic and Reconstructive Surgery, Massachusetts General Hospital, Harvard, Boston, MA, USA

Rodney K. Chan US Army Burn Center, US Army Institute of Surgical Research, San Antonio, TX, USA

Kellen Chen Department of Surgery, College of Medicine – Tucso, The University of Arizona, Tucson, AZ, USA

Caitrin M. Curtis Atrium Health Wake Forest Baptist Hospital, Winston-Salem, NC, USA

Wake Forest University School of Medicine, Winston-Salem, NC, Belgium

Lot Demuynck OSCARE, Antwerp, Belgium

University of Antwerp, Rehabilitation Sciences and Physiotherapy, Antwerp, Belgium

Teruyuki Dohi Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School Hospital, Tokyo, Japan

Rei Ogawa Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan

Hiko Hyakusoku Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan

Matthias B. Donelan Division of Plastic Surgery, Shriners Hospital for Children, Boston, MA, USA

Katharina S. Berryman Department of Surgery, College of Medicine – Tucson, The University of Arizona, Tucson, AZ, USA

Jianhua Gao Department of Plastic and Reconstructive Surgery, Nanfang Hospital, Southern Medical University, Guangzhou, China

Paul M. Glat Department of Plastic and Reconstructive Surgery, St. Christopher's Hospital for Children, Philadelphia, PA, USA

Marc A. Gorvet Department of Plastic and Reconstructive Surgery, St. Christopher's Hospital for Children, Philadelphia, PA, USA

Pascal Granier Burns and Plastic Surgery Unit, Montpellier University Hospital, Montpellier, France

Geoffrey C. Gurtner Department of Surgery, The University of Arizona College of Medicine – Tucson, Tucson, AZ, USA

William W. Hahn Department of Surgery, College of Medicine – Tucson, The University of Arizona, Tucson, AZ, USA

Minoru Hayashi Department of Plastic and Reconstructive Surgery, St. Mary's Hospital, Fukuoka, Japan

Jared S. Holley Department of Surgery, College of Medicine – Tucson, The University of Arizona, Tucson, AZ, USA

Andrew C. Hostler Department of Surgery, College of Medicine – Tucson, The University of Arizona, Tucson, AZ, USA

Chenyu Huang Department of Dermatology, Beijing Tsinghua Changgung Hospital, School of Clinical Medicine, Tsinghua University, Beijing, China

Reiko Kazuki Department of Plastic, Reconstructive, and Aesthetic Surgery, Nippon Medical School, Reiko Kaziki Co Ltd, Tokyo, Japan

Kouji Kinoshita Akasaka Clinic, Tokyo, Japan

Taro Kono Department of Plastic Surgery, Tokai University School of Medicine, Kanagawa, Japan

Isao Koshima Departments of Plastic and Reconstructive Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan

Jake Laun Department of Plastic Surgery, University of South Florida, Tampa, FL, USA

Allen Liu Division of Plastic Surgery, Brigham and Women's Hospital, Boston, MA, USA

Feng Lu Department of Plastic and Reconstructive Surgery, Southern Medical University, Guangzhou, China

Loelita Marcelia Lumintang Department of Surgery, Faculty of Medical and Health Sciences, Warmadewa University/Sanjiwani General Hospital, Denpasar, Bali, Indonesia

Koen Maertens OSCARE, Antwerp, Belgium

Vrije Universiteit Brussel, Department of Clinical and Lifespan Psychology, Brussels, Belgium

Musa Mateev Department of Plastic, Reconstructive and Microsurgery and Hand Surgery, National Hospital of Kyrgyz Republic, Bishkek, Kyrgyzstan

Hajime Matsumine Department of Plastic and Reconstructive Surgery, Tokyo Women's Medical University, Tokyo, Japan

Hajime Matsumura Department of Plastic and Reconstructive Surgery, Tokyo Medical University, Tokyo, Japan

Jill Meirte OSCARE, Antwerp, Belgium

University of Antwerp, Rehabilitation Sciences and Physiotherapy, Antwerp, Belgium

Makoto Mihara Departments of Plastic and Reconstructive Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan

Toru Miyanaga Department of Plastic Surgery, Kanazawa Medical University, Ishikawa, Japan

Hiroshi Mizuno Department of Plastic and Reconstructive Surgery, Juntendo University School of Medicine, Tokyo, Japan

Joseph A. Molnar Atrium Health Wake Forest Baptist Medical Center, Winston-Salem, NC, USA

Peter Moortgat OSCARE, Antwerp, Belgium

Maria Gracia Mora Pinos Department of Surgery, College of Medicine – Tucson, The University of Arizona, Tucson, AZ, USA

Naoki Morimoto Department of Plastic and Reconstructive Surgery, Graduate School of Medicine, Kyoto University, Sakyo-ku, Kyoto, Japan

Masahiro Murakami Department of Plastic, Reconstructive and Regenerative Surgery, Nippon Medical School, Tokyo, Japan

Mitsunaga Narushima Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan

Shimpei Ono Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan

Junya Oshima Department of Plastic, Reconstructive, and Hand Surgery, University of Tsukuba, Tsukuba, Japan

Sami Otman Burns and Plastic Surgery Unit, Montpellier University Hospital, Montpellier, France

Burak Ozkan Plastic and Reconstructive Surgery, Baskent University Faculty of Medicine, Ankara, Turkey

Brian M. Parrett Division of Plastic Surgery and Microsurgery, The Buncke Clinic, California Pacific Medical Center, San Francisco, CA, USA

Nelson de Paula Piccolo Department of Plastic Surgery, Pronto Socorro Para Queimaduras Ltda, Goiânia, Goiás, Brazil

Mônica Sarto Piccolo Department of Plastic Surgery, Pronto Socorro Para Queimaduras Ltda, Goiânia, Goiás, Brazil

Nelson Sarto Piccolo Department of Plastic Surgery, Pronto Socorro Para Queimaduras Ltda, Goiânia, Goiás, Brazil

Roberta Piccolo Lobo Department of Radiology, IRG Hospital, Goiânia, Goiás, Brazil

Bohdan Pomahac, MD Department of Surgery, Division of Plastic and Reconstructive Surgery, Yale School of Medicine, New Haven, CT, USA

Julian J. Pribaz Department of Plastic Surgery, Morsani College of Medicine, University of South Florida, Tampa, FL, USA

Whitney Laurel Quong Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan

Hans-Oliver Rennekampff Klinik für Plastische, Hand- und Verbrennungschirurgie, RheinMaas Klinikum, Würselen, Germany

Lior Rosenberg Department of Plastic and Reconstructive Surgery, Soroka University Medical Center and The Rosenberg Museum of Medicine, Ben Gurion University of the Negev, Beer Sheva, Israel

Hiroyuki Sakurai Department of Plastic and Reconstructive Surgery, Tokyo Women's Medical University, Tokyo, Japan

Jennifer L. Schiefer Clinic of Plastic, Reconstructive, Hand and Burn Surgery, Burn Center, Hospital Cologne Merheim, University of Witten-Herdecke, Köln, Germany

Mitsuru Sekido Department of Plastic, Reconstructive, and Hand Surgery, University of Tsukuba, Tsukuba, Ibaraki, Japan

Mariana Torminn Senna Department of Radiology, IRG Hospital, Goiânia, Goiás, Brazil

Kenichi Shimada Department of Plastic Surgery, Kanazawa Medical University, Ishikawa, Japan

Victor Bong-Hang Shyu Department of Surgery, Division of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Keelung Branch, Keelung City, Taiwan

Yang Sifen Department of Plastic and Cosmetic Surgery, The Sixth People's Hospital of Dongguan, Guangdong Province, China

Viola A. Stögner, MD Department of Surgery, Division of Plastic and Reconstructive Surgery, Yale School of Medicine, New Haven, CT, USA

Courtney E. Stone Wake Forest University School of Medicine, Winston-Salem, NC, USA

Shigehiko Suzuki Hamamatsu Rosai Hospital, Shizuoka, Japan

Yoshihiro Takami Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan

Mayer Tenenhaus Department of Plastic and Reconstructive Surgery, UC San Diego Medical Center, San Diego, CA, USA

T. C. Teo Department of Plastic and Reconstructive Surgery, Queen Victoria Hospital, East Grinstead, UK

Mamiko Tosa Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School Hospital, Tokyo, Japan

Chia-Hsuan Tsai College of Medicine, Chang Gung University, Taoyuan, Taiwan

Department of Surgery, Division of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Keelung Branch, Keelung, Taiwan, Tao-Yuan, Taiwan

Cagri A. Uysal Department of Plastic, Reconstructive and Aesthetic Surgery, Baskent University Faculty of Medicine, Ankara, Turkey

Tran Van Anh Department of Plastic and Reconstructive Surgery, Vietnam National Institute of Burn, Thanh-Tri, Hanoi, Vietnam

Ulrike Van Daele OSCARE, Antwerp, Belgium

University of Antwerp, Rehabilitation Sciences and Physiotherapy, Antwerp, Belgium

Vu Quang Vinh Department of Plastic and Reconstructive Surgery, Vietnam National Institute of Burn, Thanh-Tri, Hanoi, Vietnam

Peter M. Vogt Klinik für Klinik für Plastische, Ästhetische, Hand- und Wiederherstellungschirurgie, Replantationszentrum Niedersachsen, Schwerbrandverletztenzentrum Niedersachsen, Hannover, Germany

Chunmei Wang Department of Plastic Surgery, Dongguan Kanghua Hospital, Guangdong Province, China

Szu-Han Wang Department of Surgery, Division of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Keelung Branch, Keelung City, Taiwan

Fu-Chan Wei Linkou Burn Center, Chang Gung Memorial Hospital and University, Taipei, Taiwan

Timothy W. Wolff Department of Plastic and Reconstructive Surgery, St. Christopher's Hospital for Children, Philadelphia, PA, USA

Fiona M. Wood Burns Service of Western Australia, Burn Injury Research Unit, University of Western Australia, Crawley, WA, Australia

Jui-Yung Yang Division of General Plastic Surgery and Burn Care, Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Linkou Branch, College of Medicine, Chang Gung University, Tao-Yuan, Taiwan

Shih-Yi Yang Department of Plastic and Reconstructive Surgery, Division of General Plastic Surgery and Burn Care, Chang Gung Memorial Hospital, Linkou Branch, Keelung City, Taiwan

Jonathan P. Yasmeh Department of Surgery, College of Medicine – Tucson, The University of Arizona, Tucson, AZ, USA

Yi Yuan Department of Plastic and Cosmetic Surgery, Nanfang Hospital, Southern Medical University, Guangzhou, China

Part I

Primary Burn Wound Management

Primary Wound Management: Assessment of Acute Burns

1

Luc Téot

Abstract

The burn is depicted as a traumatic lesion provoked by several possible agents (thermal, chemical, mechanical, or electrical) involving different skin layers to a certain degree. Assessment of the clinical situation is based on (1) evaluation of the total body surface of the burns and (2) estimation of burn depth.

Keywords

Skin layer · Traumatic lesion · Sensory ending · Superficial dermis · Functional issue

1.1 Introduction

The burn is depicted as a traumatic lesion provoked by several possible agents (thermal, chemical, mechanical, or electrical) involving different skin layers to a certain degree. Assessment of the clinical situation is based on (1) evaluation of the total body surface of the burns and (2) estimation of burn depth.

Visual assessment and vascular evaluation of the wound are crucial [1, 2].

1.2 Evaluation of the Total Body Surface of the Burns

1.2.1 Estimation of Burn Depth (Tables 1.1 and 1.2)

Burn depth is traditionally defined in three degrees, and clinical observation remains the main source of information for the clinician, even though some complementary examinations can be useful to determine the exact extent of deep burns. In the majority of cases, the surgical indication for excision and grafting depends upon the visual evaluation of the wound. This part of burn assessment remains difficult and cannot be done with precision, even with experience, before the third day post-injury. In second-degree burns, the first assessment has been estimated to be accurate in less than 70% of cases.

Table 1.1 Rule of 9

Anatomical area	Head	Upper limb	Lower limb	Ant body (chest + abdomen)	Post body (thorax + back)	Genital area
Estimated % of surface	9	9	9	2 × 9	2 × 9	1

Table 1.2 TBSA following age

Anatomical area	Adult TBSA (% for each side of the structure)	Fifteen-year TBSA (% for each side of the structure)	Ten-year TBSA (% for each side of the structure)
Head	3.5	4.5	5.5
Neck	1	1	1
Trunk	13	13	13
Arm	2	2	2
Forearm	1.5	1.5	1.5
Hand	1.25	1.25	1.25
Genital area	1	1	1
Buttock	2.5	2.5	2.5
Thigh	4.75	4.5	4.25
Leg	3.5	3.25	3
Foot	1.75	1.75	1.75

L. Téot (✉)
Burns and Plastic Surgery Unit, Montpellier University Hospital, Montpellier, France
e-mail: l-teot@chu-montpellier.fr

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_1

1.3 Clinical Evaluation (Table 1.3)

1.3.1 First Degree

The first degree corresponds to a shallow wound. The aspect is red, and the area is extremely painful, as the sensory endings remain intact. A typical example of this is sunburn. Only the superficial layer of the epidermis is involved. When the total body surface is important, complications like cerebral edema can be encountered, but the wound remains easy to heal.

1.3.2 Superficial Second Degree

Superficial second-degree burns usually present as blisters, appearing some hours after the accident. Once the blister is removed, the wound can be observed. Redness is uniform, and pain is extreme, rarely allowing the physician to touch the lesion. Healing time is short, usually within the first 2 weeks, without aesthetic sequelae. The superficial dermis is exposed, without involving the basal membrane, which guarantees a quick healing in the superficial aspect of the skin (Figs. 1.1, 1.2, 1.3, 1.4, and 1.5).

Table 1.3 Degrees of burns

Degrees of burns	First	Second superficial	Second deep	Third
Anatomical structure involved	Epidermis	Dermis above basal membrane	Dermis below basal membrane	Whole skin
Color	Red	Red below the blister	Red–white below the blister	White or black
Skin hardness and vascular density	Supple	Humid	Medium-hard	Hard, thick, dry
Bleeding at contact	No bleeding	High	Moderate	No
Pain	Painful	Extremely painful	Painful	No pain
Time for closure	No wound	Less than 2 weeks	Within 3–4 weeks. Sometimes, it needs a skin graft	Needs skin replacement (graft, VAC, and flap)
Scar formation	No scar	No scar	Notable scar formation and contractures	Notable scar formation and contractures

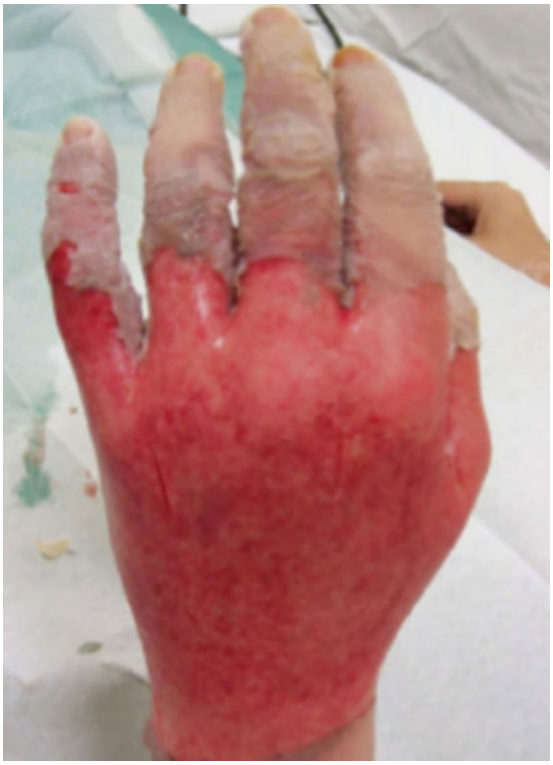


Fig. 1.1 Early assessment of second-degree burns over the dorsum of the hand. The blister has just been removed. Difficult to evaluate if deep. Reevaluate the next day and the day after

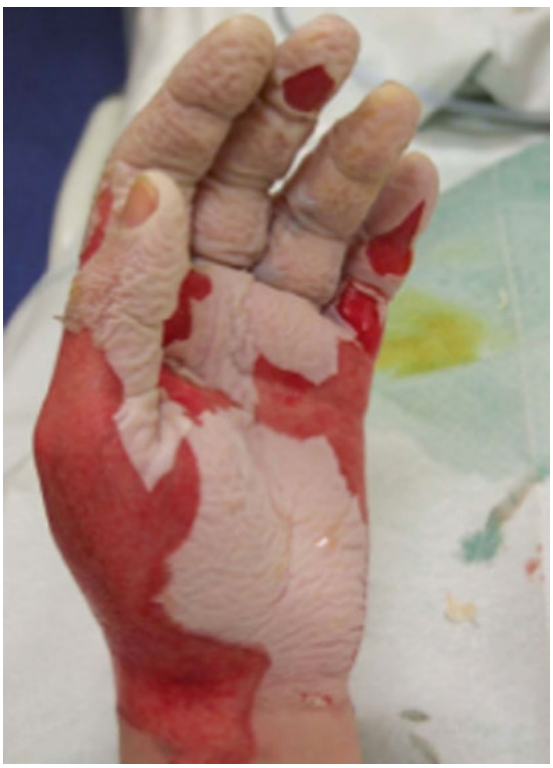


Fig. 1.2 Palmar aspect of the same hand. Same difficulty, but the fact that both aspects of the hand are involved is worse than when only one is involved

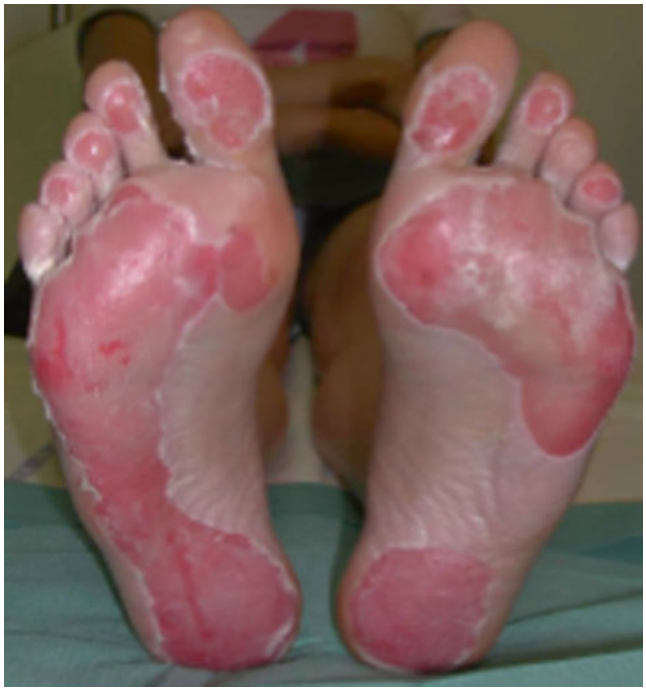


Fig. 1.3 Sand burns on the palmar aspect of the feet after walking over a long distance on a hot beach. Second degree, superficial

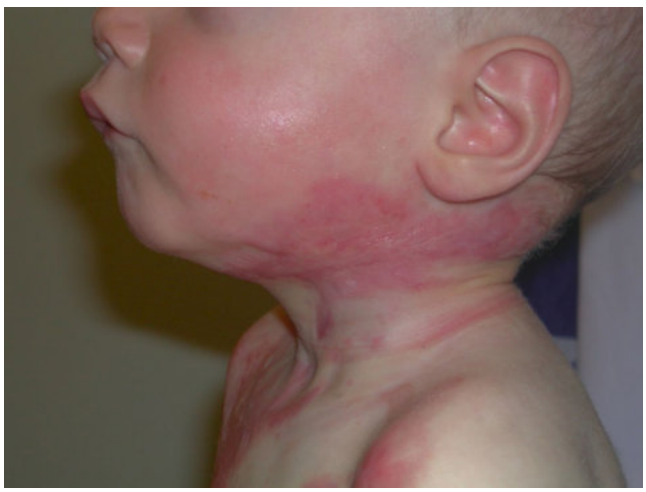


Fig. 1.4 Fresh scald burns (second degree). Blister appearing progressively. Reevaluate after some hours before establishing a prognosis

1.3.3 Deep Second Degree

Deep second-degree burns also present blisters, but after removal, the aspect is white or similar to patchwork. Sensibility to touch is not as important as in more superficial lesions, due to a partial destruction of sensory endings. Blanching of the skin under digital pressure cannot be obtained. These burns have a tendency to heal spontaneously, except in critical general conditions or if the TBS burnt is extensive. The wound will stay unhealed or deteriorate and transform into a third-degree burn. Usually, healing can be observed within 2–3 weeks, but as the deep dermis is exposed, a permanent scar will remain. These wounds can sometimes require an excision and a skin graft (Fig. 1.6).

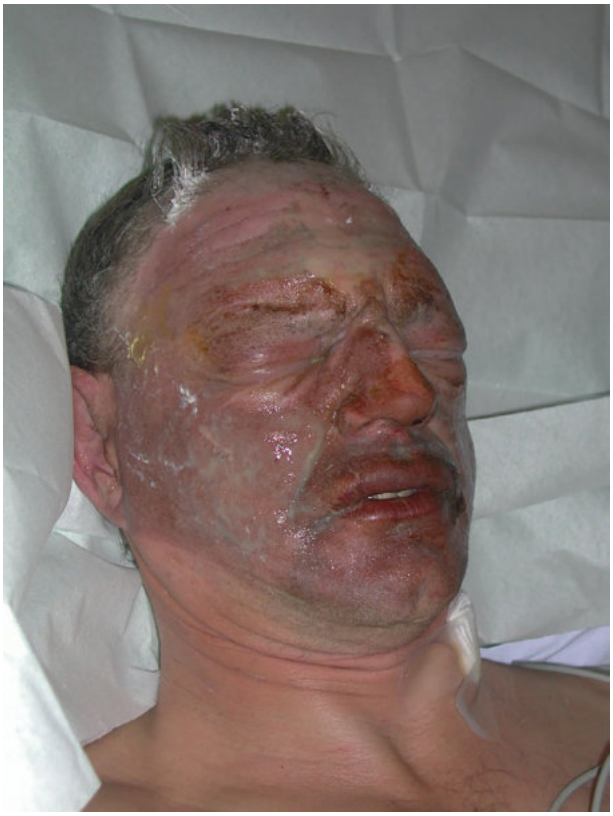


Fig. 1.5 Fresh burns of the face. Ophthalmologic assessment. Removal of blisters is necessary before a proper assessment of the burns

1.3.4 Third Degree

Third-degree burns are deep burns involving the subdermal structures. Extent in depth can be important, reaching aponeurosis or even bones. Lesions are sometimes circular on the limbs, a source of ischemia for the distal segments, necessitating emergency surgical procedures of discharge incisions to reestablish a normal distal blood flow. Lesions present with a white color, and the tissues are hard. A black eschar will be observed after carbonization (Figs. 1.7 and 1.8).

Establishing the risk of a vital issue is an important step, most of the time to be realized in an emergency. Factors like surface, location of deep burns around the orifices, and prevention of infection have to be determined urgently. Above a surface of >10% TBSA in adults and >5% TBSA in children, burns are considered serious. In over 30% of adults and 10%

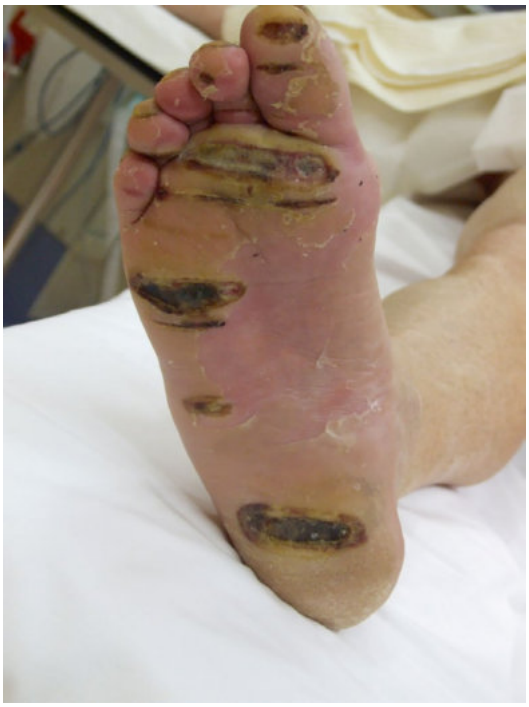


Fig. 1.6 Deep grill burns of the plantar aspect of the foot on a diabetic patient. Excision and grafting

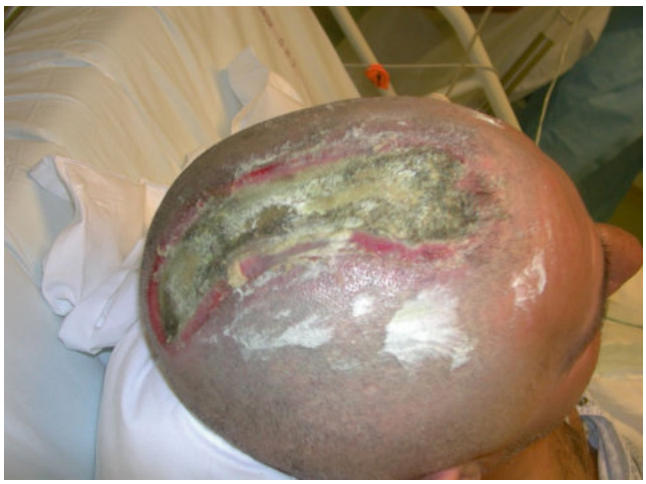


Fig. 1.7 Electric burns of the scalp: third degree with possible cortical bone involvement. Deep excision and preoperative assessment of the bone. If necrosed, removal of the outer cortex. The use of NPT may then be necessary before skin grafting

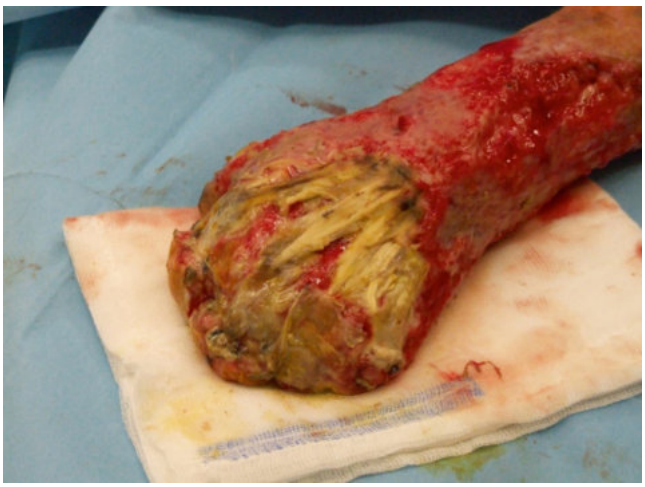


Fig. 1.8 Deep necrotic burns of the hand after digital amputation. Exposed tendons can be covered with negative pressure therapy, with serial excisions of still necrotic structures before skin grafting

of children, life-threatening difficulties can be encountered. It is important to check the face, nostrils, and hair to assess the risk of tracheal and pulmonary burns (an endoscopy is often needed for diagnosis when in doubt). The risk of burns infection is higher when initial management is delayed (septicemia).

1.4 Conclusion

Establishing the risk of functional issues is focused on reestablishing the limb vascularization and the need for discharge incisions when third-degree burns are circumferential. Other functional issues are linked to possible exposure of joints. Immobilization of interphalangeal joints on the hands or ankles must be realized as soon as possible.

References

1. Jackson DM. The diagnosis of the depth of burning. Br J Surg. 1953;40:588–96.
2. Kim DE, Phillips TM, Jeng JC, Rizzo AG, Roth RT, Stanford JL, Jablonski KA, Jordan MH. Microvascular assessment of burn depth conversion during varying resuscitation conditions. J Burn Care Rehabil. 2001;22(6):406–16.

Primary Wound Management: Strategy Concerning Local Treatment

2

Luc Téot

Abstract

The primary wound burn strategy depends on burn wound assessment. Deep second-degree and third-degree burns are candidates for surgery such as excision and grafting, while superficial burns can be treated using topical antimicrobials. In superficial burns, emergency management is based on cooling using water at a mild temperature. Burns are irrigated with water for a period of 5–10 min. Essentially, the aim of cooling is to remove pain. Antiseptics are applied to the wound, soaked with sterile water and dried using gauze.

Keywords

Skin graft · Primary wound · Cerium nitrate · Dermal substitute · Negative pressure therapy

2.1 Introduction

The primary wound burn strategy depends on burn wound assessment. Deep second-degree and third-degree burns are candidates for surgery such as excision and grafting, while superficial burns can be treated using topical antimicrobials. In superficial burns, emergency management is based on cooling using water at a mild temperature. Burns are irrigated with water for a period of 5–10 min. Essentially, the aim of cooling is to remove pain. Antiseptics are applied to the wound, soaked with sterile water and dried using gauze.

2.2 Blister Management

Blisters are encountered both in superficial and deep second-degree burns. A blister is an obstacle for the assessment of burns and should be removed. The top of the blister is gently cut with a sharp scalpel, allowing the liquid to leak out, and then the whole nonadherent epidermis is excised while trying to prevent painful contact with the base of the wound (Fig. 2.1).

L. Téot (✉)
Burns and Plastic Surgery Unit, Montpellier University Hospital, Montpellier, France
e-mail: l-teot@chu-montpellier.fr

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_2

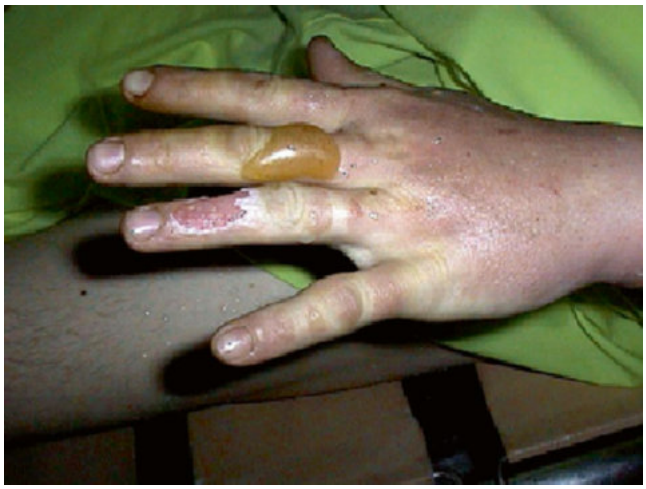


Fig. 2.1 Blister is removed on the fourth finger and not removed on the third finger. Debridement of theblister allows a right assessment of the burn wound

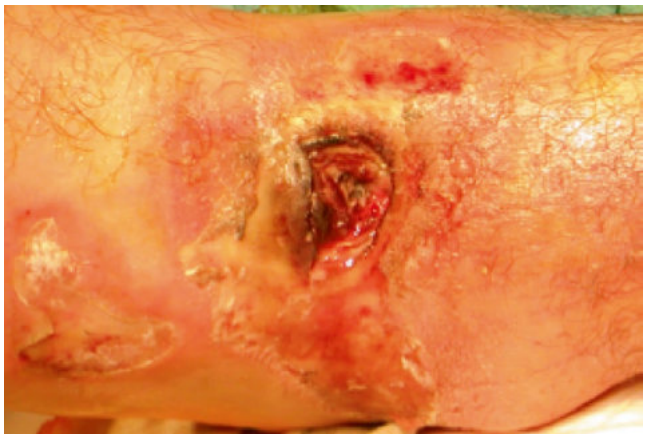


Fig. 2.2 Before, during and after the debridement of a deep electrical burn wound using a high-power hydrojet

2.3 When to Operate

Assessment is determinant for strategy but cannot be conclusive during the first examination. Surgical excision and grafting in deep second-degree burn wounds will be decided after a period of 2–3 days, as the evolution of the burn wound can be positive. Diagnosis of burn depth is difficult during the first days. Thirty percent of burn experts cannot determine the exact wound depth when analyzing the burns at the first assessment. On the contrary, observation of a frank third-degree burn will necessitate a surgical decision of immediate excision followed by a skin graft (Figs. 2.2 and 2.3).

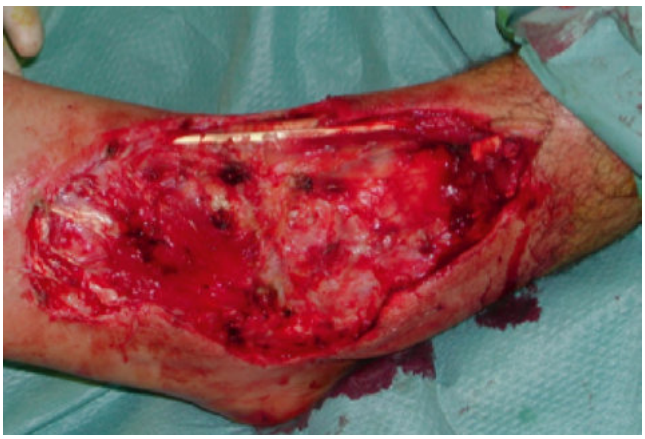


Fig. 2.3 Before, during and after the debridement of a deep electrical burn wound using a high-power hydrojet

2.4 Local Dressings (Table 2.1)

Silver sulfadiazine cream is the most commonly used local treatment worldwide. This drug is a combination of sulfonamides and silver, with a low risk of resistance and allergy, proposed in various situations. The cream modifies the local ground and can be applied over a period of 3 weeks. The need for a persistent antimicrobial dressing during the whole evolution of superficial burns has to be revisited (Demling). Most of the authors propose the use of non-antimicrobial dressings as soon as the diagnosis of superficiality is complete. Dressings formed by hydrofiber, a texturized carboxymethylcellulose frame including and delivering silver, have been successfully proposed in the local management of second-degree burn wounds. Silicone-coated dressings (Safetac technology), aimed at reducing pain during dressing changes, are often used in superficial burns (Heymans).

Table 2.1 Local dressings

Indication for use	Acute second degree (1–3 days)	Clear superficial second degree	Clear, deep second degree	Third degree
Silver sulfadiazine	++	±	++	±
Modern dressing (foam, silicone)	±	++	±	±
Flammacerium	–	–	–	+ (waiting for a solution before grafting)
Excision skin grafting	–	–	+	++
Negative pressure after excision	–	–	–	++ if noble tissue is exposed

2.5 Pain Management

Pain should be correctly managed during the first hours after the accident, then regularly reassessed. Assessment tools for pain are numerous and should be selected depending on the condition of the patient. The visual assessment scale is the most common mode of quantifying pain when the patient can communicate. Other scales may be suggested when the patient is under general anaesthesia. Pain is more pronounced when the burns are superficial, granulation tissue is present, and repetitive dressings are done. Pain at dressing change is a specific issue, more easily managed when using adapted modern dressings.

2.6 Surgery

The aim of surgery is to remove potentially infected materials from the wound, cover the exposed tissues using skin grafting and reduce the length of stay in the hospital. This coverage can be done using either a split-thickness skin graft, a full-thickness skin graft or step-by-step reconstruction of the skin using bioengineered tissues like artificial dermis (Fig. 2.4).

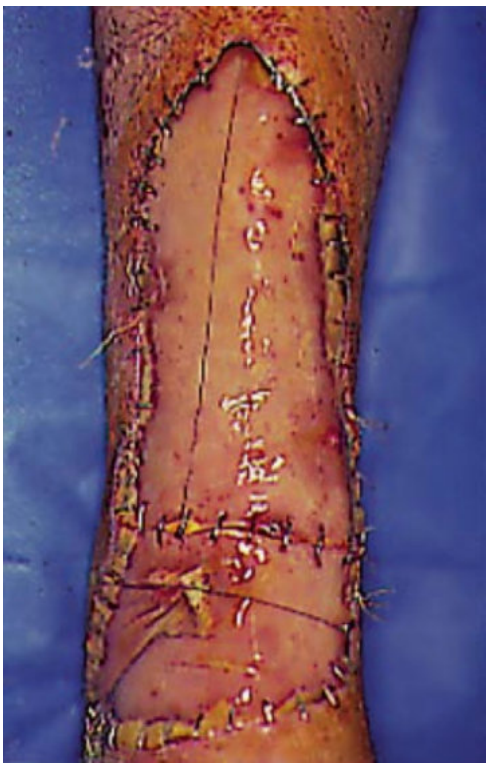


Fig. 2.4 Non-cellularized dermal substitute before skin grafting after deep burns of the lower limb. Revascularization can be sped up by the use of negative pressure therapy

2.7 Dermis and/or Skin Substitutes

Early excision and skin grafting is the most traditional method, where a skin graft is harvested from different possible areas (skull, thigh, legs, back and abdomen). Depending on the extent of surfaces to cover, the skin graft may be amplified using mesh grafts (×1.5, 2, 4, 6). The uniformity and regularity of the scar obtained with these methods mostly varies with the possibility to use unmeshed skin grafts. In moderate surfaces, the colour matching of the skin graft is also an issue and is better matched when harvested close to the recipient zone. When using a skin graft coming from further away, such as thigh skin to resurface a cheek, the risk of having a bad colour match is higher, leading to a permanent hyperchromia of the transferred skin.

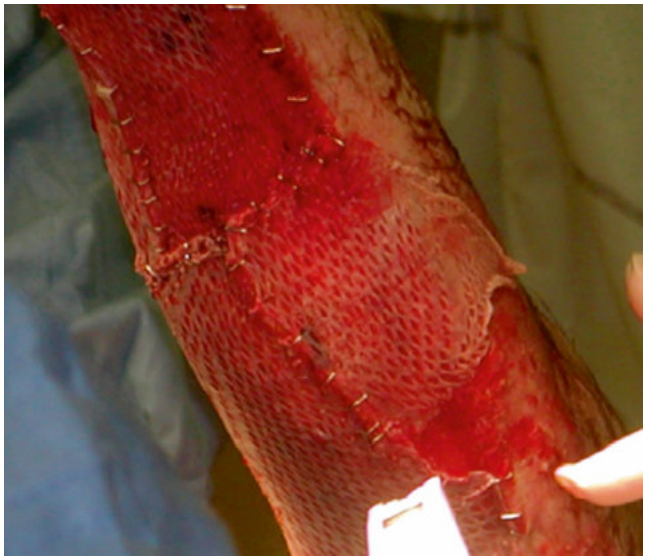


Fig. 2.5 Mesh grafting (×2) over the lower limb burns

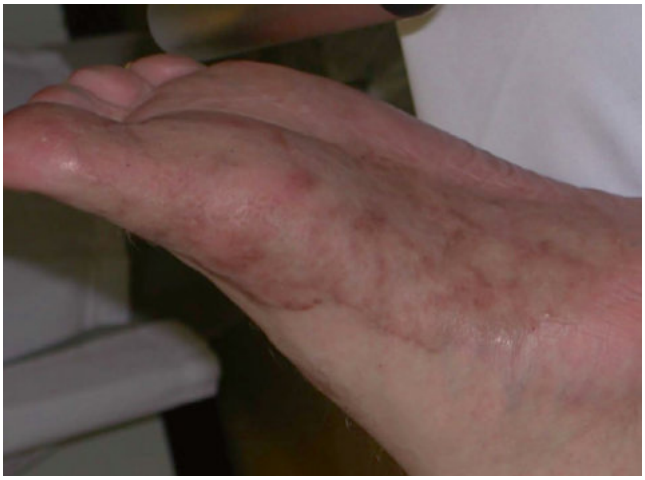


Fig. 2.6 Late result of skin grafting of the plantar aspect of the skin. Elasticity is required, and the use of a dermal substitute may help

The use of dermal substitutes will be dealt with in Chap. 13.

Scar improvement was observed when using double-layer dermal substitutes (Integra, Purdue, Heimbach, Renoskin, Hyalomatrix Pelnac), and more recently with single-layer dermal substitutes (Matriderm™) being immediately covered using thin skin grafts (Van Zuijlen).

Cadaver skin can safely be used, especially to cover temporarily deep burn wounds (Sheridan). The use of these materials is dependent on the availability, which is an issue linked to tissue banks, which are necessary to store them under adapted freezing conditions. Allografts can be used as a sandwich technique when autograft donor sites are limited (extensive TBSA) or when the patient is in poor general health, thereby limiting the possibility of general anaesthesia. Autografts can be extensively meshed (×6) and covered using ×2 meshed allografts (Fig. 2.5). Keratinocyte autologous cell cultures provide hope for the future if a functional dermis has been obtained (Rheinwald, Compton, Boyce).

The use of xenografts has also been proposed, either to replace dermal components or to secure skin grafts.

Early skin grafting may be contraindicated due to various situations such as contraindications for surgery or exposure of joints, tendons or vascular bundles.

Flammacerium (silver sulfadiazine plus 2% cerium nitrate) was proposed in the 90 s and was mainly used over extensive surfaces of third-degree burns where surgery cannot be performed on a single occasion. Flammacerium presents the unique possibility of combining with necrotic tissue, transforming it into a calcified tissue strongly adhering to the wound edges for a very long period of time. This powerful antimicrobial agent should be used only over limited surfaces (no more than 30% TBSA), the risk of inducing methemoglobinaemia being a real and life-threatening complication (Fig. 2.6) (Wassermann).

Negative pressure therapy is not the treatment of choice for burns but presents some interesting capacities to promote granulation tissue over noble exposed tissues like joints, tendons or vascular pedicles after complete surgical excision of the burnt tissues. This technique has indications when doubts persist on the vitality of the exposed tissues before skin grafts.

2.8 Conclusion

Burns management is mainly based on excision and grafting techniques in deep burns with the recent introduction of the use of dermal substitutes and on the use of antimicrobials in superficial burns with the recent use of modern dressings.

References

1. Van Zuijlen PP, Vloemans JF, van Trier AJ, Suijker MH, van Unen E, Groenevelt F, Kreis RW, Middlekoop E. Dermal substitution in acute burns and reconstructive surgery: a subjective and objective long-term follow-up. Plast Reconstr Surg. 2001;108(7):1938–46.
2. Boyce ST, Kagan RJ, Yabukoff KP, Meyer NA, Rieman MT, Greenhalg DG, Warden GD. Cultured skin substitutes reduce donor skin harvesting for closure of excised, full-thickness burns. Ann Surg. 2002;235(2):269–79.
3. Purdue GF, Hunt JL, Still JM. A multicenter clinical trial of a biosynthetic skin replacement, Dermagraft-TC, compared with cryopreserved human cadaver skin for temporary coverage of excised burn wounds. J Burn Care Rehabil. 1997;18:52–7.
4. Demling RH, DeSanti L. Management of partial thickness facial burns (comparison of topical antibiotics and bio-engineered skin substitutes). Burns. 1999;25(3):256–61.

5. Sheridan R, Choucair R, Donelan M, Lydon M, Petras L, Tompkins R. Acellular allodermis in burn surgery: a 1-year results of a pilot trial. J Burn Care Rehabil. 1998;19:528–30.
6. Heimbach D, Luterman A, Burke J, Cram E, Herndon D, Hunt J, Jordan M, McManus W, Solim L, Warden G, et al. Artificial dermis for major burns. A multicenter randomized clinical trial. Ann Surg. 1988;208:313–20.
7. Rheinwald JG, Green H. Serial cultivation of strains of human epidermal keratinocytes: the formation of keratinizing colonies from single cells. Cell. 1975;6:448–51.
8. Gallico GG, O'Connor NE, Compton CC, Kehind O, Green H. Permanent coverage of large burn wounds with autologous cultured human epithelium. N Engl J Med. 1984;311:448–51.
9. Compton CC, Hickerson W, Nadire K, Press W. Acceleration of skin regeneration from cultured epithelial autografts by transplantation to homograft dermis. J Burn Care Rehabil. 1993;14:653–62.
10. Wassermann D, Schlotterer M, Lebreton F, Levy J, Guelfi MC. Use of topically applied silversulfadiazine plus cerium nitrate in major burns. Burns. 1989;15:257–60.
11. Chang KP, Tsaii CC, Lin TM, Lai CS, Lin SD. An alternative dressing for skin graft immobilization: negative pressure dressing. Burns. 2001;27(8):839–42.
12. Tredget EE, Shankowsky HA, Groenveld A, Burell R. A matched-pair, randomized study evaluating the efficacy and safety of Acticoat® silver-coated dressing for the treatment of burn wounds. J Burn Care Rehabil. 1998;19:532–7.
13. Janzekovic Z. A new concept in the early excision and immediate grafting of burns. J Trauma. 1970;10:1103–8.

Debridement of the Burn Wound

3

Hans-Oliver Rennekampff, Mayer Tenenhaus, and Jennifer L. Schiefer

Abstract

At first glance, the rationale for debriding a burn wound seems evident. Nonviable, necrotic cells and tissue debris should be removed, and a clean, viable, and well-vascularized wound bed should be established, allowing for subsequent wound closure. In the case of burn wounds, biochemical burden in the wound affects not only the rate of wound healing but may also pose systemic risk to the patient. Adequate debridement is the first step in burn reconstruction surgery for minimizing scar formation.

Keywords

Debridement · Tangential excision · Selective debridement · Enzymatic debridement · Bioburden

3.1 Rationale for Debridement

At first glance, the rationale for debriding a wound, a burn wound for example, seems evident. Nonviable, necrotic cells and tissue debris should be removed, and a clean, viable, and well-vascularized wound bed should be established, allowing for subsequent wound closure; and yet, what concrete evidence do we have to justify this approach?

Several experimental burn wound models have clearly demonstrated that toxic products are released from burned skin and that these substances manifest a negative and potentially lethal systemic effect. In the last century, Allgöwer et al. [1] identified burn tissue-derived toxins responsible for severe immunosuppression and mortality. A lipoprotein complex with high toxicity has subsequently been isolated from the thermally injured skin, and neutrophils derived from the burn wound have been shown to produce leukotoxins, which have been associated with both morbidity and mortality in the burn patient. Hansbrough et al. were able to show that the presence of thermally injured skin has a systemic immunosuppressive effect on the individual [2]. Burn eschar, a reservoir of damaged and dying cells, releases endogenous host-derived molecules termed damage-associated molecular patterns (DAMPs), which bind to receptors expressed on innate immune cells, notably Toll-like receptors (TLRs), promoting an inflammatory response.

Necrotic, nonperfused tissue may serve as a nidus for bacteria and fungi, and as such, debridement of such tissue can potentially reduce the incidence of wound infection. While topical antimicrobial ointments may penetrate into the nonviable burned skin, systemic antibiotics may not reach the nonperfused tissues. Local bioburden does not only pose a risk for delayed wound healing and further tissue loss but may also systemically compromise the patient when sepsis occurs. A bioburden of more than 10^5 bacteria/gram of tissue is considered to be an invasive infection, which impairs wound healing, leads to graft loss, and may similarly impair the successful application of temporary wound dressings. The successful reduction of bioburden below concentrations of 10^5 bacteria/gram of tissue is a key element of surgical wound debridement [3].

3.2 Debridement of Blisters

The management of burn blisters has been a source of ongoing debate for many years [5]. While others have suggested that intact burn blisters may act as biologic bandages, keeping the underlying tissues safe from further trauma and des-

H.-O. Rennekampff (✉)
Clinic of Plastic Surgery, Hand Surgery and Burn Surgery, RheinMaas Klinikum, Würselen, Germany
e-mail: hans-oliver.rennekampff@rheinmaasklinikum.de

M. Tenenhaus
Department of Plastic and Reconstructive Surgery, UC San Diego Medical Center, San Diego, CA, USA

J. L. Schiefer
Clinic of Plastic, Reconstructive, Hand and Burn Surgery, Burn Center, Hospital Cologne Merheim, University of Witten-Herdecke, Köln, Germany

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_3

iccation, numerous researchers and clinicians have shown that blister fluid derived from the burn wound setting, in contradistinction to dermatologic and immunologically induced blisters, contains products that are inflammatory and vasoconstrictive in nature. In vitro testing has similarly shown inhibition of various key cellular elements involved in the epithelialization process. These findings have generally promoted the trend toward early debridement and cytoprotective strategies. This affords a proactive approach to the evaluation of the depth of injury while promoting standard wound-healing strategies. This is particularly true of cases in which the mechanism of injury is known to have been deep in nature, i.e., contact burns in aesthetically and functionally critical areas or when presented with large and fragile blisters as well as blisters that have broken.

3.3 Timing of Debridement

Is there an optimal time for debridement? Groundbreaking work by Janzekovic [6] demonstrated the clinical advantage of early debridement (3–5 days postinjury) and grafting vs. conservative management with 2–3 weeks of autolytic debridement, antimicrobial dressings, and finally skin grafting. In a number of subsequent studies [7, 8], early debridement was shown to reduce length of stay; however, no difference in mortality was found as compared to late debridement. In contrast to these studies, Herndon et al. [9] could demonstrate that in the group aged 17–30, without inhalation injury, an early intervention (<72 h post burn) could reduce mortality. Caldwell et al. [10] stated that early autologous grafting and subsequent wound closure could be of greater importance than early excision without autologous grafting. Important studies [11] in pediatric patients investigated the advantage of early excision. A 2006 meta-analysis [12] reviewed prospective studies comparing early excision and grafting with delayed grafting after eschar separation (historical approach) in burn patients without inhalation injury. In this meta-analysis, early excision was reported as spanning a period from as early as <24 h post-burn to the sixth post-burn day, making a recommendation on exact timing difficult. A very recent review of regrouped data described that mortality was lower in late excision (>7 days) compared to early excision (<6 days), while early excision reduced septic episodes and length of stay [13]. A significant reduction in length of stay, infectious complications, and metabolic demands was shown. However, overaggressive excision of indeterminate burn depth areas should be avoided. The impact, or "second hit," of surgical debridement may ask for thoughtful planning establishing damage control surgery principles. Conservative wound management can reduce the overall need for skin grafting in selected patients [12–14].

3.4 Technical Considerations

The decision to perform extensive excisions in a single setting vs. staged procedures is dependent upon the hemodynamic stability of the patient, the availability of resources, and the meticulous coordination of all parties involved in the care of the patient. No difference in survival has been shown when comparing either strategy. Single-stage excisions have been shown to shorten length of stay, and major excisions by simultaneous experienced teams can be performed safely and efficiently when well coordinated [15]. Planning the sequence of excisions in extensive surface area burns is an art and philosophy onto its own, dependent to a degree upon training, familiarity, surgical team size, injury distribution, the existence of concomitant injuries (i.e., cervical spine stability consideration), and pulmonary and hemodynamic considerations. Critical aesthetic and functional areas pose their own significant challenges, as it often takes longer to establish the absolute depth and extent of injury in these locations, and they often take much longer to meticulously excise and cover. For patients who have suffered extensive injuries, we prefer to address these areas on the second surgical intervention after the majority of the biologic and bacterial burden has been addressed. We do feel that this should be done rather quickly and yet expertly to minimize collateral injury, the effects of prolonged inflammation, and edema while expediting coverage so gentle range of motion, pressure, and rehabilitative therapies can be applied.

Blood losses can prove particularly challenging in larger excisions, and this is especially true when there is a delay in presentation [16]. Inflamed and infected wounds tend to bleed more during tangential excision. As always, clinical judgment and experience should guide this decision. Numerous methods are employed, often in combination, to optimize hemostasis and minimize blood losses during burn surgery. These include meticulous attention to maintaining the patients' core body temperature. Burn surgery is commonly performed in a very warm environment, and isolated surgical fields are patterned to minimize losses from wide-span exposure. The use of Bair huggers (warm air blankets), warming lights, warm and humidified air circuits for inhalation anesthesia, and even actively warming peripheral and core intravenous fluids are all measures to this end. Efforts to minimize blood losses include the use of cautery, the application of topical epinephrine solutions, topical thrombin solutions, topical H_2O_2 solutions, topical fibrin sealants, and injecting dilute epinephrine solution below the eschar, all of which have their advocates. Excision of burns from the extremities under tourniquet control can significantly minimize bleeding with the added benefit of improving critical structural visualization. This technique does, however, require a learning curve, as it can be quite challenging early on to differentiate vital from nonvital tissue without the generally relied upon endpoint of punctate bleeding.

3.5 Debridement of Hand Burns

Debridement of the hand requires special attention. Limited availability of specialized soft tissue coverage, the challenging contour of the hand and fingers with complex curves and concavities, and the superficial nature of critical neuromuscular elements make this area among the most difficult to judiciously excise. Full-thickness injuries require excision and autografting as soon as possible (see above) with the best available autologous skin. While fascial excision is often required for very deep burns to the dorsum of the hand, precise preservation of the paratenon as a graftable bed is sometimes difficult to accomplish (Fig. 3.1). Whenever viable fat or dermal remnants are still present (Fig. 3.2), we try to preserve this and cover the wound bed with a dermal substitute, e.g., Matriderm™, in an effort to improve subsequent graft take and potentially minimize contracture.

Superficial depth burns can be surgically debrided and covered with a temporary skin substitute in an effort to promote reepithelialization. If reepithelialization cannot be achieved within 21 days, an additional excisional debridement and skin grafting is necessary. Indeterminate-depth burns and deep partial-thickness burns can be surgically debrided or debrided by enzymatic means. Postdebridment a decision has to be made for grafting or conservative management. Burns to the palmar hand have to be carefully assessed. The specialized anatomy of palmar skin and its underlying fascial expansion is not readily replaced by a skin graft, and resultant contractures are particularly difficult to manage. Debridement should include removal of blisters and general wound management principles applied. A thickened palmar epithelium and deeply buried keratinocyte stem cells favor conservative management of palmar burns. However, if healing will not occur within 3 weeks, subcutaneous debridement and grafting with a skin graft are necessary.

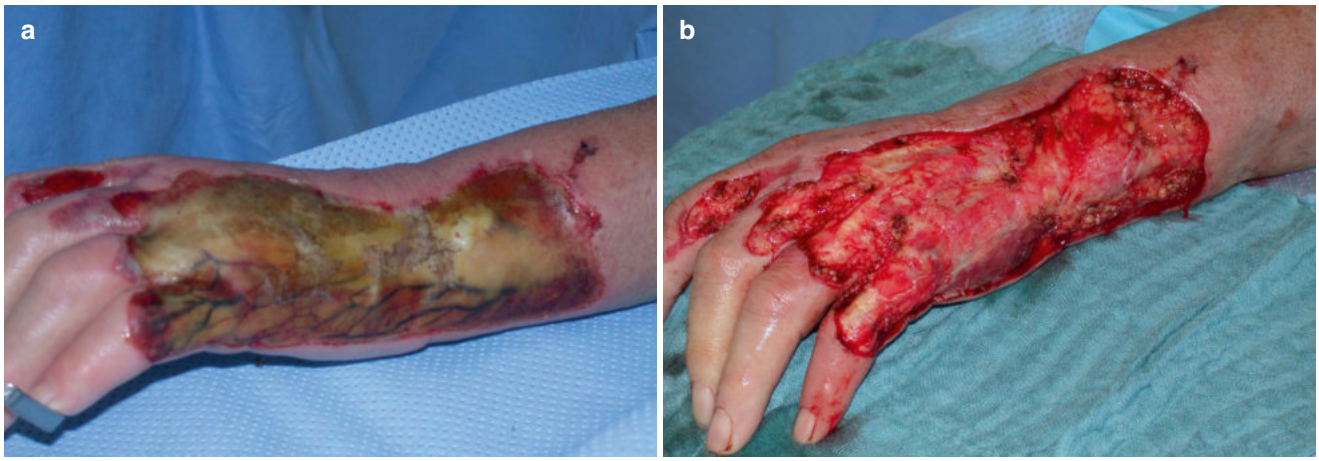


Fig. 3.1 Full-thickness burn to the dorsum of the hand (**a**). Fascial excision was intended. In some areas, like the extensor hood of the fifth finger, the paratenon could not be preserved; part of the extensor hood had to be debrided (**b**)

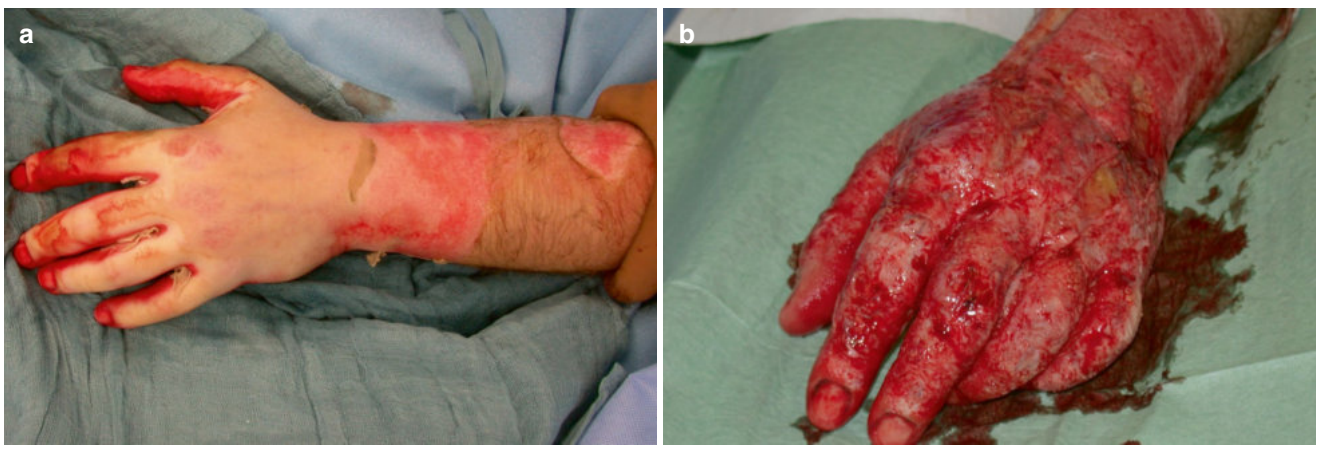


Fig. 3.2 Deep partial- to full-thickness burn to the dorsum of the hand (**a**). Tangential excision was performed down to viable tissue. Dermal remnants and subcutaneous tissue were preserved (**b**)

3.6 Debridement in Facial Burns

As in the case of the burned hand and fingers, the management of the burned face requires specialized attention. Optimal aesthetic and functional outcomes challenge the burn surgeon in both the acute and reconstructive phases. Despite the critical nature of these areas, a critical review of the literature reveals a rather limited subset of articles describing a formal reconstructive plan while demonstrating subsequent results [17, 19]. The initial management generally encompasses the removal of blisters and loose debris, followed by the application of topical antimicrobial wound care. Areas that are likely to heal within 3 weeks are debrided with the Versajet system or enzymatically, and a temporary dressing is applied. Full-thickness wounds should be addressed in the first week postburn with excision and allografting if the patient is stable enough. Indeterminate and partial-thickness facial wounds should be reassessed at approximately postburn day #10 to determine which areas will not heal within 3 weeks postburn. It is classically advocated that those areas that will not heal within 3 weeks require debridement and grafting. The concept of acute aesthetic unit excision vs. only excising the burned areas continues to be a source of ongoing debate. Many practitioners acutely preserve as much specialized tissue as possible, leaving formal aesthetic reconstructional strategies for later, while others (Klein/Engrav [15, 16]) have advocated complete acute excision of aesthetic units if the deeply burned area constitutes greater than 80% of the aesthetic unit.

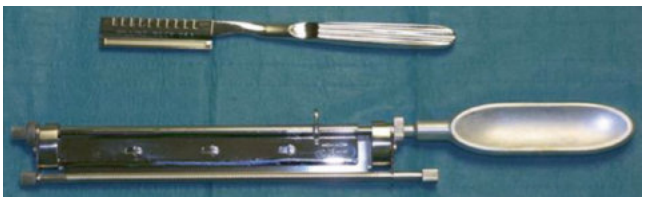


Fig. 3.3 The Goulian/Weck knife (*above*) and Humby knife (*below*) with attached guards, which allow for defined levels of tissue excision

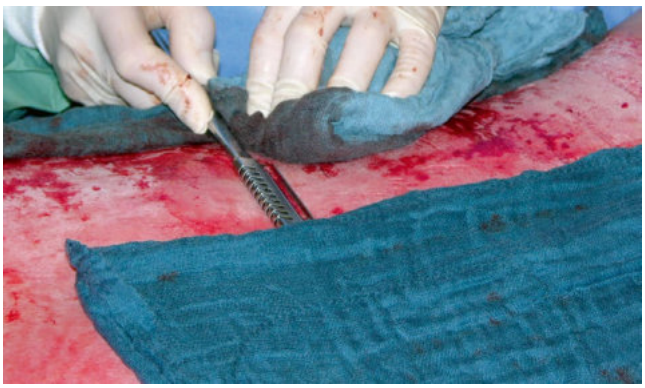


Fig. 3.4 Tangential excision with the Gouilan knife is performed until punctate bleeding is observed. Hemostasis is performed with topical application of epinephrine-soaked towels

3.7 Tangential Excision

Tangential excision describes the sequential and layered excision of devitalized tissues to a vital wound bed, generally recognized by punctate bleeding. The hypothesis is that preserving vital dermis under a split-thickness skin graft will improve functional outcome and reduce scar formation. It has similarly been reported [18] that early judicious tangential excision accelerates reepithelialization in partial-thickness wounds by reducing the biologic burden effects of the overlying eschar and its byproducts. An inadequately excised wound is more likely to become infected and is unsuitable for flap or skin graft take, necessitating further surgery. Tangential debridement is generally performed with the Humby or Goulian knife (Figs. 3.3 and 3.4), which have attached fixed-depth guards. Tangential debridement can also be achieved with enzymatic debridement, e.g., bromelain-containing ointments.

3.8 Fascial Excision

Fascial excision involves the complete excision of all skin and subcutaneous tissues down to the muscle fascia layer where defined vascular perforators are individually controlled, minimizing blood loss (Fig. 3.5). Experienced surgeons can perform this form of excision very quickly using electrocautery, and as a result, this technique can prove lifesaving when faced with very deep injuries in a hemodynamically challenged patient. While skin grafting on fascia or muscle is generally very successful, this technique results in a permanently disfiguring cavitary appearance. Fascial excision and grafting is inferior to skin grafting on the subcutaneous level with respect to late functional outcome, and as such, is usually reserved for massive burns.

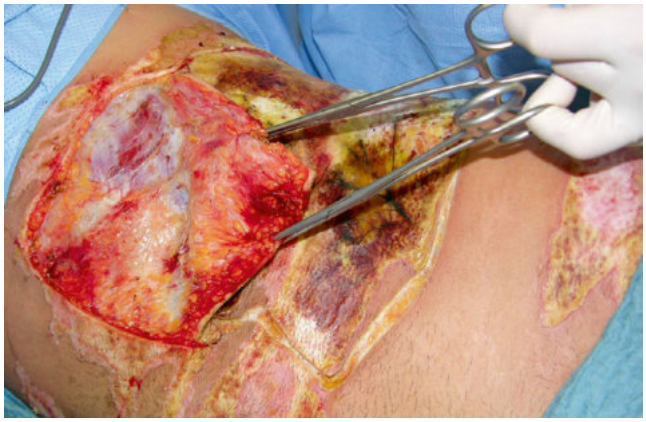


Fig. 3.5 Fascial excision is performed down to the muscle fascia

3.9 Hydrosurgical System Versajet

In our experience [20], the use of waterjet debridement (Versajet, Smith, and Nephew) has proven to be a great asset in wound bed preparation and surgical debridement by improving precision and control of debridement. Our clinical results demonstrate that the Versajet™ System can precisely and safely ablate burned necrotic tissue in vivo (Fig. 3.6). A controllable high-power water stream allows adjustment to the clinically anticipated depth of necrosis. In areas where the skin is of critical thickness, like the hand and the face, a tool like the Versajet™ System is likely to spare vital tissue. It is these protected and vital skin appendages that are necessary for timely wound healing and the subsequent reduction of scarring, as it is well established that the process of successful reepithelialization is dependent upon the presence of an appropriate dermal substrate on which keratinocytes can migrate. In comparison with the difficulties often incurred during the use of a cold knife, a cutting width of 14 mm allows for a very precise and contoured debridement in areas like the web spaces of the hand and foot, as well as in areas of the face like the nasolabial fold and eyelids. In larger areas necessitating rapid necrectomy, the maximum cutting width of 14 mm poses a potential disadvantage. An increase in the vacuum to debride at the faster speeds required for full-thickness wounds results in a continuous decrease in cutting precision. We and others have found the Versajet™ System, in its present form, inadequate for the excision of full-thickness and leathery dried eschar.

Middermal-level burn wounds are effectively debrided using the Versajet™ System with the Exact handpiece (Fig. 3.6). We advocate beginning at very low setting levels until comfort and efficacy are established. In general, several passes at settings ranging from five to seven are required to treat these deeper wounds. Deep partial-thickness wounds require multiple passes with settings ranging from seven to ten to obtain complete debridement.

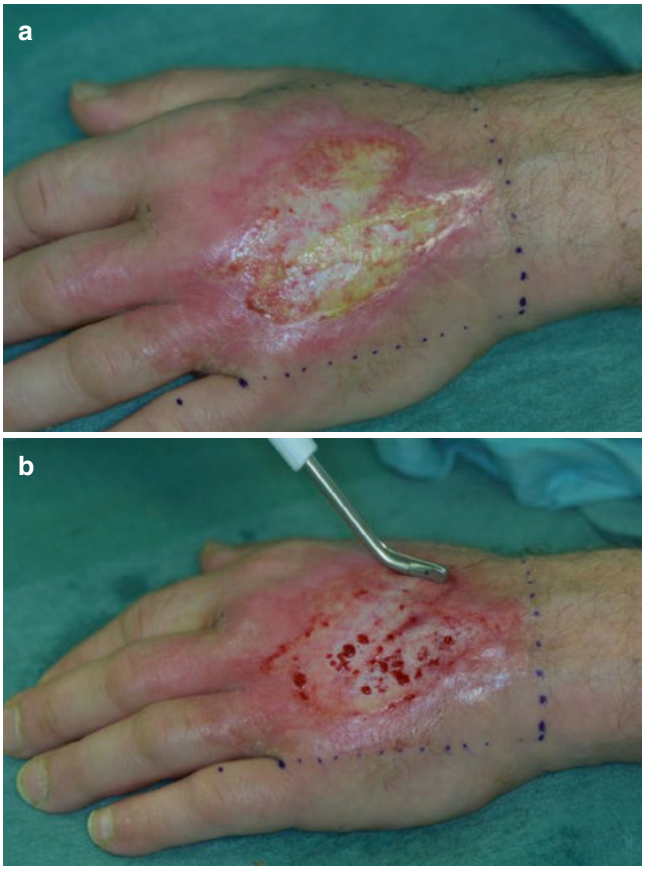


Fig. 3.6 Delayed presentation of a partial thickness burn to the hand (**a**). The Versajet is used to debride down to viable dermis (**b**). Debridement is stopped as soon as punctate bleeding is observed. The wound is then grafted with a split-thickness skin graft

3.10 Enzymatic Debridement

Since 2013 a bromelain-based enzyme mixture made from the stem of the pineapple plant, *Ananas comosus* (NexoBrid®, Mediwound), has been used by the authors [4] for debridement of burn wounds. The use of this modality has significantly improved burn wound debridement and offers an alternative to operative eschar removal, which has been found to be most beneficial in mid- to deep dermal burns and mixed depth patterns but can also be used in full thickness burns [21]. Enzymatic debridement, such as Nexobrid®, allows very selective removal of the burned tissue without destroying the intact tissue. Chemical burns and electrical burns are currently no indication for enzymatic debridement. Facial burns and hand burns have been described as good indications for selective enzymatic debridement [22]. Through preserving the maximal amount of tissue, wound healing is faster and scarring is better compared to traditional debridement.

Enzymatic debridement requires surface analgesia either by local or regional anesthesia or by general anesthesia, depending on the size and location of the burn wound [23].

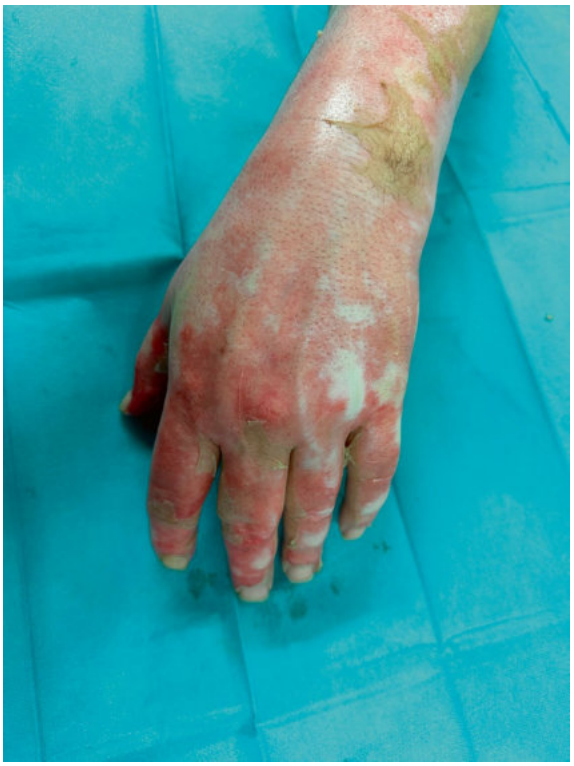


Fig. 3.7 Initial presentation of a superficial and deep partial-thickness burn of the hand after mechanical cleaning

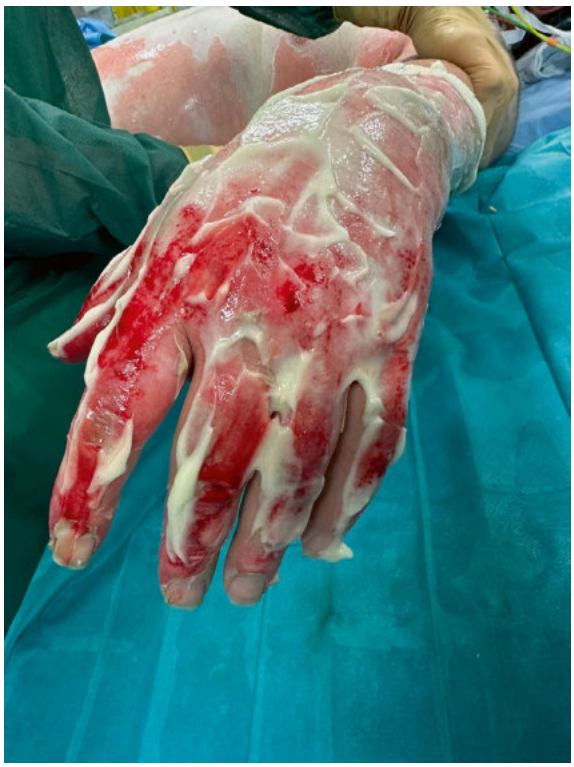


Fig. 3.8 Application of NexoBrid®

At present the manufacturer recommends a maximum of 15% TBSA for enzymatic debridement, but clinical experience has shown that sequential enzymatic debridement of larger areas is possible under adequate monitoring of the patient. Timing of enzymatic debridement is important, as the best results have been obtained with early treatment. Apart from circular burns with the risk of compartment syndrome, a presoaking of the mechanically cleaned burn wound (Fig. 3.7) is usually performed, followed by an application of Nexobrid® (Fig. 3.8) for 4 h. Afterwards the "slime" (Fig. 3.9) should be mechanically cleaned and the wound depth re-evaluated. Then, a post-soaking dressing should be applied for approximately 12 h. This additional wet-to-damp procedure leads to overall better results. Based on clinical appearance, subsequent therapy with either a temporary dressing or skin graft is planned.

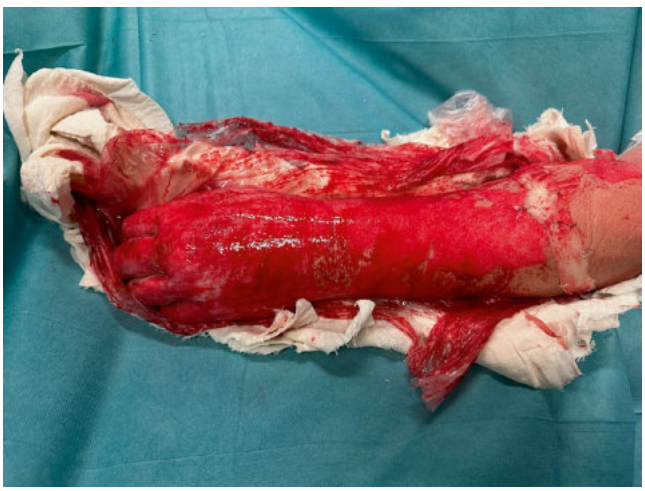


Fig. 3.9 Removal of the occlusive dressing after 4 h of NexoBrid® treatment. Reevaluation of the wound depth and decision for further treatment

References

1. Allgöwer M, Burri C, Cueni L, Engley F, Fleisch H, Gruber UF, Harder F, Russell RG. Study of burn toxins. Ann. N. Y. Acad. Sci. 1968;150:807–15.
2. Hansbrough JF, Zapata-Sirvent RL, Peterson VM, Bender E, Claman H, Boswick JA. Characterization of the immunosuppressive effect of burned tissue in an animal model. J Surg Res. 1984;37:383–93.
3. Robson MC, Heggers JP. Delayed wound closure based on bacterial counts. J Surg Oncol. 1970;2:379–83.
4. Schulz A, Perbix W, Shoham Y, et al. Our initial learning curve in the enzymatic debridement of severely burned hands-management and pit falls of initial treatments and our development of a post debridement wound treatment algorithm. J Burns. 2017;43:326–36.
5. Sargent RL. Management of blisters in the partial-thickness burn: an integrative research review. J Burn Care Res. 2006;27:66–81.
6. Janzekovic Z. A new concept in the early excision and immediate grafting of burns. J Trauma. 1970;10:1103–8.
7. Primary burn excision and immediate grafting: a method shortening illness. Burke JF, Bondoc CC, Quinby WC. J Trauma. 1974;14(5):389–95.
8. Sorensen B, Fisker NP, Steensen JP, Kalaja E. Acute excision or exposure treatment? Scand J Plast Reconstr Surg. 1984;18:87–93.
9. Thompson P, Herndon DN, Abston S, Rutan T. Effect of early excision on patients with major thermal injury. J Trauma. 1987;27:205–7.
10. Caldwell FT Jr, Wallace BH, Cone JB. Sequential excision and grafting of the burn injuries of 1507 patients treated between 1967 and 1986: end results and the determinants of death. J Burn Care Rehabil. 1996;17:137–46.
11. Xiao-Wu W, Herndon DN, Spies M, Sanford AP, Wolf SE. Effects of delayed wound excision and grafting in severely burned children. Arch Surg. 2002;137:1049–54.
12. Ong YS, Samuel M, Song C. Meta-analysis of early excision of burns. Burns 2006;32:145–150.
13. Wong L, Rajandram R, Allorto N. Systematic review of excision and grafting in burns: Comparing outcomes of early and late surgery in low and high-income countries. Burns 2021;47:1705–13.
14. Jeffrey SLA. Debridement of pediatric burns. In: Granick MS, Gamelli RL, editors. Surgical wound healing and management. Informa Health Care; 2007. p. 53–6.
15. Bishop JF. Burn wound assessment and surgical management. Crit Care Nurs Clin North Am. 2004;16:145–77.
16. Steadman PB, Pegg SP. A quantitative assessment of blood loss in burn wound excision and grafting. Burns. 1992;18:490–1.
17. Cole JK, Engrav LH, Heimbach DM, Gibran NS, Costa BA, Nakamura DY, Moore ML, Blayney CB, Hoover CL. Early excision and grafting of face and neck burns in patients over 20 years. Plast Reconstr Surg. 2002;109:1266–73.
18. Klein MB, Moore LM, Costa B, Engrav LH. Primer on the management of face burns at the University of Washington. J Burn Care Rehabil. 2005;26:2–6.
19. Davis SC, Mertz PM, Bilevich ED, et al. Early debridement of second degree burn wounds enhances the rate of reepithelialization—an animal model to evaluate burn wound therapies. J Burn Care Rehabil. 1996;17:558–61.
20. Rennekampff HO, Schaller HE, Wisser D, Tenenhaus M. Debridement of burn wounds with a water jet surgical tool. Burns. 2006;32:64–9.
21. Shoham Y, Gasteratos K, Singer AJ, Krieger Y, Silberstein E, Goverman J. Bromelain-based enzymatic burn debridement: a systematic review of clinical studies on patient safety, efficacy and long-term outcomes. Int Wound J. 2023;20:4364. https://doi.org/10.1111/iwj.14308.
22. Schulz A, Shoham Y, Rosenberg L, et al. Enzymatic versus traditional surgical debridement of severely burned hands: a comparison of selectivity, efficacy, healing time, and three-month scar quality. J Burn Care Res. 2017;38:e745–55.
23. Schiefer JL, Lipensky A, Fuchs PC, Heitzmann W, Schulz A. Patients' satisfaction with anesthesia in enzymatic debridement from a surgical perspective. Burns. 2020;46:1073–82.

NexoBrid Enzymatic Debridement and Minimally Invasive Modality for Burn Care

4

Lior Rosenberg and Hajime Matsumura

Abstract

Thermal tissue injuries lead to heat denatured necrotic tissue, commonly known as burn eschar. This eschar can induce both local and systemic complications, including inflammation and infection which also contribute to the breakdown of the eschar through autolysis. This process of "conservative" treatment through topical wound medication and dressing changes exacerbates both local and systemic insults as well as the development of granulation tissue, ultimately leading to heavy scarring through healing by secondary intention.

Keywords

Burns · Bromelain · NexoBrid · Minimally invasive modality for burn care · MIM · Enzymatic debridement · Enzymatic escharotomy · Enzymatic surgery · Burn Mass Casualties Incident (BMCI) · Surge capacity

Thermal tissue injuries lead to heat denatured necrotic tissue, commonly known as burn eschar. This eschar can induce both local and systemic complications, including inflammation and infection which also contribute to the breakdown of the eschar through autolysis. This process of "conservative" treatment through topical wound medication and dressing changes exacerbates both local and systemic insults as well as the development of granulation tissue, ultimately leading to heavy scarring through healing by secondary intention.

L. Rosenberg
Department of Plastic and Reconstructive Surgery, Soroka University Medical Center and The Rosenberg Museum of Medicine, Ben Gurion University of the Negev, Beer Sheva, Israel

H. Matsumura (✉)
Department of Plastic and Reconstructive Surgery, Tokyo Medical University, Tokyo, Japan
e-mail: hmatsu@tokyo-med.ac.jp

Over the past five decades, the established standard of care (SOC) for burn injuries is based on early surgical removal of burn eschar by tangential excision (surgical, excisional debridement). This results in large and deep skin defects that should be autografted for wound closure. This strategy is effective in reducing mortality, morbidity, and some hypertrophic scarring in burn patients. However, excisional surgery and autografting are extremely traumatic. They involve general anesthesia, massive tissue, blood and heat losses and they depend on experienced, precious surgical teams and facilities.

Since 2012 the conventional surgery-based SOC for thermal injuries has begun being replaced by an early, fast, efficient, and selective enzymatic debridement using NexoBrid (NXB), a Bromelain-based gel medicament. NexoBrid completes eschar removal in deep burns in a single 4 h topical application, effectively preventing or releasing burn induced compartment syndrome (BICS).

When evaluating alternative debridement methods or strategies, the selection process considers five key criteria: *safety* (including the need for intensive care unit [ICU] support, blood and heat losses), *efficacy* (complete debridement and effective escharotomy) *selectivity* (preservation of all not-injured tissues), *speed* (early and fast, within hours post admission complete eschar removal), and *cost efficacy*. Assessing the merits and drawbacks of each criterion can be facilitated through the Debridement Index chart (Fig. 4.1) [1].

Burn care with NXB has been compared to the standard of care (SOC) in numerous controlled studies, consensus papers, and publications. The results (e.g. adults & pediatrics phase III RCTs) demonstrate that NexoBrid: [2–8]:

1. Achieves significantly earlier, more rapid, complete and selective eschar removal (1–0.9 vs. 3.8–5.9 days).
2. The fast and early debridement prevents or resolves enzymatically burn induced compartment syndrome (BICS).

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_4

Debridement Index Assessment Chart (For burns, calculated for a 5%TBSA fresh burn)

	The feature	Maximum score	Credit	Debit	
	A. Safety (systemic safety)	23			
1	No systemic toxicity or trauma, not pyretic		5	excessive trauma	10
2	Wide dosage/application safety margin		5		
3	Not allergenic		5		
4	Does not cause bleeding		3		
5	Debridement may start immediately		5	each additional day	X 3
	B. Selectivity (local safety)	25			
6	No need to protect surrounding local tissue		1		
7	Destroys only the eschar (highly selective)		15		
8	Does not harm epithelium		3		
9	Does not harm dermal components		3		
10	Accurate visual diagnosis of the debrided bed		3		
	C. Efficacy % of eschar debrided	40			
11	A completely clean bed in a single use		15	For any additional procedure to reach clean bed	X 3
12	No need for surgical excision to reach clean bed		15		
13	Can be used for fast (>2Hours) escharotomy		10		
	D. Speed				
14				Time to complete debridement	1 x hour
15				Recovery between procedures	1 x hour
	E. Cost & Simplicity for 5% TBSA				
16				MDs needed per procedure	X 3
17				Specialized MDs (Surg. Anesth)	X 4
18				Nurses needed per procedure	X 2
19				Cost all material & manpower needed, for every SUS: 100	X 1
20	20. Could be debrided as an outpatient		3		
21	21. No need for pain medication (not IV)		1		
22	22. No need for IV pain medication		3		
23	23. No need for IV sedation		4		
24				Need general anesthesia	5
25	No need for O.R. facilities		3		
26	No need for blood bank facilities		3		
	Grand Total				

Fig. 4.1 The Debridement Index: "Debridement Index" chart can be used to compare two or more debriding means or strategies (e.g. tangential excision vs. hydrosurgery vs. dermabrasion) following five criteria. Each of these criteria is composed of several factors which have to be assessed independently. Each factor has its own "positive" and "negative" score with score-value relative to the importance of the specific factor in the grand scheme of the debridement process. After tallying up the positive "credit" and the negative "debit" points the higher total score corresponds to a better debridement agent and method. Obviously, each factor may have a different score depending on the type of the specific wound and eschar but for a given type of eschar all the debriding means can be judged using the same criteria and score. The score of large eschars such as burns are calculated according to a standard given area. Deep burn wound of 15%TBSA illustrates in this chapter the Debridement Index. Similar indices with the same criteria and factors but with different scores may be used for other types of wounds and eschars [1]

3. Results in significantly reduced surgical burden: excisional debridement 4–8.3% vs. 72–64.4% (and additionally surgical escharotomy and autografting).
4. Demonstrates very significant reductions in blood loss for both adults and children (14–32 cc vs. 815–202.6 cc, respectively).
5. Results in comparable or improved final outcomes of cosmesis (approximately 25% MVSS reduction) and function.
6. Results in comparable or better times to wound closure.
7. Shows benefits in treating pediatric burns, as well as burns to the hands and face.
8. Results in comparable or improved mortality and morbidity rates in severe burns.
9. Reduces dependency on sophisticated and costly facilities, such as surgical personnel, operation rooms, blood bank, general anesthesia and ICU resources.

10. A potential role in Burn Mass Casualties Incidents (BMCI) by increasing surge- capacity.

NXB is the base for a minimally invasive modality (MIM) in burn care by being a non-surgical fast, effective and selective topical debriding agent that complete debridement of deep burns early on admission in a single 4 h topical application. The large areas of preserved dermis can be healed by epithelialization over dermis with autografting reserved only for full thickness and non-healing wounds. NexoBrid use from case selection to post treatment management must follow appropriate training. Assistance with initial cases by experienced physicians will facilitate a smooth learning curve and integration of NXB into standard clinical practice.

4.1 Introduction and Background

The thermal insult rapidly coagulates, denatures, and annihilates all cutaneous components—cells, matrix, vascular and neural structures, forming the burn eschar within seconds. Following the primary trauma, a violent local inflammatory response ensues, with the burn eschar triggering additional local and systemic inflammation-infection insults. Locally, the damage extends to the surrounding, non-injured tissues, adversely affecting the zones of hyperaemia and stasis that surround the central zone of necrosis. This prompts "burn wound propagation" or "progression," deepening and extending the initially destroyed tissue.

Within 2 or 3 days, the normal cutaneous bacterial flora, often accompanied by germs from patients' orifices, treating personnel, and surrounding facilities, contaminate the eschar, transforming it into a source not only for local and systemic inflammation but also for infection. This can lead to systemic inflammatory response syndrome (SIRS), bacteraemia, sepsis, and potentially death. The eschar and bacteria elicit a potent inflammatory response from the surrounding viable tissue, attracting neutrophils that release proteolytic enzymes and inflammatory mediators, ultimately leading to the maceration of the eschar through "autolysis" and "sloughing" in 2–3 weeks.

Bacterial activity within the eschar as their substrate, and related infectious and inflammatory processes, depend on the eschar's quantity (thickness and surface area) and how long it remains in contact with the body, serving as the source of local and systemic infectious insults, bacteremia, sepsis and death. Locally, the prolonged inflammatory-infectious response induces the formation of granulation and hypergranulation tissue, which can evolve into dense, deforming, and hypertrophic scars (HS). Delaying eschar removal increases the incidence and severity of early and late eschar-related local and systemic complications, especially in more extensive burns [8–23].

An immediate component of the inflammatory response is the rapidly increasing tissue edema that under the non-resilient eschar rapidly elevates the interstitial/compartment pressure. This mounting pressure compromises venous return, increasing congestion, swelling, and pressure. This further reduces blood supply to the already compromised cutaneous supply, further reducing perfusion to vital structures such as nerves and muscles, causing a burn-induced compartment syndrome (BICS). Early diagnosis, within hours post injury, of the developing or potential BICS and the release of the constricting eschar by deep incisions (surgical escharotomy) may prevent and resolve this process. Delay or hesitation in diagnosing BICS and reluctance to perform an adequate surgical escharotomy, especially in borderline cases or where experienced burn surgeons are not readily available, may lead to irreversible damage to the skin, muscles and nerve. Adequate surgical escharotomy releases compartment pressure but leaves extensive scars and has the potential to harm important underlying structures (i.e., nerves, vessels), leading to complications and permanent disabilities [24–27].

Thus, burn severity, depth, and extent are not static conditions but a dynamic process where injury progression depends on factors such as the severity of the initial thermal injury, anatomic site, time from injury, intensity of the inflammatory and infectious processes, vasoconstriction, use of vasoconstricting agents, skin resilience and looseness, as well as physical factors like local skin tension, pressure, desiccation, and temperature. These factors can dramatically extend the original damage. A diagnosis-based treatment strategy relies on timely assessment of burn size, depth, and the potential or presence of BICS. Even for experts, accurately performing such a diagnosis early post-injury is challenging. Often, the diagnosis is postponed for a few days until the secondary damage has completed its course or after the opaque eschar covering the wound bed has been removed [26–31]. Only early and complete eschar removal, debridement, can prevent or mitigate eschar-related complications and initiate the healing process, marking the first stage of any wound care strategy.

4.1.1 Debridement and Timing

The timing of debridement is crucial as earlier debridement improves the treatment outcomes with reduced risk for complications [24–27, 30–36].

(a) *Immediate Debridement:* Completing debridement within a few hours post-burn injury may enhance the survival of the zone of stasis and reverse the zone of hyperaemia. It has the potential to attenuate or prevent various related local and systemic inflammatory-

infectious reactions and may also prevent or release BICS.

(b) *Early Debridement* (Within 1–3 Days): Although too late to prevent or release BICS, early debridement during the first 3 days still reduces the risk of infection by reducing bacterial load, critical colonization, and inflammation, mitigating their associated outcomes.

(c) *Early-Delayed Debridement* (Up to 7 Days): Debridement within the first week post-burn, although exposing the patient to most eschar-related complications, may, if combined with wound closure (autografting), prevent healing by secondary intention and consequent scarring, ultimately improving the final outcome.

(d) *Delayed Debridement* (After 1 Week): A week delayed debridement exposes the patient to all eschar-related complications and increases the risk of scarring in the final outcome.

4.1.2 Autolytic, Non-surgical Debridement

This involves the use of topical wound care means such as dressing changes, baths, showers, topical ointments, and medications to induce "eschar separation" (sloughing or autolysis) and reduce infection. This practice has been in use since humans were first exposed to fire. Despite early recognition of the need for early eschar removal, several enzymes reached the market and found to be ineffective and some also dangerous. Only collagenase that is very slow (may take 2 weeks to debride the burn eschar) has remained in the market as a debriding enzyme until recently [27]

4.1.3 Surgical Debridement

Formally introduced by Zora Janzekovic in 1970 [8] that used dermatomes that were originally developed for harvesting skin grafts: for tangential excision (escharectomy). Such excisional debridement that ends in a practically full thickness defect is followed by split-thickness skin graft (STSG) wound closure. This method, currently the standard of care (SOC) for deep burns, requires surgically "shaving" the burn eschar down to the level of viable, bleeding tissue to ensure the STSG "take." However, this usually involves the removal of up to 30–50% of viable tissues up to the entire dermis, which could have potentially healed spontaneously by epithelialization [38–43]. In order to save some of this otherwise sacrificed dermis, more selective surgical procedures (dermabrasion, hydro-surgery) can be used. These are slow, skill-dependent procedures that require general anesthesia, operation theaters and ICU resulting in blood and heat losses as well as spraying potentially contaminated particles into the OR environment. The need of autograft following surgical debridement for closing the wound by primary intention requires additional sacrifice of not injured, large, donor site's areas with related morbidities, rarely appreciated by the surgeons. Healed autografted wounds still result in up to 80% incidence of scarring, often HS at the graft's edges, incisions (i.e. meshing) and donor sites.

In order to reduce these costs of burn surgery, especially in burns of uncertain depth, challenging diagnosis or in unstable patients, one may start the treatment by the "conservative", non-surgical autolytic approach, until the diagnosis is clearer, the patient is more stable and the final surgical or non-surgical burn care strategy is chosen. This "wait and see" approach is a slow (days), gradual process of eschar decomposition where some areas may still be covered by the decomposing eschar while other areas, already devoid of eschar, are granulating and epithelializing. If late surgery is chosen, it may be associated with both the "conservative" as well as the surgical, local and systemic complications. The gradual development of hypergranulation tissue often results in HS even when autografted with the contracted scar tissue developed under and at the edges of the grafts [38–41].

4.1.4 Choosing a Debridement Means

In any wound care and especially burns, debridement is the first step of the entire treatment strategy that will determine the final outcome. The challenging choice of a debridement method or strategy for a specific wound can be facilitated by weighing and comparing objectively the five different criteria of debridement: safety, selectivity, efficacy, speed, and availability/user-friendliness/cost efficacy:

A. *Safety:* The debriding method must be safe for use on critically ill patients by non-specialized personnel, with no adverse, local or systemic effects, including blood and heat losses.

B. *Selectivity:* The debridement technique should selectively remove only dead tissue, sparing non-traumatized remnants, particularly the dermis. This allows for an accurate visual diagnosis of the burn's true extent, even by non-specialized medical professionals. The salvaged dermis can heal spontaneously by epithelialization, reducing need for autografting and scarring.

C. *Efficacy:* The chosen method should effectively remove the entire dead eschar in a preferably single, short procedure, capable of preventing or resolving BICS.

D. *Speed:* The debridement means should be safely used immediately or early on admission, completing the procedure, including resolution or prevention of BICS, within a few hours. This swift action reduces the risk of

inflammation and infection, facilitating an accurate diagnosis of the burn bed's extent and condition and initiating the wound closure care.

E. *Availability, User Friendliness, and Cost Efficacy*: The debridement method should be easily accessible, cost-effective, and straightforward to use. It should be applicable early in the treatment process, independent of highly trained personnel, surgical facilities, and intensive care units and ideally, it can be performed at the patient's bedside.

To facilitate the comparative evaluation of debridement methods and means, an assessment chart: a "Debridement Index" (Fig. 4.1) [1] can be utilized. This index considers each criterion, composed of several factors, positive and negative, that should be individually assessed.

4.2 NexoBrid and Enzymatic Debridement

NexoBrid, a concentrate of Bromelain-Based proteolytic enzymes (Anacaulase BCDB), is an approved debriding medicament (NexoBrid®, NXB, MediWound Ltd., Yavne, Israel) for deep, partial, and full-thickness thermal burns. Extracted from the pineapple stem (Ananas comosos), approved medical grade Bromelain is the active pharmaceutical ingredient (API) in NexoBrid, displaying an affinity for burn's denatured eschar collagen and selectively digesting it.

Apart from its potent proteolytic and exfoliative properties, Bromelain exhibits additional therapeutic benefits, including anti-inflammatory, anti-oedema, analgesic, anti-thrombotic, anti-tumor/pro-apoptotic effects. These effects are mediated through the kallikrein-kinin and arachidonic acid pathways, as well as influences cell-mediated immunity [44–46].

4.2.1 Indication

NexoBrid has been approved in the EU in 2012 and the US in 2023 as a biological drug and is indicated for eschar removal in adults (and in the EU also children) of deep partial (DPT) and full-thickness (FT) thermal burns covering up to 15% Total Body Surface Area (TBSA) in a single session.

4.2.2 Dosage and Administration

The product comprises a lyophilized enzymatic powder, which is mixed with a vehicle gel at a ratio of 1/10 with 2 gr or 5 gr of NXB in 20 gr or 50 gr of the gel, respectively. 2 gr of NXB in 20 gr of gel is sufficient to cover in a 1.5–3 mm thick layer 1% TBSA of an adult (180–200 cm^2). Obviously in pediatric patient where the %TBSA area is smaller, the dosing is decided only by the surface area (2 gr in 20 gr. gel for 180–200 cm^2). The mixed NXB gel is applied onto the burn eschar in an occlusive dressing for 4 h, during which the enzymes selectively and completely digest the burn eschar, revealing a dermal or subdermal viable bed (Fig. 4.2).

4.2.3 Safety and Contraindication

As in any protein preparation, hypersensitivity/allergic reaction may occur. NXB is contraindicated in patients with known hypersensitivity to anacaulase-bcdb, bromelain, pineapples, or to any of the other components as well as known hypersensitivity to papayas or papain because of the risk of cross-sensitivity.

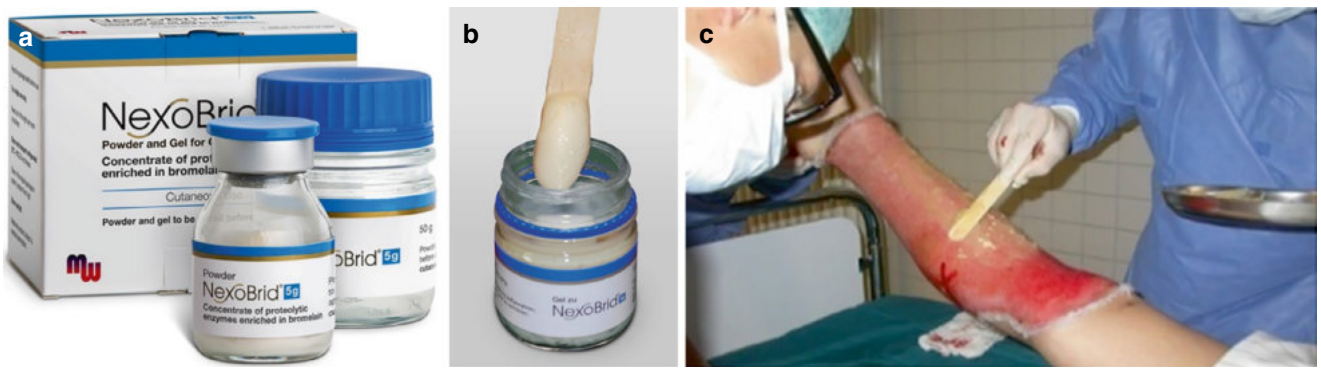


Fig. 4.2 (**a**) The NexoBrid vial of lyophilized enzyme and jar of vehicle gel. (**b**) Mixing enzyme and vehicle to prepare the active NexoBrid Gel. (**c**) Applying NexoBrid gel from the jar or from a larger sterile container

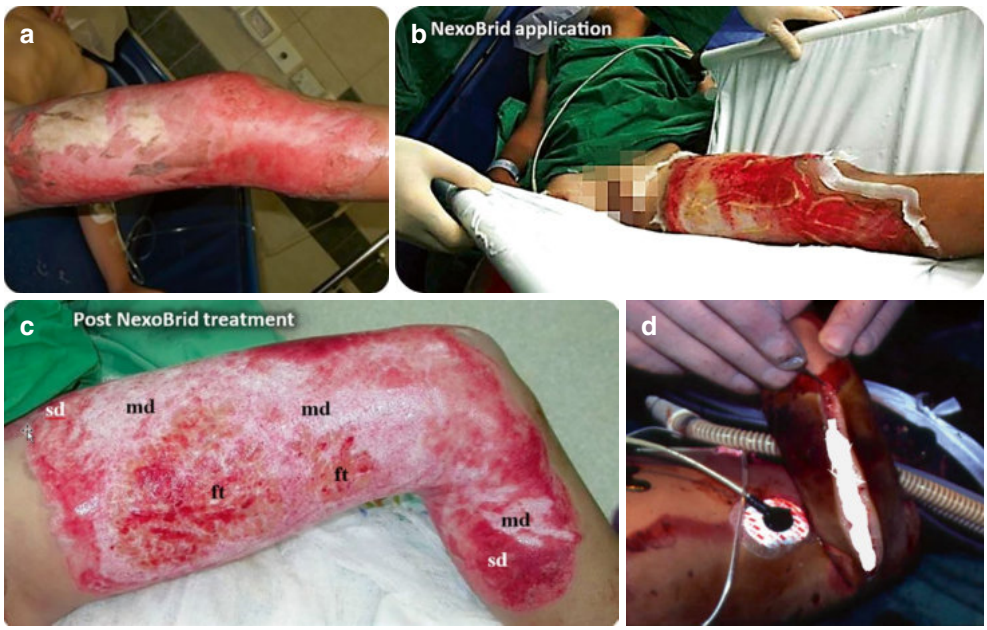


Fig. 4.3 (**a**) Deep flame burns of the thigh on admission. (**b**) Application of NXB on admission day. The Vaseline ointment (adhesive barrier) that surrounds the burn area to debride, covered with NXB with the occlusive film to be applied over the entire area. (**c**) Post NXB debridement: sd superficial dermal burn, md mid-deep reticular dermal burn, ft. full thickness burn with exposed fat and deep exposed sartorius muscle. (**d**) Protection of escharotomy incision or abraded skin prior to NXB application by fatty ointment

4.2.4 NXB Application

Enzymatic debridement does not mandate an operating theater, surgical personnel, or facilities and can be performed at the patient's bedside very early after cleansing. It should be performed by a trained health care provider (Fig. 4.3).

- *Preparation of the Burn* by a thorough cleansing of the burn to be debrided using saline or an antiseptic solution, removing all remnants of medications and blisters that may insulate the eschar from the debriding gel. Carefully scrap away adherent charred blisters that might adhere to the eschar especially in deep flame or contact burns. The presence of heavy metals such as silver (Hg) or iodine (I) (following SSD or Iodine based medicaments) in eschar may interfere with enzymatic activity.
- *Moisten the Wound Bed* by soaking for at least 2 h with an antiseptic/antibacterial solution before applying NXB to ensure moisture and reduce bacterial burden. Just before applying NXB gel sprinkling normal saline will effectively moisten the eschar' surface.
- *Pain Management:* The NXB potent activity may cause a breakthrough acute pain, especially in the more superficial/partial thickness burns during application for 30–45 min and upon removal after 4 h. Patients should be prepared by thoroughly informed that NXB debridement may induce temporary pain without appropriate analgesia. To ensure a pain-free and comfortable NXB procedure it is important to adhere to standard pain and sedation medication as routinely practiced in burn care and outlined in the European consensus guidelines and numerous publications. Routine pain prevention should be initiated 10–15 min before NXB application [4–7]. Such practices may include non-steroidal anti-inflammatory drugs (NSAIDs), opioids (Morphine, Fentanil, Oxicodon, Methadone, Hydromorphin, Codein, Hydrocodein), anesthetic agents like Propofol, ketamine, +/− sedation (e.g., midazolam), Pentrox inhaler (3 cc. Methoxyfluran), and/or local-regional blocks and for the more cooperative patients: patient controlled analgesia (PCA).
- *Preparation of Active NXB Gel* using aseptic technique and sterile tongue depressor mixing the NXB powder with the corresponding gel vehicle in 1–10 ratio (2/20 or 5/50) by pouring the powder into the vehicle jar or both into a larger sterile container.
- *Preparation of NXB Gel Containing Occlusive Dressing* for the 4-h topical treatment should be prepared by surrounding the burn with a fatty ointment (e.g., Vaseline) adhesive barrier a few centimeters away from the burn edge.
- *Moisturizing the Treated Burn:* spraying a few cc of saline onto the cleansed burn just before application will ensure adequate moisture.
- *NXB Gel Application* onto the entire burn surface (1.5–3 mm thick layer) using a sterile wooden tongue

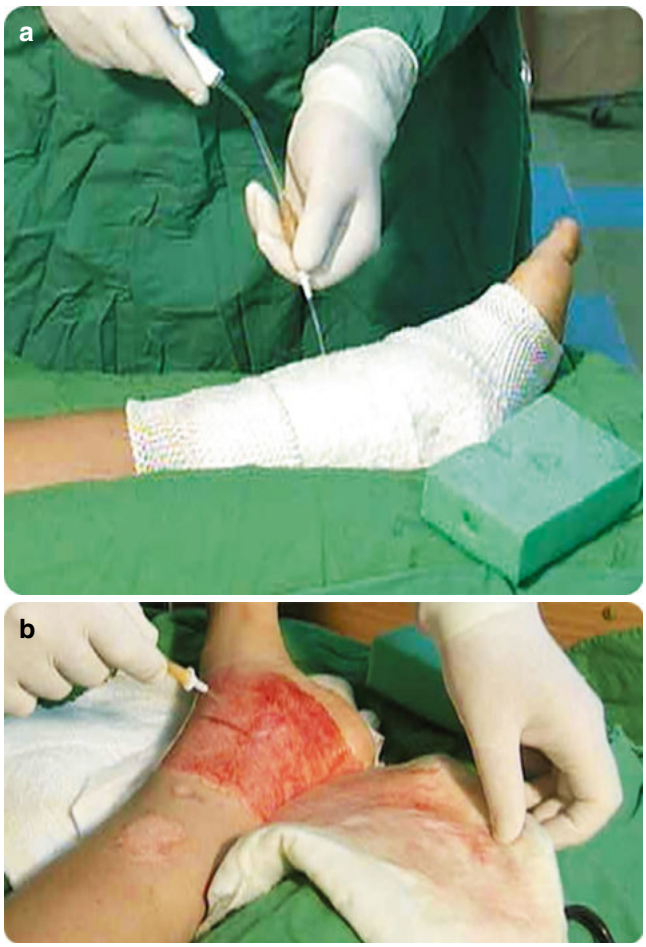


Fig. 4.4 (**a**) Post NXB application, soaking dressing. (**b**) Removal of the wet-to-dry dressing: the absorbed remnants of the NXB gel and dissolved eschar stains the dressing

depressor or spatula and the area is covered with an occlusive film adhering to the surrounding fatty adhesive barrier. The entire anatomical area is dressed with a loose cotton bandage (e.g., Kerlex) to stabilize the NXB dressing and the patient is restricted to bed for the 4-h treatment to avoid disrupting the dressing.

- *Open Lacerations or Escharotomy Incisions* should be protected-insulated from NXB with sterile fatty ointment of fatty gauze to prevent enzymatic erosion of exposed blood vessels.

4.2.5 Post-application Process

After 4 h, the occlusive dressing filled with NXB gel and seral exudates tinted with blood is removed. The adhesive barrier is wiped away with a sterile tongue depressor. Using another sterile tongue depressor the NXB gel and dissolved eschar are scraped clean until the appearance of punctuate bleeders on the background of white dermal matrix or yellow subdermal fat. This follows with >2 h of wet-to-dry antibacterial soaking to remove remnants of NXB and dissolved eschar. On exposed dermis, soaking may create a fibrin-based "pseudoeschar". The white pseudoeschar should be diagnosed as such and not excised or removed as epithelialization can progress under it. It should only be excised for autografting (Fig. 4.4).

4.2.6 The Enzymatically Debrided Bed

The fast and selective debridement spares and exposes non-injured tissues, allowing accurate assessment of burn depth at every point. Post NXB, the diagnosis of the exposed wound bed may differ from the pre-debridement diagnosis.

The appearance of the enzymatically debrided bed is different from the surgically debrided wound. The clean debrided bed is covered with irregular, furry, corduroy-like tissue that follows the different depths of the thermal insult corresponding to the burn depths, chatacterized by the exposed red punctuate bleedings and white dermal matrix. The different wound beds correlate with potential spontaneous epithelialization under appropriate wound care (Fig. 4.5). In nearly full thickness or full-thickness burns that will not healed by epithelialization over dermis, visible yellow fat hue, lobules or surface indicates the potential need for autografting. Non-healing deep wounds under granulation control for weeks should also be considered for autografting.

- *The pseudoeschar*. Enzymatically debrided bed may often, especially in the more superficial dermal burns, develop after soaking a white layer that initially is fibrin based but later may include components of the medications and dressings used. This pseudoeschar layer is *not* an eschar thus, the epithelialization process can complete its course underneath until healing. The pseudoeschar should not be excised away

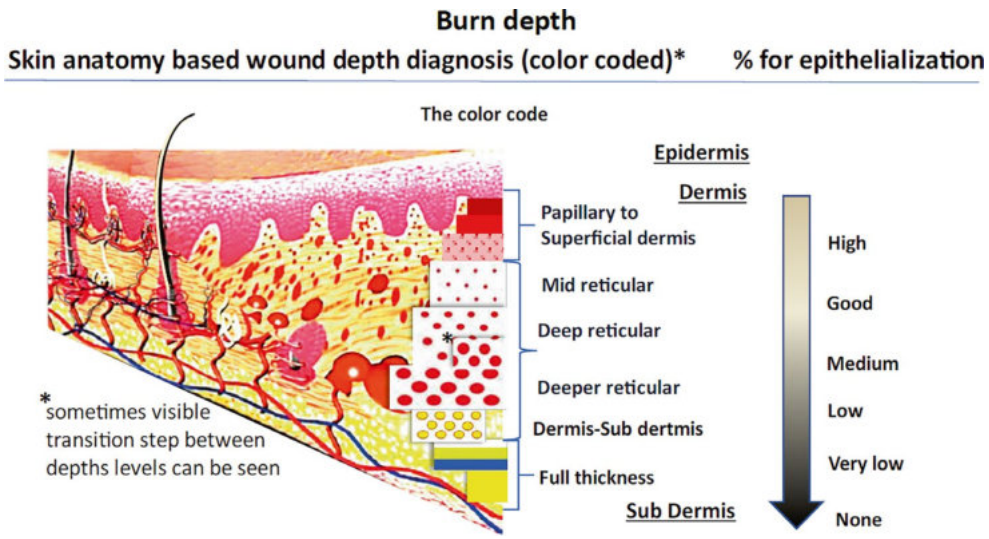


Fig. 4.5 A color-coded diagnosis scheme: The diagnosis of the NXB debrided burn bed relays on the skin anatomy with its different vascular nets with their red color on the white collagen matrix background. After soaking this pattern may be hidden by the pseudoeschar that will not interfere healing

Papillary dermis: The three first layers represent the papillary dermis with its capillary net:

Dark red: The more superficial dense minute capillaries

Red: Mid level of the papillary dermis

Dark pink: the transition between the papillary dermis and the upper reticular dermis

Reticular dermis: the blood vessels are small and numerous at the superficial dermis and become larger but fewer toward the deep dermis. Thus, the white collagen matrix that surrounds the blood vessels is less dense at the surface and becomes denser toward the deeper dermis

The different levels will appear as:

Small, pinpoint bleeder on a white background in more superficial reticular dermis burns

Larger but fewer bleeders with more of the white reticular collagen matrix (mid dermis)

Debridement by the selective NXB may often end with different levels of the debrided bed

Few, large bleeders on white background in deep dermis

In the very deep dermis, yellow fat lobules may protrude from the yellow subdermal fat layer

Subdermal fat layer appears as continuous, lobular yellow layer

Healing potential: more superficial the burn is, more epidermal and dermal elements and capillary provide the conditions for spontaneous epithelialization over dermis. In the very deep dermis and deeper: without any dermal elements and few epidermal foci of the hair follicles, epithelialization is difficult and may end in granulation tissue, healing by secondary intention and scarring

causing additional trauma and tissue loss (unless for autografting) but be treated conservatively with fatty or moisturizing dressings to prevent desiccation and promote sloughing until complete healing (*see* Figs. 4.6c and d and 4.7c and d).

4.2.7 Post-debridement Wound Care

After enzymatic debridement with NXB, the debrided bed mirrors the original thermal insult, presenting varying proportions of superficial, mid, and deep dermis, as well as full-thickness areas. Unlike the typically observed bleeding, clean wound bed after surgical debridement, the selective enzymatic debridement results in larger than usually seen clean viable dermal bed, allowing for spontaneous healing by epithelialization over the dermis. The focus of wound care for these areas should be on protecting the viable, raw surfaces, primarily from desiccation, and creating optimal conditions for epithelialization (Figs. 4.6 and 4.7).

- *Desiccation Prevention*: Desiccation of clean, unprotected raw wound bed will create a new eschar. Biocompatible adherent covers, ointments, or hydrocolloid dressings will prevent desiccation and offer favorable conditions for epithelialization.

  Exercise caution with temporary covers of animal or human origin, as they may pose risks of inflammatory, infectious, desiccation or biohazard complications [49, 76].

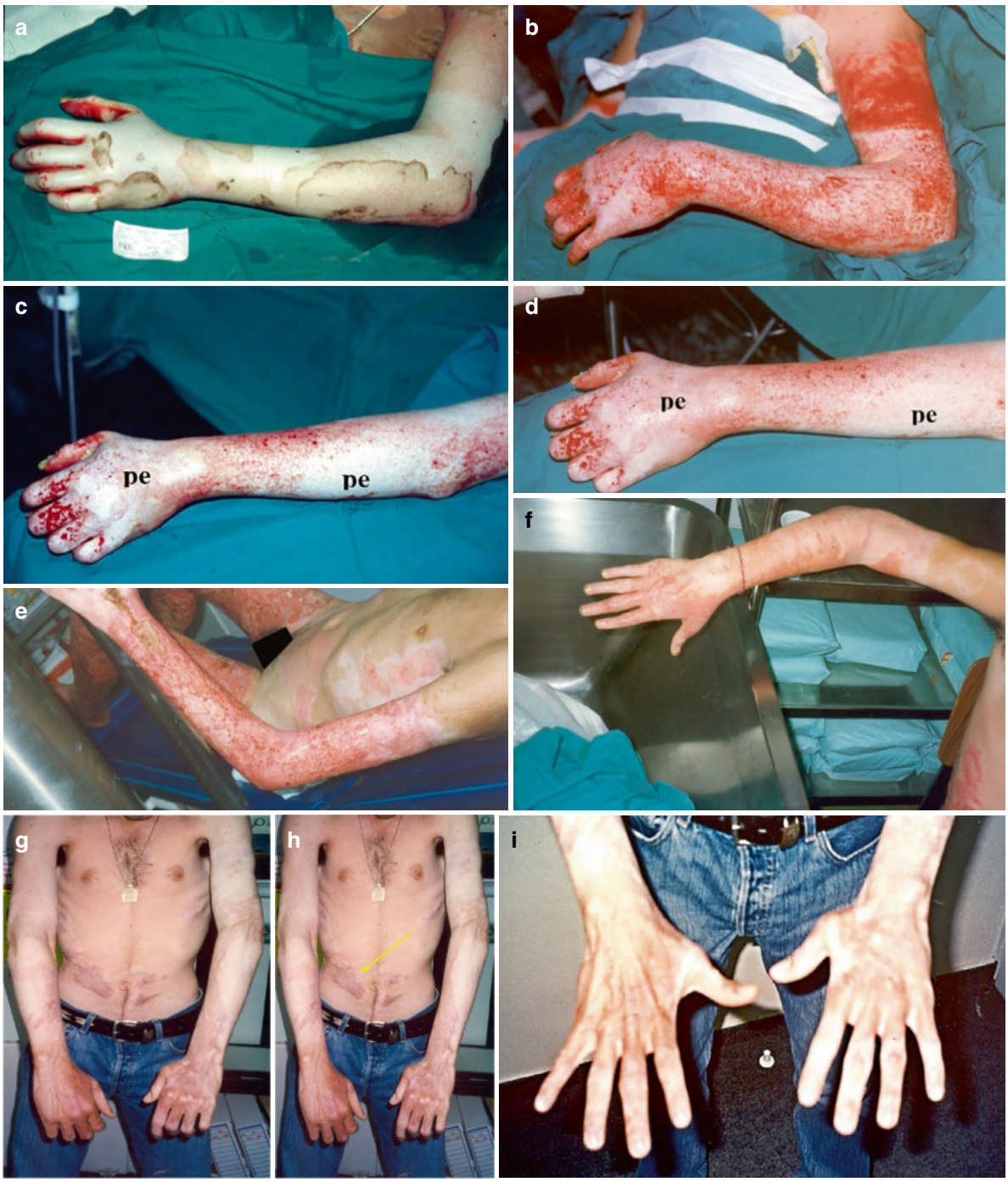


Fig. 4.6 An NXB-based MIM case-study: A 19 year old male caught in fire. On admission, 2 h post injury he was diagnosed as having deep, full thickness flame burns on both upper and lower extremities totalling 56%TBSA. BICS measured 70 mmHg. in both hands and he also had mid dermal facial burns. Both upper extremities were debrided an hour post admission at his bed, BICS resolved (pressure decreased from 70 mmHg. to 25 mmHg.). The lower extremities followed and were debrided 12 h post injury. All debrided areas were covered by meshed allograft and Nitrofurazone gauze for 12 days followed by daily fatty ointments and alternate steroid ointments to control granulation. At day 21 non healing 6% TBSA at the medial aspects of the thighs were autografted. All burns healed with good cosmetic and functional results, of the 56% TBSA deep burns indicated for excisional surgery and autograft none was excised and only 6% TBSA (mid thighs) had to be autografted. Upper extremity. (**a**) Left upper extremity 3 h post injury, after cleansing and removing blisters, just before NXB application diagnosed as full thickness burns with BICS, direct interstitial pressure measurement: 70 mmHg. (**b**) NXB dressing removed after 4 h and the dissolved eschar scraped away (7 h post injury) with normal (25 mmHg.) interstitial pressure. Complete debridement is diagnosed with preserved, clean, deep dermis. At the upper arm that was partially protected by the sleeve, a bleeding pattern typical of superficial dermis (red color) (see Fig. 4.5). (**c**) Post NXB soaking removed after 2 h. White pseudoeschar (**pe**) is seem on mid dermal bed less on the deeper wound bed with larger bleeders. (**d**) Post additional 12 h soaking (1 day post injury). (**e**) Conservative treatment by meshed allograft for 10 days followed by daily fatty ointments dressings and after additional week: additional steroid ointment every 4-6 days to prevent granulation tissue. After 51 days post admission 95% spontaneous epithelialization. (**f**) Week 2 post complete, spontaneous healing (72 days post injury). (**g–j**) Year 3 post injury: good cosmetic and functional results. Yellow arrow points to donor sites scars of the autografts to inner thighs (following parts **e**, **h**, **i**)

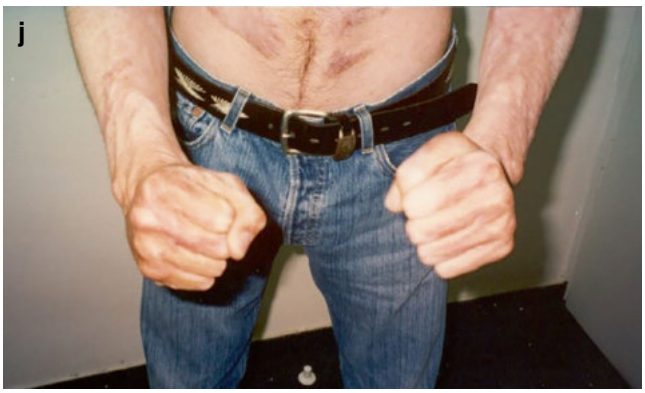
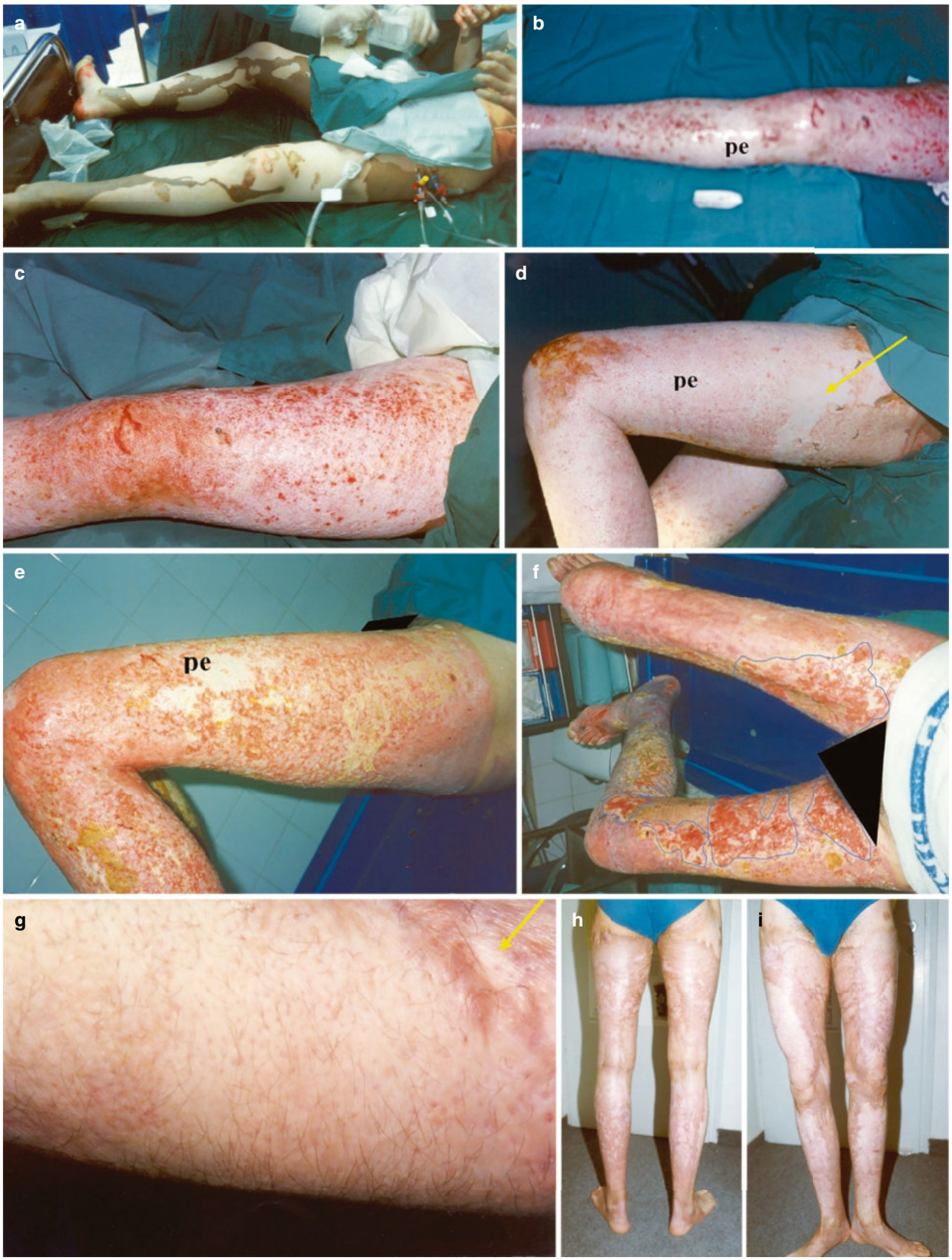


Fig. 4.6 (continued)

- *Granulation Tissue Modulation:* Granulation tissue, appearing as red dots after a couple of weeks, should be immediately controlled by short courses of steroid ointment that also will indirectly promote epithelialization.
- *Epithelialization:* epithelialization over dermis yields the best outcome with minimal cost to the patient. Adequate conditions for this process include moist and viable dermal surface, biological cover that maintains moisture offering propagation surfaces for the keratocytes and granulation modulation. Pseudoeschar usually will allow epithelialization underneath acting like a biological cover and should not be excised. Addition of auto-keratocytes as an epithelialization-promoting measure, as described by Yamashita et al. in October 2023 [50] may enhance and introduce another layer to the epithelialization process.

In summary, the post-debridement wound care strategy is based on protecting the viable bed by preventing desiccation using biocompatible covers, ointments, or hydrocolloid dressings, modulating granulation tissue with a steroid ointment, and autografting full thickness and non-healing (>3 weeks) wounds.

Fig. 4.7 Lower extremity, same patient as Fig. 4.6. (**a**) Lower extremities on admission, 2 h post injury, diagnosed as full thickness burns potentially planned for avulsion debridement. Both hands are seen at the right upper edge of the photo. (**b**) Left leg immediately after removal of NXB dressing and before wiping the dissolved eschar (~12 h post injury). Complete debridement with good dermis and large bleeders widely spaced typical to deep dermal burn. (**c**) Post NXB 2 h soaking. A white pseudoeschar (**pe**) is seen on lateral side. On the anterior side, deeper mid dermal burn with pinpoint bleeders. (**d**) Post additional 12 h soaking (~1 day post injury). A thin pseudoeschar of the mid dermal bed is seen throughout the wound bed with pinpoint bleeders that are not closed to each other. The yellow arrow points to a not debrided eschar, an area where a fold in the sheets pressed on the occlusive dressing squeezing away the NXB from the wound. (**e**) All areas were treated with meshed allografts for 10 days followed by daily fatty ointments dressings and after 2 weeks: steroid ointment every 4–6 days to prevent granulation tissue. At 21 days post admission good spontaneous epithelialization covers the anterior and lateral sides. (**f**) Not healing deep dermal and full thickness burns of the inner thighs (surrounded by thin blue line) are planned for autografting next day. All burns healed at 51 days post injury. (**g**) The lateral thigh 3 years post injury. All debrided burns healed completely and naturally with hair growing in preserved dermis whereas the not-debrided burn (yellow arrow, **d**) healed by sloughing and granulation (secondary intention) ended with hypertrophic scar (yellow arrow). Anterior (**h**) and (**i**) posterior views at year 3 post injury: good cosmetic and functional results


a
b
pe
c
d
pe
e
pe
f
g
h
i

4.3 Data Review

Following years of extensive preclinical and clinical studies, NXB obtained approval from the European Medicines Agency (EMA) in 2012 and, more recently, from the U.S. Food and Drug Administration (FDA). To date, over 12,000 burn patients have been treated by NXB [1–7, 37, 44–47, 51–56]. A wealth of knowledge has been amassed through the publication of 10 EMA and FDA prospective Randomized Controlled Trials (RCTs) and over 100 Investigator Initiated Trials and Consensus Statements including an European Consensus White Papers and various European countries consensuses, (including Italy, Spain, Romania, and Poland). These and all other published findings are comprehensively reviewed in a recent publication [4].

4.3.1 Efficacy Data: Acute Stage

In all conducted studies, a 4-h application of NXB achieved complete debridement in 90–97% of cases. The failures were primarily attributed to technical challenges such as insufficient blister removal, insulation of NXB from the eschar, prior treatment of eschars with SSD and/or Iodine medicaments, dry eschars, and disruption of occlusive dressing, hindering the contact between NXB and the eschar.

- *Reduction in Time to Complete Debridement*: Across all studies, NXB completed debridement on the day of application, compared to the 4–7 days required in the SOC.
- *Reduction in Surgical Debridement*: Early NXB debridement consistently led to a substantial reduction in the need for surgical debridement.
- *Reduction in Autografting*: Selective debridement by NXB preserved viable dermal remnants, allowing for spontaneous wound closure by epithelialization. Although epithelialization may take a few days longer, the ultimate scarring outcome is significantly improved.
- *Hand Burns and BICS*: In publications addressing deep hand burns and/or BICS, early NXB debridement demonstrated effectiveness and practicality. It enabled selective debridement, early prevention and resolution of BICS and earlier physical/occupational therapy. The good spontaneous healing and autografting reserved for full-thickness burns end in favorable final outcomes compared to SOC [56–68, 70].
- *Facial Burns*: In a Randomized Controlled Trial (RCT) by Schulz et al. (2017), involving 26 patients with deep facial burns and assessed through objective measures (e.g., exameter® MX 180, Patient and Observer Scar Assessment Scale), NXB patients exhibited significantly superior functional and cosmetic outcomes compared to surgical debridement [71].
- *Reduction of Blood and Heat Losses:* In comparison to surgical debridement, where an anticipated blood loss of 0.5–1 cc per 1 cm^2 excised is expected, in NXB eschar removal blood loss measured 0.013 cc per 1 cm^2 (<2% of SOC: 14 cc vs. 815 cc). It is crucial to note that while the occlusive dressing may contain blood-stained fluids at the end of the treatment, this may be misleading. To accurately assess real blood loss, the volume of NXB used, along with the estimated wound exudates, should be subtracted from the measured fluids volume in the dressing. For a precise estimate, the Hemoglobin (Hb) level of these fluids should be measured. Changes in Hb patient's levels should be interpreted in the context of fluids administered and the patient's hydration status. Applying NXB over burns with incisions (such as escharotomy), deep abrasions, or lacerations may cause bleeding so exposed blood vessels and must be adequately insulated from NXB using a thick layer of fatty ointment or fatty gauze (*see* Fig. 4.2).
- *Heat Loss* and hypothermia are reduced by the occlusive dressing employed during NXB application that impedes heat dissipation seen in surgical procedures. Consequently, patients undergoing NXB debridement remain normothermic throughout the entire process. In some cases, particularly during the debridement of larger areas and children, patients may even experience a temporary increase in body temperature, manifested as pyrexia or fever. This induced temporary pyrexia is a manageable and expected response proactively mitigated by the post-debridement soaking, as outlined in the instruction and published literature [4–7].

4.3.2 Outcomes

Time to Wound Closure: In general, wounds treated with NXB displayed a comparable healing timeline to those treated with SOC, typically averaging around 27 days. It is important to note that while some wounds may exhibit a slightly prolonged healing time due to epithelialization, effective granulation tissue control using topical steroid ointment has proven to promote favorable final outcomes of function and cosmesis. The surgical based SOC wound care depends on excisional debridement followed or combined with harvesting and engrafting autograft with healing challenges of both, the burn and donor site wounds. In NXB based MIM treatmnet, the dissociation between the earlier debridement and the following wound closure treatment offers a flexible, comprehensive burn care strategy with optimal exploitation of the burn center resources maintaining similar or better final outcome [4–6].

Scarring Across all conducted studies and reports, scarring in patients treated with NXB, as measured by the Modified Vancouver Scar Scale (MVSS) 12 months after wound closure, consistently was similar or improved compared to SOC cohorts. This superior scarring outcomes were observed in patients whose wounds were closed by epithelialization rather than autografting, irrespective of the time taken for wound closure (consistently exceeding 21 days for both cohorts) [4–6]. This finding is probably due to the preserved dermis by the selective NXB debridement and its healing by epithelialization instead of more dermal sacrifice that necessitates closure by autografting.

4.3.3 Results of Two Last Clinical Randomized Controlled Trials

The outcomes of both adult and pediatric FDA Phase III RCTs provide positive evidence not only to the debridement efficacy of NXB but also to the impact of early, safe and selective non-surgical debridement [4, 5].

- *Adult Phase III RCT:*

The recent DETECT study (NCT #: NCT04040660) involved major burn centers across the US, Europe, and Israel demonstrated the superiority of NXB over the Gel (placebo) cohort as well as the SOC. NXB exhibited a remarkable incidence of complete debridement (93.3% vs. 4% in the Gel cohort, similar to SOC) and a faster debridement process compared to SOC (1 day vs. 3.8 days). NXB debridement caused a significant reduced blood loss compared to SOC (14 cc vs. 815 cc) and a lower incidence of surgical excision (4% vs. 72%). Autograft procedures in DPT wounds were also less than half in the NXB group (the full thickness burns always need autografting). In spite of reduced surgery and somewhat prolonged time to wound closure, the MVSS score of the NXB cohort 1 year post-treatment was significantly superior to the SOC cohort.

- *Pediatric Phase III RCT:*

The pediatric study, known as CIDS, (NCT #: NCT02278718) mirrored the adult trial's results, confirming the consistent NXB' outcomes across diverse patient populations. NXB exhibited superiority and a faster complete debridement compared to SOC (0.9 day vs. 5.9 days). Lower incidences of surgical excision (8.3% vs. 64.4%) and autograft procedures (25.6% vs. 37.6%) with significant reduced blood loss (32 cc vs. 202.6 cc) and Hemoglobin were observed with NXB. The MVSS score of the NXB cohort 1 year post-treatment was significantly better (~25% improvement) than the SOC cohort in the pediatric study (Fig. 4.8).

The time to wound closure was similar in both adult and pediatric studies, reconfirming the consistent NXB' outcomes across diverse patient populations.

4.3.4 Safety Profile

The NXB enzymatic eschar removal, despite its seemingly straightforward application as a gel dressing (especially if compared to the surgical burn SOC), is a potent and active enzymatic medicament and as such, should be regarded as an "enzymatic surgery" procedure.

- *Safety and Tolerance:* In numerous adult and pediatric studies and publications, NXB has consistently demonstrated safety and good tolerability without specific concerns.
- *Pain:* NXB application and removal related pain should and can be effectively managed with adequate analgesia/sedation in well prepared patients following the basic pain-free-medicine techniques as practiced in any potentially painful medical procedure [71–74].
- *Patient Selection:* NXB enzymatic eschar removal, like surgical debridement, is not recommended in infected or highly contaminated wounds to avoid exacerbating the infectious process. Eschar saturated with SSD, Iodine preparations or desiccated is less prone to NXB dissolution that obviously will not be effective if the dressing is disrupted or if not in contact with the eschar (e.g. insulated by blisters).
- *Patient Preparation*: Although less traumatic than surgery, NXB still inflicts a local insult. Patients undergoing NXB should be physiologically well-balanced and adequately hydrated, as for similar surgery. Patients with pathologies such as cardiopulmonary, metabolic, smoke inhalation, infection, sepsis etc. are at risk for any surgery or anesthesia as well for extensive NXB treatment. Such patients should be prepared for the treatment and monitored throughout the acute phase. While blood loss is much reduced, it remains a possibility especially when NXB is applied on deep lacerations or incisions (e.g. prior escharotomy) that should be protected by fatty ointment or gauze.
- *Pyrexia:* reduced heat dissipation by NXB's occlusive dressing may cause temporary temperature increase especially in children. Post NXB treatment soaking will mitigate this temporary pyrexia as well as by the wet-to-dry effect will remove remnants of NXB gel and dissolved eschar and infectious germs.
- *Hypersensitivity and Allergic Reaction:* NXB is contraindicated in patients with known hypersensitivity to pineapple or papaya' products because of cross-sensitivity risk.

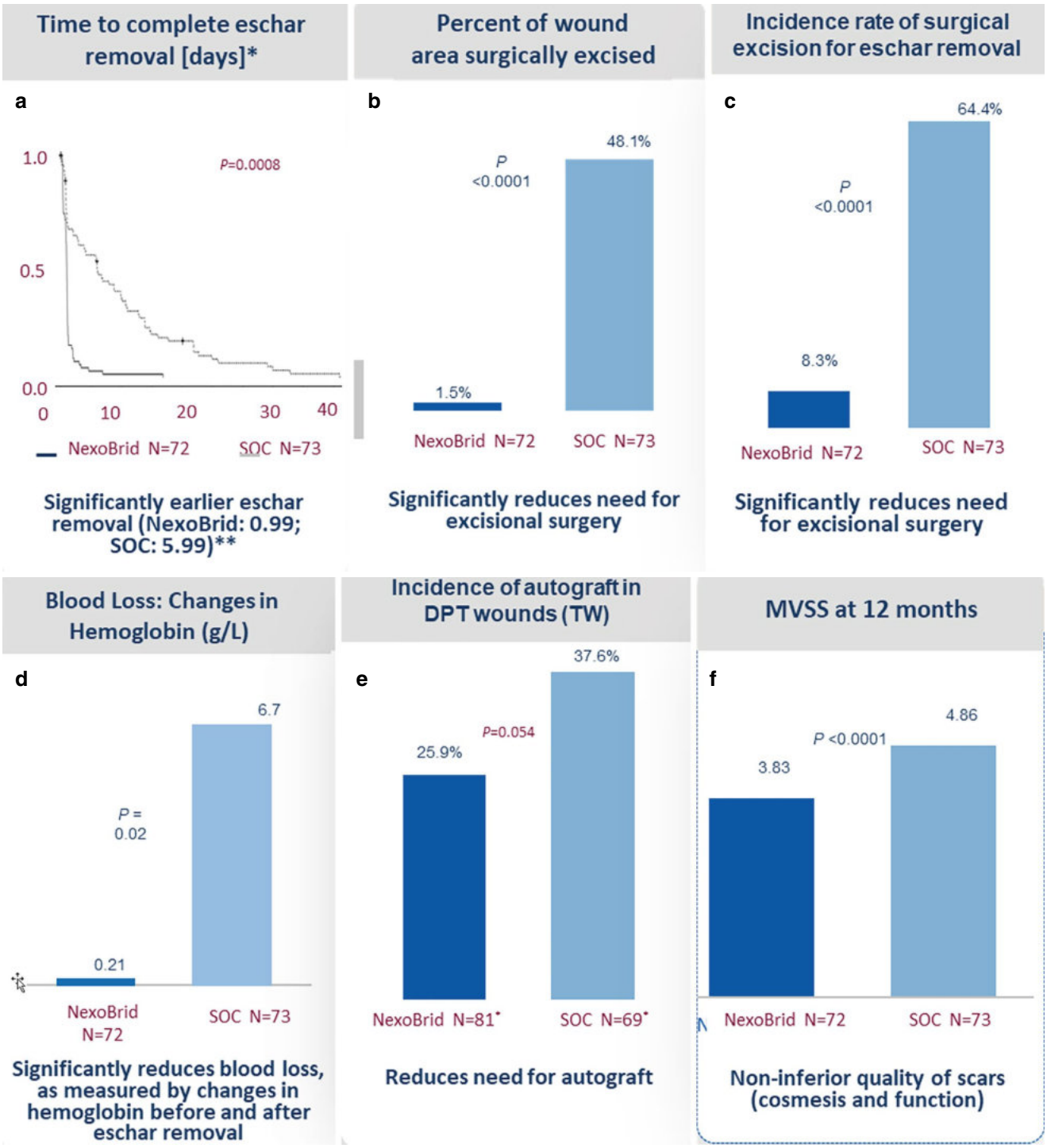


Fig. 4.8 Main results from the pediatrics Phase III RCT. Incidence rate of complete eschar removal: similar rates above 90% of NXB, SOC (includes surgical and non-surgical) and very low (4%) in Gel Vehicle placebo are seen in all studies. Non-inferiority established in time to complete wound closure, no safety issues after 24 months follow-up and these data are consistent with the European Phase III clinical trial, and with Phase III study in pediatric population. (**a**) Time to complete eschar removal [Estimated median time in days]. Kaplan-Meier analysis. (**b**) Percent of wound area excised. (**c**) Incidence of surgical eschar removal. (**d**) Changes in Hemoglobin following Eschar Removal procedures. (**e**) Incidents of autografting deep partial thickness wounds (all full thickness wounds should be grafted regardless). (**f**) MVSS scores at 12 months: Modified Vancouver Scar Scale (lower score = better scarring)

As in any protein preparation, hypersensitivity/allergic reaction are potentially possible though there were no more than a handful reports of allergic reactions. Part of the patient monitoring should include awareness to this possibility. Local expression of NXB application (i.e. cutaneous irritation, redness) may be mistaken with similar symptoms of allergic rection such as rashes and hives. Stomach symptoms of burn- related acute gastric dilatation (i.e. vomiting) should be differentiated from similar anaphylacsis symptoms or medication related (i.e. opiates) symptoms. Anaphylacsis systemic symptoms such as tachycardia, decreased blood pressure, tachypnea, dizziness etc. should be differentiated from the expression of the sedative/analgesic overmedication or reaction to surging pain and/or anxiety and fear in undertreated sedation/analgesia.

- *Coagulopathy and Infection Risks:* A preclinical and two clinical studies of enzymatic debridement in burn patients ($n = 40$ and 132) with a mean TBSA of 17% investigating the theoretical potential risks of coagulopathy and burn wound infection concluded that there is no strong evidence of these adverse events, no increase coagulation abnormalities (INR), aPTT, fibrinogen, factor-XIII and platelet counts compared to the regular surgical approach. This safety profile was confirmed by investigating trends in systemic inflammatory reaction, bleeding, hemodynamic stability, and electrolytes [78]. It is important to remember that coagulopathy is often associated with the burn pathophysiology itself and caution should be exercised by healthcare providers with patients on anticoagulants, with thrombocytopenia, or in other causes of increased risk of bleeding [4, 5, 46, 76–78].
- *Bromelain Dust Inhalation Risk:* Historical concerns regarding bromelain dust inhalation during NXB preparation were addressed in a study by Smolle et al. The study found very low exposure levels of inhalable particles during the mixing process and concluded that adherence to the manufacturer's instructions for safe product preparation and use is sufficient [76].
- *Microbiological Pattern of Burn Wounds:* Research by Sharaf et al. evaluating the microbiological pattern of burn wounds treated with NXB found that it closely resembled cases treated with both surgical and non-surgical SOC debridement throughout all stages of wound healing. This suggests that NXB does not significantly alter the microbial profile compared to traditional SOC approaches [79].

In summary, NXB enzymatic eschar removal has demonstrated a favorable safety, tolerability and efficacy profile in various clinical scenarios. Prudent patient selection, preparation, and adherence to safety guidelines and monitoring are important as in the care of any burn patient [4, 5, 46, 75–77].

4.3.5 Cost-Efficacy

Numerous reports confirm that thousands of dollars can be saved by reducing ICU care, length of stay (LOS), need for surgical excision and autografting. NXB use that reduces operating room utilization, allows its exploitation for other profitable surgical procedures [80]. Reimbursement was approved in Belgium based on a market access calculation that NXB will realize yearly savings of at least 30.000€, [81] Farahati et al. projected a potential cumulative economic spillovers of this public investment, assuming integration of NXB into the US burn care system of up to $1.8 billion, depending on the extent of reduction in hospital LOS, the number of autografts performed, and peak market share in 10 years [82]. Similarly, a cost analysis was performed by Giuduce et al. who estimated savings worth 53,300€ by using NXB in ten patients [83]. These findings underscore the economic value and long-term financial advantages associated with integrating NXB into burn care practices following the less- efficient learning-curve phase.

4.4 Discussion and Implications: The MIM (Minimally Invasive Modality) Paradigm Shift

In 1998, the paradigm shift (alternatively called "Primum Non Nocera" or PNN modality) of the Enzymatic Debridement-based Minimally Invasive Modality (MIM) of Burn Care, was introduced at the tenth ISBI Jerusalem congress based on the first 240 NXB-treated burn patients.

Compared to SOC, NXB early and selective debridement involves reduced surgery (excisional debridement and autografting): in adults 4% vs. 72% and in children 8.3%, significantly reducing autografting and surgical escharotomy. This translates into reduction of surgery-related blood and heat losses and the increased preservation of viable dermis that increases the potential of wound closure by epithelialization of the salvaged dermis, minimizing skin graft closure and donor site sacrifice and morbidity. Autografting is reserved to not healing deep partial thickness and full thickness wounds.

Prerequisites and Adaptations: The shift from surgery-based burn care to non-surgical enzymatic early selective debridement and wound care requires several prerequisites and adaptations in the burn care routine.

4.4.1 Training

As in any new medical practice, a comprehensive medical training of the burn center' team prior to the use of NXB (a requirement by EMA in EU) (NexoBrid: https://www.ema.europa.eu/en/medicines/human/EPAR/nexobrid; European Medicines Agency: https://www.ema.europa.eu/en) is very important to prevent misuse or potential complications. This training is provided by MediWound or the local distributors and continues with follow-up of the first patients treated in order to solve challenges and pitfalls that may rise during this new approach. In this training the experience of hundreds of users around the world is shared and discussed and is readily available.

4.4.2 Adaptations to Routine

Some alterations in the routine burn management may be needed. For example, upon admission, a thorough removal of all blisters prior to NXB application, avoiding the use of Silver Sulfadiazine or Iodine-based ointments. Gaining patient compliance [84] and adequate pain management are important for the first NXB application and also for following sequential NXB applications in treating large burns (up to 15% TBSA per session) that may require additional monitoring and hemodynamic support [4–6, 78].

4.4.3 Diagnosis of the Debrided Bed

The appearance of the NXB debrided bed is different from the tangentially excised bed. The assessment can be made accurately immediately after removal of NXB and after 2 h of wet-to-dry soaking. The diagnosis may be assisted by a color-coded drawing illustrating the schematic presentation of NXB debrided bed at different cutaneous anatomical levels. Certain learning curve may be needed for the assessment of the post-enzymatically debrided wound bed, its appearance post soaking, with or without pseudoeschar that the SOC burn surgeon may not be accustomed to encounter before. This learning is needed for the prediction and educated choice of the wound closure strategy (grafting or spontaneous wound healing by epithelialization) (Fig. 4.5) [85–87].

Laser Doppler Imaging (LDI), [88, 89] and ultrasound for assessing burn depth [90] may be helpful as long as they do not delay treatment. Eschar removal should be done as early as possible on admission, much before the suggested timing for LDI (3 days). Visual diagnosis of the debrided bed and remaining dermal elements by experience and trained burn physician is the standard method for assessing the post-enzymatically debrided wound bed.

4.4.4 Transition from Surgery-Based Burn Care to NXB-Based MIM

MIM approach is based on a very early NXB "dressing" application (often at the patient bed in the ward), completing fast and selective eschar removal and preventing/releasing BICS followed by epithelialization-aimed wound care of the salvaged dermis requires understanding and practice for surgeons that are used to tangential excision followed by autograft. There are several wound covers that may be used if addressing the following requirements of the NXB debrided bed:

(a) Desiccation prevention. This is the main concern as the raw surface is susceptible to dry even in few minutes' exposure. Occlusive dressings, hydrocolloids, fatty ointments will form a moist layer underneath.
(b) Avoid inflammation: some of the animal/human derive dressings are rejected after few days inciting inflammatory reaction, granulation tissue formation and scarring.
(c) Granulation tissue modulation: granulation tissue may start 10–14 days after initiation of healing process. Topical application of steroid ointment for few days will attenuate granulation and allow for faster epithelialization. No report of infection nor any adverse events related to such topical steroid treatment were published [91–93].
(d) Autograft of full thickness NXB debrided bed could be done immediately or delayed (12–24 h to few days even 2 weeks), wet-to-dry soakings to ensure a moist environment were reported to promote graft take. The autograft recipient site should be refreshed (brisk brushing) to open occluded, dissolved blood vessels and remove remnants of sediments, slough or pseudoeschar. Full thickness or not healing deep wounds may be grafted anytime as long as granulation tissue is modulated [1–7, 37, 44–47, 57].

4.4.5 Autologous Cell Therapy [50, 93–95]

This novel approach is based on the complete and selective eschar removal by NXB. The re-epithelialization of the preserved healthy dermis in deep dermal burns is promoted by the use of cell therapy (Recell®). Autologous skin graft (about 6/1000 inch) is harvested and enzymatically dissolved. It contains epidermal cells together with the cells surrounding the basement membrane, melanocytes, vascular endothelial cells, and fibroblasts. The suspension of these cells is sprayed onto the debrided deep dermal bed. A 4–48 h of wet-to-dry soaking that removes all enzyme and dissolved eschar' remnants will prevent enzymatic insult by the NXB

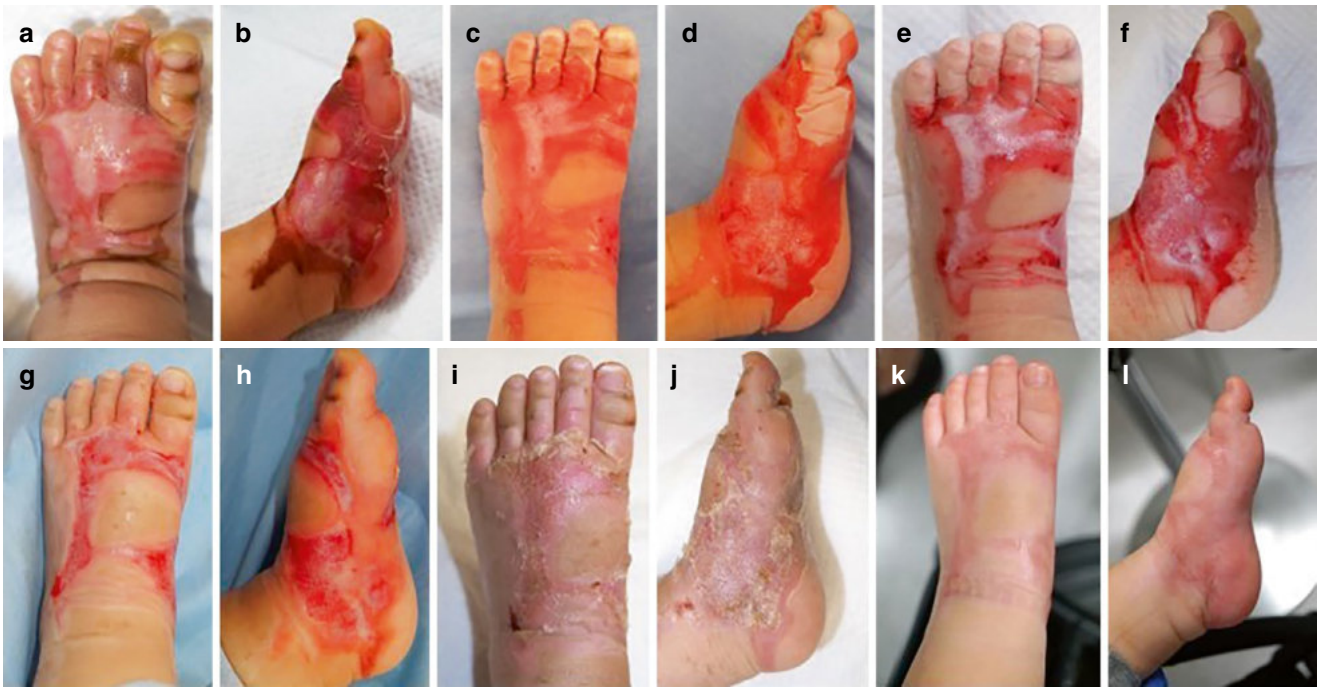


Fig. 4.9 Combined cell therapy. (**a** and **b**) Day 7 post-injury, initial visit (referral from another clinic); mixed SDB, DDB, and DB. (**c** and **d**) Day 8 post-injury, after presoaking prior to application from the previous night. Adequate maceration was achieved. (**e** and **f**) After removal of NexoBrid®. (**g** and **h**) Two days after NXB debridement, just before RECELL procedure. (**i** and **j**) Day 21posy injury, 10 days after Recall procedure, complete epithelization was achieved. (**k** and **l**) Two months after NXB and RECELL, no hypertrophic scarring and no contracture

remnants to the sprayed cells. This combination non-surgical treatment achieves rapid wound healing by dermal re-epithelialization, potentially reducing hypertrophic scarring and contractures, with better cosmetic results (Fig. 4.9).

4.4.6 Time to Wound Closure

Time to Wound Closure by epithelialization-over-dermis by all of the above may take longer than 3 weeks. In the controlled studies, similar time to wound closure, longer than 21 days were reported for both SOC and NXB arms. However, all the studies and publications attest to at least as good as SOC and usually better final end-result of cosmesis (scarring MVSS), Quality of Life and function (e.g., Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, the Michigan Hand Outcomes Questionnaire (MHOQ), skin preservation, reduced need for skin grafting as well as decreased hypertrophic scarring and faster healing times [3, 60–69, 96].

4.4.7 Off Label Uses

Multiple studies and consensus papers report positive outcomes for off-label uses (e.g., burn-induced compartment syndrome (BICS), [60–69] paediatric burns, electrical burns, [4–7, 75] chemical burns, [97] hard to heal chronic wounds, [98] genital burns, [99] >15%TBSA burns, [78, 100] and delayed NXB application) [101].

4.4.8 Burn Mass Casualty Incidents (BMCIs)

The NXB MIM principles may be applied in BMCIs. Non-surgical, rapid, effective and selective debridement-escharotomy has the potential to increase surge capacity in the very initial, immediately after triage acute treatment phase. The increased spontaneous epithelialization that replaces much of the grafting procedures further reduces the challenges of the initial acute phase as well as the later wound-care phases, with additional increase surge capacity. The US government through the Biological Advanced Research and Development Authority (BARDA) recognized NXB as a potential solution to thermal or nuclear events with number of burns where conventional burn care methods would prove insufficient adding it to the arsenal of medical countermeasures [102]. During the 2015 nightclub fire in Romania NXB was used to treat 39 patients in 2 days in 3 hospitals [103]. Bowers et al. presented their experience of immediate NXB treatment of five victims injured in a house explosion, advocating NXB for handling BMCIs [104].

4.5 Summary and Conclusion

Extensive RCTs, controlled and field studies report NXB to be a safe, selective, effective and fast non-surgical eschar removal tool [4, 104, 105]. It offers a very early and faster debridement-escharotomy. Its use decreases debridement and autografting surgery, surgery related blood and heat losses as well as reducing mortality, sepsis, length of stay and healing times with improved final outcome of scarring, function and cosmesis. The incorporation of NXB into the burn care routine requires adaptation and training of the surgeons in a new Minimally Invasive Modality strategy [106].

References

1. Rosenberg L. Enzymatic debridement of burn wounds. In: Total burn care. 4th ed. Elsevier Inc.; 2012. p. 131–135.e1. https://doi.org/10.1016/B978-1-4377-2786-9.00011-4.
2. Rosenberg L, et al. A novel rapid and selective enzymatic debridement agent for burn wound management: a multi-center RCT. Burns. 2014;40(3):466–74.
3. Rosenberg L, et al. Minimally invasive burn care: a review of seven clinical studies of rapid and selective debridement using a bromelain-based debriding enzyme (NexoBrid®). Ann Burns Fire Disasters. 2015;28(4):264.
4. Shoham L, Gasteratos K, Singer A, Krieger Y, Silberstein E, Goverman J. Bromelain-based enzymatic burn debridement: a systematic review of clinical studies on patient safety, efficacy and long-term outcomes. Int Wound J. 2023;20:1–20. https://doi.org/10.1111/iwj.14308.
5. Shoham Y, Narayan RP, Monstrey S, et al. 49 bromelain based enzymatic debridement of pediatric deep burns: top line results of a multicenter RCT. J Burn Care Res. 2022;43(Suppl_1):S33–4.
6. Hirche C, Kreken Almeland S, Dheansa B, et al. Eschar removal by bromelain based enzymatic debridement (Nexobrid®) in burns: European consensus guidelines update. Burns. 2020;46(4):782–96.
7. Korzeniowski T, Strużyna J, Chrapusta AM, et al. A questionnaire-based study to obtain a consensus from 5 polish burns centers on eschar removal by bromelain-based enzymatic debridement (Nexobrid®) in burns following the 2020 updated European consensus guidelines. Med Sci Monit. 2022;28:e935632.
8. Janžekovič Z. A new concept in the early excision and immediate grafting of burns. J Trauma Injury Infect Crit Care. 1970;10(12):1103–8. https://doi.org/10.1097/00005373-197012000-00001.
9. Gray DT, Pine RW, Harnar TJ, Marvin JA, Engrav LH, Heimbach DM. Early surgical excision versus conventional therapy in patients with 20 to 40 percent burns. A comparative study. Am J Surg. 1982;144(1):76–80.
10. Heimbach DM. Early burn excision and grafting. Surg Clin North Am. 1987;67(1):93–107.
11. Deitch EA. A policy of early excision and grafting in elderly burn patients shortens the hospital stay and improves survival. Burns Incl Therm Inj. 1985;12(2):109–14.
12. Engrav LH, Heimbach DM, Reus JL, Harnar TJ, Marvin JA. Early excision and grafting vs. nonoperative treatment of burns of indeterminant depth: a randomized prospective study. J Trauma. 1983;23(11):1001–4.
13. Mann R, Heimbach D. Prognosis and treatment of burns. West J Med. 1996;165(4):215–20.
14. Pietsch JB, Netscher DT, Nagaraj HS, Groff DB. Early excision of major burns in children: effect on morbidity and mortality. J Pediatr Surg. 1985;20(6):754–7.
15. Liu HF, Zhang F, Lineaweaver WC. History and advancement of burn treatments. Ann Plast Surg. 2017;78(2 Suppl 1):S2–8.
16. Ahuja RB, Bhattacharya S. An analysis of 11,196 burn admissions and evaluation of conservative management techniques. Burns. 2002;28(6):555–61.
17. Chamania S, Patidar GP, Dembani B, Baxi M. A retrospective analysis of early excision and skin grafting from 1993–1995. Burns. 1998;24(2):177–80.
18. Branski LK, Herndon DN, Barrow RE. 1 - A brief history of acute burn care management. In: Herndon DN, editor. Total burn care. 5th ed. Elsevier; 2018. p. 1–7.e2.
19. Lewis GM, Heimbach DM, Gibran NS. Evaluation of the burn wound: management decision. In: Herndon DN, editor. Total burn care. 4th ed. Saunders-Elsevier; 2012. p. 783.
20. Sheridan RL. Comprehensive treatment of burns. Curr Probl Surg. 2001;38(9):657–756.
21. Kagan, et al. American Burn Association white paper Surgical Management of the Burn Wound and Use of Skin Substitutes. American Burn Association; 2009.
22. Orgill DP. Excision and skin grafting of thermal burns. N Engl J Med. 2009;360(9):893–901.
23. Silver GM, et al. Standard operating procedures for the clinical management of patients enrolled in a prospective study of Inflammation and the Host Response to Thermal Injury. J Burn Care Res. 2007;28(2):222–30.
24. Tredget EE. Management of the acutely burned upper extremity. Clin. 2000;16(2):187–203.
25. Orgill DP, Piccolo N. Escharotomy and decompressive therapies in burns. J Burn Care Res. 2009;30(5):759–68.
26. Wong L, Spence RJ. Escharotomy and fasciotomy of the burned upper extremity. Hand Clin. 2000;16(2):165–74. vii
27. Saffle JR, Zeluff GR, Warden GD. Intramuscular pressure in the burned arm: measurement and response to escharotomy. Am J Surg. 1980;140(6):825–31.
28. Heimbach D, et al. Burn depth: a review. World J Surg. 1992;16(1):10–5.
29. Rosenberg L, et al. Use of the Doppler effect in visible laser light to assess tissue viability by capillary blood flow. Ann Plast Surg. 1982;8(3):206–12.
30. Burke-Smith A, Collier J, Jones I. A comparison of non-invasive imaging modalities: infrared thermography, spectrophotometric intracutaneous analysis and laser Doppler imaging for the assessment of adult burns. Burns. 2015;41(8):1695–707.
31. Jaskille AD, et al. Critical review of burn depth assessment techniques: part I. Historical review. J Burn Care Res. 2009;30(6):937–47.
32. Jaskille AD, et al. Critical review of burn depth assessment techniques: part II. Review of laser doppler technology. J Burn Care Res. 2010;31(1):151–7.
33. Voinchet V, et al. Advantages of early burn excision and grafting in the treatment of burn injuries of the anterior cervical region. Burns. 1995;21(2):143–6.
34. Barret, et al. Total burn wound excision of massive paediatric burns in the first 24 hours post inury. Ann Burns Fire Disasters. 1999;12:25.
35. Barret, Herndon. Effects of burn wound excision on bacterial colonization and invasion. Plast Reconstr Surg. 2002:744.
36. Barret JP, Herndon DN. Modulation of inflammatory and catabolic responses in severely burned children by early burn wound excision in the first 24 hours. Arch Surg. 2003;138(2):127–32.
37. Klasen HJ. A review on the nonoperative removal of necrotic tissue from burn wounds. Burns. 2000;26(3):207–22.

38. Gurfinkel R, et al. Histological assessment of tangentially excised burn eschars. Can J Plast Surg. 2010;18(3):e33–6.
39. McDonald WS, Deitch EA. Hypertrophic skin grafts in burned patients: a prospective analysis of variables. J Trauma. 1987;27(2):147–50.
40. Deitch EA, et al. Hypertrophic burn scar: analysis of variables. J Trauma. 1983;21(10):895.
41. Page RE, Barclay TL. Correlation of scald depth and hypertrophic scar formation. Burns. 1980;7:173–5.
42. Holmes J, Muir I, Rayner C. A hypothesis of the healing of deep dermal burns and the significance for treatment. Br J Surg. 1983;70(10):611–3.
43. Holmes J, Rayner C. The technique of late dermabrasion for deep dermal burns. Implications for planning treatment. Burns Incl Therm Inj. 1984;10(5):349–54.
44. Houck JC, Chang CM, Klein G. Isolation of an effective debriding agent from the stems of pineapple plants. Int J Tissue React. 1983;5(2):125–34.
45. Muhammad ZA, Ahmad T. Therapeutic uses of pineapple-extracted bromelain in surgical care – a review. J Pak Med Assoc. 2017;67(1):121–5.
46. Orsini RA, Plastic Surgery Educational Foundation Technology Assessment Committee. Bromelain. Plast Reconstr Surg. 2006;118(7):1640–4.
47. Rosenberg L, et al. Selectivity of a bromelain based enzymatic debridement agent: a porcine study. Burns. 2012;38(7):1035–40.
48. Pritzkow S, Gorski D, Ramirez F, Soto C. Prion dissemination through the environment and medical practices: facts and risks for human health. Clin Microbiol Rev. 2021;34(15):e00059–19. https://doi.org/10.1128/CMR.00059-19.
49. Bonda DJ, Manjila S, Mehndiratta P, Khan F, Miller BR, Onwuzulike K, Puoti G, Cohen ML, Schonberger LB, Cali I. Human prion diseases: surgical lessons learned from iatrogenic prion transmission. Neurosurg Focus. 2016;41(1):E10.
50. Waldner M, Ismail T, Lunger A, et al. Evolution of a concept with enzymatic debridement and autologous in situ cell and platelet-rich fibrin therapy (BroKerF). Scars Burns Heal. 2022:8, 205951312110523. https://doi.org/10.1177/20595131211052394.
51. Rosenberg L, et al. Safety and efficacy of a proteolytic enzyme for enzymatic burn debridement: a preliminary report. Burns. 2004;30(8):843–50.
52. Singer AJ, et al. The effects of rapid enzymatic debridement of deep partial-thickness burns with Debrase on wound reepithelialization in swine. J Burn Care Res. 2010;31(5):795–802.
53. Singer AJ, et al. Rapid and selective enzymatic debridement of porcine comb burns with bromelain-derived Debrase: acute-phase preservation of noninjured tissue and zone of stasis. J Burn Care Res. 2010;31(2):304–9.
54. Singer AJ, et al. Reepithelialization of mid-dermal porcine burns after rapid enzymatic debridement with Debrase(R). J Burn Care Res. 2011;32(6):647–53.
55. Koller J, et al. Enzymatic necrolysis of acute deep burns–report of preliminary results with 22 patients. Acta Chir Plast. 2008;50(4):109–14.
56. Varma P, Kazzazi D, Anwar MU, Muthayya P. The impact of COVID-19 on adult burn management in the United Kingdom: a regional center experience. J Burn Care Res. 2021;42(5):998–1002.
57. Serracanta J, Baena J, Martinez-Mendez JR, et al. Bromelain-based enzymatic burn debridement: Spanish multidisciplinary consensus. Eur J Plast Surg. 2022;46(2):271–9. https://doi.org/10.1007/s00238-022-01999-2.
58. Ranno R, Vestita M, Maggio G, et al. Italian recommendations on enzymatic debridement in burn surgery. Burns. 2021;47(2):408–16.
59. Marinescu SA. A new bromelain-enriched proteolytic enzymes concentrate treatment in patients with extensive burns: Romanian consensus. Farmacia. 2021;69(4):792–8.
60. Schulz A, Shoham Y, Rosenberg L, et al. Enzymatic versus traditional surgical debridement of severely burned hands: a comparison of selectivity, efficacy, healing time, and three-month scar quality. J Burn Care Res. 2017;38(4):e745–55.
61. Corrales-Benítez C, González-Peinado D, González-Miranda Á, Martínez-Méndez JR. Evaluation of burned hand function after enzymatic debridement. J Plast Reconstr Aesthet Surg. 2022;75(3):1048–56.
62. Cherubino M, Valdatta L, Baroni T, et al. Selective enzymatic debridement for the management of acute upper limb burns. Ann Burns Fire Disasters. 2021;34(4):328–33.
63. Dadras M, Wagner JM, Wallner C, et al. Enzymatic debridement of hands with deep burns: a single center experience in the treatment of 52 hands. J Plast Surg Hand Surg. 2020;54(4):220–4.
64. Rivas-Nicolls D, Aguilera-Sáez J, Gallardo-Calero I, et al. Does enzymatic debridement allow us to perform conservative treatment on clinically deep hand burns? A retrospective review. Ann Burns Fire Disasters. 2020;33(3):239–44.
65. Alekseev AA, Malyutina NB, Bobrovnikov AE, Shoham Y. Enzymatic debridement of deep thermal burns in The Russian Federation: first experience. Life. 2023;13(2) https://doi.org/10.3390/life13020488.
66. Ziegler B, Hundeshagen G, Cordts T, Kneser U, Hirche C. State of the art in enzymatic debridement. Plast Aesthet Res. 2018;5(8):33.
67. Fischer S, Haug V, Diehm Y, et al. Feasibility and safety of enzymatic debridement for the prevention of operative escharotomy in circumferential deep burns of the distal upper extremity. Surgery. 2019;165(6):1100–5.
68. Mataro I, Lanza A, Di Franco S, et al. Releasing burn-induced compartment syndrome by enzymatic Escharotomy-debridement: a case study. J Burn Care Res. 2020;41(5):1097–103.
69. Krieger Y, Rubin G, Schulz A, et al. Bromelain-based enzymatic debridement and minimal invasive modality (mim) care of deeply burned hands. Ann Burns Fire Disasters. 2017;30(3):198–204.
70. Grünherz L, Michienzi R, Schaller C, Rittirsch D, Uyulmaz S, Kim BS, Giovanoli P, Lindenblatt N. Enzymatic debridement for circumferential deep burns: the role of surgical escharotomy. Burns. 2023;49:304–9.
71. Schulz A, Fuchs PC, Rothermundt I, et al. Enzymatic debridement of deeply burned faces: healing and early scarring based on tissue preservation compared to traditional surgical debridement. Burns. 2017;43(6):1233–43.
72. Galeiras R, Mourelo M, Pértega S, López ME, Esmorís I. Procedural sedation and analgesia during enzymatic debridement of burn patients. Ann Burns Fire Disasters. 2018;31(3):223–7.
73. Claes KEY, Amar S, Hoeksema H, et al. Pain management during a bromelain-based selective enzymatic debridement in paediatric and adult burn patients. Burns. 2022;48(3):555–67.
74. Schiefer JL, Lipensky A, Fuchs PC, Heitzmann W, Schulz A. Patients' satisfaction with anesthesia in enzymatic debridement from a surgical perspective. Burns. 2020;46(5):1073–82.
75. Hickerson WL, Goverman J, Blome-Eberwein SA, et al. T2 one year follow up results of the DETECT enzymatic debridement multicenter RCT. J Burn Care Res. 2021;42(Suppl_1):S1–2.
76. Smolle C, Wurzer P, Tuca A, et al. Low exposure levels of respirable particles during the preparation of NexoBrid® bromelain powder. Saf Health. 2015;1(1) https://doi.org/10.1186/s40886-015-0012-3.
77. Pfister P, Garcia Wendel PD, Kim BS, et al. Coagulation side effects of enzymatic debridement in burned patients. Burns. 2022; https://doi.org/10.1016/j.burns.2022.11.008.

78. Hofmaenner DA, Steiger P, Schuepbach RA, et al. Safety of enzymatic debridement in extensive burns larger than 15% total body surface area. Burns. 2021;47(4):796–804.
79. Sharaf A, Muthayya P. Microbial profile of burn wounds managed with enzymatic debridement using bromelain-based agent, NexoBrid®. Burns. 2022;48(7):1618–25.
80. Kern MA, von Depka N, Schackert C, Henkel W, Hirche CR. Enzymatic burn wound debridement with NexoBrid®: cost simulations and investigations on cost efficiency. Gesundheitsökon Qualitätsmanag. 2018;23(01):21–8.
81. Claes K, Hoeksema H, Lafaire C, et al. The process to obtain reimbursement for enzymatic debridement in clinically deep burns. Acta Chir Belg. 2021;123:290–300.
82. Farahati F, Nystrom S, Howell DR, Jaffe R. Economic spillovers from public Investments in medical countermeasures: a case study of a burn debridement product. Disaster Med Public Health Prep. 2017;11(6):711–9.
83. Giudice G, Filoni A, Maggio G, Bonamonte D, Vestita M. Cost analysis of a novel enzymatic debriding agent for management of burn wounds. Biomed Res Int. 2017;2017:9567498.
84. Schulz A, Perbix W, Shoham Y, et al. Our initial learning curve in the enzymatic debridement of severely burned hands-management and pit falls of initial treatments and our development of a post debridement wound treatment algorithm. Burns. 2017;43(2):326–36.
85. Di Lonardo A, Nardini V, De Rosa M, et al. Enzymatic escharolysis with nexobrid® on partial thickness burn wounds: pre- and post-debridement histological assessment. Ann Burns Fire Disasters. 2018;31(1):23–7.
86. Mataro I, Giudice G, Elia R, et al. The accuracy of burn depth diagnosis: clinical assessment before and after enzymatic debridement. Burns Open. 2021;5(4):36–9.
87. Siegwart LC, Böcker AH, Diehm YF, et al. Enzymatic debridement for burn wound care: interrater reliability and impact of experience in post-intervention therapy decision. J Burn Care Res. 2021;42(5):953–61.
88. Claes KEY, De Decker I, Monstrey S, et al. Helpful hints in deciding what and when to operate after enzymatic debridement. Burns. 2023;49(1):80–90.
89. Korzeniowski T, Strużyna J, Torres K. Evaluation of bromelain-based enzymatic debridement combined with laser doppler imaging and healing of burn wounds. Med Sci Monit. 2022;28 https://doi.org/10.12659/msm.936713.
90. Fakih Gómez I, Sánchez Balado A, Lorda BE. Ultrasonografía cutánea: una herramienta objetiva para la toma de decisiones tras desbridamiento enzimático en pacientes quemados. Cir Plást Iberolatinoam. 2019;45(1):73–80.
91. Jaeger M, et al. Treatment of hypergranulation tissue in burn wounds with topical steroid dressings: a case series. Int Med Case Rep J. 2016;11(9):241–5.
92. Roland P. The formation and management of middle ear granulation tissue in chronic ear disease. Ear Nose Throat J. 1004;83(1 Suppl):5–8.
93. Mandrea E. Topical diflorasone ointment for treatment of recalcitrant, excessive granulation tissue. Dermatol Surg. 1998;24:1409–10.
94. McShane D, Bellet J. Treatment of hypergranulation tissue with high potency topical corticosteroids in children. Pediatr Dermatol. 2012;29(5):675–8.
95. Yamashita K, Aoki K, Yokota A, Yamaguchi M, Konishi H, Ito N, Shimada K, Komiya T, Tettelbach W, Matsumura H. Deep palm burn treated with enzymatic debridement followed by autologous skin cell suspension: a case study. J Wound Care. 2023;32(Sup10a):S30–4.
96. Gravante G, Di Fede MC, Araco A, Grimaldi M, De Angelis B, Arpino A, Cervelli V, Montone A. A randomized trial comparing ReCell system of epidermal cells delivery versus classic skin grafts for the treatment of deep partial thickness burns. Burns. 2007;33(8):966–72.
97. Claes KEY, Vyncke T, De Wolf E, Hoeksema H, Verbelen J, Monstrey S. Enzymatic debridement as an effective treatment for combined flame and chemical burns caused by e-cigarettes. Am J Emerg Med. 2020;38(6):1199–202.
98. Harats M, Haik J, Cleary M, Vashurin I, Aviv U, Kornhaber R. A retrospective review of an off-label bromelain-based selective enzymatic debridement (Nexobrid®) in the treatment of deep, partial, and full thickness burns and hard to heal wounds. Isr Med Assoc J. 2020;22(2):83–8.
99. Schulz A, Ribitsch B, Fuchs PC, Lipensky A, Schiefer JL. Treatment of genital burn injuries: traditional procedures and new techniques. Adv Skin Wound Care. 2018;31(7):314–21.
100. Ojeda-Regidor Á, Martínez-Méndez JR, González-Miranda Á, Casado-Pérez C. Evaluation of surgical times and transfusions in burn patients treated with enzymatic debridement. Cir Plást Iberolatinoam. 2017;43(3):223–30.
101. Waldner M, Zucal I, Gentzsch T, et al. Delayed enzymatic debridement in severe burns: proof of concept. Burns Open. 2021;5(4):24–8.
102. Larsen JC, Disbrow GL. Project BioShield and the biomedical advanced research development authority: a ten year progress report on meeting U.S. preparedness objectives for threat agents. Clin Infect Dis. 2017;64(10):1430–4.
103. Rosenberg L, Shoham Y, Singer A. The role of rapid enzymatic Escharotomy and eschar removal in burn mass casualty incidents. Prehosp Disaster Med. 2017;32(S1):S8.
104. Bowers C, Randawa A, Sloan B, Anwar U, Phipps A, Muthayya P. Enzymatic debridement in critically injured burn patients – our experience in the intensive care setting and during burn resuscitation. Burns. 2022;48(4):846–59.
105. Loo YL, Goh BKL, Jeffery S. An overview of the use of bromelain-based enzymatic debridement (Nexobrid®) in deep partial and full thickness burns: appraising the evidence. J Burn Care Res. 2018;39(6):932–8.
106. Edmondson SJ, Ali Jumabhoy I, Murray A. Time to start putting down the knife: a systematic review of burns excision tools of randomised and non-randomised trials. Burns. 2018;44(7):1721–37.

Application of VAC Therapy in Burn Injury

5

Caitrin M. Curtis, Courtney E. Stone, and Joseph A. Molnar

Abstract

One of the great frustrations in burn care is the phenomenon of burn wound progression. In the first few days following injury, the inflammatory cascade and progressive tissue edema can contribute to further metabolic compromise of tissue and ultimate evolution of burn wounds. Such evolution produces a significant challenge in the clinical management of acute burns. The development of negative pressure wound therapy in the 1990s offered surgeons a weapon against damaging tissue edema and progressive injury. Its technology has proved successful on the microscopic level and has produced instrumental change in the field of burn care.

Keywords

Colloid osmotic pressure · Improve blood flow · Wound exudate · Subatmospheric pressure · Polyurethane sponge

5.1 Burn Wound Paradigm

The phenomenon of burn wound progression can prove to be challenging for the surgeon. In this process, the depth of the burn worsens in the first few days after injury even with optimal medical care. Jackson [1, 2] explained this phenomenon with three zones of injury (Fig. 5.1). By this paradigm, the zone of coagulation in the center of the wound is the deepest and consists of a zone of nonviable tissue. The outermost zone, the zone of hyperemia, is a superficial injury much like a first-degree burn and will go on to heal uneventfully almost regardless of the treatment provided. Between these two zones is the zone of stasis. In this zone, the tissue is severely metabolically compromised due to poor blood flow (stasis), leading to progressive tissue damage and ultimate burn wound progression. The etiology of this phenomenon is multifactorial and involves cytokines, free radicals, clotting cascade, and other factors involved with tissue damage and the inflammatory response that leads to progressive loss of blood flow and more tissue ischemia [3–6]. While infection will hasten this process, it is not a requirement for burn wound progression.

Edema is a particularly harmful byproduct of burn injury that leads to progressive tissue damage. Acute burn injury leads to capillary leak that results in the development of interstitial edema [3–6]. The edema alters cell shape and cellular activities, leading to progressive cellular injury [7]. In addition, the increase in tissue volume results in decreased vascular density, increased diffusion distances, and ultimately stretching of the vessels, decreased blood flow, and altered colloid osmotic pressure (Fig. 5.2). These factors are also an integral part of the progressive tissue damage in burn injury [8].

C. M. Curtis
Atrium Health Wake Forest Baptist Hospital, Winston-Salem, NC, USA

C. E. Stone · J. A. Molnar (✉)
Wake Forest University School of Medicine, Winston-Salem, NC, USA
e-mail: jmolnar@wakehealth.edu

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_5

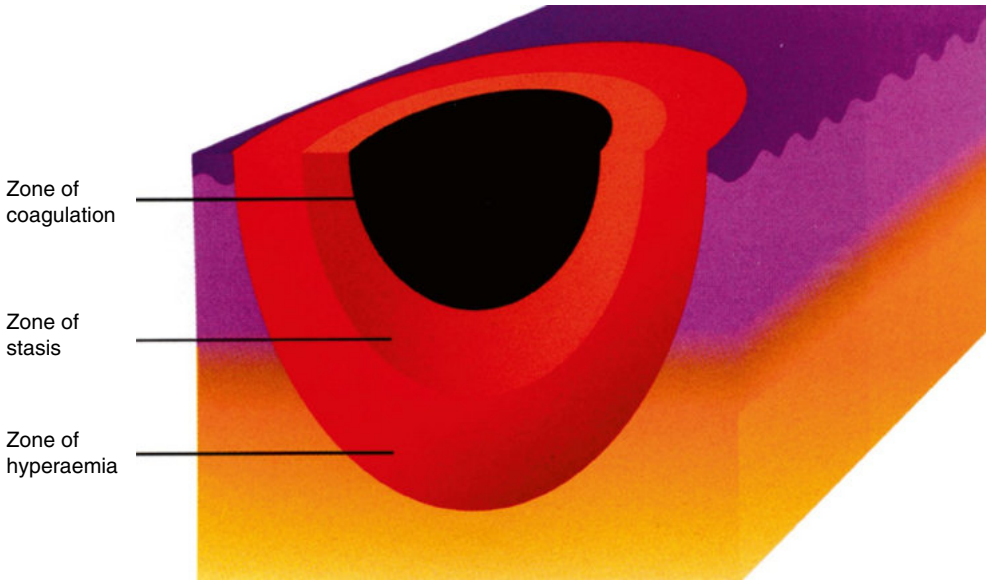


Fig. 5.1 Jackson's paradigm of burn injury. The central zone of coagulation is nonviable and cannot be recovered. The outer zone of hyperemia will heal almost regardless of the treatment. The zone related to burn wound progression is the intermediate zone of stasis. How the wound and patient are managed may result in improvement or worsening of this zone

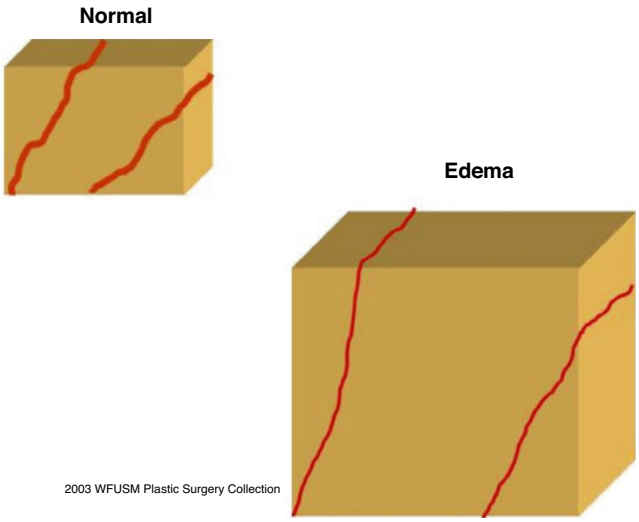


Fig. 5.2 In a "normal" state, the number of vessels is in balance with the needs of the tissue. "Edema" results in an enlargement of tissue volume and, of necessity, a decreased vascular density and increased diffusion distances. Ultimately, the vessels stretch and decrease flow, and with altered osmotic pressures, there is worsening of tissue ischemia

5.2 Subatmospheric Pressure Wound Therapy

In the 1990s, Argenta and Morykwas revolutionized modern wound care with the development of a new device. It was created as a simple closed-cell polyurethane sponge placed in the wound that was sealed off with an adherent drape, allowing subatmospheric pressure (SAP) (−125 mmHg) to be applied, now widely recognized as the wound vac or negative pressure wound therapy (NPWT). While the original concept was primarily to contain and remove wound exudate, subsequent studies demonstrated that NPWT resulted in increased blood flow, decreased edema, decreased bacterial counts, and earlier wound closure [8–10]. The mechanism for this effect on wounds is unclear but may involve macrodeformations and microdeformations, as well as the removal of inflammatory mediators and other yet undetermined effects [10, 11]. Despite these uncertainties, it is apparent that the specific nature of the sponge is important and not just the SAP exposure [10, 12].

It was logical that such treatment would be helpful in the management of the burn wound. Initial studies in an animal model showed that VAC therapy of burn wounds resulted in improved blood flow and decreased tissue damage when compared to standard wound care [13] (Figs. 5.3 and 5.4). Results were also better if the device was placed earlier, suggesting an effect on the early response to burn injury (Fig. 5.5).

Following initial success in animal models, this technique was then applied to acute human burn wounds. After initial anecdotal success with a partial-thickness flash burn, use of the VAC was then evaluated in a prospective fashion in two studies (Fig. 5.6) [8, 14–16]. Patients with bilateral hand burns were evaluated so that each patient could be in his or her own control, allowing for optimal statistical power. In the initial study, it appeared that hands treated with SAP had less edema and improved range of motion (Fig. 5.7). The device also proved very useful to splint hands in the "intrinsic plus" position, optimizing range of motion in patients who are not able to actively participate in therapy.

In a prospective, randomized, controlled, blinded, multicenter trial of the effect of SAP on burn wounds, evaluation of the size of burn wounds was accomplished with a standardized digital photography technique, and edema was measured by volume displacement [16, 17]. This study

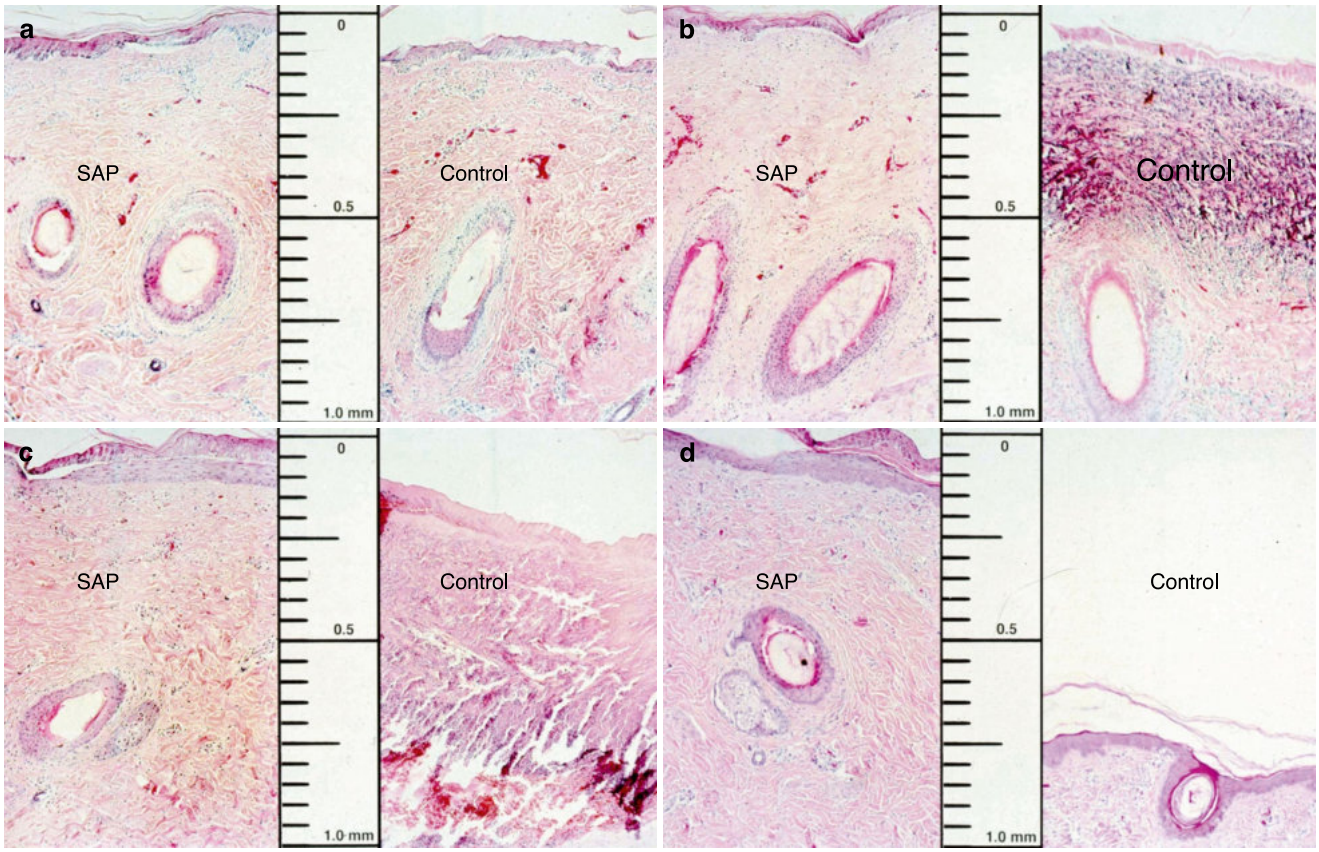


Fig. 5.3 Histologic changes with burn injury in an animal model [13]. Identical burns were treated with conventional dressings (control) or subatmospheric pressure (SAP). At days 1(**a**), 3(**b**), 5(**c**), and 9 (**d**), biopsies showed a relative amelioration of burn wound progression using SAP. With the healed wounds on day 9 (**d**), it is readily apparent that much more tissue was salvaged using the SAP treatment (depth of control burns = 0.885 ± 0.115 mm; SAP-treated burns (0-h delay) = 0.095 ± 0.025 mm). (With permission from Morykwas et al. [13])

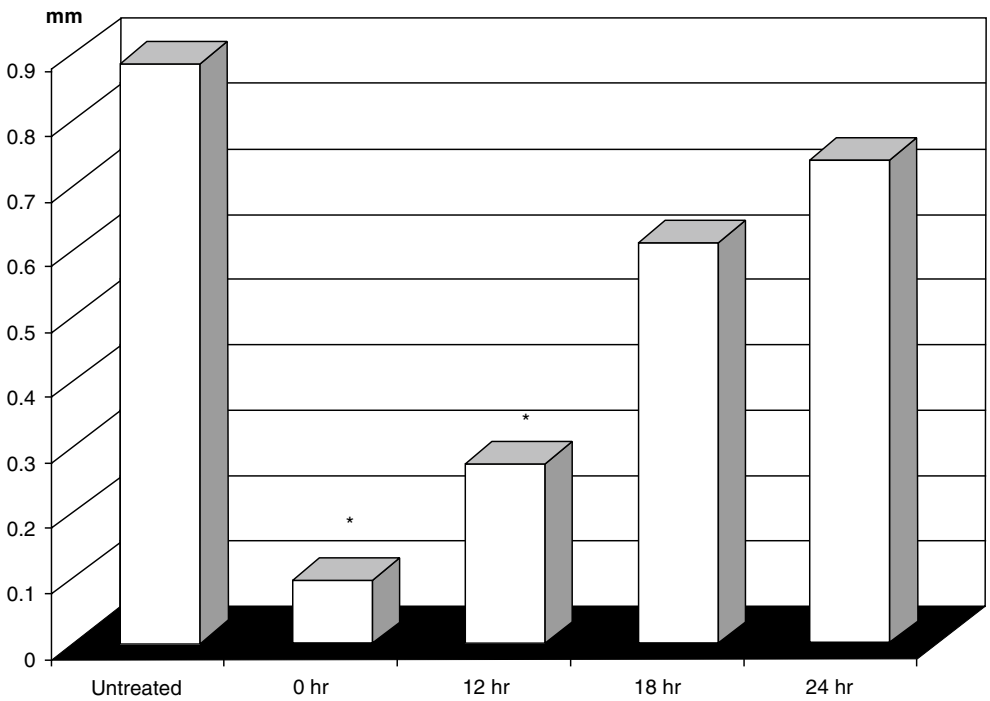


Fig. 5.4 Graphic representation of histologic findings with SAP applied at various time intervals after burn injury in the swine model of Fig. 5.3. The Y axis (mm) indicates the depth of burn. The X axis represents the delay time after burn injury until placement of the SAP treatment. The differences in tissue salvage are only statistically different at 0 and 12 h (*asterisk*). As predicted, the prevention of burn wound progression was greatest when applied early after injury [13]

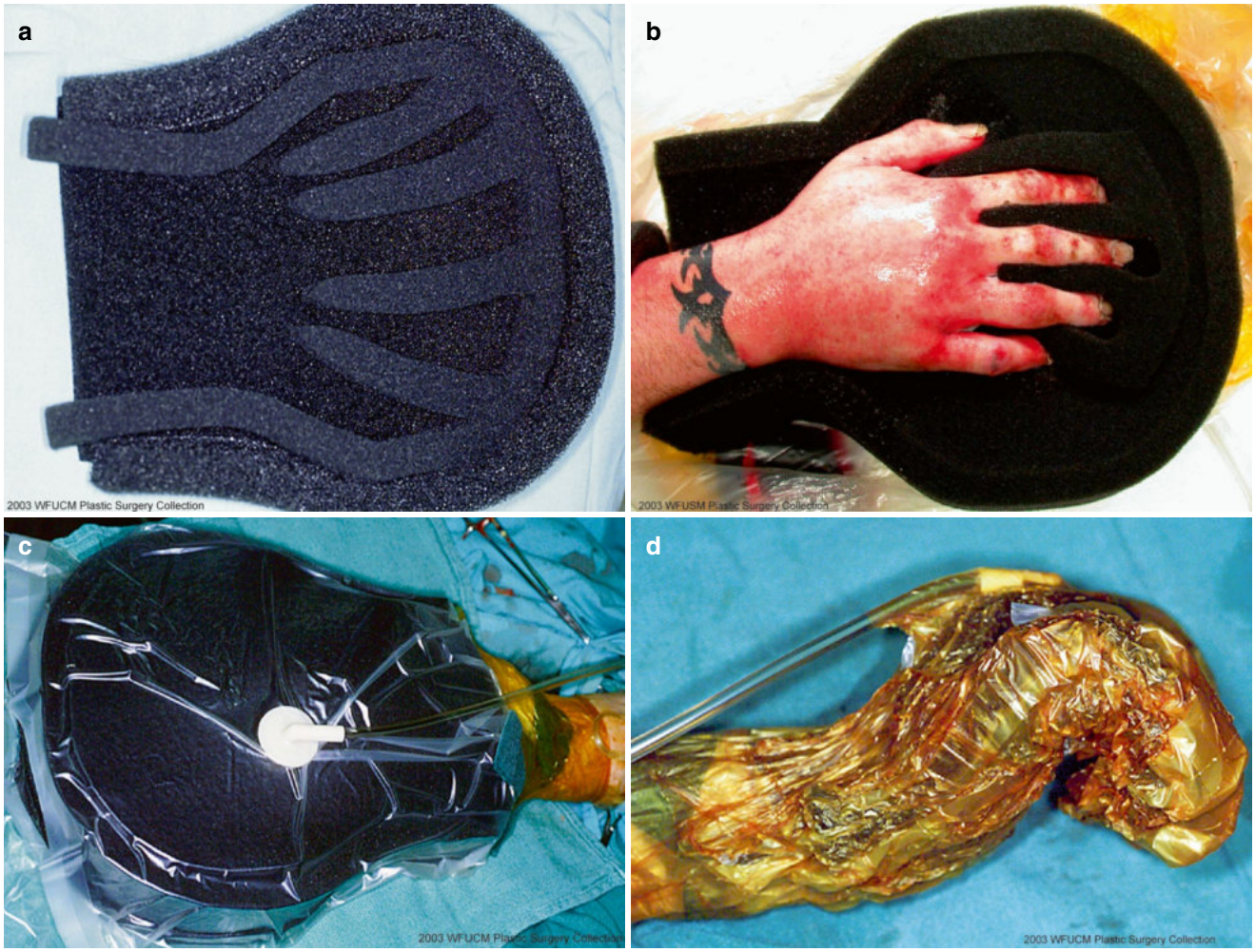


Fig. 5.5 (**a**) The hand dressing as supplied by KCI, Inc. (**b**) The polyurethane sponge must have components between the digits to avoid potential pressure damage to the skin by direct digital contact. (**c**) Once the sponge is sealed off and SAP applied, the patient may be kept in the "intrinsic plus" position. (**d**) To optimize range of motion when the dressing is discontinued, care should be taken to avoid the intrinsic minus position, which can cause damage to the tissue over the proximal interphalangeal joints

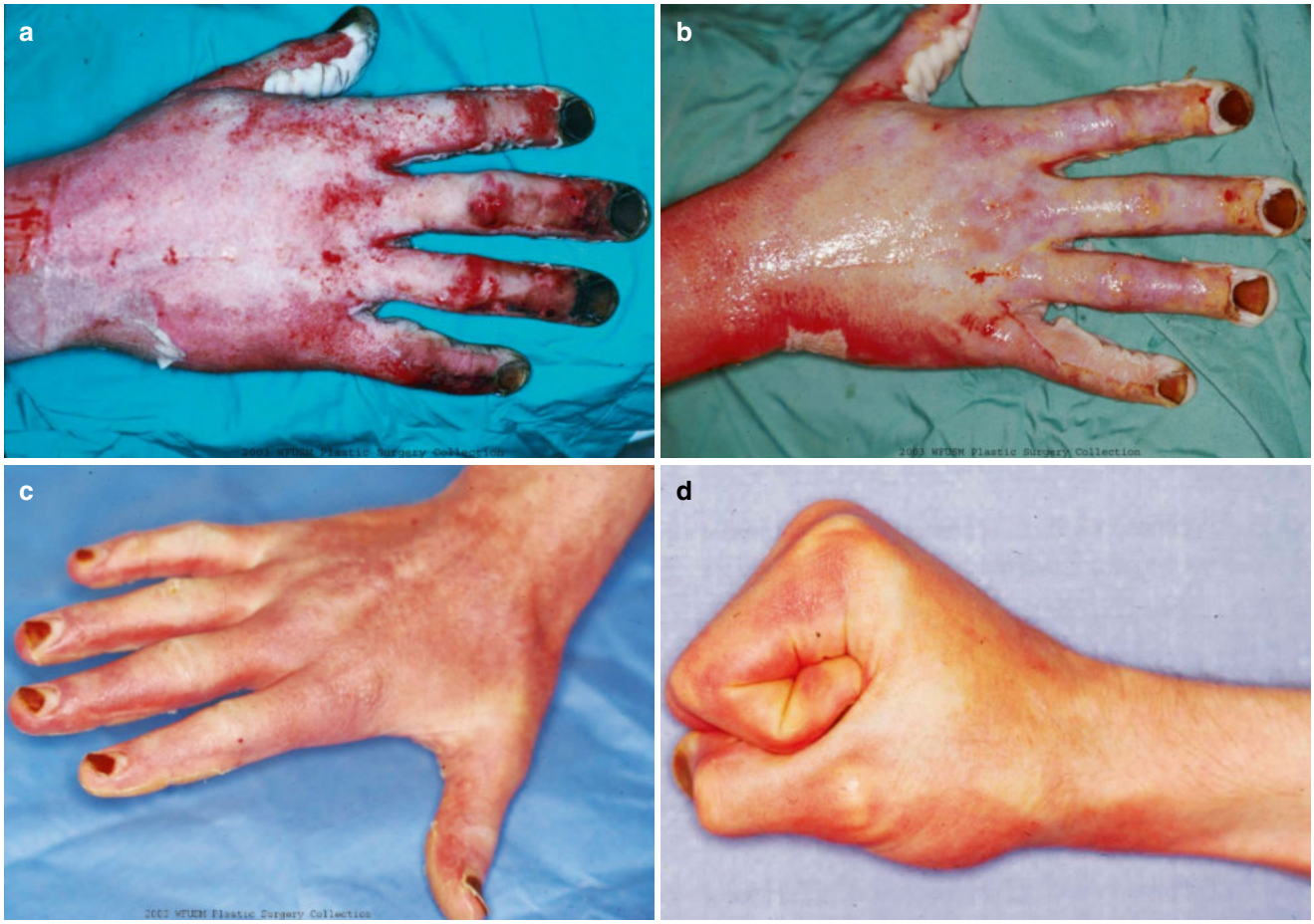


Fig. 5.6 Acute flash burn of the *right* upper extremity treated with SAP [14]. (**a**) Acute injury suggesting deep partial thickness injury. (**b**) Hand after 2 days of treatment with SAP. (**c** and **d**) Ultimate complete healing without skin grafting viewed at 5 weeks after injury. Note the healing of fingernails, indicating the depth of burn

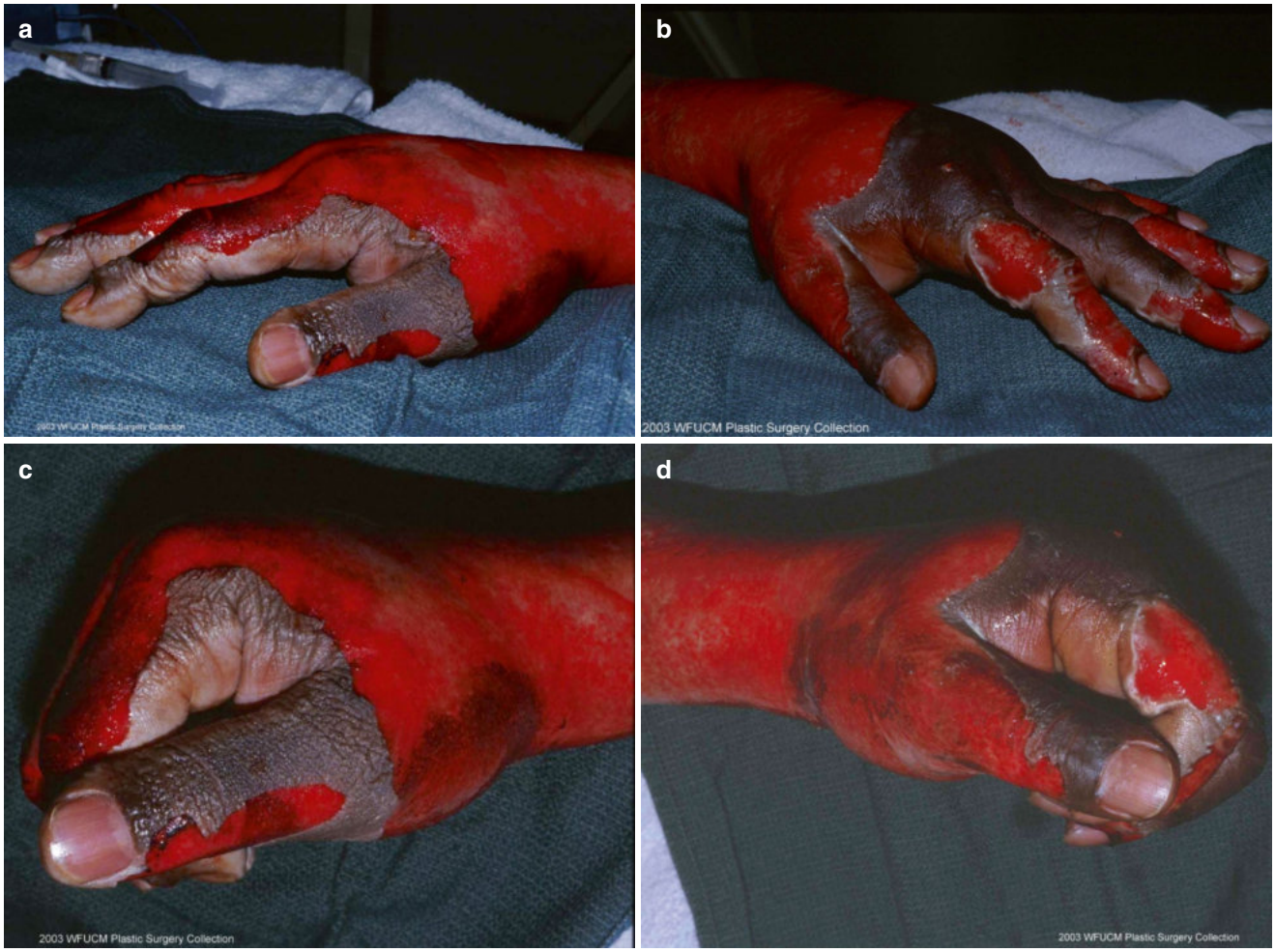


Fig. 5.7 In a prospective clinical study of the effect of the application of SAP to acute bilateral hand burns, each patient could be his or her own control by treating one hand with traditional antibacterial dressings while treating the other with SAP. (**a**) Right hand treated with SAP for 2 days after burn injury. (**b**) Left hand of same patient as (**a**) treated with silver sulfadiazine dressings. Note that despite the right hand having a more extensive burn, the dorsal hand edema is subjectively less after SAP treatment. (**c**) Right hand treated with SAP for 2 days after burn injury. (**d**) Left hand of the same patient treated with silver sulfadiazine. Note that the range of motion of the subatmospheric-treated hand is greater than the control hand, despite the control-receiving hand therapy during this 2-day interval while the subatmospheric-treated hand did not receive such therapy

indicates that SAP treatment of acute burns has a positive and statistically significant effect to minimize burn wound progression and minimize edema. Areas of burn wound progression were decreased by approximately 15%. Similar findings have been demonstrated by others [18, 19]. In addition to reduced edema in the acute burn setting, SAP therapy allows for a reduced frequency of dressing care. Thus, in addition to the direct benefits of VAC therapy in the microenvironment of the burn, it can serve as a temporizing measure until critically ill patients become physiologically stable for surgical intervention [20].

5.3 Summary

Studies have suggested the positive effect of SAP in minimizing burn wound progression and may prove to be an appropriate alternative dressing in the setting of acute burns. While decreased edema has been observed with this technique, other possible mechanisms for this positive effect include microdeformational changes, removal of inflammatory mediators and free radicals, and improved blood flow. Further studies will be required to determine the mechanism

of this change and the appropriate indications for this dressing.

References

1. Jackson DM. The diagnosis of the depth of burning. Br J Surg. 1953;40:588–96.
2. Jackson DM. Second thoughts on the burn wound. J Trauma. 1969;9:839–62.
3. Gibran NS, Heimbach DM. Current status of burn wound pathophysiology. Clin Plast Surg. 2000;27:11–22.
4. Branemark PI, Breine U, Joshi M, et al. Part I. Pathophysiology of thermal burns. Microvascular pathophysiology of burned tissue. Ann N Y Acad Sci. 1968;150:474–94.
5. Arturson MG. The pathophysiology of severe thermal injury. J Burn Care Rehabil. 1985;6:129–46.
6. Melikan V, Laverson S, Zawacki B. Oxygen-derived free radical inhibition in the healing of experimental zone-of-stasis burns. J Trauma. 1987;27:151–4.
7. Nozaki M, Guest MM, Bond TP, et al. Permeability of blood vessels after thermal injury. Burns. 1979;6:213–21.
8. Molnar JA. The role of topical negative pressure in burns. In: Banwell P, Teot L, editors. Topical negative pressure therapy. TXP Communications; 2004. p. 150–8.
9. Morykwas MJ, Argenta LC, Shelton-Brown EI, et al. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg. 1997;38:553–62.
10. Argenta LC, Morykwas MJ, Marks MW, DeFranzo AJ, Molnar JA, David LR. Vacuum assisted closure; state of the clinical art. Plast Reconstr Surg. 2006;117(7 Suppl):127S–42S.
11. Greene AK, Puder M, Roy R, Arsenault D, Kwei S, Moses MA, Orgill DP. Microdeformational wound therapy: effects on angiogenesis and matrix metalloproteinases in chronic wounds of 3 debilitated patients. Ann Plast Surg. 2006;56(4):418–22.
12. Scherer SS, Pietramaggiori G, Mathews JC, Prsa MJ, Huang S, Orgill DP. The mechanism of action of the vacuum-assisted closure device. Plast Reconstr Surg. 2008;122(3):786–97.
13. Morykwas MJ, David LR, Schnieder AM, et al. Use of subatmospheric pressure to prevent progression of partial-thickness burns in a swine model. J Burn Care Rehabil. 1999;20:15–21.
14. Molnar JA, Simpson JL, Voignier DM, et al. Management of an acute thermal injury with subatmospheric pressure. J Burns Wounds. 2005;4:108–18.
15. Molnar JA. The use of a hypobaric device in acute human burns. In: 10th Annual Regional Burn Seminar, Chapel Hill, North Carolina; 1997. December 6.
16. Molnar JA, Heimbach D, Gibran N, Tredgett E, Mozingo D, Bauling P, Kemalyan N, Still J, Lennox P, Lozano D. Evaluation of subatmospheric pressure treatment of acute burn injury in a prospective, randomized, controlled, blinded, multicenter trial. In: Australian and New Zealand Burn Association Annual Scientific Meeting 2005, Sydney, Australia; 2005. September 15.
17. Molnar JA, Lew WK, Rapp DA, Gordon ES, Voignier D, Rushing S, Willner W. Use of standardized, quantitative digital photography in a multicenter web-based study. Eplasty. 2009;9:19–26.
18. Schrank C, Mayr M, Overesch M, et al. Ergebnisse der Vakuumtherapie (V.A.C.®-Therapie) von oberflächlich und tiefdermalen Verbrennungen. Zentralbl Chir. 2004;129:51–3.
19. Kamolz LP, Willy C. Vacuum therapy in the treatment of acute burns—an overview. In: Willy C, editor. The theory and practice of vacuum therapy. Ulm: Lindquist Book; 2006.
20. Kantak NA, Mistry R, Halvorson EG. A review of negative-pressure wound therapy in the management of burn wounds. Burns. 2016;42(8):1623–33.

6 Use of Negative Pressure Wound Therapy and Dermal Regeneration Template in Reconstructive Burn Surgery

Courtney E. Stone, Caitrin M. Curtis, and Joseph A. Molnar

Abstract

Skin grafting has long served as a solution to both partial and full thickness defects of skin resulting from burn injury. However, split-thickness grafting commonly heals to an inflexible, cosmetically undesirable result distinct from natural skin. In cases of larger surface area burns, lack of donor skin can arrest reconstructive efforts and worsen patient outcomes. To address these problems, a series of innovative dermal regeneration templates were bioengineered, serving as artificial skin in early injury and acting as dermal scaffolds to promote cellular restoration of the wound bed and support subsequent grafting. The marriage of these templates and overlying negative pressure wound therapy has proven a powerful reconstructive tool, accelerating vascularization and reducing overall healing time.

Keywords

Skin graft · Normal skin · Negative pressure wound therapy · Skin substitute · Subatmospheric pressure

6.1 Integra as a Skin Substitute

As the largest organ of the body, the skin plays a critical role in maintaining homeostasis, and its damage can lead to serious problems. While skin grafting has long been a reliable and widely accepted method for addressing skin loss, it has its limitations. In cases of full-thickness skin defects, split-thickness skin grafting often results in stiff, fragile, scar-like coverage rather than the natural appearance of skin. Moreover, skin grafting is not always feasible in cases of large surface area burns where there is not enough available skin for donor sites. The ideal solution would be a product that would accurately simulate the physical and biological properties of skin and remain integrated in the healing process, so the final result is more like normal skin than a scar. This visionary concept became a reality through the groundbreaking work of Dr. John Burke and Dr. Ioannis Yannas, who introduced the innovative skin substitute known as Integra® Dermal Regeneration Template (Integra Life Sciences, Plainsboro, NJ, USA) [1–3]. This entirely bioengineered artificial skin represents an early application of "regenerative medicine" in action.

Since skin is bilaminate, it is logical that a bioengineered skin organ substitute should also be bilaminate. Integra consists of a temporary silicone "epidermal" substitute and a permanent dermal regeneration template (DRT) made of collagen and the glycosaminoglycan, chondroitin-6-phosphate. Once applied to the wound, the dermal matrix is invaded with fibroblasts and becomes vascularized, integrating with the recipient bed and directing cellular activities. Four distinct phases of dermal regeneration can be demonstrated histologically: imbibition, fibroblast migration, neovascularization, and remodeling and maturation. The wound is ready for skin grafting (STSG) once the color underneath the silicone layer changes from tan to pink or peach [4]. Once this dermal matrix is vascularized, the temporary silicone "epidermis" is removed and a thin split-thickness autograft is applied to complete the process. In this manner, the silicone layer provides a barrier to bacterial invasion and desiccation, while the collagen/glycosaminoglycan matrix provides a template to produce a neodermis [1–3]. Histologic data and subjective evaluations have suggested that this construct looks more like skin and has more distensibility than split-thickness skin grafting alone, but this remains controversial [5, 6].

While initial reports demonstrated that Integra could be a lifesaving skin substitute for burn injury, the rates of engraftment were often disappointing, being as low as 40% [6–8].

C. E. Stone · J. A. Molnar (✉)
Atrium Health Wake Forest Baptist Medical Center, Winston-Salem, NC, USA
e-mail: jmolnar@wakehealth.edu

C. M. Curtis
Wake Forest University School of Medicine, Winston-Salem, NC, USA

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_6

Rarely were engraftment rates reported to be above 90%, except by the inventor, suggesting that the process of learning to work with the product was slow. Much like skin grafting, loss of Integra was due to hematoma, seroma, shear forces, infection, etc. Numerous attempts were made to find the best dressing to prevent these complications, but there was no one widely accepted answer [6–8]. In addition, engraftment took 2–4 weeks prior to placing a skin graft. While this delay was acceptable in acute burn care, this was an undesirable characteristic for reconstructive surgery.

Since the development of Integra, various matrix-like products have been created and are frequently employed in burn care [9]. One such innovation is the Novosorb® Biodegradable Temporizing Matrix (BTM, PolyNovo Limited, Melbourne, Australia), a synthetic, bilayer dermal scaffold. The dermal layer consists of biodegradable 2-mm-thick foam bonded to a polyurethane film, serving as a neoepidermis. The polyurethane top layer stays in place until the BTM is ready for grafting. In contrast to Integra, BTM gradually hydrolyzes and is resorbed by 18 months [10]. MatriDerm (MedSkin Solution Dr. Suwelack AG, Billerbeck, Germany) is a bovine-derived collagen (I, II, V) and elastin hydrolysate that acts as a dermal replacement. The collagen scaffold supports regeneration, cell migration, proliferation, and neovascularization, while the elastin encourages early neoangiogenesis and elastin synthesis. MatriDerm is intended for use in a single-stage approach, but it may be utilized in a two-stage approach like other templates [11]. Alloderm (LifeCell Corp., Branchburg, NJ, USA) is an allogenic dermal transplant of freeze-dried cadaveric tissue. Epithelial elements are removed, resulting in an acellular and immunologically inert DRT. Like MatriDerm, it can be used in a single step [12]. Overall, direct comparative studies among the dermal regenerative templates are lacking.

Integra and other matrix-like products may be considered in several scenarios for a patient with an acute burn injury. In patients with extensive burns, a scaffold can be utilized to achieve temporary wound closure to allow for physiological stability in critically ill patients prior to final skin grafting. The use of these products also permits coverage of wounds while awaiting reepithelization of donor sites.

6.2 Negative Pressure Wound Therapy

Approximately 15 years after the first clinical reports of the use of Integra, the subatmospheric pressure wound treatment device, now known as the VAC® (KCI, Inc., San Antonio, TX, USA), was developed by Argenta and Morykwas [13–15]. This negative pressure wound therapy (NPWT) device was shown to promote healing of wounds with rapid vascularization, granulation, epithelialization, decreasing of bacterial counts, and removal of fluid from the wound. The device consists of a polyurethane foam sponge placed in the wound sealed by an occlusive dressing. A tube is inserted into the foam, and subatmospheric pressure, applied. As a whole, the device promotes wound healing, and recent data have shown that the individual components of NPWT are uniquely suited to wound healing. Attempts at similar but different components have yielded unpredictable results [16, 17]. The VAC has proven to be an ideal treatment for skin grafts since the subatmospheric pressure causes the sponge to conform to the shape of the wound, removes fluid, promotes neovascularization, and protects from bacterial contamination and shear forces [18]. It was logical that if this device was a superior dressing for skin grafts, it would be useful in optimizing engraftment of the skin substitute, Integra.

6.3 NPWT and DRT

Our initial laboratory studies in a swine model showed that the use of the VAC with Integra resulted in faster vascularization and improved adherence in the first 3–5 days when compared to a standard bolster dressing [19]. This information allowed us to rapidly apply this technique to reconstructive surgery, including acute burns [20]. Currently, this is our preferred dressing for use of Integra and has proven to have routine engraftment rates of approximately 95%, and, with vascularization, usually within 1 week instead of the previously reported 2–4 weeks [20].

The application of NPWT to the dermal regeneration template created a *technological synergy*. The regenerative template had sometimes been challenging to obtain engraftment. When used with NPWT, it became much more reliable and could be used in ways not imagined in the original development of the device.

The use of the VAC and Integra in complex wounds with exposed bone, tendon, ligaments, and joints has proven to be a powerful tool for reconstructive surgery. Poorly vascularized structures such as tendons cannot provide the metabolic needs of a skin graft placed directly on them, and uniformly the graft dies before it can become vascularized. Since Integra is initially not viable but becomes incorporated into the body through the process of fibroblast ingrowth and vascularization, it can be placed directly on poorly vascularized structures awaiting vascularization. In fact, it can be placed directly over an open joint and still vascularize. While this might be possible with only routine dressings, the VAC facilitates healing with immobilization of the joint much like a splint, minimizing shear forces and speeding vascularization (Fig. 6.1).

With experience, we have found this to be an ideal dressing in an outpatient setting [21]. Patients undergoing reconstructive surgery may have the Integra placed and covered directly over the silicone layer with the VAC. These patients typically stay in the hospital overnight for pain management and to ensure that there are no leaks in the seal. They rou-

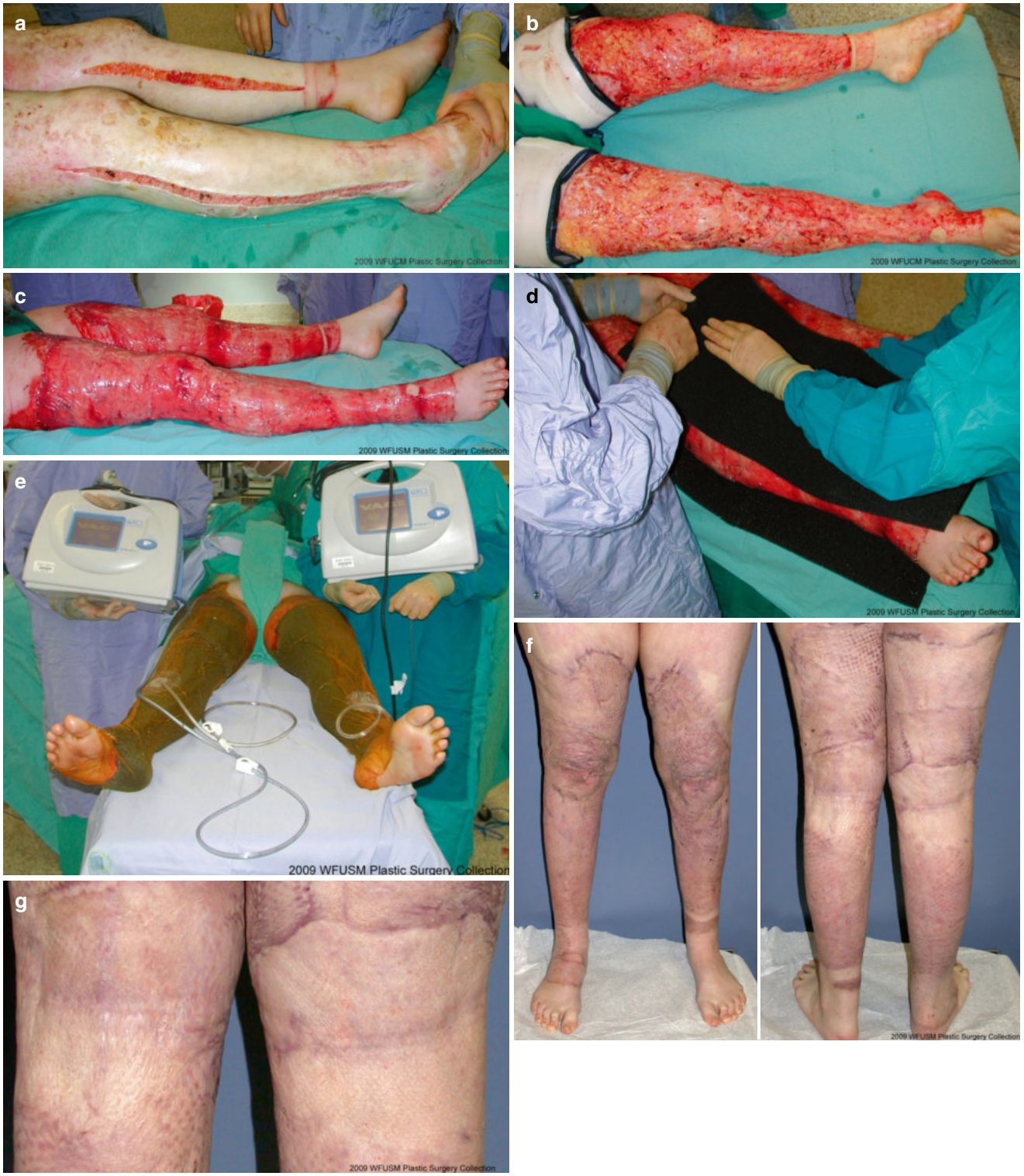


Fig. 6.1 A 16-year-old girl received full-thickness burns to her lower extremities from groin to ankle. (**a**) Acute injury after escharotomies. (**b**) In the first 3–5 days, the patient underwent full-thickness excision, sparing the viable subcutaneous tissue. It is crucial to have meticulous hemostasis and a wound free of necrotic debris that could be a nidus for infection before placing the Integra. (**c**) Integra is stapled onto the patient before dressing application. (**d**) Wrapping the legs with polyurethane sponges (VAC, KCI, Inc., San Antonio, TX, USA) often requires at least two members of the team. (**e**) Once the sponge is sealed with adherent drape, 125 mmHg subatmospheric pressure is applied using the proprietary VAC pump. Use of wall suction is discouraged due to the variable pressure that may interfere with healing and allow the possibility of exsanguination. In this case, one pump is used for each leg to simplify problem solving in the case of leaks. With the VAC dressing in place, there is no need for splinting across the ankle or knee since minimal motion is possible once the subatmospheric pressure is applied. The dressing remains in place for at least 1 week to allow vascularization prior to skin grafting. (**f**) Results at 6 months. The patient has full range of motion and returned to competitive swimming. (**g**) Close-up of popliteal fossa showing lack of scarring and full extension

tinely return in 1 week when the VAC is removed in the operating room and the split-thickness skin graft is applied. The skin graft is covered with a nonadherent dressing such as Adaptic® (Johnson & Johnson, Inc., New Brunswick, NJ, USA) and the VAC is reapplied. The patient returns in 5–7 days to the clinic for VAC removal. The grafted construct is then again covered with nonadherent dressing and gauze. Range of motion of extremities begins immediately, and outpatient therapy is ordered. This technique is even feasible in small children (Fig. 6.2).

Additional studies have demonstrated our ability to use this technique for one-stage engraftment of Integra and not wait for the period of vascularization [22]. While this has been applied clinically, in our practice this is more routinely used in ideally vascularized beds rather than complex wounds.

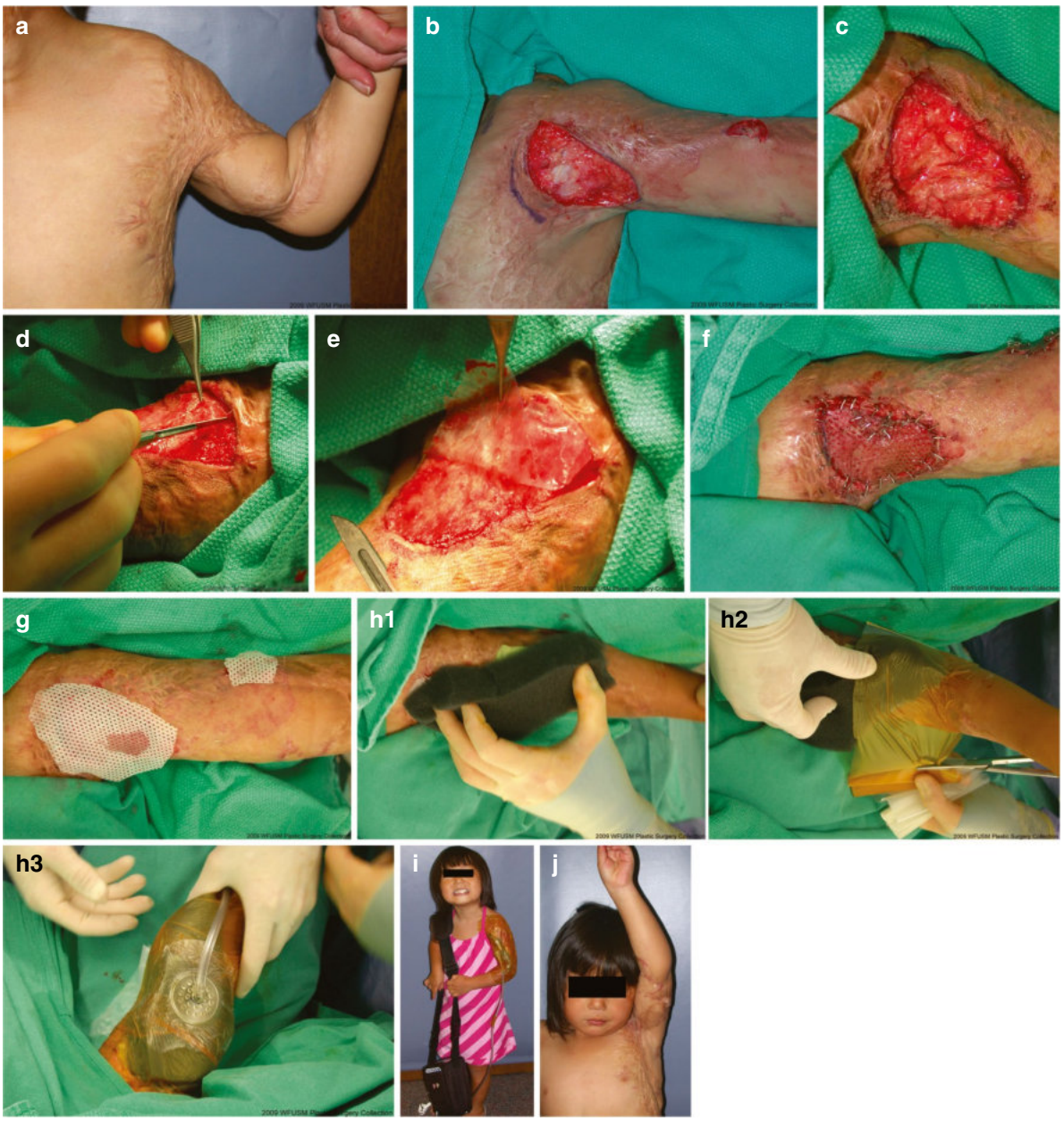


Fig. 6.2 (**a**) Four-year-old female with fixed axillary scar contracture due to injuries received at 9 months of age. (**b**) The axilla is released on the arm to avoid injury to the breast tissue with a simple incision revealing the required tissue to allow axillary movement to 90° abduction. The Integra was stapled into place, and the VAC subatmospheric pressure dressing was applied. After an overnight stay for pain management, the patient was discharged home ambulatory with the VAC. (**c**) After the placement of Integra and subatmospheric pressure treatment for 1 week, the patient is reevaluated in the operating room. The Integra is adherent and well-vascularized. (**d** and **e**) The silicone layer is teased free of the dermal regeneration template in order to avoid disturbing the adherent and vascularized dermal construct. (**f**) A 0.010 split-thickness skin graft is applied. (**g**) The skin graft is covered with Mepitel (Molnlycke Health Care, Norcross, GA, USA) and the VAC dressing is applied. (**h**1–3) The VAC Sponge is sealed with adherent drape, and the suction tubing is attached. (**i**) The patient was treated as an outpatient for 1 week with subatmospheric pressure. (**j**) Result at 4 months with improved range of motion

References

1. Yannas IV, Burke JF. Design of an artificial skin. I. Basic design principles. J Biomed Mater Res. 1980;14(1):65–81.
2. Yannas IV, Burke JF, Warpehoski M, Stasikelis P, Skrabut EM, Orgill D, Giard DJ. Prompt, long-term functional replacement of skin. Trans Am Soc Artif Intern Organs. 1981;27:19–23.
3. Burke JF, Yannas IV, Quinby WC, et al. Successful use of a physiologically acceptable artificial skin in the treatment of extensive burn injury. Ann Surg. 1981;194(4):413–28.
4. Moiemen N, Vlachou E, Staiano JJ, Thawy Y, Frame JD. Reconstructive surgery with Integra dermal regeneration template: histologic study, clinical evaluation, and current practice. Plast Reconstr Surg. 2006;117(7S):160S–74S.
5. Orgill DP, Straus FH II, Lee RC. The use of collagen-GAG membranes in reconstructive surgery. Ann N Y Acad Sci. 1999;888:233–48.
6. Moiemen NS, Staiano JJ, Ojeh NO, et al. Reconstructive surgery with a dermal regeneration template: clinical and histologic study. Plast Reconstr Surg. 2001;108(1):93–103.
7. Clayton MC, Bishop JF. Perioperative and postoperative dressing techniques for Integra artificial skin: views from two medical centers. J Burn Care Rehabil. 1998;19(4):358–63.
8. Machens HG, Berger AC, Mailaender P. Bioartificial skin. Cells Tissues Organs. 2000;167(2–3):88–94.
9. Mason SA, Pham TN. Use of dermal regenerative templates for burns. J Burn Care Res. 2023;44(Suppl_1):S19–25.
10. Greenwood JE, Schmitt BJ, Wagstaff MJD. Experience with a synthetic bilayer Biodegradable Temporising Matrix in significant burn injury. Burns Open. 2018;2:17–34.
11. Ryssel H, Gazyakan E, Germann G, Ohlbauer M. The use of MatriDerm in early excision and simultaneous autologous skin grafting in burns—a pilot study. Burns. 2008;34:93–7.
12. Callcut RA, Schurr MJ, Sloan M, Faucher LD. Clinical experience with Alloderm: a one-staged composite dermal/epidermal replacement utilizing processed cadaver dermis and thin autografts. Burns. 2006;32:583–8.
13. Morykwas MJ, Argenta LC, Shelton-Brown EI, et al. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg. 1997;38(6):553–62.
14. Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. Ann Plast Surg. 1997;38(6):563–76.
15. Argenta LC, Morykwas MJ, Marks MW, DeFranzo AJ, Molnar JA, Daivd LR. Vacuum-assisted closure: state of clinic art. Plast Reconstr Surg. 2006;117(7 suppl):127S–42S.
16. Saxena V, Hwang CW, Huang S, Eichbaum Q, Ingber D, Orgill DP. Vacuum-assisted closure: microdeformations of wounds and cell proliferation. Plast Reconstr Surg. 2004;114(5):1086–96.
17. Orgill DP, Manders EK, Sumpio BE, Lee RC, Attinger CE, Gurtner GC, Ehrlich HP. The mechanisms of vacuum assisted closure: more to learn. Surgery. 2009;146(1):40–7.
18. Schneider AM, Morykwas MJ, Argenta LC. A new and reliable method of securing skin grafts to the difficult recipient bed. Plast Reconstr Surg. 1998;102(4):1195–8.
19. Molnar JA, Shrimanker N, Morykwas MJ, Argenta LC. Improved skin graft adherence and vascularizaton of Integra® using subatmospheric pressure—a laboratory study. In: American Burn Association 34th Annual Meeting, April 24–27. Chicago, Illinois; 2002.
20. Molnar JA, Defranzo AJ, Hadaegh A, et al. Acceleration of integra incorporation in complex tissue defects with subatmospheric pressure. Plast Reconstr Surg. 2005;113(5):1339–46.
21. Park CA, Defranzo AJ, Marks MW, Molnar JA. Outpatient reconstruction using Integra and subatmospheric pressure. Ann Plast Surg. 2009;62:164–9.
22. Newman CE, Morykwas M, Park CA, Gordon S, Simpson J, DeRoberts D, Molnar JA. Immediate skin grafting on an engineered dermal substitute. J Burn Care Rehabil. 2005;26(2 suppl):S89.

Prevention of Scar Using bFGF

7

Sadanori Akita

Abstract

Prompt wound healing and closure are key to preventing subsequent scars and contractures, as well as eliminating systemic infections such as burn wound sepsis and even shock (Hughes et al., Burns 47:349–370, 2021). Hypertrophic scars or keloid scars caused by burns are sometimes problematic when functional regions such as articular joints or conspicuous areas on the face or extremities are involved (Edgar and Brereton, BMJ 329:343–345, 2004). Massive burn wound scars have a tendency to develop progressive hypertrophic scars, and earlier skin grafting may improve the overall skin quality as well as shorten the hospital stay (Fujii, Acta Chir Plast 32:46–56, 1990). Humoral and cellular mediators have been considered for the pathogenesis of burn wound-induced hypertrophic scars. One possible role of the growth factors or cytokines in wound healing is to promote high cellular proliferation, differentiation, and migration of keratinocytes of the epidermis and the recruitment of inflammatory cells (Kibe et al., Br J Dermatol 143:720–727, 2000). A basic fibroblast growth factor (bFGF) may play a pivotal role in cutaneous wound healing by activating local macrophages, with the effects continuing up to the remodeling stage, several weeks after the initial injury. Burn wound fluids or skin graft wound fluids limited to the dermis contain lower concentrations of bFGF compared to surgical wounds, which are deeper than the dermis with subsequently lower endothelial cell proliferative and chemotactic activities (Nissen et al., J Trauma 54:1205–1210, 2003). The bFGF is increased by silicone gel application in normal and fetal fibroblast cultures and may result in the prevention of hypertrophic scars. The healing of burn wounds is more complicated than acute wound healing. Sustained burn wounds are more susceptible to bacterial contamination and bring about unfavorable results, particularly in children (Akita et al., J Burn Care Res 27:333–338, 2006). Faster wound healing is highly expected to prevent severe systemic damage or sequelae such as invasive wound infection and sepsis. The bFGF was effective for second-degree burn wound healing in a randomized control trial, although bovine recombinant bFGF was employed (Fu et al., Lancet 352:1661–1664, 1998). The bFGF was regulated in spatial and temporal expression in accordance with the recruitment of inflammatory cells and interaction with keratinocytes (Kibe et al., Br J Dermatol 143:720–727, 2000) and was lower in second-degree burn wound fluid, therefore decreasing endothelial cell proliferative and chemotactic activity (Nissen et al., J Trauma 54:1205–1210, 2003). Wounds treated with bFGF produced scars that were significantly less hard 1 year after final wound closure (Akita et al., Burns 31:855–858, 2005).

Keywords

Skin grafting · Hypertrophic scar · Keloid scar · Cutaneous wound healing · Artificial dermis

7.1 Background of the Method

Hypertrophic scars or keloid scars caused by burns are sometimes problematic when functional regions such as articular joints or conspicuous areas on the face or extremities are involved [1]. Massive burn wound scars have a tendency to develop progressive hypertrophic scars, and earlier skin grafting may improve the overall skin quality as well as shorten the hospital stay [2]. Humoral and cellular mediators have been considered for the pathogenesis of burn wound-induced hypertrophic scars. One possible role of the growth factors or cytokines in wound healing is to promote high cellular proliferation, differentiation, and migration of keratinocytes of the epidermis and the recruitment of inflammatory

S. Akita (✉)
Fukushima Medical University, Fukushima, Japan

Tamaki Aozora Hospital, Tokushima, Japan
e-mail: akitas@hf.rim.or.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_7

cells [3]. A basic fibroblast growth factor (bFGF) may play a pivotal role in cutaneous wound healing by activating local macrophages, with the effects continuing up to the remodeling stage, several weeks after the initial injury. Burn wound fluids or skin graft wound fluids limited to the dermis contain lower concentrations of bFGF compared to surgical wounds, which are deeper than the dermis, with subsequently lower endothelial cell proliferative and chemotactic activities [4]. The bFGF is increased by silicone gel application in normal and fetal fibroblast cultures and may result in the prevention of hypertrophic scars. The healing of burn wounds is more complicated than acute wound healing. Sustained burn wounds are more susceptible to bacterial contamination and bring about unfavorable results, particularly in children [5]. Faster wound healing is highly expected to prevent severe systemic damage or sequelae such as invasive wound infection and sepsis [6]. The bFGF was effective for second-degree burn wound healing in a randomized control trial, although bovine recombinant bFGF was employed [7]. The bFGF was regulated in spatial and temporal expression in accordance with the recruitment of inflammatory cells and interaction with keratinocytes [3] and was lower in second-degree burn wound fluid, therefore decreasing endothelial cell proliferative and chemotactic activity [4]. Wounds treated with bFGF produced scars that were significantly less hard 1 year after final wound closure [8].

Pediatric burn wounds can be problematic since accurate evaluation is difficult due to anatomically immature vasculature or immobilization failure, especially in second-degree burns, and the burn surface areas and the burn depth tend to worsen over time. Delayed wound healing results in unsightly scarring, such as hypertrophic scars, which are problematic both esthetically and functionally. Among cytokines and growth factors, bFGF is clinically proven, having demonstrated accelerated acute and chronic wound healing. Accelerated wound healing may lead to improved scarring. To elucidate the effects of bFGF on second-degree pediatric burn wounds, a comparative study was performed. bFGF-treated pediatric burn wounds demonstrated better scarring and well-organized stratum corneum after healing, both clinically and by moisture meter analysis [5].

The bFGF demonstrated endogenous immunolocalization in the human dermis in partial-thickness burns from day 4 to day 11. The bFGF participates in cutaneous wound healing by activating local macrophages up to the remodeling phase, which occurs several weeks after injury. The bFGF in burn wounds may be a presynthesized mediator that is released locally from injury sites and thus may play an important role in early wound healing [9]. In adult second-degree burns, the topical application of bFGF within 5 days postinjury demonstrated significantly better regeneration of granulation tissues and newly formed capillaries in a randomized-control clinical trial.

Our therapeutic regimens of bFGF treatment for the second-degree burns in this investigation started as early as on the arrival day postburn, and burn wound healing was completed at 12 days for the bFGF-treated group; this may be compatible with the endogenous bFGF expressions observed during day 4 to day 11 as observed in rat immunohistochemically [10].

Reconstruction of the lower extremities can be a concern. After extensive soft tissue defects due to metabolic changes such as diabetes, atherosclerosis, and subsequent osteomyelitis, as well as local infection, contusion, traffic accident, or tumor resection, it is more difficult to resurface the skin if the raw surface consists of bone and tendon tissues. The combination of an artificial dermis with the topical administration of bFGF is the only angiogenic cytokine currently available in Japan. The bFGF also demonstrated acceleration and improvement in burn wounds in terms of the healing rate and hardness of the postskin grafting.

Staged lower extremity reconstruction with daily bFGF-treated artificial dermis and subsequently thinner split-thickness skin grafting was beneficial for the quality of reconstructed skin in comparison with the artificial dermis and split-thickness skin grafting alone in terms of hardness and moisture parameters such as transepidermal water loss (TEWL), water content, and thickness. The bFGF-treated reconstruction demonstrated almost equal values in water content and thickness, consistent with the softer and thus better nature of the reconstructed lower extremity.

The advantages of using an artificial dermis include immediate coverage for deeper tissue exposure, such as tendon and bone; protection from fluid, protein, and electrolyte loss; protection from microorganism invasion; and reduced secondary donor-site morbidity, as only thinner skin grafting is required. Also, the combination of artificial dermis with bFGF demonstrated the reconstruction of deep diabetic soft tissue loss, diabetic pressure ulcer healing in a mouse model, and intractable fingertip ulcers caused by burn injury [11].

In mobile regions such as the neck, a burn contracture may impair mastication, phonics, or breathing, accompanied by pain and aesthetically unfavorable results. The use of bFGF in wound bed preparation before split-skin grafting brings about better outcomes [12].

7.2 Characterization and Indication of the Method

Genetically recombinant basic human fibroblast growth factor (bFGF) is used for spraying: the recombinant human bFGF with 154/153 aa residues (E. *coli*). The molecular weight of the recombinant human bFGF is 17 kDa. The isoelectric point is 10.1, basic, and a nonglycosylated single-chain peptide. The beginning of bFGF use varied from 2 to

4 days postburn injury. The concentration of bFGF is 30 μg of bFGF per 30 cm^2 area, as 100 μg of freeze-dried bFGF is dissolved in 1 mL of benzalkonium chloride solution, with 300 μL sprayed over a 30 cm^2 area from 5 cm distance, and 0.3 mL of such concentration solution is applied by this method. Ointment-impregnated gauze is applied to wounds treated with bFGF after waiting for 30 s. The bFGF administration continues until the wound has healed.

For comparison, the non-bFGF treatment group receives only ointment-impregnated gauze without bFGF spraying. Standard procedures for stabilizing the burn wounds are applied for all the cases.

For application with artificial dermis, the bFGF-containing solution, which is reconstituted in the same way as the spray form, at a concentration of 1 μg/cm^2, is delivered to the undersurface of the artificial dermis.

7.3 Specific Points of the Method

1. The reconstituted bFGF solution, either spray form or solution form, should be stored at 4° until use, and each vial should be used up within a 2-week period.
2. Major foreign bodies or large necrotized tissues should be debrided off before applying bFGF.
3. The principle is once per day application. Even another dressing change is required within 24 h.
4. Prevent the eyes from contacting bFGF directly.

7.4 Clinical Cases

7.4.1 Case 1

A 78-year-old woman living alone in a remote hilly house. The fire from a candle spread over her clothes, and she fell down on the floor. The bilateral buttocks and posterior thighs and part of the leg developed a total of 12% surface area burns. Eight percentage of TBSA was third degree and required debridement and split-thickness skin grafting. This patient was also suffering from dementia; she thus had little understanding of why the burn was so little. In 5 days, after she was found and brought to us by ambulance, the first debridement and skin grafting were performed. In third-degree burn areas in posterior thighs, debridement was performed up to the fat tissues, and sheet grafts were placed over bilateral ischiums, and the majority of the wound was covered with mesh or patched grafts.

In 18 months, the left buttock with bFGF spray demonstrated softness and more durability to trauma compared to the right buttock (control). The histology in both buttocks showed quite different findings. The bFGF-treated wound demonstrated stratified epithelia and matured collagen fiber in the transverse direction; on the other hand, the control histology demonstrated thinner epithelia and loss of rete ridges, along with the deranged dermis and partly hyalinized collagens, which was consistent with the durometer readings (Fig. 7.1a–d).

7.4.2 Case 2

A 2.5-year-old girl mistakenly spilled hot water over her forearm and upper arm. In the forearm (left of Fig. 7.2a), the bFGF spray as well as the ointment-impregnated gauze was applied, and the arm side (right of Fig. 7.2a) was treated with the ointment-impregnated gauze daily. The depth of the burn wounds in both the upper arm and forearm seems comparable and indistinguishable between superficial dermal burn (SDB) and deep dermal burn (DDB) initially. In 1 year after complete healing, the appearance of the scar was much better in the bFGF-treated wounds in terms of color, hardness, and height (Fig. 7.2a and b).

7.4.3 Case 3

An 80-year-old woman who developed a sudden-onset infection in the left lower extremity. The severe cellulitis after a minor burn wound and partial infection to the bones and some tendons were exposed.

In 5 days after she was referred to our hospital, the secondary debridement, bFGF spray for the wound bed, and the artificial dermis were applied. The bFGF injection was continued at 30 μg up to the secondary split-thickness skin grafting.

After the continuation of 14-day bFGF from the side of the artificial dermis, 10/1000 inch-split-thickness skin grafting was performed over the bFGF-treated wound bed.

In 3 years after skin grafting, the wound healed uneventfully with softer and much more normalized appearances (Fig. 7.3a–e).

7.4.4 Case 4

An 82-year-old man who mistakenly spilled the flamed kerosene over his upper back, posterior neck, and arms. There was a DDB area in the upper left back. Daily bFGF spraying along with the ointment-impregnated gauze dressing up to 14 days when all the wounds completely healed. In 1 year after healing, the scar is pliable and color-matches favorably with the adjacent intact skin (Fig. 7.4a and b).

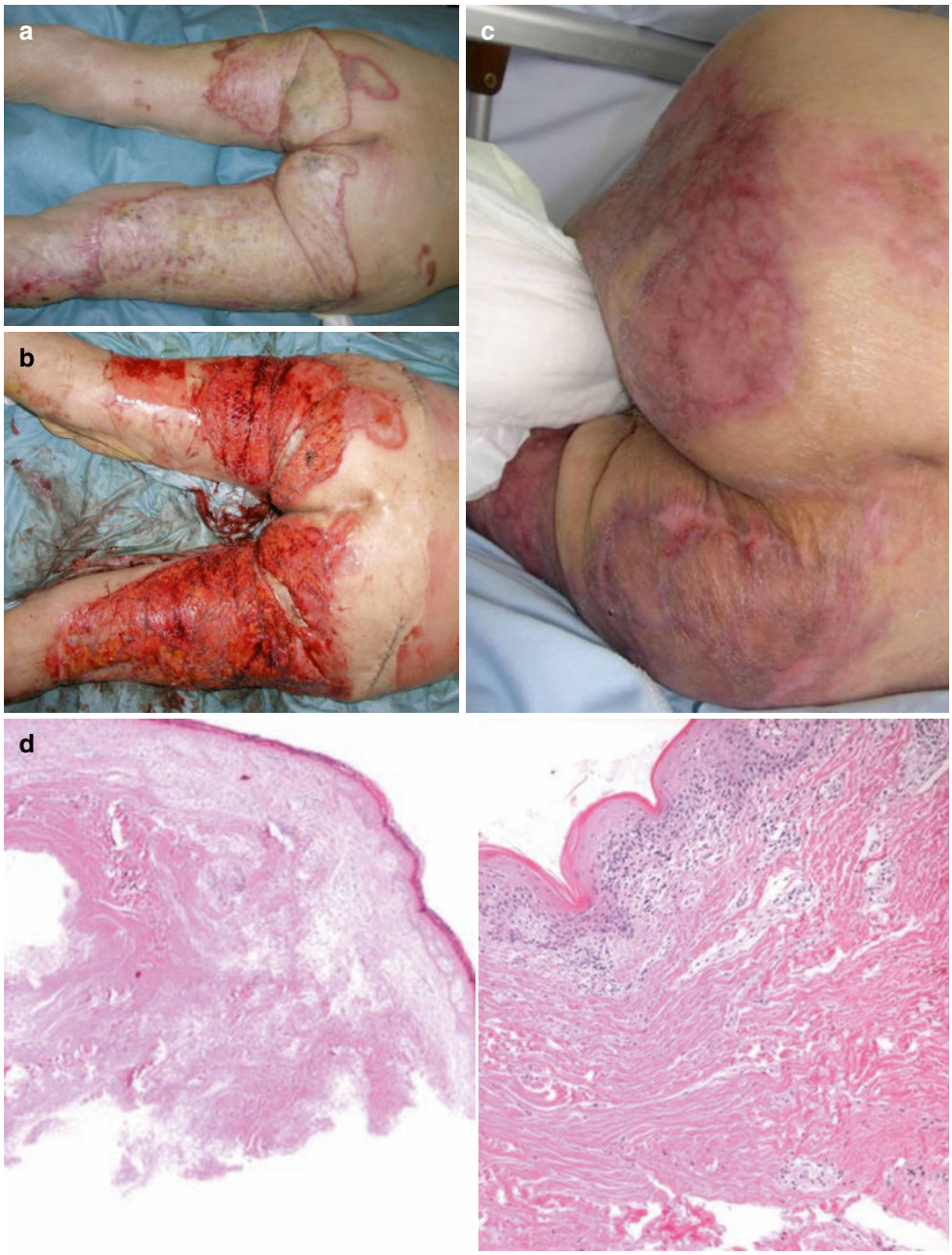


Fig. 7.1 78-year-old woman demonstrated a total 12% BSA IIIrd-degree flame burn (**a**). Immediately after debridement (**b**). Histology of the control scar in 18 months. There is a randomized array of the collagen fibers (×100) (**c**). Histology of the bFGF-treated scar in 18 months. There is an organized array, and the rete ridges are obtained (×100) (**d**)

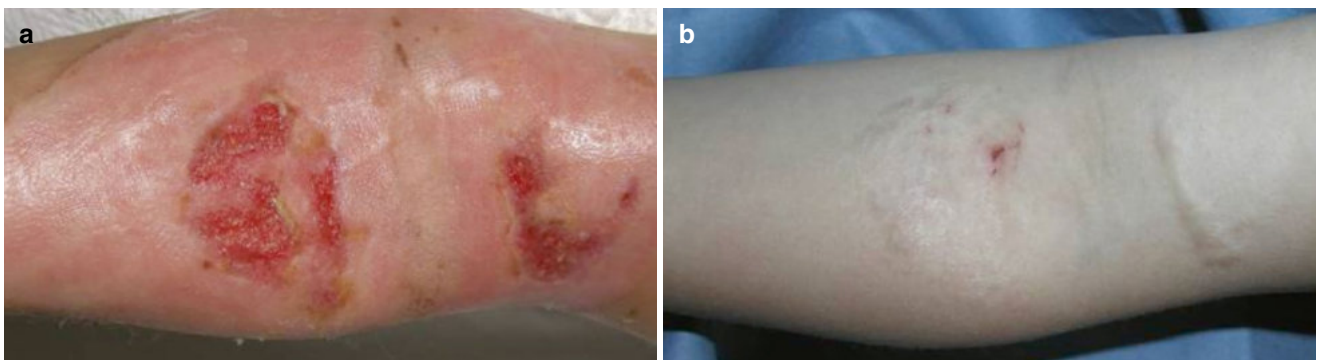


Fig. 7.2 2.5-year-old girl with scald burn. The left (forearm) was treated with the bFGF, and the right was the control (**a**). One year after complete wound healing. The bFGF-treated scar is much flatter, softer, and well-matched in color with surrounding tissue (**b**)

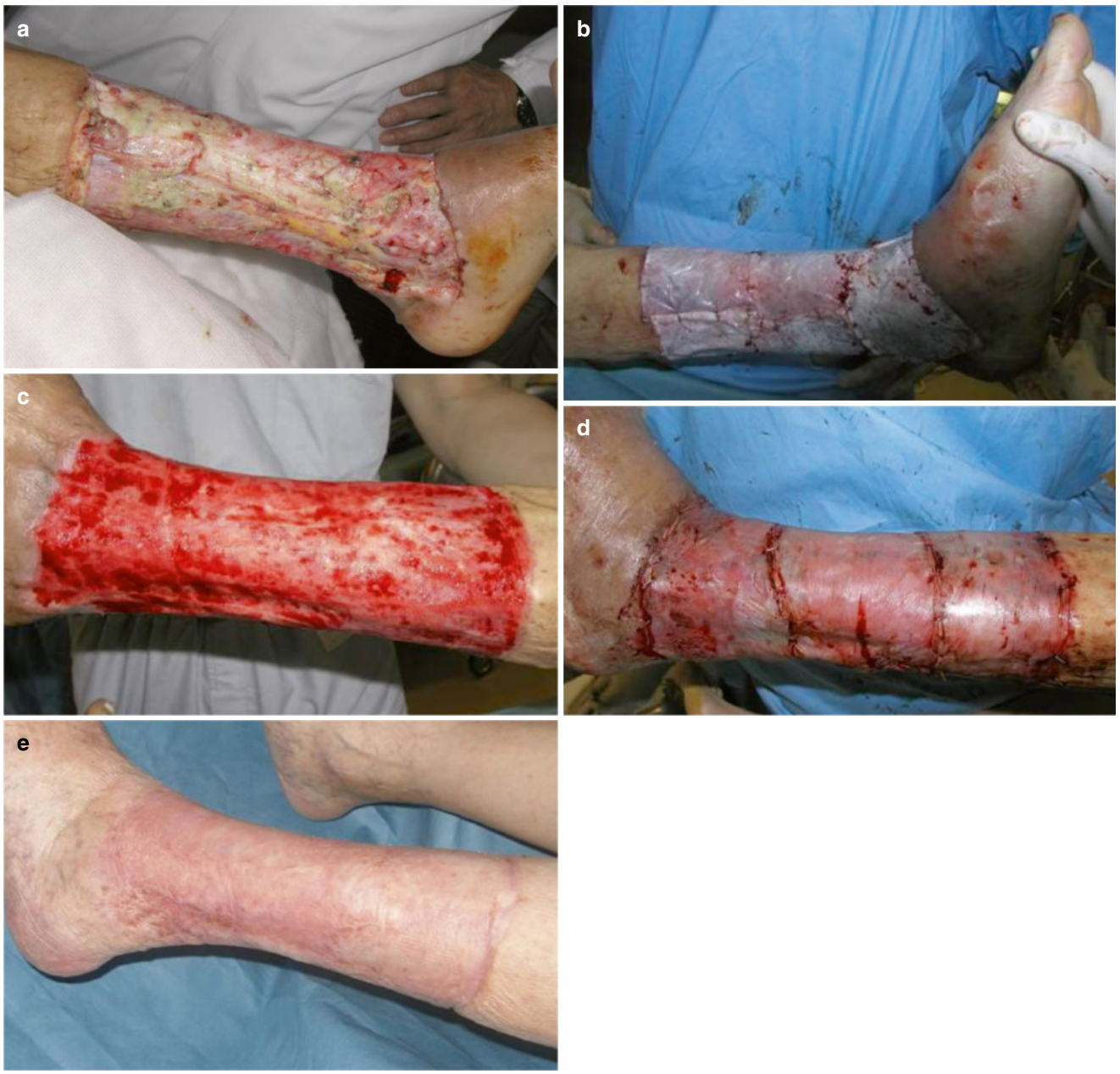


Fig. 7.3 80-year-old woman developed the severe cellulitis of sudden onset in the left calf (**a**). After thorough debridement, the bFGF was sprayed over the wound and covered with the artificial dermis (**b**). With 14-day continuous injection of the bFGF from the side of the artificial dermis, the wound bed was optimally ready for secondary skin grafting (**c**). Right after 10/1000 inch-split-thickness skin grafting was applied (**d**). In 3 years after the final surgery, the scar is softer and demonstrates a normal appearance (**e**)

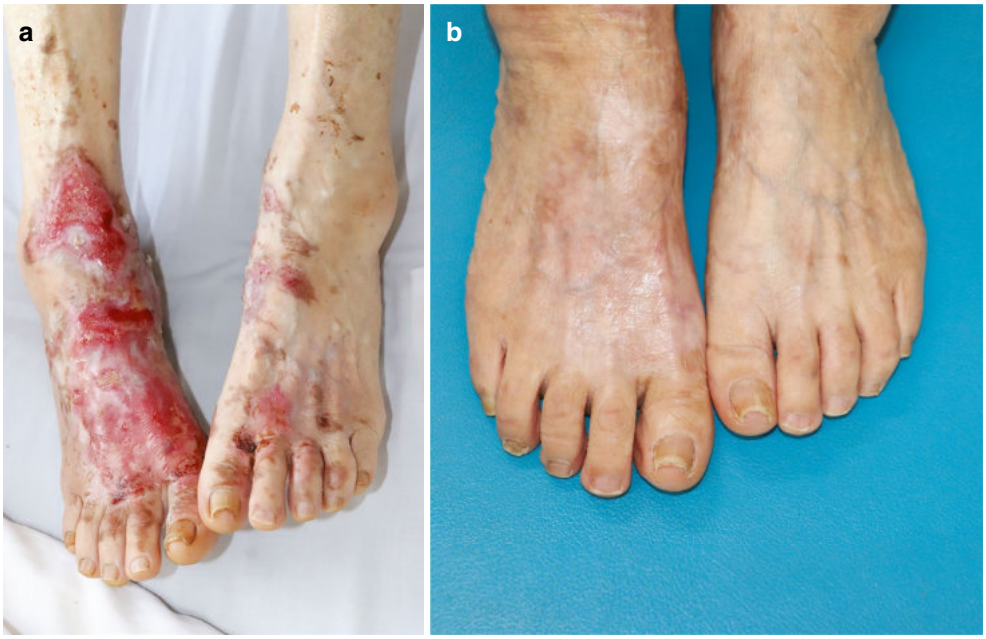


Fig. 7.4 An 84-year-old woman developed DB and DDB in her lower extremities, such as the knees, calves, and feet (**a**). After 13 days of continuous spraying of bFGF on the right foot, complete closure with texture and color matching was achieved (**b**)

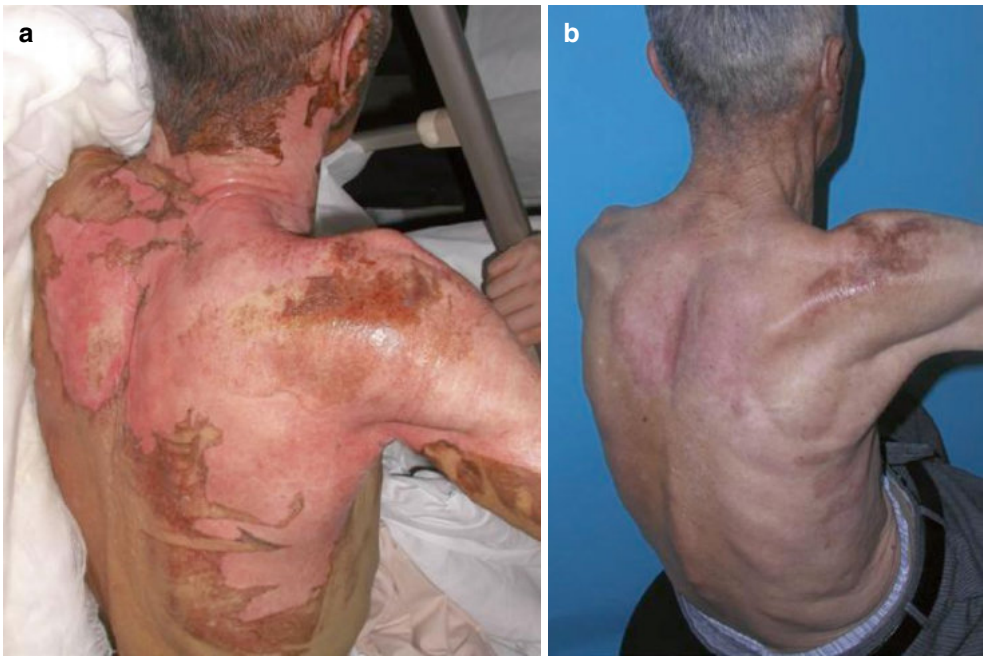


Fig. 7.5 82-year-old man spilled the flamed kerosene over his back, neck, and arms (**a**). With 14-day continuous spraying of the bFGF until wound healing, it is pliable, color-matched scars in 1 year (**b**)

7.4.5 Case 5

An 84-year-old woman, who dropped a candle and had flames burn her clothes and socks, developed DDB to DB over her knees, calves, and feet. The DB areas on the knees, calves, and the right medial sole were treated with split-thickness skin grafting, and the dorsum of the right foot was treated for 13 consecutive days before the surgery. The dorsum of the right foot completely healed without surgery in the 1-year follow-up (Fig. 7.5a and b).

References

1. Edgar D, Brereton M. Rehabilitation after burn injury. BMJ. 2004;329:343–5.
2. Fujii T. Local treatment for extensive deep dermal thickness burn and follow-up study. Acta Chir Plast. 1990;32:46–56.
3. Kibe Y, Takenaka H, Kishimoto S. Spatial and temporal expression of basic fibroblast growth factor protein during wound healing of rat skin. Br J Dermatol. 2000;143:720–7.
4. Nissen NN, Gamelli RL, Polverini PJ, DiPietro LA. Differential angiogenic and proliferative activity of surgical and burn wound fluids. J Trauma. 2003;54:1205–10.
5. Akita S, Akino K, Imaizumi T, Tanaka K, Anraku K, Yano H, Hirnao A. The quality of pediatric burn scars is improved by early administration of basic fibroblast growth factor. J Burn Care Res. 2006;27:333–8.
6. Hughes A, Almeland SK, Leclerc T, Ogura T, Hayashi M, Mills JA, Norton I, Potokar T. Recommendations for burns care in mass casualty incidents: WHO Emergency Medical Teams Technical Working Group on Burns (WHO TWGB) 2017–2020. Burns. 2021;47(2):349–70.
7. Fu X, Shen Z, Chen Y, Xie J, Guo Z, Zhang M, Sheng Z. Randomised placebo-controlled trial of use of topical recombinant bovine basic fibroblast growth factor for second-degree burns. Lancet. 1998;352:1661–4.
8. Akita S, Akino K, Imaizumi T, Hirano A. A basic fibroblast growth factor improved the quality of skin grafting in burn patients. Burns. 2005;31:855–8.
9. Gibran NS, Isik FF, Heimbach DM, Gordon D. Basic fibroblast growth factor in the early human burn wound. J Surg Res. 1994;56:226–34.
10. Akita S, Akino K, Imaizumi T, Hirano A. A basic fibroblast growth factor accelerates and improves 2nd degree burn wound healing. Wound Repair Regen. 2008;16:635–41.
11. Akita S, Akino K, Tanaka K, Anraku K, Hirnao A. A basic fibroblast growth factor improves lower extremity wound healing with a porcine-derived skin substitute. J Trauma. 2008;64:809–15.
12. Akita S, Hayashida K, Takaki S, Kawakami Y, Oyama T, Ohjimi H. The neck burn scar contracture: a concept of effective treatment. Burns Trauma. 2017;5:22. https://doi.org/10.1186/s41038-017-0086-8. eCollection 2017

Burn Wound Dressing

8

Hajime Matsumura

Abstract

Wound dressings for burn injuries promote wound healing by maintaining a moist environment while avoiding bacterial invasion from the outside. The choice of wound dressing should be based on its ability to absorb exudate, ranging from contact layers, such as silicone gauze, which do not absorb exudate, to fiber products, which retain exudate to a greater extent.

Keywords

Wound dressing material · Exudate · Polyurethane films · Hydrocolloids · Polyurethane foams · Hydrofibers · Alginates · Chitin hydrogels · Amnion · Antimicrobial dressing · Silicone adhesive

Wound dressings for burn injuries promote wound healing by maintaining a moist environment while avoiding bacterial invasion from the outside. The choice of wound dressing should be based on its ability to absorb exudate, ranging from contact layers, such as silicone gauze, which do not absorb exudate, to fiber products, which retain exudate to a greater extent.

Among successive dressings, those that use silicone adhesives, which reduce pain during dressing changes and lessen disruption to the regenerating epithelium, are also available.

In addition, some dressings contain Ag and exhibit antimicrobial properties. This reduces the frequency of dressing changes.

In recent years, new products that promote the granulation and healing of deep burns, such as amniotic membrane products, which conventionally require a flap, have also been introduced.

H. Matsumura (✉)
Department of Plastic and Reconstructive Surgery, Tokyo Medical University, Tokyo, Japan
e-mail: hmatsu@tokyo-med.ac.jp

8.1 Purpose of Using Burn Wound Dressings

Dressing materials are used to absorb exudates and maintain a moist wound environment and to prevent damage to the regenerating epithelium and periwound stratum corneum during the healing process when changing dressings. Thus, contact layers that are non-adherent can be peeled off without pain. In addition, to further improve convenience, adhesive dressings are used in some cases, for example, when simplicity is required without the need for a secondary dressing.

Some additional functions include a coating material containing a silver agent that provides an antimicrobial effect on the surface to which the dressing is applied or is inside the dressing material. This is intended to prevent local infection, thus reducing the number of dressing changes. Some products contain the chelating agent ethylenediaminetetraacetic acid or surfactants to remove biofilms and improve the antimicrobial performance of silver ions [1].

8.2 Structure and Types of Wound Dressings

Wound dressings have been recently developed using various medical-grade materials, and new products have been introduced into the market continuously.

Wound dressings can be broadly classified into polyurethane films, hydrocolloids, polyurethane foams, hydrofibers, alginates, chitinous materials, and hydrogels, depending on the material used.

The most important factor in the selection of wound dressings is the exudate volume. The water absorption of each wound dressing decreased in the following order: hydrofiber > alginate > polyurethane foam > hydrocolloid. Suitability should be determined based on burn [2, 3]. If the dressing is severely contaminated at the time of dressing change and leakage of exudate is observed, it should be

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_8

changed to a more absorbent or thicker dressing or changed more frequently.

The next section summarizes how to use each dressing material.

8.2.1 Nonadherent Gauze (e.g., Adaptec Dressing, 3 M, and Nonadhesive Silicone Gauze)

In combination with appropriate secondary dressings, they can be used in a wide range of burns, from first- to third-degree burns. The non-adherent silicone gauze does not adhere to moist wounds. When used as a contact layer, it reduces the risk of pain and tissue damage, including injury and maceration of the surrounding skin and wound margins (Fig. 8.1) [4].

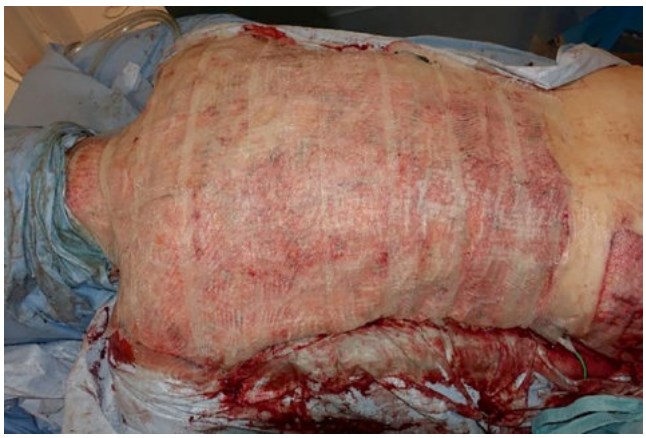


Fig. 8.1 ADAPTIC™ Non-Adhering Dressing (3 M, USA). Acts as a contact layer. Secondary dressings such as gauze are required to absorb exudates. This method could also be used to treat extensive burns

8.2.2 Hydrocolloid Dressings (e.g., DuoACTIVE, Combatec, etc.)

Superficial dermal burns (SDB) with small areas of low exudate are a good indication. Hydrocolloid dressings can block the entry of foreign bodies and bacteria. They absorb exudates and gels to maintain a moist environment within the wound. Hydrocolloids absorb approximately twice their weight in water. Water absorption is also low (Fig. 8.2) [5].

8.2.3 Polyurethane Foam (e.g., Mepilex, Mölnlycke Health Care; ALLEVYN Dressing, Smith, Nephew)

This is a good indication for SDB and deep dermal burns (DDB) with high exudate levels. Polyurethane foams have structures consisting of small pores (cells). Capillary action draws moisture into the cells and retains it, maintaining a moist environment on the wound surface. Excess exudate is eventually expelled from the outer layer as water vapor [6].

Therefore, reducing the frequency of dressing changes, particularly in pediatric burn cases, is important. Thus, by using an Ag-containing polyurethane foam dressing, the author changes the dressing every few days if no signs of infection are noted (Fig. 8.3) [7, 8].

8.2.4 Hydrophilic Fibers: Hydrofiber, Alginate (e.g., Aquacel, Combatec; KALTOSTAT, Combatec; Algoderm; Smith and Nephew)

SDB-DDB with high exudate content is a good indication. A large amount of water (approximately 30 times its own

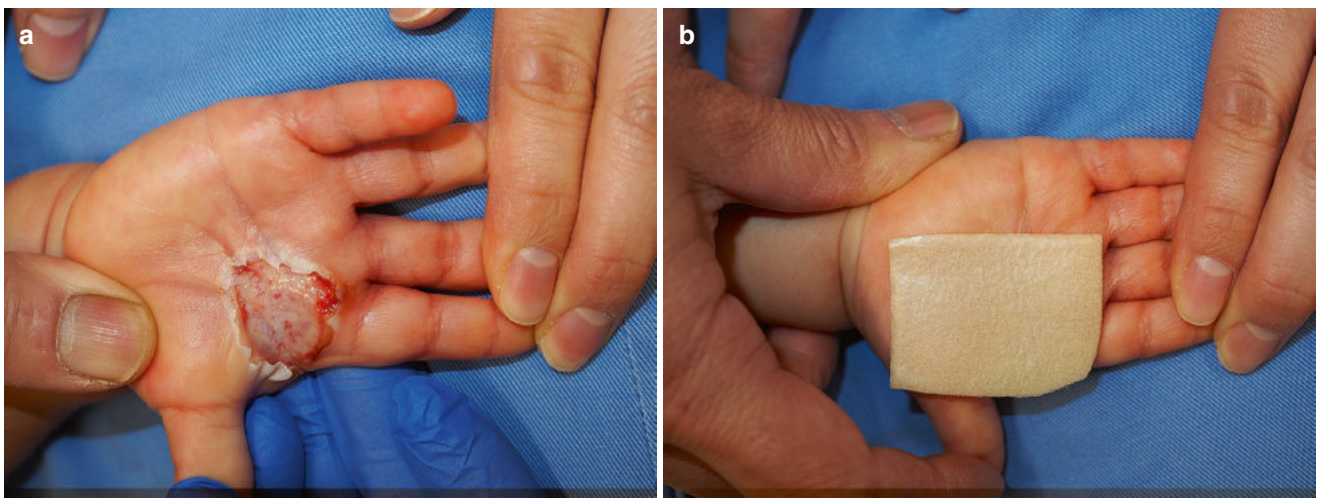


Fig. 8.2 (**a** and **b**) DuoActive CGF (Convatec, USA). Used for second- or third-degree hand burns in children. This dressing is suitable for burns with moderate amounts of exudates

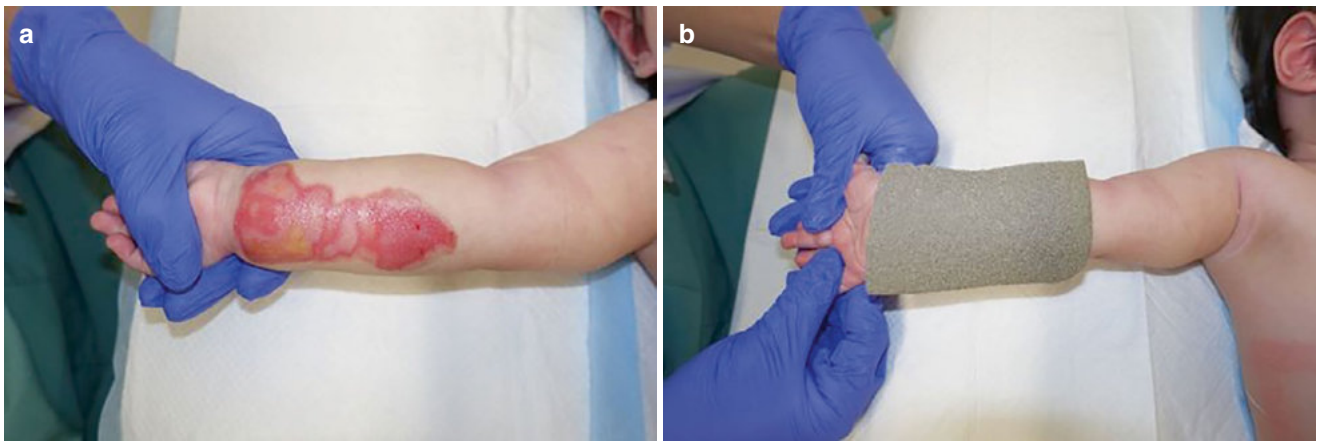


Fig. 8.3 (**a** and **b**) Mepilex Ag foam dressing (Molnlycke Health Care, Sweden). Used for second-degree burns in children. The product uses soft silicone as the adhesive, which makes it less painful to change and is useful for children

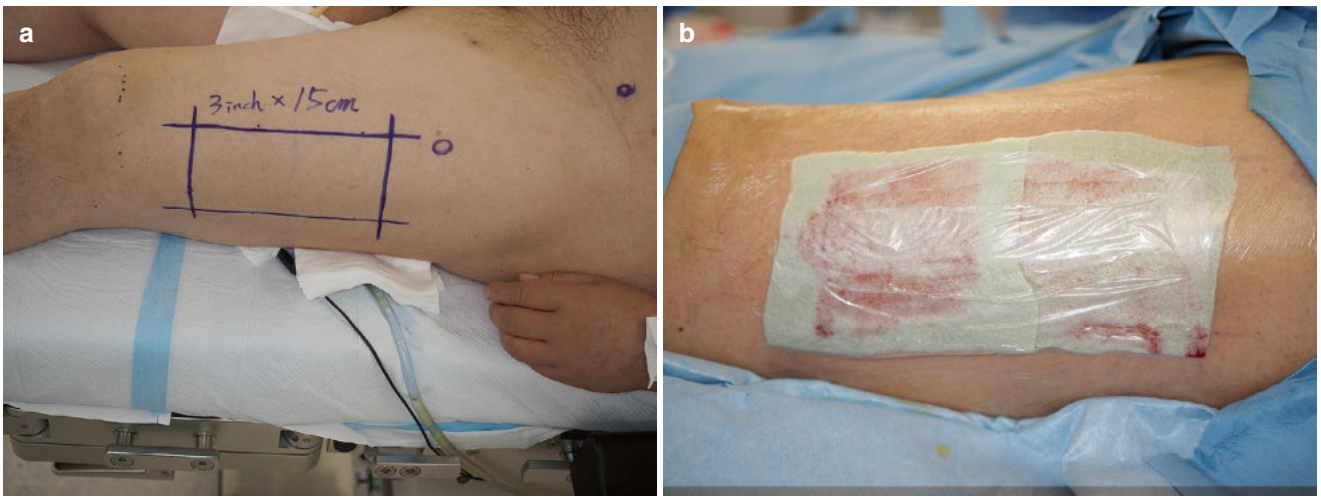


Fig. 8.4 (**a** and **b**) An alginate dressing (ALGODERM TRIONIC, Smith and Nephew, UK) was used to dress the donor site. This is expected to have a hemostatic effect

weight) is absorbed by the gels, thereby forming a moist environment. As water is absorbed directly into the fiber structure, the water-retention capacity is high.

In addition, the calcium ions released during the gelation of alginate have a local hemostatic effect similar to blood coagulation factor IX; therefore, alginate dressing is useful for dressing donor sites (Fig. 8.4) [9].

8.2.5 Polyurethane Film (Tegaderm Transparent Film, 3 M; IV3000®, Smith and Nephew, etc.)

Polyurethane film is used to secure nonadherent dressings. The films were characterized based on their microporous nature. Moisture and bacteria cannot penetrate these pores.

Therefore, the exudate can be stored in the wound to form a moist environment and prevent bacterial invasion. However, water vapor can pass through these pores without disturbing perspiration or oozing, thereby reducing the maceration of the periwound skin [10]. Water vapor permeability varies by product. Although transparent-to-semi-transparent products provide excellent visibility of the wound surface and pain relief, they are not suitable for wounds with high exudates as they have no water absorption capacity.

8.3 Antimicrobial Wound Dressing

Wound dressings have the disadvantage of being susceptible to infection because they are intended to keep the wound sealed. To overcome this disadvantage and facilitate their use in burn wounds with a high risk of infection, wound dressings that contain silver and have antibacterial activity have been developed. Free silver ions interfere with DNA transcription and electron transfer. It is characterized by its antimicrobial activity, broad antimicrobial spectrum, and resistance to the formation of resistant bacteria [11–16].

When silver-containing wound dressings are used in combination with iodine disinfectants, silver ions become silver iodide, thereby decreasing their antimicrobial activity.

When an artificial dermis is used to treat burns, the spread of infection to the artificial dermis is a major failure, often forcing the removal of the entire artificial dermis. If eschar remains around the artificial dermis, infection of the artificial dermis can occur easily. In such cases, debrided areas around the artificial dermis can be created, and an antimicrobial wound dressing can be used to prevent eschar infection in the surrounding area (Fig. 8.5).

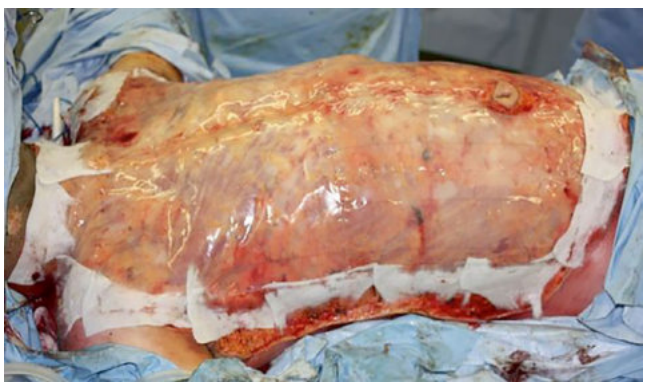


Fig. 8.5 An antimicrobial dressing, AQUACEL Ag + (Convatec, USA), was used on the debrided area around the artificial dermis to prevent spread of infection from the surrounding wound surface where eschar remained

8.4 Selection of Wound Dressing Materials by Burn Depth

In the treatment of burns, selecting wound dressings based on the amount of exudate from the burn wound and the presence or absence of an infection is crucial. Moreover, the choice of topical agents and wound dressings should be considered depending on whether the future treatment plan involves conservative or surgical debridement.

8.4.1 Second-Degree Burns (Partial-Thickness Burns)

If the wound is considered a second-degree burn, the blister cap is removed after several days of observation, and silver-containing foam (Mepirex®Ag) is often used for dressing. One of the advantages of antimicrobial wound dressings is the ability to reduce the frequency of dressing changes as long as infection is not aggravated (Fig. 8.6) [7, 8].

8.4.2 Third-Degree Burns (Full-Thickness Burns)

Third-degree burns extend from the entire dermis to the subcutaneous tissue, and relatively little exudation from the burn wound surface can be observed.

Surgical debridement is the first choice of treatment, and early surgical debridement is recommended for severe and extensive burns that require intensive care unit management. Therefore, the use of topical agents and wound dressings should be considered during preoperative and postoperative surgical debridement.

During the preoperative period of surgical debridement, the wound should be kept free of infections. In many cases, topical agents rather than dressings are used [17].

After debridement and skin grafting, the wound is generally managed with a non-adherent contact layer and a secondary dressing, such as gauze (*see* Fig. 8.1).

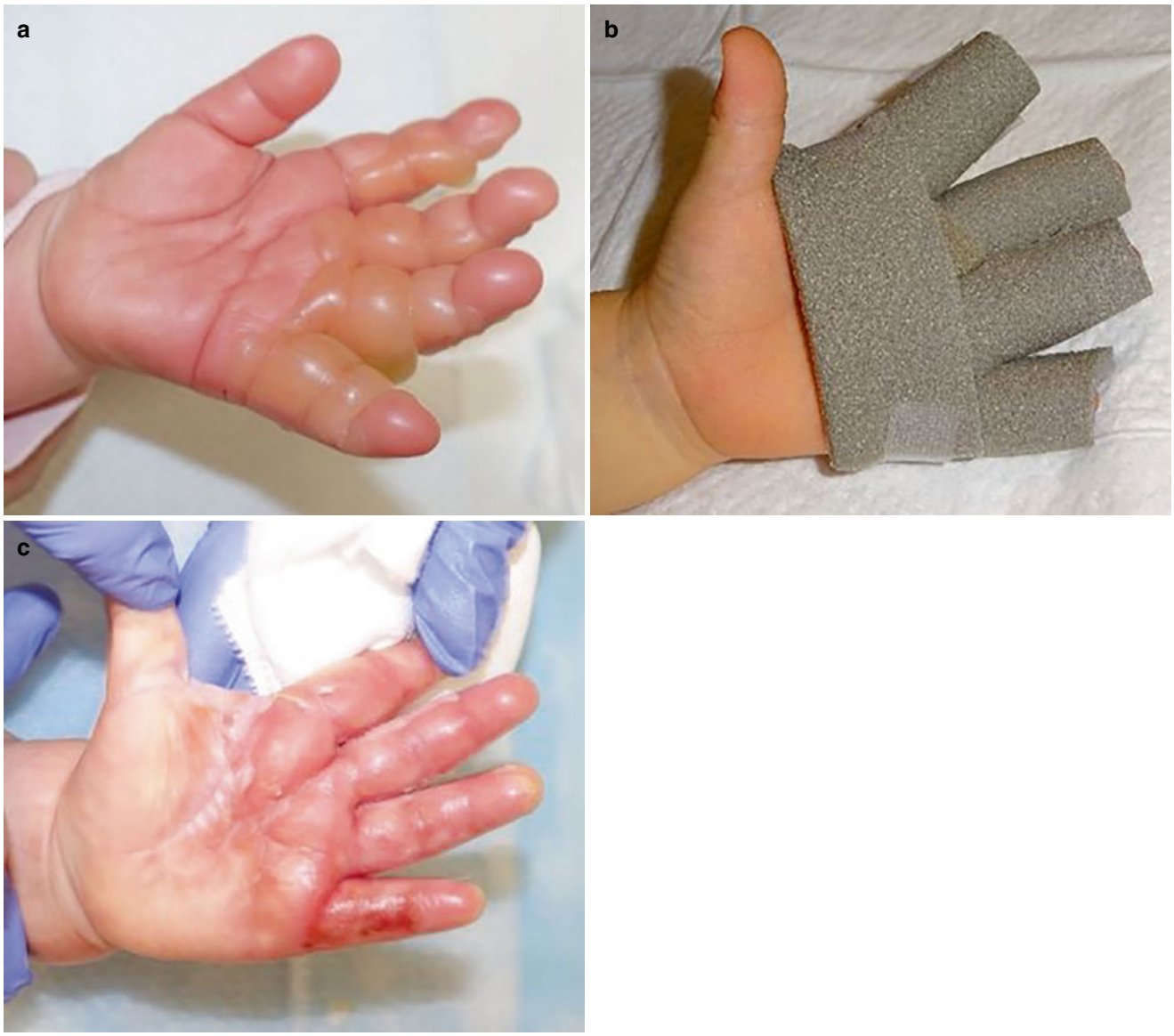


Fig. 8.6 (**a**–**c**) Second-degree burns on the palmar side of the child's hand. After the blisters were removed, Mepilex Ag (Molnlycke Healthcare, Sweden) was applied. The burn wound epithelialized well, with minimal pain during dressing changes

8.5 Absorbable Dressing to Promote Epithelialization of Burn Wounds

SUPRATHEL® is a synthetic, absorbable, one-time application membrane for the treatment of split-skin donor sites and burns. It provides a low rate of infections, significant pain relief, and less care (no change of SUPRATHEL® membrane, outer dressing changes only) [18].

8.6 Amniotic Membrane

AMNIOBURN®/EPIBURN® is a tissue allograft composed of dehydrated human amnion/chorion membrane (DHACM) that has been shown effective for the treatment of difficult-to-heal wounds [19, 20]. AMNIOBURN/EPIBURN provides a protective barrier that supports the healing cascade and protects the wound bed to aid in the development of granulation tissue in acute and chronic closures (e.g., partial-thickness and full-thickness burns). The product is a biocompatible human extracellular matrix and retains 300+ regulatory proteins (Fig. 8.7) [21].

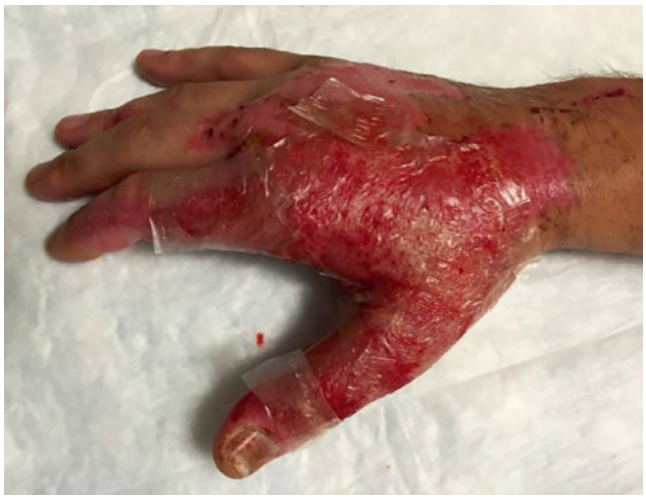


Fig. 8.7 Full-thickness burn on the dorsum of the hand. EpiBurn (MiMedx Group Inc., US) was applied. (Images courtesy of MiMedx Group, Inc.)

References

1. Brown MS, Ashley B, Koh A. Wearable technology for chronic wound monitoring: current dressings, advancements, and future prospects. Front Bioeng Biotechnol. 2018;6:47.
2. Skórkowska-Telichowska K, Czemplik M, Kulma A, Szopa J. The local treatment and available dressings designed for chronic wounds. J Am Acad Dermatol. 2013;68:e117–26.
3. Schultz GS, Sibbald RG, Falanga V, Ayello EA, Dowsett C, Harding K, et al. Wound bed preparation a systematic approach to wound management. Wound Repair Regen. 2003;11:S1–28.
4. Terrill PJ, Varughese G. A comparison of three primary non-adherent dressings applied to hand surgery wounds. J Wound Care. 2000;9:359–63.
5. Wasiak J, Cleland H, Campbell F, Spinks A. Dressings for superficial and partial thickness burns. Cochrane Database Syst Rev. 2013;2013:CD002106.
6. Pahlevanneshan Z, Deypour M, Kefayat A, Rafienia M, Sajkiewicz P, Neisiany RE, Enayati MS. Polyurethane-nanolignin composite foam coated with propolis as a platform for wound dressing: synthesis and characterization. Polymers. 2021;13:3191.
7. Tang H, Lv G, Fu J, Niu X, Li Y, Zhang M, et al. An open, parallel, randomized, comparative, multicenter investigation evaluating the efficacy and tolerability of Mepilex ag versus silver sulfadiazine in the treatment of deep partial-thickness burn injuries. J Trauma Acute Care Surg. 2015;78:1000–7.
8. Morena AG, Ivanova K, Perez S, Sanchez-Soto M, Tzanov T, et al. Antibacterial polyurethane foams with incorporated lignin-capped silver nanoparticles for chronic wound treatment. Ind Eng Chem Res. 2020;59(10):4504–14.
9. Khan MA, Mujahid M. A review on recent advances in chitosan based composite for hemostatic dressings. Int J Biol Macromol. 2019;124:138–47.
10. Gultekin G, Atalay-Oral C, Erkal S, Sahin F, Karastova D, Tantekin-Ersolmaz SB, Guner FS. Fatty acid-based polyurethane films for wound dressing applications. J Mater Sci Mater Med. 2009;20:421–31.
11. Percival SL, Bowler PG, Dolman J. Antimicrobial activity of silver-containing dressings on wound microorganisms using an invitro biofilm model. Int Wound J. 2007;4:186–91.
12. Percival SL, Bowler PG, Russell D. Bacterial resistance to silver in wound care. J Hosp Infect. 2005;60:1–7.
13. Jones SA, Bowler PG, Walker M, et al. Controlling wound bioburden with a novel silver-containing hydro-fiber dressing. Wound Repair Regan. 2004;12:288–94.
14. Lansdown ABG. Silver I: its antibacterial properties and mechanism of action. J Wound Care. 2002;11:125–30.
15. Trial C, Darbas H, Lavigne JP, et al. Assessment of the antimicrobial effectiveness of a new silver alginate wound dressing. A RCT J Wound Care. 2010;19:20–6.
16. Muangman P, Pundee C, Opasanon S, et al. A prospective, randomized trial of silver containing hydrofiber dressing versus 1% silver

sulfadiazine for the treatment of partial thickness burns. Int Wound J. 2010;7:271–6.
17. Gacto-Sanchez P. Surgical treatment and management of the severely burn patient: review and update. Med Intensiv. 2017;41:356–64.
18. Uhlig C, Rapp M, Hartmann B, Hierlemann H, Planck H, Dittel K-K. Suprathel-an innovative, resorbable skin substitute for the treatment of burn victims. Burns. 2007;33:221–9.
19. Matsumura H, Aoki K, Furukawa M, Forsyth RA, Tanaka R, Ohyama T, Tettelbach WH. First use of dehydrated human amnion/chorion membrane allografts in the treatment of hard-to-heal diabetic foot ulcers in Japan: a case series. Wounds Asia. 2023;6(1)
20. Fetterolf DE, Snyder RJ. Scientific and clinical support for the use of dehydrated amniotic membrane in wound management. Wounds. 2012;24:299–307.
21. Lei J, Priddy LB, Lim JJ, Massee M, Koob TJ. Identification of extracellular matrix components and biological factors in micronized dehydrated human amnion/chorion membrane. Adv Wound Care (New Rochelle). 2017;6(2):43–53.

Strategies for Skin Regeneration in Burn Patients

9

Andrew C. Hostler, Jonathan P. Yasmeh, Katharina S. Berryman, Maria Gracia Mora Pinos, Jared S. Holley, William W. Hahn, Kellen Chen, and Geoffrey C. Gurtner

Abstract

Burn injuries have been devastating and life-threatening throughout history, resulting in physical, psychosocial, and physiological dysfunction in afflicted victims. Our cumulative understanding of burn pathophysiology and therapeutic management has evolved significantly over the past few centuries. Although advancements in surgical techniques, antimicrobial therapy, wound care, and analgesia have improved conventional medical outcomes, burns and ensuing burn-related morbidities (e.g., wounds and hypertrophic scaring) remain prevalent throughout society. Burn-related wounds often present wound healing challenges due to the injury modality, area of involvement, varying depth of penetration, and both local and systemic effects. As both cellular and non-cellular elements constitute the wound microenvironment, understanding their dynamic interactions may help elucidate the temporal and spatial molecular underpinnings that promote skin tissue regeneration instead of fibrotic tissue deposition. A multifaceted approach, utilizing the current gold standard treatments in conjunction with novel cellular and non-cellular therapies, will promote the regeneration of skin structure, function, and aesthetics after tissue injury.

Keywords

Hypertrophic scarring · Skin regeneration · Tissue repair · Epidermal stem cell · Burn · Wound healing · Full-thickness burn · Partial-thickness burn · Skin homeostasis · Thermal injury

A. C. Hostler · J. P. Yasmeh · K. S. Berryman · M. G. Mora Pinos
J. S. Holley · W. W. Hahn · K. Chen · G. C. Gurtner (✉)
Department of Surgery, College of Medicine – Tucson,
The University of Arizona, Tucson, AZ, USA
e-mail: andrewhostler@arizona.edu; jpyasmeh@arizona.edu;
katharinafischer@arizona.edu; mgmorapinos@arizona.edu;
jaredholley@arizona.edu; wwhahn@arizona.edu;
kellenchen@arizona.edu; gurtner@surgery.arizona.edu

9.1 Evolution of Burn Treatment

Burn injuries are a major medical problem that have resulted in significant morbidity and mortality worldwide for centuries. Reports recounting burn injuries and treatment modalities have existed and evolved since ancient times [1]. Early recordings in Egyptian texts described the use of topical-based therapies for burn management [1]. The Egyptian Smith Papyrus (c. 1600 BCE [Before Common Era]) advocated for the application of a resin and honey mixture, and the Ebers Papyrus (c. 1500 BCE) described the use of a composite topical regimen consisting of cattle excrement, oil, mud, and additional substances [2, 3]. Centuries later (c. 600 BCE), the Chinese reported using tinctures and extracts from tea leaves [1]. In Ancient Greece, Hippocratic doctrine (c. 400 BCE) promoted lukewarm vinegar lavage and emollient-based (e.g., pig fat, bitumen, and resin) infused ointment bandages in burn care [1, 4, 5]. As civilization progressed through the post-classical era (c. 500–1500 CE [Common Era]), treatments such as scalding oil for war wounds were gradually replaced with science-based therapies.

Throughout the modern era (1500 CE—present), our fundamental understanding of burn pathology and treatment methodologies has exponentially expanded. Renowned surgical luminaries in the early modern era (c. 1500–1800), such as Ambroise Paré and John Hunter, laid the foundation for modern evidence-based medical practice [6–9]. The late modern era (c. 1800–1945) marked a period of pronounced advancements in evidence-based approaches. For example, Dupuytren's development of the burn classification system and Reverdin's work describing burn surface area and burn wound skin grafting helped accelerate our understanding of burn pathophysiology [9, 10]. In parallel, Pasteur's discovery of microorganisms and Lister's contributions to antisepsis further transformed wound care and post-operative outcomes [11]. These advancements laid the foundation for an era of sterile wound care and multidimensional medical and surgical management in the contemporary era (c. 1945—present) [12].

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_9

Current evidence-based strategies to manage burn injuries require a multifaceted approach, including fluid resuscitation, pain management, nutrition, thromboprophylaxis, thermoregulation, chemoprophylaxis, surgical intervention, and burn wound care [13, 14]. As burn-associated conventional clinical outcomes (e.g., complications, mortality, etc.) have improved, a newfound emphasis has been placed on innovations aimed at restoring anatomical, functional, and aesthetic outcomes. Currently, surgical techniques (e.g., burn wound excision, skin grafting, contracture release, and tissue flaps) can be combined with novel tissue and cell-based regenerative medicine therapeutics (e.g., acellular dermal matrices, synthetic dermal matrices, stem cells, CO_2 lasers, and autologous cultured keratinocytes) to augment physiological wound healing and potentially regenerate skin tissue [15–17].

9.2 Seed Versus Soil Paradigm

Although burn wound healing follows canonical wound healing stages, burn wounds present unique challenges during healing compared to other wound types. These challenges correlate with the extent of total body surface area involvement, varying depth of tissue penetration within the same wound area (e.g., superficial, superficial/deep partial-thickness, full-thickness, etc.), and both local and systemic stress-induced physiological alterations [18, 19]. The "seed vs. soil" paradigm provides a conceptual framework for the complex wound microenvironment (Fig. 9.1) [20, 21]. Cellular components such as fibroblasts, keratinocytes, stem cells, neutrophils, dendric cells, and macrophages constitute the "seeds" of the wound. Non-cellular elements, such as the extracellular matrix (ECM), mechanical forces, oxygen tension, and the cytokine milieu, make up the "soil" [20–22]. The interactions between both cellular and non-cellular elements direct the wound healing trajectory and influence whether a fibrotic or regenerative phenotype results [23]. Thus, seamless coalescence of both the seed and the soil is necessary to maximize complex tissue regeneration.

9.3 Understanding Skin Regeneration

Skin regeneration following tissue damage should recapitulate embryogenesis and skin morphogenesis (Fig. 9.2) [24–27]. Prior literature has documented the regenerative capabilities of various organisms throughout the animal kingdom [28, 29]. For example, molecular studies in regenerative organisms, such as the salamander and zebrafish, have revealed a diverse array of cellular mechanisms involved in recreating the complex physiological tissue structure [28, 29]. Limb regeneration studies in salamanders have demonstrated their ability to regenerate patterned bone when skin tissue is transplanted onto severed limbs [30, 31]. Furthermore, studies examining damaged cardiac tissue in zebrafish demonstrated that cardiac tissue regeneration is directed by resident, differentiated cardiomyocytes [32, 33]. Although simple organisms and lower vertebrates display these impressive

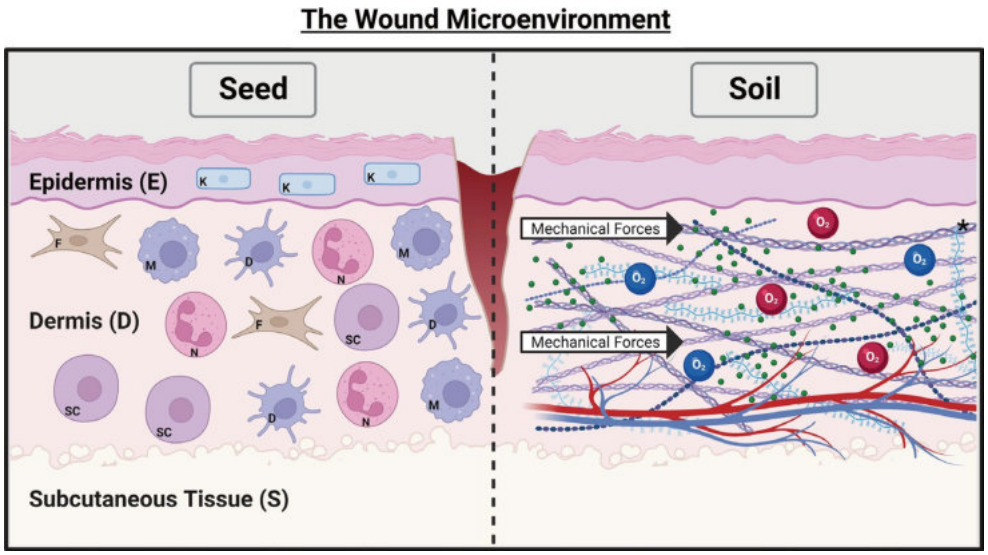


Fig. 9.1 The wound microenvironment seed vs. soil theorem. Cellular (aka. "seed") components of the wound microenvironment include, fibroblasts (F), keratinocytes (K), stem cells (SC), neutrophiles (N), dendritic cells (D), and macrophages (M). Non-cellular (aka. "soil") components include extracellular matrix (*), mechanical tension (arrow), oxygenation status (O_2), vasculature/angiogenesis, and the cytokine milieu (green spheres). Dynamic, multifaceted interactions between cellular and non-cellular elements modulate the degree of regenerative or fibrotic architecture in restoring skin tissue integrity

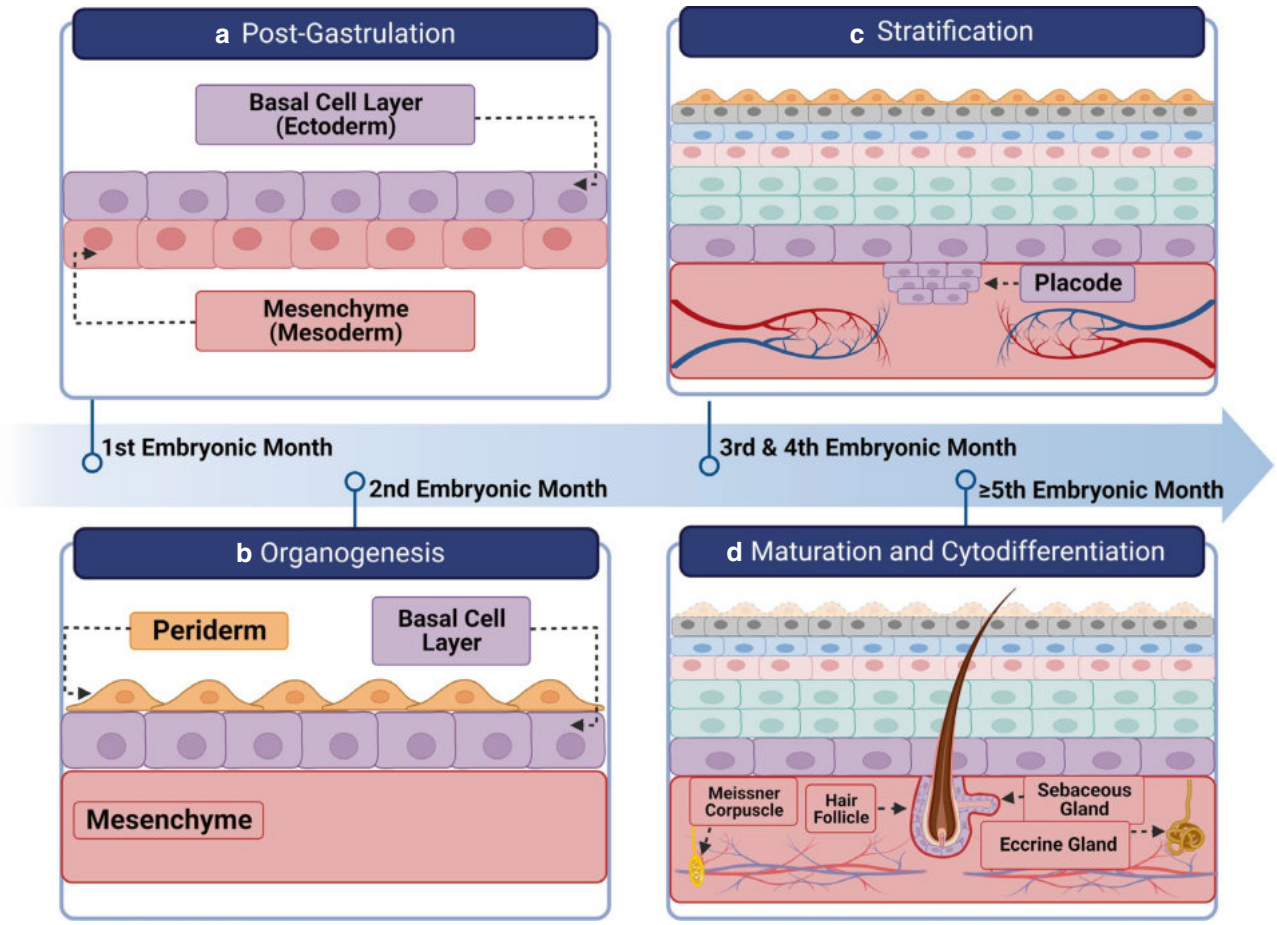


Fig. 9.2 Embryogenesis and morphogenesis of the integumentary system. The formation of the integumentary system begins immediately following embryonic gastrulation (an early stage of embryogenesis in which three distinct germ line cell layers form: ectoderm, mesoderm, and endoderm). (**a**) Post-gastrulation (within the first embryonic month), the basal cell layer (ectoderm; primordial epidermis) and mesenchyme (mesoderm; primordial dermis) will form the foundation of embryonic skin development. (**b**) During the second embryonic month, initiation of skin organogenesis results in selective mesenchymal expansion and division of the basal layer, forming a layer of squamous epithelial cells atop the basal cell layer known as the periderm. (**c**) From the third through fourth embryonic month, the epidermal basal cells give rise to the stratum germinativum (e.g., intermediate cell layer), which further proliferates and stratifies, giving rise to four distinct epidermal layers (e.g., corneum, lucidum, granulosum, and spinous). Simultaneously, epithelial-mesenchymal crosstalk initiates placode (multi-focal regions of basal cell hyperplasia) formation and progression into the underlying dermis, resulting in hair follicle organogenesis. (**d**) Following the fourth month, the periderm layer begins to recede, and epidermal keratinization is initiated and progresses. Epidermal and dermal maturation continues, epidermal appendages form, and hair follicle cytodifferentiation occurs

regenerative capabilities, the ability to restore injured or diseased organs has also not been entirely lost in higher vertebrates. Human fetal skin also demonstrates scarless healing up to the third trimester, which is partially attributed to the primitive inflammatory profile, increased angiogenic potential, and decreased mechanical properties of fetal skin tissue [34–36]. Furthermore, some adult human organs, most notably the liver, display regenerative potential characterized by cellular differentiation, de-differentiation, trans-differentiation, and proliferation of progenitor cell populations [37].

In adult humans, cutaneous injury results in aberrant fibrotic tissue deposition [38]. Compared to physiological unwounded skin, scars lack characteristic archetypal and architectural features of cutaneous tissue such as hair follicles, dermal appendages, sebaceous glands, and a "basket weave" ECM structure [38]. The absence of these physiological cutaneous features alters the tissue mechanics of the scar microenvironment, which is characterized by reduced tensile strength and pliability [16, 39]. Wound depth also positively correlates with increased reticular fibroblast (i.e., deep dermal fibroblast) activation [40]. Deep dermal fibroblasts are larger in size, proliferate slower, produce greater amounts of collagen, and have decreased collagenase production [40]. Thus, injuries that penetrate deeper skin layers, such as burns, result in an increased incidence of pathologic fibrosis phenotypes [20, 41–45].

Hypertrophic scarring is recognized as a significant burn-related morbidity, occurring in an estimated 30–90% of burn

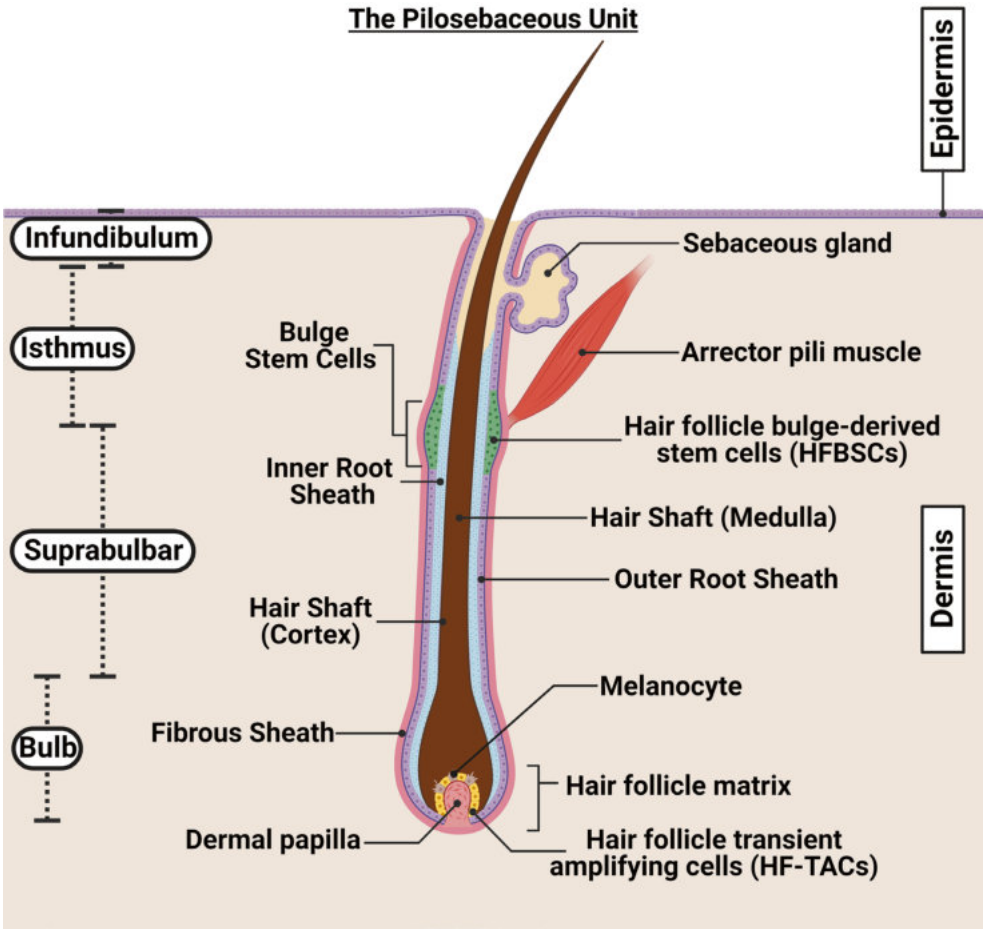


Fig. 9.3 Pilosebaceous unit stem cells help maintain and restore skin tissue integrity. The pilosebaceous unit is composed of the hair shaft, hair follicle, and sebaceous gland. Hair follicle bulge-derived stem cells (HFBSCs) are a population of multipotent epidermal stem cells located in the bulge region of the outer root sheath of the hair follicle. Self-renewing HFBSCs differentiate into cell lineages that comprise the sebaceous gland, epidermis, vasculature, and hair follicles to maintain physiological skin homeostasis and response to cutaneous injury, aiding in tissue regeneration. Hair follicle transient amplifying cells (HF-TACs), the progeny of HFBSCs located in the hair follicle matrix, are an intermediate cell lineage that proliferates and differentiates into adult cell lines that are involved in cyclic hair formation and tissue repair/regeneration

victims [46, 47]. Burn wounds induce biomolecular desynchronization facilitated by a wound-localized pro-inflammatory state and systemic immunosuppression [48]. Delays in wound healing due to these complications have been identified as a central predisposition to hypertrophic scar formation [49]. Although burn-related wounds present unique challenges to physiological tissue repair, novel strategies that leverage physiology continue to emerge. For example, human hair follicle budge-derived stem cells (HF-BSCs) and their daughter hair follicle transient amplifying cells (HF-TACs) (Fig. 9.3) contribute to skin morphogenesis, hair regeneration, epidermal maintenance, and tissue repair [50–52]. Therapies utilizing these skin-specific cells and other multipotent mesenchymal stem cells (e.g., adipose tissue-derived mesenchymal stem cells [ADSCs] and bone marrow-derived mesenchymal stem cells [BM-MSCs]) demonstrate promising progenitor cell-based therapies that improve burn wound repair and decrease scar contracture [53–56]. The wound microenvironment's cellular and molecular elements may modulate the skin's regenerative and fibrotic potential.

9.4 Current Research and Strategies for Skin Regeneration

Human cutaneous tissue displays remarkable plasticity [57], which may be harnessed to supplement the intrinsic regenerative potential of skin. Inflammation is a compelling target for anti-fibrotic therapy due to its critical role in the development and progression of fibrosis. A number of inflammatory cytokines, including transforming growth factor-beta family (TGF-β1 and -β2)) [58], tumor necrosis factor-alpha (TNF-α) [59], and several interleukins (e.g., IL-6) [60], are known to induce fibrosis. The TGF-β family has 3 isoforms: TGF-β1, −β2, and -β3. TGF-β1 and -β2 stimulate fibroblast differentiation, ECM production and deposition, re-epithelization, angiogenesis, granulation tissue formation, and scarring during wound healing [61, 62]. In contrast, TGF-β3 is involved in reduced scar density and depth [63]. During wound healing, TNF-a plays a role in modulating stromal cell activity, amplifying of the immune response, ECM synthesis, and matrix metalloproteinase synthesis [64, 65]. In animal wound healing models, inhibition of TNF-α

accelerated wound healing through reduced NFκB binding, induced ECM synthesis, and decreased recruitment of inflammatory cells [66, 67]. Human studies using the topical anti-TNF-α therapies infliximab and adalimumab on chronic wounds resulted in decreased wound size and accelerated wound healing [68, 69]. IL-6 is a central inflammatory interleukin that induces proinflammatory cytokine release by stromal and inflammatory cells [70]. IL-6 has been shown to modulate fibroblast differentiation into myofibroblasts, influencing pathological scarring phenotypes [71]. Attenuation of IL-6 in murine burn wound models demonstrated decreased expression of TGF-B and VEGF, which are markers of fibrosis [72]. While the therapeutic potential of these growth factors and cytokines remain under investigation, these molecular signals are promising targets to modulate inflammation and fibrosis [73, 74].

Biologic scaffolds provide wound coverage, structural support, and facilitate re-epithelialization [75] by preventing wound desiccation, stimulating cell adhesion proliferation and differentiation, promoting ECM deposition and angiogenesis, and accelerating granulation tissue formation [75–77].Several types of biologic scaffolds exist for soft tissue applications, such as allografts, xenografts, human amnions, and hydrogels [77–85]. In burn wound management, an ideal biologic scaffold should possess three characteristics: biocompatibility [77], bioactivity [86], and biodegradability [87]. All natural polymer-based scaffolds derived from organic sources meet these characteristics [76], including those made of polysaccharide (e.g., hyaluronic acid [88] and cellulose [89]), polypeptide (e.g., fibrin-based [90, 91], collagen [92, 93]), and polynucleotide (e.g., DNA [94]). Clinical examples of natural polymer scaffolds include Alloderm [decellularized allograft], Oasis [decellularized xenograft]) [78, 79, 95], Aligraft [collagen-based xenograft] and EZ Derm [collagen-based xenograft]) [96, 97]. In addition, augmenting scaffolds with naturally occurring bioactive compounds (e.g., growth factors) and cell-based therapies (e.g., stromal and stem cells) can provide a favorable burn wound microenvironment to promote angiogenesis and tissue regeneration [20, 23, 98–100].

Bioengineered scaffolds, such as hydrogels, are a developing product for burn wound care with immense promise for improving burn wound clinical outcomes [101–103]. Hydrogels have been shown to promote wound healing by improving neovascularization [104], wound moisture retention [98], and cellular migration and proliferation [105]. For example, one study using burn wound rodent models treated with hydrogel scaffolds observed accelerated granulation tissue deposition and tissue re-epithelialization [103]. Although research optimizing hydrogels as a translational skin regeneration template is ongoing, several commercial products are available (e.g., DermaSyn and AquaDerm) [106, 107].

Cell-based therapies, such as cultured epithelial autografts (CEAs), have proven useful when applied to extensive burns, chronic ulcers, or other large wounds when there is limited donor tissue for conventional autografting [108, 109]. These tissue grafts have been shown in several studies to promote re-epithelialization, improve wound closure, and reduce scarring [108, 110]. CEAs offer several additional advantages, including reduced morbidity of donor sites, the ability to cover large wound areas, and improved wound healing outcomes [108]. Nonetheless, clinical adoption is limited given the resources required for processing and maintenance [108, 111]. Autologous and allogeneic cell-based therapies, using stromal or progenitor cells, have emerged as promising therapies for burn wounds (Fig. 9.4) [17, 84, 112–120].

Stem cell-based therapies, derived from various sources, have also demonstrated promising potential in accelerating tissue repair and regeneration following cutaneous injury [63, 112, 113, 116–120]. For example, embryonic stem cells are the most pluripotent cell type; however, ethical concerns have hindered their use throughout medicine [120, 121]. Adult progenitor cells are readily available and include epidermal stem cells, which are a diverse population of skin progenitors critically involved in skin maintenance and repair. BM-MSCs have also been implicated in skin repair, primarily due to their ability to differentiate into various cell types, including fibroblasts and endothelial cells [122]. Hematopoietic stem cells (HSCs) and umbilical cord-derived mesenchymal stem cells (UC-MSCs) have been used in human burn injuries to accelerate wound healing, reduce scar contracture, and decrease the incidence of hypertrophic scarring [119, 123]. Peripheral blood-derived stem cells harbor pro-angiogenic properties, making them particularly useful in enhancing neovascularization. ADSCs have also been shown to improve wound healing through dermal matrix delivery and have even been used to fabricate new skin [124]. Finally, induced pluripotent stem cells (iPSCs) have shown promise for skin regeneration as they demonstrate tremendous versatility and can be guided to differentiate into various skin-specific cell lines, including keratinocytes, fibroblasts, melanocytes, and endothelial cells [120]. They can further be used in the creation of skin organoids, although challenges remain regarding tumorigenicity, immunogenicity, and cost [120, 125, 126]. These instigations highlight the tremendous potential of progenitor-based therapies, providing novel paradigms to repair and regenerate skin tissue following burn injury. Within the past decade, evidence has emerged implicating cellular mechanotransduction in wound healing and fibrosis [38, 127–129]. During wound healing, cells sense and actively respond to the increased activation of mechanical signaling pathways to drive fibrotic scar tissue

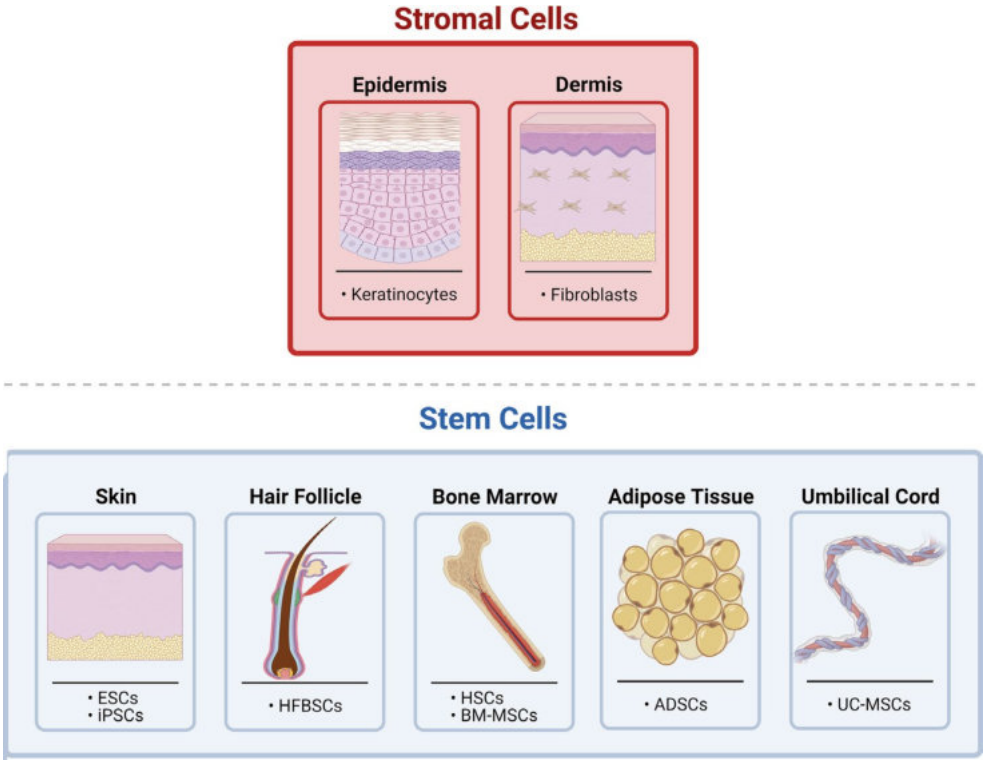


Fig. 9.4 Somatic and progenitor cell-based tissue regeneration therapies. Cells are a dynamic cornerstone component in tissue-engineering therapeutics for burn wounds. Both somatic and stem cells can be used in tissue regeneration therapies. Common somatic cells used in clinical practice and research are keratinocytes and fibroblasts. The stem cell populations currently under investigation include epidermal stem cells (ESCs), BM-MSCs, ADSCs, HFBSCs, umbilical cord mesenchymal stem cells (UC-MSCs), hematopoietic stem cells (HSCs), and induced pluripotent stem cells (iPSCs)

deposition [38, 127, 128]. Notably, focal adhesion kinase (FAK), a non-receptor tyrosine kinase, is an important integrin-mediated central regulator of the intracellular transmission of extracellular mechanical forces [127, 128]. Pharmacological inhibition of FAK in full-thickness wounds has been shown to improve wound healing, reduce scar formation, and promote the restoration of skin appendages [130]. Inhibiting FAK in cultured fibroblasts upregulated genes that reduce fibrosis and promote wound healing [130]. Recent work investigating scar contracture of wounds repaired with split-thickness skin grafting (STSG) identified early mechanotransduction transcriptional changes in inflammatory cells [130, 131]. Disrupting myeloid mechanotransduction with a FAK inhibitor (FAKI) promoted proregenerative myeloid transcriptional profiles that correlated to downstream reduced fibrotic scar deposition and contracture [130, 131]. These findings highlight the critical role of inflammatory-mechanotransduction cell signaling during wound repair and demonstrate that small-molecule targeting of this pathway may prove to be a successful anti-fibrotic therapy for restoring physiological cutaneous tissue integrity.

9.5 Future of Regenerative Medicine in Burn Therapy

Unraveling the molecular modalities underlying wound repair will elucidate novel strategies to induce skin regeneration. Prospective burn therapies require researchers and clinicians to implement a multifaceted approach that leverages existing and novel cellular and non-cellular biotechnologies (Fig. 9.5). These therapies must consider the importance of cytokine expression, extracellular matrix architecture, stem cell differentiation, and mechanical signaling pathways, as these have all been importantly implicated in the context of burn wound healing. These promising translational research discoveries may make their way to the bedside and the operating room so that burn patients and physicians can expect a complete functional and aesthetic recovery.

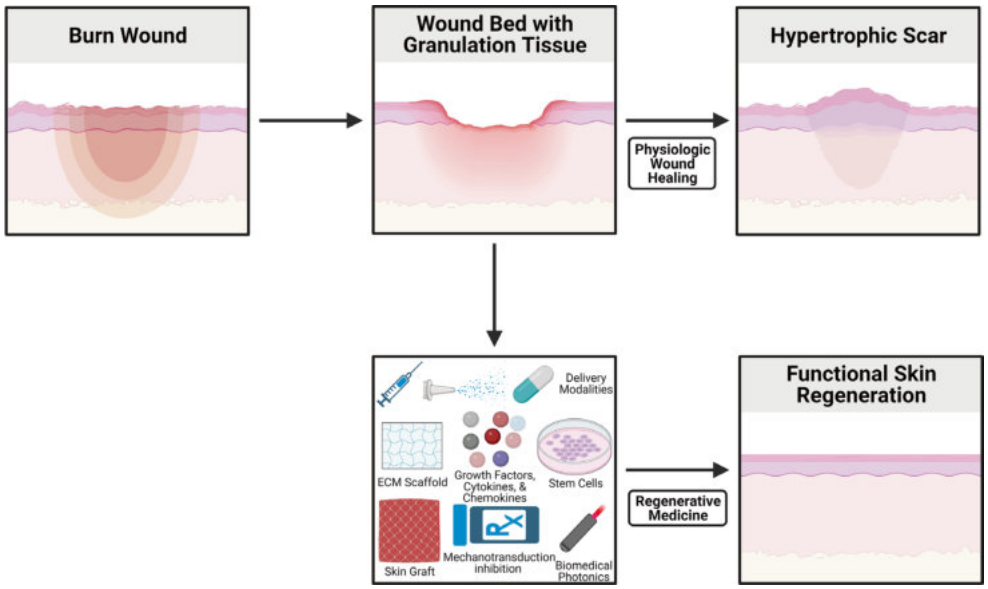


Fig. 9.5 Skin tissue regeneration post-burn injury requires a multifaceted methodology. To efficaciously treat burn wounds and the subsequent morbidities that arise, a dynamic multidimensional evidence-based strategy is warranted to supplement and augment the physiological burn-wound microenvironment. A multifaceted approach to burn wound healing may implement controlled-release growth factor gradients, tissue-engineered matrix scaffolds, stomal and stem cell-based therapies, mechanotransduction antagonists, targeted inflammatory response regulation, photonic biomedical devices, and novel therapy delivery systems. The precision of these therapeutics in combination with current gold standard evidence-based strategies holds promise in recapitulating the full regenerative potential of skin tissue

Acknowledgments The authors gratefully acknowledge the contribution of Victor W. Wong to this chapter as it appeared in the first edition of the book.

References

1. Majno G. The healing hand: man and wound in the ancient world. Harvard University Press; 1975.
2. Bryan CP. The papyrus ebers. London: Geoffrey Bles; 1930.
3. Pećanac M, Janjić Z, Komarcević A, Pajić M, Dobanovacki D, Misković SS. Burns treatment in ancient times. Med Pregl. 2013;66(5–6):263–7.
4. Pinnegar MD, Pinnegar FC. History of burn care: a survey of important changes in the topical treatment of thermal injuries. Burns. 1986;12(7):508–17. https://doi.org/10.1016/0305-4179(86)90079-3.
5. Liu H-F, Zhang F, Lineaweaver WC. History and advancement of burn treatments. Ann Plast Surg. 2017;78(2):S2–8. https://doi.org/10.1097/sap.0000000000000896.
6. Gurlt EJ. Geschichte der Chirurgie und ihre Ausubung. BD I. Berlin: A. Hirschwald; 1898.
7. Lee KC, Joory K, Moiemen NS. History of burns: the past, present and the future. Burns Trauma. 2014;2(4):169–80. https://doi.org/10.4103/2321-3868.143620.
8. Nicoli Aldini N, Fini M, Giardino R. From Hippocrates to tissue engineering: surgical strategies in wound treatment. World J Surg. 2008;32(9):2114–21. https://doi.org/10.1007/s00268-008-9662-1.
9. Ozhathil DK, Tay MW, Wolf SE, Branski LK. A narrative review of the history of skin grafting in burn care. Medicina (Kaunas). 2021;57(4). https://doi.org/10.3390/medicina57040380.
10. Ang GC. History of skin transplantation. Clin Dermatol. 2005;23(4):320–4. https://doi.org/10.1016/j.clindermatol.2004.07.013.
11. Davis JS. Address of the president: the story of plastic surgery. Ann Surg. 1941;113(5):641–56. https://doi.org/10.1097/00000658-194105000-00001.
12. Kandela P. Sketches from the lancet. Lancet. 1999;353(9156):937. https://doi.org/10.1016/S0140-6736(05)75056-X.
13. Snell JA, Loh N-HW, Mahambrey T, Shokrollahi K. Clinical review: the critical care management of the burn patient. Crit Care. 2013;17(5):241:241. https://doi.org/10.1186/cc12706.
14. Muller MJ, Pegg SP, Rule MR. Determinants of death following burn injury. Br J Surg. 2002;88(4):583–7. https://doi.org/10.1046/j.1365-2168.2001.01726.x.
15. Lineen E, Namias N. Biologic dressing in burns. J Craniofac Surg. 2008;19(4):923–8. https://doi.org/10.1097/SCS.0b013e318175b5ab.
16. Tottoli EM, Dorati R, Genta I, Chiesa E, Pisani S, Conti B. Skin wound healing process and new emerging Technologies for skin wound care and regeneration. Pharmaceutics. 2020;12(8) https://doi.org/10.3390/pharmaceutics12080735.
17. Shpichka A, Butnaru D, Bezrukov EA, Sukhanov RB, Atala A, Burdukovskii V, et al. Skin tissue regeneration for burn injury. Stem Cell Res Ther. 2019;10(1):94. https://doi.org/10.1186/s13287-019-1203-3.
18. Kaddoura I, Abu-Sittah G, Ibrahim A, Karamanoukian R, Papazian N. Burn injury: review of pathophysiology and therapeutic modalities in major burns. Ann Burns Fire Disasters. 2017;30(2):95–102.
19. Hussain Z, Thu HE, Rawas-Qalaji M, Naseem M, Khan S, Sohail M. Recent developments and advanced strategies for promoting burn wound healing. J Drug Deliv Sci Technol. 2022;68:103092. https://doi.org/10.1016/j.jddst.2022.103092.
20. Aarabi S, Longaker MT, Gurtner GC. Hypertrophic scar formation following burns and trauma: new approaches to treatment. PLoS Med. 2007;4(9):e234. https://doi.org/10.1371/journal.pmed.0040234.

21. Hyun JS, Montoro DT, Lo DD, Flynn RA, Wong V, Chung MT, et al. The seed and the soil: optimizing stem cells and their environment for tissue regeneration. Ann Plast Surg. 2013;70(2):235–9. https://doi.org/10.1097/SAP.0b013e31826a18fb.
22. Henn D, Zhao D, Sivaraj D, Trotsyuk A, Bonham CA, Fischer KS, et al. Cas9-mediated knockout of Ndrg2 enhances the regenerative potential of dendritic cells for wound healing. Nat Commun. 2023;14(1):4729. https://doi.org/10.1038/s41467-023-40519-z.
23. Gurtner GC, Werner S, Barrandon Y, Longaker MT. Wound repair and regeneration. Nature. 2008;453(7193):314–21. https://doi.org/10.1038/nature07039.
24. Miao Q, Hill MC, Chen F, Mo Q, Ku AT, Ramos C, et al. SOX11 and SOX4 drive the reactivation of an embryonic gene program during murine wound repair. Nat Commun. 2019;10(1):4042. https://doi.org/10.1038/s41467-019-11880-9.
25. Martin P, Parkhurst SM. Parallels between tissue repair and embryo morphogenesis. Development. 2004;131(13):3021–34. https://doi.org/10.1242/dev.01253.
26. Hu MS, Borrelli MR, Hong WX, Malhotra S, Cheung ATM, Ransom RC, et al. Embryonic skin development and repair. Organogenesis. 2018;14(1):46–63. https://doi.org/10.1080/15476278.2017.1421882.
27. Fuchs E. Scratching the surface of skin development. Nature. 2007;445(7130):834–42. https://doi.org/10.1038/nature05659.
28. Tanaka EM, Reddien PW. The cellular basis for animal regeneration. Dev Cell. 2011;21(1):172–85. https://doi.org/10.1016/j.devcel.2011.06.016.
29. Stoick-Cooper CL, Moon RT, Weidinger G. Advances in signaling in vertebrate regeneration as a prelude to regenerative medicine. Genes Dev. 2007;21(11):1292–315. https://doi.org/10.1101/gad.1540507.
30. Dunis DA, Namenwirth M. The role of grafted skin in the regeneration of X-irradiated axolotl limbs. Dev Biol. 1977;56(1):97–109.
31. Kragl M, Knapp D, Nacu E, Khattak S, Maden M, Epperlein HH, Tanaka EM. Cells keep a memory of their tissue origin during axolotl limb regeneration. Nature. 2009;460(7251):60–5.
32. Oberpriller JO, Oberpriller JC. Response of the adult newt ventricle to injury. J Exp Zool. 1974;187(2):249–59.
33. Jopling C, Sleep E, Raya M, Martí M, Raya A, Belmonte JCI. Zebrafish heart regeneration occurs by cardiomyocyte dedifferentiation and proliferation. Nature. 2010;464(7288):606–9.
34. Gurtner GC, Callaghan MJ, Longaker MT. Progress and potential for regenerative medicine. Annu Rev Med. 2007;58(1):299–312. https://doi.org/10.1146/annurev.med.58.082405.095329.
35. Lorenz HP, Whitby DJ, Longaker MT, Adzick NS, Fetal wound healing. The ontogeny of scar formation in the nonhuman primate. Ann Surg. 1993;217(4):391–6. https://doi.org/10.1097/00000658-199304000-00011.
36. Wilgus TA, Ferreira AM, Oberyszyn TM, Bergdall VK, Dipietro LA. Regulation of scar formation by vascular endothelial growth factor. Lab Investig. 2008;88(6):579–90. https://doi.org/10.1038/labinvest.2008.36.
37. Michalopoulos GK, Bhushan B. Liver regeneration: biological and pathological mechanisms and implications. Nat Rev Gastroenterol Hepatol. 2021;18(1):40–55. https://doi.org/10.1038/s41575-020-0342-4.
38. Mascharak S, des Jardins-Park HE, Davitt MF, Griffin M, Borrelli MR, Moore AL, et al. Preventing Engrailed-1 activation in fibroblasts yields wound regeneration without scarring. Science 2021;372(6540):eaba2374. https://doi.org/10.1126/science.aba2374.
39. Erickson JR, Echeverri K. Learning from regeneration research organisms: the circuitous road to scar free wound healing. Dev Biol. 2018;433(2):144–54. https://doi.org/10.1016/j.ydbio.2017.09.025.
40. Sorrell JM, Baber M, Caplan A. Site-matched papillary and reticular human dermal fibroblasts differ in their release of specific growth factors/cytokines and in their interaction with keratinocytes. J Cell Physiol. 2004;200(1):134–45.
41. Frank DE, Carter WG. Laminin 5 deposition regulates keratinocyte polarization and persistent migration. J Cell Sci. 2004;117(8):1351–63.
42. Poole K, Khairy K, Friedrichs J, Franz C, Cisneros DA, Howard J, Mueller D. Molecular-scale topographic cues induce the orientation and directional movement of fibroblasts on two-dimensional collagen surfaces. J Mol Biol. 2005;349(2):380–6.
43. Zhang Z-G, Bothe I, Hirche F, Zweers M, Gullberg D, Pfitzer G, et al. Interactions of primary fibroblasts and keratinocytes with extracellular matrix proteins: contribution of α2β1 integrin. J Cell Sci. 2006;119(9):1886–95.
44. Wilgus TA, Matthies AM, Radek KA, Dovi JV, Burns AL, Shankar R, DiPietro LA. Novel function for vascular endothelial growth factor receptor-1 on epidermal keratinocytes. Am J Pathol. 2005;167(5):1257–66.
45. Finnerty CC, Jeschke MG, Branski LK, Barret JP, Dziewulski P, Herndon DN. Hypertrophic scarring: the greatest unmet challenge after burn injury. Lancet. 2016;388(10052):1427–36.
46. Oosterwijk AM, Mouton LJ, Schouten H, Disseldorp LM, van der Schans CP, Nieuwenhuis MK. Prevalence of scar contractures after burn: a systematic review. Burns. 2017;43(1):41–9. https://doi.org/10.1016/j.burns.2016.08.002.
47. Bloemen MCT, van der Veer WM, Ulrich MMW, van Zuijlen PPM, Niessen FB, Middelkoop E. Prevention and curative management of hypertrophic scar formation. Burns. 2009;35(4):463–75. https://doi.org/10.1016/j.burns.2008.07.016.
48. Sarrazy V, Billet F, Micallef L, Coulomb B, Desmoulière A. Mechanisms of pathological scarring: role of myofibroblasts and current developments. Wound Repair Regen. 2011;19:s10–s5.
49. Deitch EA, Wheelahan TM, Rose MP, Clothier J, Cotter J. Hypertrophic burn scars: analysis of variables. J Trauma. 1983;23(10):895–8.
50. Roh C, Tao Q, Photopoulos C, Lyle S. In vitro differences between keratinocyte stem cells and transit-amplifying cells of the human hair follicle. J Invest Dermatol. 2005;125(6):1099–105. https://doi.org/10.1111/j.0022-202X.2005.23958.x.
51. Lyle S, Christofidou-Solomidou M, Liu Y, Elder DE, Albelda S, Cotsarelis G. The C8/144B monoclonal antibody recognizes cytokeratin 15 and defines the location of human hair follicle stem cells. J Cell Sci. 1998;111(21):3179–88.
52. Oshima H, Rochat A, Kedzia C, Kobayashi K, Barrandon Y. Morphogenesis and renewal of hair follicles from adult multipotent stem cells. Cell. 2001;104(2):233–45.
53. Gambardella L, Barrandon Y. The multifaceted adult epidermal stem cell. Curr Opin Cell Biol. 2003;15(6):771–7. https://doi.org/10.1016/j.ceb.2003.10.011.
54. Levy V, Lindon C, Zheng Y, Harfe BD, Morgan BA. Epidermal stem cells arise from the hair follicle after wounding. FASEB J. 2007;21(7):1358–66. https://doi.org/10.1096/fj.06-6926com.
55. Heidari F, Yari A, Rasoolijazi H, Soleimani M, Dehpoor A, Sajedi N, et al. Bulge hair follicle stem cells accelerate cutaneous wound healing in rats. Wounds Compend Clin Res Pract. 2016;28(4):132–41.
56. Surowiecka A, Chrapusta A, Klimeczek-Chrapusta M, Korzeniowski T, Drukała J, Strużyna J. Mesenchymal stem cells in burn wound management. Int J Mol Sci. 2022;23(23):15339.
57. Donati G, Watt FM. Stem cell heterogeneity and plasticity in epithelia. Cell Stem Cell. 2015;16(5):465–76.
58. Lichtman MK, Otero-Vinas M, Falanga V. Transforming growth factor beta (TGF-β) isoforms in wound healing and fibrosis. Wound Repair Regen. 2016;24(2):215–22. https://doi.org/10.1111/wrr.12398.

59. Fukaya S, Matsui Y, Tomaru U, Kawakami A, Sogo S, Bohgaki T, et al. Overexpression of TNF-α-converting enzyme in fibroblasts augments dermal fibrosis after inflammation. Lab Investig. 2013;93(1):72–80. https://doi.org/10.1038/labinvest.2012.153.
60. Paquet P, Piérard GE. Interleukin-6 and the skin. Int Arch Allergy Immunol. 1996;109(4):308–17. https://doi.org/10.1159/000237257.
61. Puolakkainen PA, Twardzik DR, Ranchalis JE, Pankey SC, Reed MJ, Gombotz WR. The enhancement in wound healing by transforming growth factor-beta 1 (TGF-beta 1) depends on the topical delivery system. J Surg Res. 1995;58(3):321–9. https://doi.org/10.1006/jsre.1995.1050.
62. Kojima K, Ignotz RA, Kushibiki T, Tinsley KW, Tabata Y, Vacanti CA. Tissue-engineered trachea from sheep marrow stromal cells with transforming growth factor β2 released from biodegradable microspheres in a nude rat recipient. J Thorac Cardiovasc Surg. 2004;128(1):147–53.
63. Li M, Qiu L, Hu W, Deng X, Xu H, Cao Y, et al. Genetically-modified bone mesenchymal stem cells with TGF-β3 improve wound healing and reduce scar tissue formation in a rabbit model. Exp Cell Res. 2018;367(1):24–9.
64. Mast BA, Schultz GS. Interactions of cytokines, growth factors, and proteases in acute and chronic wounds. Wound Repair Regen. 1996;4(4):411–20.
65. Eming SA, Krieg T, Davidson JM. Inflammation in wound repair: molecular and cellular mechanisms. J Invest Dermatol. 2007;127(3):514–25.
66. Ashcroft GS, Jeong M-J, Ashworth JJ, Hardman M, Jin W, Moutsopoulos N, et al. Tumor necrosis factor-alpha (TNF-α) is a therapeutic target for impaired cutaneous wound healing. Wound Repair Regen. 2012;20(1):38–49. https://doi.org/10.1111/j.1524-475X.2011.00748.x.
67. Regan MC, Kirk SJ, Hurson M, Sodeyama M, Wasserkrug HL, Barbul A. Tumor necrosis factor-α inhibits in vivo collagen synthesis. Surgery. 1993;113(2):173–7.
68. Streit M, Beleznay Z, Braathen LR. Topical application of the tumour necrosis factor-α antibody infliximab improves healing of chronic wounds. Int Wound J. 2006;3(3):171–9.
69. Fox JD, Baquerizo-Nole KL, Keegan BR, Macquhae F, Escandon J, Espinosa A, et al. Adalimumab treatment leads to reduction of tissue tumor necrosis factor-alpha correlated with venous leg ulcer improvement: a pilot study. Int Wound J. 2016;13(5):963–6.
70. Johnson BZ, Stevenson AW, Prêle CM, Fear MW, Wood FM. The role of IL-6 in skin fibrosis and cutaneous wound healing. Biomedicines. 2020;8(5) https://doi.org/10.3390/biomedicines8050101.
71. Gallucci RM, Sugawara T, Yucesoy B, Berryann K, Simeonova PP, Matheson JM, Luster MI. Interleukin-6 treatment augments cutaneous wound healing in immunosuppressed mice. J Interf Cytokine Res. 2001;21(8):603–9. https://doi.org/10.1089/10799900152547867.
72. Barayan D, Abdullahi A, Vinaik R, Knuth CM, Auger C, Jeschke MG. Interleukin-6 blockade, a potential adjunct therapy for postburn hypermetabolism. FASEB J. 2021;35(5):e21596. https://doi.org/10.1096/fj.202100388R.
73. Iglesias-Bartolome R, Uchiyama A, Molinolo AA, Abusleme L, Brooks SR, Callejas-Valera JL, et al. Transcriptional signature primes human oral mucosa for rapid wound healing. Sci Transl Med. 2018;10(451):eaap8798.
74. Sorkin M, Huber AK, Hwang C, Carson WF IV, Menon R, Li J, et al. Regulation of heterotopic ossification by monocytes in a mouse model of aberrant wound healing. Nat Commun. 2020;11(1):722.
75. Hermans MH. Preservation methods of allografts and their (lack of) influence on clinical results in partial thickness burns. Burns. 2011;37(5):873–81.
76. Talikowska M, Fu X, Lisak G. Application of conducting polymers to wound care and skin tissue engineering: a review. Biosens Bioelectron. 2019;135:50–63.
77. Negut I, Dorcioman G, Grumezescu V. Scaffolds for wound healing applications. Polymers (Basel). 2020;12(9) https://doi.org/10.3390/polym12092010.
78. Wainwright D. Use of an acellular allograft dermal matrix (AlloDerm) in the management of full-thickness burns. Burns. 1995;21(4):243–8.
79. Juhász I, Kiss B, Lukacs L, Erdei I, Peter Z, Remenyik E. Long-term followup of dermal substitution with acellular dermal implant in burns and postburn scar corrections. Dermatol Res Pract. 2010;2010
80. MacLeod T, Cambrey A, Williams G, Sanders R, Green C. Evaluation of Permacol™ as a cultured skin equivalent. Burns. 2008;34(8):1169–75.
81. Papadogeorgakis N, Petsinis V, Christopoulos P, Mavrovouniotis N, Alexandridis C. Use of a porcine dermal collagen graft (Permacol) in parotid surgery. Br J Oral Maxillofac Surg. 2009;47(5):378–81.
82. Murphy KC, Whitehead J, Zhou D, Ho SS, Leach JK. Engineering fibrin hydrogels to promote the wound healing potential of mesenchymal stem cell spheroids. Acta Biomater. 2017;64:176–86.
83. Rowan MP, Cancio LC, Elster EA, Burmeister DM, Rose LF, Natesan S, et al. Burn wound healing and treatment: review and advancements. Crit Care. 2015;19:243. https://doi.org/10.1186/s13054-015-0961-2.
84. ISBI Practice Guidelines for Burn Care. Burns. 2016;42(5):953–1021. https://doi.org/10.1016/j.burns.2016.05.013.
85. Zhong S, Zhang Y, Lim C. Tissue scaffolds for skin wound healing and dermal reconstruction. Wiley Interdiscip Rev Nanomed Nanobiotechnol. 2010;2(5):510–25.
86. Boateng J. Therapeutic dressings and wound healing applications. John Wiley & Sons; 2020.
87. Shevchenko RV, James SL, James SE. A review of tissue-engineered skin bioconstructs available for skin reconstruction. J R Soc Interface. 2010;7(43):229–58.
88. Armour A, Scott PG, Tredget EE. Cellular and molecular pathology of HTS: basis for treatment. Wound Repair Regen. 2007;15(s1):S6–S17. https://doi.org/10.1111/j.1524-475X.2007.00219.x.
89. Fu L, Zhang J, Yang G. Present status and applications of bacterial cellulose-based materials for skin tissue repair. Carbohydr Polym. 2013;92(2):1432–42.
90. van der Veer WM, Bloemen MCT, Ulrich MMW, Molema G, van Zuijlen PP, Middelkoop E, Niessen FB. Potential cellular and molecular causes of hypertrophic scar formation. Burns. 2009;35(1):15–29. https://doi.org/10.1016/j.burns.2008.06.020.
91. Rajangam T, An SSA. Fibrinogen and fibrin based micro and nano scaffolds incorporated with drugs, proteins, cells and genes for therapeutic biomedical applications. Int J Nanomedicine. 2013;3641-62
92. Burke JF, Yannas IV, Quinby WC Jr, Bondoc CC, Jung WK. Successful use of a physiologically acceptable artificial skin in the treatment of extensive burn injury. Ann Surg. 1981;194(4):413–28. https://doi.org/10.1097/00000658-198110000-00005.
93. Dieckmann C, Renner R, Milkova L, Simon JC. Regenerative medicine in dermatology: biomaterials, tissue engineering, stem cells, gene transfer and beyond. Exp Dermatol. 2010;19(8):697–706. https://doi.org/10.1111/j.1600-0625.2010.01087.x.
94. Colangelo MT, Belletti S, Govoni P, Guizzardi S, Galli C. A biomimetic polynucleotides–hyaluronic acid hydrogel promotes wound healing in a primary gingival fibroblast model. Appl Sci. 2021;11(10):4405.
95. Mostow EN, Haraway GD, Dalsing M, Hodde JP, King D, Group OVUS. Effectiveness of an extracellular matrix graft (OASIS

wound matrix) in the treatment of chronic leg ulcers: a randomized clinical trial. J Vasc Surg. 2005;41(5):837–843.
96. Karr JC. Retrospective comparison of diabetic foot ulcer and venous stasis ulcer healing outcome between a dermal repair scaffold (PriMatrix) and a bilayered living cell therapy (Apligraf). Adv Skin Wound Care. 2011;24(3):119–25.
97. Troy J, Karlnoski R, Downes K, Brown KS, Cruse CW, Smith DJ, Payne WG. The use of EZ Derm® in partial-thickness burns: an institutional review of 157 patients. Eplasty. 2013;13:e14.
98. Rippon MG, Ousey K, Cutting K. Wound healing and hyper-hydration: a counterintuitive model. J Wound Care. 2016;25(2):68–75.
99. Kampmann A, Lindhorst D, Schumann P, Zimmerer R, Kokemüller H, Rücker M, et al. Additive effect of mesenchymal stem cells and VEGF to vascularization of PLGA scaffolds. Microvasc Res. 2013;90:71–9.
100. Park KM, Gerecht S. Harnessing developmental processes for vascular engineering and regeneration. Development. 2014;141(14):2760–9. https://doi.org/10.1242/dev.102194.
101. Reddy MSB, Ponnamma D, Choudhary R, Sadasivuni KK. A comparative review of natural and synthetic biopolymer composite scaffolds. Polymers (Basel). 2021;13(7) https://doi.org/10.3390/polym13071105.
102. Surowiecka A, Strużyna J, Winiarska A, Korzeniowski T. Hydrogels in burn wound management-a review. Gels. 2022;8(2) https://doi.org/10.3390/gels8020122.
103. Nacer Khodja A, Mahlous M, Tahtat D, Benamer S, Larbi Youcef S, Chader H, et al. Evaluation of healing activity of PVA/chitosan hydrogels on deep second degree burn: pharmacological and toxicological tests. Burns. 2013;39(1):98–104. https://doi.org/10.1016/j.burns.2012.05.021.
104. Sun G, Zhang X, Shen Y-I, Sebastian R, Dickinson LE, Fox-Talbot K, et al. Dextran hydrogel scaffolds enhance angiogenic responses and promote complete skin regeneration during burn wound healing. Proc Natl Acad Sci. 2011;108(52):20976–81.
105. Khodja AN, Mahlous M, Tahtat D, Benamer S, Youcef SL, Chader H, et al. Evaluation of healing activity of PVA/chitosan hydrogels on deep second degree burn: pharmacological and toxicological tests. Burns. 2013;39(1):98–104.
106. Aswathy S, Narendrakumar U, Manjubala I. Commercial hydrogels for biomedical applications. Heliyon. 2020;6(4).
107. Gao C, Xiao L, Zhou J, Wang H, Zhai S, An Q. Immobilization of nanosilver onto glycine modified lignin hydrogel composites for highly efficient p-nitrophenol hydrogenation. Chem Eng J. 2021;403:126370. https://doi.org/10.1016/j.cej.2020.126370.
108. Atiyeh BS, Costagliola M. Cultured epithelial autograft (CEA) in burn treatment: three decades later. Burns. 2007;33(4):405–13. https://doi.org/10.1016/j.burns.2006.11.002.
109. Dhar S, Chrisman T, Simman R. Clinical indications of cultured epithelial autografts. Ann Plast Surg. 2023;91(4):433–40. https://doi.org/10.1097/sap.0000000000003558.
110. Heard J, Sen S, Greenhalgh D, Palmieri T, Romanowski K. Use of cultured epithelial autograft in conjunction with biodegradable temporizing matrix in massive burns: a case series. J Burn Care Res. 2023;44:1434. https://doi.org/10.1093/jbcr/irad076.
111. Wood FM, Kolybaba ML, Allen P. The use of cultured epithelial autograft in the treatment of major burn injuries: a critical review of the literature. Burns. 2006;32(4):395–401. https://doi.org/10.1016/j.burns.2006.01.008.
112. Ojeh N, Pastar I, Tomic-Canic M, Stojadinovic O. Stem cells in skin regeneration, wound healing, and their clinical applications. Int J Mol Sci. 2015;16(10):25476–501. https://doi.org/10.3390/ijms161025476.
113. Kucharzewski M, Rojczyk E, Wilemska-Kucharzewska K, Wilk R, Hudecki J, Los MJ. Novel trends in application of stem cells in skin wound healing. Eur J Pharmacol. 2019;843:307–15. https://doi.org/10.1016/j.ejphar.2018.12.012.
114. Beumer G, Van Blitterswijk C, Bakker D, Ponec M. A new biodegradable matrix as part of a cell seeded skin substitute for the treatment of deep skin defects: a physico-chemical characterisation. Clin Mater. 1993;14(1):21–7.
115. Moustafa M, Bullock AJ, Creagh FM, Heller S, Jeffcoate W, Game F, et al. Randomized, controlled, single-blind study on use of autologous keratinocytes on a transfer dressing to treat nonhealing diabetic ulcers. 2007.
116. Li Y, Zhang J, Yue J, Gou X, Wu X. Epidermal stem cells in skin wound healing. Adv Wound Care. 2017;6(9):297–307.
117. Kølle S-FT, Fischer-Nielsen A, Mathiasen AB, Elberg JJ, Oliveri RS, Glovinski PV, et al. Enrichment of autologous fat grafts with ex-vivo expanded adipose tissue-derived stem cells for graft survival: a randomised placebo-controlled trial. Lancet. 2013;382(9898):1113–20.
118. Kim K, Blasco-Morente G, Cuende N, Arias-Santiago S. Mesenchymal stromal cells: properties and role in management of cutaneous diseases. J Eur Acad Dermatol Venereol. 2017;31(3):414–23.
119. Abo-Elkheir W, Hamza F, Elmofty AM, Emam A, Abdl-Moktader M, Elsherefy S, Gabr H. Role of cord blood and bone marrow mesenchymal stem cells in recent deep burn: a case-control prospective study. Am J Stem Cells. 2017;6(3):23–35.
120. Gorecka J, Kostiuk V, Fereydooni A, Gonzalez L, Luo J, Dash B, et al. The potential and limitations of induced pluripotent stem cells to achieve wound healing. Stem Cell Res Ther. 2019;10(1):87. https://doi.org/10.1186/s13287-019-1185-1.
121. Lo B, Parham L. Ethical issues in stem cell research. Endocr Rev. 2009;30(3):204–13. https://doi.org/10.1210/er.2008-0031.
122. Chen L, Tredget EE, Wu PYG, Wu Y. Paracrine factors of mesenchymal stem cells recruit macrophages and endothelial lineage cells and enhance wound healing. PLoS One. 2008;3(4):e1886. https://doi.org/10.1371/journal.pone.0001886.
123. Malgieri A, Kantzari E, Patrizi MP, Gambardella S. Bone marrow and umbilical cord blood human mesenchymal stem cells: state of the art. Int J Clin Exp Med. 2010;3(4):248–69.
124. Hong SJ, Jia SX, Xie P, Xu W, Leung KP, Mustoe TA, Galiano RD. Topically delivered adipose derived stem cells show an activated-fibroblast phenotype and enhance granulation tissue formation in skin wounds. PLoS One. 2013;8(1):e55640. https://doi.org/10.1371/journal.pone.0055640.
125. Saha K, Jaenisch R. Technical challenges in using human induced pluripotent stem cells to model disease. Cell Stem Cell. 2009;5(6):584–95. https://doi.org/10.1016/j.stem.2009.11.009.
126. Medvedev SP, Shevchenko AI, Zakian SM. Induced pluripotent stem cells: problems and advantages when applying them in regenerative medicine. Acta Nat. 2010;2(2):18–28.
127. Wong VW, Rustad KC, Akaishi S, Sorkin M, Glotzbach JP, Januszyk M, et al. Focal adhesion kinase links mechanical force to skin fibrosis via inflammatory signaling. Nat Med. 2011;18(1):148–52. https://doi.org/10.1038/nm.2574.
128. Rustad KC, Wong VW, Gurtner GC. The role of focal adhesion complexes in fibroblast mechanotransduction during scar formation. Differentiation. 2013;86(3):87–91. https://doi.org/10.1016/j.diff.2013.02.003.
129. Kuehlmann B, Bonham CA, Zucal I, Prantl L, Gurtner GC. Mechanotransduction in wound healing and fibrosis. J Clin Med. 2020;9(5) https://doi.org/10.3390/jcm9051423.
130. Chen K, Kwon SH, Henn D, Kuehlmann BA, Tevlin R, Bonham CA, et al. Disrupting biological sensors of force promotes tissue regeneration in large organisms. Nat Commun. 2021;12(1):5256. https://doi.org/10.1038/s41467-021-25410-z.
131. Chen K, Henn D, Januszyk M, Barrera JA, Noishiki C, Bonham CA, et al. Disrupting mechanotransduction decreases fibrosis and contracture in split-thickness skin grafting. Sci Transl Med. 2022;14(645):eabj9152. https://doi.org/10.1126/scitranslmed.abj9152.

Part II

Burn Scar Management

Mechanobiology of Scarring

10

Teruyuki Dohi and Rei Ogawa

Abstract

Scarring is an inevitable consequence of wound healing, and mechanical forces fundamentally influence this process at both tissue and cellular levels. This chapter mainly explores the mechanobiology of scarring in burn injuries, examining how mechanical forces regulate the transition from normal wound healing to pathological scar formation. Current understanding of mechanotransduction pathways reveals that mechanical stress significantly influences cellular behavior and tissue remodeling through specific molecular mechanisms. In burn injuries, the importance of mechanical forces is particularly evident, as demonstrated by the high incidence of pathological scarring in areas subjected to repetitive mechanical loading during daily activities. Mechanosensitive pathways, including PIEZO1/TRPV4 channels, integrin-FAK signaling, and transcriptional regulators such as YAP/TAZ and MRTFA-SRF, form an integrated network that determines scarring outcomes. Understanding these principles has led to the development of therapeutic strategies that combine mechanical force modulation with inflammatory control. This mechanobiological perspective provides both the theoretical framework for understanding post-burn scar formation and the practical basis for therapeutic approaches in burn reconstruction, while also offering insights applicable to other forms of pathological scarring, including keloids.

Keywords

Mechanobiology · Burn scar · Mechanotransduction · Mechanical stress · Mechanical strain · YAP/TAZ · MRTFA-SRF · Hypertrophic scar · Keloid · Scar contracture

T. Dohi (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School Hospital, Tokyo, Japan

R. Ogawa
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

10.1 Wound Healing Process and Scar Formation

Wound healing is one of the most complex biological processes essential for maintaining life [1]. When skin and underlying soft tissue sustains thermal injury, multiple biological pathways are immediately activated and coordinated to initiate the repair process. The course of this repair process diverges significantly depending on both the depth and extent of burn injury [2].

In cases where thermal damage is limited to the epidermis or superficial dermis (superficial partial-thickness burns), tissue repair occurs in a manner that closely resembles the original structure. This is achieved through epithelialization by epidermal stem cells in the basal layer and production of extracellular matrix by fibroblasts in the superficial dermis, resulting in the reconstruction of near-normal tissue architecture [3, 4]. However, when burns extend into the mid to deep dermis (deep partial-thickness burns) or full thickness, the tissue undergoes a complex wound healing process that results in scar formation. This process progresses through the following four distinct phases.

10.1.1 Hemostasis Phase

In burn injuries, tissue undergoes immediate thermal denaturation and coagulative necrosis, with microvascular thrombosis due to thermal damage of blood vessels [5]. The extent of this thermal destruction depends on both temperature and duration of exposure, creating a zone of coagulation surrounded by zones of stasis and hyperemia [6]. These initial responses, while destructive, provide a provisional matrix that serves as a scaffold for subsequent healing processes (Fig. 10.1).

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_10

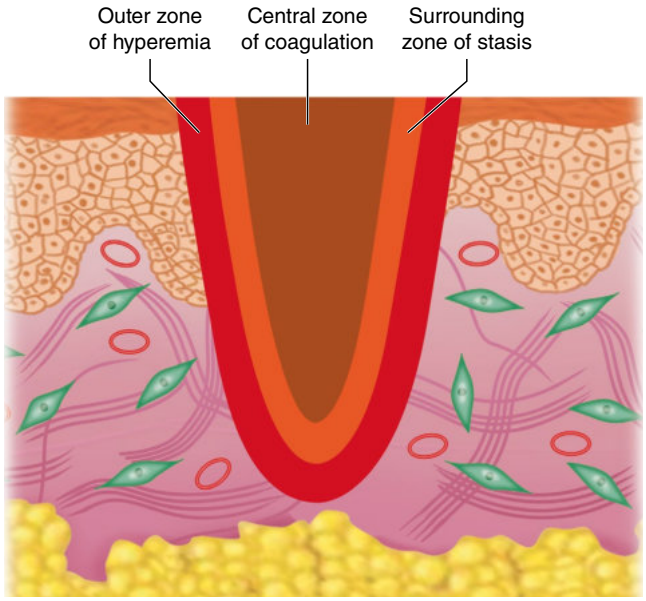


Fig. 10.1 Zones of thermal injury in burn wounds. Schematic representation of burn tissue showing three distinct zones of thermal injury that develop based on the temperature and duration of exposure: the central zone of coagulation (marked by tissue necrosis and vascular thrombosis), the surrounding zone of stasis (showing compromised blood flow), and the outer zone of hyperemia (characterized by inflammatory vasodilation) [6]. These initial tissue responses, while representing thermal damage, create a framework for subsequent wound healing processes

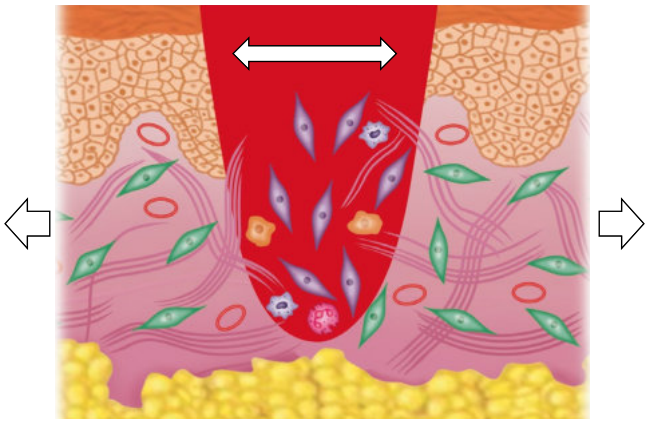


Fig. 10.2 Cellular response during early burn wound healing. Illustration of the inflammatory phase showing recruitment and activation of key cellular components. Neutrophils and macrophages migrate to the wound site through damaged blood vessels. These inflammatory cells release various growth factors and cytokines, which stimulate fibroblast activation and initiate the wound healing cascade. The diagram demonstrates the complex cellular interactions that characterize the early inflammatory response in burn wounds. The wound bed depicted here represents a post-debridement environment, where necrotic tissue has been removed, allowing for active inflammation and subsequent tissue repair

10.1.2 Inflammatory Phase

Lasting from 24 hours to approximately one week post-burn, this phase is characterized by the accumulation of inflammatory cells, including neutrophils and macrophages, in the wound site [5]. These cells not only remove thermally damaged tissue and provide defense against infection but also play a crucial role in regulating subsequent tissue repair by secreting various growth factors and cytokines. In burn wounds, this inflammatory response can be particularly intense and prolonged. (Fig. 10.2).

10.1.3 Proliferative Phase

Following the inflammatory phase, this 2–3 week period is marked by active fibroblast proliferation and extracellular matrix production. This phase involves granulation tissue formation, angiogenesis, collagen production, and wound contraction. Additionally, re-epithelialization occurs through migration and proliferation of epidermal cells from the wound edges and any surviving skin appendages. In deep burns, where skin appendages are destroyed, re-epithelialization can only occur from the wound edges, making the healing process more prolonged and complex.

10.1.4 Maturation Phase

This phase extends from several months to years after the proliferative phase. During this period, excessive extracellular matrix undergoes remodeling, and collagen fiber orientation improves. The number of blood vessels and fibroblasts in the granulation tissue gradually decreases as the scar tissue matures. In burn injuries, this phase is particularly critical as it determines the final characteristics of the scar tissue.

In deep partial-thickness or full-thickness burns, the dermal structure is significantly disrupted, making complete regeneration impossible. Consequently, the normal dermal structure is replaced by fibrous scar tissue [7]. While this scar formation represents an important defense mechanism for repairing wounds and restoring tissue continuity, as discussed in the next section, excessive activation of this repair process can lead to pathological scarring, a particularly common complication in burn injuries [8].

10.2 Mechanobiology of Pathological Scar Formation

During the wound healing process, tissue repair can sometimes deviate from normal scar formation, leading to pathological scarring. The progression and duration of wound healing vary significantly based on both burn depth and mechanical forces.

In superficial partial-thickness burns, where dermal damage is limited to the superficial layer, re-epithelialization typically completes within two weeks, resulting in minimal scarring. However, when burns extend into the deep dermis (deep partial-thickness burns) or involve full-thickness injury, the healing process becomes prolonged and more complex.

The risk of pathological scarring is particularly high in burn injuries compared to other types of trauma for several reasons. First, the extensive tissue damage and prolonged inflammatory response characteristic of burn wounds, often exacerbated by retained necrotic tissue, create conditions conducive to excessive scarring [9]. Second, in deep burns, inadequate debridement can significantly delay wound healing and increase the risk of infection, which may further extend wound depth. These pathological processes often result in deep dermal wounds, where the damaged tissue becomes continuously subjected to mechanical tension from daily activities, further increasing the risk of pathological scar formation. Such complex wound healing typically extends over several weeks to months.

The mechanical tension generated during daily activities and body movements significantly influences cellular behavior and matrix organization during healing [10, 11]. This is particularly evident in deep burn wounds, where the damaged dermis can no longer effectively accommodate these mechanical forces. Once scar tissue forms, it demonstrates poor extensibility and increased stiffness compared to normal skin tissue [12]. Due to these characteristics, the scar tissue experiences greater mechanical stress concentration than the surrounding tissue [13]. This mechanical loading becomes particularly problematic in areas where skin normally undergoes significant stretching during daily activities [14]. (Fig. 10.3).

This sustained mechanical loading affects the tissue in multiple ways: the poor extensibility of scar tissue can lead to impaired local blood flow, while mechanical stress

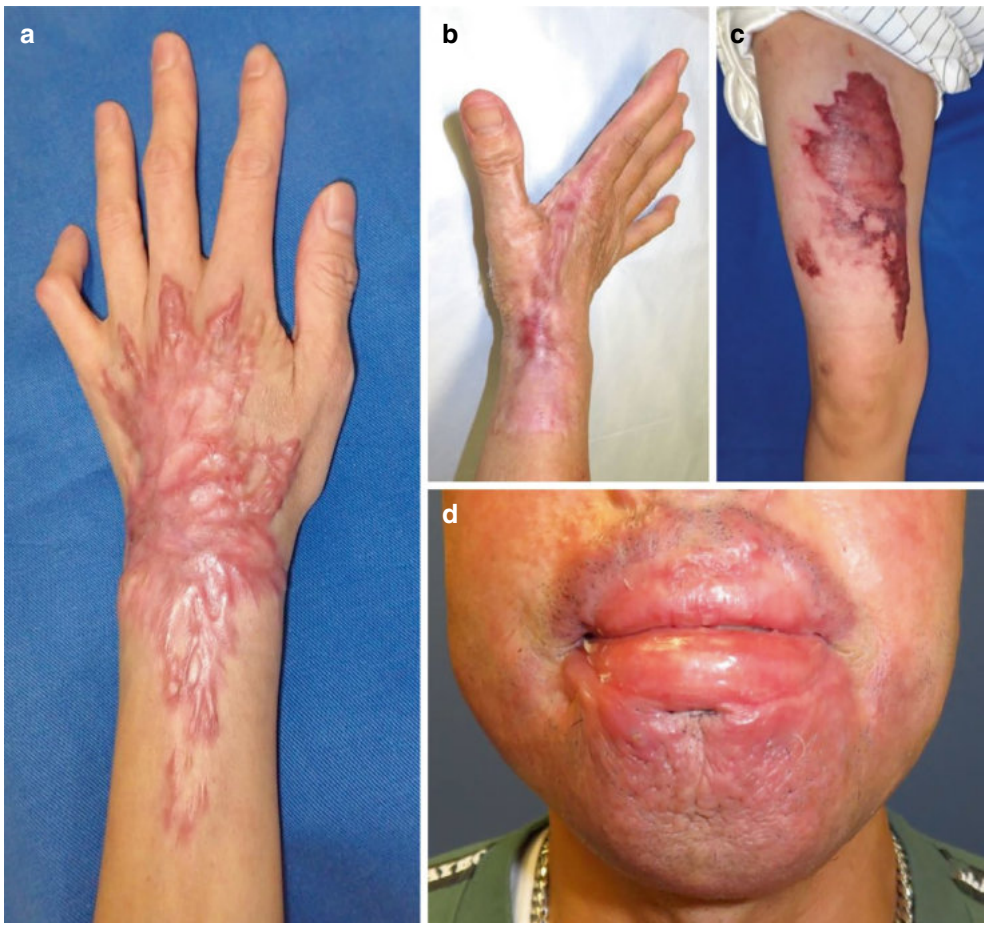


Fig. 10.3 Pathological scarring in areas subjected to daily mechanical stress. Clinical photographs showing characteristic patterns of burn scar formation in areas of repetitive mechanical loading. (**a**, **b**) Hypertrophic scarring of the hands, where frequent joint movements during daily activities create sustained mechanical stress. (**c**) Thigh scarring demonstrating the effects of repetitive stretching during walking and movement. (**d**) Perioral scarring resulting from continuous mechanical stress generated by facial expressions, speaking, and eating. These cases illustrate how routine mechanical stretch in different anatomical locations influences pathological scar development after burn injury, particularly in areas subjected to regular movement

on endothelial cells alters their function, leading to changes in angiogenesis and inflammatory responses [15]. Mechanical forces also promote fibroblast activation and subsequent collagen production [16]. The mechanical stimulation induces prolonged inflammatory response through mechanotransduction pathways, promoting excessive activation of the wound healing process. In burn injuries, this process is often more pronounced due to the initial extensive tissue damage and subsequent inflammatory response.

10.3 Mechanotransduction Pathways in Scarring

Mechanotransduction, the conversion of mechanical forces into biochemical signals, plays a fundamental role in pathological scar formation. Cells sense mechanical forces through various mechanosensors on their membrane, including mechanosensitive ion channels, integrins, and growth factor receptors (Fig. 10.4) [17].

The major mechanotransduction pathways involved in scarring include mechanosensitive ion channels (PIEZO1 and TRPV4), integrin-FAK signaling, YAP/TAZ, and MRTFA-SRF pathways (Fig. 10.1). PIEZO1 and TRPV4 trigger Ca2+ influx when activated by mechanical deformation, leading to inflammatory responses particularly in conditions of high tissue stiffness. The integrin-FAK pathway, activated through mechanical force-induced integrin clustering, promotes inflammatory mediator production and fibroblast activation, ultimately leading to hypertrophic scar formation [16].

Mechanical stress also drives nuclear translocation of YAP/TAZ transcriptional coactivators, promoting profibrotic gene expression and myofibroblast differentiation [18]. Mechanical forces promote actin polymerization, which releases MRTFA from G-actin, enabling its nuclear translocation and complex formation with SRF, promoting both myofibroblast differentiation and ECM production [19] . Other important mechanosensitive pathways include TGF-β/Smad signaling and various G protein-coupled receptor pathways, which interact with these core pathways through RhoA/ROCK signaling and ERK to form an interconnected regulatory network [20].

These mechanosensitive pathways form an integrated signaling network that determines scarring outcomes (Fig. 10.4). For example, integrin-mediated mechanosensing activates RhoA/ROCK signaling, leading to cytoskeletal reorganization, while mechanical stress promotes YAP/TAZ nuclear translocation through cytoskeletal reorganization and direct mechanical force sensing [21]. Additionally, specific GPCR subtypes activate distinct downstream pathways that contribute to the overall mechanotransduction response [22]. Understanding these complex pathway interactions has led to the development of therapeutic strategies targeting mechanical signaling to prevent or treat pathological scarring.

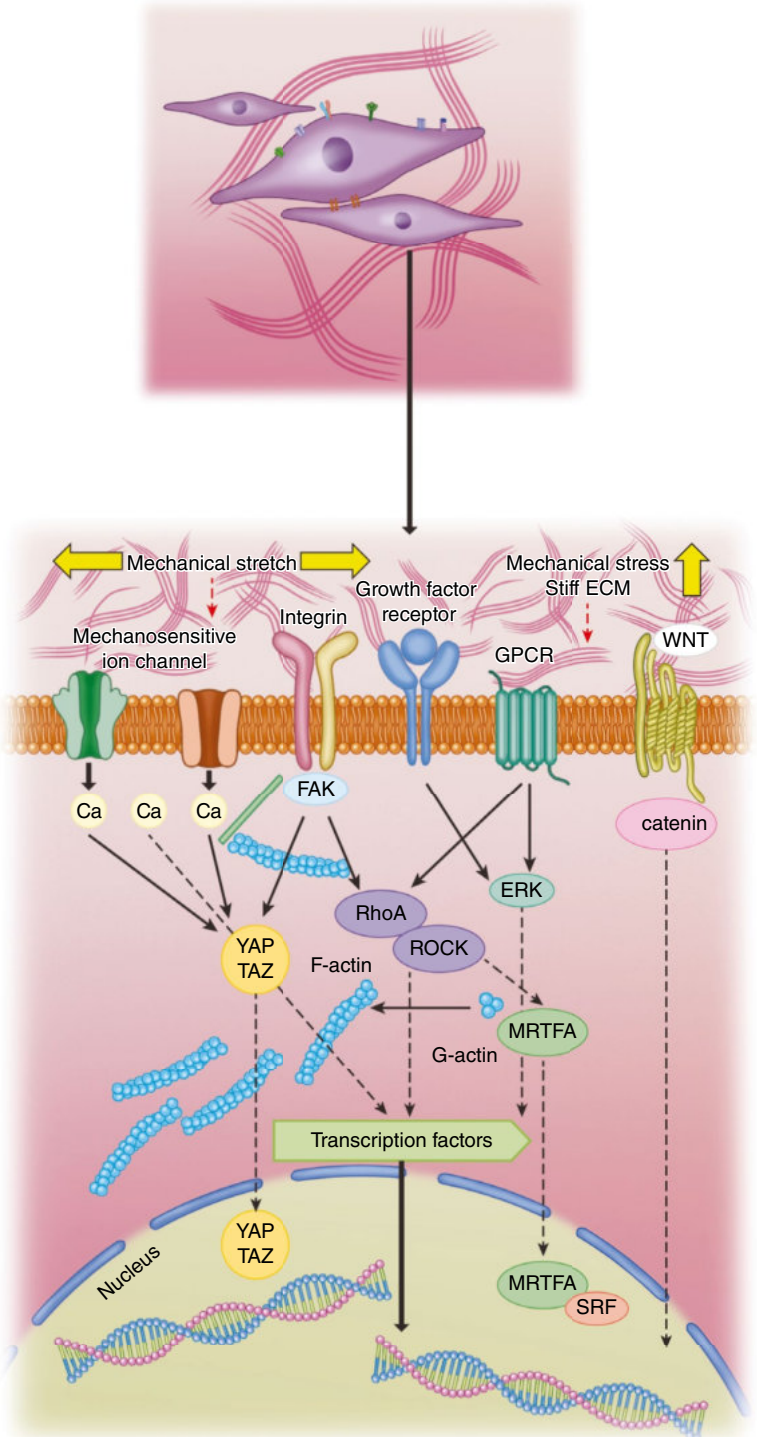


Fig. 10.4
Mechanotransduction pathways in pathological scar formation. Mechanical forces exerted on burn tissue are sensed at the cellular level through various mechanosensors, triggering intracellular signaling cascades that regulate scarring responses. The diagram shows key mechanotransduction pathways: cell membrane mechanosensors include mechanosensitive ion channels (PIEZO1 and TRPV4), integrins, growth factor receptors, and G protein-coupled receptors (GPCRs). Upon mechanical stress, these sensors activate distinct but interconnected signaling cascades. PIEZO1 and TRPV4 mediate Ca2+ influx in response to mechanical deformation. Integrin clustering activates FAK and subsequent RhoA/ROCK signaling, leading to cytoskeletal reorganization. This mechanical force-induced cytoskeletal remodeling promotes YAP/TAZ nuclear translocation, while actin polymerization releases MRTFA from G-actin, enabling its nuclear translocation and complex formation with SRF. GPCR activation and TGF-β/Smad signaling interact with these pathways through RhoA/ROCK and ERK signaling. The coordinated action of these pathways regulates myofibroblast differentiation and extracellular matrix production, ultimately determining scarring outcomes

10.4 Pathological Scar Types and Clinical Features

Pathological scars after burn injury manifest primarily as hypertrophic scars and keloids [7], with mechanical stress playing a crucial role in their development (Fig. 10.5). Hypertrophic scars are characterized by excessive scar tissue formation within the boundaries of the original wound and tend to regress naturally over time. However, when constantly subjected to tension, such as around joints, they may not regress due to continuous mechanical stimulation, often leading to scar contracture.

A particularly significant clinical manifestation in burn patients is scar contracture, especially in joint areas [23]. Due to the poor extensibility and inherent stiffness of scar tissue, it fails to provide the necessary skin elasticity during joint movement, resulting in limited range of motion [12, 24]. This condition can create a vicious cycle where limited joint movement leads to further tissue fibrosis, resulting in even more reduced tissue extensibility. However, in burn cases, the initial contracture may be partially caused by inflammatory hypertrophic scarring, which can improve over time as the inflammation subsides and the contracture becomes more localized [8, 23]. For this reason, surgical intervention for burn scar contractures is often delayed for up to one year unless severe functional impairment exists, allowing time for potential spontaneous improvement through the natural maturation process.

Keloids represent a more severe form of pathological scarring, characterized by growth beyond the original wound boundaries and rare spontaneous regression. While both hypertrophic scars and keloids occur in areas of high mechanical tension during daily activities, they show different patterns of development. Hypertrophic scars typically form in areas directly subjected to joint movement, while keloids often develop in locations that experience sustained mechanical forces during prolonged postural changes, such as the chest, shoulders, and lower jaw areas [13, 25].

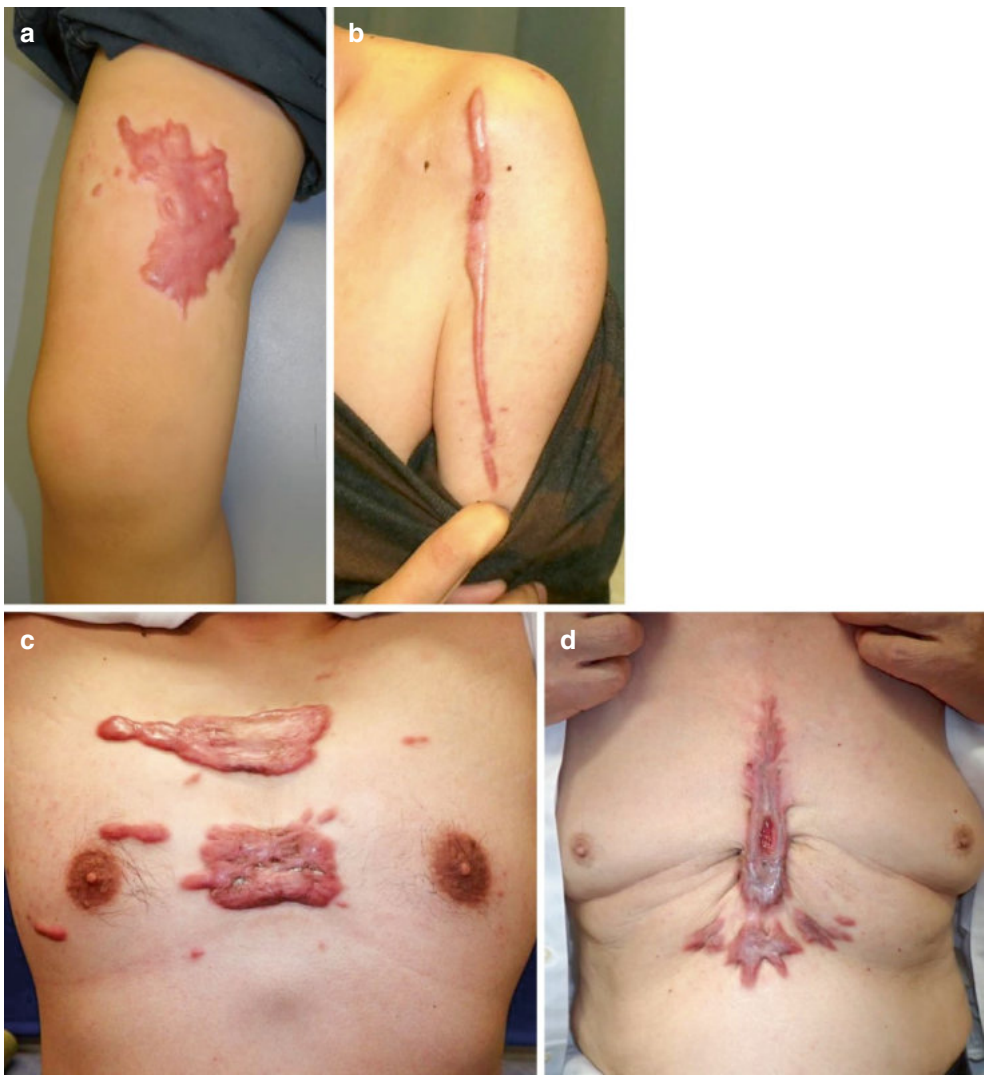


Fig. 10.5 Comparison of hypertrophic and keloid scars. Clinical photographs showing characteristic features of hypertrophic scars (**a**) post-burn hypertrophic scar, (**b**) post-surgical hypertrophic scar) and keloids (**c**) post-acne keloid, (**d**) post-surgical keloid). Hypertrophic scars remain within the original wound boundaries, while keloids demonstrate characteristic growth pattern beyond the initial injury site

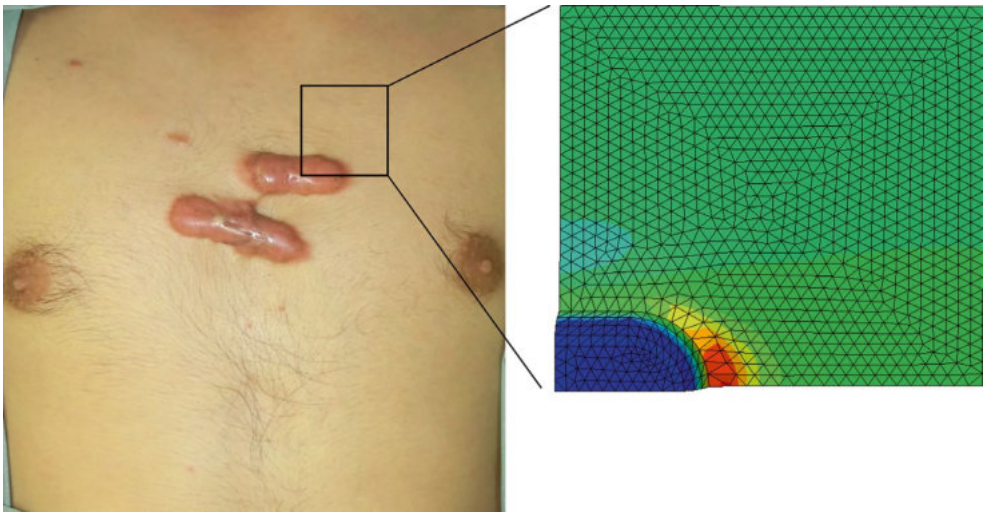


Fig. 10.6 Mechanical stress and strain distribution in pathological scars. Finite element analysis showing mechanical strain distribution patterns in and around pathological scar tissue. The model demonstrates increased strain in the surrounding normal skin at the scar periphery, while the stiff scar tissue itself shows limited strain due to its reduced extensibility. This reduced extensibility of the scar tissue results in increased mechanical stress within the scar, though not directly shown in this strain analysis. This mechanical principle helps explain how the stiff scar tissue and surrounding normal skin interact during daily mechanical loading. For detailed quantitative analysis of both mechanical stress and strain distributions, see referenced literature [12]

Mechanical analysis has revealed that stress concentrates at the keloid periphery, while strain occurs in the surrounding normal skin, contributing to their characteristic growth patterns (Fig. 10.6) [13].The development of keloids appears to have both genetic and mechanical components, though the interaction between these factors remains to be fully understood [26]. Additionally, systemic conditions such as hypertension and pregnancy can worsen existing keloids.

These pathological scars should be understood not merely as abnormal tissue repair but as an excessive manifestation of the body's defensive response aimed at ensuring mechanical stability of the tissue. This understanding provides the foundation for mechanobiology-based treatment strategies discussed in subsequent sections.

10.5 Mechanobiology-Based Therapeutic Concepts

Understanding the role of mechanical forces in scar formation has led to the development of specific therapeutic strategies. The management approach must be tailored to both the type of pathological scarring and the degree of functional impairment. Optimal outcomes often require a combination of mechanical force control and inflammatory response modulation.

Conservative management focuses on controlling mechanical forces during the healing and maturation phases through the use of stabilization materials such as silicone gel sheets and surgical tape fixation. These mechanical interventions are typically combined with anti-inflammatory treatments such as steroid therapy to comprehensively address both mechanical and inflammatory aspects of pathological scarring (detailed in subsequent chapters).

When surgical intervention is necessary, the choice of technique should consider mechanical force distribution. For example, surgical designs should minimize mechanical stress on the resulting scar, and reconstructive techniques should be selected based on the mechanical requirements of the site. Post-treatment care integrates both mechanical support and inflammatory control to optimize outcomes.

10.6 Summary

Mechanical forces play a fundamental role in post-burn scarring, significantly influencing both normal and pathological scar formation processes. The progression from initial thermal injury to scar formation involves complex interactions between mechanical forces and biological responses, mediated through specific mechanotransduction pathways. In burn injuries, mechanical loading particularly affects areas subjected to daily movement, often leading to pathological scarring and functional impairment. Treatment strategies based on these principles integrate both mechanical force modulation and inflammatory control, from conservative management to surgical intervention. Understanding these mechanobiological principles is essential for optimizing therapeutic outcomes in burn reconstruction. Further research into the interaction between mechanical forces and

cellular responses will continue to advance our ability to prevent and treat pathological scarring in burn patients.

References

1. Gurtner GC, Werner S, Barrandon Y, Longaker MT. Wound repair and regeneration. Nature. 2008;453(7193):314–21.
2. Jeschke MG, van Baar ME, Choudhry MA, Chung KK, Gibran NS, Logsetty S. Burn injury. Nat Rev Dis Primers. 2020;6(1):11.
3. Aragona M, Dekoninck S, Rulands S, Lenglez S, Mascré G, Simons BD, et al. Defining stem cell dynamics and migration during wound healing in mouse skin epidermis. Nat Commun. 2017;8:14684.
4. Tracy LE, Minasian RA, Caterson EJ. Extracellular matrix and dermal fibroblast function in the healing wound. Adv Wound Care (New Rochelle). 2016;5(3):119–36.
5. Korkmaz HI, Flokstra G, Waasdorp M, Pijpe A, Papendorp SG, de Jong E, et al. The complexity of the post-burn immune response: an overview of the associated local and systemic complications. Cells. 2023;12(3)
6. Hettiaratchy S, Dziewulski P. ABC of burns: pathophysiology and types of burns. BMJ. 2004;328(7453):1427–9.
7. Finnerty CC, Jeschke MG, Branski LK, Barret JP, Dziewulski P, Herndon DN. Hypertrophic scarring: the greatest unmet challenge after burn injury. Lancet. 2016;388(10052):1427–36.
8. Chiang RS, Borovikova AA, King K, Banyard DA, Lalezari S, Toranto JD, et al. Current concepts related to hypertrophic scarring in burn injuries. Wound Repair Regen. 2016;24(3):466–77.
9. Comish PB, Carlson D, Kang R, Tang D. Damage-associated molecular patterns and the systemic immune consequences of severe thermal injury. J Immunol. 2020;205(5):1189–97.
10. Humphrey JD, Dufresne ER, Schwartz MA. Mechanotransduction and extracellular matrix homeostasis. Nat Rev Mol Cell Biol. 2014;15(12):802–12.
11. Hosseini M, Brown J, Khosrotehrani K, Bayat A, Shafiee A. Skin biomechanics: a potential therapeutic intervention target to reduce scarring. Burns. Trauma. 2022;10:tkac036.
12. Corr DT, Hart DA. Biomechanics of scar tissue and uninjured skin. Adv Wound Care (New Rochelle). 2013;2(2):37–43.
13. Dohi T, Padmanabhan J, Akaishi S, Than PA, Terashima M, Matsumoto NN, et al. The interplay of mechanical stress, strain, and stiffness at the keloid periphery correlates with increased Caveolin-1/ROCK signaling and scar progression. Plast Reconstr Surg. 2019;144(1):58e–67e.
14. Ogawa R, Okai K, Tokumura F, Mori K, Ohmori Y, Huang C, et al. The relationship between skin stretching/contraction and pathologic scarring: the important role of mechanical forces in keloid generation. Wound Repair Regen. 2012;20(2):149–57.
15. Katoh K. Effects of mechanical stress on endothelial cells in situ and in vitro. Int J Mol Sci. 2023;24(22)
16. Berry CE, Downer M, Morgan AG, Griffin M, Liang NE, Kameni L, et al. The effects of mechanical force on fibroblast behavior in cutaneous injury. Front Surg. 2023;10:1167067.
17. Yin J, Zhang S, Yang C, Wang Y, Shi B, Zheng Q, et al. Mechanotransduction in skin wound healing and scar formation: potential therapeutic targets for controlling hypertrophic scarring. Front Immunol. 2022;13:1028410.
18. Liu F, Lagares D, Choi KM, Stopfer L, Marinković A, Vrbanac V, et al. Mechanosignaling through YAP and TAZ drives fibroblast activation and fibrosis. Am J Physiol Lung Cell Mol Physiol. 2015;308(4):L344–57.
19. Sidorenko E, Vartiainen MK. Nucleoskeletal regulation of transcription: actin on MRTF. Exp Biol Med (Maywood). 2019;244(15):1372–81.
20. Di X, Gao X, Peng L, Ai J, Jin X, Qi S, et al. Cellular mechanotransduction in health and diseases: from molecular mechanism to therapeutic targets. Signal Transduct Target Ther. 2023;8(1):282.
21. Dasgupta I, McCollum D. Control of cellular responses to mechanical cues through YAP/TAZ regulation. J Biol Chem. 2019;294(46):17693–706.
22. Yu OM, Brown JH. G protein-coupled receptor and RhoA-stimulated transcriptional responses: links to inflammation, differentiation, and cell proliferation. Mol Pharmacol. 2015;88(1):171–80.
23. Goverman J, Mathews K, Goldstein R, Holavanahalli R, Kowalske K, Esselman P, et al. Adult contractures in burn injury: a burn model system National Database Study. J Burn Care Res. 2017;38(1):e328–e36.
24. Schouten HJ, Nieuwenhuis MK, van Baar ME, van der Schans CP, Niemeijer AS, van Zuijlen PPM. The degree of joint range of motion limitations after burn injuries during recovery. Burns. 2022;48(2):309–18.
25. Cho H, Dohi T, Wakai H, Quong WL, Linh NDT, Usami S, et al. In the face and neck, keloid scar distribution is related to skin thickness and stiffness changes associated with movement. Wound Repair Regen. 2024;32(4):419–28.
26. Xia G, Dohi T, Abdelhakim M, Tosa M, Ogawa R. The effects of systemic diseases, genetic disorders and lifestyle on keloids. Int Wound J. 2024;21(4):e14865.

Molecular Mechanisms of Scarring

11

Mamiko Tosa

Keywords

Normal scarring · Hypertrophic scarring · Keloid scarring · Molecular mechanisms · Burn scarring

When human skin is injured, the wound-healing process is immediately initiated. If the injury is sustained during the fetal period in late pregnancy, the tissue regenerates without leaving a scar. By contrast, if the injury occurs after birth, the tissue repair results in scar formation. This is particularly true if the injury extends beyond the basement membrane into the deep dermis: this is because the dermal gap becomes filled with fibrotic collagenous tissue that disrupts the original tissue structure [1]. In some cases, the genetic, systemic, and/or local characteristics (e.g. strong skin tension) of the individual patient can amplify this fibrotic wound-healing response and lead to pathologically growing scars called hypertrophic scars and keloids [2]. Indeed, as shown by Fig. 11.1, a common cause of these scars is burns that involve the deep dermis. By contrast, superficial burns generally lead to mature scars.

The normal wound-healing process in adult skin consists of four sequential but overlapping stages, namely, hemostasis, inflammation, proliferation, and remodeling. Many different cells and pathways are involved and all stages must be initiated, implemented, and terminated in the correct order and time-frame [1] (Fig. 11.2). This is particularly true of the inflammatory stage, which is initiated within 24 hours of wounding, is intense in the first 5 days, and normally lasts for up to 2 weeks. This stage starts with the release of several proinflammatory cytokines that attract a large number of cells, including neutrophils, mast cells, and macrophages to the wound bed. These cells drive the next stage, namely, the proliferative stage. Specifically, the inflammatory cells release chemokines that induce bone marrow-derived fibroblasts to migrate into the wounded tissue from the blood. Along with resident wound-bed fibroblasts, these cells are activated by the local immune cells and factors, including the pleiotropic cytokine transforming-growth factor (TGF)β1, and start producing abundant amounts of collagen and extracellular-matrix (ECM) components such as collagen, elastin, proteoglycans, and hyaluronic acid [3]. The resulting scaffold of ECM components is called granulation tissue and it serves to fill the dermal gap. The TGFβ1 in the wound bed also eventually causes the fibroblasts to undergo fibroblast-to-myofibroblast transition. The resulting myofibroblasts are highly contractile and pull the wound edges together to close the gap in the tissue [4]. The also dominate the last stage, namely, remodeling, which normally continues for 6–24 months. Here, the myofibroblasts produce matrix-metalloproteinases (MMPs), which degrade the type-III collagen in the granulation tissue, thereby permitting its replacement with new type-I collagen produced by the (myo) fibroblasts. This balanced ECM synthesis/degradation process eventually leads to a flat mature scar that has much of the strength of the original tissue [5].

However, if the inflammatory stage is abnormally long or chronic, the fibroblasts remain activated and continue to lay down abundant amounts of ECM. This leads to abnormal fibrosis and pathologically growing scars [6].

Thus, to develop new interventions that prevent scarring and/or effectively treat existing abnormal scars, it is necessary to understand both the homeostatic wound-healing process and how it can be deranged by certain factors, thus leading to pathological scarring. Below, we will first focus on the key cellular contributors to normal wound healing. Thereafter, new discoveries in relation to pathological-scarring mechanisms will be discussed.

M. Tosa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School Hospital, Tokyo, Japan
e-mail: tosa-m@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_11

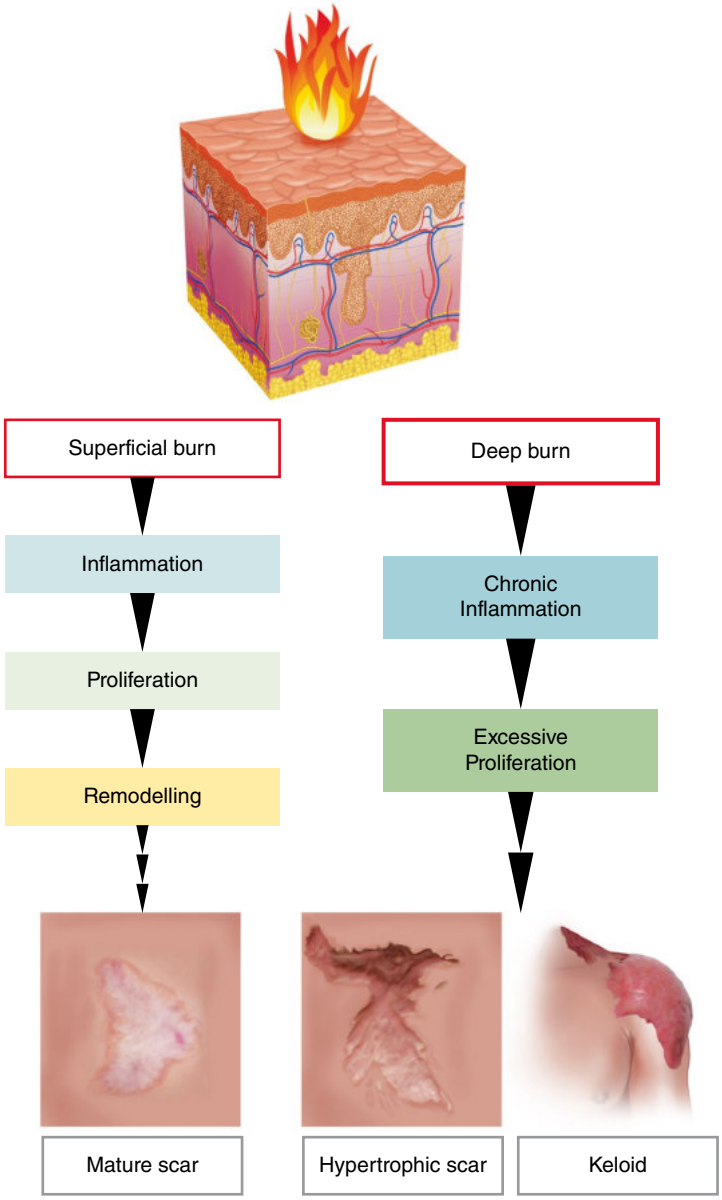


Fig. 11.1 Normal and abnormal post-burn scars. The outcome of skin burn depends on the extent and particularly the depth of the injury. Superficial burns eventually heal into flat pale mature scars. However, if the burned area is wide and affects the deep dermis, chronic inflammation can ensue. This induces skin fibrosis. Consequently, the scar becomes hard and protuberant. In hypertrophic scars, the scar grows vertically but generally starts to subside after a few years. By contrast, keloids grow unrelentingly in both the vertical and horizontal directions. The associated pain and itching of these abnormal scars can greatly reduce patient quality of life

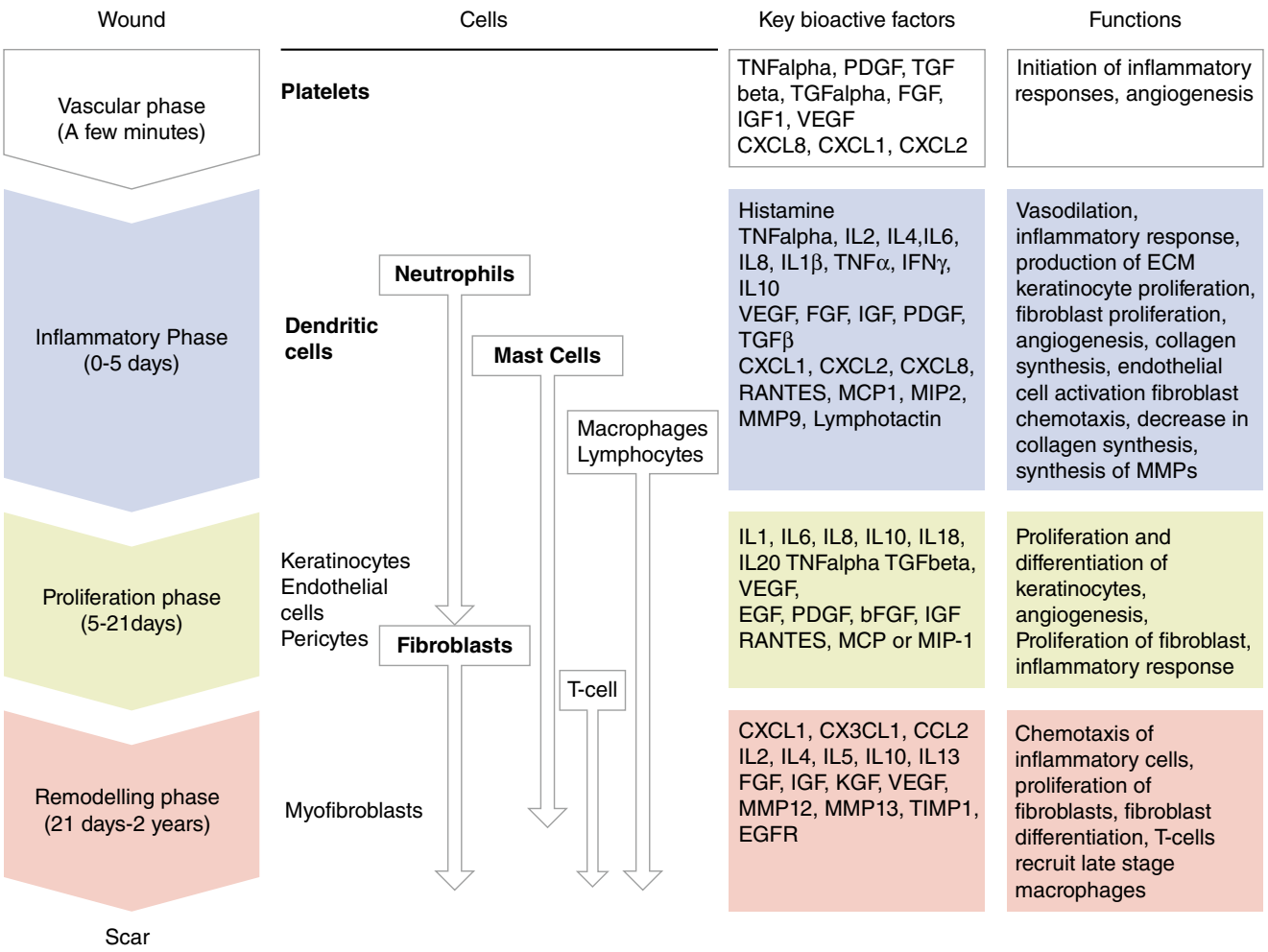


Fig. 11.2 The normal wound-healing process consists of four sequential but overlapping stages: hemostasis, inflammation, proliferation, and tissue remodeling. Each stage has its own immunological phenotype, as determined by its key immune cells and their chemical messengers (growth factors, cytokines, and chemokines). Some cells/messengers play roles in several stages. Hemostasis occurs in the first few minutes and involves the attachment of platelets to the injured blood vessels and their production of PDGF and other growth/chemokine factors. The inflammatory stage is initiated quickly and is highly active in the first 5 days. It is characterized by the influx of neutrophils, mast cells, and dendritic cells, which recruit macrophages and lymphocytes via chemokines. The latter cells then secrete pro-inflammatory cytokines and growth factors. The proliferation stage is initiated around day 5, which is followed by ~2 weeks of resident-fibroblast proliferation that is largely initially driven by pro-inflammatory (M1) macrophages. Re-epithelialization and angiogenesis also occur during this stage: these processes are promoted by macrophages and other cells. Eventually, there is a switch to anti-inflammatory (M2) macrophages and T cells, which work together in the remodeling stage to resolve the inflammation and fibroblast proliferation. Myofibroblasts also differentiate from fibroblasts via the fibroblast-to-myofibroblast transition. These cells contract the wound and produce MMPs and different ECM components, thus promoting the granulation-tissue remodeling that strengthens the repaired tissue. Meanwhile, re-epithelialization continues. When it is completed, remodeling of the dermis continues for up to 2 years

11.1 Key Cells in Normal Wound Healing

Figure 11.2 shows the four normal wound-healing stages and the key cellular players, their bioactive factors, and their main functions.

11.1.1 Platelets (Stage: Hemostasis)

The first cells that enter the injured skin are platelets, which bind to the damaged endothelium [4].and secrete cytokines and growth factors such as platelet-derived growth factor (PDGF), TGFβ1, and vascular endothelial growth factor (VEGF), which are involved in thrombus formation, fibroblast activation, and endothelial-cell differentiation. Growth factors such as PDGF activate neutrophils and macrophages and act as mitogenic agents and chemoattractants for fibroblasts and smooth-muscle cells. Platelets also stimulate inflammatory responses by secreting prostaglandins, leukotrienes, and thromboxanes [5].

11.1.2 Neutrophils (Stage: Inflammatory)

Neutrophils arrive in the wound within 1 hour of injury. Their migration to the wound site is promoted by PDGF and connective tissue chemokine-activating peptide (CTAP)III [7]. Once they aggregate in the lesion, they release multiple growth factors, proinflammatory mediators, and chemokines, including VEGF, tumor-necrosis factor (TNF)α, interleukin (IL)-1β, IL-6, IL-8 (also known as CXCL8), and monocyte chemoattractant protein (MCP)1. These factors further promote inflammation and activate angiogenesis and fibroblast and keratinocyte proliferation. The neutrophils then disappear from the lesion after 24–36 hours [5].

11.1.3 Mast Cells (Stages: Inflammatory and Remodeling)

Mast-cell numbers and evidence of their degranulation start increasing in the wound within 3 hours of injury. Normally, these responses settle to normal values 21 days after injury. These cells promote hemostasis by releasing TNFα, which increases the local expression of factor XIIIa by dermal dendritic cells (DCs). Mast cells also release inflammatory mediators (histamine, VEGF, IL-6, IL-8, and TNFα) that augment endothelial permeability; this allows monocytes and neutrophils to migrate into the lesion from the blood. Mast cells also stimulate early fibroblast migration from the blood and fibroblast proliferation and collagen deposition. Later, mast cells promote the fibroblast-to-myofibroblast transition, which leads to the release of MMPs and the remodeling of the ECM [8].

11.1.4 Macrophages (Stages: Inflammatory, Proliferative, and Remodeling)

Macrophages arrive in the lesion within 48–72 hours of wounding and participate in various ways in the last three stages of wound healing. First, they promote the inflammatory stage by releasing growth factors such as TGFβ and epidermal growth factor (EGF): these factors stimulate inflammatory responses, angiogenesis, and keratinocyte migration.

Second, they help drive the proliferative phase by stimulating angiogenesis further. This activity is mediated by their release of IL-1, which activates endothelial-cell proliferation. Moreover, IL-1 and other macrophage-derived factors, namely, fibroblast growth factor (FGF)β, TNFα1, and IL-6, promote collagen, fibronectin, and proteoglycan formation and epithelialization.

Third, macrophages participate in the remodeling stage by releasing MMPs. They also ingest and induce the apoptosis of fibroblasts, myofibroblasts, and endothelial cells, thus regulating the resolution of wound healing [9].

Macrophages can be broadly divided into two subtypes, namely, pro-inflammatory M1 and anti-inflammatory M2 macrophages. M1 macrophages are activated soon after wound healing by pathogen-associated molecular patterns (PAMPs) and DAMPs that are released by the injured tissue; these molecules bind to Toll-like receptor (TLR)4 on monocytes and convert them into macrophages that produce interferon (IFN)γ and IL-1. Later, the macrophage population assumes the reparative anti-inflammatory M2 macrophage phenotype. This change is mediated by IL4 and/or IL13, which are produced by T cells and/or innate immune cells such as mast cells. The M2 macrophages release several growth factors, including PDGF, FGFα, FGFβ, TGFα, and TGFβ [5].

11.1.5 Dendritic Cells (Stage: Inflammatory)

DCs in the skin include Langerhans cells in the epidermis, conventional dermal DCs, and plasmacytoid DCs. CD1a- and CD207/langerin-expressing Langerhans cells are first-line defenders of the host and rapidly increase in number within 1 hour of injury. Dermal DCs are rarely seen in <1-day-old wounds but 3–14-day-old wounds demonstrate the accumulation of these cells due to differentiation of monocyte precursors that were recruited to the wound by early chemokines. This differentiation event is dependent on TGFβ and TNFα from mast cells. While the role of Langerhans cells and DCs in wound healing is poorly under-

stood, it is likely that they are activated by the TLRs on their surface and promote early fibroblast proliferation by producing TGFβ [10]]. Similarly, plasmacytoid DCs rapidly infiltrate the wound and undergo activation when the TLRs on their surface are stimulated by PAMPs/DAMPs. They then secrete type I IFNs that help initiate the inflammatory stage [11].

DCs are important in wound healing since mice lacking DCs demonstrate poor granulation tissue formation and wound closure [12].

11.1.6 Lymphocytes (Stage: Inflammatory, Proliferation, and Remodeling)

T cells are attracted to the wound by macrophage-derived IL-1 and reach the wound site 72 hours after injury. The antigen-presenting cells (macrophages and DCs) and IFNγ and TNFα in the skin microenvironment activate these cells. They then secrete chemokines such as MCP1, IFNγ-induced protein 10 kDa (IP10; also known as CXCL10), monokine induced by IFNγ (MIG; CXCL9), and macrophage-derived chmokine (MDC; CCL22) [9] and growth factors such as EGF and FGFβ. Recent studies have also shown that regulatory T cells (Tregs), which are immunosuppressive T cells, accumulate soon after wounding and demonstrate upregulation of EGF receptors. This is important for wound healing since lineage-specific deletion of these receptors delays wound closure and increases M1-macrophage accumulation [13].

11.1.7 Keratinocytes (Stage: Inflammation, Proliferation, and Remodeling)

Local keratinocytes are rapidly activated by TLRs on their surface, which recognize the PAMPs and DAMPs released by the injured tissue. They secrete various cytokines and chemokines, including IL-1, IL-6, IL-8, IL-10, IL-18, IL-20, and TNFα, and growth factors, that stimulate the influx and activation of other immune cells [14].

The IL-8 produced by themselves and local fibroblasts then induce the proliferation of the keratinocytes in the basal-cell layer [15] and their migration towards the wound edge and then over the wound bed to reinstate the epithelial barrier. This migration starts in the first 24 hours and is mediated by basal-keratinocyte expression of MMP1. It also requires new keratinocyte expression of CD44 [5], CXC chemokine receptor (CXCR)2, IL-8 receptors, and GROα [15].

Together with other immune cells, the keratinocytes also control the fibroblast-to-myofibroblast differentiation in the remodelin stage by establishing a microenvironment in which the pro-inflammatory cytokines are balanced with TGFβ (Fig. 11.3) [5].

11.1.8 Endothelial Cells (Stage: Hemostasis and Proliferation)

Immediately after wounding, endothelial cells lining damaged blood vessels produce the von Willebrand factor (VWF) that induces platelet adhesion. Endothelial cells also act during the proliferative phase. Specifically, endothelial-progenitor cells (EPCs) that express CD146, VWF, and VEGFR2 are recruited from the bone marrow into the wound bed, where they establish blood vessels in the new ECM [16]. This activity is induced by multiple factors, including MCP1, Regulates on Activation Normal T-cell Expressed and Secreted (RANTES), IL-8, IP10, MIG, GROα, GROβ (CXCL2), GROγ (CXCL3), CTAPIII, β-thromboglobulin, neutrophil-activating peptide (NAP)2, and particularly the Glu-Leu-Arg (ELR) motif, which is a potent promoter of angiogenesis [5]. FGF, PDGF, and stromal-derived growth factor (SDF)1 are also important because they promote endothelial-cell proliferation and chemotaxis, which is a complex process that involves changes in cytoskeletal reorganization, adhesion molecules, and signal transduction [17].

11.1.9 Pericytes (Stage: Inflammatory, Proliferation, and Remodeling)

Pericytes are stromal cells that lie on the surface of blood vessels and regulate vascular function. Relatively little is known about their role in wound healing but they are likely to participate in both neovascularization and shaping the caliber of the new blood vessels by communicating with the underlying endothelial cells. They also may act synergistically with macrophages during the inflammatory, proliferation, and remodeling stages by conducting phagocytosis, inducing lymphocyte infiltration by secreting SDF-1, CXCL9, and CXCL12, presenting antigen and activating T cells, and undergoing PDGF-mediated differentiation into myofibroblasts [18].

11.1.10 Fibroblasts (Stage: Inflammation, Proliferation, and Remodeling)

Fibroblasts play a particularly crucial role in wound healing. First, they strongly promote the inflammatory phase by secreting cytokines and growth factors (TNFα, IFNγ, IL-6, and IL-12) and releasing a wide range of chemokines (CXCL1, CX3CL1, and CCL2). They also facilitate cell-cell

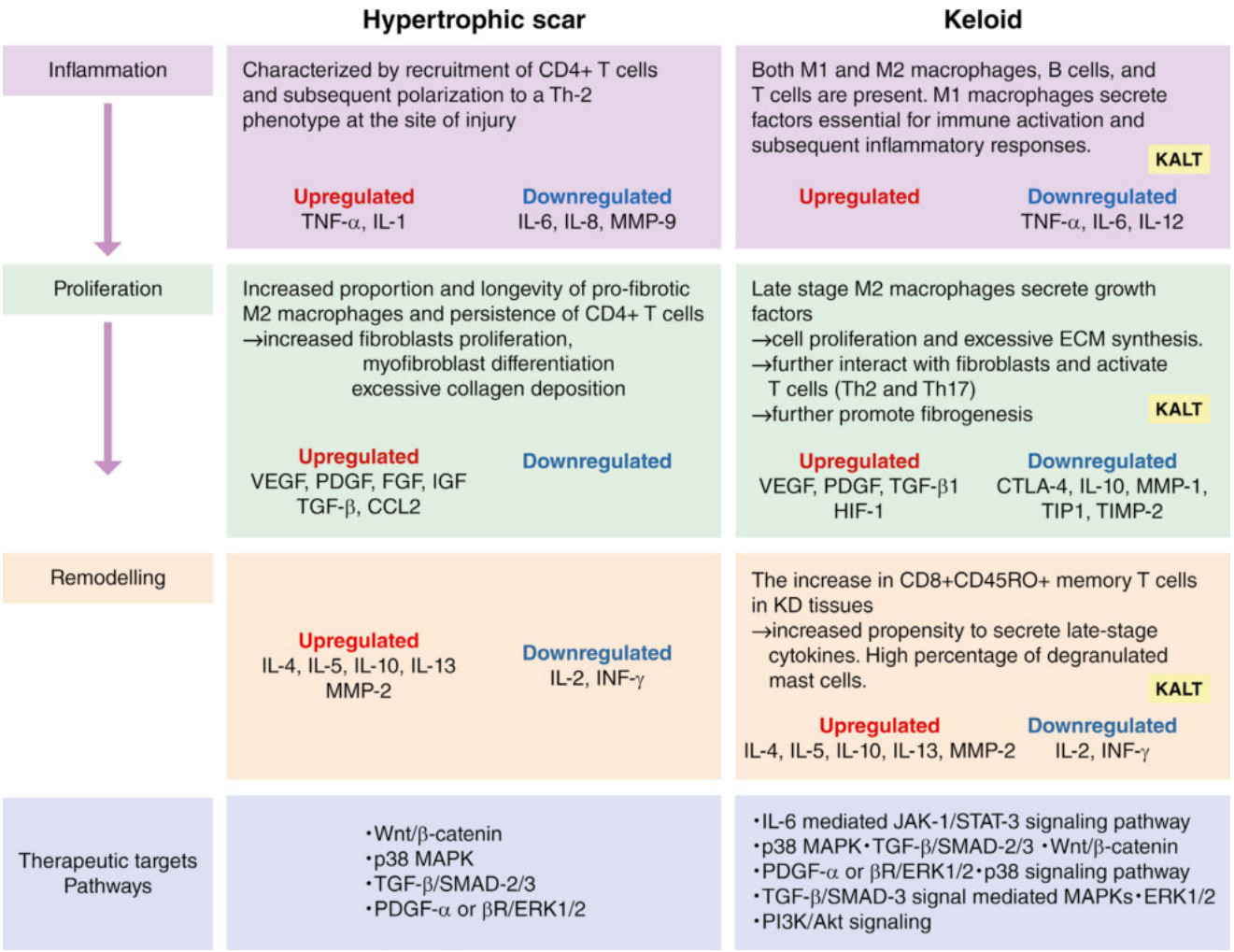


Fig. 11.3 Similarities and differences of hypertrophic scars and keloids in terms of wound-healing phenotypes. Th2 T cells, M1 macrophages, and TNFα dominate in the inflammatory stage of hypertrophic scars whereas M2 macrophages dominate in keloids and TNFα is present at low levels. The proliferative stage is similar in both scar types: VEGF, PDGF, and TGF-β are upregulated and M2 macrophages promote fibrosis by increasing fibroblast proliferation, myofibroblast differentiation, and collagen deposition. However, in keloids, HIF-1 is also upregulated and MMP-1 is downregulated. Both scar types have similar immunological phenotypes in the remodeling stage except keloids also demonstrate KALTs, more activated mature mast cells and Th2 cells, and their M2 macrophages promote fibrosis particularly strongly. Potential therapeutic targets for the two scar types are also listed

interactions by expressing ICAM1 (CD54) and CD40, which stimulates DC antigen-presenting activity.

The transition from the inflammatory stage to the proliferative stage is induced by macrophage secretion of PDGF, TGFβ, FGF, VEGF, and other growth factors, which causes fibroblasts to migrate and proliferate, and then engage in their most well-known activity, namely, their production of ECM. Most of the ECM production is conducted by the resident fibroblasts in the reticular dermis. The fibroblasts in the papillary dermis, which must regenerate, play a more minor role and only later in healing.

Fibroblasts also act during the proliferative stage to promote angiogenesis. This is mediated by their release of factors such as VEGF, FGF, angiopoietin (ANG)1, and thrombospondin (TSP) [19].

Fibroblasts also play key roles in the remodeling of the immature ECM during the last wound-healing stage. This is mediated by their fibroblast-to-myofibroblast transition and

their subsequent secretion of MMPs, which may be upregulated by chemokines such as MCP1 [20].

11.1.11 Myofibroblasts (Stage: Maturation and Remodeling)

Myofibroblasts differentiate from local fibroblasts. This is regulated by the TFGβ1 in the skin microenvironment [21]. These cells are potent producers of ECM molecules and also have powerful contractile properties that are important for contraction of the granulation tissue. Once tissue integrity is restored, myofibroblasts become inactive and some are killed by apoptosis by mechanisms that are as yet not fully understood [21].

11.1.12 Growth Factors, Cytokines, and Other Molecules (All Stages)

The above makes clear that much of wound healing is driven by cytokines and other small messengers that are secreted by tissue and immune cells, starting with the DAMPs and PAMPs that are released by the injured skin. Key molecules are: the pro-inflammatory cytokines IL-1β, TNFα, and IL-6, which are released by neutrophils, mast cells, and macrophages and attract inflammatory cells to the wound site; the growth factors PDFG and TGFβ, which are secreted by platelets and macrophages and attract proliferating fibroblasts to the wound bed; FGF2 (bFGF), keratinocyte-growth factor (KGF), FGF7, EGF, hepatocyte-growth factor (HGF), TGFα, and IGF1, which are produced by macrophages and active fibroblasts and stimulate epithelialization; and VEGF (and also PDGF), which are secreted by platelets, fibroblasts, keratinocytes, and macrophages and activate endothelial cells, thereby initiating angiogenesis [9].

11.2 Aberrant Wound Healing

Any disturbances in the interactions between the resident and immune cells in the wound bed can derange wound healing [22], which in turn can lead to hypertrophic scars or keloids. These cells are growing hard, red, and painful scars [23]. Moreover, since the affected skin lacks skin appendages such as hair follicles and sebaceous glands, the area is difficult to sweat and prone to severe itching and sweating that can significantly reduce patient quality of life. Hypertrophic scars and keloids have different clinical behaviors. Thus, hypertrophic scars grow only vertically, tend to respond well to treatment, and will resolve spontaneously over months or years, unless they are on joints. The latter reflects the key contribution of local mechanical factors to pathological scarring: repeated and/or strong pulling tension on the wound/scar may promote endothelial dysfunction, which helps establish the chronic inflammation that drives fibroblasts to lay down abundant ECM. Fibroblasts themselves are also highly sensitive to mechanical forces. By contrast, keloids grow both in the horizontal and vertical directions, are highly refractory to treatment and prone to recurrence, and never resolve spontaneously. This likely reflects the added contribution of genetics, as shown by familial and ethnic links to keloids (Fig. 11.1).

The mechanisms that drive hypertrophic and keloidal scarring are described below. They include prolonged inflammation, epithelialization dysregulation, excessive ECM deposition, and atypical ECM remodeling (Fig. 11.3) [23].

11.2.1 Hypertrophic Scars

Multiple studies suggest that hypertrophic scarring is driven by prolonged inflammation in the wound/scar bed [24], specifically the sustained production of the inflammatory cytokines IL-1 [25–27], IL-6 [23], IL-10 [27], and TNF-α [27], the growth factors TGF-β1 [26, 27], PDGF [25, 26], and VEGF; and the chemokine CCL2: when these factors remain elevated during the remodeling phase, the scar will demonstrate ongoing and excessive ECM deposition. The cells responsible for these elevated molecules include platelets, macrophages (particularly M2 macrophages), CD4+ T cells, resident Langerhans cells, and mast cells. As discussed above, the prolongation of inflammation may be driven by local mechanical tension on the wound/scar, which maintains the activation of mechanosensitive cells such as endothelial cells and fibroblasts (especially myofibroblasts). It has also been suggested that an inherently enhanced T-helper (Th)2 response to injury by CD4+ T cells and mast cells promotes hypertrophic scarring because it elevates local levels of TGF-β and the fibrogenic Th2 cytokines IL4 and IL10 [14]. The chemokine receptor CX3CR1 may also participate since studies have shown that downregulating it prevents hypertrophic scarring. Similarly, IL-1α and PDGF from Langerhans cells, macrophages, and platelets have been identified as molecular targets in pathological wound healing.

Hypertrophic scars are also characterized by excessive epidermal proliferation and migration. The resulting accelerated epithelialization may also promote hypertrophic scarring, possibly by interfering with dermal repair. This excessive epithelialization may be due to the early overproduction of IGF1 and FGF1 by Langerhans cells, which promote fibroblast proliferation and the recruitment of monocyte-derived macrophages [26]. Early keratinocyte-overproduction of CXCR2 (IL-8Rβ), which is an essential mediator of neutrophil chemotaxis, may also participate [26]. Indeed, manipulating neutrophil and macrophage num-

bers and the levels of their associated chemokines and receptors not only slows down the excessive epitheialization, it also prevents hypertrophic scarring.

11.2.2 Keloids

Keloids are nonmalignant but demonstrate unrelenting growth. Like hypertrophic scars, they display intense chronic inflammation and fibroblast proliferation and ECM deposition. Unlike in hypertrophic scars, these activities do not resolve spontaneously in keloids.

Keloid-derived fibroblasts, which are the most abundant cells in the lesion and are directly responsible for its growth, bear many differences from normal dermal fibroblasts: they produce large amounts of ECM, are highly proliferative, have different cytokine profiles, and express low levels of apoptosis-related genes (e.g. p53) and are resistant to apoptosis. It is likely that these features of keloid-derived fibroblasts are driven by the chronic inflammation in the scar, which is marked by four distinct features, as follows (*see* Fig. 11.3) [28].

First, keloids contain organized lymphoid aggregates that resemble those in tertiary-lymphoid tissue and mucosa-associated lymphoid tissue. They are called keloid-associated lymphoid tissues (KALTs) [27]. They are composed of M2 macrophages, fibroblasts, and activated Th2 and Th17 T cells, and their microvessel endothelia express the embryonic stem-cell markers OCT4, SOX2, pSTAT3, and NANOG [28]. These markers associate with the endothelial-mesenchymal transition of mesenchymal-stem cell intermediates, which produces abnormal fibroblasts and myofibroblasts. This transition may be driven by TGF-β1 [14]. The KALTs may thus play a vital role in keloid fibrosis. This suggests they could be immunotherapeutic targets. However, further research is needed.

Second, compared to normal skin, the mast cells in keloids are much more prone to degranulation and are more likely to be mature [28]. Mast cells have been strongly implicated in driving scar formation. In particular, they play a key role in the transition from scarless to fibrotic healing in fetal/neonatal humans and rodents. Activated mast cells may promote fibroblast activity by initiating the extracellular signal-regulated kinase 1 and 2 (ERK1/2) cascade and phosphatidylinositol-3-kinase (PI3K)/Akt signaling pathway, which promotes the accumulation of hypoxia-inducible facor (HIF)1α in keloid-fibroblast:mast-cell co-cultures [14]. These pathways may thus be potential therapeutic targets.

Third, the macrophages in keloids display some peculiarities. Specifically, M1 and M2 macrophages display altered major histocompatibility complex (MHC) II expression [28], and M2 macrophages produce elevated levels of the profibrotic molecules TGF-β, VEGF, connective-tissue growth factor (CTGF), and PDGF [14].

Fourth, while Th1 immune responses that promote inflammation are stimulated in normal wound healing, Th2 responses are upregulated during keloid formation [20]. Thus, IL-6, which promotes Th2 differentiation and inhibits Th1 differentiation, is upregulated in keloids along with IL-6-mediated responses. The latter involve the Janus kinase (JAK)/Stat3 transcription factor signaling pathway [29] and have been shown to promote keloid-fibroblast proliferation and ECM synthesis [23]. Moreover, keloids demonstrated upregulated signaling and responses to the Th2 cytokines IL-4/IL-13. In addition, compared to patients without keloids, a keloid patient demonstrated elevated IL-13 levels in both his keloid lesions and normal skin [30]. Thus, Th2-associated molecules may be therapeutic targets.

11.3 Conclusions

It is currently believed that chronic ongoing inflammation that involves many different cellular players and their factors during the wound-healing process plays a major role in abnormal scarring. Further studies are needed to identify the key cells and cytokines that could be targeted to prevent or ameliorate hypertrophic scars and keloids. While this objective is hindered by the lack of animal models of keloids, multifaceted analytical approaches, including omics, may help elucidate why the inflammatory stage does not resolve and thereby leads to the formation and progression of hypertrophic scars and keloids.

References

1. Bayat A, McGrouther DA, Ferguson MWJ. Skin scarring. BMJ. 2003;326:88–92.
2. Ogawa R, Dohi T, Tosa M, et.al. The latest strategy for keloid and hypertrophic scar prevention and treatment: the Nippon medical school protocol. J Nippon Med Sch 2021; 88(1):2–9.
3. Bakhtyar N, Amini-Nik S, Jeschke MG. OMICS approaches evaluating keloid and hypertrophic scars. Int J Inflam. 2022;2022:1–15.
4. Mohammadreza P, Ali F, Mohsen KM, Aziz G. Critical role of transforming growth factor Beta in different phases of wound healing. Adv Wound Care. 2013;2(5):215–24.
5. Montserrat FG, Maria LHB, Stefano B. Cellular and molecular Pprocesses in wound healing. Biomedicines. 2023;11:2526–47.
6. Bagabir R. Site-specific immunophenotyping of keloid disease demonstrates immune upregulation and the presence of lymphoid aggregates. Br J Dermatol. 2012;167:1053–66.
7. Brandt E., Peterse F., Ludwig A., et.al. The thromboglobulins and platelet factor 4: blood platelet derived CXC chemokines with divergent roles in early neutrophil regulation. J Leukoc Biol 2000; 67: 471–478.

8. Bacci S. Fine regulation during wound healing by mast cells, a physiological role not yet clarified. Int J Mol Sci. 2022 Feb;23(3):1820–31.
9. Tyavambiza C, Meyer M, Meyer S. Cellular and molecular events of wound healing and the potential of silver based Nanoformulations as wound healing agents. Bioengineering. 2022;9:712–29.
10. Yara A, Armand B, Laurence M. Cutaneous wound healing: a review about Iinnate immune response and current therapeutic applications. Mediat Inflamm. 2022:5344085:1–16.
11. Josh G, Stephan M, Curdin C. Plasmacytoid dendritic cells sense skin injury and promote wound healing through type I interferons. J Exp Med. 2010;207(13):2921–30.
12. Vinish M, Cui W, Stafford E, et al. Dendritic cells modulate burn wound healing by enhancing early proliferation. Wound Repair Regen. 2016;24(1):6–13.
13. Audrey N, Nicolas P, Hong-An T. Cutting edge: regulatory T cells facilitate cutaneous wound healing. J Immunol. 2016;196(5):2010–4.
14. Elvis BK, Maribanyana L, Jyoti RS, et al. Immune cells and associated molecular markers in dermal fibrosis with focus on raised cutaneous scars. Exp Dermatol. 2023;32:570–87.
15. Engelhard, E., Toksoy A., Goebeler M., et.al. Chemokines IL-8, GRO, MCP-1, IP-10, and Mig are sequentially and differentially expressed during phase-specific infiltration of leukocyte subsets in human wound healing. Am J Pathol 1998; 153: 1849–1860.
16. Qing C. The molecular biology in wound healing & non-healing wound. Chin J Traumatol. 2017;20(4):189–93.
17. Morbidelli L, Genah S, Cialdai F. Effect of microgravity on endothelial cell function, angiogenesis, and vessel remodeling during wound healing. Front Bioeng Biotechnol. 2021;9:1–15.
18. Richard J Bodnar, Latha Satish, Cecelia C Yates, et.al. Pericytes: a newly recognized player in wound healing. Wound Repair Regen 2016; 24(2): 204–214.
19. Pavlos Omorphos, N., Gao, C., Tan, S. S. et.al. Understanding angiogenesis and the role of angiogenic growth factors in the vascularisation of engineered tissues. Mol Biol Rep 2021; 48(1): 941–950.
20. Yamamoto T., Eckes B., Mauch C. et.al. Monocyte chemoattractant Protein-1 enhances gene expression and synthesis of matrix metalloproteinase-1 in human fibroblasts by an autocrine IL-1 loop. J Immunol 2000; 164: 6174–6179.
21. Monika P, Waiker P.V., Chandraprabha M.N, et.al. Myofibroblast progeny in wound biology and wound healing studies. Wound Repair Regen 2021; 29: 531–547.
22. Landén NX, Li D, Ståhle M. Transition from inflammation to proliferation: a critical step during wound healing. Cell Mol Life Sci. 2016;73(20):3861–85.
23. Tosa M, Ghazizadeh M, Shimizu H,et.al. Global gene expression analysis of keloid fibroblasts in response to electron beam irradiation reveals the involvement of interleukin-6 pathway. J Invest Dermatol2005; 124(4):704–713.
24. Ogawa R. Keloid and hypertrophic scars are the result of chronic inflammation in the reticular dermis. Int J Mol Sci. 2017;18(606):1–10.
25. Niessen FB, Andriessen MP, Schalkwijk J, et.al. Keratinocyte-derived growth factors play a role in the formation of hypertrophic scars. J Pathol 2001;194(2):207–216.
26. Krotzsch-Gomez FE, Furuzawa-Carballeda J, Reyes-Marquez R, et.al. Cytokine expression is downregulated by collagen-polyvinylpyrrolidone in hypertrophic scars. J Invest Dermatol 1998;111(5):828–834.
27. Armour A, Scott PG, Tredget EE. Cellular and molecular pathology of HTS: basis for treatment. Wound Repair Regen. 2007;15(S1):S6–S17.
28. Bagabir R, Byers RJ, Chaudhry IH, et al. Site-specific immunophenotyping of keloid disease demonstrates immune upregulation and the presence of lymphoid aggregates. Br J Dermatol. 2012;167(5):1053–66.
29. Ghazizadeh M, Tosa M, Shimizu H, et al. Functional implications of the IL-6 signaling pathway in keloid pathogenesis. J Invest Dermatol. 2007;127(1):98–105.
30. Diaz A, Tan K, He H, et al. Keloid lesions show increased IL-4/IL-13 signaling and respond to Th2-targeting dupilumab therapy. J Eur Acad Dermatol Venereol. 2019;34(4): e161–4.

Diagnosis, Assessment, and Classification of Scar Contractures

12

Rei Ogawa and Julian J. Pribaz

Keywords

Skin grafting · Free flap · Split thickness skin graft · Local flap · Entire circumference

12.1 Diagnosis of Post-Burn Scar Contractures

Since burn-scar contractures are often treated empirically, it is important to establish evidence-based treatment methods [1]. An important aspect of treating burn-scar contractures is differential diagnosis between ankylosis and contracture and between the contracture subtypes (Fig. 12.1). The term "ankylosis" refers to joint stiffness that is due to involvement of the deeper tissues, including the bone, cartilage, and joint capsule. It can vary from moderate to severe and may require orthopedic surgical release. By contrast, contracture refers to tightness of the soft tissues around a joint that limits movements. The soft tissue can be the muscles, whose contracture is generally due to neurological damage, or the connective tissue, which has been injured by wounding or burn. Consequently, before planning surgical reconstruction of connective-tissue contractures, myogenic/neurogenic contractures should be excluded. The connective-tissue contractures should then be subjected to differential diagnosis according to the anatomical structures that are affected. These include (a) cutaneous, subcutaneous, or fascial contracture; (b) tendon contracture; (c) ligament contracture; and (d) muscle contracture. Many burn-scar contractures can be classified as cutaneous/subcutaneous contractures. However, if tendon, ligament, and/or muscle contracture is diagnosed, surgeons should not only release the scar contractures, they should also consider replacing/reconstructing the other affected tissue(s) with various methods (Fig. 12.1). This chapter describes a body region-specific classification of the superficial-scar contractures that affect the cutaneous, subcutaneous, and/or fascial tissues.

R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

J. J. Pribaz
Department of Plastic & Reconstructive Surgery, University of South Florida, Tampa, FL, USA
e-mail: jpribaz@usf.edu

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_12

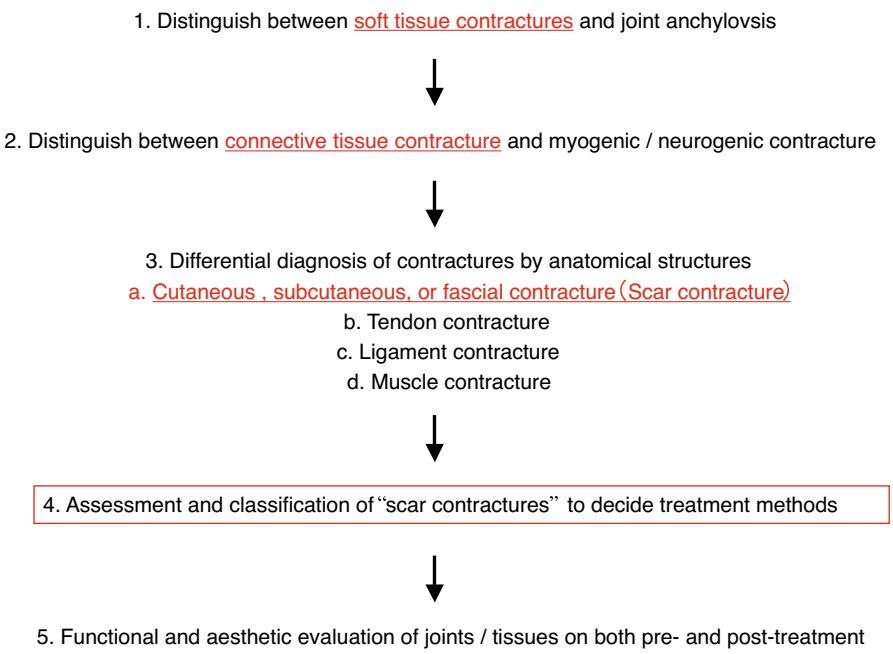


Fig. 12.1 Differential and exclusive diagnosis of post-burn scar contractures

12.2 Assessment and Classification of Post-Burn Contractures

Scar contractures are diagnosed when the patient has a scar that induces the abnormal resting position of an anatomical structure or prevents the joints and/or other tissues from moving normally. To determine how to treat scar contractures, it is important to carefully assess and classify them according to the affected site (Fig. 12.2). The shape and depth of the scars should be diagnosed pre- and/or intraoperatively. The relative success and complications of the selected method(s) should also be assessed post-operatively.

12.2.1 Periorbital Region (Fig. 12.3)

If the periorbital contracture is associated with mild dysfunction of eye closure over 3 months after burn injury (type I), it can be treated with a minimal incision that releases the contracture, followed by wound closure with local flaps. If the conjunctiva and middle lamella are intact but there is severe dysfunction of eye closure (type II), skin grafting should be used. Local flaps are also available for partial contracture (type IIa). With respect to skin grafting, split-thickness skin grafts (STSGs) have been used frequently for the mobile upper eyelids. By contrast, depending on the donor site, whose skin thickness can vary, slightly thicker STSGs or full-thickness skin grafts (FTSGs) have been employed for the lower lids [2, 3]. This practice reflects the thinner skin on the upper eyelid compared to the lower lid. While burns rarely result in complete eyelid loss, the conjunctiva and/or middle lamella can be damaged (type III). In this case, skin grafting or local/free flaps should be selected on a case-by-case basis depending on whether materials such as cartilage and fascia must also be transferred [4].

12.2.2 Perioral Region (Fig. 12.4)

Perioral contracture that results in mild dysfunction of mouth movements (type I) should be reconstructed with minimal scar release and with FTSGs, relatively thick STSGs, or local flaps. Contracture that induces severe dysfunction without commissure contracture (type II) should be reconstructed with FTSGs according to the aesthetic units/sub-units theory [5–7]. If the contractures are partial but the commissure is contractured (type IIIa), local flaps as well as FTSGs should be used to completely release the contracture and reconstruct the commissure. If the contracture is extensive and the commissure is also contractured (type IIIb), extensive release and reconstruction with flaps such as a pedicled regional flap, a free flap, or a prefabricated flap should be selected on a case-

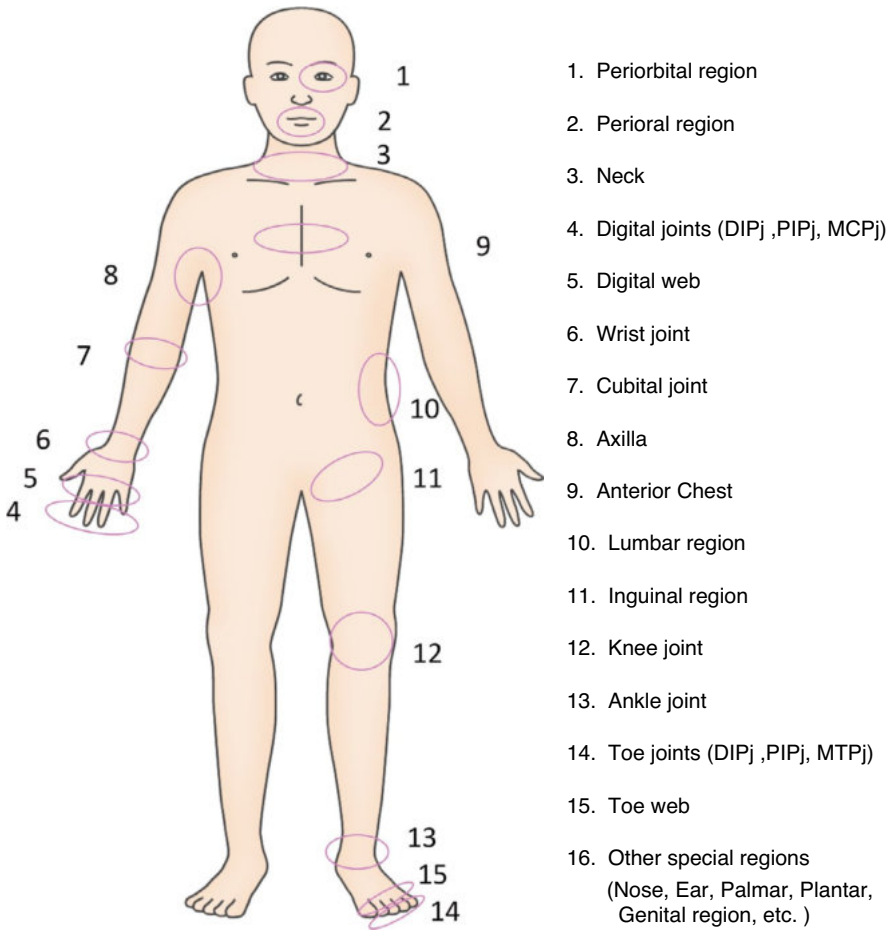


Fig. 12.2 Therapeutic-objective sites of post-burn scar contractures

by-case basis [8]. In the case of male patients, flaps harvested from the beard region can be used for beard and mustache reconstruction [6].

12.2.3 Chin and Anterior Neck (Fig. 12.5)

Short linear chin/anterior neck contractures (type I) can be released by using single z-plasty or small local flaps. However, long linear contractures that extend to the next unit (type II) should be reconstructed with multiple z-plasties, local flaps, or skin grafting. With respect to the skin grafting, FTSG should be selected to prevent re-contracture. Broadband contracture should be released completely and reconstructed with FTSGs or thin flaps. If the removal of scar tissue leaves wounds that have platysma at the base (type IIIa), FTSG can be selected. However, if the platysma is missing (type IIIb), thin flaps should be used. Thin flaps harvested from the chest [9] or dorsal region [10, 11], perforator flaps [12], and supraclavicular flaps [13] can be used. Broadband contractures that extend to the next units (type IV) should be reconstructed with a sheet of large and thin flap, such as the perforator-supercharged "super-thin flap." Whether the platysma muscle is preserved or not necessitates careful selection of the surgical technique. If the platysma cannot be preserved, it is advisable to use a thin skin flap.

12.2.4 Digital Joints (DIP, PIP, and MCP) (Fig. 12.6)

Short linear contractures on a digital joint (type I) can be released by a z-plasty or a small rotation or transposition local flap that is designed next to the contracture. However, long linear contractures with wide scars (type II) should be reconstructed with multiple z-plasties or skin grafting. Broadband contractures (type III) should generally be reconstructed with skin grafting, but a contracture that runs less than a quarter of the digital circumference (type IIIa) can be reconstructed by z-plasties or local flaps. In this case, flaps such as a digital artery flap or a metacarpal artery flap may be used. Contracture that involves the entire digital circumference (type V) can be treated by not only skin grafting but also distant abdominal or groin flaps [14].

Fig. 12.3 Periorbital region

Lower eyelid Type IIa

Lower eyelid Type IIb

* Upper eyelid and lower eyelid should be evaluated separately

I Contractures with mild dysfunction of eye closure

II Contractures with severe dysfunction of eye closure (with normal conjunctiva and middle lamella)

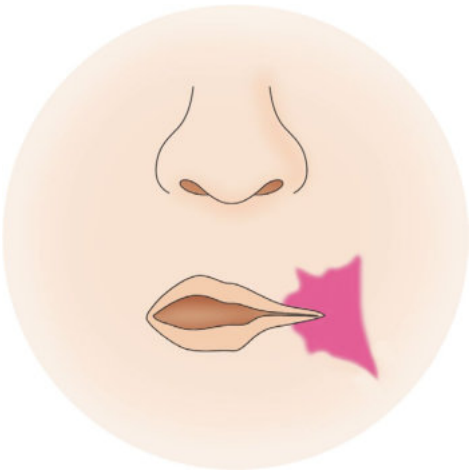
IIa Partial contractures

IIb Extensive contractures

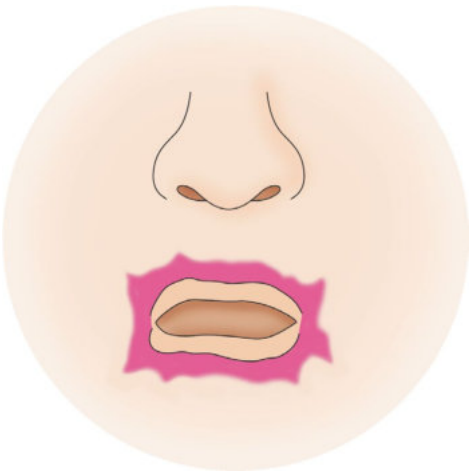
III Contractures with severe dysfunction of eye closure (with contracture of conjunctiva and/or middle lamella)

IV Unclassified

Fig. 12.4 Perioral region



Lower lip Type IIb



Uper / Lower lip Type IIIb

* Upper lip and lower lip should be evaluated separately

I Contractures with mild dysfunction of mouth movements

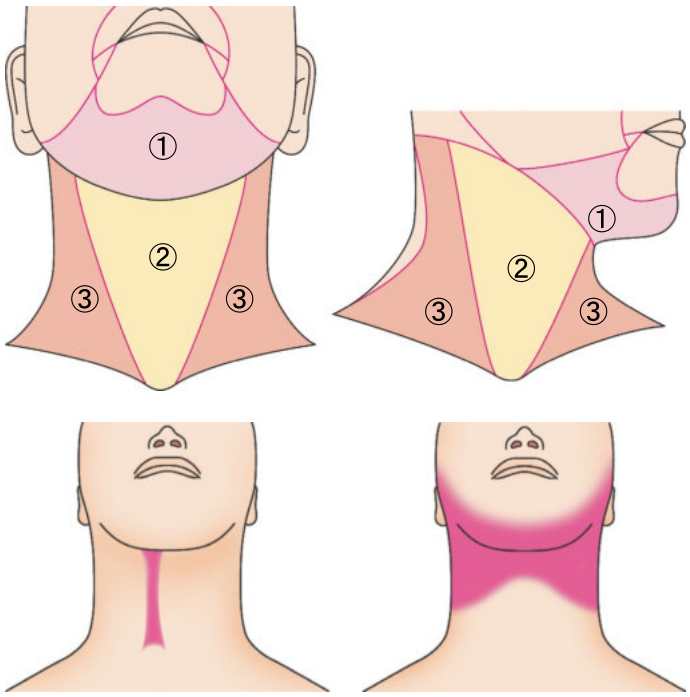
II Contractures with severe dysfunction of mouth movements (with normal commisure)

III Contractures with severe dysfunction of mouth movements (with contractures of commisure)

IIIa Partial contracture

IIIb Extensive contracture

IV Unclassified



Anterior neck
Type I

Mental-submental/Anterior neck
Type IV

* Mental-submental, anterior neck, and lateral neck on both sides should be evaluated separately

I Short linear contracture within the unit

II Long linear contracture extended to next unit

III Broadband contracture within the unit

IIIa not including platysma

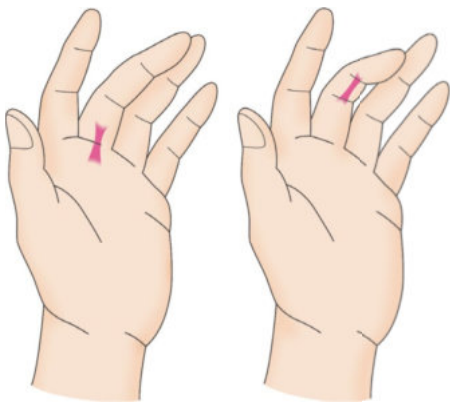
IIIb including platysma

IV Broadband contracture extended to next units

V Unclassified

Fig. 12.5 Chin and anterior neck

Fig. 12.6 Digital joints (DIP, PIP, and MCP)



MCPj
Type I

DIPj / PIPj
Type II

* DIPj, PIPj and MCPj should be evaluated separately

I Short linear contracture on one of joints

II Long linear contracture extended to next joint

III Broadband contracture

IIIa less than a quarter of circumferences

IIIb over a quarter of circumferences

IV Contractures of entire circumferences

V Unclassified

12.2.5 Digital Web (Fig. 12.7)

Single digital-web contractures (type I) should be reconstructed with a local flap such as a square flap [15, 16] that is based on the web or a five-flap z-plasty that is designed on the intact side. Contractures on both the palmar and dorsal regions (type II) can be reconstructed by skin grafting or a digital artery flap. If the web contracture severely affects adjacent digits (type III), the contracture should be completely released and reconstructed with skin grafting or a combination of flaps and skin grafting.

12.2.6 Wrist Joint (Fig. 12.8)

Linear contractures on the wrist joint (type I) should be excised completely and can be closed primarily with zig-zag sutures (e.g., z-plasty and w-plasty) that align with wrist creases. Broadband contracture on one surface (type II) should be reconstructed by skin grafting, but extensive contractures that extend to subsequent surfaces (type III) should be reconstructed with skin grafting or local flaps that are designed on intact surfaces. If the entire circumference of the wrist is affected by the contracture (type IV), skin grafting as well as flaps designed on the proximal forearm, distant abdominal or groin flaps, or free flaps can be used.

12.2.7 Cubital Fossa/Elbow Joint (Fig. 12.9)

Linear contracture of the cubital fossa/elbow (type I) should be excised completely and can be closed primarily with z-plasties or w-plasty to release tension. In cases where the patient has linear scar contractures on both the radial and ulnar surfaces (type Ib), the contractures can be released by propeller flaps that are designed on the cubital fossa. Broadband contracture on one surface (type IIa) should be reconstructed by skin grafting or local flaps designed on the intact surface [17]. However, if the broadband contracture affects both the radial and ulnar surfaces (type IIb), a propeller flap [18] that is designed on the cubital fossa can be used. Broadband contractures that extend to the next surfaces (type III) sometimes require vascular-pedicled, relatively large flaps that are harvested from the upper arm or forearm. In the case of contracture of the entire circumference of the cubital fossa/elbow region (type IV), flaps such as vascular-pedicled flaps or free flaps are useful for preventing re-contracture.

12.2.8 Axilla (Fig. 12.10)

Minor areas of contracture within the axillary area (type I) can be reconstructed with skin grafting. Single linear contractures (type II) can be released with a large z-plasty, multiple z-plasties, or other local flaps. However, this can result in division of the hair-bearing regions. A square flap that is designed on the intact surface is a good choice for these cases [19]. When there is a double linear contracture on both the anterior and posterior axillary lines (type IIIa), it can be reconstructed with a propeller flap that is designed on the center of the axilla; this releases the contracture at the same time. If a contracture is found between linear contractures (type IIIb), the entire contractured area should be excised and reconstructed with local or regional flaps from the chest or dorsal region. Broadband contracture over the axillary area (types IV and V) should also be reconstructed by regional flaps or free flaps.

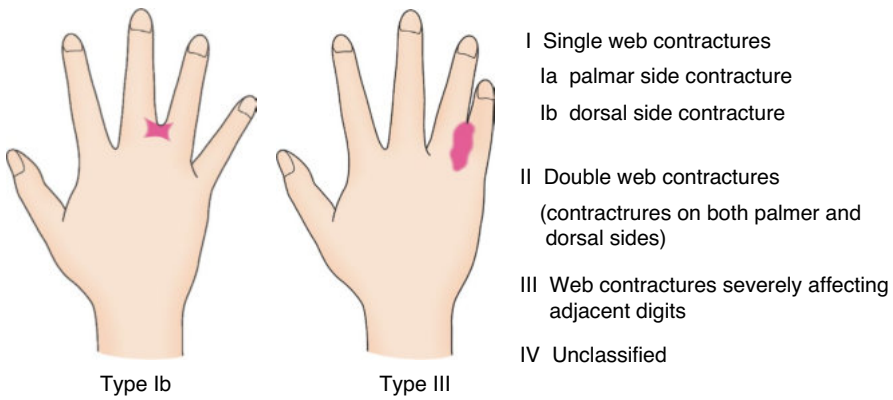


Fig. 12.7 Digital web

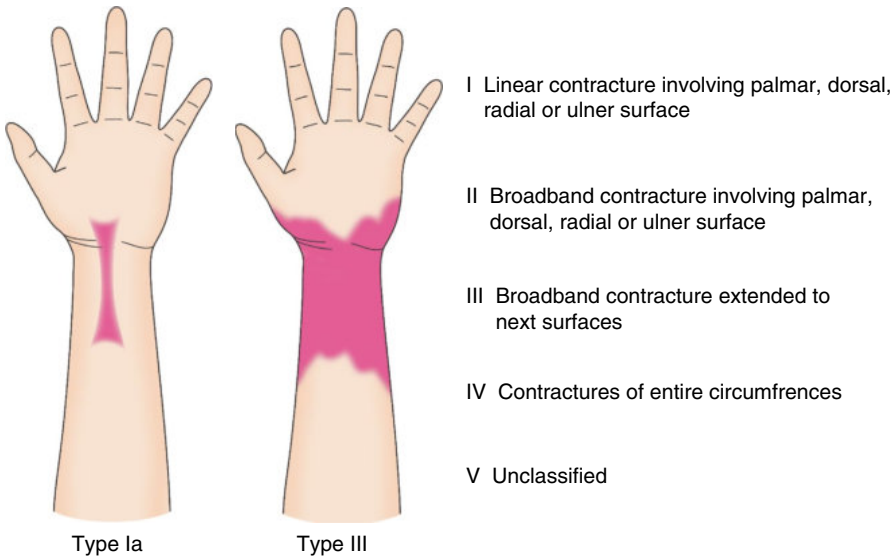


Fig. 12.8 Wrist joint

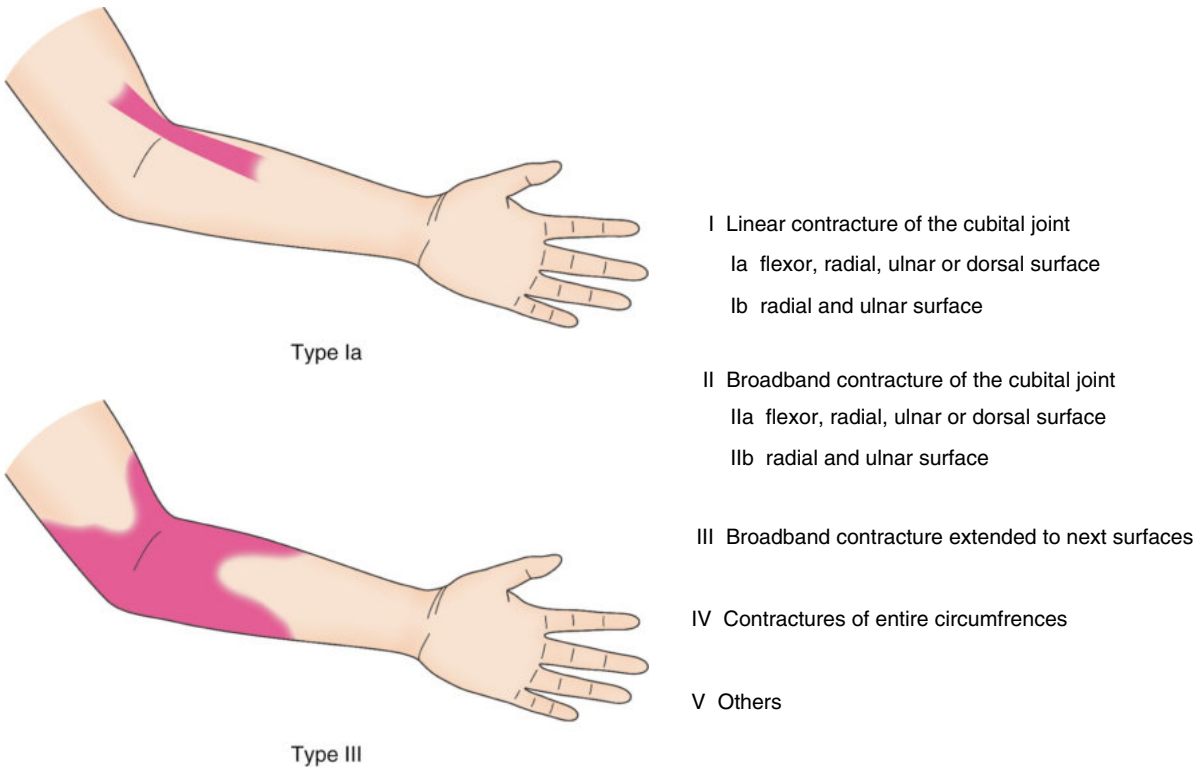
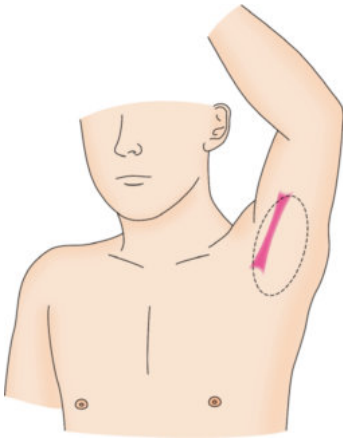
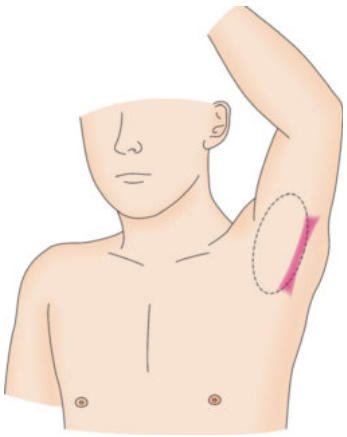


Fig. 12.9 Cubital Fossa/elbow joint

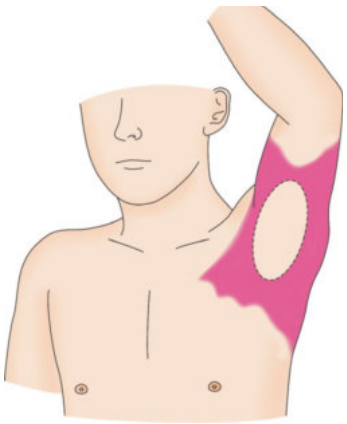
Fig. 12.10 Axilla



Type IIa



Type IIb



Type IIIa

I Minor area of contracture within the axillary area

II Single linear contractures

IIa anterior axillary line

IIb posterior axillary line

III Double linear contractures

IIIa Both anterior and posterior line with normal tissues between the lines

IIIb Both anterior and posterior line with contractures between the lines

IV Broadband contracture over the axillary area

IVa The contractures extended to the chest

IVb The contractures extended to the back

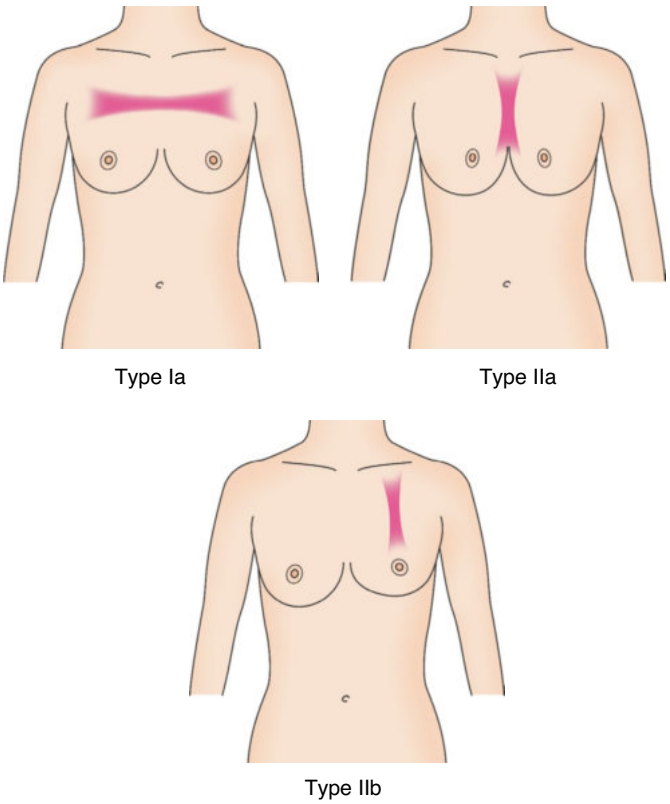
IVc The contractures extended to the upper arm

V Broadband contractures surrounded with scars

VI Others

12.2.9 Anterior Chest (Fig. 12.11)

Anterior chest contractures should be mainly reconstructed by skin grafting, although linear contractures can be reconstructed with z-plasty. In the case of a hemilateral contracture (types Ib and IIb), displacement of the nipple after skin grafting should be avoided. In the case of contractures with displacement of the nipple (types III and IV), the contracture should be released completely and reconstructed with an FTSG that is of adequate size and thickness to prevent recontracture. Very severe cases should be reconstructed with STSGs. In cases where breast reconstruction should also be conducted, it is necessary to consider methods such as pregrafting sufficiently thick skin beforehand and then using implants or considering immediate breast reconstruction using skin flaps.



I Contractures with no displacement of the nipple
- Ia Central contracture
- Ib Hemilateral contracture
- Ic Bilateral contracture

II Contractures with displacement of the nipple
- IIa Central contracture
- IIb Hemilateral contracture
- IIc Bilateral contracture

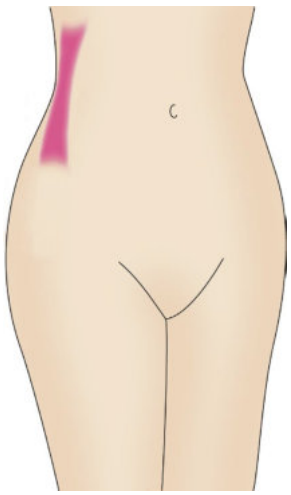
III Entire chest contractures with normal breathing

IV Entire chest contractures with breathing difficulty

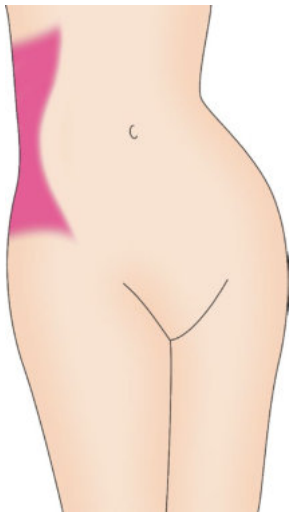
V Unclassified

Fig. 12.11 Anterior chest

Fig. 12.12 Lumbar region



Type I



Type III

* Right and left lumbar regions should be evaluated separately

I Linear contractures

II Broadband contractures without lateral curvature

IIa Minor broadband contractures within the luber region

IIb Major broadband contractures extended to other regions with no lateral curvature

III Broadband contractures with lateral curvature

IV Unclassified

12.2.10 Lumbar Region (Fig. 12.12)

Linear contractures on the lumbar region (type I) can be excised completely and closed primarily with z-plasties or w-plasty to release tension. However, broadband contractures (type II) should be reconstructed with skin grafting or local flaps harvested from the abdomen or dorsal area. If there is lateral curvature (type III), it is necessary to completely resect the scars and reconstruct them with a sufficiently large STSG.

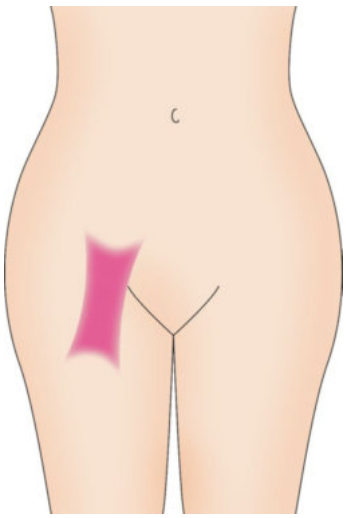
12.2.11 Inguinal Region (Fig. 12.13)

Linear contractures on the inguinal region (type I) can be excised completely and closed primarily with z-plasties or w-plasty to release tension. However, broadband contractures that compromise anterior thigh extension (type II) should be reconstructed with skin grafting or local flaps that are harvested from the abdomen or anterior thigh. Broadband contractures that are surrounded by scars (type III) should be reconstructed by using STSGs.

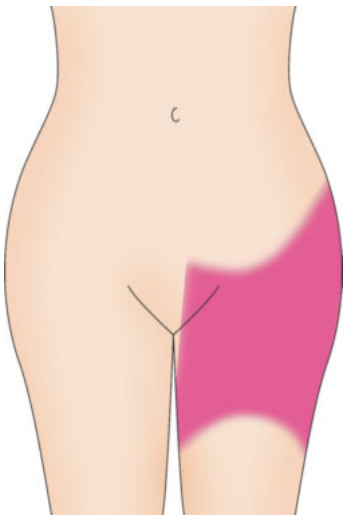
12.2.12 Knee Joint (Fig. 12.14)

Linear contractures on the knee joint (type Ia) should be excised completely and can be closed primarily with z-plasties or w-plasty to release tension. If the scar-excised wound cannot be closed primarily, local flaps should be designed. In cases where linear scar contractures are located on both the tibial and peroneal surfaces (type Ib), the contractures can be released by propeller flaps that are designed on the center of the posterior knee. Broadband contracture on one surface (type IIa) should be reconstructed with skin grafting or local flaps that are designed on the intact surface.

Fig. 12.13 Inguinal region



Type I



Type III

* Left side and right side should be evaluated separately

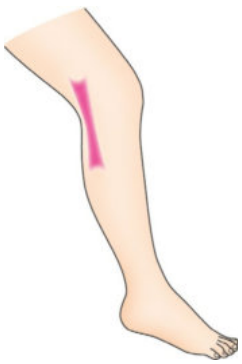
I Minor contractures with the normal anterior thigh extension

II Broadband contractures with difficulty of the anterior thigh extension

III Broadband contractures surrounded with scars

IV Unclassified

Type Ia



Type Ib

Type III

I Linear contracture on the knee joint
- Ia anterior, posterior, tibial or peroneal surface
- Ib tibial and peroneal surface

II Broadband contracture on the knee joint
- IIa anterior, posterior, tibial or peroneal surface
- IIb tibial and peroneal surface

III Broadband contracture extended to next surfaces

IV Broadband contracture of entire circumfrences

V Others

Fig. 12.14 Knee joint

Broadband contractures on both the tibial and peroneal surfaces (type IIb) can be reconstructed with propeller flaps that are designed on the popliteal fossa. Broadband contractures that extend to adjacent surfaces (type III) sometimes need vascular-pedicled relatively large flaps that are harvested from the thigh or lower leg. In the case of contracture of the entire circumference of the knee joint (type IV), flaps such as vascular-pedicled flaps or free flaps are useful to prevent re-contracture.

12.2.13 Ankle Joint (Fig. 12.15)

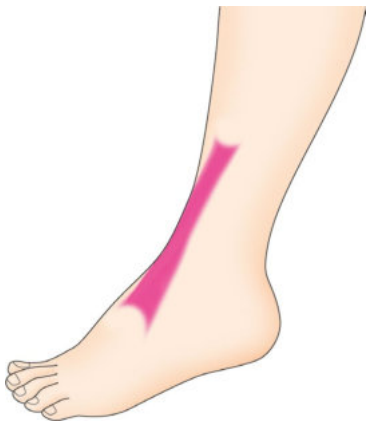
Linear contractures on the ankle joint (type I) should be excised completely and can be closed primarily with z-plasties and w-plasty [12] to release tension. If the scar-excised wound cannot be closed primarily, local flaps can be designed. Broadband contracture on one surface (type II) should be reconstructed with skin grafting. Extensive contractures that extend to adjacent surfaces (type III) should be reconstructed with skin grafting or local flaps that are designed on intact surfaces. In the case of contracture of the entire ankle circumference (type IV), skin grafting as well as flaps that are designed on the lower leg or free flaps can be used.

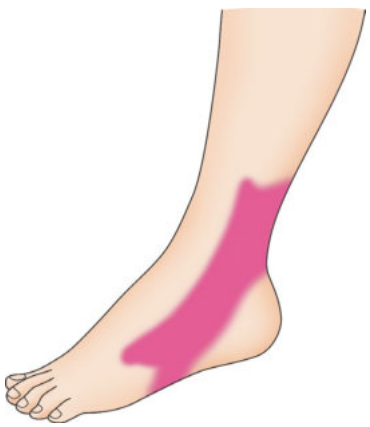
12.2.14 Toe Joints (DIP, PIP, and MTP) (Fig. 12.16)

Short linear contractures on toes (type I) can be released by a small rotation or transposition local flap or z-plasty that is designed next to the contracture. However, long linear contractures (type II) can be reconstructed with multiple z-plasties or skin grafting. Broadband contractures (type III) should be reconstructed by skin grafting. A contracture that is less than a quarter of the toe circumference (type IIIa) can be reconstructed with a local flap that is designed next to the digit. Contracture of the entire toe circumference (type V) should be treated by skin grafting.

12.2.15 Toe Web (Fig. 12.17)

Single toe-web contracture (type I) should be reconstructed with a local flap such as a square flap or a five flap z-plasty that are designed on the intact side. Contractures on both the plantar and dorsal regions (type II) should be reconstructed by skin grafting. If the web contracture is severely affecting the adjacent digits (type III), the contracture should be completely released and reconstructed with skin grafting.





I Linear contracture involving plantar, dorsal, tibial or peroneal surface

II Broadband contracture involving plantar, dorsal, tibial or peroneal surface

III Broadband contractures extended to next surfaces

IV Broadband contractures of entire circumfrences

V Unclassified

Fig. 12.15 Ankle joint

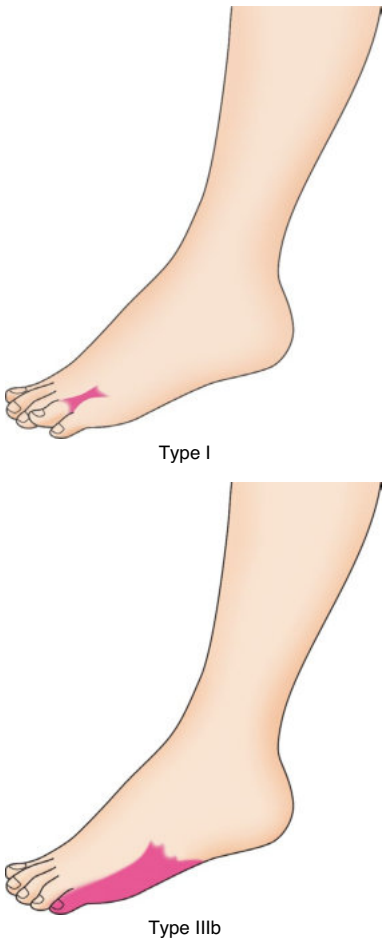


Fig. 12.16 Toe joints (DIP, PIP, and MTP)

* DIPj, PIPj and MTPj should be evaluated separately

I Short linear contracture on one of joints

II Long linear contracture extended to next joints

III Broad band contracture extended to next joints
IIIa less than a quarter of entire circumflerences
IIIb over a quarter of entire circumflerences

V Major contractures of entire circumfrences

VI Unclassified

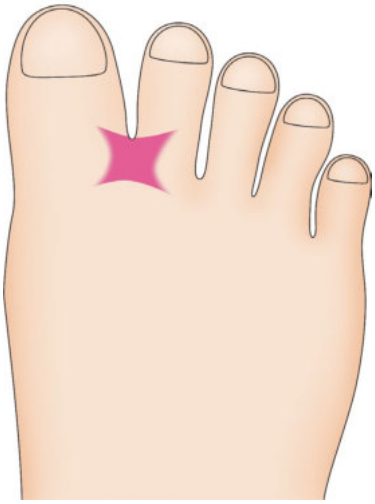
12.2.16 Other Special Regions (Nose, Ear, Genital Regions, etc.) (Table 12.1)

Other regions should be evaluated with regard to the degree of cosmetic and functional dysfunction and the size and depth of the tissue defects. From a cosmetic perspective, it is preferable to choose local flaps, FTSGs, and STSGs, in that order. In terms of restoring function, skin-pedicled local flaps are the first choice. Depending on the case, it is advisable to use FTSGs or flaps [19] (Fig. 12.18).

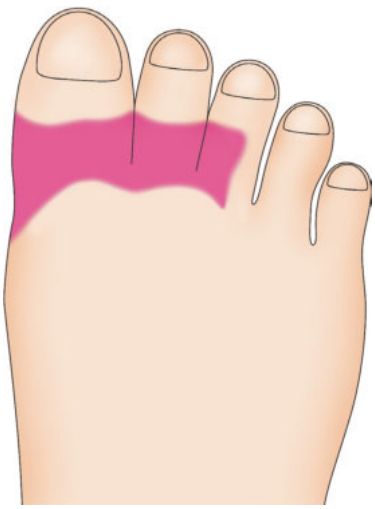
Table 12.1 Other special regions (nose, ear, genital regions, etc.)

I	Cosmetic dysfunction with no major tissue defects
II	Cosmetic dysfunction with major tissue defects
III	Cosmetic and functional abnormality with no major tissue defects
IV	Cosmetic and functional abnormality with major tissue defects
V	Unclassified

Fig. 12.17 Toe web



Type Ib



Type III

I Single web contractures

Ia plantar side contracture

Ib dorsal side contracture

II Double web contractures

(contractrures on both planter and dorsal sides)

III Web contractures severely involved with next toes

IV Unclassified

I Cosmetic dysfunction with no major tissue defects

II Cosmetic dysfunction with major tissue defects

III Cosmetic and functional abnormality with no major tissue defects

IV Cosmetic and functional abnormality with major tissue defects

V Unclassified

Fig. 12.18 Special regions

References

1. Stekelenburg CM, Marck RE, Tuinebreijer WE, de Vet HC, Ogawa R, van Zuijlen PP. A systematic review on burn scar contracture treatment: searching for evidence. J Burn Care Res. 2015;36(3):e153–61.
2. Mandrekas AD, Zambacos GJ, Anastasopoulos A. Treatment of bilateral severe eyelid burns with skin grafts: an odyssey. Burns. 2002;28:80–6.
3. Orgill DP, Ogawa R. Current methods of burn reconstruction. Plast Reconstr Surg. 2013;131(5):827e–36e.
4. Gonzarez-Ulloa M, Castillo A, Stevens E, Alvarez FG, Leonelli F, Ubaldo F. Preliminary study of the total restoration of the facial skin. Plast Reconstr Surg. 1954;13:151–61.
5. Gonzarez-Ulloa M. Restoration of the face covering by means of selected skin in regional aesthetic units. Br J Plast Surg. 1956;9:212–21.
6. Gonzarez-Ulloa M, Stevens E. Reconstruction of the nose and forehead by means of regional aesthetic units. Br J Plast Surg. 1961;13:305–9.
7. Gonzalez-Ulloa M. Regional aesthetic units of the face. Plast Reconstr Surg. 1987;79:489–90.
8. Ogawa R, Ono S, Hyakusoku H, Rennekampff HO. A case of upper lip and moustache reconstruction using a submental artery perforator (SMAP) flap. Eur J Plast Surg. 2008;31:33–5.
9. Kondo A, Dohi T, Izumi N, Ochi T, Ogawa R. Anterior neck-scar contracture reconstruction using a long skin-pedicled flap.
10. Hyakusoku H, Gao JH. The "super-thin" flap. Br J Plast Surg. 1994;47(7):457–64.
11. Ogawa R, Hyakusoku H, Murakami M. Color Doppler ultrasonography in the planning of microvascular augmented "super-thin" flaps. Plast Reconstr Surg. 2003;112(3):822–8.
12. Mun GH, Jeon BJ, Lim SY, Hyon WS, Bang SI, Oh KS. Reconstruction of postburn neck contractures using free thin thoracodorsal artery perforator flaps with cervicoplasty. Plast Reconstr Surg. 2007;120(6):1524–32.
13. Vinh VQ, Ogawa R, Van Anh T, Hyakusoku H. Reconstruction of neck scar contractures using supraclavicular flaps: retrospective study of 30 cases. Plast Reconstr Surg. 2007;119(1):130–5.
14. Winspur I. Distant flaps. Hand Clin. 1985;1(4):729–39.
15. Hyakusoku H, Fumiiri M. The square flap method. Br J Plast Surg. 1987;40(1):40–6.
16. Huang C, Ogawa R. Three-dimensional reconstruction of scar contracture-bearing axilla and digital webs using the square flap method. Plast Reconstr Surg Glob Open. 2014;2(5):e149.
17. Ogawa R. Surgery for scar revision and reduction: from primary closure to flap surgery. Burns Trauma. 2019;7:7.
18. Hyakusoku H, Yamamoto T, Fumiiri M. The propeller flap method. Br J Plast Surg. 1991;44(1):53–4.
19. Yoshino Y, Kubomura K, Ueda H, Tsuge T, Ogawa R. Extension of flaps associated with burn scar reconstruction: a key difference between Island and skin-pedicled flaps. Burns. 2018;44(3):683–91.

Scar Assessment Scales

13

Whitney Laurel Quong, Hajime Matsumura, and Rei Ogawa

Keywords

Scar assessment · Scar evaluation · Measurement · Patient-reported outcome measures · Clinician-reported outcome measures · SCAR-Q · Vancouver Scar Scale

Scars are a heterogeneous entity, with varying appearances, associated symptoms, and psychosocial impacts specific to the person who carries them. Scars also change over time due to the normal maturation process, abnormal inflammation, repeat trauma, or as a result of therapeutic intervention. Systematic evaluation of scars is therefore necessary to document scar status and track changes over time, while also facilitating communication between healthcare providers and allowing for comparisons between scars/patients. Many scar assessment tools have been developed to fulfill these needs.

Scar assessment tools should be clinically relevant, valid, reliable, responsive, feasible, and interpretable in order to be useful. Not all tools, however, have been developed with such rigorous standards in mind. In general, scar assessment tools can be divided into clinician-reported outcome measures (CROMs) and patient-reported outcome measures (PROMs). Both CROMs and PROMs have a role in scar assessment and can be used concurrently in routine scar care. Likely the most applied CROM is the Vancouver Scar Scale, while the most rigorously developed PROM is the SCAR-Q. Many other scar assessment tools exist, each with their own strengths and disadvantages. Thus, in choosing a scar assessment tool, its limitations must be understood, and it should be applied properly to its intended target population. Ultimately, different assessment tools may be preferable for different scar applications, and the co-existence of many different measurement instruments merely reflects the heterogeneity of scars as a unique entity.

W. L. Quong (✉) · R. Ogawa
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: whitney.quong@mail.utoronto.ca; r.ogawa@nms.ac.jp

H. Matsumura
Department of Plastic and Reconstructive Surgery, Tokyo Medical University, Tokyo, Japan
e-mail: hmatsu@tokyo-med.ac.jp

13.1 The Importance of Scar Assessment

Scars are the lasting result of dermal injury. Yet, despite a common pathobiological origin, scars are considerably heterogeneous, and evolve over time. Every scar has a unique appearance, physical texture, and impact specific to the person who carries it. This impact may be functional and associated with physical symptoms, as well as psychological, emotional, and mental ones. Systematically accounting for this heterogeneity is therefore necessary, and scar assessment tools have been developed for these indications.

Firstly, scar assessment tools, or instruments, succinctly summarize or describe a scar at a point in time. The output may be used to differentiate a good/optimal scar versus a poor/suboptimal scar. From these results, scale outputs can then be used to compare scars over time (to assess change) or between patients (to evaluate outcomes of different treatments), for example. Standardized assessment also simplifies communication between scar care providers, ensuring a common understanding of the scar and facilitating continuity of care. In acknowledging the uniqueness of scars, along with the needs of documentation, standardized measurement, differentiation, comparison, and communication, the importance of scar assessment becomes self-evident.

13.2 Defining Useful Scar Assessment Scales

To be useful and meaningful, a scar assessment tool should be:

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_13

- Rigorously developed: The tool should be developed in a multi-phase approach, involving initial conceptualization and development, modification, field-testing, and refinement. Throughout development, relevant stakeholders (clinicians, patients, other users) should be involved. Their input should be accounted for, and subsequent iterations of the tool should reflect this feedback.
- Clinically relevant: The tool should include items that are important to clinicians, patients, researchers, and other stakeholders, and reflect the scar construct (*content validity*) [1].
- Valid: Meaningful data depends on the assessment tool appearing to measure what it purports to (*face validity*), as well as actually measuring the construct of interest (*construct validity*) [2].
- Reliable: The tool must produce consistent results. These results should be similar between raters (*inter-rater reliability*) and subsequent evaluations by the same rater (*intra-rater reliability*). Repeat evaluations should also yield the same results (*test-retest reliability*) [3].
- Responsive: To be used to evaluate treatment-related or temporal change, the instrument must be able to reliably detect change when it has occurred (*responsiveness*) [4].
- Feasible: The tool should be succinct and practical to complete without too much burden on the clinician or patient. Ideally the instrument should be completable without any additional equipment or specialized hardware.
- Interpretable: The instrument must produce a metric that is easy to understand and communicate. Ideally, the output should also be understandable in comparison to a reference set of values or accepted norms.

Relevant clinimetric properties have been italicized. The COnsensus-based Standards for the selection of health Measurement Instruments (COSMIN) checklist [3] comprehensively outlines the preferred psychometric properties for health-related outcome instruments and requirements to evaluate such properties, as well as study design requirements and preferred statistical methods to do so.

13.3 Types of Scar Assessment Scales

Many scar assessment tools exist, and they can be broadly categorized based on whether they are completed by the scar care provider or the patient—known as clinician-reported outcome measures (CROMs) and patient-reported outcome measures (PROMs), respectively. This chapter provides an overview of the more commonly used scales and those that were designed to be used for burn scars, but it is not intended to be a comprehensive discussion of all available scales. Such reviews can be found elsewhere [5–10].

13.3.1 Clinician-Reported Outcome Measures

The first scar assessment scales were an attempt to objectify and quantitatively describe scars and largely fall into the CROM category. In fact, overall, most scar assessment tools are CROMs. While somewhat variable between instruments, the scar parameters of color (vascularization, pigmentation), thickness (height—clinical or histological), relief (surface texture/irregularity), pliability (elasticity), and surface area (scar contraction or expansion) are commonly included in most CROMs.

13.3.1.1 Vancouver Scar Scale (VSS)

The most commonly used scar evaluation tool is the VSS and modified versions of it. The VSS was originally described in 1990 by Sullivan and includes the parameters of pigmentation, vascularity, pliability, and scar height [11]. An ordinal value is assigned to each parameter (accompanied by a description to assist the rater), and the values are summed to produce a total score. Scores generally range from 0 to 14, where 14 represents the worst scar outcome/most severe scar. While originally developed for burn scars, the VSS has been applied extensively to assess scars of various etiologies, particularly in studies evaluating treatment effectiveness [5].

The VSS is particularly favored for its relative ease of use and low time to completion. However, this simplicity may sacrifice comprehensiveness, and the nuances within large scars that are irregular with mixed thickness/pliability/color, can be lost. Furthermore, the VSS has been criticized for its low inter-rater reliability/agreement and for being prone to operator-dependent error [12]. This observation is likely a consequence of the parameters being inherently subjective. To mitigate this, it has been suggested that at least three raters are used for each VSS scar assessment. The VSS's validity has also been questioned, with frequent modifications [13] complicating the ability to assess this clinimetric property (Fig. 13.1).

13.3.1.2 Visual Analog Scale (VAS)

The VAS is a broadly applicable tool used to measure respondent opinions about a target construct and has been applied to evaluate scars of various types in numerous applications [5, 14]. In essence, the VAS is a line where one end is marked with a score of 0 and one end is marked with a score of 10. These values are typically accompanied by descriptors, for example, "normal skin" and "poor scar" [14], respectively, or "worst scar," and "best scar" [15], respectively. The continuum of scores between these ends denotes the range of scar quality. The rater simply marks their perception of the scar's appearance at any point along the line. The VAS is the most straightforward and easy-to-use scar assessment tool. While the VAS can be used to evaluate a patient's own

Scar Characteristic		Score
Vascularity		
Normal	0	
Pink	1	
Red	2	
Purple	3	
Pigmentation		
Normal	0	
Hypopigmentation	1	
Mixed	2	
Hyperpigmentation	3	
Pliability		
Normal	0	
Supple – *flexible with minimal resistance*	1	
Yielding – *giving way to pressure*	2	
Firm – *inflexible, not easily moved*	3	
Banding – *rope-like tissue that blanches with extension of scar*	4	
Contracture – *permanent shortening of scar, producing deformity*	5	
Height		
Flat	0	
<2 mm	1	
2-5 mm	2	
>5 mm	3	
	Total /14	

Fig. 13.1 The Vancouver Scar Scale is the most frequently used scar assessment scale and is a clinician-reported outcome measure. A frequently used modified version is shown. Higher scores reflect more severe scars

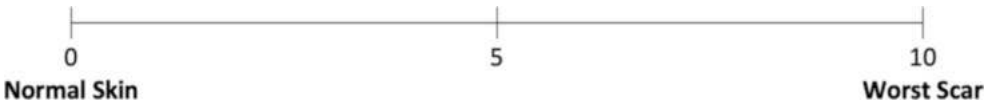


Fig. 13.2 A conceptual version of the Visual Analog Scale for scar rating. The rater (clinician or patient) is instructed to mark any point along the line to denote their perception of the scar based on the descriptors given

perception of their scar, it is more typically applied by an observer (i.e., clinician) to assess patient scars.

Although rudimentary, the VAS demonstrates good validity, correlating with pigmentation, vascularity, observer comfort, and acceptability [16], as well as color, radiance, contour, distortion, and texture [17]. The VAS also demonstrates high inter-rater reliability among plastic surgeons. However, like the VSS, the VAS's simplicity compromises its ability to account for scar nuances and may therefore be more suitable as an initial appearance evaluation tool as opposed to a comprehensive scar metric (Fig. 13.2).

13.3.1.3 Manchester Scar Scale (MSS)

The MSS was described by Beausang in 1998 and was designed to be applicable to a wide range of scars [17]. The instrument is comprised of two components: an overall VAS score of the scar appearance (from 0 to 10) and a scoring of five scar attributes (from 0–4; color, radiance, contour, distortion, and texture). The values are summed, with higher totals reflecting more clinically severe scar outcomes. The MSS is easy to use and quick to administer.

By combining a VAS with attributes of the VSS, the MSS is more nuanced. The tool has been shown to correlate well with histologic scar characteristics [17]—thereby pointing to its validity—while inter-rater reliability is also high for the total score [7]. However, despite robust clinimetric features, the MSS has been only rarely used in research, with the VSS being vastly more popular [5].

13.3.1.4 Matching Assessment of Photographs and Scars (MAPS)

With a focus on optimizing inter-rater reliability, Yeong proposed a burn-specific scar assessment scale (the Seattle Scale) that included scar surface, thickness, border height, and color parameters [18]. Pigmentation was added by Masters subsequently [19]. The modification also included a

set of usage instructions, standardized recording sheets, selected reference photographs (suitable for visual matching that demonstrated different severity scars), and a novel method of localizing specific scar sites to produce the manual Matching Assessment of Scars and Photographs (MAPS) for assessing long-term changes in burn scars [19]. Inter-rater reliability was good for border height, thickness, and color, but only fair for surface. The design of the numeric scales allows for negative values to be assigned to the scar parameters, however, and therefore significantly complicates the interpretability, feasibility, and usability of the MAPS tool.

13.3.2 Patient-Reported Outcome Measures

From the patient's point of view, their scar may be the only visible reminder of a trauma, burn, or surgery. Overall coping with an event, or satisfaction with a procedure, can therefore largely be dictated by their thoughts and feelings related to the scar. Such cosmetic concerns, associated symptoms and functional effects, and the psychosocial/emotional impact can only be gleaned from direct reports by the patient. Ideally, this information is recorded without reinterpretation by the clinician. Scar-specific PROMs have been developed to facilitate this process and systematically account for the patient perspective in scar assessment.

13.3.2.1 SCAR-Q

The SCAR-Q [20–22] is a PROM for scars and was designed to account for the scar experience of any person at least 8 years of age with a scar of any type. The SCAR-Q is comprised of three different scales—an Appearance Scale, a Symptom Scale, and a Psychosocial Impact Scale. The Appearance and Symptom scales are comprised of 12 questions each, while the Psychosocial Impact Scale has five questions. Each scale is scored from 0 to 100, where 100 represents the best scar outcome from the patient's point of view. Along with English, the SCAR-Q is currently available in 11 translations, including Arabic, Chinese, French, Japanese, and Spanish.

In addition to its broad target population (all scar etiologies, both adult and pediatric patients), the SCAR-Q is particularly notable for having been iteratively developed according to rigorous standards, including Rasch Analysis [22, 23]. This process first involved extracting relevant scar concepts (as direct patient quotes) from qualitative datasets of adult surgical groups and pediatric patients with facial differences. Data were then compiled and coded to develop a conceptual framework covering relevant patient-reported outcomes for scars and to populate a set of scales spanning three themes: appearance, scar symptoms, and quality of life impact. From this, a preliminary SCAR-Q was developed. Forty-five cognitive interviews were then completed to further refine the instrument in three scar samples, including burns, trauma, and surgery. Expert opinion was sought in order to ensure that the instrument was clinically relevant [22]. The preliminary instrument was subsequently field-tested in a heterogeneous scar population of 731 scar patients internationally [21]. The data were used to further refine the instrument to its current form. Test-retest reliability was high, and correlation between the SCAR-Q and the POSAS also pointed to its validity. Studies are currently ongoing to evaluate the responsiveness and minimally clinically important difference (MCID) of the SCAR-Q, as well as to define a set of reference values.

13.3.2.2 Patient-Reported Impact of Scars Measure (PRISM)

Developed in 2010 by Brown, the PRISM is a 37-item instrument for measuring quality of life and physical symptoms of patients with scars of various types [24]. The tool has two domains: psychosocial well-being (24 items), and symptoms (13 items). All items are answered as "true," or "not-true." The PRISM was developed through a multi-phase process, centering on interviews with both patients and experts, and underwent a rigorous psychometric (Rasch) analysis [23]. The tool demonstrates good internal consistency and test-retest reliability. However, the tool's symptom component is subject to a floor effect, with 26.7% of patients reporting minimal symptoms. Overall, the PRISM has also been criticized for lacking an appearance domain.

13.3.2.3 Burn-Specific Health Scale (BSHS)

The BSHS is a 114-item scale that quantifies dysfunction and distress across six domains following burn injuries. As one of the only tools designed specifically for burn survivors, it has been used widely and adapted across different cultural contexts [25–28]. It is not, however, specifically focused on scar outcomes (with only a few items related to the functional impact of the burn scar) and has been criticized for its length and low feasibility. A brief version of the scale (BSHS-B) [29] has therefore been developed and is more commonly used.

13.3.2.4 Brisbane Burn Scar Impact Profile (BBSIP)

The BBSIP was developed in 2013 to assess the scar-specific health-related quality of life in patients with burn scars. The BBSIP underwent a rigorous development process including

semi-structured interviews, content validation surveys, and cognitive interviews to establish and refine the instrument [30]. The BBSIP is available in four versions—adult, children 8–18 years of age, caregivers of children less than 8 years of age, and caregivers of children 8 years of age or older. The BBSIP$^{0-8}$ is the only mentioned PROM that attempts to evaluate this population—albeit through proxy report—and has been shown to have good longitudinal validity [30].

13.3.3 Patient and Observer Scar Assessment Scale (POSAS)

The POSAS [31] has two distinct components, the patient scale (PSAS) and the observer scale (OSAS), and therefore straddles the PROM/CROM dichotomy. Developed in 2004, version 2.0 of the scale was, in fact, the first to incorporate both the patient and clinician viewpoint [31]. At the time, the authors believed that no scar scale had been shown to have adequate reliability, consistency, validity, as well as feasibility. Furthermore, the authors acknowledged that while increasing the number of scar raters would improve instrument reliability, this is generally not feasible in the clinical setting. Attaching weight to the patient opinion addresses this reliability issue encountered by other tools.

The patient scale includes six items (pain, itching, color, stiffness, thickness, and irregularity), while the observer scale scores six parameters (vascularization, pigmentation, thickness, relief, pliability, and surface area). Each item is rated on a 10-point ordinal scale, where 1 signifies "normal skin," and 10 denotes the "worst scar imaginable." Higher summed scores indicate worse scars. Overall, the POSAS version 2.0 has also demonstrated robust clinimetric properties, with high internal consistency, acceptable inter-rater reliability, and validity of the patient component. Furthermore, compared to the VSS, the POSAS has been found to be more consistent, reliable, and feasible. Among more recent reviews, the POSAS has been the most commonly used scar assessment scale [5]. Despite its strengths and popularity, however, the POSAS is still limited in its ability to capture the scar's quality of life implications. In fact, the PSAS was not developed with any patient input or review. The tool's relevance/validity is therefore uncertain, and implementation of the scale may therefore be limited. An updated version of the POSAS (version 3.0) has been recently developed and made available for use in acknowledgement of some of its limitations. However, there are numerous differences with the more widely used version 2.0, and little is known about its clinimetric properties and performance given its relative newness (Fig. 13.3).

13.3.4 Japan Scar Workshop (JSW) Scar Scale (JSS)

The JSS was first described in 2011 and subsequently modified in 2015 [32, 33]. Uniquely, the scale was developed to differentiate between mature, hypertrophic, and keloid scars and evaluate their response to therapy. The JSS consists of two tables—a classification table and an evaluation table. The classification table is used to differentiate between keloid and hypertrophic scars and itself has two parts—a six-item risk factor assessment and a six-item present symptom evaluation. Each item on the table has 2–3 categories, accompanied by values from 0 to 2. The values are summed, with total scores from 0 to 5, indicating a mature scar, 6–15 denoting a hypertrophic scar, and 16–25 signifying a likely keloid scar. The evaluation table has 6 items—induration, elevation, scar redness, surrounding erythema, spontaneous and pressing pain, and itch. Each item is rated on an ordinal scale from 0 to 3 (none to strong). The six items are summed, with higher totals reflecting more severe scars. The evaluation table is intended to be used to track scar change over time, with symptom improvement denoted by decreasing scores.

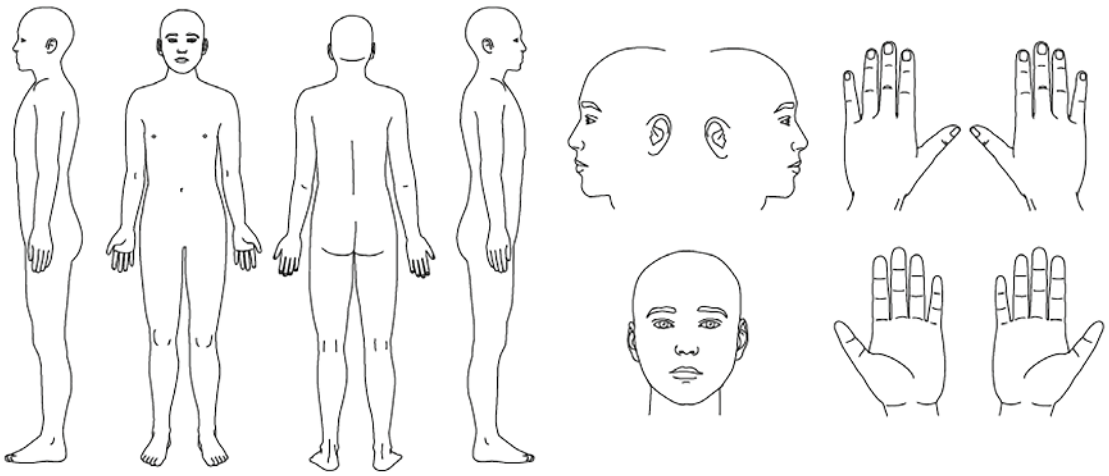
By accounting for some scar symptoms that can only be gleaned from the patient, the JSS has some features of a PROM. It is, however, largely more similar to a CROM, with the clinician tasked with completing both tables. The JSS has been used in a small number of studies in Japan and one in Taiwan [34], but has been relatively underutilized in comparison to other instruments. The developers acknowledge that further region-specific modifications may be necessary to facilitate its broader application [32]. The tool may also benefit from dedicated evaluation of its clinimetric properties as well (Figs. 13.4, 13.5, and 13.6).

a

POSAS Observer scale

The Patient and Observer Scar Assessment Scale v2.0 / EN

Date of examination:	**Name of patient:**
Observer:	
Location:	**Date of birth:**
Research / study:	**Identification number:**



1 = normal skin — worst scar imaginable = 10

PARAMETER	1	2	3	4	5	6	7	8	9	10	CATEGORY
VASCULARITY	○	○	○	○	○	○	○	○	○	○	PALE | PINK | RED | PURPLE | MIX
PIGMENTATION	○	○	○	○	○	○	○	○	○	○	HYPO | HYPER | MIX
THICKNESS	○	○	○	○	○	○	○	○	○	○	THICKER | THINNER
RELIEF	○	○	○	○	○	○	○	○	○	○	MORE | LESS | MIX
PLIABILITY	○	○	○	○	○	○	○	○	○	○	SUPPLE | STIFF | MIX
SURFACE AREA	○	○	○	○	○	○	○	○	○	○	EXPANSION | CONTRACTION | MIX
OVERALL OPINION	○	○	○	○	○	○	○	○	○	○	

Explanation

The observer scale of the POSAS consists of six items (vascularity, pigmentation, thickness, relief, pliability and surface area).
All items are scored on a scale ranging from 1 ('like normal skin') to 10 ('worst scar imaginable').
The sum of the six items results in a total score of the POSAS observer scale. Categories boxes are added for each item. Furthermore, an overall opinion is scored on a scale ranging from 1 to 10.
All parameters should preferably be compared to normal skin on a comparable anatomic location.

Explanatory notes on the items:

- VASCULARITY Presence of vessels in scar tissue assessed by the amount of redness, tested by the amount of blood return after blanching with a piece of Plexiglas
- PIGMENTATION Brownish coloration of the scar by pigment (melanin); apply Plexiglas to the skin with moderate pressure to eliminate the effect of vascularity
- THICKNESS Average distance between the subcutical-dermal border and the epidermal surface of the scar
- RELIEF The extent to which surface irregularities are present (preferably compared with adjacent normal skin)
- PLIABILITY Suppleness of the scar tested by wrinkling the scar between the thumb and index finger
- SURFACE AREA Surface area of the scar in relation to the original wound area

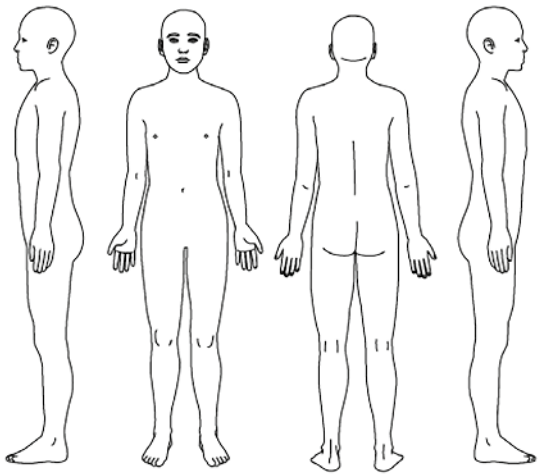
Fig. 13.3 The Patient and Observer Scar Assessment Scale—version 2.0. The POSAS has two components: (**a**) the Observer, and (**b**) the Patient scar assessment scales

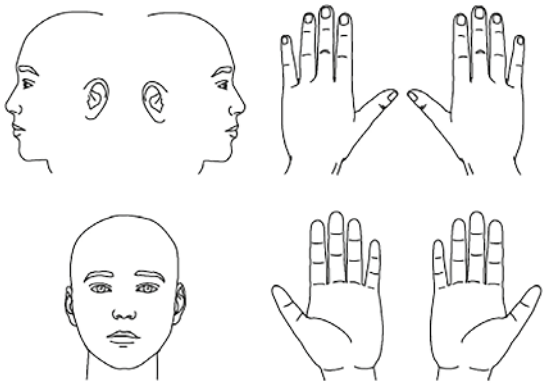
b

POSAS Patient scale

The Patient and Observer Scar Assessment Scale v2.0 / EN

Date of examination:	**Name of patient:**
Observer:	
Location:	**Date of birth:**
Research / study:	**Identification number:**





	1 = no, not at all									yes, very much = 10
	1	2	3	4	5	6	7	8	9	10
HAS THE SCAR BEEN PAINFUL THE PAST FEW WEEKS?	○	○	○	○	○	○	○	○	○	○
HAS THE SCAR BEEN ITCHING THE PAST FEW WEEKS?	○	○	○	○	○	○	○	○	○	○

	1 = no, as normal skin									yes, very different = 10
	1	2	3	4	5	6	7	8	9	10
IS THE SCAR COLOR DIFFERENT FROM THE COLOR OF YOUR NORMAL SKIN AT PRESENT?	○	○	○	○	○	○	○	○	○	○
IS THE STIFFNESS OF THE SCAR DIFFERENT FROM YOUR NORMAL SKIN AT PRESENT?	○	○	○	○	○	○	○	○	○	○
IS THE THICKNESS OF THE SCAR DIFFERENT FROM YOUR NORMAL SKIN AT PRESENT?	○	○	○	○	○	○	○	○	○	○
IS THE SCAR MORE IRREGULAR THAN YOUR NORMAL SKIN AT PRESENT?	○	○	○	○	○	○	○	○	○	○

	1 = as normal skin									very different = 10
	1	2	3	4	5	6	7	8	9	10
WHAT IS YOUR OVERALL OPINION OF THE SCAR COMPARED TO NORMAL SKIN?	○	○	○	○	○	○	○	○	○	○

Fig. 13.3 (continued)

JSW Scar Scale (JSS) 2015 (Classification and Evaluation of Keloids and Hypertrophic Scars)

Classification (For grading and selection of appropriate treatment methods)

Risk factors		
1. Human race	Africans	2
	Others	1
	Caucasians	0
2. Familial tendency	Clearly exists	1
	Not clearly	0
3. Number	Multiple	2
	Solitary	0
4. Region	Anterior chest, Scapular-Shoulder, Suprapubic	2
	Others	0
5. Age at onset	0—30 y/o	2
	31—60 y/o	1
	60— y/o	0
6. Causes	Unknown or minute	3
	Specific wound type such as surgery	0
Present symptoms		
7. Size (cm^2)	Over 20cm^2	1
	Under 20cm^2	0
8. Vertical growth (Elevation) (Figure C-1)	Clearly exists	2
	Not clearly	0
9. Horizontal growth (Figure C-2)	Clearly exists	3
	Not clearly	0
10. Shape (Figure C-3)	Characteristic shape	3
	Others	0
11. Erythema around scars (Figure C-4)	Clearly present	2
	Not present	0
12. Subjective symptoms	Always exist	2
	Intermittent	1
	None	0
		Total 0—25

Remarks		
0—5	Character like matured scars	(intractability : low risk)
6—15	Character like hypertrophic scars	(intractability : middle risk)
16—25	Character like keloids	(intractability : high risk)

Evaluation (For judging treatment results and for following-up)

1. Induration			
0 : None	1 : Weak	2 : Mild	3 : Strong
2. Elevation (Figure E-1)			
0 : None	1 : Weak	2 : Mild	3 : Strong
3. Redness of scars (Figure E-2)			
0 : None	1 : Weak	2 : Mild	3 : Strong
4. Erythema around scars (Figure E-3)			
0 : None	1 : Weak	2 : Mild	3 : Strong
5. Spontaneous and pressing pain			
0 : None	1 : Weak	2 : Mild	3 : Strong
6. Itch			
0 : None	1 : Weak	2 : Mild	3 : Strong
			Total 0-18

Remarks

Weak : symptoms exist in less than 1/3 of the area, or are intermittently

Strong : symptoms exist in the entire region, or are continuous

Mild : between weak and strong

Ogawa R, Akaishi S, Akita S, Okabe K, Shimizu T, Sunaga A, Tosa Y, Nagao M, Yamawaki S. JSW Scar Scale Working Group. Japan Scar Workshop (JSW) Scar Scale 2015. Available online at: http://www.scar-keloid.com/en/index.html

Fig. 13.4 The Japan Scar Workshop Scar Scale (JSS). The scale consists of two parts—the Classification Table and the Evaluation Table. The Classification Table differentiates mature, hypertrophic, and keloid scars, while the Evaluation Table can be used to track scar changes over time

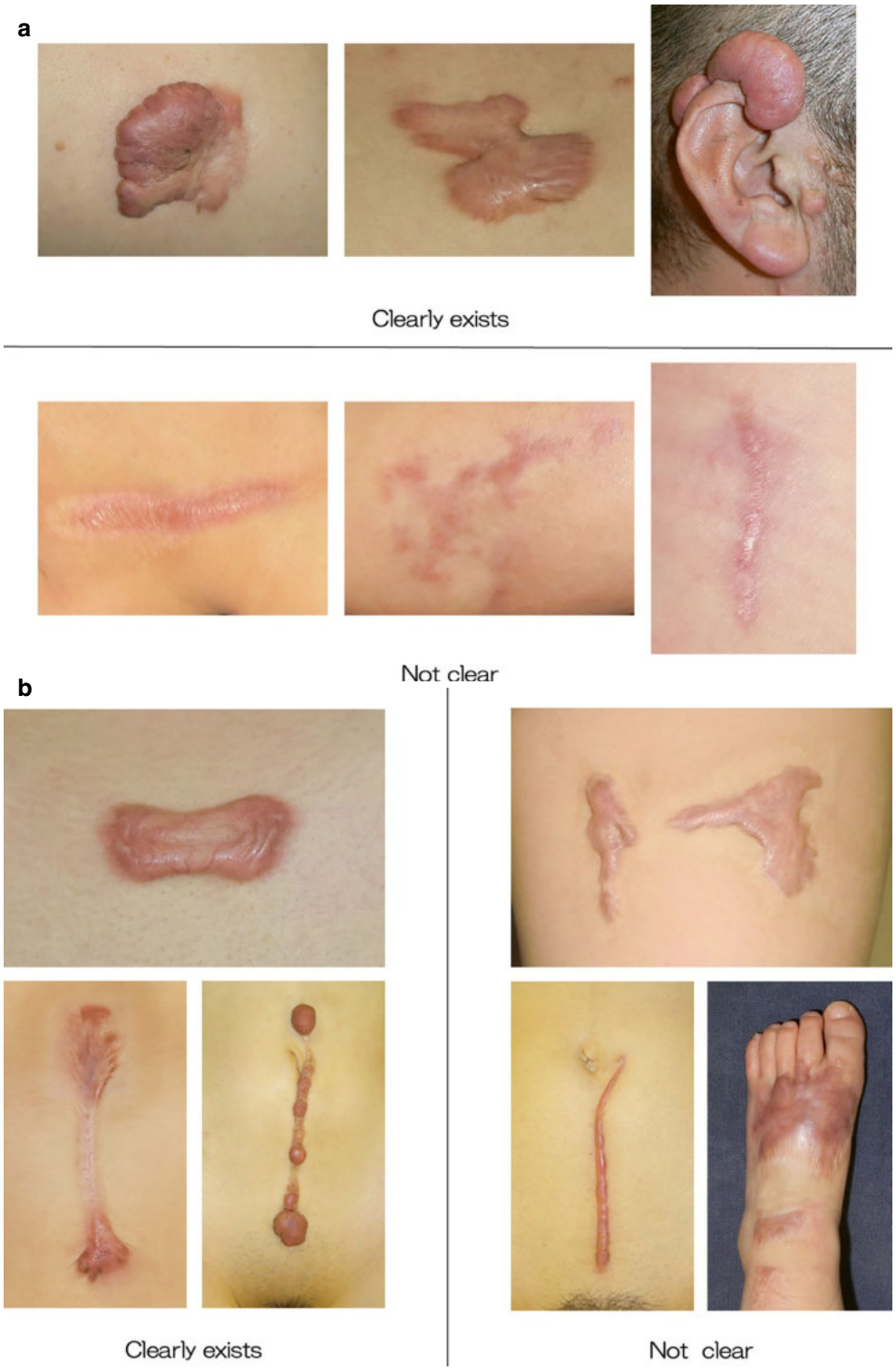


Fig. 13.5 Supplemental figures to assist scoring the Classification Table of the JSS. Guidance for scoring (**a**) vertical growth, (**b**) horizontal growth, (**c**) shape, and (**d**) erythema around the scars is shown

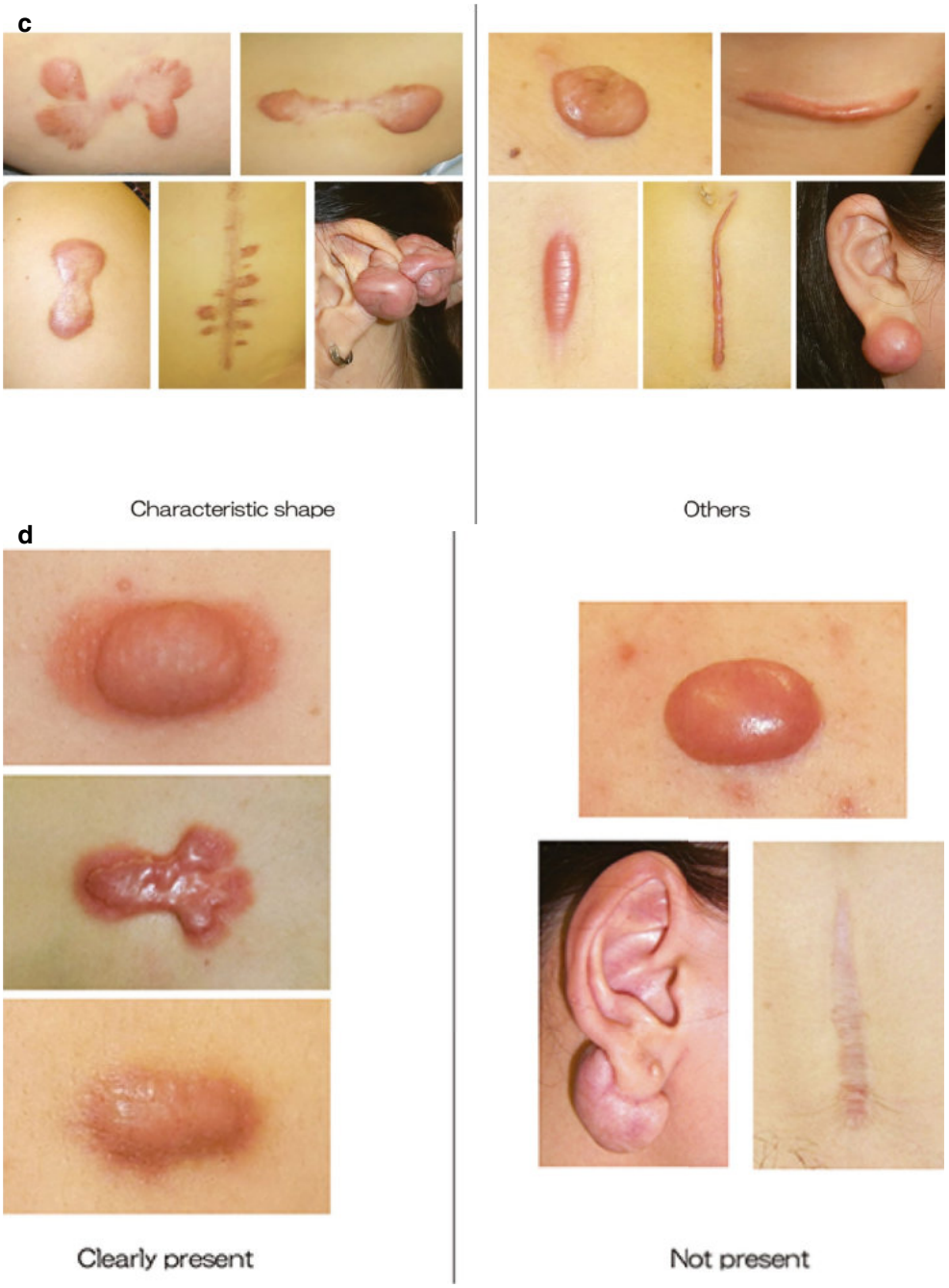


Fig. 13.5 (continued)

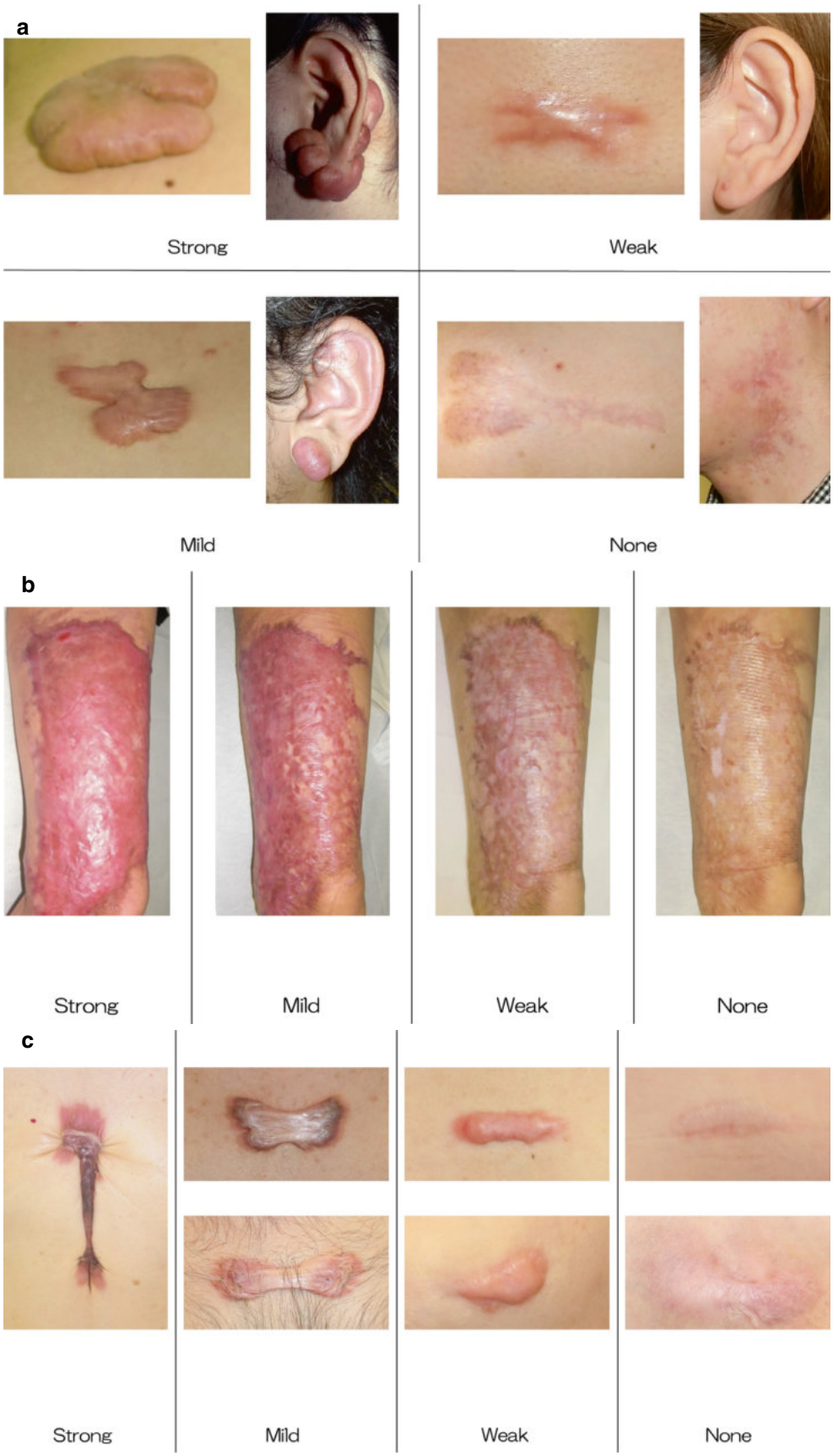


Fig. 13.6 Supplemental figures to assist scoring the Evaluation Table of the JSS. Guidance for scoring (**a**) elevation, (**b**) redness of scars, and (**c**) erythema around the scars is shown

13.4 Choosing a Scar Assessment Tool

With numerous assessment tools, selecting which to use in a research or clinical application can be challenging. This process should be purposeful, considering factors related to both the research goals and methodology, as well as those related to the scar assessment scale itself. Firstly, given the dichotomy between the clinician-reported and patient-reported scales, the target of measurement must be well defined. That is, does the study/assessment want to capture the clinician's or the patient's viewpoint? Deciding on this will immediately narrow down the potential scales. Next, the purpose of the tool should be outlined. If the instrument is to be used to assess change—either within the same scar over time or pre-post treatment, for example, a tool that has demonstrated responsiveness would be preferable. Alternatively, if there is significant interest in comparing scar outcomes between different studies, applying a tool that has been used widely may be preferable. While by no means exhaustive, some broad suggestions to assist selection of a scar assessment tool follow. Ultimately, the most appropriate tool for a specific application will depend on various factors and is best chosen on a case-by-case basis.

- Where outcomes will be compared to other studies, a tool that has been applied broadly is preferred: VSS and POSAS.
- If a single scar outcome measure is used, the scientific rigor of that tool may be key, and a tool that has undergone a rigorous developmental and validation process should be selected: SCAR-Q and PRISM.
- Where one tool that captures both the clinician and patient viewpoint is preferred: POSAS.
- If a cross-cultural comparison will be performed or the influence of language/regional variation is of interest, a tool that has undergone translation/cross-cultural validation is needed: SCAR-Q and BSHS.
- Where scar outcomes are to be compared to a standard set of reference values, or a "normal," non-clinical score: SCAR-Q (reference values pending).

13.5 Limitations and Future Directions

Given the ubiquity and personal nature of scars, striving to rigorously measure them is worthwhile. Particularly as scars often carry a great weight in the patient's overall perspective of a trauma or surgery, accounting for scars is a prerequisite to health outcome assessment. Exactly which scar assessment to choose, however, continues to pose a challenge for the clinician and researcher. No tool can adequately assess all relevant features of a scar while also comprehensively accounting for the impact on the individual patient. Furthermore, no single tool is universally the most applicable in every scenario, and more than one tool may be necessary for a particular study. Given the number of already available tools, future study may be best directed at further validating existing instruments and elucidating their clinimetric/psychometric properties, as opposed to developing tools de novo. In fact, a more thorough understanding of these available tools will likely enable better matching of the scar assessment tool to the particular application.

13.6 Summary

Scars are much more than merely a skin mark. They are complex, personal, and unique—both from a physical and psychosocial viewpoint. To capture this heterogeneity, facilitate tracking over time, allow comparison between scars, and enable communication between clinicians, many different scar assessment tools have been developed. These tools can generally be categorized as CROMs or PROMs, which are completed by clinicians and patients, respectively. Each instrument has its own strengths, as well as limitations. Choosing an instrument for a particular application should therefore be a considered process and dependent on the specific target of measurement. With the patient viewpoint becoming more relevant in healthcare system evaluations, the SCAR-Q is a particularly favorable scar assessment tool. Rigorously developed in accordance with specific standards, easy to use, and available in 12 different languages, the SCAR-Q provides a holistic overview of the patient's scar experience.

References

1. Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al. The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient-reported outcomes. J Clin Epidemiol. 2010;63(7):737–45. https://doi.org/10.1016/j.jclinepi.2010.02.006.
2. de Vet HC, Terwee CB, Bouter LM. Current challenges in clinimetrics. J Clin Epidemiol. 2003;56(12):1137–41. https://doi.org/10.1016/j.jclinepi.2003.08.012.
3. Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al. The COSMIN checklist for assessing the methodological quality of studies on measurement properties of health status measurement instruments: an international Delphi study. Qual Life Res. 2010;19(4):539–49. https://doi.org/10.1007/s11136-010-9606-8.
4. Beaton DE, Bombardier C, Katz JN, Wright JG. A taxonomy for responsiveness. J Clin Epidemiol. 2001;54(12):1204–17. https://doi.org/10.1016/s0895-4356(01)00407-3.
5. Bae SH, Bae YC. Analysis of frequency of use of different scar assessment scales based on the scar condition and treatment method. Arch Plast Surg. 2014;41(2):111–5. https://doi.org/10.5999/aps.2014.41.2.111.

6. Tyack Z, Simons M, Spinks A, Wasiak J. A systematic review of the quality of burn scar rating scales for clinical and research use. Burns. 2012;38(1):6–18. https://doi.org/10.1016/j.burns.2011.09.021.
7. Vercelli S, Ferriero G, Sartorio F, Stissi V, Franchignoni F. How to assess postsurgical scars: a review of outcome measures. Disabil Rehabil. 2009;31(25):2055–63. https://doi.org/10.3109/09638280902874196.
8. Idriss N, Maibach HI. Scar assessment scales: a dermatologic overview. Skin Res Technol. 2009;15(1):1–5. https://doi.org/10.1111/j.1600-0846.2008.00327.x.
9. Lipman K, Wang M, Berthiaume E, Holloway J, Da Lio A, Ting K, et al. Evaluating current scar assessment methods. Ann Plast Surg. 2020;84(2):222–31. https://doi.org/10.1097/SAP.0000000000002029.
10. Mundy LR, Miller HC, Klassen AF, Cano SJ, Pusic AL. Patient-reported outcome instruments for surgical and traumatic scars: a systematic review of their development, content, and psychometric validation. Aesth Plast Surg. 2016;40(5):792–800. https://doi.org/10.1007/s00266-016-0642-9.
11. Sullivan T, Smith J, Kermode J, McIver E, Courtemanche DJ. Rating the burn scar. J Burn Care Rehabil. 1990;11(3):256–60.
12. Baryza MJ, Baryza GA. The Vancouver scar scale: an administration tool and its interrater reliability. J Burn Care Rehabil. 1995;16(5):535–8. https://doi.org/10.1097/00004630-199509000-00013.
13. Carriere ME, Kwa KAA, de Haas LEM, Pijpe A, Tyack Z, Ket JCF, et al. Systematic review on the content of outcome measurement instruments on scar quality. Plast Reconstr Surg Glob Open. 2019;7(9):e2424. https://doi.org/10.1097/GOX.0000000000002424.
14. Duncan JAL, Bond JS, Mason T, Ludlow A, Cridland P, O'Kane S, et al. Visual analogue scale scoring and ranking: a suitable and sensitive method for assessing scar quality? Plast Reconstr Surg. 2006;118(4):909–18. https://doi.org/10.1097/01.prs.0000232378.88776.b0.
15. Quinn JV, Drzewiecki AE, Stiell IG, Elmslie TJ. Appearance scales to measure cosmetic outcomes of healed lacerations. Am J Emerg Med. 1995;13(2):229–31. https://doi.org/10.1016/0735-6757(95)90100-0.
16. Micomonaco DC, Fung K, Mount G, Franklin J, Yoo J, Brandt M, et al. Development of a new visual analogue scale for the assessment of area scars. J Otolaryngol Head Neck Surg. 2009;38(1):77–89.
17. Beausang E, Floyd H, Dunn KW, Orton CI, Ferguson MW. A new quantitative scale for clinical scar assessment. Plast Reconstr Surg. 1998;102(6):1954–61. https://doi.org/10.1097/00006534-199811000-00022.
18. Yeong EK, Mann R, Engrav LH, Goldberg M, Cain V, Costa B, et al. Improved burn scar assessment with use of a new scar-rating scale. J Burn Care Rehabil. 1997;18(4):353–5; discussion 2. https://doi.org/10.1097/00004630-199707000-00014.
19. Masters M, McMahon M, Svens B. Reliability testing of a new scar assessment tool, Matching Assessment of Scars and Photographs (MAPS). J Burn Care Rehabil. 2005;26(3):273–84.
20. Klassen A, Pusic A. SCAR-Q©: A User's Guide for Researchers and Clinicians https://qportfolio.org/wp-content/uploads/2021/08/SCAR-Q-USERS-GUIDE.pdf. August 2021. Accessed 13 Aug 2021.
21. Ziolkowski NI, Pusic AL, Fish JS, Mundy LR, Wong She R, Forrest CR, et al. Psychometric findings for the SCAR-Q patient-reported outcome measure based on 731 children and adults with surgical, traumatic, and burn scars from four countries. Plast Reconstr Surg. 2020;146(3):331e–8e. https://doi.org/10.1097/PRS.0000000000007078.
22. Klassen AF, Ziolkowski N, Mundy LR, Miller HC, McIlvride A, DiLaura A, et al. Development of a new patient-reported outcome instrument to evaluate treatments for scars: the SCAR-Q. Plast Reconstr Surg Glob Open. 2018;6(4):e1672. https://doi.org/10.1097/GOX.0000000000001672.
23. Wright BD. Solving measurement problems with the Rasch model. J Educ Meas. 1977;14:97–116.
24. Brown BC, McKenna SP, Solomon M, Wilburn J, McGrouther DA, Bayat A. The patient-reported impact of scars measure: development and validation. Plast Reconstr Surg. 2010;125(5):1439–49. https://doi.org/10.1097/PRS.0b013e3181d4fd89.
25. Ferreira E, Dantas RA, Rossi LA, Ciol MA. The cultural adaptation and validation of the "Burn Specific Health Scale-Revised" (BSHS-R): version for Brazilian burn victims. Burns. 2008;34(7):994–1001. https://doi.org/10.1016/j.burns.2007.12.006.
26. Gandolfi S, Auquit-Auckbur I, Panunzi S, Mici E, Grolleau JL, Chaput B. Validation of the French version of the Burn Specific Health Scale-Brief (BSHS-B) questionnaire. Burns. 2016;42(7):1573–80. https://doi.org/10.1016/j.burns.2016.04.011.
27. Muller A, Smits D, Jasper S, Berg L, Claes L, Ipaktchi R, et al. Validation of the German version of the Burn Specific Health Scale-Brief (BSHS-B). Burns. 2015;41(6):1333–9. https://doi.org/10.1016/j.burns.2015.02.006.
28. Shakya R, Manandhar M, Dangol R, Shrestha A. Cross cultural adaptation and validation of burn specific health scale- brief in Nepali (BSHS-B-Np). J Patient Rep Outcomes. 2020;4(1):25. https://doi.org/10.1186/s41687-020-00190-0.
29. Kildal M, Andersson G, Fugl-Meyer AR, Lannerstam K, Gerdin B. Development of a brief version of the Burn Specific Health Scale (BSHS-B). J Trauma. 2001;51(4):740–6. https://doi.org/10.1097/00005373-200110000-00020.
30. Tyack Z, Ziviani J, Kimble R, Plaza A, Jones A, Cuttle L, et al. Measuring the impact of burn scarring on health-related quality of life: development and preliminary content validation of the Brisbane Burn Scar Impact Profile (BBSIP) for children and adults. Burns. 2015;41(7):1405–19. https://doi.org/10.1016/j.burns.2015.05.021.
31. Draaijers LJ, Tempelman FR, Botman YA, Tuinebreijer WE, Middelkoop E, Kreis RW, et al. The patient and observer scar assessment scale: a reliable and feasible tool for scar evaluation. Plast Reconstr Surg 2004;113(7):1960–5; discussion 6–7.
32. Ogawa R. Japan scar workshop (JSW) scar scale (JSS) for assessing keloids and hypertrophic scars. In: Téot L, Mustoe TA, Middelkoop E, Gauglitz GG, editors. Textbook on scar management: state of the art management and emerging technologies. Cham: Springer International Publishing; 2020. p. 133–40.
33. Ogawa R, Akita S, Akaishi S, Aramaki-Hattori N, Dohi T, Hayashi T, et al. Diagnosis and treatment of keloids and hypertrophic scars-Japan scar workshop consensus document 2018. Burns Trauma. 2019;7:39. https://doi.org/10.1186/s41038-019-0175-y.
34. Koike S, Akaishi S, Nagashima Y, Dohi T, Hyakusoku H, Ogawa R. Nd:YAG laser treatment for keloids and hypertrophic scars: an analysis of 102 cases. Plast Reconstr Surg Glob Open. 2014;2(12):e272. https://doi.org/10.1097/GOX.0000000000000231.

Compression Therapy, Gel Sheeting, and Taping Fixation

14

Rei Ogawa, Satoshi Akaishi, and Kouji Kinoshita

Abstract

Hypertrophic scars are primarily caused by thermal damage to the reticular layer of the dermis (Ogawa R, Int J Mol Sci 18(3):606, 2017). This deep dermal injury initiates wound-healing responses, including the early inflammatory stage. However, the inflammatory stage can be aberrantly prolonged by various factors. The resulting chronic inflammation activates wound fibroblasts, which lay down excessive amounts of extracellular material, thereby inducing scar growth. A key inflammation-exacerbating factor that leads to post-burn hypertrophic scarring is sustained/repetitive mechanical tension on the wound/scar. This explains why hypertrophic scars are particularly severe at specific anatomical sites, notably the anterior chest, anterior neck, elbow joint, dorsal hand, and fingers: these regions typically experience considerable skin stretching due to routine bodily movements. Conversely, hypertrophic scarring is less common and less severe on the anterior lower leg, where the skin overlies bone with minimal subcutaneous fat and is subjected to less tensile stress. These observations suggest that minimizing mechanical stress on healing wounds and thus allowing the wounds to rest could help reduce inflammation and thereby prevent hypertrophic scarring.

Keywords

Corticosteroid injection · Hypertrophic scar · Complete surgical resection · Compression therapy · Scar contracture

R. Ogawa (✉) · S. Akaishi
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

K. Kinoshita
Akasaka Clinic, Tokyo, Japan

14.1 Mechanisms of Hypertrophic-Scar Formation

Hypertrophic scars are primarily caused by thermal damage to the reticular layer of the dermis [1]. This deep dermal injury initiates wound-healing responses, including the early inflammatory stage. However, the inflammatory stage can be aberrantly prolonged by various factors. The resulting chronic inflammation activates wound fibroblasts, which lay down excessive amounts of extracellular material, thereby inducing scar growth. A key inflammation-exacerbating factor that leads to post-burn hypertrophic scarring is sustained/repetitive mechanical tension on the wound/scar. This explains why hypertrophic scars are particularly severe at specific anatomical sites, notably the anterior chest, anterior neck, elbow joint, dorsal hand, and fingers: these regions typically experience considerable skin stretching due to routine bodily movements. Conversely, hypertrophic scarring is less common and less severe on the anterior lower leg, where the skin overlies bone with minimal subcutaneous fat and is subjected to less tensile stress. These observations suggest that minimizing mechanical stress on healing wounds and thus allowing the wounds to rest could help reduce inflammation and thereby prevent hypertrophic scarring.

Consequently, after epithelialization of the burn wound, it is advisable to stabilize the newly formed skin by using adhesive tapes or gel sheets. Moreover, since inflammation increases neovascularization, and hypertrophic scars typically exhibit higher venous blood content and congestion compared to adjacent non-scarred tissue, it is important to administer compression therapy after epithelialization. This not only promotes wound healing by inducing vascular collapse and reducing blood flow, it also decreases local inflammation, thereby enhancing scar maturation. Here, we discuss the methods that are commonly used to stabilize and compress post-burn wounds.

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_14

14.2 Gel Sheeting

In 1983, Perkins et al. reported that when 42 patients with burn wounds of varying severity were treated with silicone-gel sheeting, it improved burn-scar maturation in all cases. At the time, the underlying mechanism was unclear, but the authors stated that it did not rely on pressure [2]. In 1985, Wessling et al. found that silicone-gel sheeting of burn-scar contractures on joints improved joint range of motion [3]. Thus, gel sheeting can treat advanced hypertrophic scarring as well as prevent its formation. In 1989, Anh et al. also observed this positive effect with relatively chronic hypertrophic scars [4]. They also speculated that the underlying mechanism does not relate to compression.

These early studies led to widespread interest in silicone-gel sheeting of post-burn wounds. A large-scale systematic review in 2013 by O'Brien et al. then concluded that silicone-gel sheeting may indeed prevent abnormal scarring in high-risk individuals, although they also noted that the studies on gel sheeting were of poor quality and highly susceptible to bias [5]. In our clinic, we have also observed good outcomes when using silicone-gel sheets (Fig. 14.1). Notably, So et al. noted an important point regarding silicone-gel sheeting, namely, patient education: when they randomized patients with hypertrophic-burn scars to receive routine or enhanced education about applying the gel sheets, the enhanced education program increased patient compliance and greatly reduced scar-border height and thickness at 6 months [6]. Thus, patient education improved the outcomes of gel sheets.

Gel sheets are commonly made of silicone, but the type of material used to construct gel sheets may not be an important factor in burn-wound/scar outcomes: the randomized-controlled trial (RCT) of de Oliveira et al. reported that nonsilicone-gel sheets improved hypertrophic-scar maturation equally as well as silicone-gel sheets [7]. In Japan, gel sheets made of polyethylene are also available, and they have the advantage of being less expensive than silicone-gel sheets. We have confirmed that polyethylene-gene sheets are

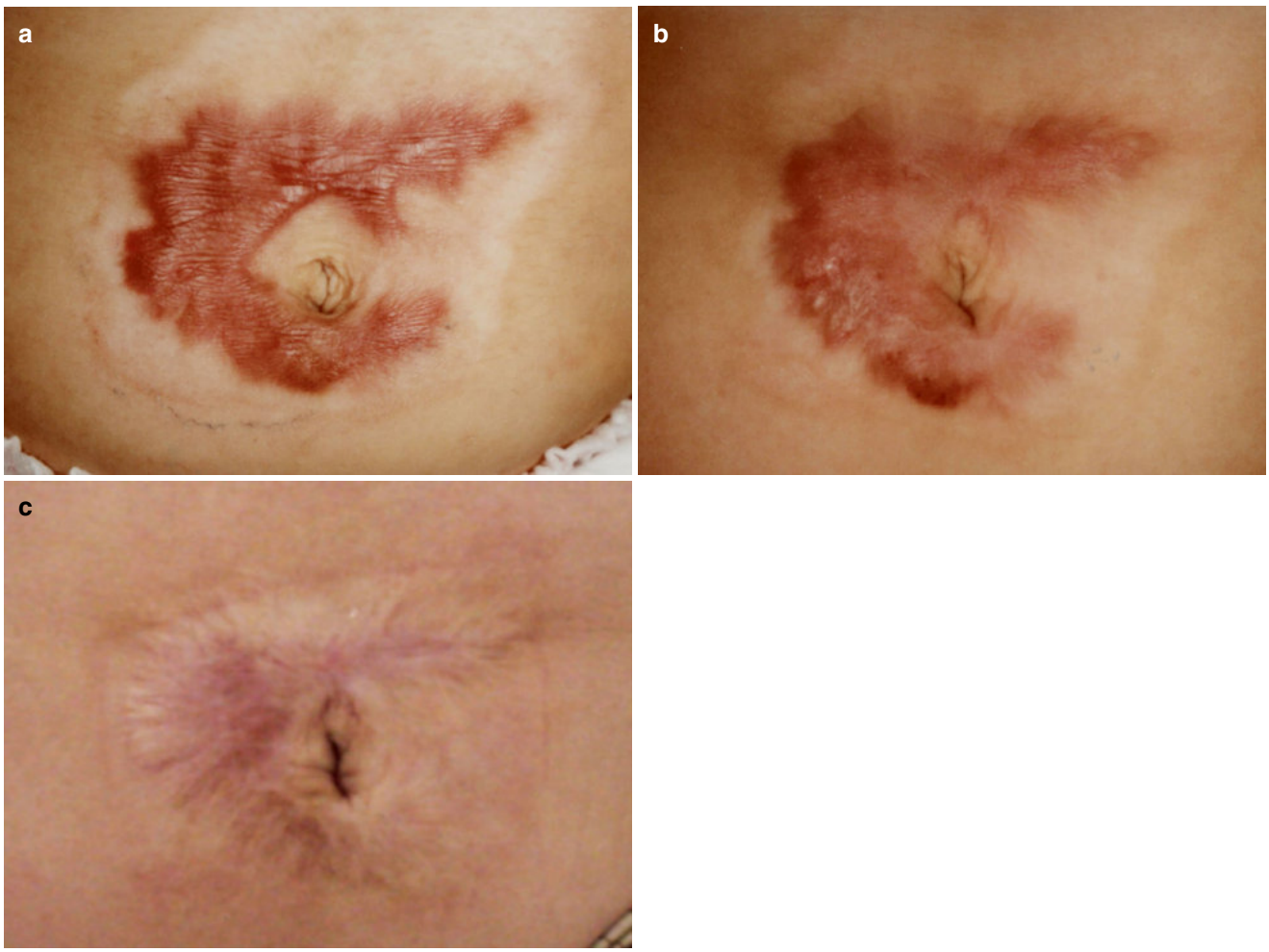


Fig. 14.1 Effect of treating a post-burn wound with silicone-gel sheets. A 1-year-old female sustained a scald burn around her umbilicus. It was a deep dermal burn that epithelialized after 4 weeks of conservative treatments. From that point onward (**a**), silicone-gel sheeting was continuously applied. The scar matured uneventfully, as shown by photographs taken 3 (**b**) and 8 (**c**) months after the burn was sustained

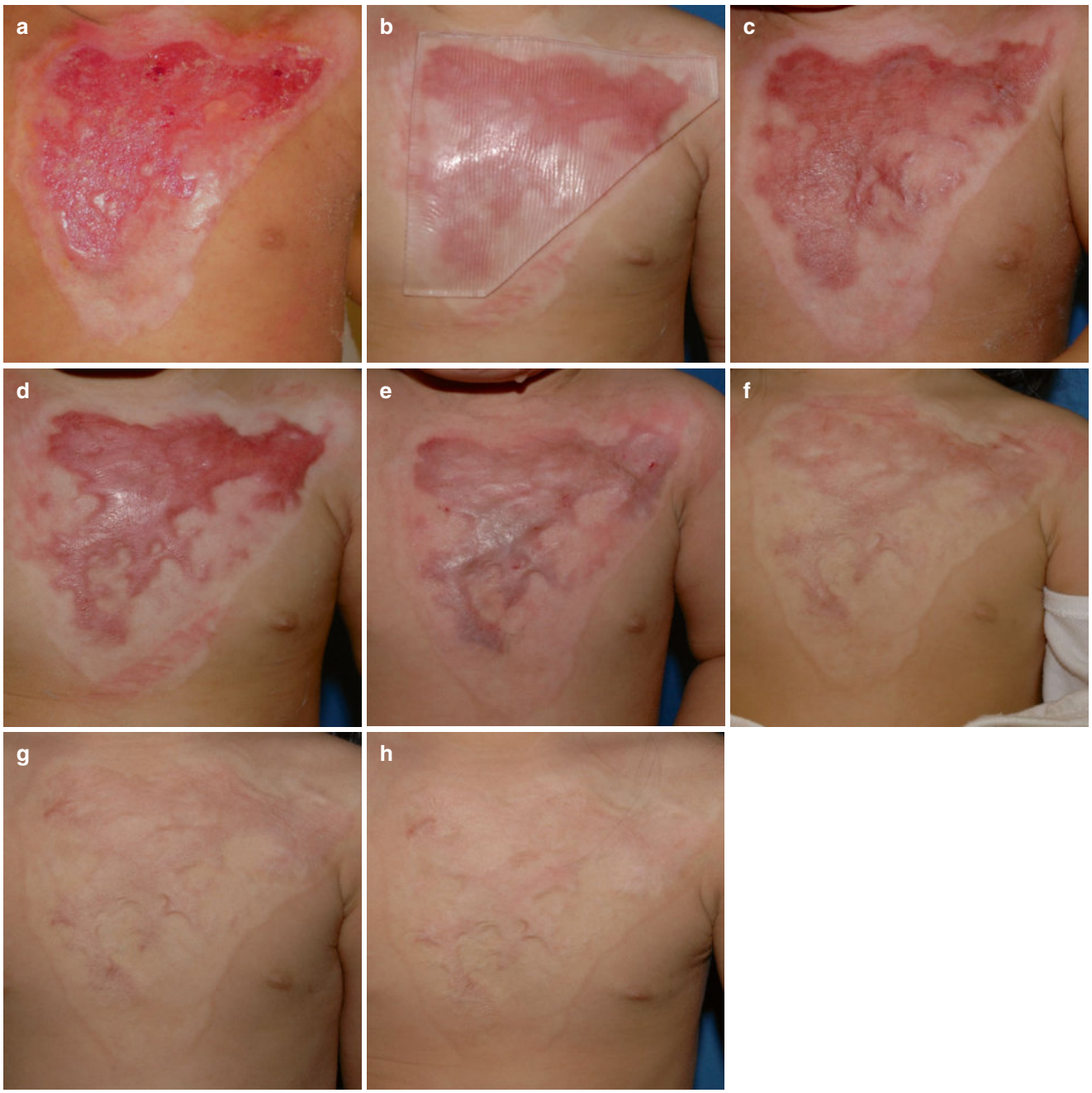


Fig. 14.2 Effect of treating a post-burn wound with polyethylene-gel sheets. A 1-year-old female sustained a scald burn on her chest. It was both a superficial and deep dermal burn. All burns epithelialized after 5 weeks of conservative treatments. (**a**) The burn wound 1 week before starting polyethylene-gel sheeting. (**b**) The wound bearing the polyethylene-gel sheet. The sheet effectively protected the scars from extraneous stimuli, and the maturation course was uneventful. Anterior-chest contractures were not observed after the treatment, as shown by photographs taken 1 (**c**), 2 (**d**), 3 (**e**), 12 (**f**), 18 (**g**), and 28 (**h**) months after the burn injury was sustained

as effective as silicone-gel sheets in terms of improving post-burn wound healing and hypertrophic-scar maturation (Fig. 14.2).

The mechanism by which gel sheets prevent/improve hypertrophic scars is now largely understood, namely, they relieve mechanical tension on the wound/scar, thereby stabilizing the wound/scar [1, 8, 9]. This was confirmed by our computer simulation of a gel-sheeted round hypertrophic scar that was subjected to strong tension from one direction. The study showed that when the gel sheet was applied, the strong force on the leading edge of the scar was transferred to the edge of the gel sheet, and that the force on the scar itself was reduced [10].

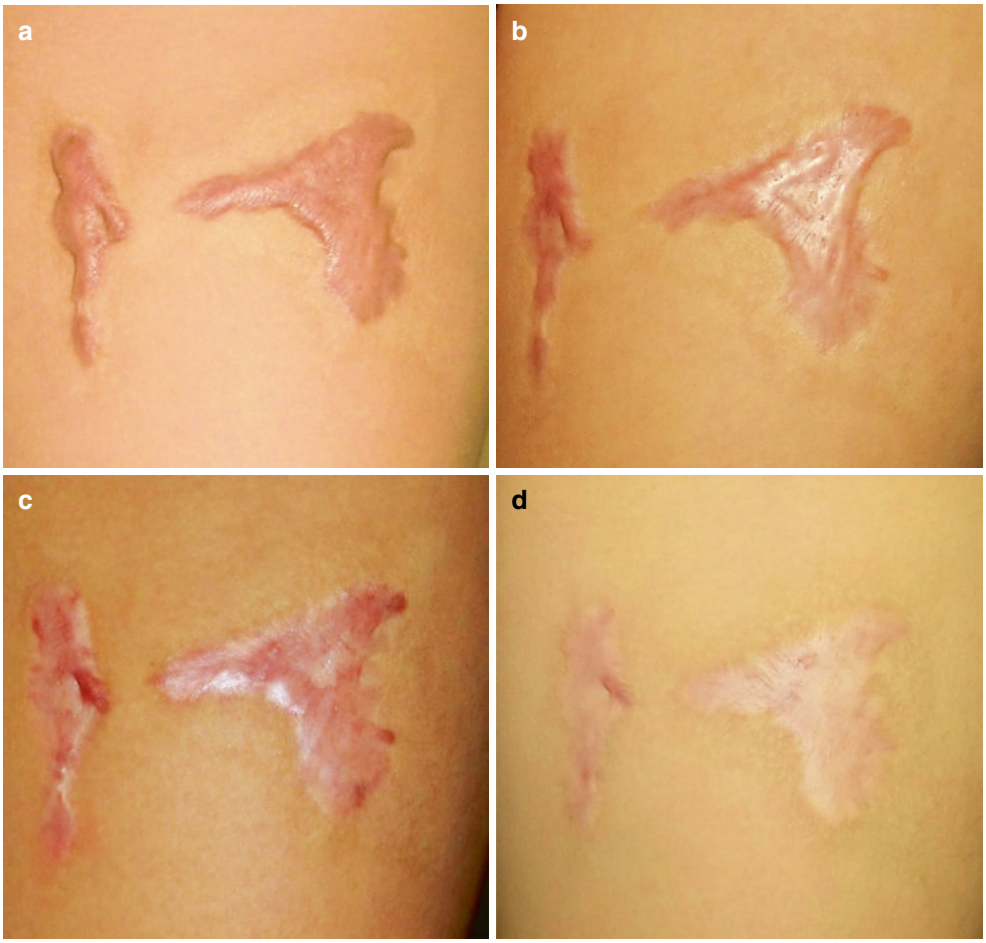


Fig. 14.3 Effect of silicone taping on hypertrophic-scar maturation. An 11-year-old female sustained a scald burn on her left thigh. It was a deep dermal burn that epithelialized after 3 weeks of conservative treatments. From that point onward (**a**), silicone tape was continuously applied. As shown by photographs taken 6 (**b**), 12 (**c**), and 24 (**d**) years after injury, the tape effectively protected the scars from extraneous stimuli, and the maturation course was uneventful

14.3 Taping Fixation

Paper or silicone tape has also been used to prevent and treat hypertrophic scars. Unlike silicone-gel sheets, clinical studies on its efficacy remain sparse. However, animal studies show paper-tape fixation can prevent hypertrophic scars as effectively as silicone-gel sheets [11]. We find they have good clinical outcomes (Fig. 14.3). Since both paper tape and silicone tape are more cost-effective and easier to use than silicone-gel sheets, they are often preferred over silicone-gel sheets. Paper tape is particularly affordable. It also permits moisture and oxygen to permeate, which means that medication can be applied on top of the tape in cases of irritant contact dermatitis. In Japan, specialized paper tapes that are designed specifically to manage scars are also available. While silicone tape is generally more expensive than paper tape, it is less likely to induce irritant contact dermatitis and is noted for its user-friendliness. However, its impermeability to moisture and oxygen may render it less suitable for use in warm conditions, such as during the summer months. This limitation is shared with silicone-gel sheets.

14.4 Compression Therapy

Chang et al. [12] conducted an RCT with 122 patients with burns that were treated with and without pressure garments. The two groups did not differ in terms of average age, surface area of the burn on the body, length of hospital stay, or time to wound maturation. By contrast, when Van den Kerckhove et al. [13] performed a similar RCT but measured the pressure applied more precisely, they found that pressure garments that deliver a pressure of at least 15 mmHg tend to accelerate scar maturation. The RCT of Donovan et al. [14] also showed that low-pressure garment therapy (4–6 mm Hg) improved the healing of unburned donor sites whose skin was used to cover burn wounds: these sites are prone to hypertrophic scarring in burn patients. We have also noted that pressure-garment therapy improves the healing of wounds after hypertrophic-scar contracture resection and coverage with skin grafts (Fig. 14.4). Compression therapy likely improves burn wound healing by constricting the vessels in the wound, thereby preventing the influx of pro-inflammatory mediators and wound inflammation. It should

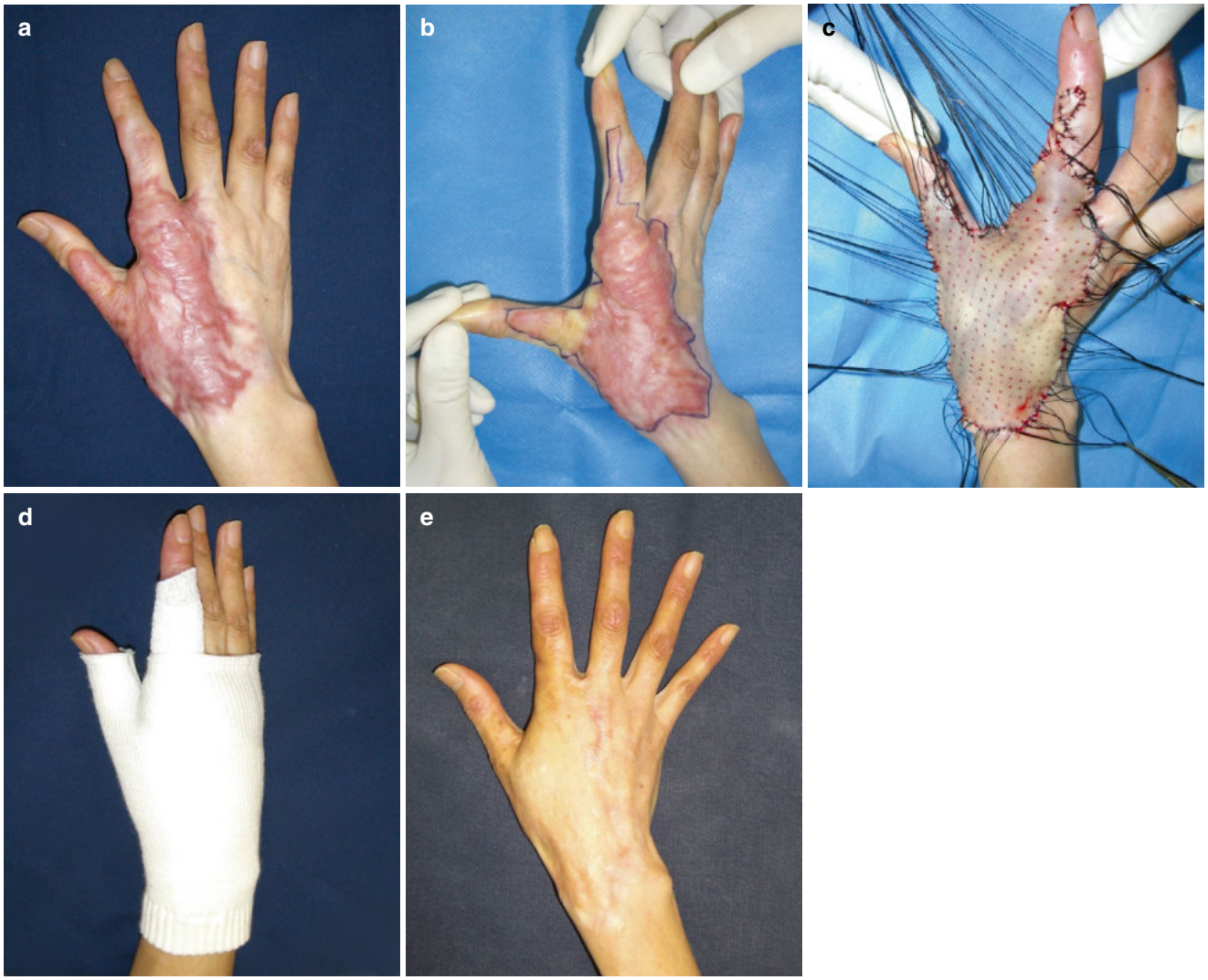


Fig. 14.4 Effect of pressure-garment therapy on wound healing after resection of hypertrophic-scar contracture and skin grafting. A 56-year-old female developed post-burn hypertrophic scars with mild contracture on the hand. (**a**, **b**) The scars 2 years after the burn injury was sustained. (**c**) The scars were completely resected, and the wound was grafted with a sheet of skin from the right inguinal region. Regular small drainage holes were made in the graft by using a spiked Japanese flower holder (kenzan). (**d**) The wound was subjected to taping fixation and bandage-induced compression. (**e**) As observed 1 year after surgery, the postoperative course was uneventful

be noted that applying appropriate amounts of pressure on existing hypertrophic scars can also accelerate their maturation.

References

1. Ogawa R. Keloid and hypertrophic scars are the result of chronic inflammation in the reticular dermis. Int J Mol Sci. 2017;18(3):606.
2. Perkins K, Davey RB, Wallis KA. Silicone gel: a new treatment for burn scars and contractures. Burns Incl Therm Inj. 1983;9(3):201–4.
3. Wessling N, Ehleben CM, Chapman V, May SR, Still JM Jr. Evidence that use of a silicone gel sheet increases range of motion over burn wound contractures. J Burn Care Rehabil. 1985;6(6):503–5.
4. Ahn ST, Monafo WW, Mustoe TA. Topical silicone gel: a new treatment for hypertrophic scars. Surgery. 1989;106(4):781–6; discussion 786-7
5. O'Brien L, Pandit A. Silicon gel sheeting for preventing and treating hypertrophic and keloid scars. Cochrane Database Syst Rev. 2006;1:CD003826.
6. So K, Umraw N, Scott J, Campbell K, Musgrave M, Cartotto R. Effects of enhanced patient education on compliance with silicone gel sheeting and burn scar outcome: a randomized prospective study. J Burn Care Rehabil. 2003;24:411.
7. de Oliveira GV, Nunes TA, Magna LA, Cintra ML, Kitten GT, Zarpellon S, Raposo D, Amaral CM. Silicone versus nonsilicone gel dressings: a controlled trial. Dermatologic Surg. 2001;27:721.
8. Ogawa R. Mechanobiology of scarring. Wound Repair Regen. 2011;19(Suppl 1):s2–9.
9. Ogawa R, Okai K, Tokumura F, Mori K, Ohmori Y, Huang C, Hyakusoku H, Akaishi S. The relationship between skin stretch-

ing/contraction and pathologic scarring: the important role of mechanical forces in keloid generation. Wound Repair Regen. 2012;20(2):149–57.
10. Akaishi S, Akimoto M, Hyakusoku H, Ogawa R. The tensile reduction effects of silicone gel sheeting. Plast Reconstr Surg. 2010;126(2):109e–11e.
11. Tollefson TT, Kamangar F, Aminpour S, Lee A, Durbin-Johnson B, Tinling S. Comparison of effectiveness of silicone gel sheeting with microporous paper tape in the prevention of hypertrophic scarring in a rabbit model. Arch Facial Plast Surg. 2012;14(1):45–51.
12. Chang P, Laubenthal KN, Lewis RW 2nd, Rosenquist MD, Lindley-Smith P, Kealey GP. Prospective, randomized study of the efficacy of pressure garment therapy in patients with burns. J Burn Care Rehabil. 1995;16:473.
13. Van den Kerckhove E, Stappaerts K, Fieuws S, Laperre J, Massage P, Flour M, Boeckx W. The assessment of erythema and thickness on burn related scars during pressure garment therapy as a preventive measure for hypertrophic scarring. Burns. 2005;31:696.
14. Donovan ML, Muller MJ, Simpson C, Rudd M, Paratz J. Interim pressure garment therapy (4-6 mmHg) and its effect on donor site healing in burn patients: study protocol for a randomised controlled trial. Trials. 2016;17(1):214.

Steroid Tape

15

Whitney Laurel Quong and Rei Ogawa

Abstract

The approach to scar management remains complex and requires considered matching between the patient, their scar, and the characteristics of the treatment strategy. Steroid tape, or steroid plaster, is a simple scar therapy that can be applied to a broad range of patients for scars that are of thin-medium thickness in both preventative, treatment, and maintenance applications. Where the patient is a child, cannot tolerate painful treatments, or cannot otherwise undergo surgery, steroid tape may be a particularly favorable and effective treatment approach.

Keywords

Steroid tape · Steroid plaster · Scar treatment · Pathologic scars · Keloids · Hypertrophic scars

The approach to scar management remains complex and requires considered matching between the patient, their scar, and the characteristics of the treatment strategy. Steroid tape, or steroid plaster, is a simple scar therapy that can be applied to a broad range of patients for scars that are of thin-medium thickness in both preventative, treatment, and maintenance applications. Where the patient is a child, cannot tolerate painful treatments, or cannot otherwise undergo surgery, steroid tape may be a particularly favorable and effective treatment approach.

While available in different formulations throughout the world, the greatest experience with steroid plaster is in Japan, where the product is used widely, and cross-sectional data supports its efficacy. Specifically, steroid tape use is associated with patient-reported improvements in relevant scar domains. The treatment is also well-tolerated, with few side effects even after prolonged use. Outside of Japan, however, steroid tape use has been relatively limited, and no randomized-controlled trials have been conducted. Given the ubiquity of scars and the large number of patients that could theoretically benefit, further evaluation of this promising scar treatment modality would therefore be prudent.

15.1 Mechanism of Action

Steroids are a longstanding first-line treatment modality and likely the most common therapeutic strategy for pathologic scars [1, 2]. The drugs (often injected triamcinolone acetonide) suppress inflammation, inhibit neovascularization and fibroblast growth, reduce collagen and glycosaminoglycan synthesis, and promote the action of collagenase [3, 4]. Fibroblast apoptosis is also induced through suppression of transforming growth factor (TGF)-β1 [5]. In fact, both hypertrophic scars and keloids are inflammatory diseases of the skin [6], with the reticular dermis demonstrating accelerated angiogenesis and collagen accumulation [7]. Thus, the overall anti-inflammatory action is likely the most important means by which steroids act on scars. However, when injected, intralesional steroids can cause pain, skin and subcutaneous atrophy, and pigmentary changes [8]. Steroid tape or plaster, on the other hand, usually avoids these side effects.

Compared to other topical delivery methods, steroid tape is easy to use, has superior adherence/localization to the scar, is inconspicuous, and provides a means of controlled medication release and subsequent absorption to the skin [9]. Along with these benefits, and perhaps most notably, in contrast to intralesional steroids, the tapes are not associated with pain. A further advantage over the injected form is related to the fact that because tape treatment is delivered over a sustained period and changes are incremental, therapy can be stopped at any time before significant pigmentary or atrophic changes occur. In addition to the pharmacologic anti-inflammatory action conferred by the steroid, the tape itself has inherent therapeutic properties.

W. L. Quong · R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: whitney.quong@mail.utoronto.ca; r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_15

The nonpharmacologic effects of steroid tape relate to the carrier tape, which likely also contributes significantly to the tape's efficacy in the treatment of scars. Firstly, the tapes are occlusive, which not only enhances the percutaneous absorption of steroids [10] but may also amplify the vasoconstrictive effect of the drug [11]. The tapes also help maintain a stable and favorable environment for the scar by facilitating heat retention [12] and maintaining hydration [13]. The decrease in water vaporization in particular is thought to lead to decreases in capillary activity and reductions in collagen deposition [14]. Finally, the tapes provide structural and mechanical support to the scar. It is widely acknowledged that scar tension is an initiating and potentiating factor for pathologic scar development [15, 16]. The ability of the tapes to bear a large component of tensile force, thereby relieving the scar of ongoing stretching, is therefore advantageous. Protection is also conferred, as the tape acts as a barrier from further shearing or mechanical forces that can exacerbate scars.

15.2 Products and Formulations

In Japan, two types of steroid tapes or plasters are available—Eclar Plaster (deprodone propionate 10 μg/cm^2; Hisamitsu Pharmaceutical Co., Inc.) and Dorenizone Tape (fludroxycortide 4 μg/cm^2; Teikoku Seiyaku Co., Ltd.) (Fig. 15.1). Eclar Plaster is the stronger of the formulations, with deprodone propionate classified as a high-potency steroid. Indications for the plasters in Japan include eczema, psoriasis, lupus erythematosus, lichen sclerosus, and other inflammatory skin conditions, including hypertrophic and keloid scars. Outside of Japan, steroid plaster exists as CORDRAN® Tape (flurandrenolide 4 μg/cm^2, Almirall, LLC) in the United States and as Haelan® Tape (fludroxycortide 4 μg/cm^2; Typharm Group) in the United Kingdom. Flurandrenolide, also known as fludroxycortide, is a medium-strength steroid. In Europe and Canada, a tape containing betamethasone valerate (30 μg/cm^2) is available under a variety of product names (Betesil®, Beteflam®, Betatape®, Cortiflam®, Cortitape®) [17] but has not been described in any scar-related treatment application.

15.3 Steroid Tape Applications in Scar Management

Identifying those scars that are most likely to benefit from steroid tape is important in the usage of the product. Unfavorable scars, including hypertrophic and keloid scars, are most likely to require intervention/treatment in order to optimize the outcome. Such scars are more common when the wound-healing mechanism of the reticular layer of the dermis is activated (i.e., when the dermis is involved in the burn). Thus, in superficial second-degree burns, where there is limited dermal involvement, there is no need to use steroid tape, as hypertrophic scars/keloids are unlikely to occur in the absence of infection or additional trauma (Fig. 15.2).

In contrast, particularly in areas of naturally higher skin tension, for example, the shoulder/scapular area and the anterior chest, burns that involve the reticular dermis are more prone to becoming hypertrophic and/or keloid scars. Genetics/race also factors into the decision as to whether steroid tape should be initiated soon after wound healing has completed. Specifically, compared to Caucasians, Asians and African Americans are at a higher risk of pathologic scar

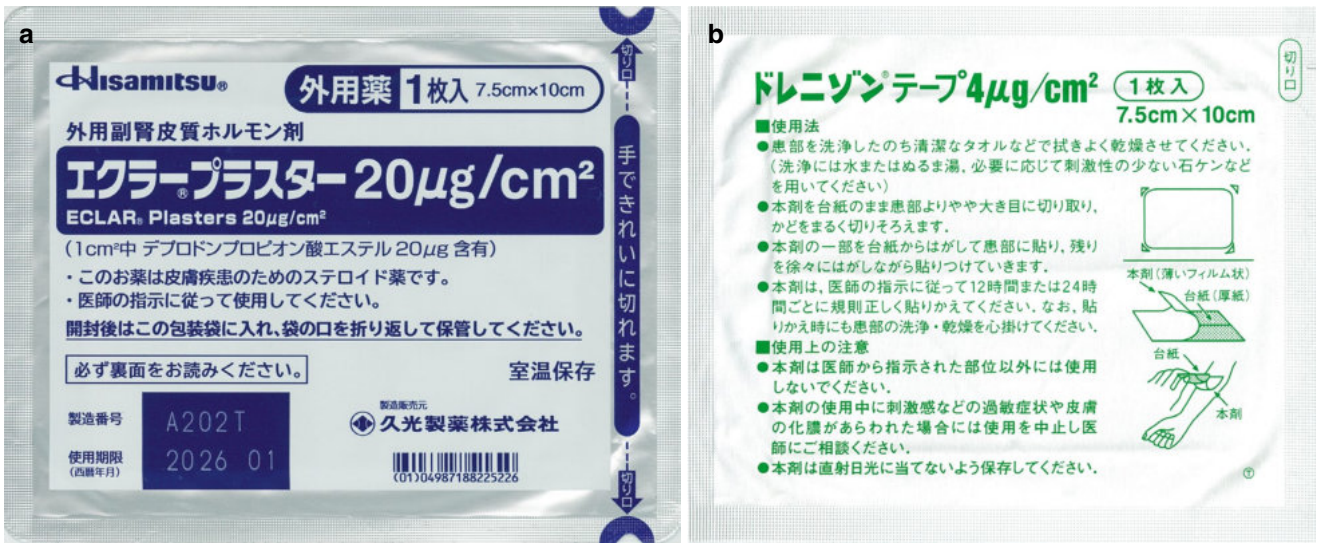


Fig. 15.1 Steroid tape products available in Japan. (**a**) Eclar Plaster has an active ingredient of deprodone propionate (10 μg/cm^2). (**b**) Dorenizone Tape contains fludroxycortide 4 μg/cm^2, and is considered the weaker product. Both products are used throughout Japan

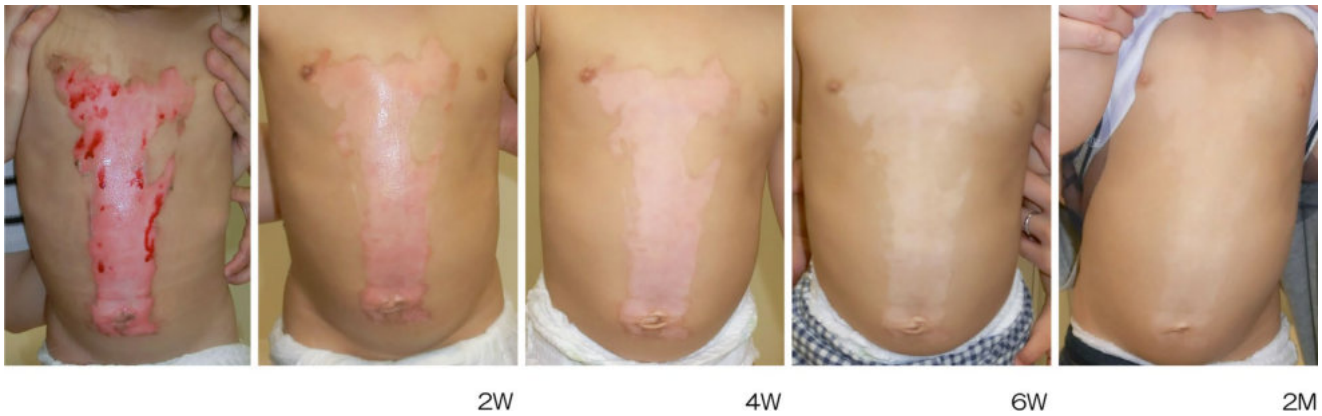


Fig. 15.2 A typical course of superficial second-degree burn in a 1-year-old girl. The burn is shown on initial presentation, 2 weeks, 4 weeks, 6 weeks, and 2 months post burn. The burn went on to heal without any surgical intervention and did not require steroid tape for scar optimization

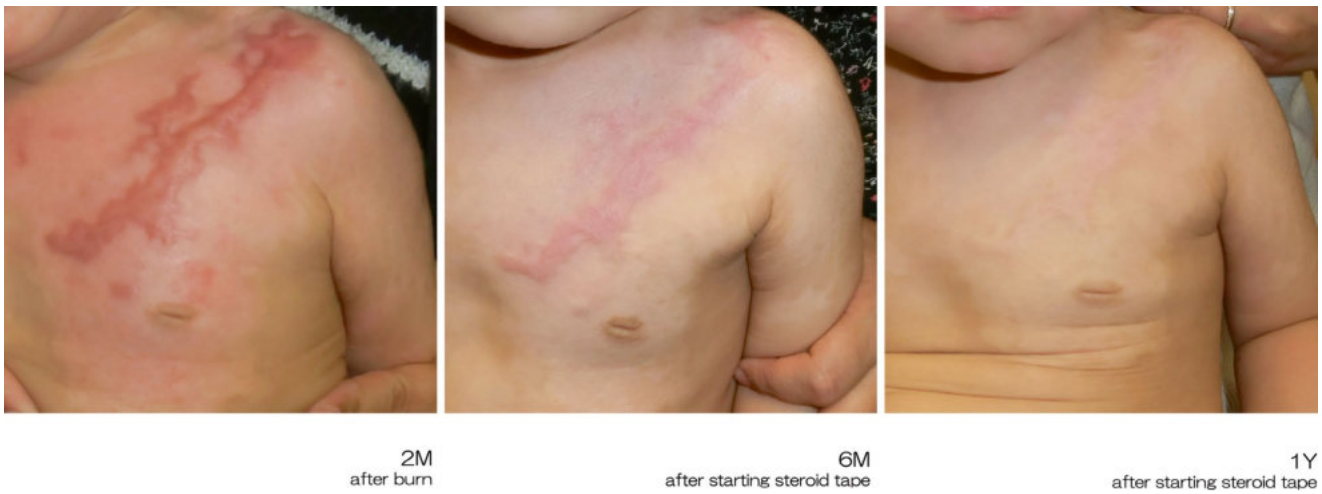


Fig. 15.3 A 2-year-old girl with a scald burn to the anterior chest and shoulder was treated successfully with steroid tape. Two months following the burn injury, she was reviewed for a symptomatic hypertrophic/keloid scar, and steroid tape was initiated. Six months after treatment, erythema of the scar was significantly reduced, and symptoms were improved. After 1 year of therapy, the scar had largely resolved with near complete flattening of the scar

development, and treatment with steroid tape should begin as soon as possible (Fig. 15.3).

15.3.1 Patient and Scar Selection

Steroid tape can be used in both preventative and maintenance applications [18], as well as being the sole therapeutic agent for select hypertrophic and keloid scars. Small scars less than 5 mm thick, scars not spanning across joints, medically complex patients unfit for operative intervention, patients preferring conservative strategies, and those who cannot tolerate painful interventions like injections are the preferred candidates for steroid tape therapy. Moreover, both pediatric and elderly patients are particularly amenable to steroid plaster therapy due to thinner dermis, which facilitates better transdermal steroid delivery. Patient motivation is necessary, however, as steroid tape is a comparatively prolonged treatment strategy requiring adequate patient compliance.

Postoperatively (either after primary surgery for other indications or following scar revision surgery), steroid tape may also be used to optimize a scar, particularly in patients who have a personal/family history of pathologic scarring. Steroid tape in this application may also be advantageous where adjunctive radiation therapy is not offered or is otherwise contraindicated. The therapy can be started once sutures/staples have been removed and the wound has

epithelialized. In addition to the pharmacologic effect conferred by the steroid, the tape also confers benefit as a form of taping fixation, providing structural support to newly healed skin.

15.3.2 Practical Considerations for Use

For maximum therapeutic benefit, patients should use steroid tape as much as possible. Thus, at the onset of steroid tape therapy, patients are instructed to wear the tape every day for a minimum of 23 h—only removing the tape before bathing and replacing it with a new plaster subsequently. The tape itself should be cut to match the shape of the scar, such that when it is applied to the scar, there is minimal overlap (approximately 5 mm) onto healthy skin.

In general, for adults, the stronger Eclar Plaster should be used at the commencement of steroid tape therapy, with consideration given to transitioning to Dorenizone Tape for the later phases of treatment. In children, however, the weaker Dorenizone Tape appears to be sufficient from the outset of treatment [19]. As the scar improves—noted as a reduction in symptoms or improvement in appearance—the therapy should be tapered. For example, the patient can consider using the tape only 5 days per week, or on alternating days, or only while sleeping. Steroid tape is generally discontinued when the scar has become flat, with no contour defect apparent, and normal pliability restored [18]. Upon discontinuation of the steroid tape, a non-steroidal cream/ointment/lotion such as those containing heparinoid analogues (Hirudoid; Maruho Co., Ltd.) or an NSAID (Ibuprofen piconol, Staderm; Torii Pharmaceutical Co., Ltd.) can be used for maintenance therapy.

The most common side effects of steroid tape include redness, itchiness, and exacerbation of acne. Systemic side effects include menstrual cycle disruption but are rarely observed. Patients should be informed of these potential side effects and instructed to discontinue the steroid plaster/tape if such issues emerge. Regular outpatient follow-up every 3–4 months is advised, particularly during the first year of therapy. At each follow-up appointment, scars should be assessed according to usual protocol, and photographs should be taken for the clinical record (Fig. 15.4). The placement of the tape should also be reviewed, with scars that are no longer stiff/firm no longer requiring tape therapy.

15.4 Evidence of Clinical Efficacy

Despite much anecdotal discussion of their efficacy, dedicated investigation of steroids for scars is relatively lacking. As well, outcome measures are often poorly defined and non-standardized, with short follow-up periods. Studies on steroid plaster/tape specifically are even fewer and further between, despite their first reported use for scars being in 1967 [20]. Additionally, the protocols between these studies vary, and they relate to mixed dermatologic conditions, not exclusively scarring. In those studies that do include scar patients, moreover, the overall proportion of keloid/hypertrophic scars is typically small. The largest of these studies, encompassing 285 patients, only includes 2 scar patients, for example. Among these studies with mixed clinical indications, the largest scar group comprised 31 patients out of the total sample of 74 [21]. Of these 19 hypertrophic and 12 keloid patients, 10 had an excellent response (defined as complete disappearance of excessive scarring manifestations) to flurandrenolone tape, 14 had a good response, and 4 noted partial improvement. The treatment protocol for these patients, however, was variable, and the duration was relatively short, ranging from 2 to 288 days [21].

Only two studies exist purposefully evaluating steroid tape specifically for scars, both of which originate from Japan. The first study, published in Japanese only, compared the effectiveness of Eclar Plaster and Dorenizone tape for pathologic scars in 30 adult and 30 pediatric patients [19]. In the adult cohort, 23 patients saw an acceptable response (post-treatment Japan Scar Workshop Scale score (JSS) [22] score $\leq$15), while the pediatric response was somewhat ambiguous. Nonetheless, the authors suggested that in children, Dorenizone tape is effective and that the stronger Eclar Plaster should be reserved for non-responsive cases. More recently, in 2023, a cross-sectional prospective, questionnaire-based study applied patient-reported outcome measures to evaluate the effect of steroid tape (Eclar Plaster) for hypertrophic and keloid scars in 163 adult patients (manuscript under review). In this cohort, steroid tape use was associated

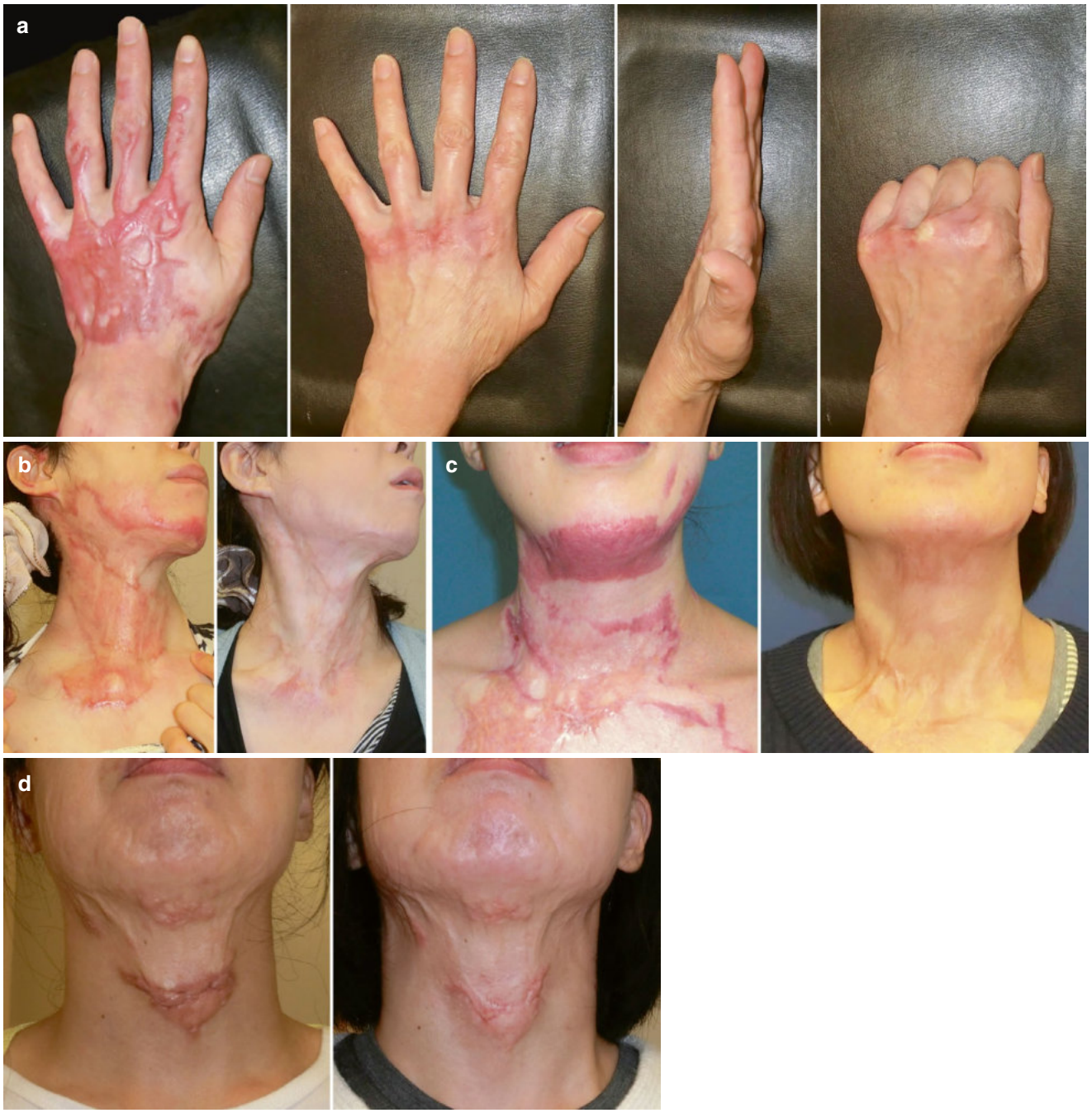


Fig. 15.4 Four clinical cases of patients treated with steroid tape for burn scars. (**a**) A 48-year-old woman with a scar on her hand at the onset of steroid tape therapy and 3 years after tape use. (**b**) A 39-year-old woman with a scar on her chin and neck at the onset of therapy and 18 months after tape treatment. (**c**) A 31-year-old woman at the start of therapy and 36 months after treatment with steroid tape. (**d**) A 46-year-old woman at the onset of therapy and 18 months after steroid tape therapy

with significant improvements in SCAR-Q scores of 14.4 ± 16.5, 17.6 ± 17.7, and 15.1 ± 18.4 (out of 100) for the Appearance, Symptom, and Psychosocial Impact scales, respectively. Global ratings of change scores were also largely improved in >90% of patients for their scar's appearance, associated symptoms, and psychosocial impact. Minor side effects were observed in 18.5% of the cohort, despite nearly three-quarters of the patients having used the tape for more than 1 year. No systemic side effects were observed. The study was, however, limited by its cross-sectional design and lack of a control group.

15.5 Limitations and Future Directions

Clinical decision-making regarding scar management is intricate, but as a simple therapy, steroid tape may have a promising and versatile role throughout scar care algorithms. This utility applies to both adult and pediatric patients, as well as in primary care and specialist settings. However, with the limited usage and experience outside of Japan, more rigorous evaluation of the product is likely necessary to bring the therapeutic device to the forefront of management paradigms worldwide. Randomized controlled trials would be the gold standard for such investigations, which should aim to evaluate efficacy through multiple outcome measures. Defining predictive criteria that may differentiate responders from non-responders would also be useful to triage cases and effectively allocate resources.

15.6 Summary

Steroids have a longstanding first-line role in scar management and are available in various forms. Steroid tapes are particularly favorable for their ease of use and applicability in a broad range of scars and patients. Through both anti-inflammatory mechanisms and mechanical support, the products address aspects of dysfunctional scar biology and improve scar appearance and texture. The tapes are common in both preventative and therapeutic applications in Japan, with their use widespread in both primary care and specialist centers. Cross-sectional studies have supported this utility, with improved patient-reported outcomes. Nonetheless, more rigorous study designs, including multicenter and randomized-controlled trials, would be ideal in future investigations. Ultimately, pathologic scarring continues to be a challenging and often treatment-resistant disease, and steroid tape can have a useful role for many patients.

References

1. Perdanasari AT, Lazzeri D, Su W, Xi W, Zheng Z, Ke L, et al. Recent developments in the use of intralesional injections keloid treatment. Arch Plast Surg. 2014;41(06):620–9.
2. Ogawa R. The Most current algorithms for the treatment and prevention of hypertrophic scars and keloids: a 2020 update of the algorithms published 10 years ago. Plast Reconstr Surg. 2022;149(1):79e–94e. https://doi.org/10.1097/PRS.0000000000008667.
3. Boyadjiev C, Popchristova E, Mazgalova J. Histomorphologic changes in keloids treated with Kenacort. J Trauma. 1995;38(2):299–302. https://doi.org/10.1097/00005373-199502000-00030.
4. Roques C, Téot L. The use of corticosteroids to treat keloids: a review. Int J Low Extrem Wounds. 2008;7(3):137–45.
5. Wu WS, Wang FS, Yang KD, Huang CC, Kuo YR. Dexamethasone induction of keloid regression through effective suppression of VEGF expression and keloid fibroblast proliferation. J Invest Dermatol. 2006;126(6):1264–71. https://doi.org/10.1038/sj.jid.5700274.
6. Ogawa R. Keloid and hypertrophic scars are the result of chronic inflammation in the reticular dermis. Int J Mol Sci. 2017;18(3) https://doi.org/10.3390/ijms18030606.
7. Huang C, Murphy GF, Akaishi S, Ogawa R. Keloids and hypertrophic scars: update and future directions. Plast Reconstr Surg Glob Open. 2013;1(4):e25. https://doi.org/10.1097/GOX.0b013e31829c4597.
8. Niessen FB, Spauwen PH, Schalkwijk J, Kon M. On the nature of hypertrophic scars and keloids: a review. Plast Reconstr Surg. 1999;104(5):1435–58. https://doi.org/10.1097/00006534-199910000-00031.
9. Goutos I, Ogawa R. Steroid tape: a promising adjunct to scar management. Scars Burn Heal. 2017;3:2059513117690937. https://doi.org/10.1177/2059513117690937.
10. Riley K. Flurandrenolone (Cordran) tape as occlusive therapy. J S C Med Assoc (1975). 1969;65(5):171–2.
11. McKenzie A. Percutaneous absorption of steroids. Arch Dermatol. 1962;86(5):611–4.
12. Frank L, Rapp Y. Occlusion, topical corticosteroids and heat in psoriasis. Arch Dermatol. 1963;87(1):32–4.
13. Tillman WJ, Higuchi T. Quantitative evaluation of the interaction of callus strips with some hydroxylic solvents. J Invest Dermatol. 1961;37:87–92. https://doi.org/10.1038/jid.1961.88.
14. Niessen FB, Spauwen P, Robinson PH, Fidler V, Kon M. The use of silicone occlusive sheeting (Sil-K) and silicone occlusive gel (Epiderm) in the prevention of hypertrophic scar formation. Plast Reconstr Surg. 1998;102(6):1962–72.
15. Ogawa R, Akaishi S, Huang C, Dohi T, Aoki M, Omori Y, et al. Clinical applications of basic research that shows reducing skin tension could prevent and treat abnormal scarring: the importance of fascial/subcutaneous tensile reduction sutures and flap surgery for keloid and hypertrophic scar reconstruction. J Nippon Med Sch. 2011;78(2):68–76. https://doi.org/10.1272/jnms.78.68.
16. Ogawa R, Okai K, Tokumura F, Mori K, Ohmori Y, Huang C, et al. The relationship between skin stretching/contraction and pathologic scarring: the important role of mechanical forces in keloid generation. Wound Repair Regen. 2012;20(2):149–57.
17. Sheng M, Chen Y, Li H, Zhang Y, Zhang Z. The application of corticosteroids for pathological scar prevention and treatment: current review and update. Burns. Trauma. 2023;11:tkad009. https://doi.org/10.1093/burnst/tkad009.

18. Ogawa R, Dohi T, Tosa M, Aoki M, Akaishi S. The latest strategy for keloid and hypertrophic scar prevention and treatment: the Nippon medical school (NMS) protocol. J Nippon Med Sch. 2021;88(1):2–9. https://doi.org/10.1272/jnms.JNMS.2021_88-106.
19. Ogawa R, Akaishi S. Effectiveness of corticosteroid tape/plasters for keloids and hypertrophic scars—comparative study of fludroxycortide and deprodone propionate tape/plasters. Scar Manag. 2016;10:55–60.
20. Goldman L, Igelman J, Kitzmiller K. Clinical investigative studies with flurandrenolone tape. Cutis. 1967;3:367–71.
21. Goldblatt S. The use of Cordran tape in dermatology. Ohio State Med J. 1969;65(11):1118–21.
22. Ogawa R. Japan Scar Workshop (JSW) Scar Scale (JSS) for assessing keloids and hypertrophic scars. In: Téot L, Mustoe TA, Middelkoop E, Gauglitz GG, editors. Textbook on scar management: state of the art Management and emerging technologies. Cham: Springer International Publishing; 2020. p. 133–40.

Shock Wave Therapy for Wound Healing and Burn Scar Treatment

16

Peter Moortgat, Lot Demuynck, Mieke Anthonissen, Jill Meirte, Koen Maertens, and Ulrike Van Daele

Abstract

Shock Wave Therapy (SWT) embodies the ideal characteristics for non-invasive scar treatment. It is safe, well tolerated by patients, cost-effective, easy to administer, has low complication rates, and is suitable for outpatient settings. SWT primarily enhances tissue homeostasis, bolstering the tissue's intrinsic healing capabilities. Its focus is on promoting tissue regeneration and matrix remodeling in vivo through mechanotransduction.

Keywords

Shock wave therapy · SWT · Mechanotransduction · Wound healing · Scars · Matrix remodeling · Function

P. Moortgat (✉)
OSCARE, Antwerp, Belgium
e-mail: peter.moortgat@oscare.be

L. Demuynck · J. Meirte · U. Van Daele
OSCARE, Antwerp, Belgium

Rehabilitation Sciences and Physiotherapy, University of Antwerp, Antwerp, Belgium
e-mail: lot.demuynck@uantwerpen.be; jill.meirte@uantwerpen.be; ulrike.vandaele@uantwerpen.be

M. Anthonissen
OSCARE, Antwerp, Belgium

Rehabilitation Sciences and Physiotherapy, University of Antwerp, Antwerp, Belgium

Department of Rehabilitation Sciences, KU Leuven, Leuven, Belgium
e-mail: mieke.anthonissen@oscare.be

K. Maertens
OSCARE, Antwerp, Belgium

Department of Clinical and Lifespan Psychology, Vrije Universiteit Brussel, Brussels, Belgium
e-mail: koen.maertens@oscare.be

Shock Wave Therapy (SWT) embodies the ideal characteristics for non-invasive scar treatment. It is safe, well tolerated by patients, cost-effective, easy to administer, has low complication rates, and is suitable for outpatient settings. SWT primarily enhances tissue homeostasis, bolstering the tissue's intrinsic healing capabilities. Its focus is on promoting tissue regeneration and matrix remodeling in vivo through mechanotransduction.

SWT has been observed to positively influence wound healing, characterized by the upregulation of angio-active factors such as nitric oxide (NO) and vascular endothelial growth factor (VEGF), which lead to induced angiogenesis. Additionally, SWT has been associated with the downregulation of alpha-SMA expression, myofibroblast phenotype, TGF-β1 expression, fibronectin, and collagen type I in scars. This results in improvements in several critical scar parameters, including height, pliability, vascularity, and pigmentation, thereby enhancing functional outcomes.

For a comprehensive treatment regimen, parameters such as energy flux density (EFD), number of pulses, pulse frequency, and the number and interval of treatments are paramount. The EFD for soft tissue applications typically ranges from 0.08 to 0.25 mJ/mm^2, while scars and fibrosis are treated with an EFD between 0.15 and 0.33 mJ/mm^2. These settings appear optimal for eliciting desirable cellular responses specific to each indication.

The findings presented are integral to advancing the understanding of SWT in reducing the fibrous component in tissues undergoing regeneration and remodeling. Nevertheless, the full potential of SWT in the realms of wound healing and scar treatment remains to be fully elucidated.

16.1 Background

To influence the transformation of an excessive scar into a more typical scar, various physical treatment modalities are available for the management of hypertrophic scarring.

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_16

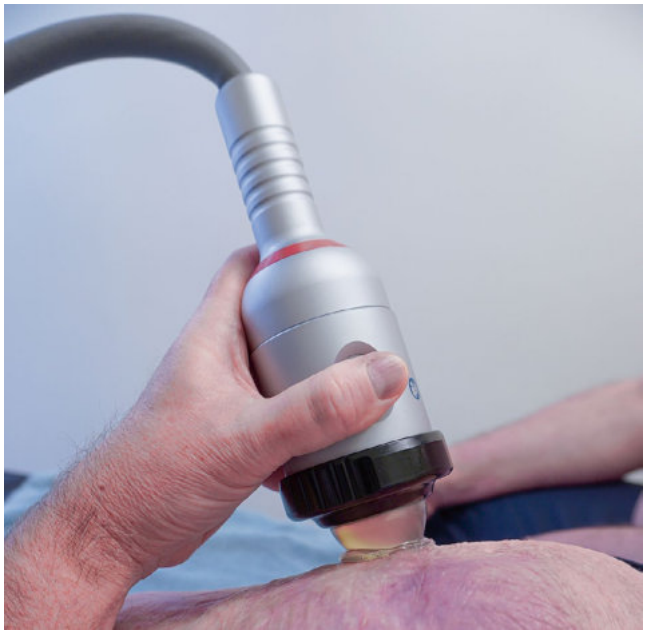


Fig. 16.1 Shockwave application © Oscare vzw

These physical treatments encompass manual and mechanical massage, physiotherapy, thermal therapy, and shock wave therapy. Manual massage confers a wide spectrum of beneficial effects on scars, such as the drainage of edema, alleviation of pain and pruritus, and enhancement of skin hydration [1]. Mechanical massage, or vacuum massage, employs gentle vacuum suction to elevate the skin and create a skin fold [2]. Given that scars have a propensity to contract and induce joint contractures, techniques like splinting, taping, and posture stretching assume a pivotal role in scar treatment. Thermal therapy encompasses high-pressure showers, needle-like showers, and high-pressure water application, with the goal of mobilizing the skin, improving flexibility, and diminishing inflammation, pain, and pruritus. While these approaches are commonly employed, empirical evidence to substantiate their efficacy remains limited [3].

The ideal non-invasive scar treatment should be characterized by safety, patient tolerance, minimal complication rates, ease of application, cost-effectiveness, and suitability for outpatient settings. Shock Wave Therapy (SWT) satisfies the aforementioned prerequisites [4–7]. Although the utilization of shock wave therapy in scar management (Fig. 16.1) remains in an exploratory phase, there have been noteworthy findings in this regard [3].

16.2 Working Mechanism of SWT in Relation to Skin Defects

SWT translates external mechanical stimuli into biochemical responses within living tissues, exemplified by gene transcription leading to collagen remodeling. This process is facilitated by mechanotransduction pathways, culminating in the activation of various cellular events that contribute to the beneficial impact of SWT on cell metabolism and the cell cycle [8]. Furthermore, akin to certain other mechanotherapies implemented in clinical settings, SWT primarily appears to be geared towards instigating tissue regeneration and matrix remodeling "in vivo" [9]. Within connective tissue, fibroblasts emerge as the predominant mechanoresponsive cells and consequently represent the principal focus of SWT [10, 11]. Notably, fibroblasts play a pivotal role in the restructuring of the extracellular matrix (ECM) by synthesizing and organizing components of connective tissue. It is widely posited that SWT exerts a modulatory influence on these fibroblast-driven actions, thereby garnering interest in its potential application for scar prevention and management.

Sukubo et al. [12] elucidated the advantageous impacts of shock wave therapy (SWT) on macrophage behavior. SWT does not elicit activation in quiescent macrophages and appears to modulate macrophage activity during the inflammatory phase of wound healing. Specifically, it inhibits the M1 (pro-inflammatory) activation during the initial inflammatory phase while concurrently augmenting the M2 (anti-inflammatory) activation in the later stages of inflammation [12].

SWT demonstrates the capacity to modulate inflammation through the TLR3 pathway across three distinct phases. During the initiation phase, it prompts a pro-inflammatory response mediated by cyclophilin A and IL6. The middle phase is characterized by a dampening of the inflammatory process, while in the limitation phase, a delayed anti-inflammatory effect is orchestrated through IL10 [13]. Both observations collectively suggest that the application of SWT during the wound healing phase or early stages of scar development holds promise for averting pathological scarring.

Berta et al. investigated the impact of low- to medium-energy shock waves on normal fibroblasts in suspension, assessing viability, growth rate, and gene expression of key repair factors, including TGF-β1 and collagen types I and III. The treatment induced fewer immediate cytodestructive effects, promoting subsequent cell proliferation. Fibroblast viability was more influenced by the number of shots than the energy level, suggesting an optimal energy/shot number ratio for minimal cytocidal effects. Shock waves exhibited a dose-dependent destructive effect on suspended cells while stimulating cell proliferation. A significant increase in proliferation rate was noted, particularly from the sixth to the twelfth day of the proliferation curve. The authors concluded that treatment at 0.22 mJ/mm^2 with 1000 impulses is optimal for fibroblast viability and growth dynamics.

Delayed wound healing is considered a primary factor contributing to the development of hypertrophic scars. SWT has consistently demonstrated efficacy in wound healing, reducing the time required for complete wound closure [4, 5, 16, 17]. Mechanobiologically, the neoangiogenic capacity of SWT has been linked to the inhibition of endothelial cell

apoptosis, particularly in the early phase (first 3 h) following SWT stimulation, as an initial response to mechanical stimulus. Notably, preparatory signals, such as the downregulation of genes associated with cell cycle, adhesion, and apoptosis, have been identified, potentially correlated with impending detachment of endothelial junctions [9].

Following a low-energy SWT treatment (800 shocks, 1 Hz, 0.03 mJ/mm^2), there was a significant upregulation in mRNA expression and protein levels of vascular endothelial growth factor (VEGF) and endothelial nitric oxide synthase (eNOS). Additionally, SWT enhanced the phosphorylation of caveolin-1 and the expression of HUTS-4, representing β1-integrin activity. These findings suggest the involvement of caveolin-1 and β1-integrin in the SWT-induced activation of angiogenic signaling pathways [14].

In summary, SWT manifests an overall enhancement of tissue homeostasis, concomitant with an improvement in the intrinsic self-healing capabilities of the tissue.

16.3 SWT Dose Effect Relationship

In delineating a comprehensive treatment regimen, paramount consideration should be given to the energy flux density (EFD), pulse quantity, pulse frequency, and the frequency and intervals of treatments, as underscored by prior research [5]. Variations in these parameters yield divergent outcomes, underscoring the dose-dependent nature of mechanotransduction events [9]. Notably, high-energy SWT has been identified to suppress cellular growth, while lower-energy shock waves exhibit the potential to enhance cell proliferation [15]. Application of SWT with an EFD ranging from 0.01 to 0.03 mJ/mm^2 demonstrates a modulatory effect on the inflammatory pathway involving macrophages [12]. Furthermore, an EFD of 0.08 mJ/mm^2 in SWT is observed to regulate inflammation via the TLR3 pathway. For soft tissue indications, the recommended EFD typically falls within the spectrum of 0.05–0.20 mJ/mm^2 [4], while scars and fibrosis necessitate treatment with an EFD ranging from 0.15 to 0.33 mJ/mm^2. Notably, SWT settings at 0.22 mJ/mm^2 with 1000 pulses appear to offer an optimal balance for fibroblast viability and growth [16]. The influence of the number of pulses on fibroblast viability is evident, with a higher pulse count correlating with an elevated risk of cell destruction [11]. It is pertinent to recognize that each cell type exhibits responsiveness to SWT, albeit potentially requiring distinct device settings and mechanical stimulation ranges, thereby eliciting varied biochemical effects [8]. In a study conducted by Lee et al., the pivotal role of EFD in targeting specific mechano-signaling pathways was elucidated, with an EFD of 0.12 mJ/mm^2 identified as the optimal dose for activating the mTOR-FAK pathway [17], while an EFD of 0.10 mJ/mm^2 demonstrated optimal results in inhibiting the TGF-β1/Smad pathway [18].

Table 16.1 Dose effect relationship between energy flux density and activation of signaling pathways

Signaling pathways	Energy flux density
Inflammatory pathways in which macrophages are involved [12]	0.01–0.03 mJ/mm^2
TLR-3 pathway [13]	0.08 mJ/mm^2
Tgf-β1/Smad pathway [18]	0.10 mJ/mm^2
mTOR-FAK pathway [17]	0.12 mJ/mm^2
Fibroblast viability and growth [16]	0.22 mJ/mm^2

Drawing upon the findings encapsulated in a meta-analysis conducted by Yang et al. [19], it can be inferred that the recommended course of action for post-burn scars involves administering one or two treatment sessions on a weekly basis over a span of 4–10 weeks. Each session should incorporate a minimum of 100 extracorporeal shock waves (ESWs) per cm^2, or alternatively, an aggregate of 2000–3000 ESWs per treatment session. The selection of the highest tolerable Energy Flux Density (EFD) by the patient is advised. In instances where an Extracorporeal Shock Wave Therapy (ESWT) device is employed, delivering ESWs with identical or nearly identical EFDs across varying frequencies (a characteristic most likely applicable to focused ESWT devices), there is no impediment to conducting treatments at the utmost achievable frequency for the purpose of time efficiency [19] (Tables 16.1).

16.4 The Effects of Shock Wave Therapy in Soft Tissue Defects

16.4.1 Wound Healing

Following SWT, the process of wound healing manifests as an up-regulation of angio-active factors, such as nitric oxide (NO) and vascular endothelial growth factor (VEGF), thereby instigating induced angiogenesis [20]. This cascade effect encompasses vasodilation, heightened vascular and capillary density, and an augmented local blood flow. The pivotal roles of NO and VEGF are underscored, exerting significance in both the early and late stages of the healing process [5, 7, 9, 11, 17]. It has been posited that the early gene response of endothelial cells to SWT involves a reduction in apoptosis and the stimulation of extracellular matrix metabolism [5, 9].

SWT contributes to a decrease in tissue necrosis during wound healing by fostering cellular proliferation and procollagen production [11, 21]. Notably, vasodilation is observed in the early stage (first 3 days), while neovascularization becomes apparent in the late-stage post-intervention [20]. In a clinical trial exploring the efficacy of ESWT in the healing of chronic, therapy-refractory ulcers, an “in vitro” examination delved into the underlying

molecular mechanisms [22]. Fibroblasts exhibited a radial and star-shaped clustered arrangement with prominent "stress" fibers. The clustering of fibroblasts was contingent on the dosage, signifying that an increased number of applications resulted in higher clustering. Shock waves induced the up-regulation of 67 genes in keratinocytes and 652 genes in fibroblasts, emphasizing the primary targeting of fibroblasts by SWT [22]. The elevation of vimentin at the mRNA level, leading to a discernible reorganization of the cytoskeleton, serves as additional evidence supporting mechanotransduction as the operative mechanism for this intervention.

In addition to its application in "general wound healing," SWT has demonstrated specific efficacy in the context of burns. Notably, when applied to donor site healing burn wounds, SWT has been shown to significantly accelerate the time required for complete epithelialization [23]. Furthermore, the assessment of burn area perfusion, conducted through laser Doppler imaging before and after SWT, revealed a significant increase in perfusion following extracorporeal shockwave therapy treatment [24]. Antonic et al.'s review posited that SWT may diminish the necessity for surgical intervention and mitigate associated morbidities in individuals with severely deep partial- or full-thickness burns [4].

Joo et al.'s investigation established that ESWT significantly alleviated burn scar pruritus severity and disturbances in activities of daily living when compared to a control group undergoing sham treatment. The employed energy flux density (EFD) ranged between 0.05 and 0.20 mJ/mm^2, proving beneficial for pruritus management in burn scars [25]. The authors hypothesized that ESWT targeted "neurogenic inflammation," an inflammation induced by the release of substances (e.g., SP and CGRP) from primary sensory nerve endings. The potential decrease in inflammation resulting from nerve fiber loss and neuropeptide depletion may contribute to itch reduction [26].

A recent meta-analysis provided compelling evidence supporting the superior therapeutic outcomes of ESWT compared to conventional wound therapy (CWT) for both acute and chronic soft tissue wounds [27]. Statistically significant enhancements were observed in the healing rate of acute and chronic soft tissue wounds, with a 2.73-fold increase ($P < 0.001$) and a 30.45% improvement in wound-healing area percentage ($P < 0.001$). ESWT also demonstrated a reduction in wound-healing time by 3 days ($P < 0.001$) for acute soft tissue wounds and 19 days ($P < 0.001$) for chronic soft tissue wounds, along with a 53% decrease in the risk of wound infection ($P = 0.03$) compared to CWT alone. Notably, no serious adverse effects were reported [27] (Tables 16.2).

16.4.2 Scar Management

SWT shows potential in modulating fibrous tissue during wound healing and scar maturation phases. Empirical evidence suggests that SWT can not only reduce fibrous tissue at the wound's inception but also remodel it during the subsequent scar formation stage. Key scar attributes such as height, pliability, vascularity, and pigmentation exhibit marked improvements post-SWT application, as noted in studies [6, 28]. These alterations in both physical and physiological parameters of scars are anticipated to facilitate functional enhancements. For example, an increase in passive range of motion (ROM) in retracting hand scars, as observed in a specific investigation, underscores this functional improvement [23]. Additionally, subjective evaluations indicate a notable reduction in pain perception at the scar site following SWT treatment [6, 28].

At the histopathological level, SWT's impact on fibrosis is diverse and significant. Observations include a reduction in alpha-SMA expression, a shift from the myofibroblast phenotype, and diminished levels of TGF-β1, fibronectin, and collagen type I. Concurrently, an increase in dermal fibroblasts characterized by low contractility and high migratory capacity, enhanced small vessel density, and an upsurge in precursors of extracellular matrix components are noted. These changes likely contribute to the formation of newer, thinner collagen fascicles aligned parallel to the dermo-epidermal junction [28–30]. Moreover, a synergistic modification in the balance of pro-fibrotic and anti-fibrotic proteins (notably TGF-β1 and MMP-2) suggests a potential diminution in capsule formation post-silicone implantation [31].

Comparative studies reveal SWT's efficacy against other treatments. In the context of keloid treatment, SWT demonstrated functional outcomes comparable to those of triamcinolone injections, along with similar scores on both patient and observer POSAS scales. Histologically, a significant decrease in collagen fibers and an upsurge in MMP-13 expression were observed, surpassing the results of intralesional steroid injections [32]. Zhao et al. documented positive impacts of Radial Extracorporeal Shockwave Therapy (RESWT) on planimetric scar features and the inhibition of the TGF-β1/Smad signaling pathway, along with reduced Scar Elevation Index, fibroblast density, and α-smooth-muscle-actin expression in hypertrophic scar tissues in a rabbit model [33].

However, not all studies yielded positive outcomes. One investigation [34] found no statistically significant difference in scar appearance, pain, or pruritus between an ESWT-treated group and a control group, both 2 weeks and 5 months post-treatment. Conversely, a study focusing on burn scars reported a more substantial reduction in scar thickness and erythema in the ESWT group compared to controls [35].

Table 16.2 Suggested SWT settings for electro-hydraulic devices when treating wounds or scars

	Energy flux density	Number of pulses	Pulse frequency	Treatment interval	Number of treatments
SWT for Wound Healing	0.05–0.20 mJ/mm^2	800–2000	4–6 Hz	1× per week	1–3
SWT for scar treatment	0.15–0.33 mJ/mm^2	2000–3000	4–6 Hz	2× per week	8–12

Among the most promising findings in SWT research on scars is a randomized placebo-controlled trial exploring SWT's effects on hypertrophic scars. The trial's objective assessments revealed a statistically significant improvement in scar elasticity, as measured by cutometry, in the SWT group [36]. This led to the conclusion that SWT, particularly when initiated within the first 3 months post-wound closure, can significantly enhance the non-invasive management of hypertrophic scars, with a notable improvement in elasticity [36].

16.5 Conclusion

The findings presented herein constitute essential knowledge for future investigations into SWT aimed at diminishing the fibrous component in tissues undergoing regeneration and remodeling. Currently, the dose-dependent nature of treatment effects is not adequately understood. Critical parameters such as energy flux density, the number of shocks, shock frequency, treatment intervals, and the number of treatments significantly influence the selection of the most appropriate device settings, particularly in relation to specific medical indications. It is imperative for future studies to incorporate these parameters as covariates in order to ascertain the most effective, indication-specific approach for each type of scar. Additionally, the full potential of SWT in applications such as wound healing, scar treatment, and cellulite reduction remains to be comprehensively explored.

References

1. Anthonissen M, Daly D, Janssens T, Van den Kerckhove E. The effects of conservative treatments on burn scars: a systematic review. Burns. 2016;42(3):508–18.
2. Moortgat P, Anthonissen M, Meirte J, Van Daele U, Maertens K, Adcock D, et al. The physical and physiological effects of vacuum massage on the different skin layers: a current status of the literature. Burns Trauma. 2016;4(1):34.
3. Middelkoop E, Monstrey S, Téot L, Vranckx J. In: Maca-Cloetens, editor. Scar management: practical guidelines. Elsene, Belgium; 2011. Available from: https://biblio.ugent.be/publication/1932721.
4. Antonic V, Mittermayr R, Schaden W, Stojadinovic A. Evidence supporting extracorporeal shock wave therapy for acute and chronic soft tissue wounds. Wounds. 2011;23(7):204–15. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25879174
5. Mittermayr R, Antonic V, Hartinger J, Kaufmann H, Redl H, Téot L, et al. Extracorporeal shock wave therapy (ESWT) for wound healing: technology, mechanisms, and clinical efficacy. Wound Repair Regen. 2012;20(4):456–65.
6. Fioramonti P, Cigna E, Onesti MG, Fino P, Fallico N, Scuderi N. Extracorporeal shock wave therapy for the management of burn scars. Dermatologic Surg. 2012;38(5):778–82. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22335776
7. Romeo P, Lavanga V, Pagani D, Sansone V. Extracorporeal shock wave therapy in musculoskeletal disorders: a review. Med Princ Pract. 2014;23(1):7–13. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24217134
8. Huang C, Holfeld J, Schaden W, Orgill D, Ogawa R. Mechanotherapy: revisiting physical therapy and recruiting mechanobiology for a new era in medicine. Trends Mol Med. 2013;19(9):555–64. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23790684
9. d'Agostino MC, Craig K, Tibalt E, Respizzi S. Shock wave as biological therapeutic tool: from mechanical stimulation to recovery and healing, through mechanotransduction. Int J Surg. 2015;24:147–53. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1743919115013461
10. Wang JHC, Thampatty BP, Lin JS, Im HJ. Mechanoregulation of gene expression in fibroblasts. Gene. 2007;391(1–2):1–15.
11. Frairia R, Berta L. Biological effects of extracorporeal shock waves on fibroblasts. A review. Muscles Ligaments Tendons J. 2011;1(4):137–46. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3666484/
12. Sukubo NG, Tibalt E, Respizzi S, Locati M, d'Agostino MC. Effect of shock waves on macrophages: a possible role in tissue regeneration and remodeling. Int J Surg. 2015;24:124–30. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1743919115011176
13. Holfeld J, Tepeköylü C, Kozaryn R, Urbschat A, Zacharowski K, Grimm M, et al. Shockwave therapy differentially stimulates endothelial cells: implications on the control of inflammation via toll-like receptor 3. Inflammation. 2014;37(1):65–70.
14. Hatanaka K, Ito K, Shindo T, Kagaya Y, Ogata T, Eguchi K, et al. Molecular mechanisms of the angiogenic effects of low-energy shock wave therapy: roles of mechanotransduction. Am J Physiol Cell Physiol. 2016;311:378–85.
15. Cai Z, Falkensammer F, Andrukhov O, Chen J, Mittermayr R, Rausch-Fan X. Effects of shock waves on expression of IL-6, IL-8, MCP-1, and TNF-α expression by human periodontal ligament fibroblasts: an in vitro study. Med Sci Monit. 2016;22:914–21. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26994898
16. Berta L, Fazzari A, Ficco AM, Enrica PM, Catalano MG, Frairia R. Extracorporeal shock waves enhance normal fibroblast proliferation in vitro and activate mRNA expression for TGF-beta1 and for collagen types I and III. Acta Orthop. 2009;80(5):612–7. Available from: http://www.tandfonline.com/doi/full/10.3109/17453670903316793
17. Lee FY, Zhen YY, Yuen CM, Fan R, Chen YT, Sheu JJ, et al. The mTOR-FAK mechanotransduction signaling axis for focal adhesion maturation and cell proliferation. Am J Transl Res. 2017;9(4):1603–17. Available from: http://www.ncbi.nlm.nih.gov/pubmed/28469768
18. Zhao JC, Zhang BR, Shi K, Wang J, Yu QH, Yu JA. Lower energy radial shock wave therapy improves characteristics of hypertrophic scar in a rabbit ear model. Exp Ther Med. 2018;15(1):933–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/29434689

19. Yang Y, Kang J, Jiang T, Schmitz C, Weng C, Zhang L. Safety and efficacy of treating post-burn pathological scars with extracorporeal shock wave therapy: a meta-analysis of randomised controlled trials. Wound Repair Regen. 2022;30(5):595–607. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/wrr.13037
20. Yan X, Zeng B, Chai Y, Luo C, Li X. Improvement of blood flow, expression of nitric oxide, and vascular endothelial growth factor by low-energy shockwave therapy in random-pattern skin flap model. Ann Plast Surg. 2008;61(6):646–53.
21. Kuo YR, Wu WS, Hsieh YL, Wang FS, Wang CT, Chiang YC, et al. Extracorporeal shock wave enhanced extended skin flap tissue survival via increase of topical blood perfusion and associated with suppression of tissue pro-inflammation. J Surg Res. 2007;143(2):385–92.
22. Aschermann I, Noor S, Venturelli S, Sinnberg T, Mnich CD, Busch C. Extracorporal shock waves activate migration, proliferation and inflammatory pathways in fibroblasts and keratinocytes, and improve wound healing in an open-label, single-arm study in patients with therapy-refractory chronic leg ulcers. Cell Physiol Biochem. 2017;41(3):890–906.
23. Ottomann C, Stojadinovic A, Lavin PT, Gannon FH, Heggeness MH, Thiele R, et al. Prospective randomized phase II Trial of accelerated reepithelialization of superficial second-degree burn wounds using extracorporeal shock wave therapy. Ann Surg. 2012;255(1):23–9.
24. Arnó A, García O, Hernán I, Sancho J, Acosta A, Barret JP. Extracorporeal shock waves, a new non-surgical method to treat severe burns. Burns. 2010;36(6):844–9.
25. Joo SY, Cho YS, Seo CH. The clinical utility of extracorporeal shock wave therapy for burn pruritus: a prospective, randomized, single-blind study. Burns. 2018;44(3):612–9.
26. Hausdorf J, Lemmens MAM, Kaplan S, Marangoz C, Milz S, Odaci E, et al. Extracorporeal shockwave application to the distal femur of rabbits diminishes the number of neurons immunoreactive for substance P in dorsal root ganglia L5. Brain Res. 2008;1207:96–101.
27. Zhang L, Fu X-B, Chen S, Zhao Z-B, Schmitz C, Weng C-S. Efficacy and safety of extracorporeal shock wave therapy for acute and chronic soft tissue wounds: a systematic review and meta-analysis. Int Wound J. 2018;15(4):590–9.
28. Saggini R, Saggini A, Spagnoli AM, Dodaj I, Cigna E, Maruccia M, et al. Extracorporeal shock wave therapy: an emerging treatment modality for retracting scars of the hands. Ultrasound Med Biol. 2016;42(1):185–95.
29. Rinella L, Marano F, Berta L, Bosco O, Fraccalvieri M, Fortunati N, et al. Extracorporeal shock waves modulate myofibroblast differentiation of adipose-derived stem cells. Wound Repair Regen. 2016;24(2):275–86.
30. Cui HS, Hong AR, Kim JB, Yu JH, Cho YS, Joo SY, et al. Extracorporeal shock wave therapy alters the expression of fibrosis-related molecules in fibroblast derived from human hypertrophic scar. Int J Mol Sci. 2018;19(1):124.
31. Fischer S, Mueller W, Schulte M, Kiefer J, Hirche C, Heimer S, et al. Multiple extracorporeal shock wave therapy degrades capsular fibrosis after insertion of silicone implants. Ultrasound Med Biol. 2015;41(3):781–9.
32. Wang CJ, Ko JY, Chou WY, Cheng JH, Kuo YR. Extracorporeal shockwave therapy for treatment of keloid scars. Wound Repair Regen. 2018;26(1):69–76.
33. Zhao JC, Zhang BR, Hong L, Shi K, Wu WW, Yu JA. Extracorporeal shock wave therapy with low-energy flux density inhibits hypertrophic scar formation in an animal model. Int J Mol Med. 2018;41(4):1931–8.
34. Aguilera-Sáez J, dos Santos BP, Serracanta J, Monte-Soldado A, Bosacoma P, Rivas-Nicolls D, et al. The effect of extracorporeal shock wave therapy in the treatment of burn scars: a prospective, randomized, controlled trial. Burns. 2021; Available from: https://pubmed.ncbi.nlm.nih.gov/34844816/
35. Lee SY, Joo SY, Cho YS, Hur GY, Seo CH. Effect of extracorporeal shock wave therapy for burn scar regeneration: a prospective, randomized, double-blinded study. Burns. 2021;47(4):821–7.
36. Moortgat P, Anthonissen M, Van Daele U, Vanhullebusch T, Maertens K, De Cuyper L, et al. The effects of shock wave therapy applied on hypertrophic burn scars: a randomised controlled trial. Scars Burn Heal. 2020;6:2059513120975624. Available from: http://www.ncbi.nlm.nih.gov/pubmed/33312712

Fat Grafting in Burn Scar Prevention and Management

17

Nelson Sarto Piccolo, Mônica Sarto Piccolo, Nelson de Paula Piccolo, Roberta Piccolo Lobo, and Mariana Torminn Senna

Abstract

Fat grafting as an ancillary treatment in wounds and in their sequelae have become more and more common around the world, as its contained adipose-derived stem cells (ADSC's) have long been known to carry a great variety of metabolic and regenerative properties.

Keywords

Fat grafting · Fat delivery · Burn wounds · Burn scars · Tendon adhesion · Palmar scars

Fat grafting as an ancillary treatment in wounds and in their sequelae have become more and more common around the world, as its contained adipose-derived stem cells (ADSC's) have long been known to carry a great variety of metabolic and regenerative properties.

The use of fat grafting and fat delivery has completely changed our treatment routine, as we initiate its use already in the wound's acute phase to promote a faster and better healing as well as to diminish the incidence of fibrosis and consequent sequelae. Patients who come to us with already established scars will also be submitted to fat grafting and fat delivery aiming at diminishing fibrosis and retractions.

We prepare and inject the fat via the Coleman Technique. We added fat delivery as a routine part of the procedure, aiming at an additional benefit, when we thought that the wound surface (or the microperforated surface/substance of the scar) could also be influenced by direct contact with these cells and the contained growth factors concentrated in the centrifuged fat. The findings were remarkable, and we now use both fat grafting and fat delivery as a compound surgical procedure, in the same setting, routinely.

We describe as fat grafting when centrifuged fat is retrogradely injected under the wound or the scar bed and fat delivery when centrifuged fat is delivered directly to the debrided wound bed or to the scar surface after microneedleing or laser treatment.

One of the most pleasant surprises and common findings for the practitioner who has recently started, or who has continuously been using this technique, is the minimal incidence of fibrosis when one performs these procedures aiming at healing the acute or subacute wound, as well as the diminishing effect on already established hypertrophic scarring and adhesions in sequelae.

17.1 Burn Wounds and Scars

The use of fat grafting has become very common in the treatment of burn wounds and burn scars all over the world. The contained mesenchymal cells and growth factors will have a direct impact on the healing as well as on the remodeling processes.

This occurs because fat grafting offers a large variety of metabolic and regenerative properties and contains and/or may be benefitted by several different (and locally specific) growth factors, which may influence practically all body tissues (e.g., epidermal growth factor, transforming growth factor-β, hepatocyte growth factor, platelet-derived growth factor, basic fibroblast growth factor, amongst others). Also, considering several other features, including its ability to increase revascularization, it is known that these cells' antioxidant and wound-healing effects are mainly mediated by the activation of dermal fibroblasts and keratinocytes [1–3].

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/978-3-031-88353-8_17.

N. S. Piccolo (✉) · M. S. Piccolo · N. de Paula Piccolo
Department of Plastic Surgery, Pronto Socorro Para Queimaduras LTDA, Goiânia, Goiás, Brazil
e-mail: nelsonpiccolo@grupopiccolo.com.br

R. P. Lobo · M. T. Senna
Department of Radiology, IRG Hospital, Goiânia, Goiás, Brazil

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_17

There is a direct effect on the natural course of wound healing, leading to an acceleration of revascularization, boosting the tissue regeneration process, yielding minimal, and occasionally, no fibrosis. This mediation is performed by the mesenchymal cells present in the fat grafted under and delivered over the treated lesion or scar [4, 5].

In addition, when fat grafting/fat delivery is performed in a patient to whom these procedures have already been used while healing, there will be a compounded (and cumulative) effect in decreasing fibrosis. This will occur on the surface and within the scar itself, as well as in areas where there could have been adhesions, such as joints and around tendons.

In those patients who had fat grafting to aid in the wound healing process and who eventually developed hypertrophic scars with retractions and/or with adhesions uncontrolled by non-surgical methods, fat grafting and fat delivery will be indicated as soon as these alterations are noted, and if necessary, repeat procedures will occur at 4- to 6-week intervals [6] (Fig. 17.1).

17.1.1 Indications

In our practice, fat grafting and fat delivery are indicated to patients with burn wounds that do not appear to be healed in 3–4 weeks and for post-healing hypertrophic scars that do not appear to be under control (with OT, PT and the use of pressure garments and inserts) at 6 weeks to 8 weeks post-healing, or at any time we see patients from other services in a similar situation.

Candidates for these procedures will be any patient of any age or weight with any type of wound with exposure of noble structures (nerve, major vessels, joints, or tendons) and deep wounds that apparently will not (or have not) heal(ed) in 3–4 weeks, including third-degree burns not immediately suitable for skin grafting, pressure sores (open and cavitarian), wounds with cavities (such as avulsion injuries, drained hematoma spaces, etc.). Our smallest patient treated by fat grafting weighed 8170 grams, and our oldest patient was 92 years old.

17.1.2 Acute and Subacute Burn Wounds

In patients with a wound that does not appear that it will heal within 3–4 weeks and is not an immediate candidate for covering with skin grafting or other "higher" procedure on the reconstruction ladder, we will indicate a fat grafting/fat delivery procedure. Also, we will indicate this combined procedure to patients who come to us with an already poorly evolving wound.

The objective is to implement additional conditions for these wounds to heal in a timely manner, with minimal or no fibrosis. This is especially important in third-degree injuries when excision (or the accident itself, or the natural course of the wound) will expose tendons, nerves, joints, major vessels, or other deep structures that could be damaged by this exposure and by further desiccation. Instead of immediately using a local (or distant) flap, fat grafting has provided a less aggressive procedure (in relation to local or distant tissue cost), often surprisingly leading to healing on these wounds. As mentioned above, in patients originally treated with fat grafting in the acute phase in whom hypertrophic scars still develop, the procedure will be repeated as soon as the diagnosis is made (Figs. 17.2 and 17.3).

17.1.3 Burn Scars

Deep second- and third-degree burns will heal with variable amounts of scar tissue. Skin regeneration occurs through a most complex interaction between different cell types, growth factors, mediators, neurovascular system actions, extracellular matrix production, and remodeling. Fat grafting contains mesenchymal cells, which will interfere in the remodeling process and aid in restoring the damaged tissues in several different ways: scar color, malleability, thickness,

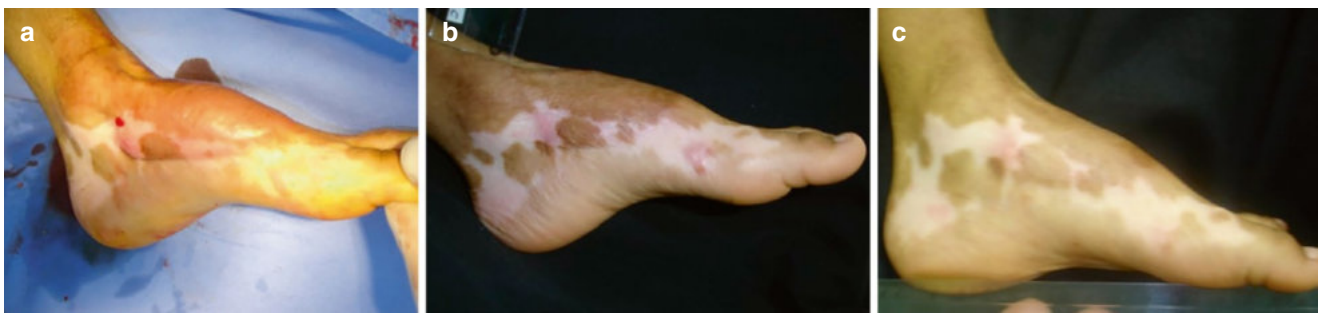


Fig. 17.1 (**a**) 3-year-old boy 6 months post burn with significant hypertrophic scarring to the dorsum of the L foot; (**b**) Aspect 6 weeks post first fat grafting procedure; (**c**) Aspect 2 months post the second fat grafting procedure. Note complete disappearance of the hypertrophic scarring

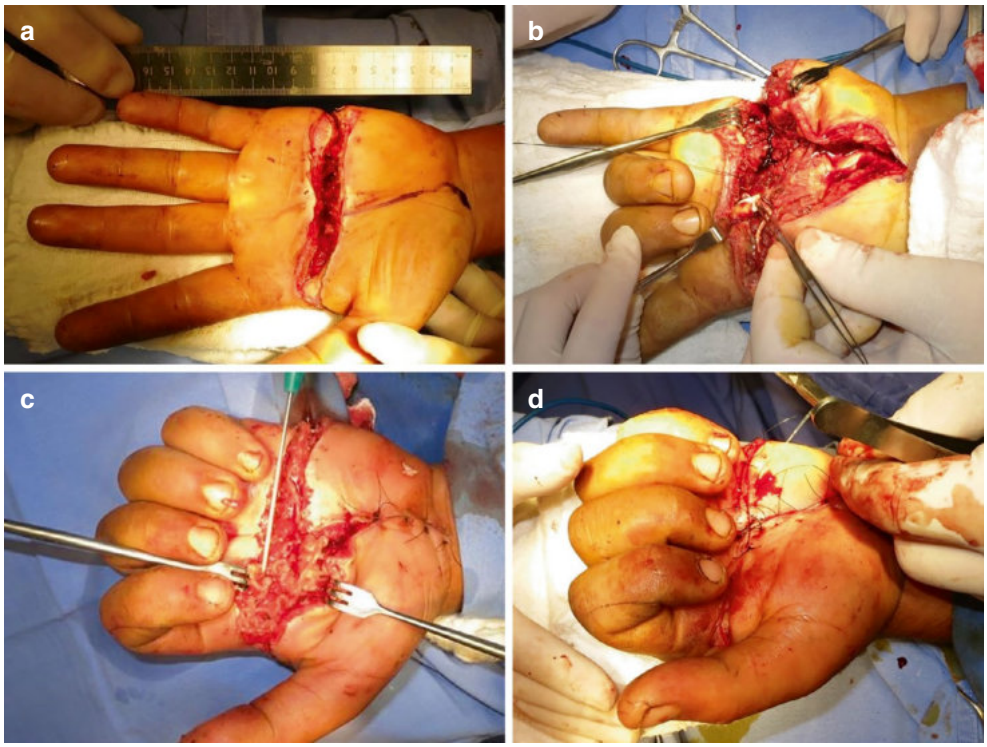


Fig. 17.2 (**a**) A 22-year-old patient 17 days after sustaining a high voltage injury while holding a metal grid; (**b**) Exploratory surgery showed eight severed tendons; (**c**) Wound and tendo debridement were performed, as well as four profundi and three superficial tendons surgical reconnection—centrifuged fat was delivered throughout the wound; (**d**) Immediate post-operative view with fingers in the flexed position

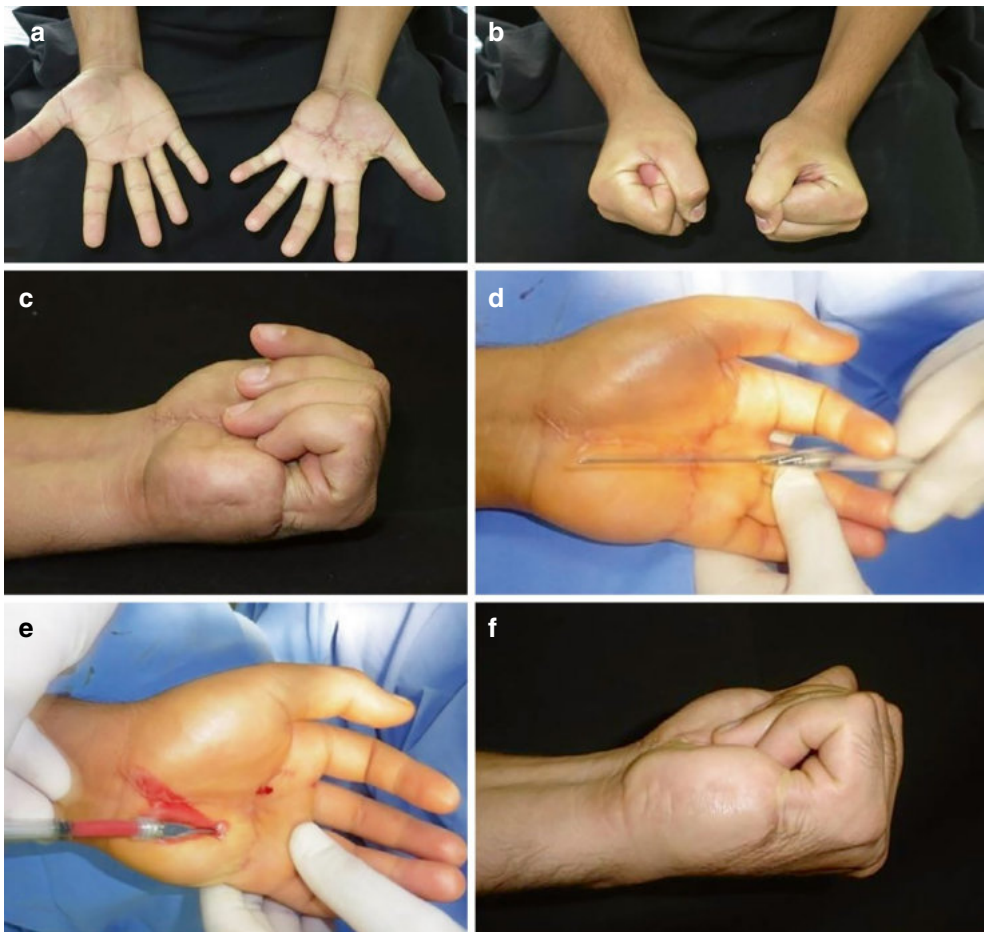


Fig. 17.3 (**a**, **b**) Same patient as in Fig. 17.2, 3 months after the procedure, showing a good result with complete extension and apparent full flexion of the fingers, despite the original topographical anastomosis "overlapping"; (**c**) Aspect of the flexed II to V fingers, when the II profundus is ineffective and the V profundus is partially ineffective due to adhesions; (**d**, **e**) Fat grafting was performed along the tendon trajectories as well at the original wound/tendon anastomosis and connection site; (**f**) Result at 6 weeks after the second fat grafting, demonstrating full recovery at the II profundus and moderate recovery at the V profundus

local symptoms such as itching and/or pain, vascularization, and occasionally, pigmentation [7–9].

Traditional treatment includes pressure garments, inserts, PT, OT, psychological counseling, and frequent follow-up visits. In our Service, patients are instructed in the need of these nonsurgical measures, always aiming at not having to be submitted to an operative procedure or to delay it as much as possible. Patients who are candidates to fat grafting procedures, coming to us from other services, will be instructed to adhere to these measures before any operative procedure is done.

17.2 Surgical Approach

We usually will take to the operating room those patients who already have a high compliance with the nonsurgical measures, which will have to be continued in the postoperative period.

At our service, we use the Coleman Technique to prepare the fat obtained through liposuction. Fat is centrifuged for 3 min at 3000 rpm on a 30° angle centrifuge. The oily and aqueous phases are discarded. This centrifuged fat is then grafted under the wound or the scar, as well as delivered to the wound surface and/or to the wound cavity after appropriate debridement, or to the surface of the scar after microneedling or laser treatment [10–12].

17.2.1 Preoperative Planning and Preparation

In wound cases, as part of the patient's general preoperative evaluation, fragments of the wound are obtained for culture and sensitivity. Patients with chronic wounds or deep burn wounds very frequently will carry multiresistant organisms on their wounds, since the vast majority has received treatment in one or more institutions prior to our evaluation. Knowing the inhabitant flora will aid in the perioperative antibiotic selection while not precluding performing the procedure.

As they are patients who may need more than one fat grafting procedure, donor areas will be "rotated" as needed, and fat most frequently is obtained from the thighs, lateral upper buttocks, or flanks—less frequently from the abdomen (if the plan is to obtain fat from the abdomen, we first order an ultrasound of the abdominal wall to verify the presence (or not) of wall defects and/or hernias, which would preclude the use of this area as a donor area).

Because the Coleman Technique implies centrifuging and discarding of the aqueous and oily phases, the actual volume of harvested lipoaspirate should be at least twice the anticipated volume planned to be grafted and at least four times this volume if one is also planning to have fat delivered to the wound or to the scar surfaces.

17.2.2 Operative Procedures in Acute/Subacute Wounds

Fat grafting is a surgical procedure and must be performed in a licensed and registered operating room. Rigors in sterile technique and usual surgical precautions are a must for the procedure to be successful.

In wound cases, the fat is obtained first, and then, and only then, drapes are removed and the recipient area will be prepped and draped.

In wounds, there is a need for removal of all dead tissue and foreign material through a rigorous debridement. This will be possible most frequently by tangential excision on thermal burn wounds or through mechanical removal of visible dead tissue. Fat grafting and fat delivery should be performed at the same operative setting (Figs. 17.4 and 17.5, Video 17.1).

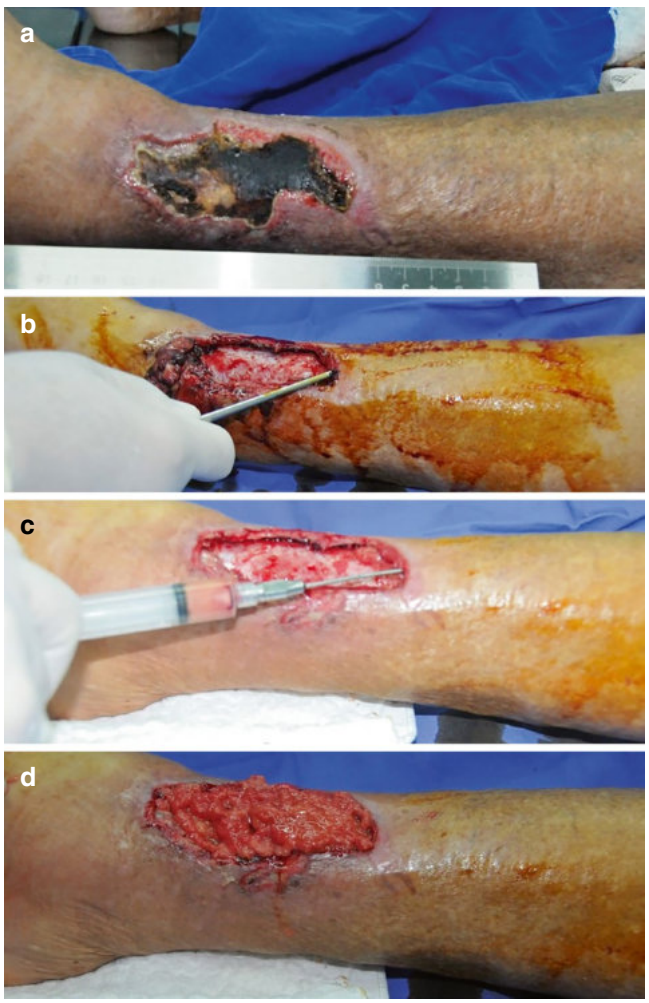


Fig. 17.4 (**a**) - 62 yo self-referred lady 21 days post crushing injury to the distal R leg; (**b**) – rigorous debridement of the wound surface and previous hematoma cavity; (**c**) – fat grafting under the entire wound; (**d**) – fat delivered to the surface of the wound

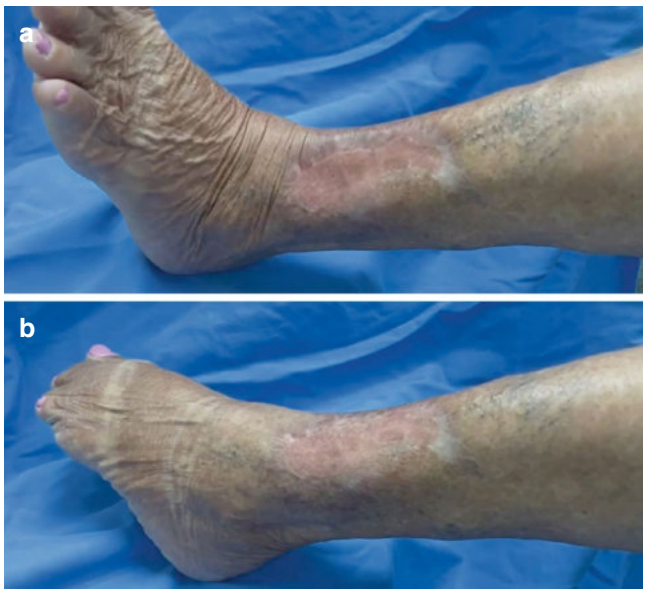


Fig. 17.5 (**a**) Same patient as in Fig. 17.3. Wound was skin grafted 13 days after the initial procedure. Result 3 months after healing showing dorsiflexion of the foot (no adhesions, no skin grafting periphery hypertrophic scars); (**b**) Result 3 months post healing showing extension of the foot (no adhesions, no skin grafting peripheral hypertrophic scarring). (Video 17.1 shows actual movement)

If dead tissue remains, either through inadequate debridement technique, when the wound thickness/tissue loss is not yet defined, or when the structure is too noble to be removed on the first procedure, sometimes as soon as in the first dressing change in 2 days, the appearance of the delivered fat will "show" whether a new debridement would be necessary (there will be a characteristic appearance wherever fat did not "take"—this area will then have to be re-debrided, and additional fat must be grafted/delivered at this site) (Figs. 17.6 and 17.7; Videos 17.2 and 17.3).

17.2.3 Operative Procedures in Scars

In scar cases, the chosen donor area and the recipient area may be prepped and draped simultaneously in the usual manner. Fat will be grafted and delivered as soon as available, after it is prepared by the Coleman Technique.

17.2.3.1 "Preparing" Scars for Future Incision and Grafting

In children, and occasionally in the elderly, when volar retractions are present at the fingers' volar aspect, there may be a need for a more secure, less risky procedure when considering the characteristics of the actual procedure itself.

Usually, in these cases, an incision is performed through the retractional scar, aiming at recovering the natural folds, without any resulting retraction or deformity. However, there is always a risk of exposing (and possibly even injuring) the neurovascular bundles and the local tendons. Thinking about these possibilities, we established a "preparing" procedure where we specifically treat the local scar but also graft a significant amount of fat under the (to be in the future operated) retractional scar, providing "cover" to the underlying noble tissues as well as offering a layer of viable, well-irrigated fat to ensure survival of the graft with no or minimal resulting hypertrophic scarring.

One or more such procedures are performed at 4- to 6-week intervals. In so doing, these procedures will ensure skin grafting success while diminishing local scarring and retraction, also minimizing the extent of the (future) release procedure (Figs. 17.8, 17.9 and 17.10).

17.2.4 Treating Burn Scars with Fat Grafting

Fat grafting scar-treating procedures may be indicated as soon as one notes that non-surgical measures have not been effective. At any time in patients from other services, which have already tried non-surgical measures (at our institution) without success, and in patients with severe deformities.

Fat grafting will be performed under the scars, and fat will also be delivered over the surface of the scar after laser treatment or microneedling (Figs. 17.11 and 17.12).

Not infrequently, fat grafting may also be directed at diminishing already established underlying noble structures' cicatricial adherences in patients who survived severe, extensive, or deep burns from several different causes. Although apparently minor, when one notices the extent of the skin burn sequelae, these patients may have specific complaints and will need immediate and effective procedures (Fig. 17.13).

Of similar importance, it may also be the case of patients of all ages who sustained deep ethanol (or other flame) burns in whom non-surgical measures have been successful in controlling and even treating most of the surface scars but have local, severely deforming or functionally depriving scars, such as in the ears and peri-oral areas (Fig. 17.14).

In the past, surgical scar removal or retraction release procedures have frequently been unsuccessful, with a high rate of recurrence. In these patients, fat grafting has yielded a very high rate of permanent success, still noticeable, with no recurrences several months to several years after the procedure (Figs. 17.15, 17.16, and 17.17).

17.2.5 Microneedling

The benefits of microneedling have been long recognized by the medical community, mostly for vaccines and drug delivery. We coined the term "fat delivery" based on the success-

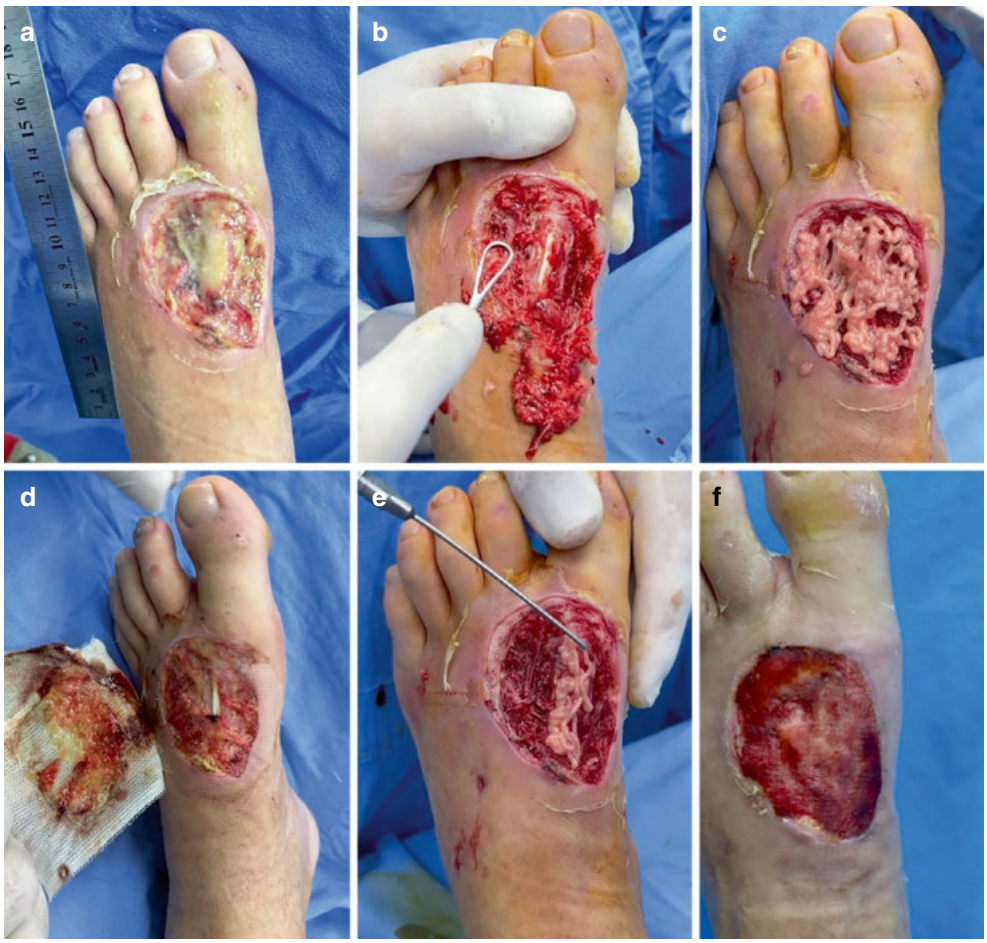


Fig. 17.6 (**a**) 43-year-old diabetic patient self-referred from another Service 18 days post hot molasses burn to dorsal left foot—please note loose tissue and exposed tendon; (**b**) Aggressive debridement exposed an already frayed extensor tendon; (**c**) Fat grafting under the wound bed and fat delivery over the entire wound were performed; (**d**) 6 days after, there is still a minor tendon exposure; (**e**) fat grafting and fat delivery are performed again; (**f**) Patient returns to the OR on day 18 when wound and tendon are covered but tendon moves with the attached previously delivered fat. (Video 17.2 shows actual debridement; Video 17.3 shows actual movement on Day 18)

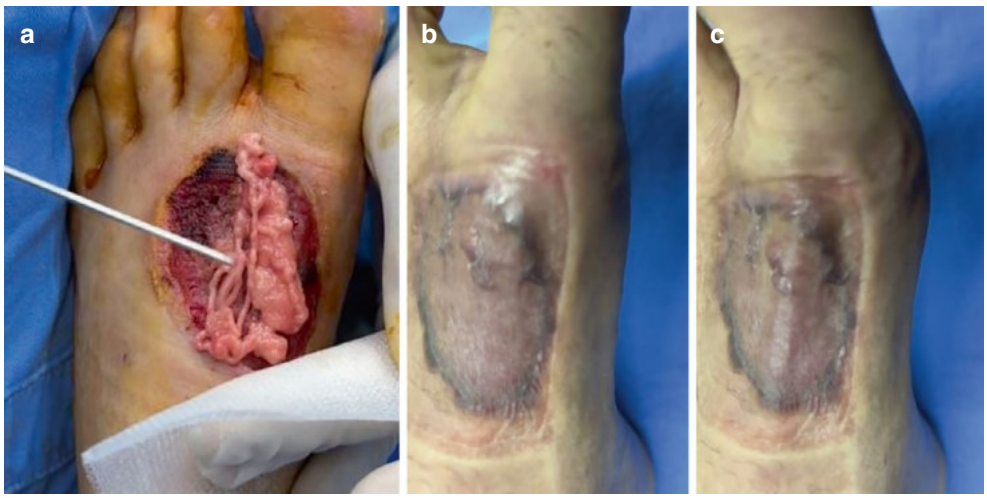


Fig. 17.7 (**a**) Same patient as in Fig. 17.1, on treatment day 18. Fat is delivered to the previously adhered fat on the tendon, aiming at a thicker coverage and adhesion prevention; (**b**) Patient was skin grafted on day 26. Appearance at 42 days after healing flexing great toe; (**c**) 42 days after healing, dorsiflexing great toe. No tendon adherence, minimal hypertrophy at the skin graft borders. (Video 7.4 shows actual movement)

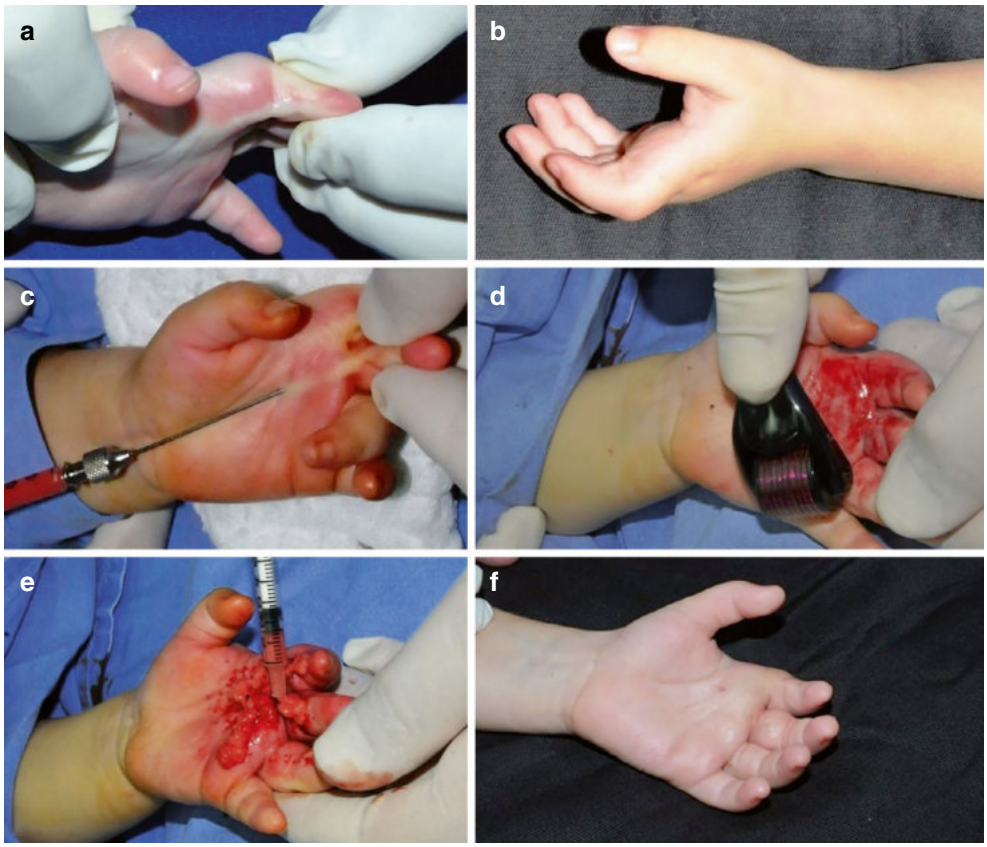


Fig. 17.8 (**a**, **b**) 2-year-old child (10.2 kg) with 6-month-old oven glass burn sequela to the palm of the hand; (**c**) Fat grafting to the retraction areas; (**d**) Microneedling of the entire surface of the scar; (**e**) Fat delivery to all micro needled area; F—Initial result at 6 weeks post op

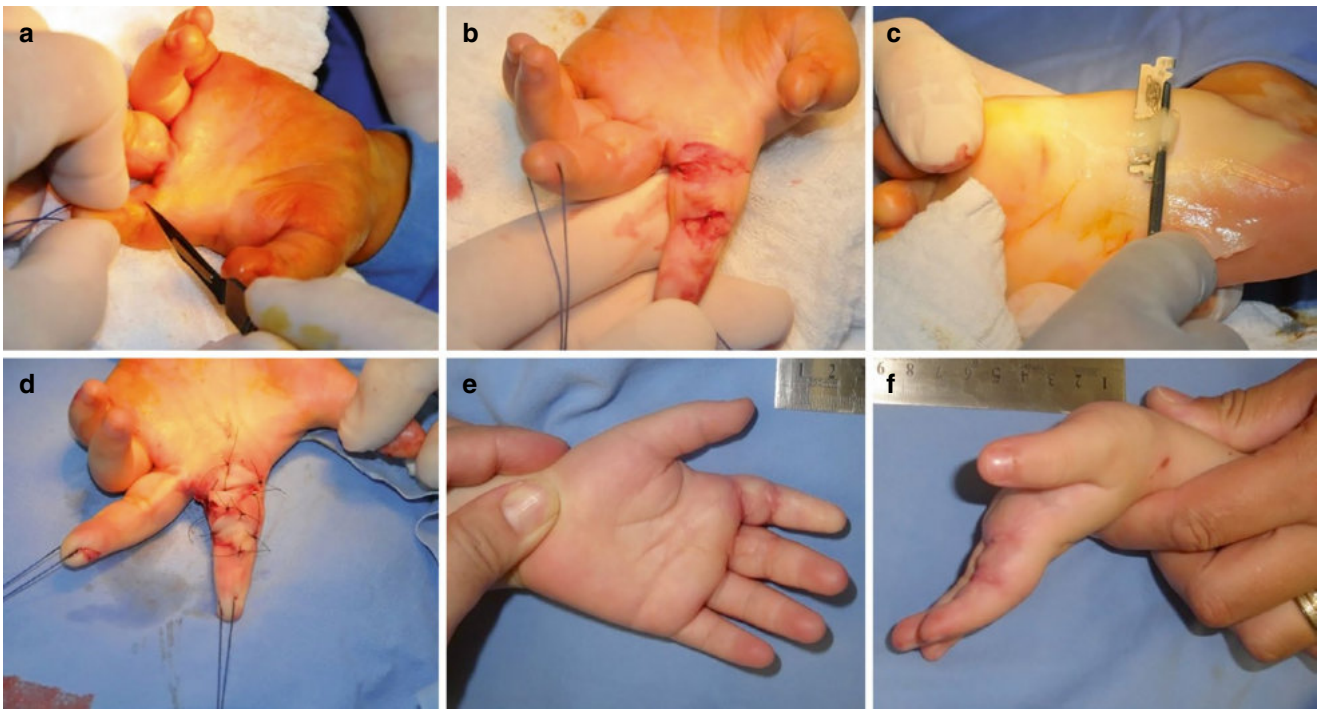


Fig. 17.9 (**a**) Same patient as in Fig. 17.10. 6 weeks after second fat grafting/fat delivery session. Incision at the proposed release site for immediate skin grafting; (**b**) Incision reveals a significant amount of viable, well irrigated fat tissue—underlying noble tissue is not visible; (**c**) Split thickness cavum plantaris skin being obtained; (**d**) Immediate aspect after colourless cavum plantaris skin grafting; (**e**, **f**) Results at 4 months post healing

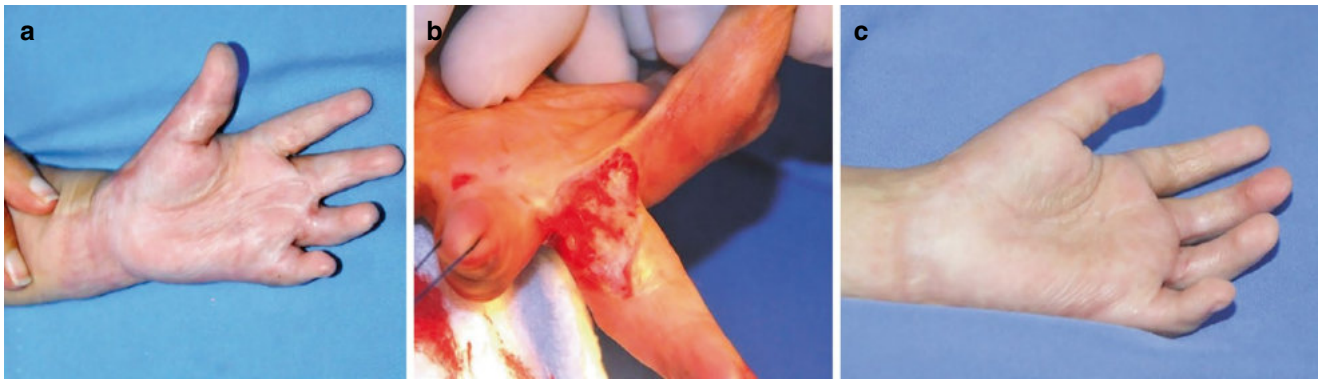


Fig. 17.10 (**a**) 18-month child (9.2 kg) with motorcycle exhaust pipe burn sequela to the volar aspect of the hand; (**b**) Incisional appearance of the pre-grafted site 4 weeks after one fat grafting/fat delivery procedure; (**c**) Result at 18 months after releasing incisions and split thickness cavum plantaris skin grafting on III, IV, and V fingers

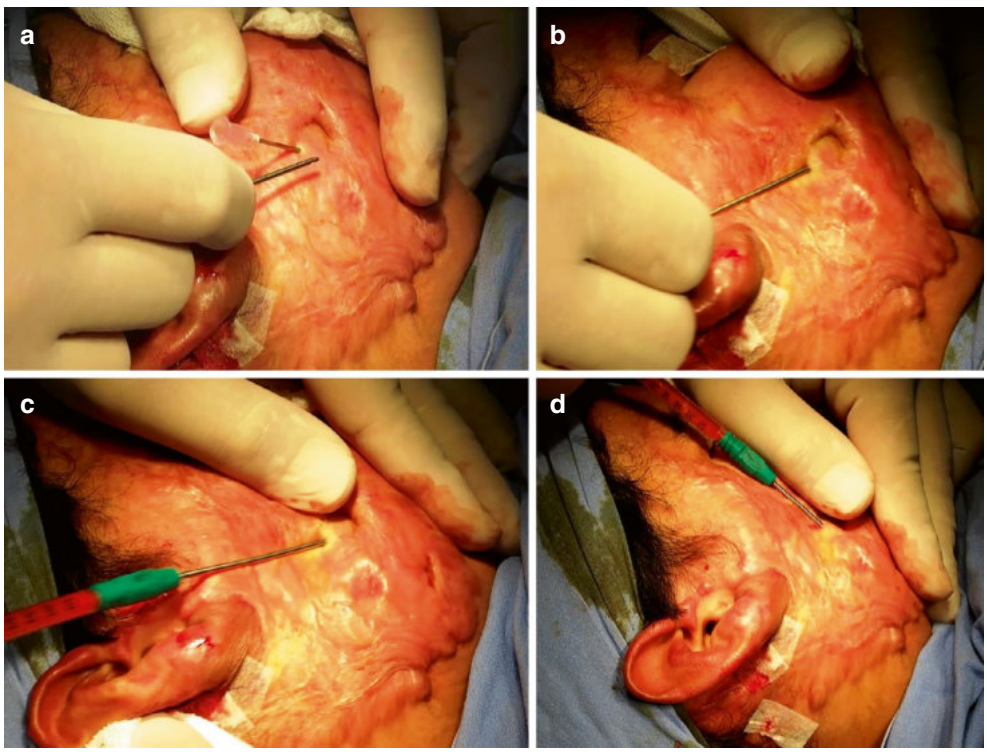


Fig. 17.11 (**a**) An entrance puncture wound is obtained using a "pink" 19 G needle, through scar or normal tissue; (**b**) An 1.8 mm wide, 70 mm long cannula with distal side port is introduced through this puncture needle wound; (**c**) After connecting the cannula to a 1 cc syringe, fat is grafted in a retrograde faction immediately under the scar tissue; (**d**) The cannula is moved in several directions to so "cover" the entire undersurface of the scar

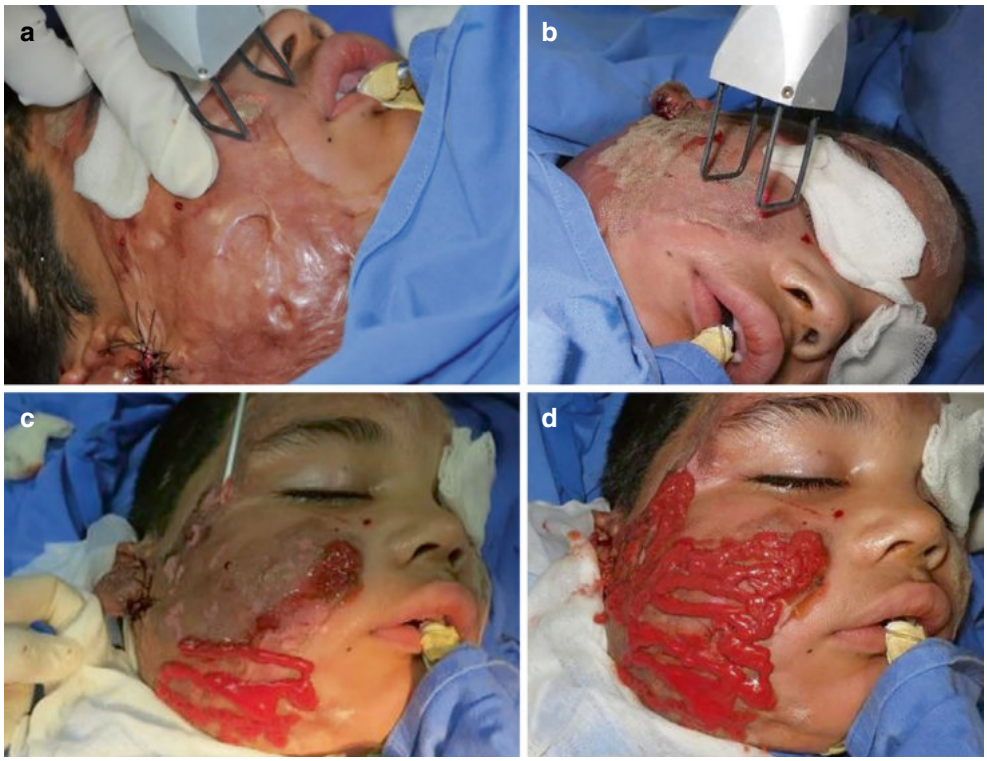


Fig. 17.12 (**a**, **b**) Same patient as in Fig. 17.20 immediately after fat grafting, with the scar surface being treated with CO_2 fractional laser; (**c**, **d**) Centrifuged fat is delivered to entire surface of the scar immediately after the laser treatment. Petrolatum gauze, cotton gauze and a bandage will protect the fat-grafted/fat-delivered sites

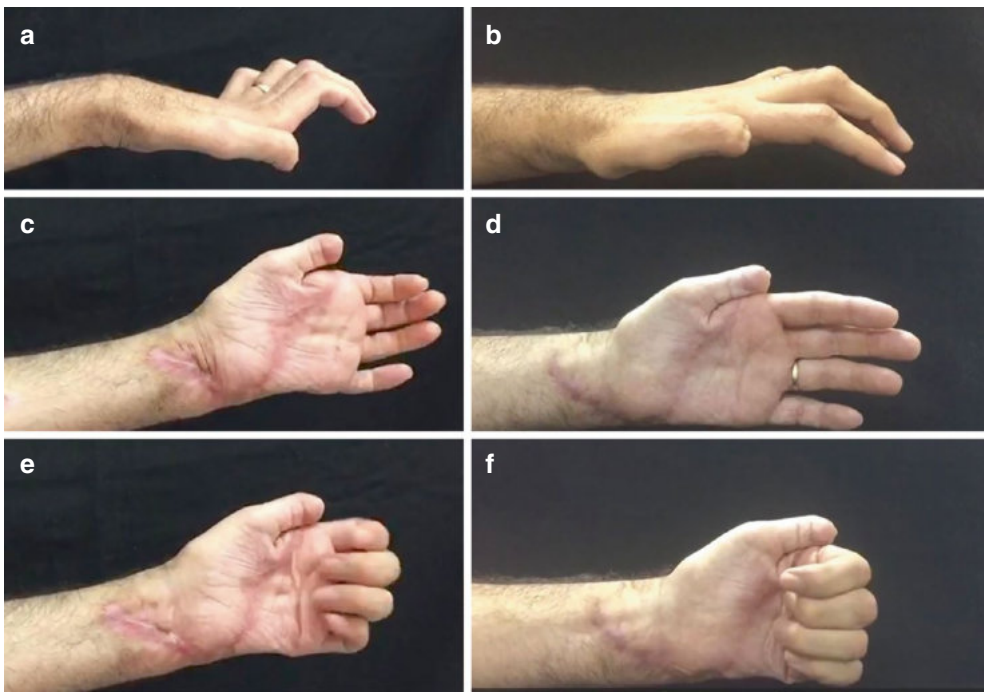


Fig. 17.13 (**a**, **c**), and (**e**) 32 yo pt 4mo post high voltage injury with cicatricial tendon adhesions and severe intrinsic muscle atrophy/movement restriction in fingers and distal forearm; (**b**, **d**, and **f**) result 8 weeks after 2nd injection (in intrinsic muscles, along nerve and tendons trajectories and at the volar adhesion) and local superficial scar revision (no surgical tenolysis was performed)

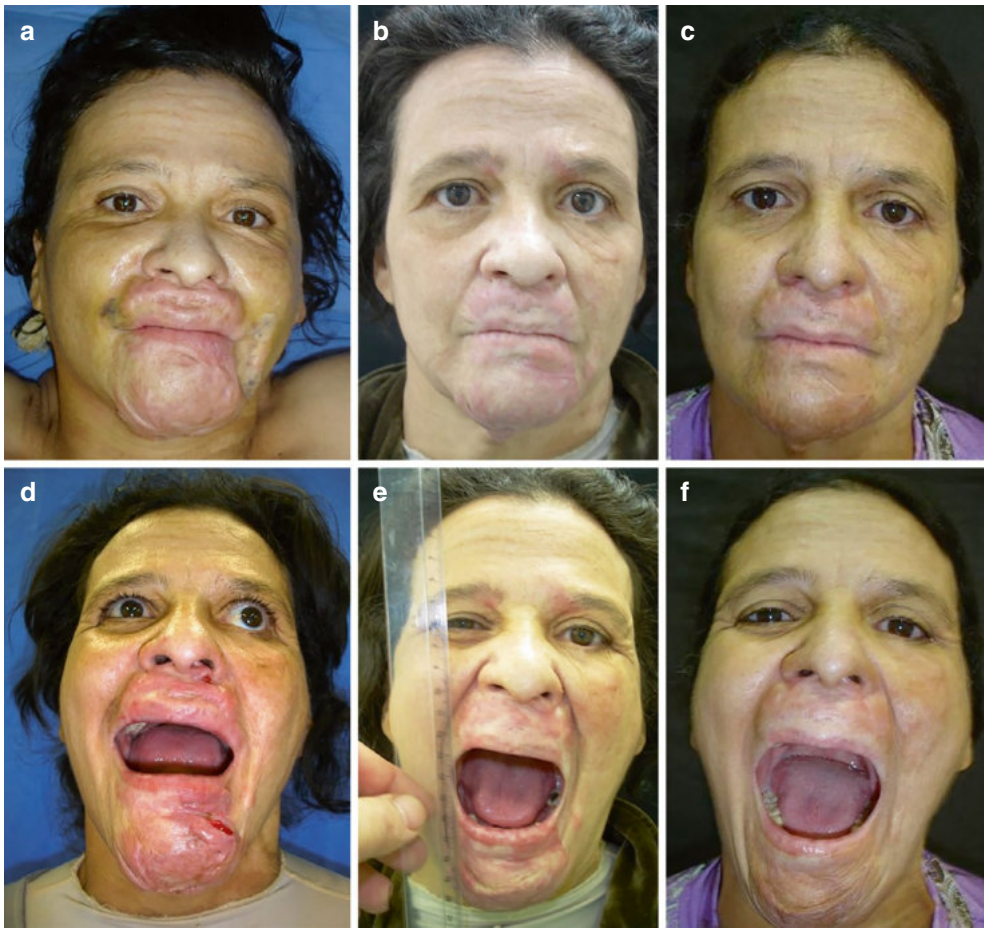


Fig. 17.14 (**a**, **d**) 46-year-old lady 4 months post ethanol burn to the face. Severe hypertrophic scarring and perioral contraction; (**b**, **e**) appearance 6 weeks after first fat grafting session. Note already significant improvement in the scar surface as well as in the perioral contraction; (**c**, **f**) 8 weeks after the second injection (8 weeks after the first one). Note normal mouth opening and marked improvement in the hypertrophic scarring volume and appearance

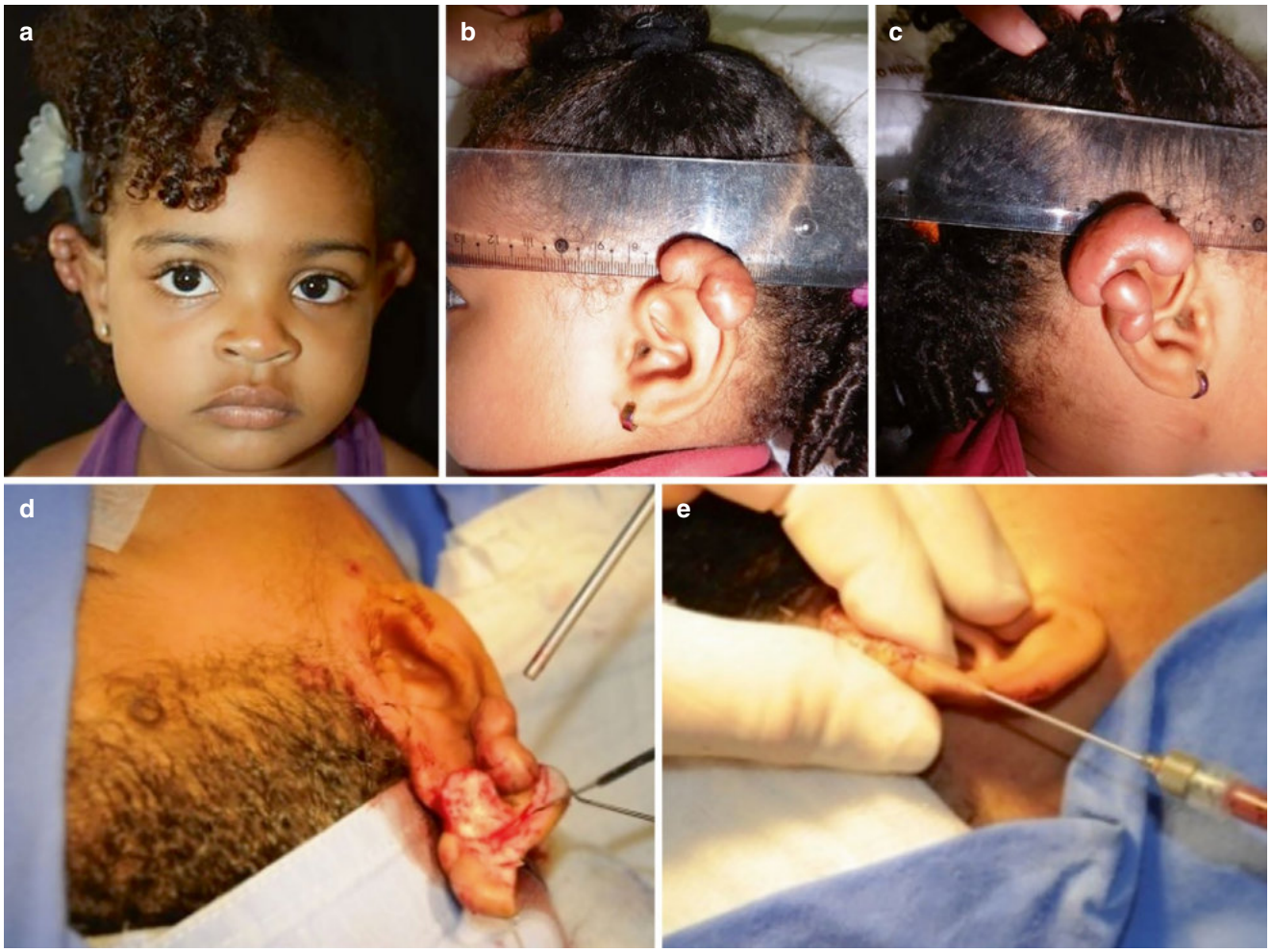


Fig. 17.15 (**a**–**c**) 2 0.5-year-old girl 4 months post ethanol burn; (**d**) Scar resection reconstructing the "normal" appearance helix border; (**e**) Fat injection within the suture line and under the residual substance of the scar

Fig. 17.16 (**a**–**c**) Same patient as in Fig. 17.15, 3 years later. Please note that there has been no recurrence; (**e**, **f**) same patient 7 years later – absolutely no recurrences

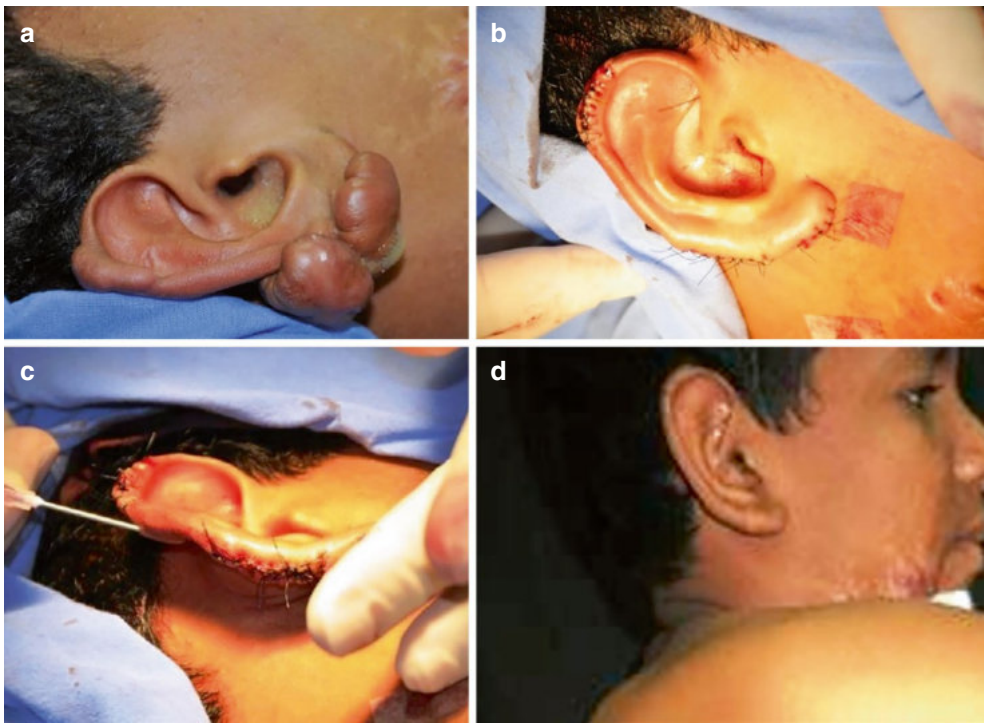


Fig. 17.17 (**a**) 14 yo boy 8 mo post ethanol burn; (**b**) complete scar resection; (**c**) fat grafting within the suture line and under the substance of the residual scar; (**d**) results at 8 mo post op

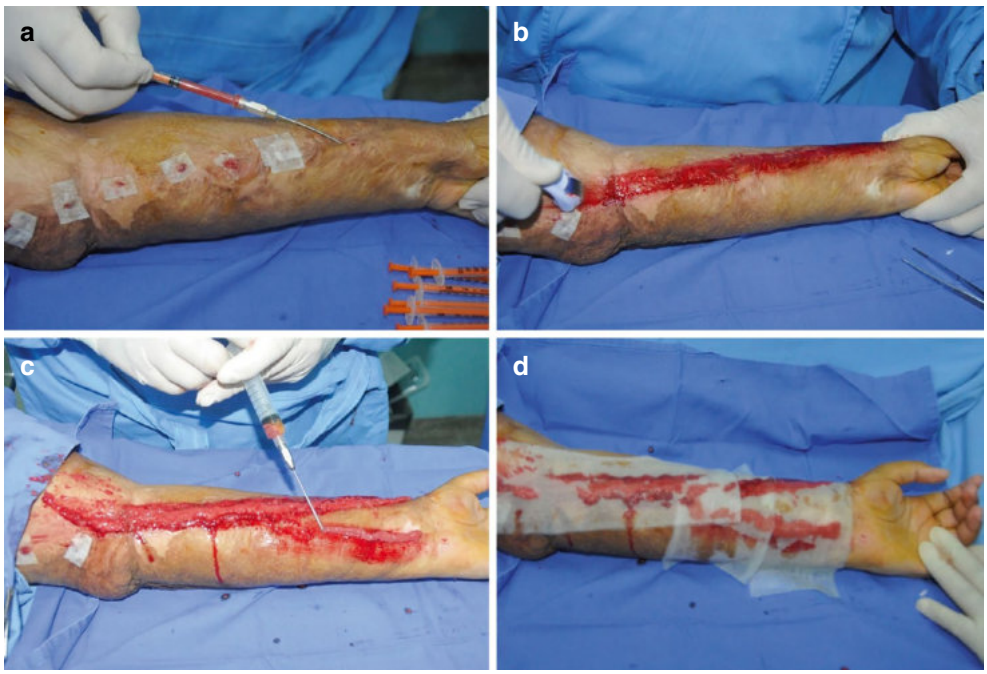


Fig. 17.18 (**a**) 15-year-old girl post ethanol burns and multiple procedures (three fat grafting procedures and multiple z plasties L forearm, 2 years ago). Progressive fat grafting along retraction band on the medial epicondyle-scaphoid axis; (**b**) Microneedling with a 1.5 mm derma roller along the scar (already fat grafted); (**c**) Fat delivery along the micro needled area; (**d**) Vaseline gauze covers the fat and the dressing is complemented by cotton gauze soaked in Dakin's solution and a bandage

ful use of "drug delivery" in laser treatment, since fractional CO_2 lasers have been used also for this (additional) purpose. We postulate that similarly, microneedling or laser treatment of the scar surface will open pores in enough quantity through the scar surface (epithelium and outer dermis or outer "scar tissue"), allowing for fat and growth factors contained in fat to penetrate and act directly within the substance of the scar. This has certainly brought an additional benefit to the already recognized benefits of subcicatricial injection of fat.

We have added this technique to every fat grafting to scars, calling it "fat delivery", as previously mentioned several times. It is performed during the same procedure, after fat grafting is completed under the scar, when fat also prepared by the Coleman Technique is directly delivered to the surface of the area being treated, right after microneedling or laser treatment. Patients who had previously been treated by once or more times with fat grafting alone and had fat grafting/fat delivery in sequence with their treatment reported a much greater (and faster) improvement. Because of these and the other reasons mentioned above, we now perform fat grafting/fat delivery as our standard technique.

It has been reported that micropores generated by microneedles in rat skin "in vivo" were opened up to 72 h after microneedle treatment when they were held under occlusive conditions, e.g., using occlusive dressings. However, micropores close shortly after microneedle application when micropores were not covered by an occlusive dressing. We recommend the use of petrolatum (vaseline impregnated) gauze, also because of its ability to keep the surface (and the fat) moist, hindering local desiccation. A cotton gauze impregnated in Dakin's solution and a bandage will complete the dressing. Dressing changes are routinely changed at 2-day intervals, and the delivered fat is usually removed on the second dressing change (postoperative Day 4) [12–16] (Fig. 17.18).

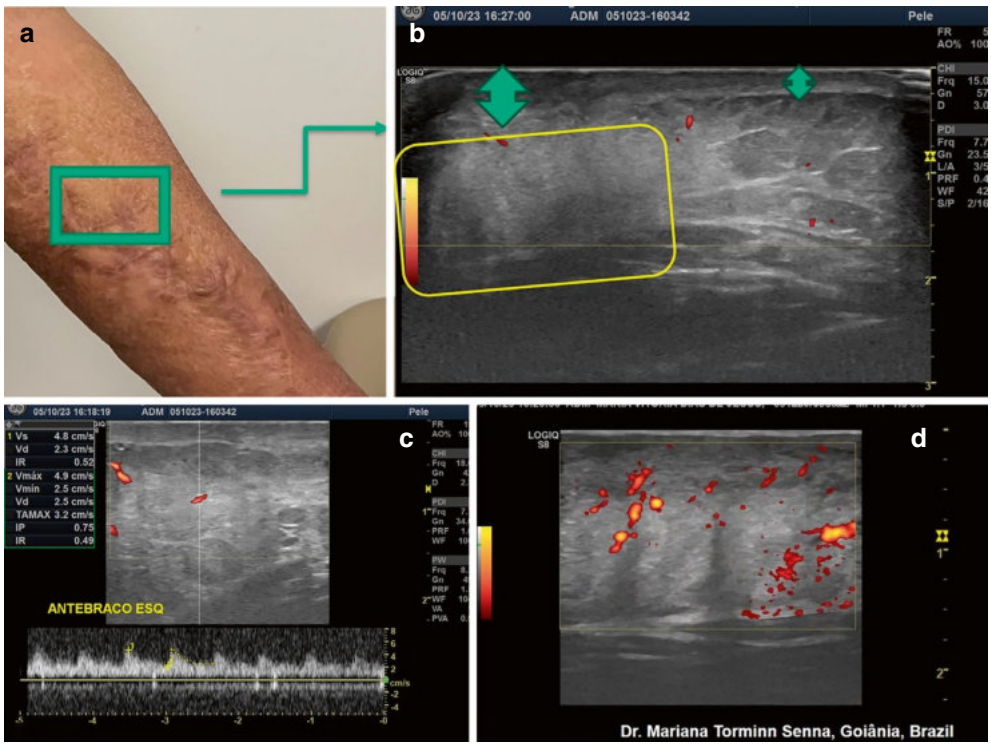


Fig. 17.19 (**a**) Same patient as in Fig. 17.18. Green rectangle indicates area where the image on B was obtained; (**b**) Yellow rectangular marking indicates area where fat was grafted; larger vertical double arrow indicate retraction band cicatricial tissue; smaller vertical double arrow indicates "normal" skin; (**c**) Spectral Doppler demonstrates a new arterial formation within the grafted fat at 7 days post op (center of the picture); (**d**) Power Doppler demonstrates significant irrigation inflow in grafted fat area, at 7 days post op (*see* Video 17.5)

17.3 Ultrasound, Power Doppler, Spectral Doppler Scar Evaluation

Scar thickness has been evaluated through several different technologies, including high-frequency ultrasound, analyzing skin and subcutaneous structures, and appendices. We have been using this method routinely for scar evaluation preoperatively as well as postoperatively in relation to the evolution/improvement of the scar tissue itself.

Our radiologist, Dr. Mariana Senna, also has been using the Power Doppler and the Spectral Doppler to evaluate the changes in vascularity in the area treated by fat grafting. There are immediate changes postoperatively, with a very noticeable augmentation in vascular irrigation growth as early as during the first week but still perceived as long as several months to years after the original fat grafting procedure.

This improvement can be easily verified by comparing a similar area (usually adjacent or even symmetrical) that was not fat grafted in the same person.

To our knowledge, this is a new use of these technologies, and we are now using them and also working on how to "volumetrize" the fat-grafted tissue that has "stayed" in the treated area (Fig. 17.19 and Video 17.5) [17, 18].

17.4 Summary

The range of utilization of fat grafting is, almost certainly, still underestimated. There are, and certainly will be, still many different entities that could benefit by the deposition of centrifuged fat directly under, over, or around the affected anatomic structure or wound or scar surface.

As for the practitioner in charge of taking care of patients with scars or wounds, one can certainly apply this treatment method with the certainty that it will definitely promote a prompter healing, with relatively little or no hypertrophy. This is also true upon returning to the scarred wound or treating a scar in consequence of a wound not previously treated by fat grafting/fat delivery, when the result may be cumulative or primary but will provide suppleness and functionality, regardless of the timing it was used.

The recent discovery of a new use of the Power Doppler and the Spectral Doppler by one of our collaborators (Dr. Mariana Senna) has definitely become a most important tool in evaluating the fate of the grafted fat, as well as eventually may be used to actually determine local volume permanency (and proportional loss) along the time of treatment and beyond.

Acknowledgments The authors would like to thank Dr. Altamiro Vieira, MD, for his most valuable help in the photographic documentation of these patients' cases.

References

1. Zuk PA, Zhu M, Mizuno H, Huang J, Futrell JW, Katz AJ, Hedrick MH. Multilineage cells from human adipose tissue: implications for cell-based therapies. Tissue Eng. 2001;7(2):211–28. https://doi.org/10.1089/107632701300062859.
2. Kim WS, Park BS, Sung JH. The wound-healing and antioxidant effects of adipose-derived stem cells. Expert Opin Biol Ther. 2009;9:879–87. https://doi.org/10.1517/14712590903039684.
3. Sarkarat F, Kahali R. Fat graft with growth factors. Atlas Oral Maxillofac Surg Clin. 2018;26(1):33–9. https://doi.org/10.1016/j.cxom.2017.10.003.
4. Sultan SM, Barr JS, Butala P, Davidson EH, Weinstein AL, Knobel D, Hazen A. Fat grafting accelerates revascularisation and decreases fibrosis following thermal injury. J Plast Reconstr Aesthet Surg. 2012;65(2):219–27. https://doi.org/10.1016/j.bjps.2011.08.046.
5. Rigotti G, Marchi A, Gali M, Baroni G, Benati D, Krampera M, Sbarbati A. Clinical treatment of radiotherapy tissue damage by Lipoaspirate transplant: a healing process mediated by adipose-derived adult stem cells. Plast Reconstr Surg. 2007;119(5):1409–22. https://doi.org/10.1097/01.prs.0000256047.47909.71.
6. Klinger M, Marazzi M, Vigo D, Torre M. Fat injection for cases of severe burn outcomes: a new perspective of scar Remodelling and reduction. Aesth Plast Surg. 2008;32(3):465–9. https://doi.org/10.1007/s00266-008-9122-1.
7. Shpichka A, Butnaru D, Bezrukov EA, Sukhanov RB, Atala A, Burdukovskii V, et al. Skin tissue regeneration for burn injury. Stem Cell Res Ther. 2019;10(1):94. https://doi.org/10.1186/s13287-019-1203-3.
8. Klinger M, Klinger F, Caviggioli F, Maione L, Catania B, Veronesi A, et al. Fat grafting for treatment of facial scars. Clin Plast Surg. 2019; https://doi.org/10.1016/j.cps.2019.09.002.
9. Fredman R, Katz AJ, Hultman CS. Fat grafting for burn, traumatic, and surgical scars. Clin Plast Surg. 2017;44(4):781–91. https://doi.org/10.1016/j.cps.2017.05.009.
10. Coleman SR. Long-term survival of fat transplants: controlled demonstrations. Aesth Plast Surg. 1995;19(5):421–5. https://doi.org/10.1007/bf00453875.
11. Coleman SR. Structural fat grafting: more than a permanent filler. Plast Reconstr Surg. 2006;118(Suppl):108S–20S. https://doi.org/10.1097/01.prs.0000234610.81672.e7.
12. Piccolo NS, Piccolo MS, Piccolo MTS. Fat grafting for treatment of burns, burn scars, and other difficult wounds. Clin Plast Surg. 2015;42(2):263–83. https://doi.org/10.1016/j.cps.2014.12.
13. Kalluri H, Banga AK. Formation and closure of microchannels in skin following Microporation. Pharm Res. 2010;28:82–94. https://doi.org/10.1007/s11095-010-0122-x.
14. Li K, et al. The microneedle roller is an effective device for enhancing transdermal drug delivery. Int J Dermatol. 2012;51:1137–9. https://doi.org/10.1111/j.1365-4632.2010.04703.x.
15. Kim YC, Park JH, Prausnitz MR. Microneedles for drug and vaccine delivery. Adv Drug Deliv Rev. 2012;64:1547–68. https://doi.org/10.1016/j.addr.2012.04.005.
16. Van der Maaden K, Jiskoot W, Bouwstra J. Microneedle technologies for (trans)dermal drug and vaccine delivery. J Control Release. 2012;161:645–55. https://doi.org/10.1016/j.jconrel.2012.01.042.
17. Ault P, Plaza A, Paratz J. Scar massage for hypertrophic burns scarring—a systematic review. Burns. 2018;44(1):24–38. https://doi.org/10.1016/j.burns.2017.05.006.
18. Lee KC, Dretzke J, Grover L, Logan A, Moiemen N. A systematic review of objective burn scar measurements. Burns Trauma. 2016;4(1):14. https://doi.org/10.1186/s41038-016-0036-x.

Medical Needling

18

Hans-Oliver Rennekampff, Matthias Aust, Ziyad Alharbi, and Peter M. Vogt

Abstract

Patients with post-burn scarring frequently request help in improving the aesthetic appearance of their residual cicatricial deformity. This quest has led to the application of many different topical therapies, which have included carbon dioxide (CO_2) laser resurfacing, dermabrasion, and deep chemical peels. All these modalities share a similar mechanism of action, topically ablating the skin to yield a more homogenous surface. However, these therapeutic modalities ablate the epidermis and the basement membrane with subsequent protracted reepithelialization, possibly causing additional dermal fibrosis. In contrast, medical needling will preserve the epidermis and restructure the dermis, leading to an improved appearance and high patient satisfaction.

Keywords

Medical needling · Microneedling · Collagen induction · Roller device · Resurfacing · PRP

H.-O. Rennekampff (✉)
Klinik für Plastische, Hand- und Verbrennungschirurgie, RheinMaas Klinikum, Würselen, Germany
e-mail: Hans-Oliver.Rennekampff@rheinmaasklinikum.de

M. Aust
Privatklinik Aust Ästhetik, Landsberg am Lech, Germany

Z. Alharbi
Plastic Surgery and Burn Unit, Fakeeh Care & Fakeeh College of Medical Sciences, Jeddah, Saudi Arabia
e-mail: Alharbi@kamc.med.sa

P. M. Vogt
Klinik für Klinik für Plastische, Ästhetische, Hand- und Wiederherstellungschirurgie, Replantationszentrum Niedersachsen, Schwerbrandverletztenzentrum Niedersachsen, Hannover, Germany
e-mail: maksymiec.christine@mh-hannover.de

18.1 Background of the Technique

Patients with post-burn scarring frequently request help in improving the aesthetic appearance of their residual cicatricial deformity. It is their hope to eradicate the physical evidence of a scar and to re-establish a normal appearance and texture to the site of injury. This quest has led to the application of many different topical therapies, which have included carbon dioxide (CO_2) laser resurfacing, dermabrasion, and deep chemical peels. All these modalities share a similar mechanism of action, topically ablating the skin in an attempt to yield a more homogenous surface. However, this therapeutic action destroys the epidermis and the basement membrane. Ablating the epidermis of already scarred skin with subsequent protracted re-epithelialization may render the skin more sensitive to photodamage and dyschromia and may possibly cause additional dermal fibrosis by the prolonged inflammatory response. Rejuvenation of scarred skin and re-establishment of a more normal appearance require the maintenance or establishment of a normal epidermis with normal color and a normal dermis with natural dermal papillae, good hydration, and normal resilience.

New therapeutic interventions have attempted to preserve the epidermis either completely, as in radiofrequency tissue heating, or partially, as effected by fractionated laser ablation. Initiating a wounding stimulus in the dermis and causing necrosis of dermal cells create a stimulus for fibrosis, inducing new collagen and elastin synthesis by fibroblasts, resulting in skin tightening.

Orentreich and Orentreich [1] and Fernandes [2] independently described "subcision" as a way of building up collagen beneath retracted scars and wrinkles by separating the tethered and depressed surface tissue from the underlying deeper scar tissue. Camirand and Doucet [3] treated scars using a tattoo gun to "needle abrade" them, and although this technique can be used on extensive areas, it is laboriously slow. The holes created in the epidermis by a tattoo gun are generally felt to be too close and too shallow to effect optimal improvement. Severing old, short, and vertically ori-

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_18

ented collagen strands, which tether the bed of the scar to the most superficial layer of the dermis, promotes the removal of damaged collagen and induces new collagen formation immediately below the epidermis. Ideally, one would prefer to affect the reticular dermis, stimulating the production of collagen and elastin fibers while avoiding excessive bleeding under the skin and scars.

Percutaneous collagen induction by medical needling results from the natural response to wounding the skin. This can be initiated through even minute injuries [4, 5]. A single needle prick created through the skin would generally cause an invisible response. A completely different picture emerges when multiple fine wounds are placed close to each other. Building upon these principles and experiences, a specialized tool was designed by Fernandes [1] employing rows of needles that range in length between 1 and 3 mm to achieve percutaneous collagen induction by medical needling. For purely aesthetic treatment of skin, various rolling devices with needle length of 0.5 mm or less are commercially available. However, these devices are not suitable for medical needling of scars and will not be described in this chapter. Ideally, medical needling is combined with topical therapies as vitamin A and C application or additional platelet-rich plasma injection in order to improve the outcome.

18.2 Topical Adjuncts

Vitamin A, as retinoic acid, is an essential vitamin, actually a hormone, for skin that expresses its influence on approximately 400–1000 skin cell-related genes. Vitamin A is thought to be essential for maintaining the normal physiologic processes of the skin, for preserving collagen content, and for ensuring quality wound healing. It controls proliferation and differentiation of all the major cells of the epidermis and dermis and is felt to be essential for rapid healing of the skin [6, 7]. Vitamin A has been shown to facilitate collagen and glycosaminoglycans production by fibroblasts and appears to control the release of transforming growth factor (TGF) β3 in preference to TGF-β1 and TGF-β2 favoring the development of a lattice-patterned collagen network as opposed to the more visible and contracted-appearing scar pattern of parallel collagen deposition.

Retinyl esters are the main form of vitamin A in the skin, and only tiny fractions of vitamin A are found as retinoic acid [8–10]. Fortunately, retinyl esters are easily and rapidly converted into retinoic acid at physiologic doses. As opposed to the retinoic acid formulations, retinyl esters are not considered cellular irritants, and as such are generally well tolerated when applied topically. It is for that reason that we have elected to utilize products with high levels of retinyl esters when treating problem scars.

Vitamin C is a potent reducing agent and is critical for the formation of normal collagen [11]. It is poorly absorbed through the skin and can be quite irritating when applied topically. Ascorbyl tetraisopalmitate has been shown to be an efficient topical form of vitamin C, easily penetrating the skin and incorporated into skin cells. Once inside the cell, it is de-esterified and becomes bioavailable as ascorbic acid.

Platelet-rich plasma (PRP) may improve the regenerative effect of medical needling by its high content of growth factors such as PDGF, TGF, VEGF, and EGF [12–14]. Autologous PRP is obtained by enriching the patient's plasma with a high concentration of platelets. Special kits are available for processing the patient's blood. In general, centrifugation of blood will yield three phases: platelet-poor plasma, PRP, and the cell fraction with erythrocytes and white blood cells. The typical concentration of platelets is around 200.00/µl. Further activation of PRP initiates degranulation of platelets, releasing the growth factors.

Autologous fat is used for a variety of indications, such as volume enlargement, scar improvement, and skin rejuvenation, among other non-cutaneous indications. Processing of crude fat results in microfat (small lobule fat) or nanofat (high concentration of adipose-derived stem cells (ADSCs) and stromal vascular fraction (SVF)) [15]. Due to released growth factors as well as the regenerative capacity of ADSC and SVF, processed fat has been used in scar treatment. Topically applied processed fat for scar improvement has been described by N.S. Piccolo [16].

18.3 Needle Depth

When performing 3-mm needling (Figs. 18.1 and 18.2), needles penetrate up to 3 mm into the dermis and initiate a complex chemical cascade. Platelets instigate the release of

Fig. 18.1 A close-up image of a derma roller with a white cylindrical head covered in small needles, attached to a metallic handle. The background shows blurred text on a paper, indicating sterile packaging. The derma roller is used for skincare treatments

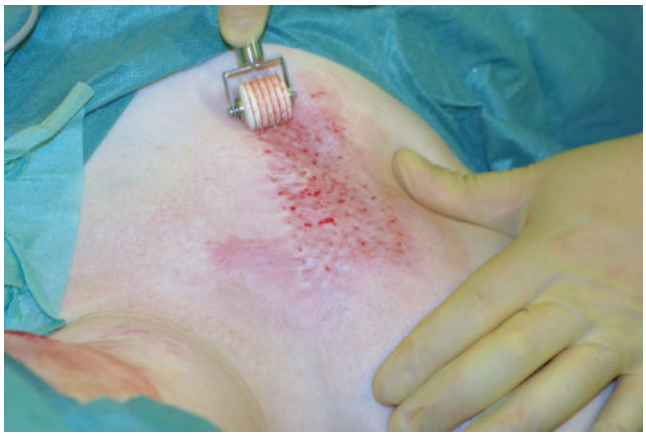


Fig. 18.2 Medical needling performed with a 3-mm roller on a post-burn scar

various growth factors. Fibroblasts migrate into the micro wound sites, and this surge of activity inevitably leads to the production of more collagen and more elastin. Keratinocytes migrate rapidly across the minute epidermal defects and then proliferate, establishing a thickened epidermis. If the 1-mm device is used for microneedling, the bleeding is microscopic and occurs entirely within the papillary and upper reticular dermis as the needles penetrate only to a depth of approximately 0.75–1 mm. Because the epidermis is, on average, 0.2 mm, one can be certain that the injury will be limited to the upper layers of the dermis. It is hypothesized that microneedling excites a smaller inflammatory response, yet the cascade of growth factors still gets initiated by the release of platelets through the puncturing of small vessels by microneedling. The possibility that with microneedling, one gets a purer stimulus for collagen synthesis without the heavy inflammatory reaction exists because subdermal fat is certainly not damaged at the same time. It is believed that because the epidermis remains intact, this might favor predominantly TGF-β3 rather than TGF-β1 and -β2, which are associated with scar collagen deposition. TGF-β3 is implicated in scarless healing and normal lattice weave collagen deposition. Percutaneous collagen induction seems to induce normal lattice weave collagen rather than scar collagen [2]; so, theoretically, TGF-β3 may play an important part in this very early phase [17–19].

18.4 Characteristics and Indication of the Method

The first step is to topically address deficiencies as well as supply the antioxidant vitamins C and E and vitamin A. Medical needling is done with a roller that is equipped with

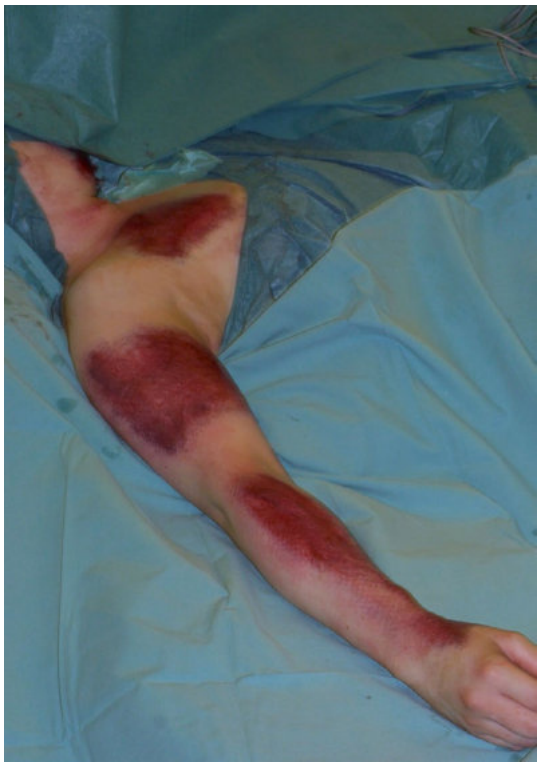


Fig. 18.3 View of the skin immediately after medical needling with a 3-mm roller; notice the bruised appearance

numerous tiny needles that penetrate the skin by 3 mm. Medical needling uses 3-mm needles to penetrate deeper into the skin, and this does cause bruising and swelling (Fig. 18.3). On the other hand, microneedling uses needles that only penetrate to a maximum of 1 mm, and this causes virtually no bruising and minimal swelling. With microneedling you can return to work the day after the treatment without any signs except some pink skin, as though you have been exposed to the sun. Stamp-like devices have been advocated for lower eyelid and perioral regions; however, care must be taken in scarred areas because of the high density of needle pricks, which may destroy the epidermis in scarred tissue.

As mentioned before, medical needling can be combined with the application of PRP or processed fat. PRP will either be additionally rolled or stamped into the skin or topically applied after needling. It was shown that penetration via the microholes will deliver substances deep into the dermis [20].

The number of treatments required will depend on how each individual responds to the treatments and the extent of damage at the beginning (Fig. 18.4). Most patients will begin to see results after the very first appointment (Fig. 18.5). Depending on the degree of improvement that is required, a series of needling sessions can be necessary.

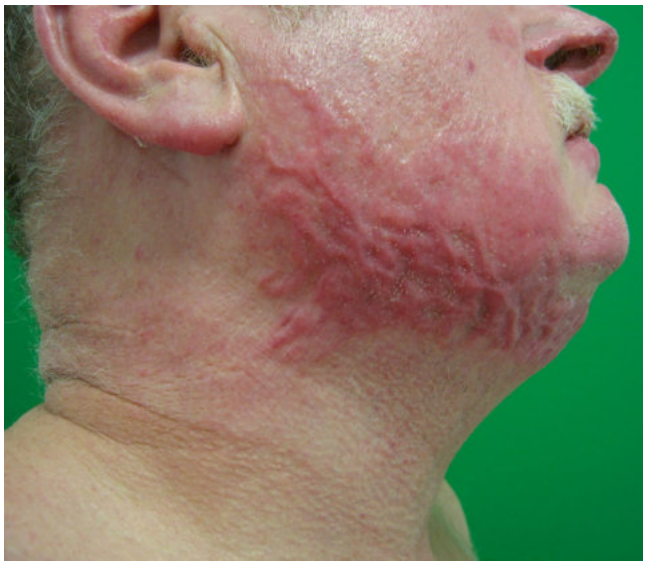


Fig. 18.4 Post-burn scarring after partial thickness burn to the lower face

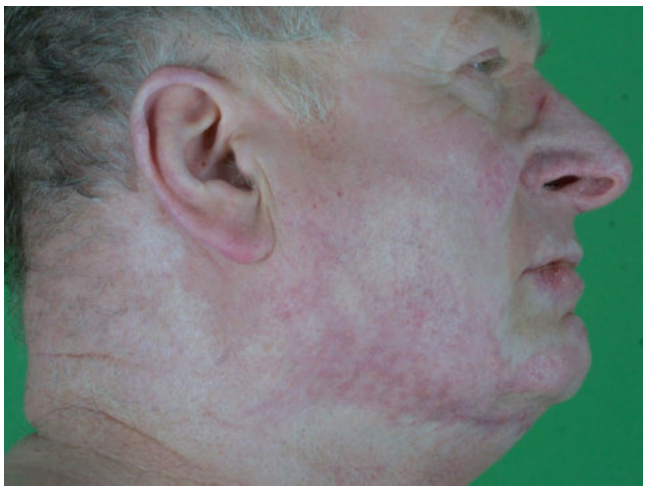


Fig. 18.5 Three months after 3-mm medical needling of the same area. The patient was very satisfied with the outcome

18.4.1 Indications for Medical Needling Post-burn Using the 1-mm Roller

1. As an alternative to dermabrasion for mild to moderate scarring.
2. Scars can be made less obvious by 1-mm needling, and if the scars are depigmented, one can achieve a better color match with the surrounding skin.

18.4.2 Indications for Medical Needling Post-burn Using the 3-mm Roller

Burn scars (Fig. 18.4).

18.4.3 Advantages of Medical Needling

1. Percutaneous collagen induction does not ablate the epidermis.
2. Any part of the body may be treated.
3. Skin becomes thicker.
4. The healing phase is short.
5. The skin does not become sun sensitive.
6. Telangiectasias may disappear.
7. Hyperpigmentation has not yet been described.

18.4.4 Disadvantages of Medical Needling

1. Exposure to blood and a sharp instrument.
2. Although we cannot achieve as intense a deposition of collagen as in CO_2 laser resurfacing, treatment can be repeated with possibly better results.
3. There is a need for anesthesia of the skin when doing 3-mm needling.
4. It takes a longer time to see the result than with laser resurfacing.
5. There is unsightly swelling and bruising for the first 4 days when 3-mm needling has been done.
6. At present no keloids have been described after medical needling, but caution should be taken in patients prone to keloid formation.

18.4.5 Specific Skills of the Method

1. The scarred skin is evaluated, and photographs should be taken pre-treatment.
2. The skin is prepared with topical vitamins A and C and antioxidants for at least 3 weeks, but preferably for 3 months.

3. Under topical, local, or general anesthesia, the skin is closely punctured with the special medical needling tool (Fig. 18.1), consisting of a rolling barrel with needles at regular intervals. It comes in a sterile plastic container and is mounted on a handle at the time of use. Various needle lengths are available; with 1 and 2.5 to 3 mm being the preferred lengths (see above "Indications"). By rolling backward and forward with some pressure in various directions, one can achieve an even distribution of the holes (Fig. 18.2). The needles penetrate through the epidermis but do not ablate it, and because the epidermis is only punctured, it will heal rapidly. The skin bleeds for a short while and develops multiple microbruises in the dermis. We use wet gauze swabs to soak up any ooze of serum when 3-mm needles have been used. At this point additional PRP can be applied (Figs. 18.6 and 18.7). Once the serous ooze has stopped, the skin is covered with a special vitamin A, C, and E oil. If the skin has been needled with the 1-mm roller, the bleeding under the skin is microscopic, and one does not get serious ooze postoperatively. If 1-mm needling has been done, the patient will only experience a flushed appearance of the skin and will not develop bruises or swelling.
4. If 3-mm needling has been done, the patient should be instructed that he/she will look bruised and become quite swollen (Fig. 18.3). The patient is encouraged to shower within a few hours of the procedure, and by day 4–5, the skin will develop a moderate pink flush that can be concealed with makeup. Some residual bruising may still be present at this time.
5. Post-treatment, the patient is encouraged to use topical vitamin A and vitamin C cream or oils to promote better healing and greater production of collagen. The addition of peptides such as palmitoyl pentapeptide could possibly ensure even better results. Iontophoresis also tends to reduce the swelling of the skin. Low-frequency sonophoresis can be used to enhance penetration of palmitoyl pentapeptide or other peptides.

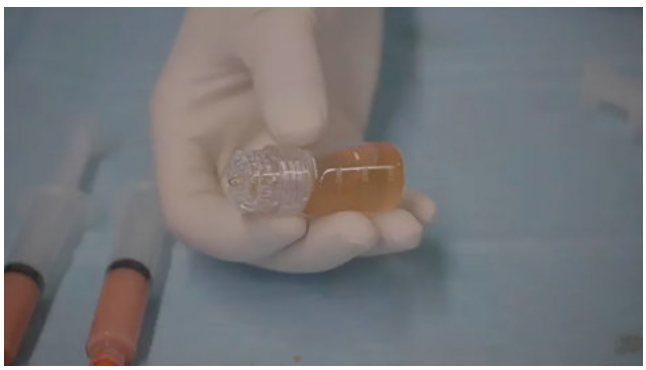


Fig. 18.6 Stamping device AQUAGOLD® fine touch™ filled with PRP

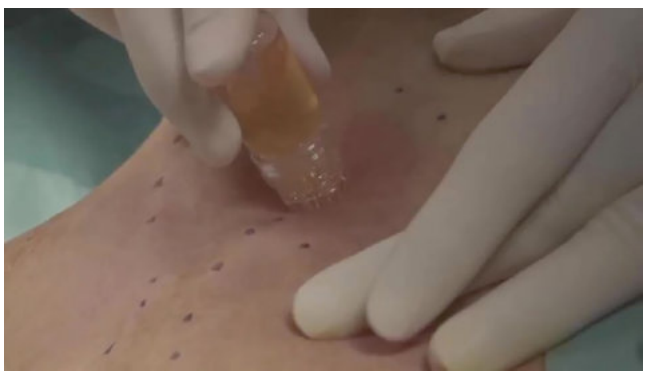


Fig. 18.7 Additional needling with the stamping device while PRP is applied

References

1. Orentreich DS, Orentreich N. Subcutaneous incisionless (subcision) surgery for the correction of depressed scars and wrinkles. Dermatologic Surg. 1995;21:543–9.
2. Fernandes D. Percutaneous collagen induction: an alternative to laser resurfacing. Aesthetic Surg J. 2002;22:315.
3. Camirand A. Needle dermabrasion. Aesth Plast Surg. 1997;21:48–51.
4. Aust MC, Fernandes D, Kolokythas P, Kaplan H, Vogt PM. Percutaneous collagen induction therapy (PCI) – an alternative treatment for scars, wrinkles and skin laxity. Plast Reconstr Surg. 2008;121:1421–9.
5. Aust MC, Reimers K, Stahl F, et al. Percutaneous collagen induction (PCI) – minimally invasive skin rejuvenation without risk of hyperpigmentation – fact or fiction? Plast Reconstr Surg. 2008;122:1553–63.
6. Chapellier B, Mark M, Messaddeq N, et al. Physiological and retinoid-induced proliferations of epidermis basal keratinocytes are differently controlled. EMBO. 2002;21:3402–13.
7. Bernard FX, Pedretti N, Rosdy M, Dequercy A. Comparison of gene expression profiles in human keratinocyte mono-layer cultures, reconstituted epidermis and normal human skin: transcriptional effects of retinoid treatments in reconstituted human epidermis. Exp Dermatol. 2002;11:59–74.
8. Sorg O, Didierjean L, Saurat JH. Metabolism of topical retinaldehyde. Dermatology. 1999;199:13–7.
9. Ito YL, Zile M, Ahrens H, DeLuca HF. Liquid-gel partition chromatography of vitamin a compounds: formation of retinoic acid from retinyl acetate in vivo. J Lipid Res. 1974;15:517–24.
10. Sass JO, Didierjean L, Carraux P, et al. Metabolism of topical retinaldehyde and retinol by mouse skin in vivo: predominant formation of retinyl esters and identification of 14-hydroxy-4, 14-retro-retinol. Exp Dermatol. 1996;5:267–71.

11. Nusgens BV, Humbert P, Rougier A, et al. Topically applied vitamin C enhances the mRNA level of collagens I and III, their processing enzymes and tissue inhibitor of matrix metalloproteinase 1 in the human dermis. J Invest Dermatol. 2001;116:853–9.
12. Miyazono K, Takaku F. Platelet-derived growth factors. Blood Rev. 1989;3:269–76.
13. Amable PR, Carias RB, Teixeira MV, et al. Platelet-rich plasma preparation for regenerative medicine: optimization and quantification of cytokines and growth factors. Stem Cell Res Ther. 2013;4:67. https://doi.org/10.1186/scrt218.
14. Hashim PW, Zachary L, Cohen JL, Goldenberg G. Microneedling therapy with and without platelet-rich plasma. Cutis. 2017;99:239–42.
15. Rihani J. Microfat and Nanofat: when and where these treatments work. Facial Plast Surg Clin North Am. 2019;27:321–30.
16. Piccolo NS, Piccolo MS, de Paula PN, et al. Fat grafting for treatment of facial burns and burn scars. Clin Plast Surg. 2020;47:119–30.
17. Ferguson MW, O'Kane S. Scar-free healing: from embryonic mechanisms to adult therapeutic intervention. Philos Trans R Soc Lond Ser B Biol Sci. 2004;359:839–50.
18. Tran KT, Griffith L, Wells A. Extracellular matrix signalling through growth factor receptors during wound healing. Wound Repair Regen. 2004;12:262–8.
19. Bandyopadhyay B, Fan J, Guan S, et al. A "traffic control" role for TGFbeta3: orchestrating dermal and epidermal cell motility during wound healing. J Cell Biol. 2006;172:1093–105.
20. Li G, Badkar A, Kalluri H, Banga AK. Microchannels created by sugar and metal microneedles: characterization by microscopy, macromolecular flux and other techniques. J Pharm Sci. 2010;99:1931–41.

Fractional Laser

19

Taro Kono

Abstract

Traditional CO_2 laser resurfacing has been the gold standard. However, results were dependent on the operator, and scar recurrence or worsening was observed. Fractional photothermolysis is characterized by the creation of microscopic zones of thermal damage with spatial separation between the columns of damaged tissue and the columns of untreated tissue. Fractional lasers enable us to predictably, effectively, and safely treat scars.

Keywords

Fractional photothermolysis · Scars · Fractional ablative laser · Fractional nonablative laser · Fractional radiofrequency · Fractional picosecond laser

19.1 Fractional Nonablative Lasers

Photothermal action plays a central role in the biological effects of lasers. The temperature of biological tissue increases upon laser irradiation, reaching 100 °C, causing water in the tissue to boil and other tissues to evaporate and vaporize. This photothermal effect is known as transpiration. Ablative lasers (CO_2, Er:YAG, and Er:YSGG lasers) in the field of cosmetic dermatology are exfoliative lasers that induce transpiration in skin tissue through photothermal action. The CO_2 laser can be categorized into two main types of oscillation: continuous wave oscillation, where the laser operates continuously, and pulsed wave oscillation, where the laser operates for a very short period. In the 1980s, CO_2 lasers were the primary choice for resurfacing treatments, but they carried a high risk of serious complications, such as scarring. The risk of scarring has significantly decreased with the development of ultra-pulsed and super-pulsed CO_2 lasers with short pulse widths [1]. However, dark-skinned patients exhibited a higher frequency of postoperative complications, including redness, swelling, and pigmentary abnormalities, compared to Caucasians [2].

In 2004, Manstein et al. introduced a new concept of cutaneous remodeling called fractional photothermolysis [3]. Fractional photothermolysis involves creating microscopic zones of thermal damage with spatial separation between the columns of damaged tissue and the columns of untreated tissue. The depth of each column can be controlled by adjusting the pulse energy. With nonablative fractional resurfacing, a parallel column of heated but not ablated tissue extends into the dermis.

The wavelengths are 1320, 1410, 1440, 1540, 1550, and 1927 nm (Figs. 19.1 and 19.2); the laser types include Nd:YAG, Raman fiber, Er:Glass fiber, and Thulium fiber; the irradiation diameter ranges from 100 to 450 μm; the irradiation patterns include roller type and stamp type (Figs. 19.3, 19.4 and 19.5); and cooling methods comprise contact type (Fig. 19.6) and air cooling type (Fig. 19.7). Because NAFL wavelengths are absorbed by water, the depth of penetration does not increase with the wavelength's increase, contrary to other wavelengths. The order of water absorptivity is 1927, 1440, 1410, 1540, 1550, and 1320 nm, while the order of depth coverage is 1320, 1550, 1540, 1410, 1440, and 1927 nm. Although the irradiation diameter is crucial, the width of the thermally solidified layer is even more significant. The width of the thermal solidification layer depends on the irradiation diameter, irradiation time, and power. The wider the coagulation layer, the more effective the treatment, but there is a higher risk of post-inflammatory hyperpigmentation [4, 5]. Skin cooling is essential. A new method has been devised and put into practical use, wherein the laser-irradiated surface is processed into a convex shape to minimize thermal damage to the epidermis while increasing the depth of penetration [6].

T. Kono (✉)
Department of Plastic Surgery, Tokai University School of Medicine, Isehara, Kanagawa, Japan

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_19

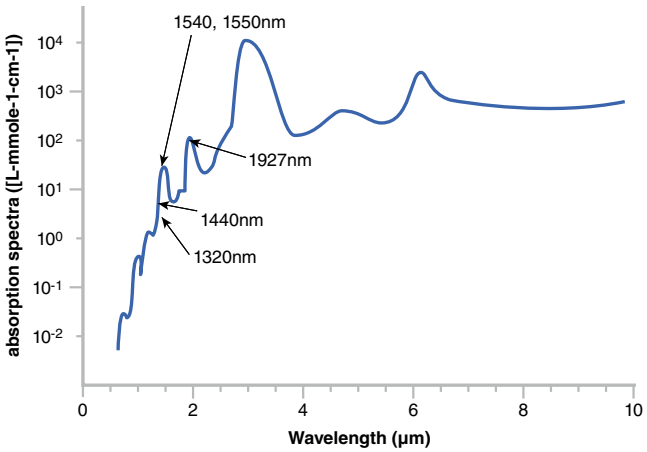


Fig. 19.1 Absorption spectra of water (nonablative fractional lasers)

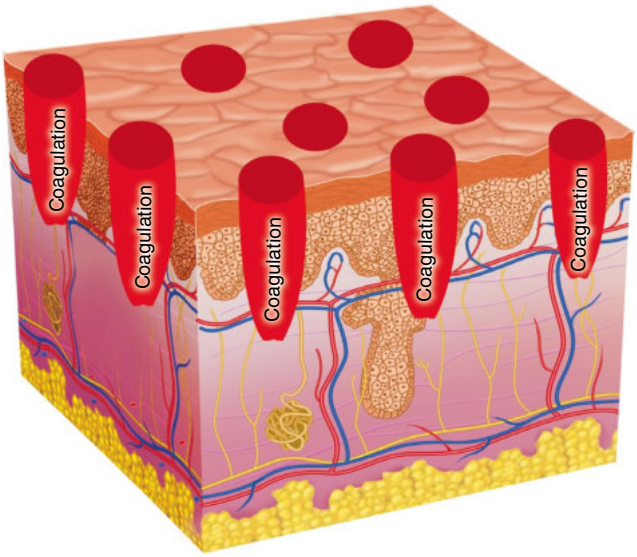
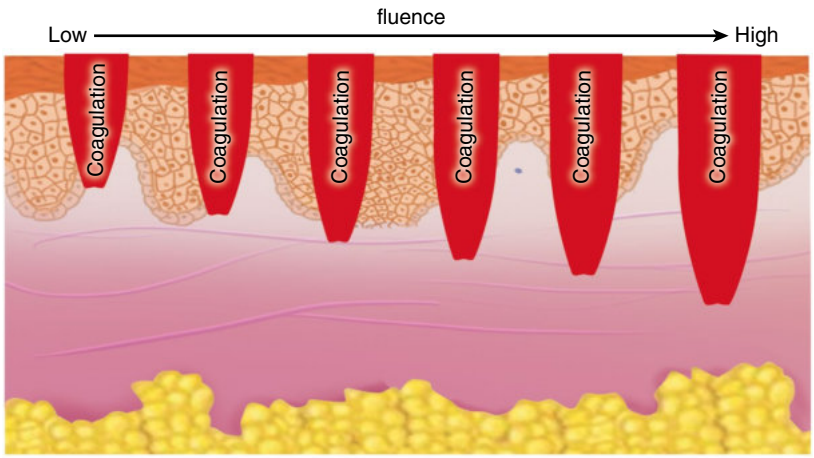


Fig. 19.2 Tissue interaction of nonablative fractional lasers

Fig. 19.3 Penetration depth of nonablative fractional laser



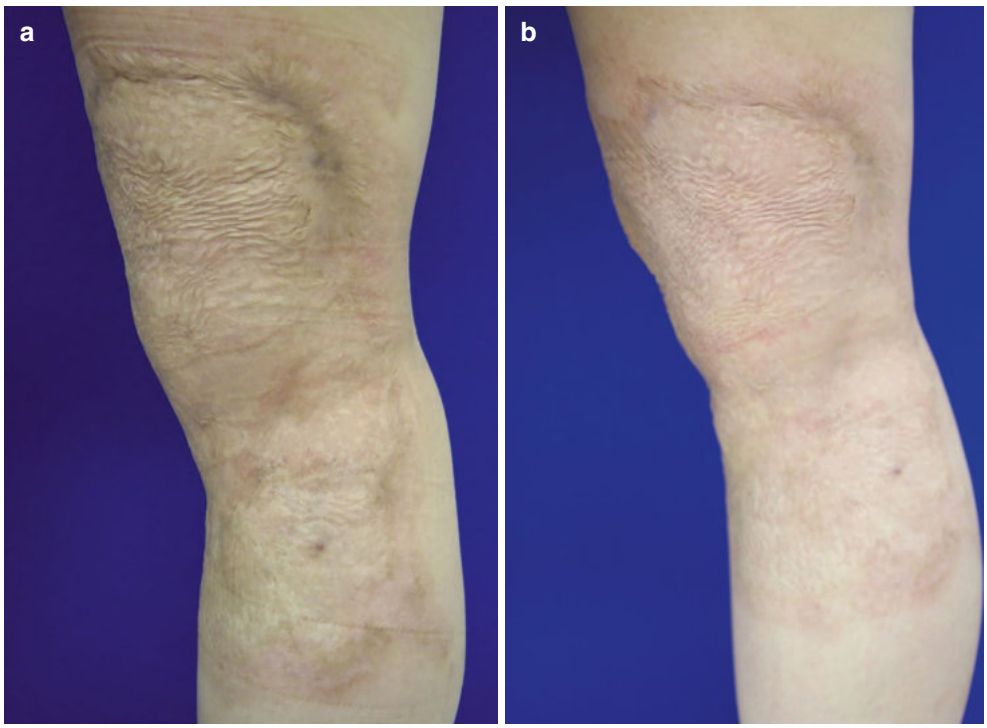


Fig. 19.4 28-year-old female. (**a**) Before treatment. (**b**) After two sessions of nonablative fractional laser treatment

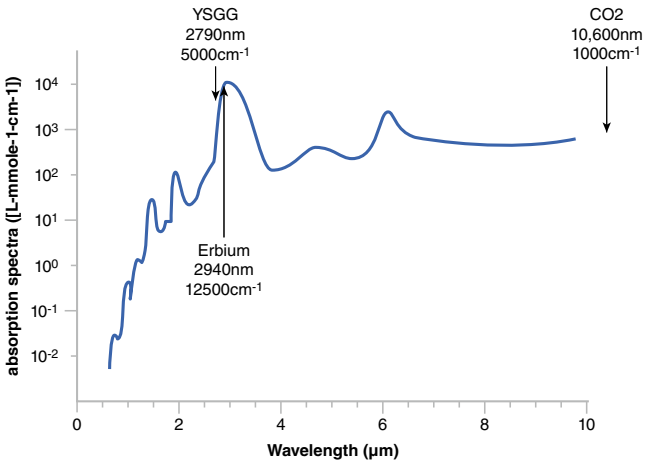


Fig. 19.5 Absorption spectra of water (ablative fractional lasers)

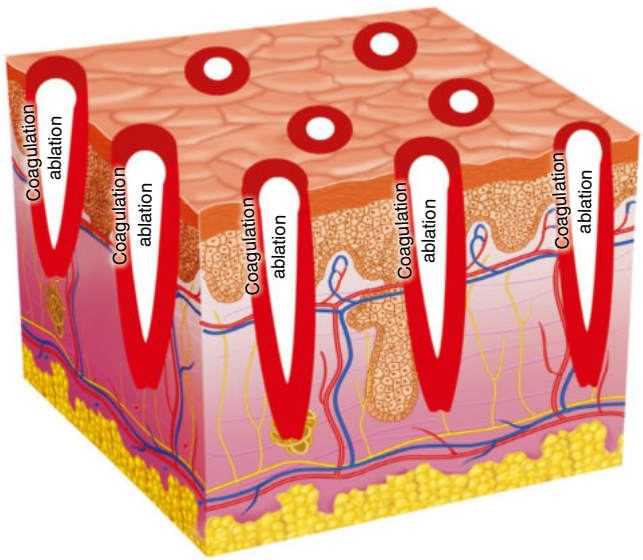


Fig. 19.6 Tissue interaction of ablative fractional lasers

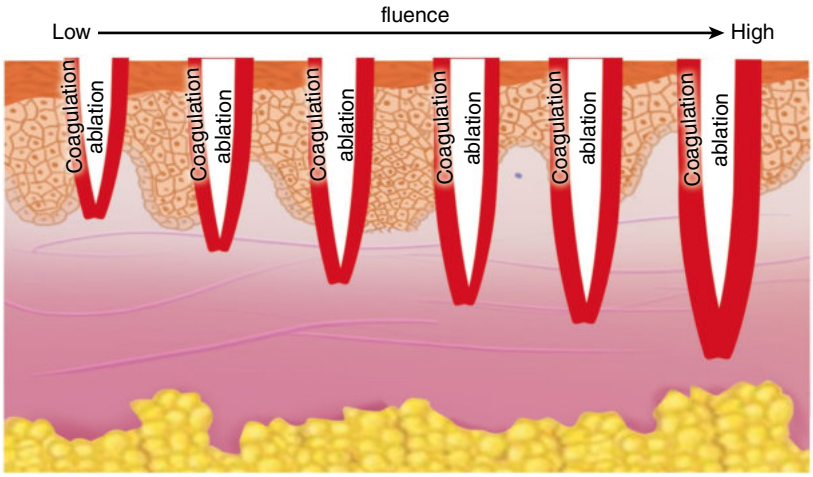


Fig. 19.7 Penetration depth of ablative fractional laser

19.2 Fractional Ablative Lasers

The same concept has been extended to ablative fractional resurfacing using the CO_2 laser. Additionally, Er:YAG and Er:YSGG lasers, characterized by high water absorption rates, have been developed, enabling less invasive treatment compared to the CO_2 laser.

In comparison with nonablative fractionated devices, fractional ablative lasers generate more intense tissue heating, leading to tissue vaporization while significantly heating adjacent dermal collagen. The substantial collateral heating volume induces thermal alterations in the helical structure of collagen molecules, resulting in tissue tightening. The fractional CO_2 laser offers a penetration depth that can vary up to 1500 micrometers, with the depth of the heated tissue determined by the pulse energy. When treating scars of any etiology, penetrating to the scar's depth provides significantly greater potential for improvement. Higher density treatment allows for better tissue tightening. However, using high density carries the potential risk of bulk heating. Low density with a multi-pass technique is safer than high density with a single pass. Common complications induced by fractional ablative lasers include hyperpigmentation, discoloration, erythema, pruritus, infection, blistering, bleeding, and swelling [7–9].

The utilization of fractional ablative laser significantly enhanced the appearance and morphology of burn scars, as evaluated through the VSS and POSAS scales. Additionally, the thickness of scars, assessed via ultrasound, exhibited a significant decrease post-treatment. The side effects and complications induced by the fractional CO_2 laser were mild and tolerable [10].

19.3 Fractional Radiofrequency

In the radio wave region, which has a longer wavelength than light, pigments such as melanin and hemoglobin remain unaffected. Hence, there is no necessity to consider variations in melanin content based on factors such as race, sunburn, or tattoos. Furthermore, since it is not light, protective goggles are unnecessary for both the surgeon and the patient. Additionally, measures like placing mirrors or implementing light-shielding curtains to prevent light leakage are not required. The fractional type is indicated for nearly the same diseases as fractional lasers [11, 12].

The higher the output, the greater the depth of penetration. At low power, only heating occurs with no tissue change, but at higher power, coagulation and degeneration take place, and at even higher power, transpiration is observed. With increased power, both the depth and area of coagulation and transpiration expand. Most of these devices are contact-type, but some involve needle insertion [13]. In the case of needle insertion, the energization time varies significantly depending on the device. The thermal energy generated is directly proportional to time. Both the depth and angle of penetration also vary, leading to distinct biological effects that require careful consideration (Figs. 19.8 and 19.9).

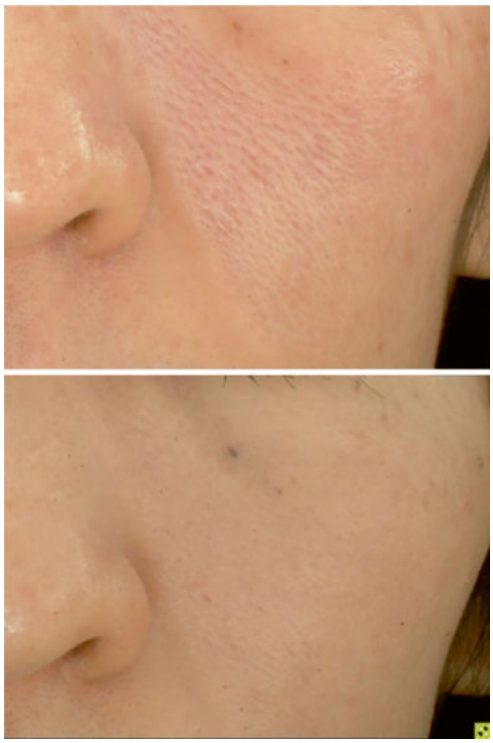


Fig. 19.8 46-year-old female. (**a**) Before treatment. (**b**) After 8 sessions of fractional CO_2 laser treatment

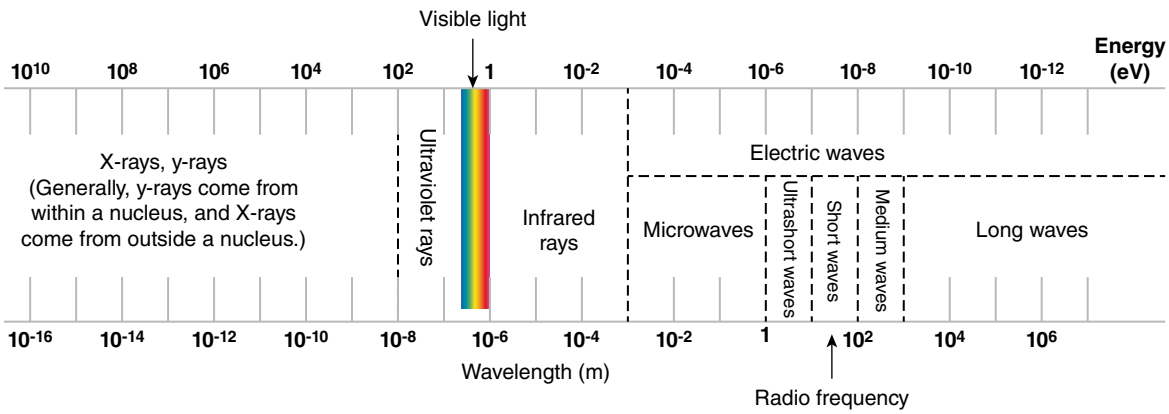


Fig. 19.9 Electromagnetic waves and radio frequency

19.4 Fractional Picosecond Laser

Picosecond lasers exhibit a very short pulse duration and high peak power density. When fractional optical delivery systems are coupled with picosecond lasers, they generate an array of concentrated microspots with high fluence surrounded by areas with low fluence. Fractional picosecond lasers induce laser-induced optical breakdown (LIOB) and laser-induced cavitation (LIC) in the epidermis and dermis, respectively, promoting skin regeneration and dermal remodeling [14]. Studies have demonstrated the positive impact of fractional picosecond lasers on scars (Figs. 19.10, 19.11, 19.12, 19.13, 19.14, 19.15 and 19.16) [15, 16].

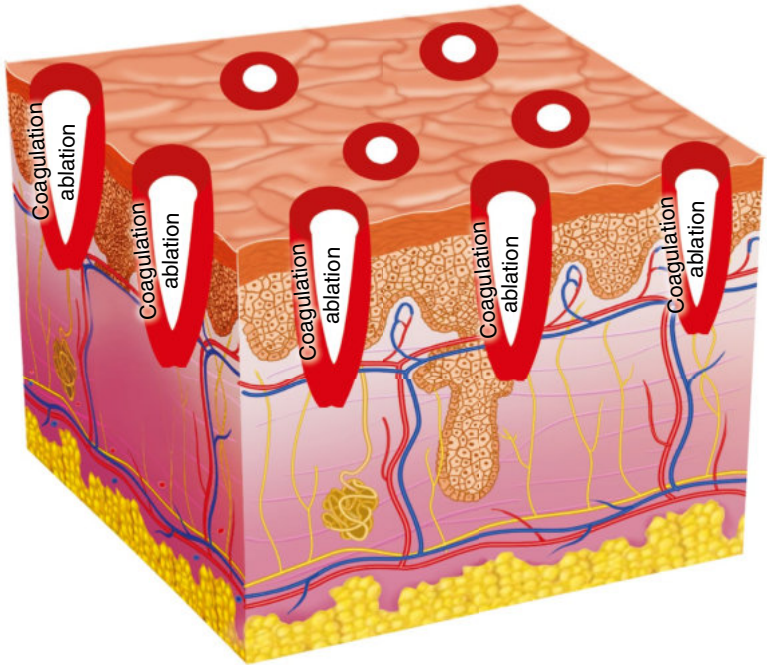


Fig. 19.10 Tissue interaction of fractional radiofrequency

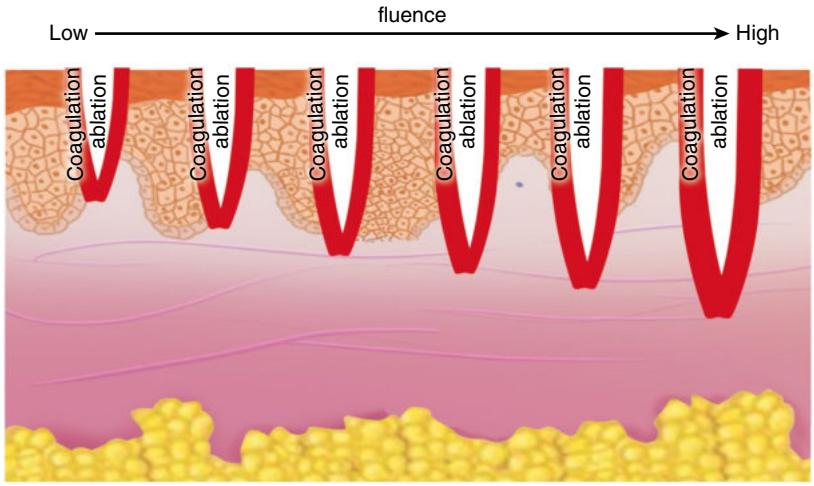


Fig. 19.11 Penetration depth of ablative fractional radiofrequency

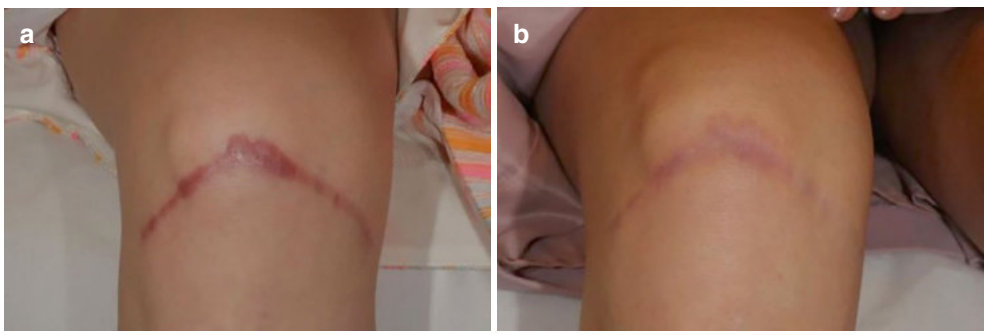


Fig. 19.12 28-year-old female. (**a**) Before treatment. (**b**) After four sessions of fractional radiofrequency treatment

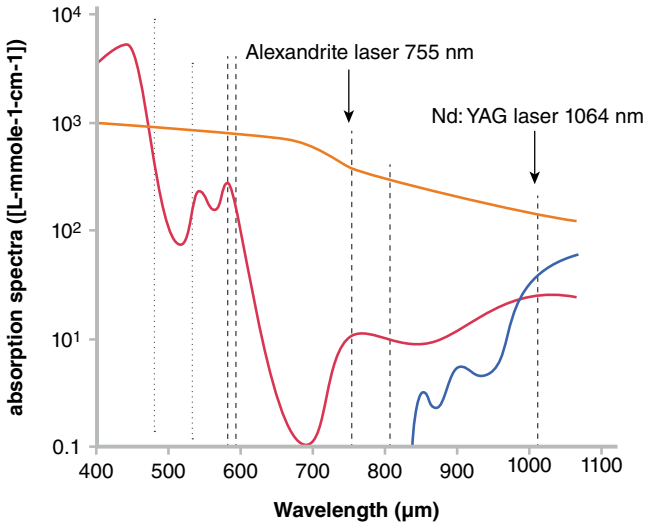


Fig. 19.13 Absorption spectra of melanin, oxyhemoglobin, and water(fractional picosecond lasers)

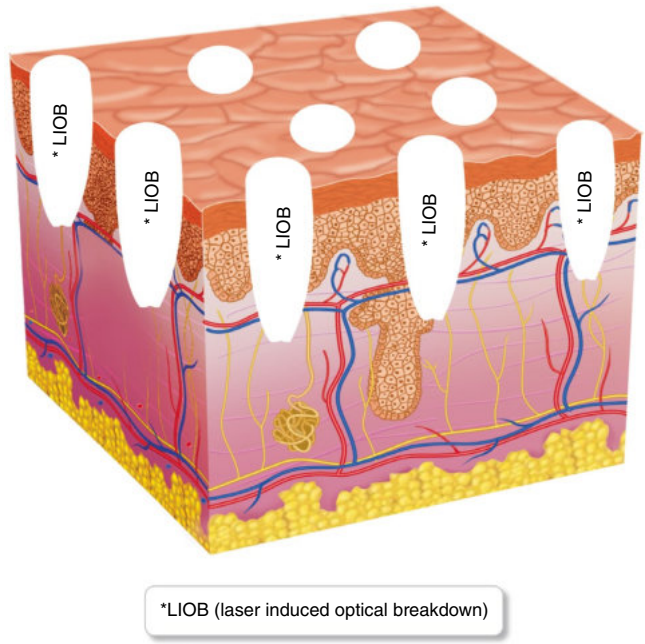


Fig. 19.14 Tissue interaction of fractional picosecond laser. LIOB, Laser-induced optical breakdown

Fig. 19.15 High-power fractional picosecond laser allows ablative treatment

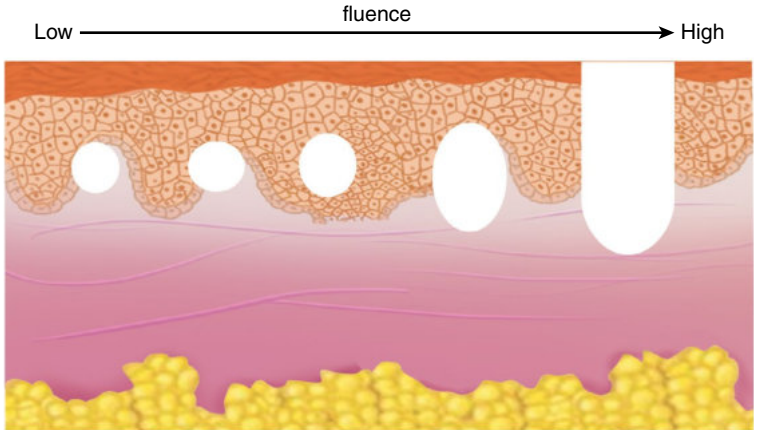
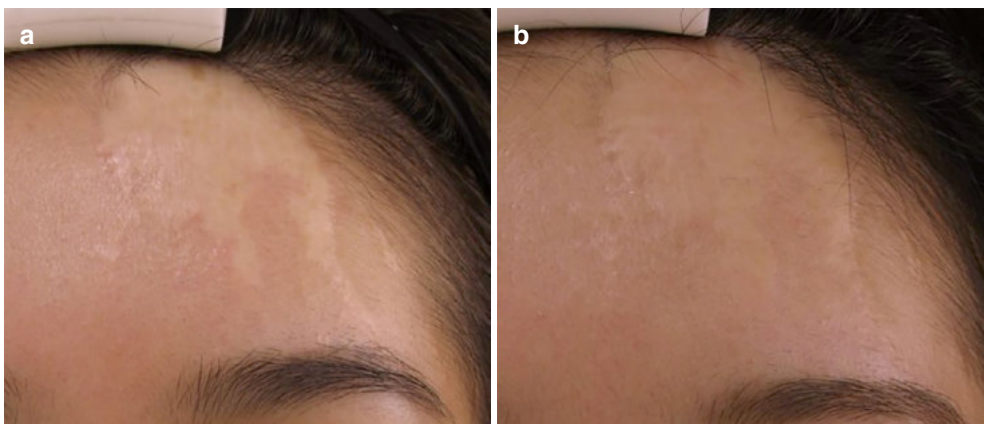


Fig. 19.16 18-year-old female. (**a**) Before treatment. (**b**) After three sessions of fractional picosecond laser treatment



19.5 Summary

Traditional CO_2 laser resurfacing has long been considered the gold standard; however, results were dependent on the operator, and scar recurrence or worsening was observed. Fractional laser and radiofrequency represent emerging technologies that allow for the predictable, efficacious, and safe treatment of scars.

References

1. Fitzpatrick RE, Goldman MP, Satur NM, Tope WD. Pulsed carbon dioxide laser resurfacing of photoaged facial skin. Arch Dermatol. 1996;132:395–402.
2. Nanni CA, Alster TS. Complications of carbon dioxide laser resurfacing. An evaluation of 500 patients. Dermatologic Surg. 1998;24(3):315–20.
3. Manstein D, Herron GS, Sink RK, et al. Fractional photothermolysis: a new concept for cutaneous remodeling using microscopic patterns of thermal injury. Lasers Surg Med. 2004;34:426–38.
4. Kono T, Chan HH, Groff WF, et al. Prospective direct comparison study of fractional resurfacing using different fluences and densities for skin rejuvenation in Asians. Lasers Surg Med. 2007;39:311–4.
5. Chan HH, Manstein D, Yu CS, et al. The prevalence and risk factors of post-inflammatory hyperpigmentation after fractional resurfacing in Asians. Lasers Surg Med. 2007;39:381–5.
6. Malekzad F, Shakoei S, Ayatollahi A, Hejazi S. The safety and efficacy of the 1540nm non-ablative fractional XD probe of star lux 500 device in the treatment of Striae Alba: before-after study. J Lasers Med Sci. 2014;5(4):194–8.
7. Metelitsa AI, Alster TS. Fractionated laser skin resurfacing treatment complications: a review. Dermatologic Surg. 2010;36(3):299–306.
8. Ross RB, Spencer J. Scarring and persistent erythema after fractionated ablative CO2 laser resurfacing. J Drugs Dermatol. 2008;7:1072–3.
9. Fife DJ, Fitzpatrick RE, Zachary CB. Complications of fractional CO2 laser resurfacing: four cases. Lasers Surg Med. 2009;41:179–84.
10. Peng W, Zhang X, Kong X, Shi K. The efficacy and safety of fractional CO2 laser therapy in the treatment of burn scars: a meta-analysis. Burns. 2021;47(7):1469–77.
11. Li J, Duan F, Kuang J. Meta-analysis of fractional radiofrequency treatment for acne and/or acne scars. J Cosmet Dermatol. 2022;21(12):6754–66.
12. Arruda S, Swearingen A, Medrano K, Sadick N. Subject satisfaction following treatment with nanofractional radiofrequency for the treatment and reduction of acne scarring and rhytids: a prospective study. J Cosmet Dermatol. 2021;20(11):3475–81.
13. Tawfic SO, Hassan AS, El-Zahraa Sh Aly F, Elbendary A, Shaker OG, Al Orbani AM. Fractional microneedle radiofrequency versus fractional carbon dioxide laser in the treatment of postburn hypertrophic scars. Lasers Surg Med. 2022;54(8):1089–98.
14. Baleisis J, Rudys R. Microlesion healing dynamics in in vivo porcine skin after treatment with 1064 nm picosecond-domain Nd:YAG laser. J Biophotonics. 2023;16(4):e202200349.
15. Li J, Duan F, Kuang J. Fractional picosecond laser for atrophic acne scars: A meta-analysis. J Cosmet Dermatol. 2023;22(8):2205–17.
16. Disphanurat W, Charutanan N, Sitthiwatthanawong P, Suthiwartnarueput W. Efficacy and safety of fractional 1064-nm picosecond laser for atrophic traumatic and surgical scars: a randomized, single-blinded, split-scar-controlled study. Lasers Surg Med. 2023;55(6):536–46.

Vascular Laser

20

Taro Kono

Abstract

Lasers play a crucial role in scar treatment, with fractional lasers proving effective for both hypertrophic and firm scars. Among vascular lasers, such as the pulsed dye laser and Nd:YAG laser, they are the preferred choice for hypertrophic scars due to their superior vascular improvement compared to fractional lasers.

Keywords

Pulse dye laser · Nd:YAG laser · Hypertrophic scar
Keloid · Scars

20.1 History of the Vascular Laser

The dye laser was developed by Sorokin at IBM in 1966, 6 years after the first ruby laser oscillation by Maiman at the Hughes Research Institute in 1960. In the 1970s, argon lasers, which absorb oxidized hemoglobin better than dye lasers, were utilized for treating vascular lesions. However, the continuous-wave emission of the argon laser led to heat accumulation, resulting in frequent complications such as pigmentary abnormalities and scarring. This occurred not only in the vascular lesion but also in the surrounding normal tissues. In 1983, Anderson et al. introduced the theory of selective photothermolysis [1] and calculated the thermal relaxation time of vascular lesions. Subsequently, in 1986, Tan et al. reported the laser treatment of capillary malformations (port-wine stain) using a pulsed dye laser with a longer pulse width than conventional lasers [2]. The dye laser then emerged as the preferred choice for treating vascular lesions, including telangiectasia. Besides pulsed dye lasers, alexandrite and YAG lasers are also indicated for vascular lesions.

20.2 Pulsed Dye Laser

Pulsed dye lasers (585–600 nm) have good absorption of oxyhemoglobin (Fig. 20.1). Since longer wavelengths increase the depth of penetration, pulsed dye lasers with a wavelength of 595 nm are currently the mainstay (Fig. 20.2). The laser irradiation time is closely related to the thermal relaxation time of the target tissue (Fig. 20.3). The thermal relaxation time of a blood vessel of 50 μm diameter is 1.2 ms. For red scars, the irradiation time is 1–10 ms, with or without purpura formation. Localized steroid injection is used if necessary. For white scars, the dye laser is less effective [3]. According to Worley's systematic review of randomized control trials, ablative laser and pulsed dye laser were the most useful laser treatments. Regression modelling showed the laser treatment response was linked to Fitzpatrick skin type. Adverse events were uncommon for all treatments and mostly transient (Fig. 20.4) [4].

T. Kono (✉)
Department of Plastic Surgery, Tokai University School of Medicine, Isehara, Kanagawa, Japan

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_20

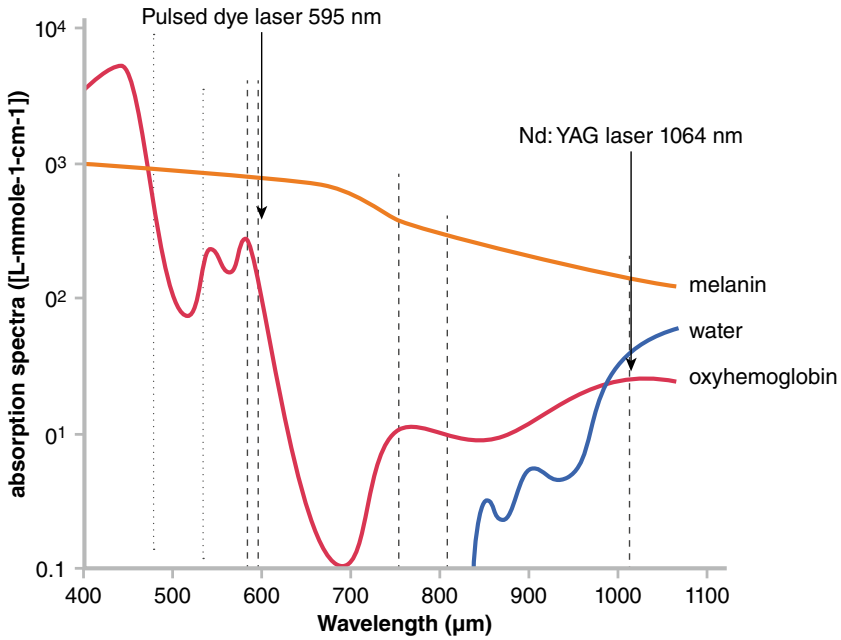


Fig. 20.1 Absorption spectra of melanin, oxyhemoglobin, and water: Pulsed dye laser is absorbed by oxyhemoglobin better than Nd:YAG laser

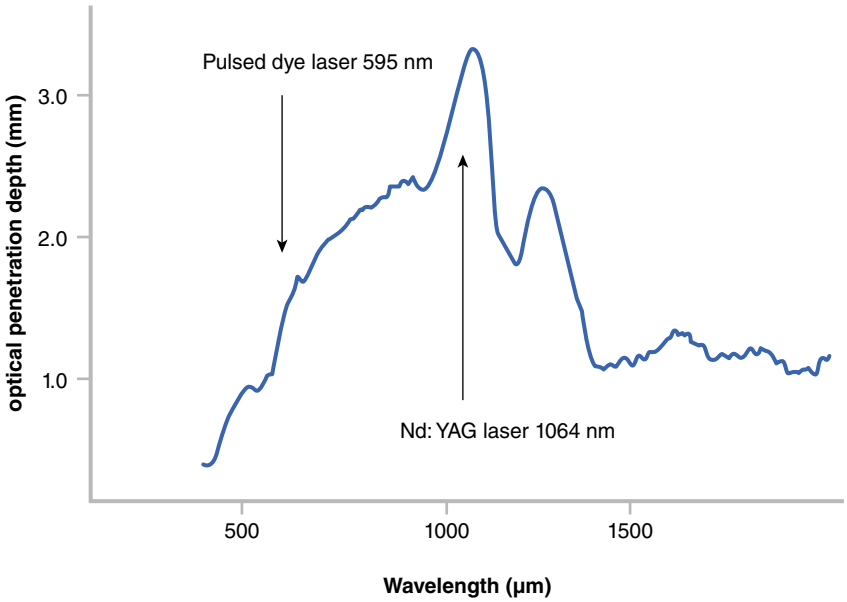


Fig. 20.2 Optical penetration depth of lasers: Pulsed dye laser is better absorbed by oxyhemoglobin than Nd:YAG laser

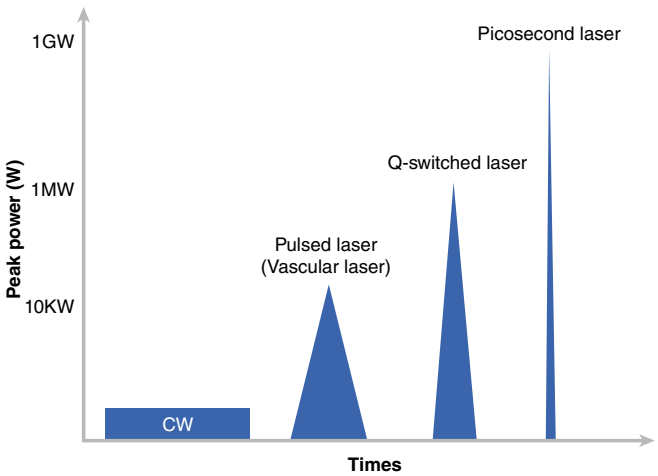


Fig. 20.3 Peak power and time emitted from lasers

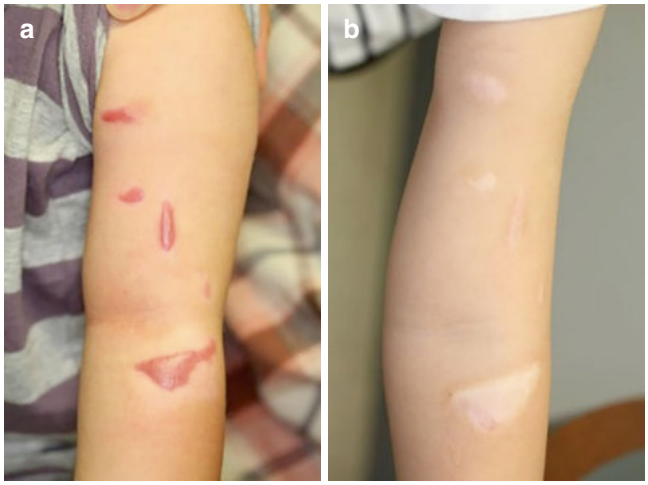


Fig. 20.4 A 2-year-old girl with burn hypertrophic scar on her arm. (**a**) Before treatment; (**b**) after three sessions of pulsed dye laser treatment

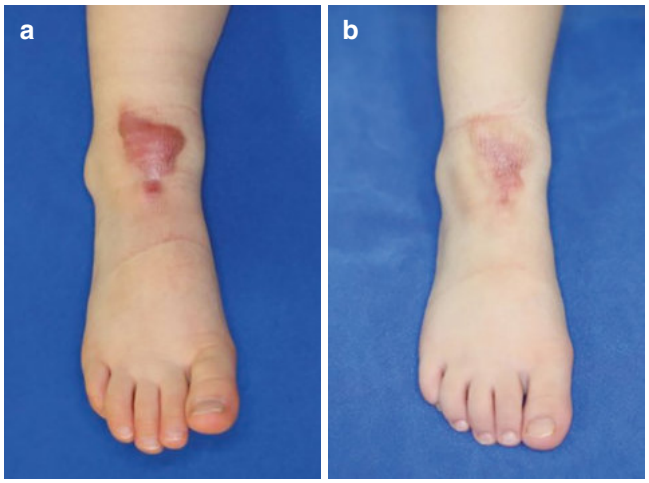


Fig. 20.5 A 2-year-old girl with burn hypertrophic scar on her foot: (**a**) Before treatment; (**b**) after two sessions of Nd:YAG laser treatment

20.3 YAG Laser

Compared to the conventional continuous-wave oscillation YAG laser, the pulsed oscillation YAG laser with a skin cooling system is safer and has a lower risk of recurrence. It also offers the advantage of greater laser depth reach compared to dye lasers [5]. According to Pan's systematic review and meta-analysis of Nd:YAG laser treatment for keloid and hypertrophic scars, the Nd:YAG laser improved the condition of both keloid and hypertrophic scars, leading to a reduced VSS score. There was no noticeable difference in the results between regions. A subgroup analysis by scar type revealed that the curative effect of the Nd:YAG laser on keloid scars was less pronounced compared to that on hypertrophic scars. When combined with other treatment methods, a more significant change in VSS score was observed. The curative effect of this approach on keloid scars was less pronounced compared to that on hypertrophic scars (Fig. 20.5) [6].

20.4 Summary

Pulsed dye lasers and Nd:YAG lasers are the preferred choice for hypertrophic scars due to their superior vascular improvement compared to fractional lasers. However, for white scars, vascular lasers are less effective.

References

1. Anderson RR, Parish JA. Selective photothermolysis: precise microsurgery by selective absorption of pulsed radiation. Science. 1983;220:524.
2. Tan OT, Sherwood K, Gilchrest BA. Treatment of children with port-wine stains using the flashlamp-pulsed tunable dye laser. N Engl J Med. 1989;320(7):416–21.
3. Altemir A, Boixeda P. Laser treatment of burn scars. Actas Dermosifiliogr. 2022;113(10):938–44.
4. Worley B, Kim K, Jain-Poster K, Reynolds KA, Merkel EA, Kang BY, Dirr MA, Anvery N, Christensen RE, Hisham FI, Ibrahim SA, Asadbeigi SN, Poon E, Alam M. Treatment of traumatic hypertrophic scars and keloids: a systematic review of randomized control trials. Arch Dermatol Res. 2023;315(7):1887–96.
5. Ogawa R. Chapter 32: Long-pulsed 1064 nm Nd:YAG laser treatment for keloids and hypertrophic scars. In: Textbook on scar management. Springer; 2020.
6. Pan L, Qin H, Li C, Zhang G, Yang L, Zhang L. Efficacy of the neodymium-doped yttrium aluminum garnet laser in the treatment of keloid and hypertrophic scars: a systematic review and meta-analysis. Aesth Plast Surg. 2022;46(4):1997–2005.

Makeup Therapy for Burn Scar Patients

21

Rintaro Asahi, Reiko Kazuki, and Rei Ogawa

Abstract

The advances in burn medicine have brought an increase in the survival rate of extensive burn patients. However, unf4ortunately, the increase in survival from severe burns is not directly connected with the happiness of the patients. According to our data, only 25% of the patients whose BSA was more than 30% could recover their original position after the discharge from the plastic surgical ward (Aoki R, Nessho 20(2):64–71, 1994). Most of them had to live on social welfare because they could not obtain jobs due to their appearance. Plastic and reconstructive surgery could help mainly functionally. For those who had injured extensively, as the donor sites for skin grafting or flaps were very limited, the aesthetic results were not satisfactory. So we introduced the makeup therapy combined with plastic and reconstructive surgical treatments.

Keywords

Hard type · Total face · Facial massage · Yellow foundation · Injured mind

21.1 Background

The advances in burn medicine have brought an increase in the survival rate of extensive burn patients. However, unfortunately, the increase in survival from severe burns is not directly connected with the happiness of the patients. According to our data, only 25% of the patients whose BSA was more than 30% could recover their original position after the discharge from the plastic surgical ward [1]. Most of them had to live on social welfare because they could not obtain jobs due to their appearance. Plastic and reconstructive surgery could help mainly functionally. For those who had injured extensively, as the donor sites for skin grafting or flaps were very limited, the aesthetic results were not satisfactory. So we introduced the makeup therapy combined with plastic and reconstructive surgical treatments.

The history of makeup therapy for the camouflage of the scar can be traced back to the 1940s. The British Red Cross nurses started to hide the scars of the soldiers who were injured in World War II [2]. They have proved that even nonmedical procedures such as makeup could ease the pain of the patients. Recently, camouflage makeup has been recognized as a good method of scar management and is utilized and researched widely [3, 4]. We have been utilizing makeup therapy combined with plastic surgical services since 2000 to find that this method is pretty effective for the improvement of the quality of life of the patients, especially those with extensive burn scars [5]. However, when we give makeup therapy, we always have to remember the patients' favor and their social or cultural background. They may not become happier or even become less happy when unfavorable makeup is applied. Improving their figure is more difficult than functional improvement. Since 2000, we have treated more than 350 patients with makeup therapy.

21.2 The Method of the Makeup

21.2.1 Moisturizing

Moisturizer such as squalane oil is applied onto the scar to moisturize it because such scars are generally too dry.

R. Asahi (✉)
Nippon Medical School, Tokyo, Japan

R. Kazuki
Department of Plastic, Reconstructive, and Aesthetic Surgery, Nippon Medical School, Reiko Kaziki Co Ltd., Tokyo, Japan
e-mail: watanabe@kazki.co.jp

R. Ogawa
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_21

21.2.2 Massage

Patients with burn scars may sometimes have edemas. Even if not so, facial massage is effective for the improvement of skin texture and color.

Massage should start with the lower eyelid laterally to medially (Fig. 21.1). Then upper eyelid massage in the opposite direction should be followed. Next, the sides of the face are massaged from top down. This massage is performed consecutively with a sponge moistened by squalane oil or face lotion.

21.2.3 Foundation

The choice of foundation should be made considering the patient's skin condition, age, social status, and makeup ability. There are various types of cosmetic foundations, such as lotion type, cream type, hard type, mixing type, and covering type.

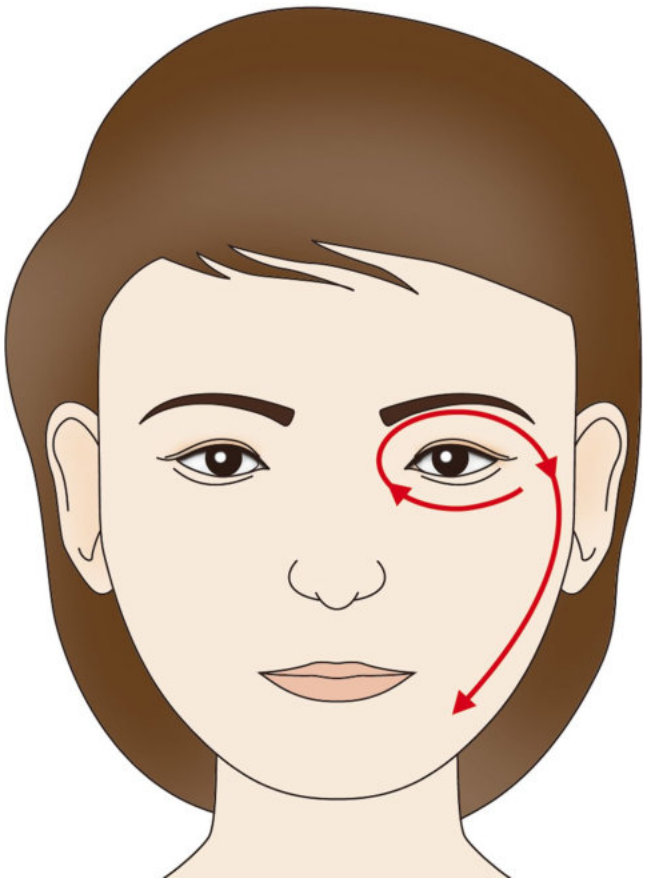


Fig. 21.1 Massage should be performed before makeup. It starts from lower eyelid to upper eyelid drawing a clockwise circle, then from temple to check

The cosmetic foundation is made in three layers: total face basement, total face upper, and local top (scar part). If the patients require quick makeup, lotion type would be selected as the base. If there is unevenness of color, yellow foundation of hard type or covering type foundation should be selected. The yellow color is good for erasing the erythema (redness) due to burn scars. For total face upper foundation, hard-type *and* cream-type foundations are used for standard patients. If patients require light cosmetic, cream type *and* mixing type should be chosen, and if strong coverage is required, cream type *or* mixing type *and* covering foundation should be used. If there are some scars that need to be covered more, covering foundation is used partially in some cases.

21.2.4 Makeup

When the scar is covered by foundation, the scar becomes less visible; however, the appearance of surrounding areas is also important for patients' satisfaction. Shaving and drawing eyebrows, eye makeup, cheek makeup, and other makeup procedures are done. At first, our makeup therapists explain the application of makeup, but the goal of makeup therapy is for the patient to independently apply makeup. Therefore, we have to consider whether the patient can apply makeup by herself if she has injured her hands. In such a case, glasses, a hat, or a scarf can help to cover the scar.

21.3 Clinical Cases

21.3.1 Case 1

A 55-year-old female who had attempted suicide had extensive burns on her face, upper arms, and trunk. She underwent operations more than 10 times, including the total nasal reconstruction with a distant flap. As her eyebrows were burnt out, only drawing eyebrows in a good shape helped her to change her impression. Also, making up her eyelids can make her eyes look larger (Fig. 21.2).

21.3.2 Case 2

A 52-year-old female was found with 55% BSA. Her mentum was reconstructed with a free flap, of which the skin, color, and texture are far different from the surrounding skin. Even after makeup, the shape of her chin could not be changed, and so a scarf was used to cover it. After makeup

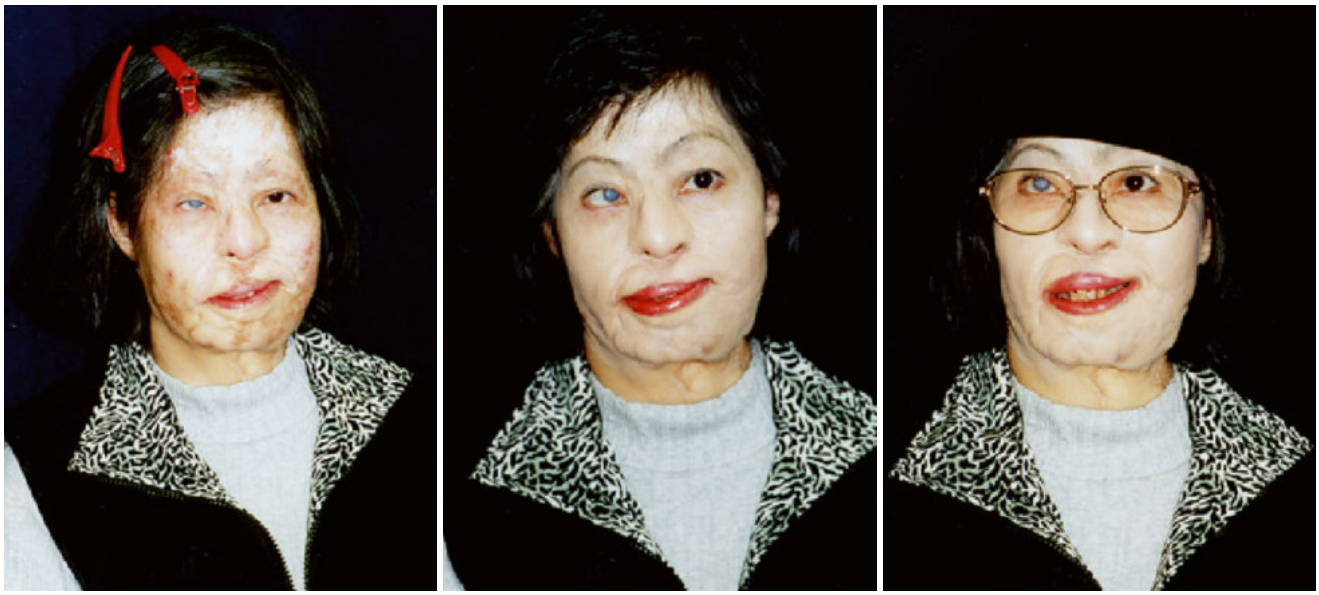


Fig. 21.2 Case 1

therapy, she was able to go outside to shop by herself, which she had not been able to do (Fig. 21.3).

21.3.3 Case 3

A 44-year-old woman was injured by boiling water from a pot spilled onto her body. Conservative treatment with ointment was performed, but a hypertrophic scar remained. Before undergoing surgery, the patient expressed a desire to go swimming, so rehabilitation makeup was applied to cover the affected area. Rehabilitation makeup significantly improved the hypertrophic scar, including its uneven surface. Rehabilitation makeup is also a good option for burn scars on the limbs (Fig. 21.4).

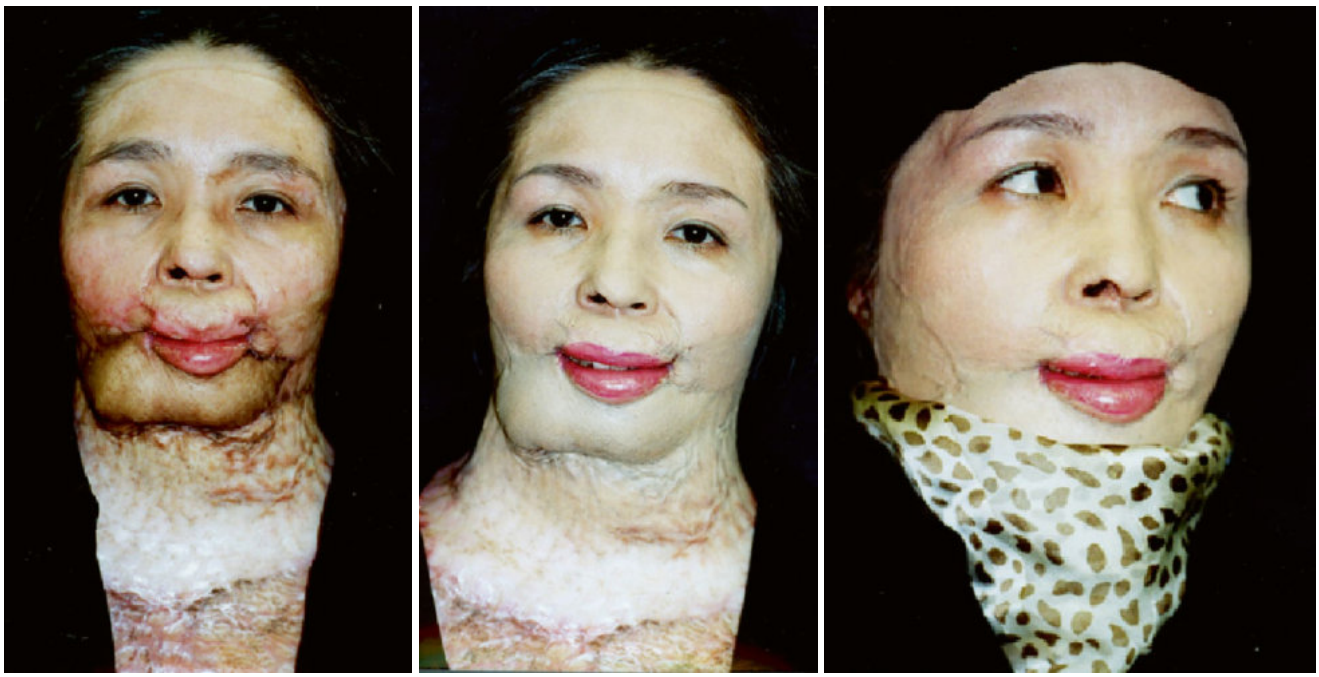


Fig. 21.3 Case 1

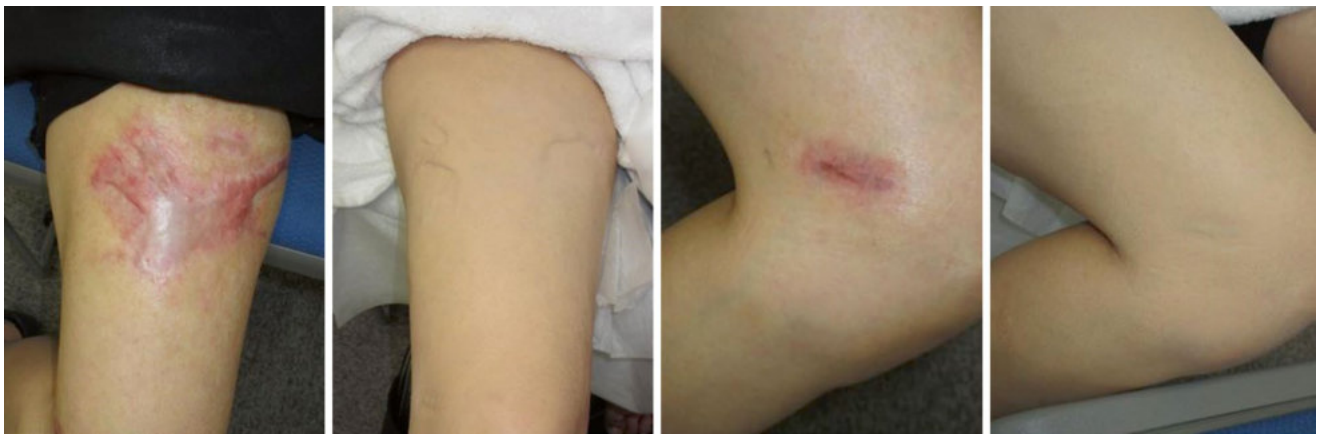


Fig. 21.4 Case 1

21.4 Meaning of Makeup Therapy

The application of makeup to cover the scar does not simply mean the treatment of the patients' injured mind, because makeup is not the method to erase the scars completely. Once the patient removes the makeup, the scar appears again. Therefore, the better the scar can be hidden, the more the patient becomes uneasy when it is removed. When the patient decides to marry or begin a job, he or she distresses over when to confess that he or she has a scar. The important thing in doing makeup therapy is not to cover and hide the scar completely, but to encourage the patients to mix with society. Most of the patients wonder whether their scar may make others uncomfortable. If the scars become less visible, it would not annoy the patients as well as the neighbors. For that purpose, Ms. Kazki, who is in charge of our makeup clinic, named her method of makeup "Rehabilitation Makeup," which emphasizes the improvement of the patients' quality of life [5]. In rehabilitation makeup, the patients are always made up not only on the scar but also on the whole face, because the key is not only to diminish the scar but also to make the patient more beautiful. The rehabilitation makeup always starts with facial massage to accelerate the venous return, which results in the deflation of the face and the improvement of facial skin color. This step also makes it easier to apply foundation powder evenly to the scar, which is too smooth for normal foundation powder to

stay on. Shaving and drawing eyebrows are also important for changing the impression of the patient. According to the survey of patients who had self-injured scars on their forearms, even though they don't have any scarring on the face, if makeup is performed on their face at the same time as the makeup over the arm scars, their scores assessed by the satisfaction of their appearance by VAS (visual analog scale) improve significantly [6].

The benefits of makeup therapy are:

1. Noninvasive. Even those who are suffering from internal organ dysfunction or disorder can have this therapy.
2. Reasonable cost. No special equipment or material is required. Only standard cosmetics are necessary. No specific license is essential, even though the staff should be trained in makeup therapy.
3. Reversible. If the patient doesn't like the appearance after makeup therapy, the patient can wash the face to recover.

Accordingly, makeup therapy is a good option for the treatment of burn scars, especially for the patients who almost finish the surgical operations. Makeup therapy is not an enemy of the medical profession and can benefit both the patient and the medical staff.

Acknowledgments The authors gratefully acknowledge the contribution of Ritu Aoki to this chapter as it appeared in the first edition of the book.

References

1. Aoki R. Social prognosis of post-burn survival patients (Japanese). Nessho. 1994;20(2):64–71.
2. Downie M. Camouflage therapy. Aust J Derm. 1984;25:89–91.
3. Rayner VL. Assessing camouflage therapy for the disfigured patient; a personal perspective. Dermatol Nurs. 1990;2(2):101–4.
4. Rayner VL. Camouflage therapy. Cosmet Derm. 1995;13(2):467–72.
5. Kazki R. Rehabilitation make-up and plastic surgery (Japanese). Keiseigeka. 2001;44:1029–36.
6. Koike S, Ogawa R, Aoki R, Kazki R. Consideration of scar plasty made by self-injury (Japanese). J Jap Soc Aest Plast Surg. 2007;29(3):155–9.

Part III

Dermal Substitutes / Skin Graft

Dermal Substitutes

22

Luc Téot, Sami Otman, and Pascal Granier

Abstract

Dermal substitutes have been developed during recent decades. Integra, a substitute for dermis, was initially developed by Burke and Yannas. This device is derived from bovine collagen and contains glycosaminoglycans. Safety issues (prions) have been solved. The device was initially proposed for burns coverage, and although randomized studies have determined the efficacy of the technique, no statistical difference has been observed in terms of scar characteristics of the obtained skin tissue. Alternative collagen or noncollagen products of different thicknesses were more recently developed, with or without silicone covering films. These products can be derived from porcine, bovine, or human origin. We may now divide dermal substitutes into two categories: double-layer DS and single-layer DS.

Keywords

Skin graft · Silicone film · Split skin graft · Dermal substitute · Negative pressure therapy

22.1 Background of the Technique

Dermal substitutes have been developed during recent decades. Integra, a substitute for dermis, was initially developed by Burke and Yannas. This device is derived from bovine collagen and contains glycosaminoglycans. Safety issues (prions) have been solved. The device was initially proposed for burns coverage, and although randomized studies have determined the efficacy of the technique, no statistical difference has been observed in terms of scar characteristics of the obtained skin tissue. Alternative collagen or noncollagen products of different thicknesses were more recently developed, with or without silicone covering films. These products can be derived from porcine, bovine, or human origin. We may now divide dermal substitutes into two categories: double-layer DS and single-layer DS.

L. Téot (✉)
Burns and Plastic Surgery Unit, Montpellier University Hospital, Montpellier, France
e-mail: l-teot@chu-montpellier.fr

S. Otman · P. Granier
Burns and Plastic Surgery Unit, Montpellier University Hospital, Montpellier, France
e-mail: s-otman@chu-montpellier.fr; info@dr-pascal-granier.fr

22.2 Double-Layer Dermal Substitutes

Integra is composed of bovine collagen and glycosaminoglycans. Initially indicated in acute burns for scar pliability improvement, this DS has demonstrated its capacity to be used over extensive burns after a sharp early excision. In a pivotal study on burns, Heimbach et al. showed an interest in using Integra to restore skin suppleness and prevent skin graft adherence to the depth of the exposed structures. Other authors, using Integra in reconstructive surgery, concluded that the product could be used in traumas, skin excision after skin cancer removal, and other types of skin replacement. The product seems particularly indicated for exposed tendons or bones in thin skin reconstruction, for example, in hand and feet skin reconstruction. Integra may be used as originally described, with a period of revascularization and neoangiogenesis lasting 3 weeks. After this period, the silicone film is removed, and a thin skin graft is applied over the collagen. It is also possible to reduce the length of revascularization by applying negative pressure therapy over the silicone layer, thereby saving a week. When using VAC™, a skin graft can be applied after a period of 10 days.

Rehabilitation should start early in order to prevent skin adherences, especially when applied over mobile structures. Transient inflammation and redness of the skin can be observed for a period of 1 year.

Renoskin™ is a double-layer DS with the same composition as Integra. This product is indicated in acute burns.

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_22

Pelnac™ is comparable to the previously described DS, presenting a capacity of dermal regeneration within a period of 3 weeks.

Hyalomatrix 3D™ is based on the principle of bringing hyaluronic acid inside the neodermis. Clinical series describing good results were recently proposed, especially in acute burns. The product allows an intense and rapid granulation tissue formation and needs a secondary skin graft.

Matriderm™ thick layer has been recently proposed by Middlekoop et al.

NovoSorb® BTM (Biodegradable Temporizing Matrix) is a synthetic, biodegradable, and biocompatible device designed to facilitate the dermis to grow within a patented polyurethane matrix. When ready, the sealing membrane is removed, leaving a fully vascularized dermis, ready for definitive closure.

The promotion of angiogenesis in the DS, using negative pressure therapy in conjunction with the application of DS, has been proposed. When negative pressure is permanently applied over the dermal substitute, this significantly shortens the delay before it is possible to apply a skin graft. Within a period of 10 days, the collagen can be revascularized. A decrease in the infection rate has also been observed, certainly due to the isolation of the treated area from external contamination. VAC therapy is applied with moderate negative pressure (50 mmHg) in order not to harm the collagen matrix.

22.3 Single-Layer Dermal Substitutes

A new generation of DS has recently been proposed. Some of them are based on the same collagen composition, while others present different properties. Reduction in the thickness of these DS and the absence of a covering silicone layer make it possible to perform an immediate skin graft during the same surgical procedure.

Matriderm™ is composed of collagen mixed with elastin fibers. This product has been proposed as a single-layer matrix in burns and reconstructive surgery. The product presents interesting capacities of hemostasis. Elasticity of the structure helps when the device is applied over irregular surfaces. The product is more suited to extensive, well-vascularized structures, particularly over the face or the skull.

Integra™ thin layer is identical in structure to Integra, without a silicone film covering. The product is under clinical evaluation.

Alloderm™, Strattice, and Permaform are derived from porcine dermis. These products may be used as solid, thick structures. Their capacity of being penetrated by vessels is lower than the previous ones. Used in dura matrix replacement, they can be proposed as fixation devices for abdominal wall reconstruction or internal brass in mammary ptosis or after reduction.

Gliaderm™ has recently been proposed by the Dutch skin bank. Clinical indications include burns coverage and trauma. The device is immediately covered using skin grafts during the same surgical procedure or some days after.

Gammagraft™ has been proposed and used in Germany.

The combination of NPT is also possible in order to reduce the length of the take of the compound skin graft-dermal substitute.

22.4 Clinical Cases

22.4.1 Case 1

A 12-year-old boy sustained flame burns over about 36% of TBSA. He was intubated and maintained under artificial respiration for resuscitation needs (Fig 22.1a–c). After stabilizing his general condition, his face and hands were operated on. A tangential excision was performed, followed by an immediate application of Matriderm™ and then a thin split skin graft. The result was good as far as healing was concerned, as the epidermis was stable after 5–7 days. A transient hyperchromic pigmentation and a retraction in the fingers were noted as minor complications. The situation of both hands and the color of the face improved after 6 months (Fig 22.1d). No retraction was noted at this time.

22.4.2 Case 2

A 14-year-old boy presented with large scar areas over the neck and the lower part of the face after extensive burns sustained at a young age (Fig 22.2a). He was operated on for scar correction. After removal of scar contractures, a skin defect (60 cm long and 45 cm wide) was immediately covered using Integra double layer (Fig 22.2b). The revascularization process took 3 weeks. The silicone film was then removed and the area covered using a split-thickness skin graft harvested on the skull. Results were good, with no seroma or hematoma observed and no infection. Rehabilitation could be started after 3 weeks (Fig 22.2c).

22.4.3 Case 3

A depressed 40-year-old was severely burnt by the autoprojection of boiling liquid (oil). She was deeply burnt over 10% of TBSA, mainly on the head, neck, and over both hands. She was intubated and artificially ventilated.

Several days later, a panfacial excision was achieved. As the cranial cortical bone was involved, an excision of the

Fig. 22.1 (**a**–**d**) Case 1

outer portion of the bone was carried out, exposing an area 30 cm long and 25 cm wide. A dermal substitute (Matriderm™) was applied over the whole defect and immediately covered using a split skin graft. The skull was used as a donor site area (Fig. 22.3a–c). Final results concerning healing, color, smoothness, hand and digit mobility, facial expressions, and periorificial muscles functions were good (Fig. 22.3d).

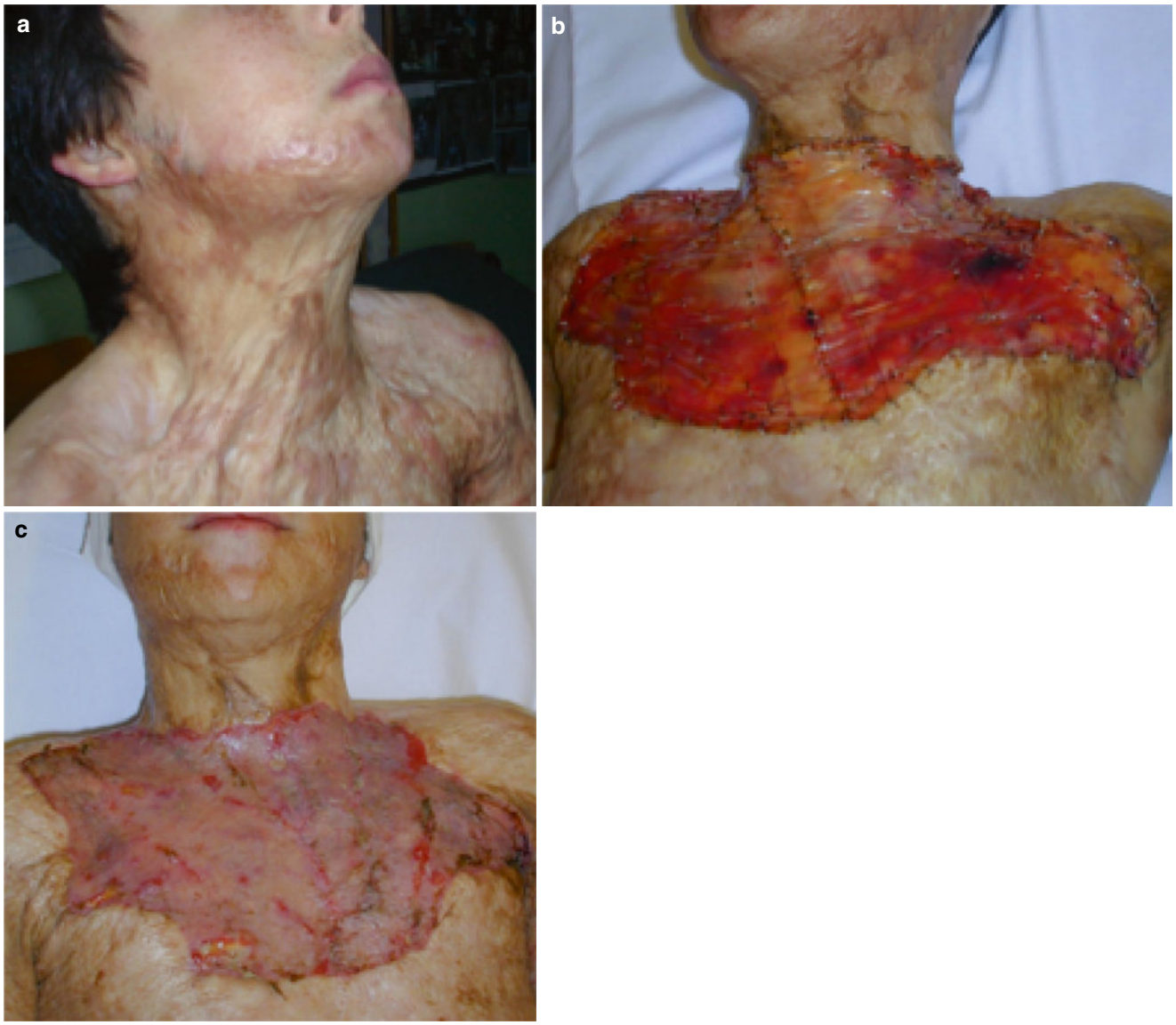


Fig. 22.2 (**a**–**c**) Case 2

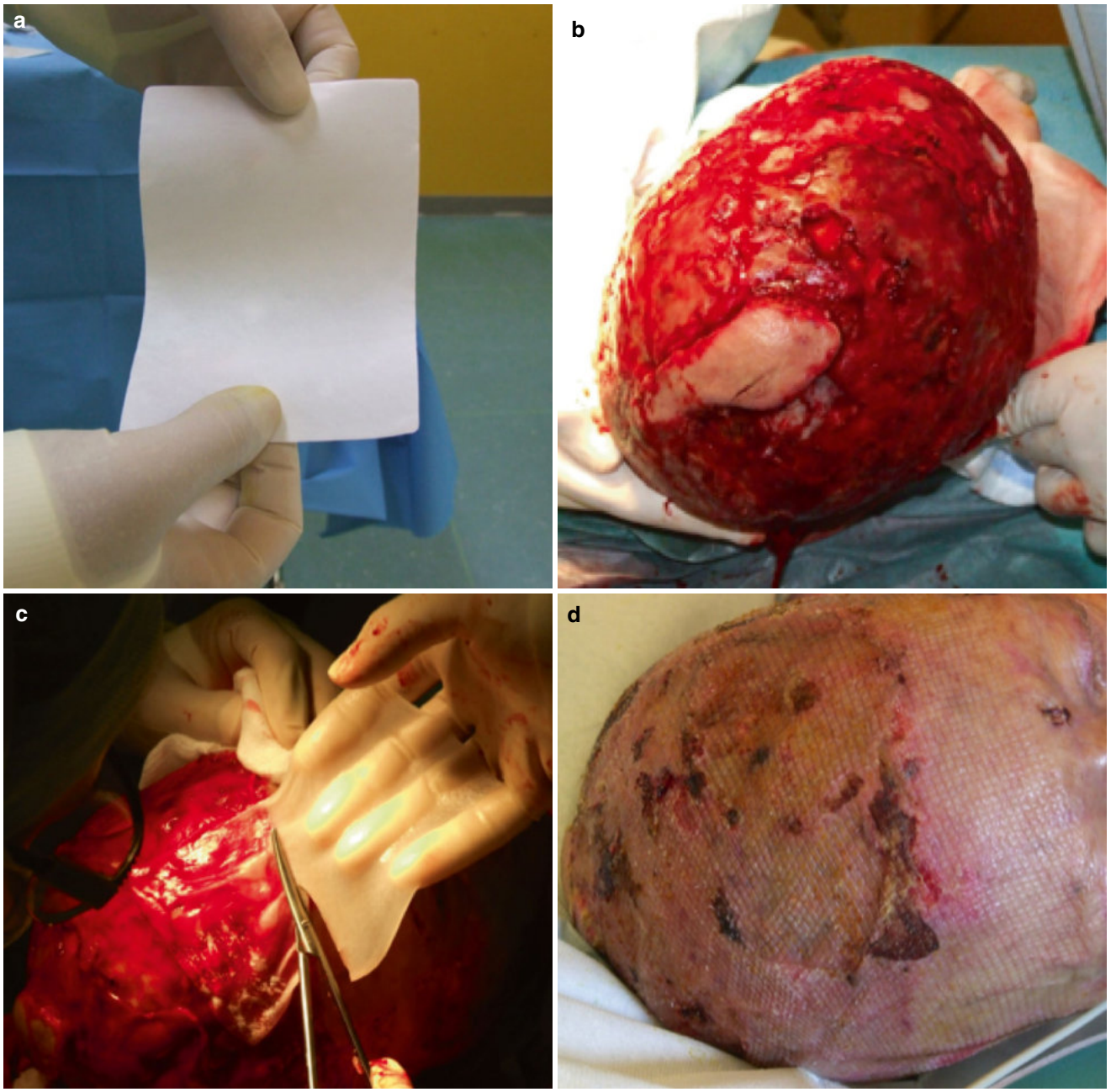


Fig. 22.3 (**a**–**d**) Case 3

22.5 Discussion

Dermal substitutes, used as temporary or permanent devices, have been developed over the previous decade. Their use is in rapid progression in reconstructive surgery, some of them replacing flaps when contraindicated or when not possible, especially in extensive burns. The purpose of the use of these techniques is to improve the quality of the scar and increase the suppleness of the final coverage by increasing the elasticity of the dermal part of the skin.

The use of negative pressure therapy contemporary to the postoperative period, which is limited in time and in level of pressure (50 mm Hg for 5 days), has been used in some cases. This technique may decrease the rate of postoperative infections.

The use of dermal substitutes looks better than using a simple skin graft, especially when applied over a bone structure. Adherence to the depth is minimized when compared to split skin grafts applied over the same anatomical area.

Functional results of Matriderm™ can be considered as good.

The skin may transitorily be hyperchromic, especially in acute burns, a return to a normal color having been observed in one patient after a period of 8 months.

Scar retractions were not observed in this series. The tendency of the scar to hypertrophy after Matriderm™ was only noted once on a facial scar reconstruction.

Limiting the number of surgical procedures has to be evaluated in terms of cost efficacy, but reducing the number of anesthetics can also be considered a positive aspect of the use of single-layer dermal substitutes that are immediately covered with a split skin graft. This has to be compared with the two-step procedures necessary until now in the use of dermal substitutes like Integra.

Suggested Reading

1. Dantzer E, Braye FM. Reconstructive surgery using an artificial dermis (Integra): results with 39 grafts. Br J Plast Surg. 2001;54(8):659–64.
2. Gravante G, Delogu D, Giordan N, Morano G, Montone A, Esposito G. The use of Hyalomatrix PA in the treatment of deep partial-thickness burns. J Burn Care Res. 2007;28(2):269–74.
3. Haslik W, Kamolz LP, Nathschläger G, Andel H, Meissl G, Frey M. First experiences with thecollagen-elastin matrix Matriderm™ as a dermal substitute in severe burn injuries of the hand. Burns. 2007;33(3):364–8. Epub 2007 Jan 22
4. Herlin C, Louhaem D, Bigorre M, Dimeglio A, Captier G. Use of Integra in a paediatric upper extremity degloving injury. J Hand Surg Eur. 2007;32(2):179–84. Epub 2007 Jan 16
5. Jeng JC, Fidler PE, Sokolich JC, Jaskille AD, Khan S, White PM, Street JH 3rd, Light TD, Jordan MH. Seven years' experience with Integra as a reconstructive tool. J Burn Care Res. 2007;28(1):120–6.
6. Jeschke MG, Rose C, Angele P, Füchtmeier B, Nerlich MN. Bolder U Development of new reconstructive techniques: use of Integra in combination with fibrin glue and negative-pressure therapy for reconstruction of acute and chronic wounds. Plast Reconstr Surg. 2004;113(2):525–30. https://doi.org/10.1097/01.PRS.0000100813.39746.5A. PMID: 14758212 Clinical Trial.
7. Ophof R, Maltha JC, Kuijpers-Jagtman AM, Von Den Hoff JW. Evaluation of a collagen-glycosaminoglycan dermal substitute in the dog palate. Tissue Eng. 2007;13(11):2689–98.
8. Ryssel H, Gazyakan E, Germann G, Ohlbauer M. The use of MatriDerm™ in early excision and simultaneous autologous skin grafting in burns–a pilot study. Burns. 2008;34(1):93–7. Epub 2007 Jul 17
9. Scuderi N, Onesti MG, Bistoni G, Ceccarelli S, Rotolo S, Angeloni A, Marchese C. The clinical application of autologous bioengineered skin based on a hyaluronic acid scaffold. Biomaterials. 2008;29(11):1620–9. Epub 2008 Jan 16
10. Shevchenko RV, Sibbons PD, Sharpe JR, James SE. Use of a novel porcine collagen paste as a dermal substitute in full-thickness wounds. Wound Repair Regen. 2008;16(2):198–207.
11. Sibbald RG, Zuker R, Coutts P, Coelho S, Williamson D, Queen D. Using a dermal skin substitute in the treatment of chronic wounds secondary to recessive dystrophic epidermolysis bullosa: a case series. Ostomy Wound Manage. 2005;51(11):22–46.
12. Tsoutsos D, Stratigos A, Gravvanis A, Zapandioti P, Kakagia D. Burned breast reconstruction by expanded artificial dermal substitute. J Burn Care Res. 2007;28(3):530–2.
13. Tufaro AP, Buck DW 2nd, Fischer AC. The use of artificial dermis in the reconstruction of oncologic surgical defects. Plast Reconstr Surg. 2007;120(3):638–46.
14. Wagstaff MJ, Schmitt BJ, Coghlan P, Finkemeyer JP, Caplash Y, Greenwood JE. A biodegradable polyurethane dermal matrix in reconstruction of free flap donor sites: a pilot study. Eplasty. 2015;15:e13. eCollection 2015

Application of Integra® and NovoSorb® Biodegradable Temporizing Matrix in Pediatric Burns

23

Timothy W. Wolff, Marc A. Gorvet, and Paul M. Glat

Abstract

Treatment of burn wounds is challenging among pediatric patients for several reasons, among them being thin skin, limited area for graft donor sites, and the increased propensity for hypertrophic scarring. These challenges become more difficult the deeper and more complex the burn injury. Dermal skin substitutes and regenerative templates, specifically Integra® and Novosorb® Biodegradable Temporizing Matrix, help mitigate these challenges and have proven especially beneficial in treating full-thickness burns within the pediatric population.

Keywords

Dermal regeneration template · Temporary epidermal layer · Matrix · Neovascularization · Neodermis · Full thickness · Wound closure

23.1 Background

Treatment of burn wounds has always proved challenging in the pediatric population. When treating large surface area or complex burn wounds, pediatric patients frequently have a limited area of graft donor sites [1]. Infants often have skin too thin to be harvested for skin grafting to provide adequate coverage for reconstruction. Additionally, hypertrophic scar formation is one of the most common late complications of pediatric burns, with incidence ranging from 30% to 90% [2, 3]. This associated morbidity, particularly when contractures develop, includes both aesthetic and functional abnormalities, which often require further surgeries to manage.

T. W. Wolff (✉) · M. A. Gorvet · P. M. Glat
Department of Plastic and Reconstructive Surgery, St. Christopher's Hospital for Children, Philadelphia, PA, USA

The traditional reconstructive ladder applies to the treatment of burn wounds as it does to other wounds. Simple, superficial partial-thickness burns can be managed with local wound care to allow for healing by secondary intention. Deeper and more complex burns may require the application of dermal substitutes, skin grafting, tissue expansion, or even soft tissue flaps for closure. Dermal substitutes have revolutionized the management of both acute burns and secondary burn scar resurfacing over the past three decades due to their potential to circumvent some issues associated with autologous grafts [4–6]. For burns requiring dermal regenerative templates (i.e., full thickness), Integra® and NovoSorb® Biodegradable Temporizing Matrix (BTM) are among the most common materials utilized [2, 5].

23.2 Integra® and NovoSorb® Biodegradable Temporizing Matrix

Integra® (Integra LifeSciences, Plainsboro, NJ) is a biosynthetic, bilayered membrane system that contains a dermal regeneration layer and a temporary epidermal layer [1, 7, 8]. The temporary epidermal layer is composed of synthetic polysiloxane polymer (silicone), which enables immediate wound closure and provides a mechanical barrier against bacterial invasion [7, 8]. It also functions similar to normal skin by retaining moisture while allowing water vapor transmission [1, 9]. The dermal regeneration layer is composed of a three-dimensional porous matrix of cross-linked bovine collagen and glycosaminoglycans (chondroitin-6-sulfate) [7, 8]. This layer functions by promoting cellular growth, collagen synthesis, and neovascularization. Biodegradation of the matrix occurs while it is being replaced with autologous dermal tissue, which typically takes a total of 2 to 4 weeks [6] (Fig. 23.1). Once vascularized, the template is grafted with a split-thickness skin graft.

NovoSorb® (PolyNovo Biomaterials Pty Ltd., Port Melbourne, VIC, Australia) is a fully synthetic, biodegradable, and biocompatible material designed to facilitate

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_23

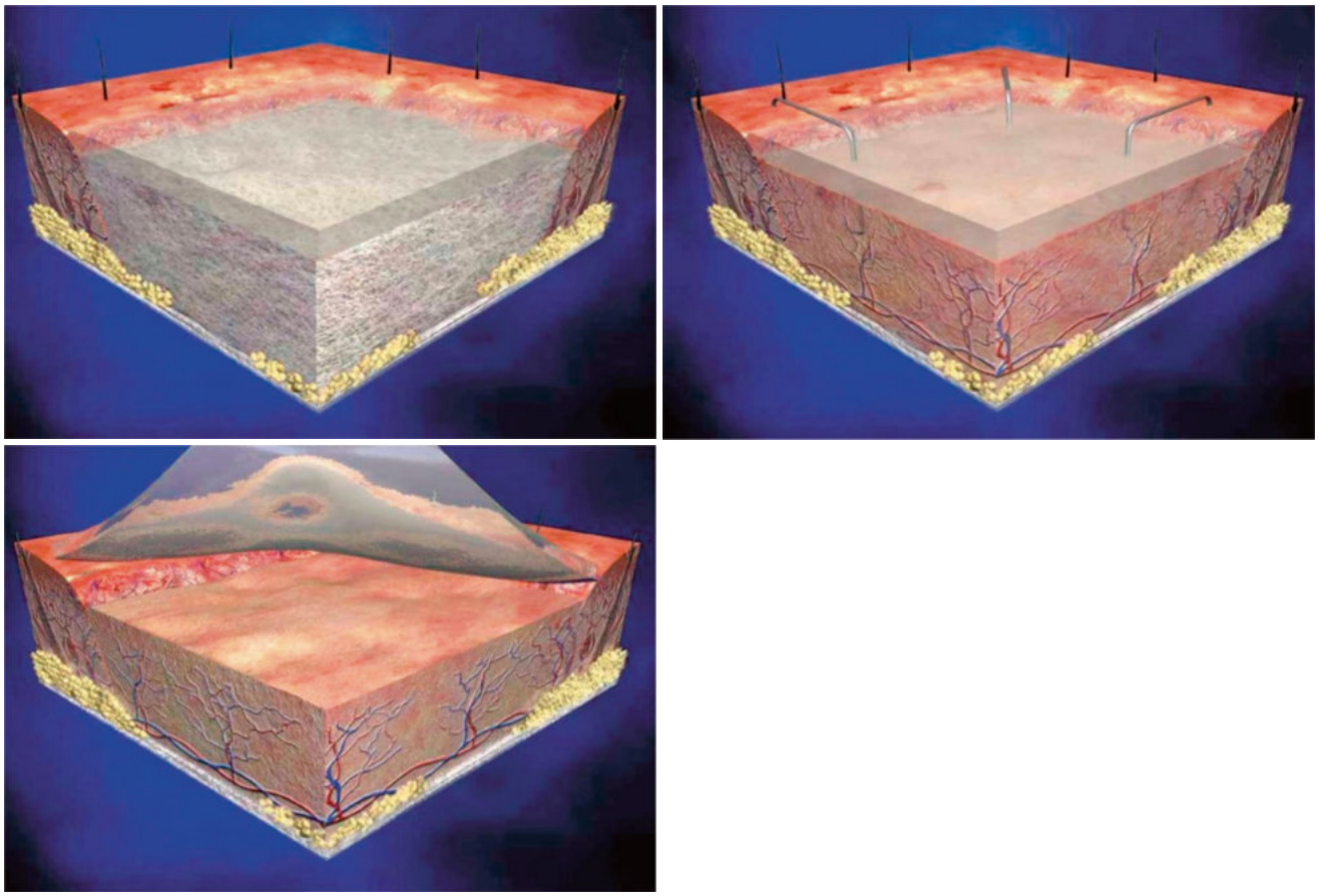


Fig. 23.1 Diagram showing the phases of dermal regeneration with Integra®. Once applied, Integra's® collagen template adheres to the wound through the influx of fluids (top left panel). Dermal cells migrate into the matrix, followed by new vessels (top right panel). The silicone layer is removed from the rebuilt neodermis prior to autografting (bottom panel) [9]

dermal growth within a patented 2-mm-thick polyurethane matrix [3, 10]. Cells and blood vessels migrate into the polyurethane open-cell foam matrix, and a vascularized neodermis is formed in typically 3 to 4 weeks [6, 10]. As this neodermis forms, the biodegradable matrix breaks down via hydrolysis. The matrix layer is covered by a nonbiodegradable sealing membrane that provides physiological wound closure, but also contains small fenestrations to prevent accumulation underneath the material [10] (Fig. 23.2). Identical to Integra®, a split-thickness skin graft is typically applied once the matrix is vascularized.

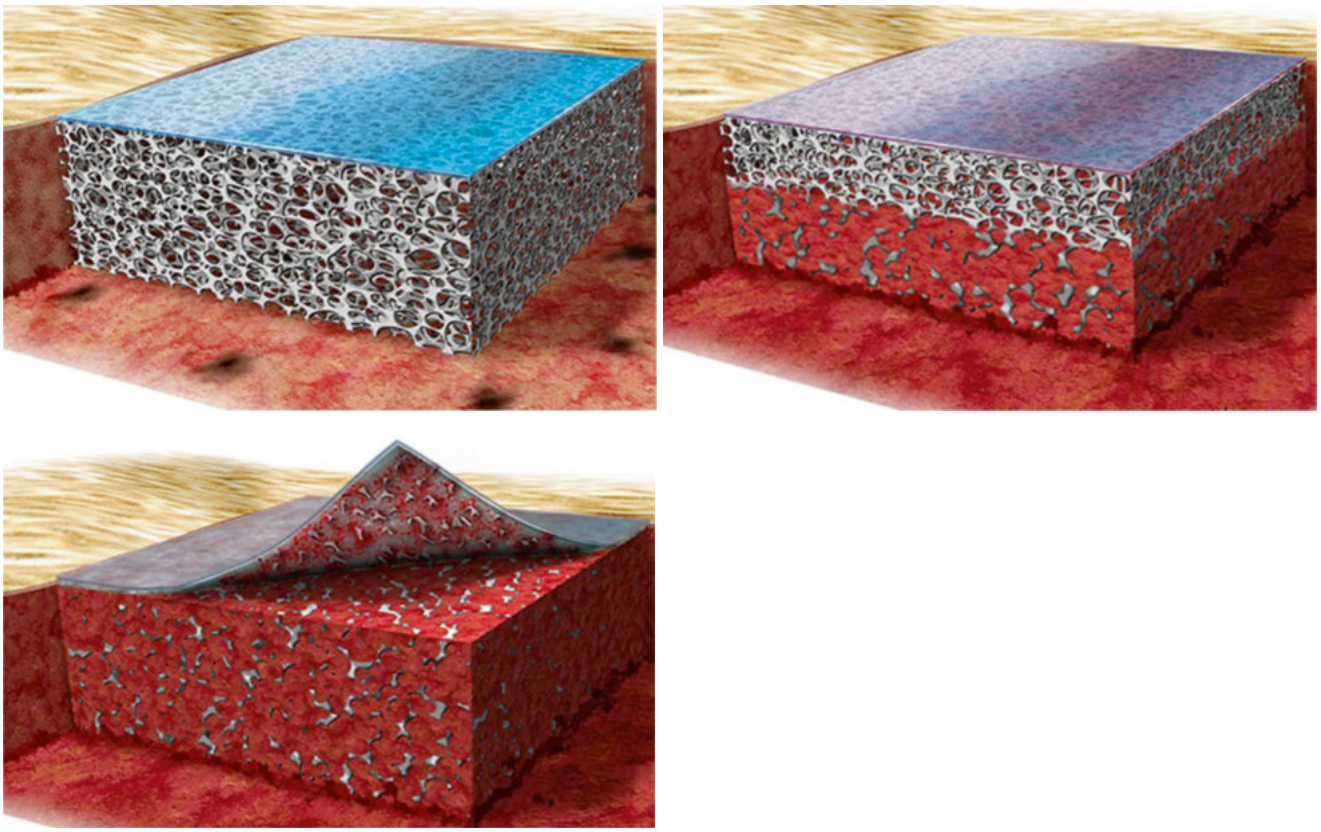


Fig. 23.2 Diagram showing the phases of dermal regeneration with BTM. Upon application, BTM is rapidly infiltrated with hemoserous fluid (top left panel). Cells and blood vessels migrate into the open-cell, nonreticulated synthetic matrix (top right panel). The sealing, nonbiodegradable membrane is removed when the neodermis is ready for secondary treatment (bottom panel) [10]

23.3 Neodermis Generation

Integra® generates a neodermis in an average of 21 days and this process can be divided into 4 phases: imbibition, cellular migration, neovascularization, and remodeling and maturation [1, 11]. During imbibition, red blood cells and fibrin assist in adhering the matrix to the wound. In the second phase (~day 7), fibroblasts migrate into the matrix and begin to produce collagen [1, 11]. Neovascularization begins when endothelial cells migrate in and carry with them blood and nutrients (~day 14) [1, 11]. Remodeling and maturation processes occur similar to normal wound healing. The matrix gradually changes color from red to peach to yellow as the neodermis generates (Fig. 23.3). Once completed, the silicone layer is removed in the operating room immediately prior to autografting.

Once NovoSorb® BTM is implanted into a surgically debrided wound bed, integration will begin to occur via the infiltration of inflammatory cells, predominantly neutrophils and lymphocytes. This will occur over a period of approximately 2 to 3 weeks [10, 12]. Fibroblasts begin to appear at around the 2-week mark and begin to lay down collagen [12]. After 4 weeks, the BTM matrix is full of collagen and blood vessels, representing the generated neodermis within the matrix [10, 12]. During the integration process, the BTM appearance will evolve from bright red to pink/opaque as the material adheres to the underlying wound bed [10]. At the end of the process, the BTM matrix becomes obscured, but will exhibit capillary refill on transient localized pressure [10] (Fig. 23.4). Once the neodermis has generated, the BTM is ready for delamination followed by autografting. The BTM progressively biodegrades via hydrolysis and is fully absorbed in approximately 18 months [10, 12].

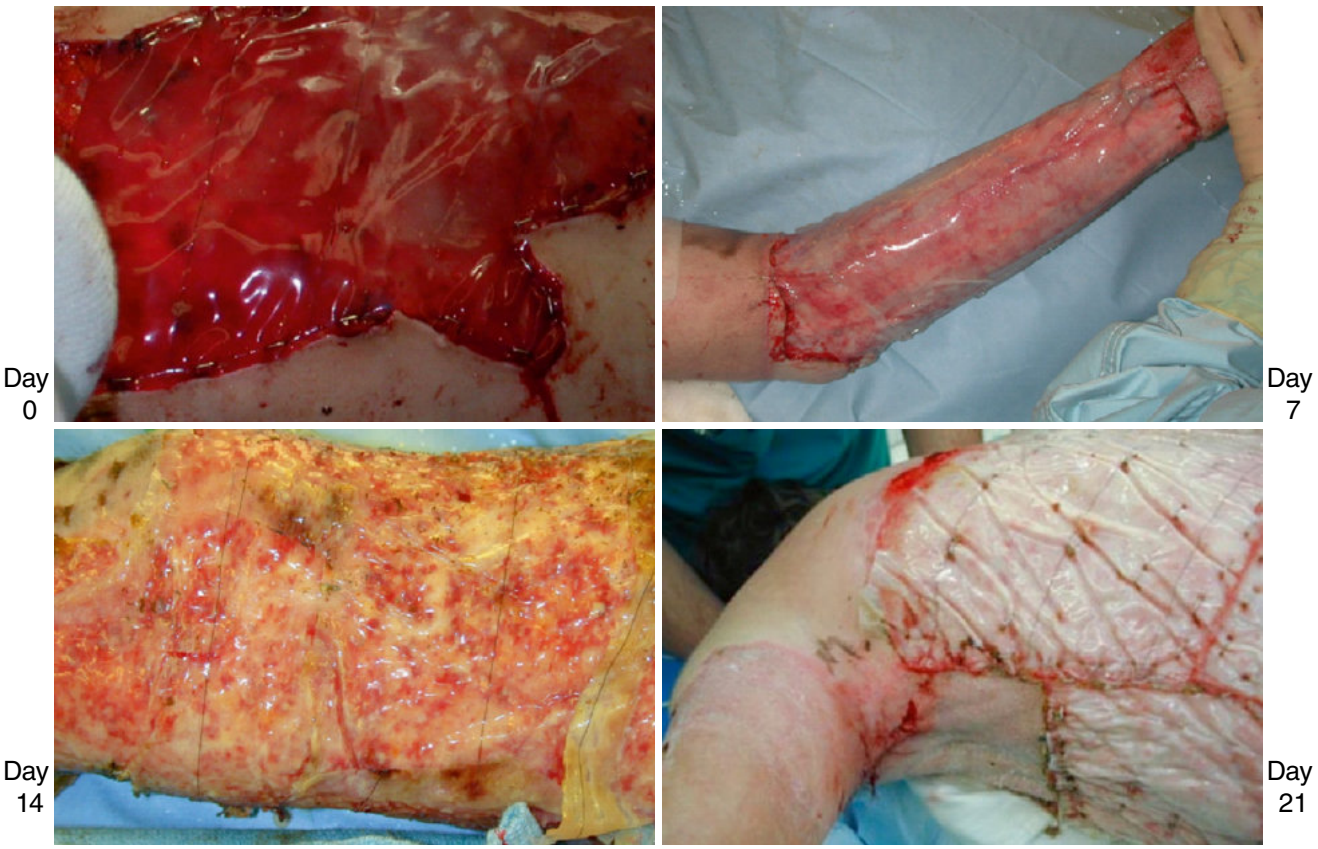


Fig. 23.3 The integration and replacement of Integra® can be divided into four phases: imbibition (day 0), cellular migration (day 7), neovascularization (day 14), and remodeling and maturation (day 21) [9]

Fig. 23.4 The appearance of BTM changes as it integrates with the wound. The matrix is initially visible through the clear sealing membrane, but quickly becomes red in color due to blood ingress. This progresses to a lighter red color during cellular integration and the matrix architecture becomes obliterated near the final stages [10]

23.4 Advantages and Disadvantages

Integra® and NovoSorb® BTM share several advantages [6, 13, 14]:

- Minimize size/number of reconstructive procedures
- Immediate availability of large quantities
- Immediate physiologic wound closure
- Potential for early ambulation/rehabilitation
- Delay in the need to create donor site wounds
- Less donor site morbidity (thinner split-thickness skin grafts)
- Pliability and cosmetic aspects of the resulting coverage

A unique advantage of BTM is that it is completely synthetic, which eliminates the possibility of interspecies immune rejection or disease transmission and avoids ethical or cultural obstacles [14]. Additionally, it has been clinically shown to retain product integrity and robustness in the presence of infection, which differentiates it from similar biological skin substitutes [10].

A comparison of the reported disadvantages of Integra® and NovoSorb® BTM is listed below (Table 23.1) [6, 13, 14].

The advantages of both Integra® and BTM far outweigh the disadvantages, with their greatest benefit being their versatility in the treatment of pediatric burn care. Both materials are treatment options at almost every level of the reconstructive ladder (Fig. 23.5).

Several representative cases are provided below as examples of the excellent results obtainable with the use of Integra® and NovoSorb® BTM (Figs. 23.6, 23.7, 23.8, 23.9).

Table 23.1 Disadvantages of Integra® and BTM

Integra®	Both	NovoSorb® BTM
Infection as leading cause for loss Expensive	Minimum of two operations Rigorous surgical technique & monitoring	Longer integration time

Fig. 23.5 The reconstructive ladder

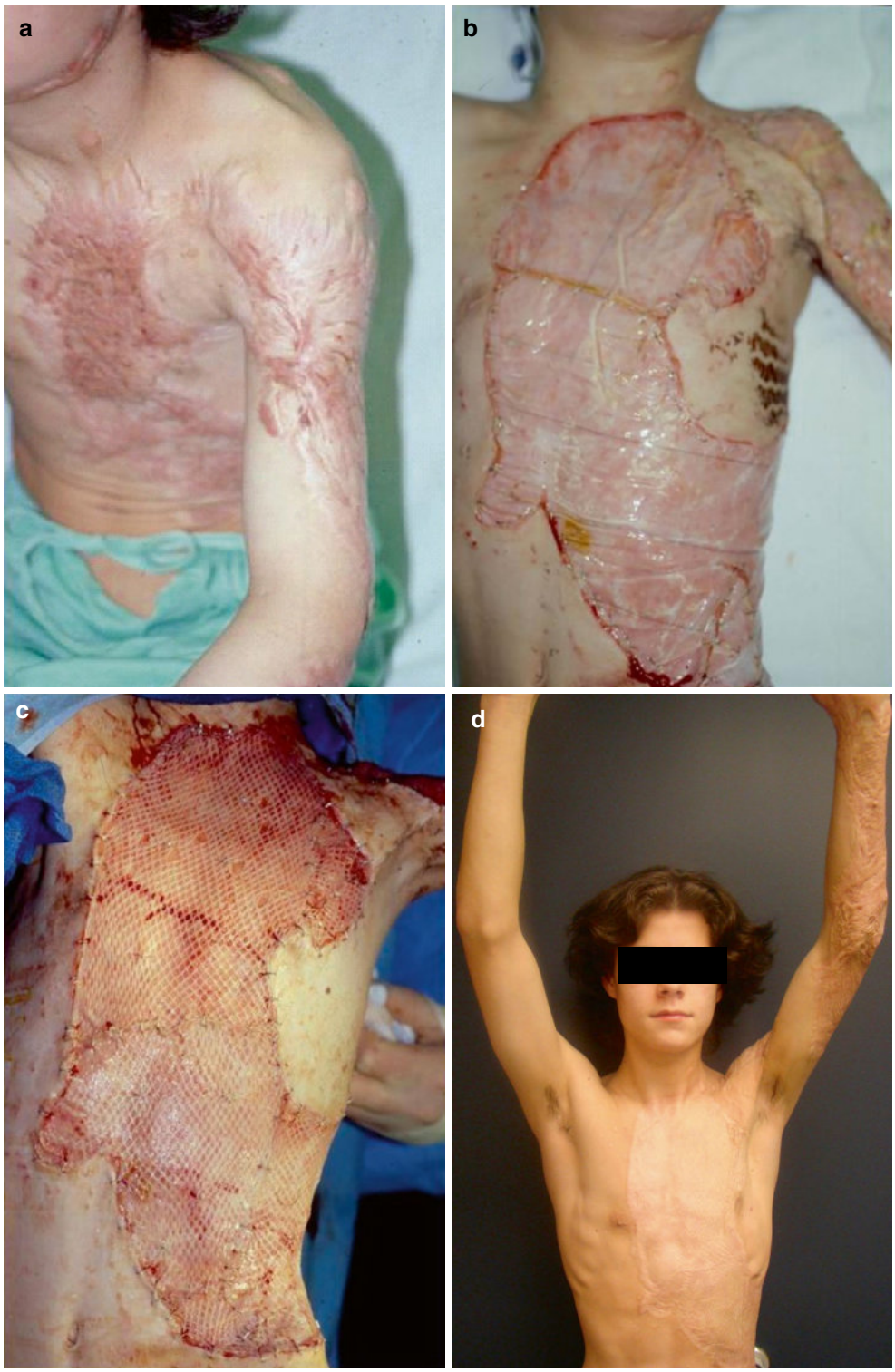


Fig. 23.6 Seven-year-old male, 2 years status post full-thickness scald burn to left chest and upper extremity treated with split-thickness skin graft. (**a**) Hypertrophic scars of the left chest and upper extremity. (**b**) Mature Integra® in place 2 weeks after excision of scar. (**c**) Thin autograft applied to neodermis in the operating room. (**d**) Well-healed Integra® with thin autograft 8 years post-operation

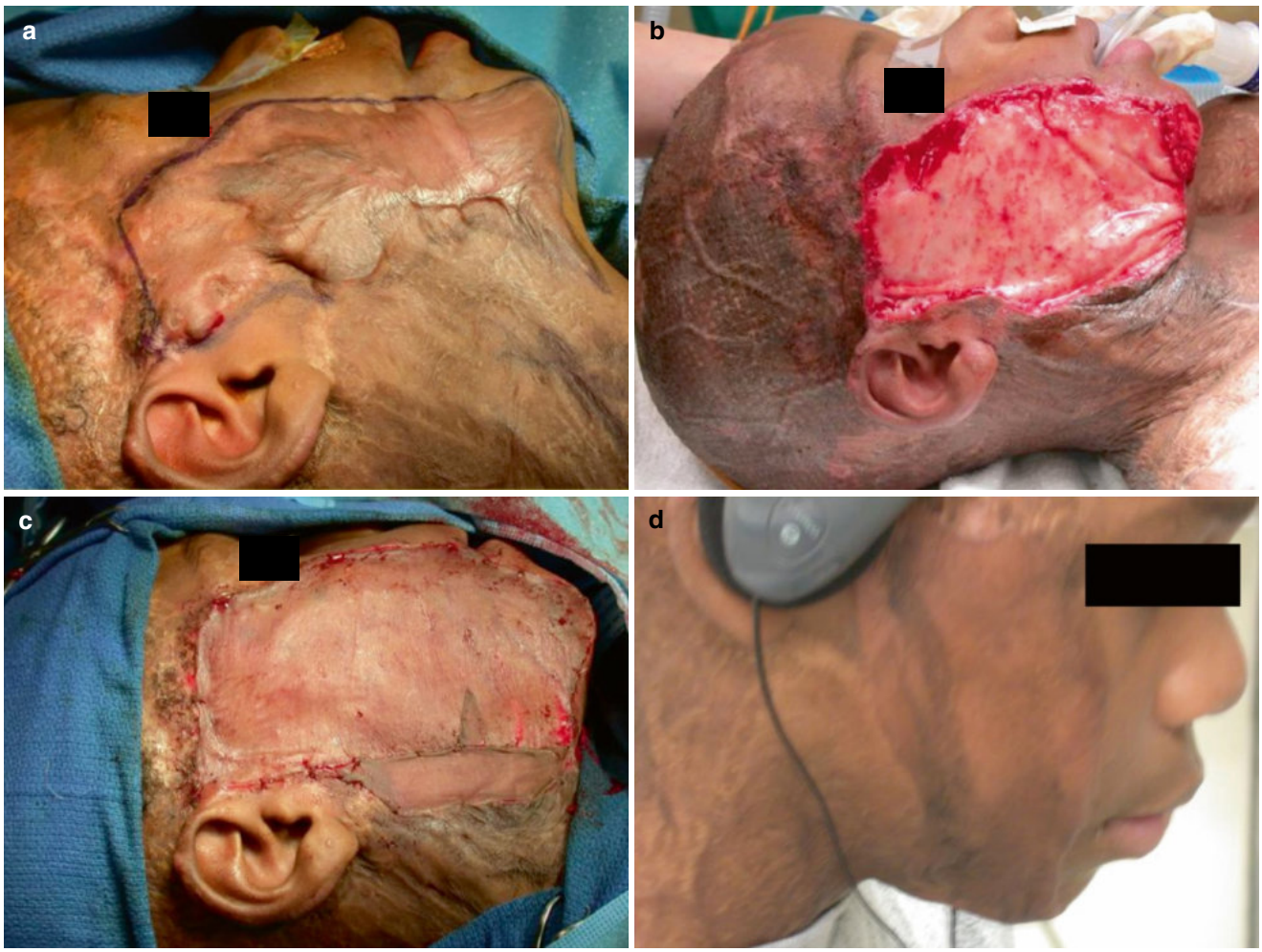


Fig. 23.7 Eighteen-year-old male, 1-year status post full-thickness burn to head and neck. (**a**) Hypertrophic right cheek scar at the time of excision in the operating room. (**b**) Mature Integra® in place 2 weeks after placement. (**c**) Thin autograft applied onto neodermis in the operating room. (**d**) Well-healed wound with Integra® 1 year post-operation. Note the good aesthetic result despite crossing aesthetic units

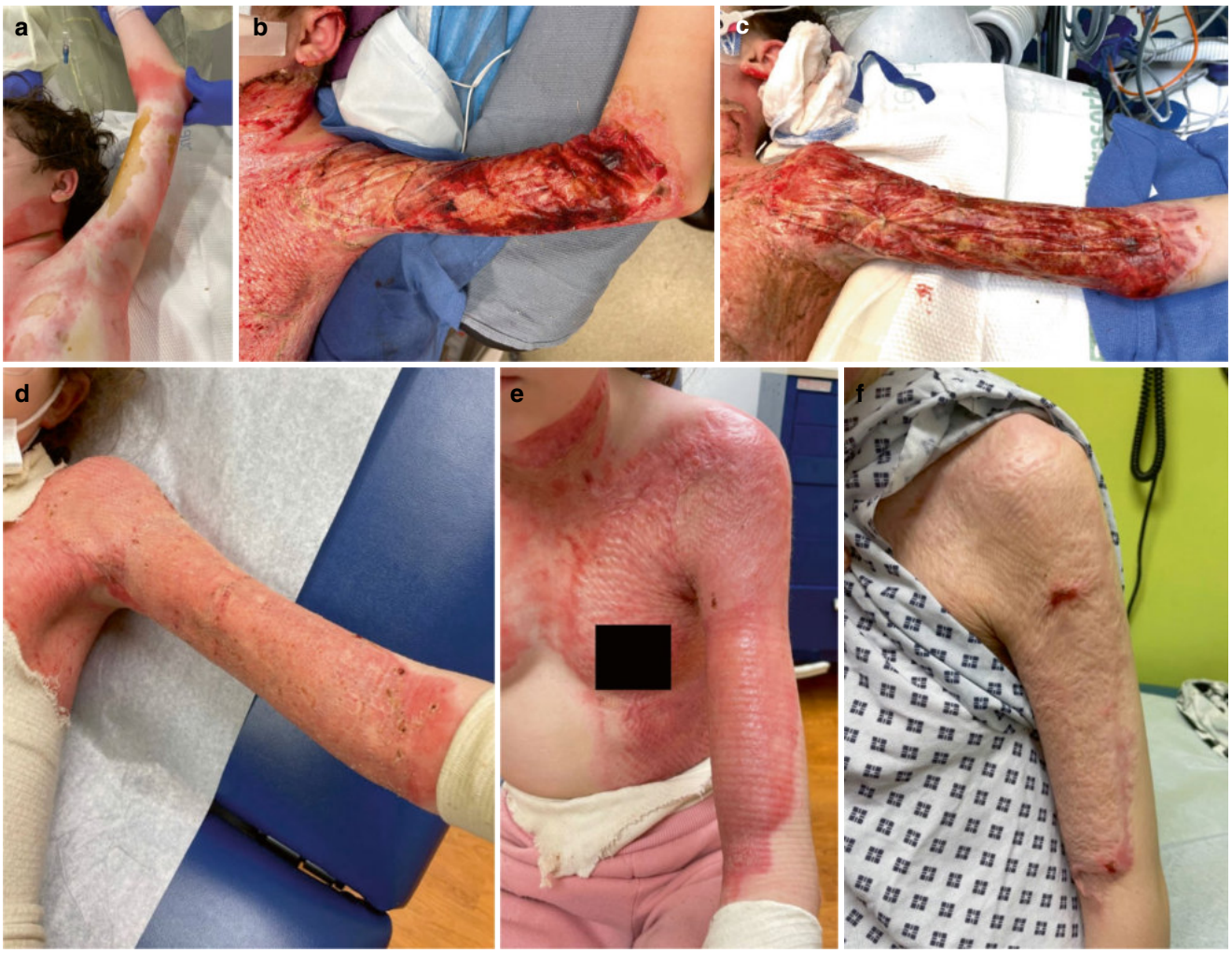


Fig. 23.8 Twelve-year-old female with partial- and full-thickness flame burns to the torso, bilateral arms, and neck. (**a**) Full-thickness burns to the left upper arm. (**b**) Partially integrated BTM 2 weeks after placement. (**c**) Completely integrated BTM 3 weeks after placement and immediately prior to delamination and split-thickness skin grafting. (**d**) Closed burn wound 4 weeks after BTM placement and 1 week after autografting. (**e**) Immature burn scar 2 months after injury and BTM placement. (**f**) Mature burn scar 9 months after BTM placement

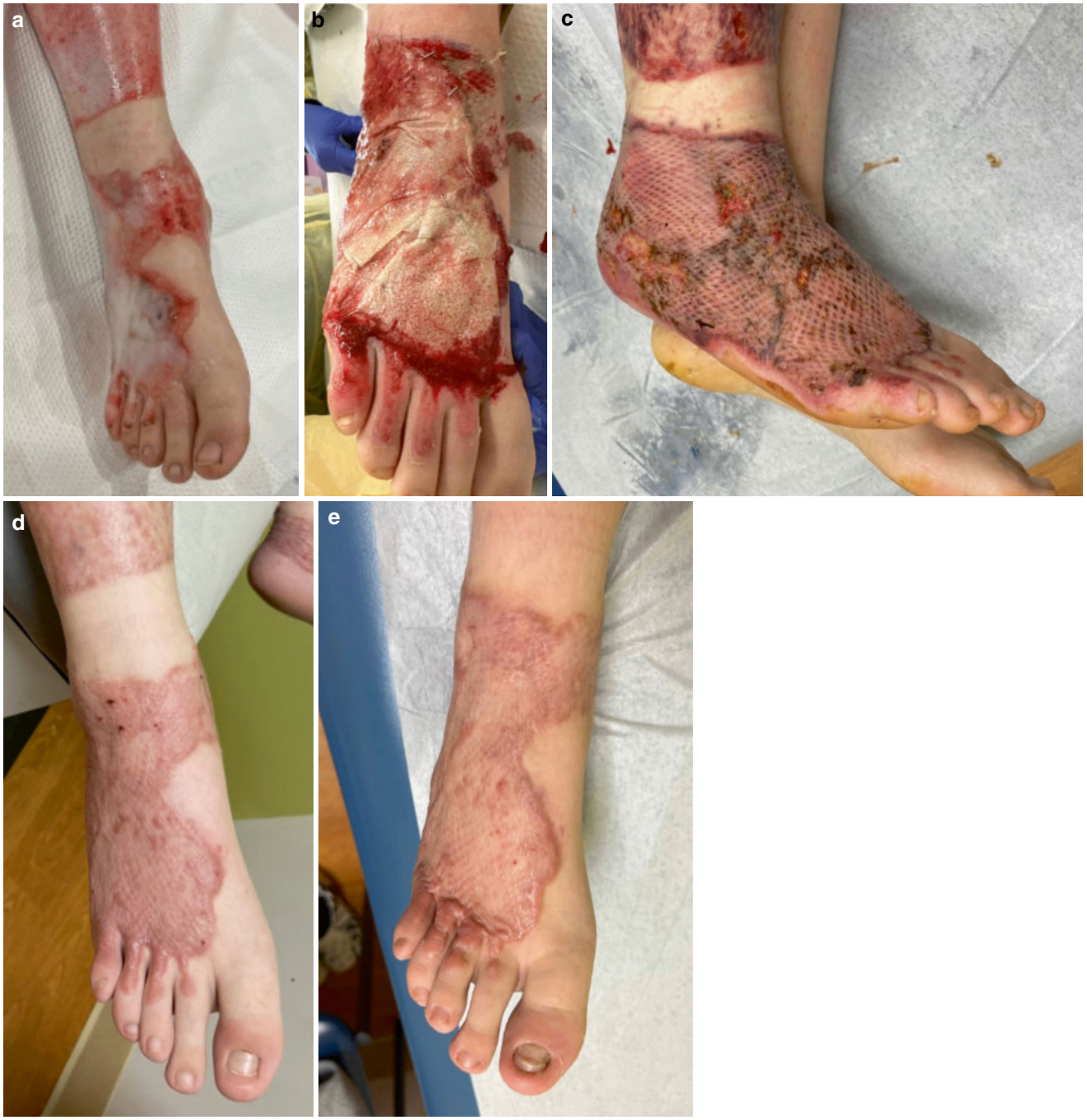


Fig. 23.9 Fifteen-year-old male with partial and full thickness flame burns to the face, torso, and extremities. (**a**) Full-thickness burns to the right foot. (**b**) Partially integrated BTM 2 weeks after placement. (**c**) Split-thickness skin graft 5 weeks after BTM placement and 2 weeks after autografting. (**d**) Immature burn scar 3 months after injury and BTM placement. (**e**) Mature burn scar 6 months after BTM placement

Acknowledgments The authors gratefully acknowledge the contributions of John F. Hsu, Wade Kubat, and Anahita Azharian to this chapter as it appeared in the first edition of the book.

References

1. Abai B, Thayer D, Glat PM. The use of a dermal regeneration template (Integra) for acute resurfacing and reconstruction of defects created by excision of giant hairy nevi. Plast Reconstr Surg. 2004;114(1):162–8.
2. Burkey B, Besner GE. Chapter 20: Burns. In: Mattei P, et al., editors. Fundamentals of pediatric surgery. 2nd ed. Springer International Publishing; 2017. p. 153–68.
3. Vinaik R, Fish J, Jeschke MG. Chapter 60: Burn hypertrophic scar in pediatric patients: clinical case. 2020 Dec 8. In: Téot L, Mustoe TA, Middelkoop E, et al., editors. Textbook on scar management: state of the art management and emerging technologies. Cham: Springer; 2020. https://doi.org/10.1007/978-3-030-44766-3_60. Available from: https://www.ncbi.nlm.nih.gov/books/NBK586087.
4. Concannon E, Damkat-Thomas L, Coghlan P, Greenwood JE. Role of skin substitutes in burn wound reconstruction. 2022 June 28. In: Maurício AC, Alvites R, Gönül M, editors. Wound healing – recent advances and future opportunities. IntechOpen; 2023. https://doi.org/10.5772/978-1-80356-226-1. Available from: https://www.intechopen.com/chapters/82038.
5. Chang DK, Louis MR, Gimenez A, Reece EM. The basics of Integra dermal regeneration template and its expanding clinical applications. Semin Plast Surg. 2019;33(3):185–9. https://doi.org/10.1055/s-0039-1693401.
6. Mason SA, Pham TN. Use of dermal regenerative templates for burns. J Burn Care Research. 2022;44:S19–25. https://doi.org/10.1093/jbcr/irac135.
7. Yannas IV, Burke JF, Orgill DP, Skrabut EM. Wound tissue can utilize a polymeric template to synthesize a functional extension of skin. Science. 1982;215:174.
8. Yannas IV, Lee E, Orgill DP, Skrabut EM, Murphy GF. Synthesis and characterization of a model extracellular matrix that induces partial regeneration of adult mammalian skin. Proc Natl Acad Sci USA. 1989;86:993.
9. Integra Brochure. Integra Life Science Corporation. (2003).
10. PolyNovo. NovoSorb BTM. Healthcare Professionals. 2024. https://polynovo.com/novosorb-btm/. Accessed 20 Mar 2024
11. Michaeli D, McPherson M. Immunologic study of artificial skin used in the treatment thermal injuries. J Burn Care Rehabil. 1990;11:21.
12. Greenwood JE, Schmitt BJ, Wagstaff MJD. Experience with a synthetic bilayer biodegradable temporising matrix in significant burn injury. Burns Open. 2018;2(1):17–34.
13. Groos N, Guillot M, Zilliox R, Braye FM. Use of an artificial dermis (Integra) for the reconstruction of extensive burn scars in children. About 22 grafts. Eur J Pediatr Surg. 2005;15(3):187–92. https://doi.org/10.1055/s-2004-821215.
14. Li H, Lim P, Stanley E, et al. Experience with NovoSorb® biodegradable Temporising matrix in reconstruction of complex wounds. ANZ J Surg. 2021;91(9):1744–50. https://doi.org/10.1111/ans.16936.

Acellular Allogenic Dermal Matrix

24

Yoshihiro Takami, Shimpei Ono, and Rei Ogawa

Abstract

Available donor skin is often insufficient for extensive burn cases, where thin meshed split-thickness skin grafts (STSG) or cultured epidermal autografts are typically used to close wounds. However, meshed STSGs can result in poor cosmetic outcomes due to insufficient dermal beds, while cultured epidermal autografts face challenges with graft survival. To address these limitations, several dermal substitutes have been developed. Among them, acellular allogenic dermal matrix (AADM), produced by decellularizing allogenic cadaver skin, closely resembles the physiological properties of normal human dermis (Livesey SA et al., Transplantation 60:1–9, 1995; Takami Y et al., Burns 22:182–190, 1996). This study investigates AADM's application for 2 purposes in burn surgery: first, as a simultaneous skin graft overlay on full-thickness burn wounds (Takami Y et al., Jpn J Burn Injuries 26:261–267, 2000), and second, as a scaffold for a tissue-engineered autologous skin equivalent (TESE) (Takami Y et al., Jpn J Plast Reconstr Surg 47:867–873, 2004; Am J Transplant 82(Suppl 3):746, 2006).

Available donor skin is often insufficient for extensive burn cases, where thin meshed split-thickness skin grafts (STSG) or cultured epidermal autografts are typically used to close wounds. However, meshed STSGs can result in poor cosmetic outcomes due to insufficient dermal beds, while cultured epidermal autografts face challenges with graft survival. To address these limitations, several dermal substitutes have been developed. Among them, acellular allogenic dermal matrix (AADM), produced by decellularizing allogenic cadaver skin, closely resembles the physiological properties of normal human dermis [1, 2]. This study investigates AADM's application for 2 purposes in burn surgery: first, as a simultaneous skin graft overlay on full-thickness burn wounds [3], and second, as a scaffold for a tissue-engineered autologous skin equivalent (TESE) [4, 5].

24.1 Preparation of Acellular Allogenic Dermal Matrix (AADM)

AADM (Fig. 24.1) was prepared using two methods: one for skin graft overlay and the other for tissue-engineered skin equivalents. For the skin graft overlay, split-thickness cryopreserved cadaver skin (0.015 inches thick) from Japan's official skin bank was thawed at 37 °C in phosphate-buffered saline (PBS). The skin was treated with 0.25% trypsin and 1 mM EDTA solution for 3 h at 37 °C to remove epidermal cells, followed by washing in a 0.25% Triton X-100 and 0.125% trypsin solution for 4 h to remove all cellular components of the dermis. The trypsin-treated AADM was stored at 4 °C, with the basement membrane removed.

For tissue-engineered skin equivalents, split-thickness cadaver skin was incubated in 1 M sodium chloride at 37 °C for 12 h to separate the epidermis from the dermis. The dermis was then agitated in PBS at room temperature for 7–10 days to remove all cellular components and stored at 4 °C. This sodium chloride-treated AADM retains the intact basement membrane structure. Preparation and clinical application of AADMs were approved by the Kyorin University ethics committee, Tokyo, Japan.

Y. Takami (✉) · S. Ono · R. Ogawa
Department of Plastic, Reconstructive and Aesthetic Surgery,
Nippon Medical School, Tokyo, Japan
e-mail: takamiyo@nms.ac.jp; s-ono@nms.ac.jp;
r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_24

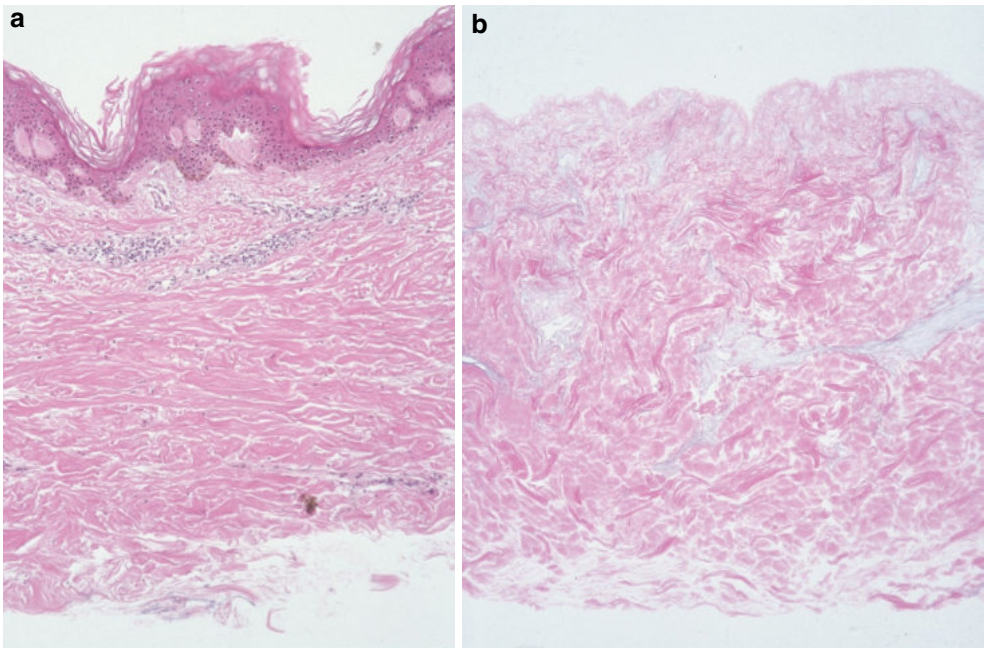


Fig. 24.1 Microscopic images of animal tissue sections. Panel (**a**) shows a cross-section of healthy skin tissue with distinct layers, including the epidermis and dermis, with visible cell nuclei. Panel (**b**) displays a section of skin tissue with altered structure, showing less defined layers and a more disorganized appearance. Both images are stained, highlighting cellular and structural details in pink hues

24.2 AADM Transplantation with Simultaneous Skin Graft Overlay

24.2.1 Clinical Results

Trypsin-treated AADMs were applied to excised full-thickness burn wounds in five cases (six wounds). Both the transplanted AADMs and the overlaid thin (less than 0.010 inches thick) STSGs (three meshed and three sheet grafts) achieved complete survival. AADM transplantation inhibited interstitial scar formation of the meshed STSG (Fig. 24.2). Histological examination revealed full vascularization of the transplanted AADM, which remained a stable dermal matrix within the wound (Fig. 24.3).

24.2.2 Discussion and Conclusion

AADM transplantation supports dermal regeneration in full-thickness burn wounds, suggesting a potential to improve scar appearance after thin meshed STSG in deep burns.

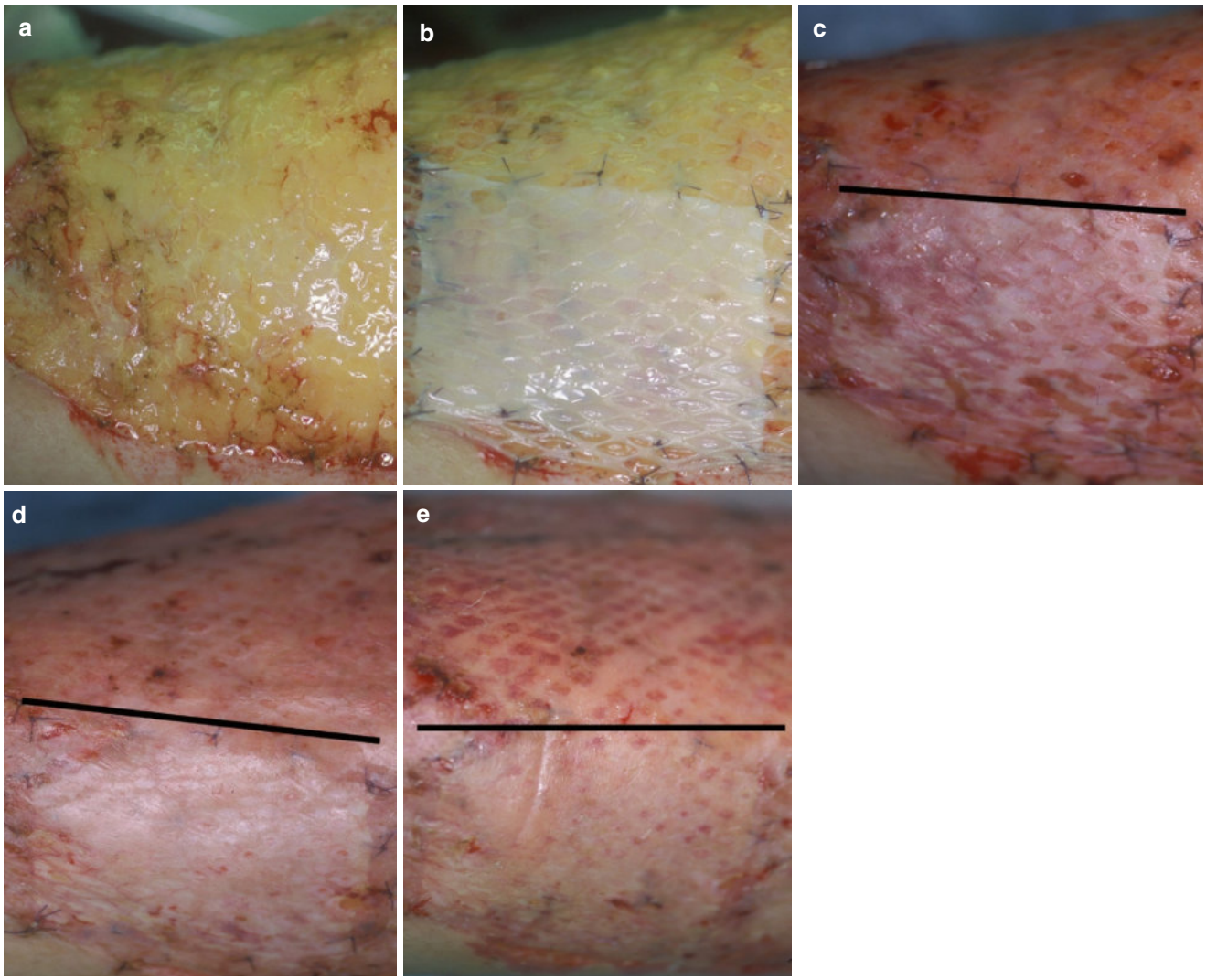


Fig. 24.2 Appearance of AADM transplantation with simultaneous STSG overlay. Case: A 38-year-old female. A third degree burn wound of the right thigh was excised. Wound before AADM transplantation (**a**) and the transplanted AADM (**b**). On the area below the black line, a 5 × 7 cm AADM was placed and overlaid with a 0.008-inch thick, meshed STSG. On the area above the black line, only thin, meshed STSG was placed. (**c**) Appearance at 7 days after the transplantation. (**d**) Appearance at 14 days after the transplantation. (**e**) Appearance at 21 days after the transplantation. The meshed scar formation was inhibited in the area with AADM transplantation (below the line)

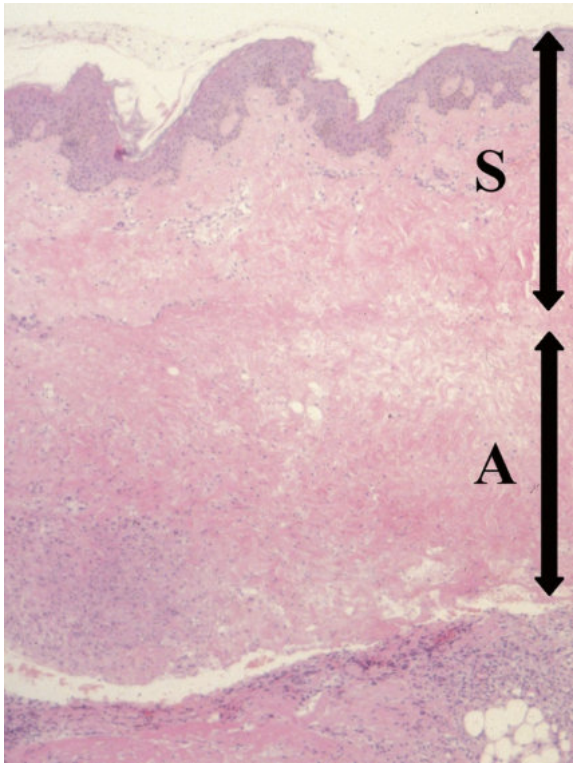


Fig. 24.3 Histological image of animal tissue showing two distinct layers. The upper layer, labeled "S," is the epidermis, characterized by a darker purple hue and a wavy surface. The lower layer, labeled "A," is the dermis, appearing lighter and more fibrous. Black arrows indicate the thickness of each layer. The image is stained to highlight cellular structures

24.3 Tissue-Engineered Autologous Skin Equivalent (TESE) Using AADM as a Scaffold

24.3.1 Preparation of TESE (Figs. 24.4 and 24.5)

Sodium chloride-treated AADMs were used for the scaffolds of TESE. To prepare autologous keratinocytes, small samples of healthy skin (about 2 cm^2) were obtained from 4 patients with extensive burns. The epidermis and dermis were separated by incubation with Dispase (Godo Shusei Co. Ltd., Tokyo, Japan) for 3 h at 37 °C. The epidermis was treated with 0.25% trypsin/1 mM EDTA for 15 min at 37 °C to disaggregate keratinocytes. The keratinocytes were collected, centrifuged, and resuspended in a keratinocyte growth medium (KGM; Defined Keratinocyte-SFM, Gibco). The separated dermis was cut into small pieces and placed in culture dishes to produce a culture of dermal fibroblasts. After the pieces of dermis had become attached to the culture dishes, 10% fetal calf serum (FCS)/Dulbecco's modified Eagle's medium was added to the dishes, which were then incubated at 37 °C in 5% CO_2/air.

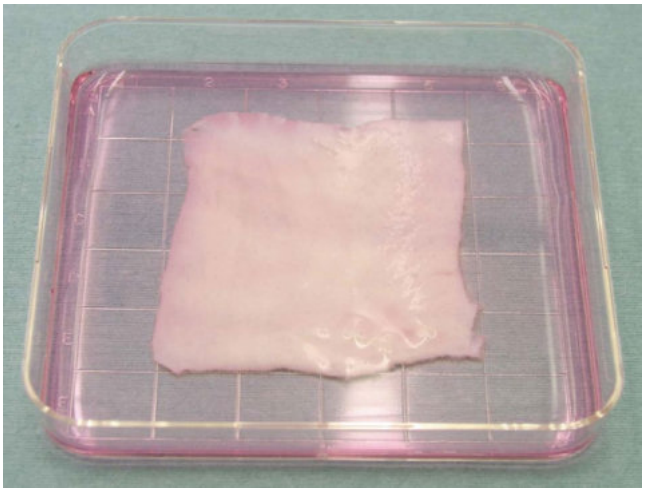


Fig. 24.4 Appearance of tissue-engineered autologous skin equivalent (TESE). A 4 × 5 cm sized TESE in a Petri dish is ready for clinical transplantation

To create the TESE, the subcultivated autologous fibroblasts were seeded on the reticular side of the AADM with 2% FCS and KGM. Two days later, subcultivated keratinocytes were seeded on the basement-membrane side of the AADM. After 2 or 3 days of culture, the medium was changed to 10% FCS/KGM to induce keratinocyte differentiation. After an additional day of culture, the cultured TASE was transferred to an air-liquid interface to promote stratification.

The resulting TESEs were washed thoroughly with Hanks's balanced salt solution, and then transplanted to patients. The average time required to create a TESE from the biopsied skin was 21 days. Histologically, TESE showed a well-developed epidermal layer, rete ridges, and normal dermal structures (Fig. 24.5c).

24.3.2 Clinical Application

Case 1 was a 29-year-old woman with third-degree burns to 75% of the body surface. One sheet of TESE (5 × 2.5 cm) was transplanted to the excised third-degree burn wound of the right thigh (Fig. 24.6).

Case 2 was a 41-year-old woman with third-degree burns to 98% of the body surface. Four sheets of TESE (mean size: 5 × 5 cm) were transplanted to the excised third-degree burn wound of the abdomen (Fig. 24.7).

Case 3 was a 36-year-old woman with third-degree burns to 46% of the body surface. Four sheets of TESE (mean size: 5 × 5 cm) were transplanted to the excised third-degree burn wound of the right thigh (Fig. 24.8).

Case 4 was a 63-year-old man with third-degree burns to 40% of the body surface. Seven sheets of TESE (four sheets of 5 × 5 cm-sized TESE and three smaller-sized TESEs) were transplanted to the excised third-degree burn wound of the abdomen (Fig. 24.9).

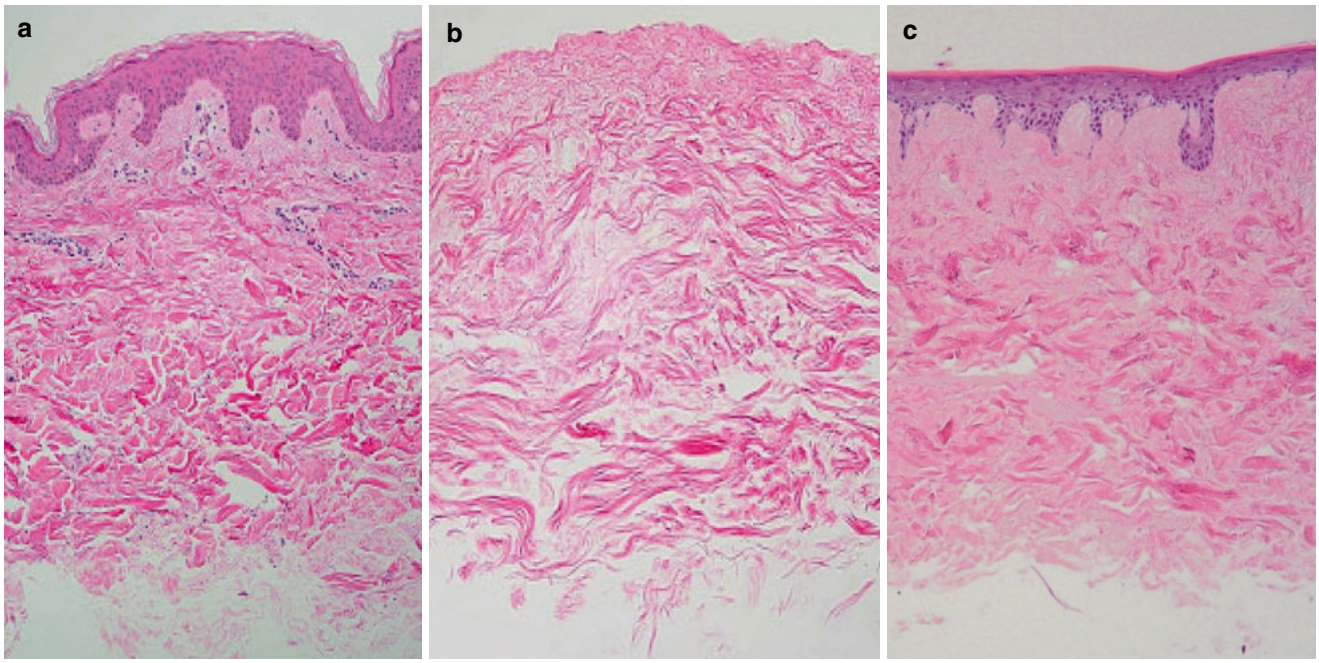


Fig. 24.5 Microscopic images of skin tissue samples in three panels labeled (**a**), (**b**), and c. Panel (**a**) shows a section with a dense layer of cells and a wavy pattern. Panel (**b**) displays a more fibrous texture with less cellular density. Panel (**c**) features a smoother surface with a uniform cell layer. The images are stained in shades of pink and purple, highlighting cellular structures and tissue organization

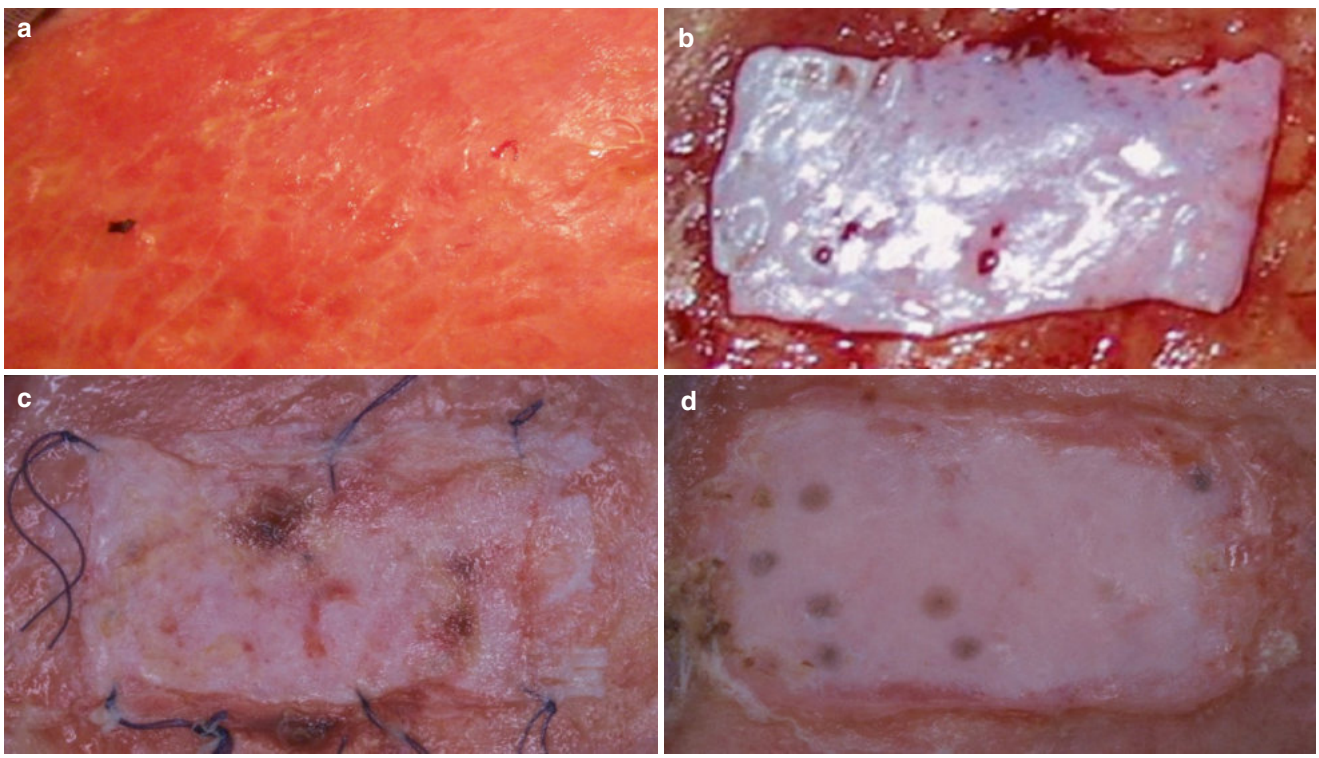


Fig. 24.6 Four-panel image showing close-up views of skin with different treatments. Panel (**a**) displays untreated skin with a reddish appearance. Panel (**b**) shows skin with a shiny, rectangular patch applied. Panel (**c**) depicts skin with a similar patch, secured with blue sutures, and some dark spots. Panel (**d**) illustrates skin with a patch and several dark circular marks. The images focus on the texture and condition of the skin in each scenario

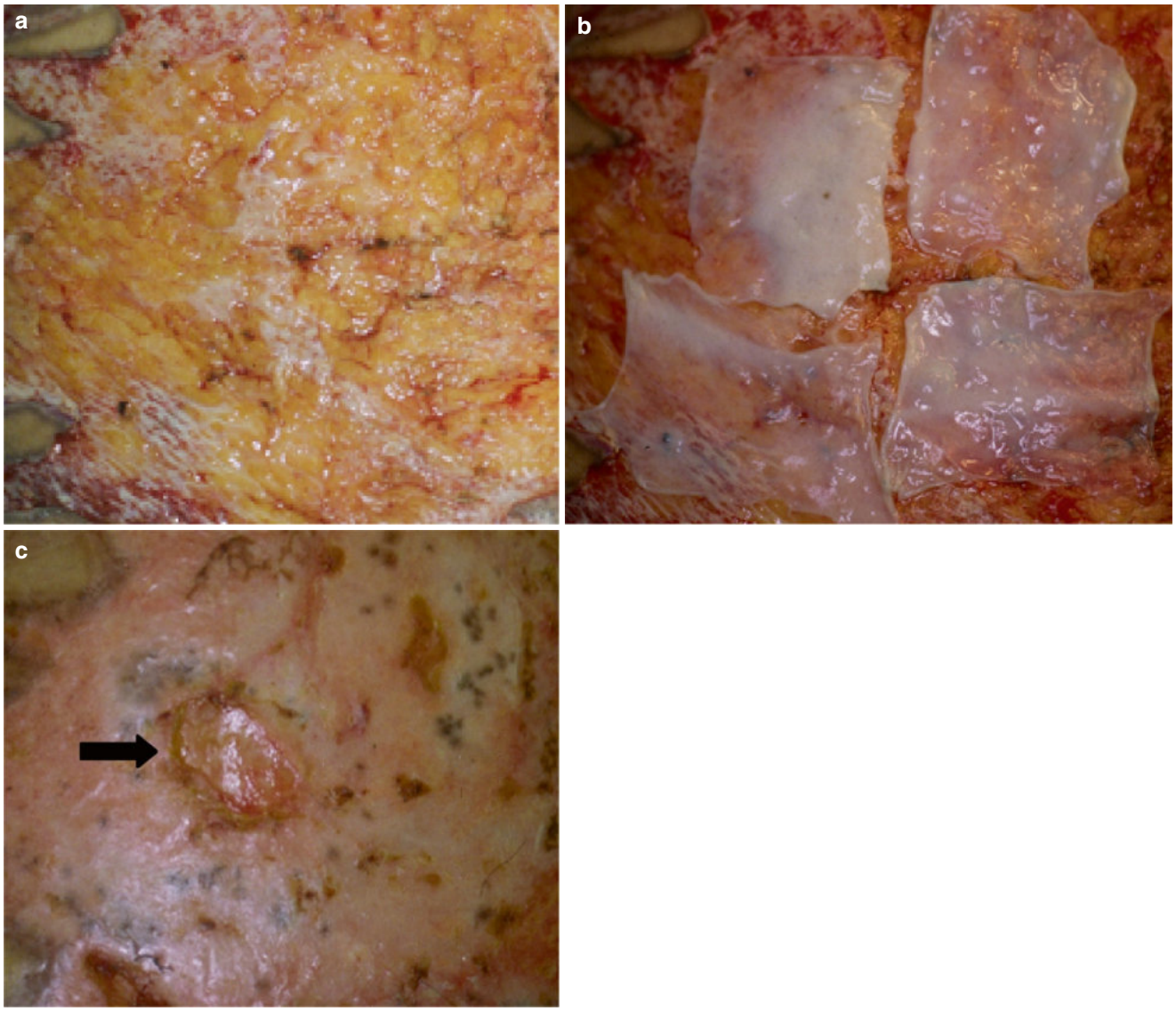


Fig. 24.7 Appearance of transplanted TESE. Excised third degree burn wound of the abdomen before TESE transplantation (**a**) and the transplanted TESE (four sheets of TESEs, mean size: 5 × 5 cm) (**b**), and 42 days after the transplantation (**c**). The TESE survived well. The arrow indicates an ulcer due to biopsy for histological examination

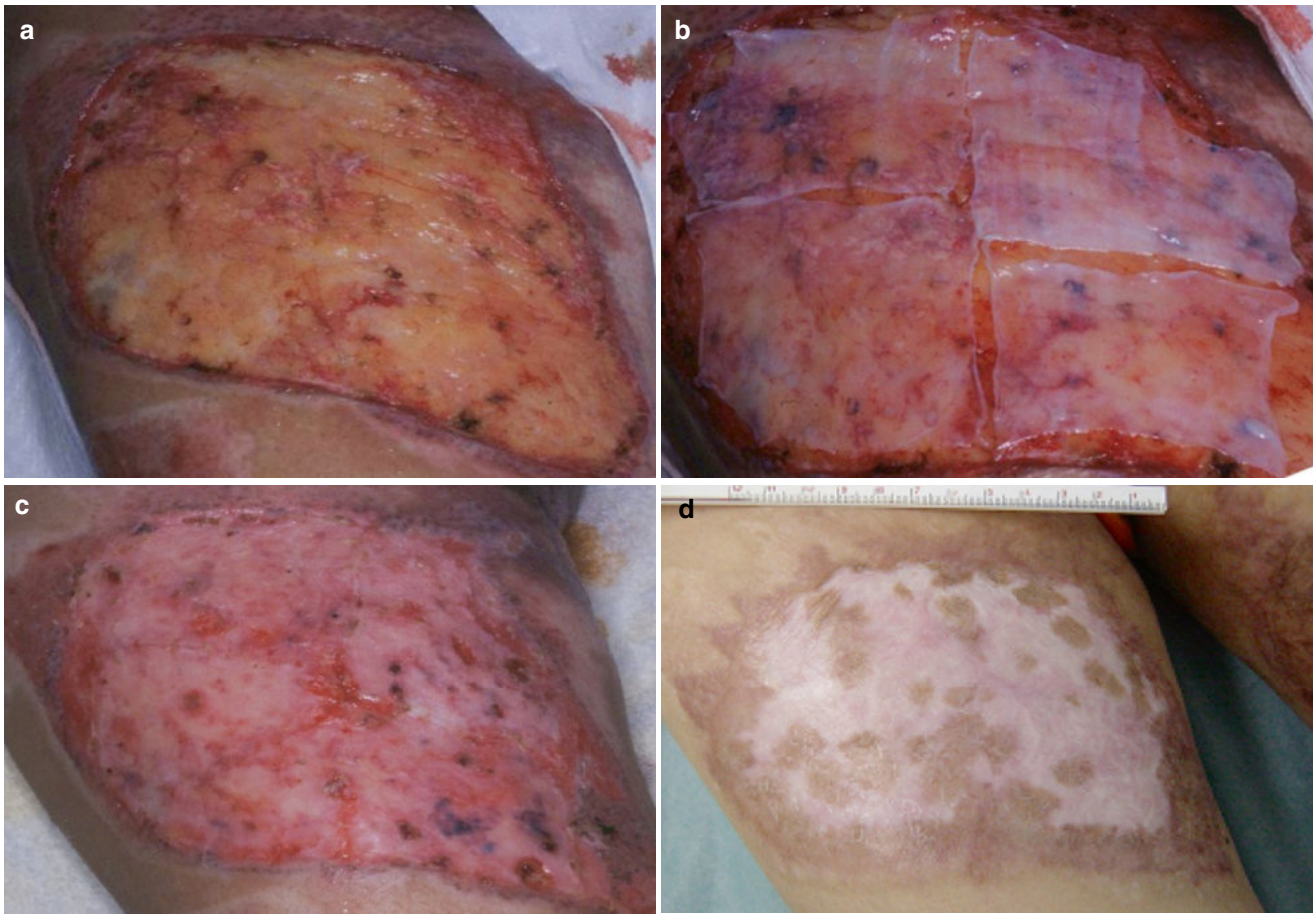


Fig. 24.8 A series of four photographs showing the stages of a medical procedure on a skin wound. Image (**a**) shows a large, exposed wound with a yellowish tissue. Image (**b**) displays the wound covered with a transparent dressing. Image (**c**) shows the wound healing with a reddish appearance. Image (**d**) depicts the wound further healed, with a pinkish tone and some scarring. A ruler is visible in the top part of image (**d**) for scale

24.3.3 Clinical Results

Graft survival was evaluated 14 days after transplantation. The survival rate was 100% for case 1, 96% for case 2, 93% for case 3, and 90% for case 4. By 28 days after surgery, the areas to which TESEs had been transplanted had become completely epithelialized. There was no delayed graft loss or graft fragility during the observation period (42–220 days). Abnormal pigmentation on the transplanted site was seen in all cases. Only case 4 suffered partial graft loss due to bacterial infection, but the wound was healed with additional TESE transplantation. Cases 1 and 2 died of multiple organ failure some 50 days after TESE transplantation. However, no evidence suggests that transplantation contributed to their deaths. Cases 3 and 4 were discharged to go home.

24.3.4 Histological Examination (Case 2)

The TESE had become keratinized with a fully stratified epidermis and normal polarity of differentiation (Fig. 24.10a). The epidermis was firmly attached to the remaining basement membrane of the AADM (Fig. 24.11a). Transplanted TESE showed stable dermal and epidermal structure with positive staining of anti-Type IV collagen (Figs. 24.10a, 24.11b). Transplanted AADM as the scaffold of TESE remained as a stable dermal matrix in the regenerated skin (Figure 24.10b).

24.3.5 Discussion and Conclusion

Although several types of AADM-based cultured skin have been introduced previously, results of the clinical trials have been far from satisfactory [6, 7]. In order to improve the clinical results, we have prepared AADMs without protease, surfactants, and further sterilizing procedures, which have been commonly used to prepare AADMs [6, 7]. It is suggested that our method of ADAM preparation retained more natural dermal structures and thus improved the property of AADMs as a scaffold of tissue-engineered skin [4, 5]. We have concluded that TESEs based on AADM as a scaffold may be a useful tool for permanent repair of full-thickness burn wounds.

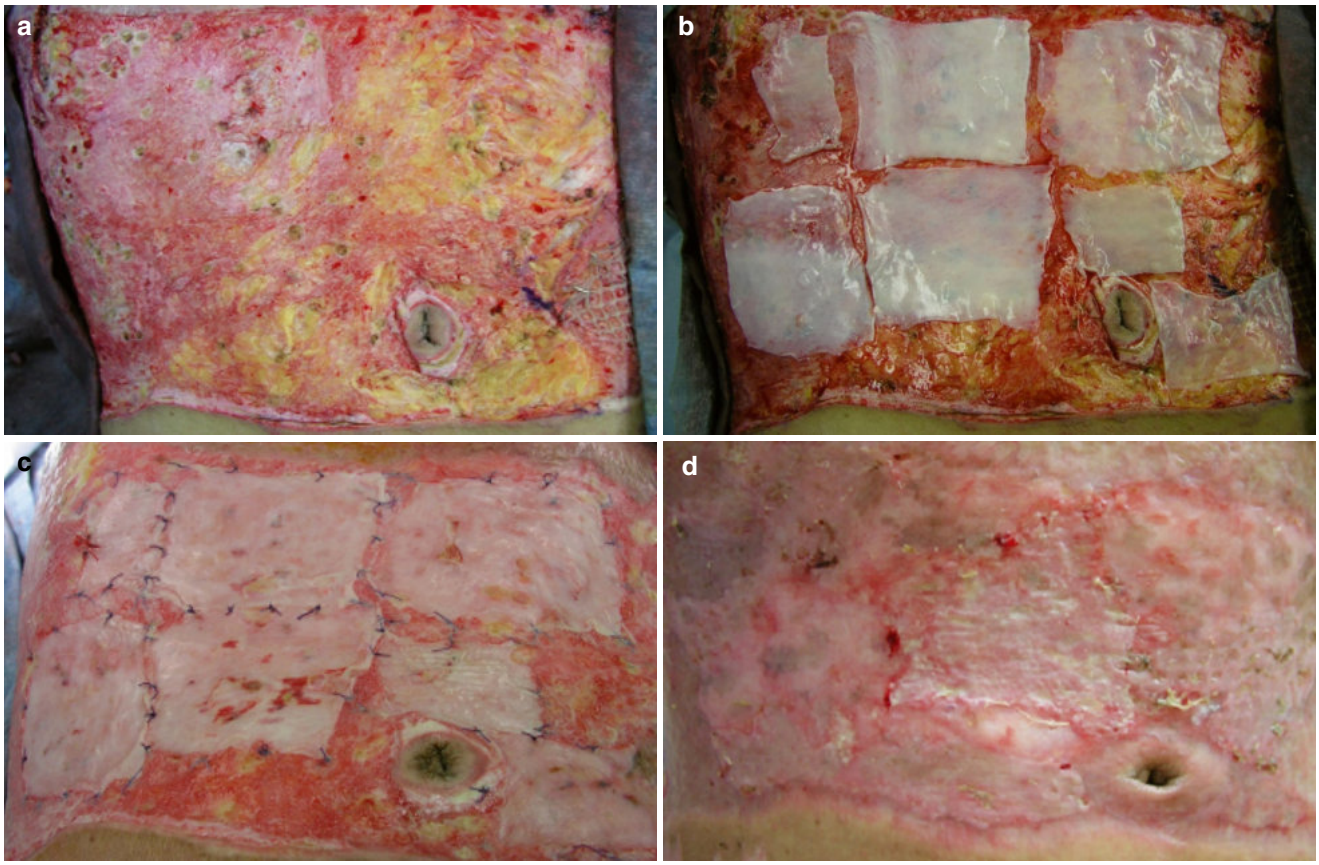


Fig. 24.9 Appearance of transplanted TESE. Panel (**a**) shows the excised third degree burn wound of the abdomen. Panel (**b**) shows transplanted TESEs (four sheets of 5 × 5 cm-sized TESEs and three smaller-sized TESEs). Panel (**c**) shows transplanted TESE 14 days after the transplantation. The TESEs survived well. Panel (**d**) shows appearance of the transplanted TESE 60 days after transplanting. Partial graft loss due to bacterial infection was observed, but the wound healed with additional TESE transplantation

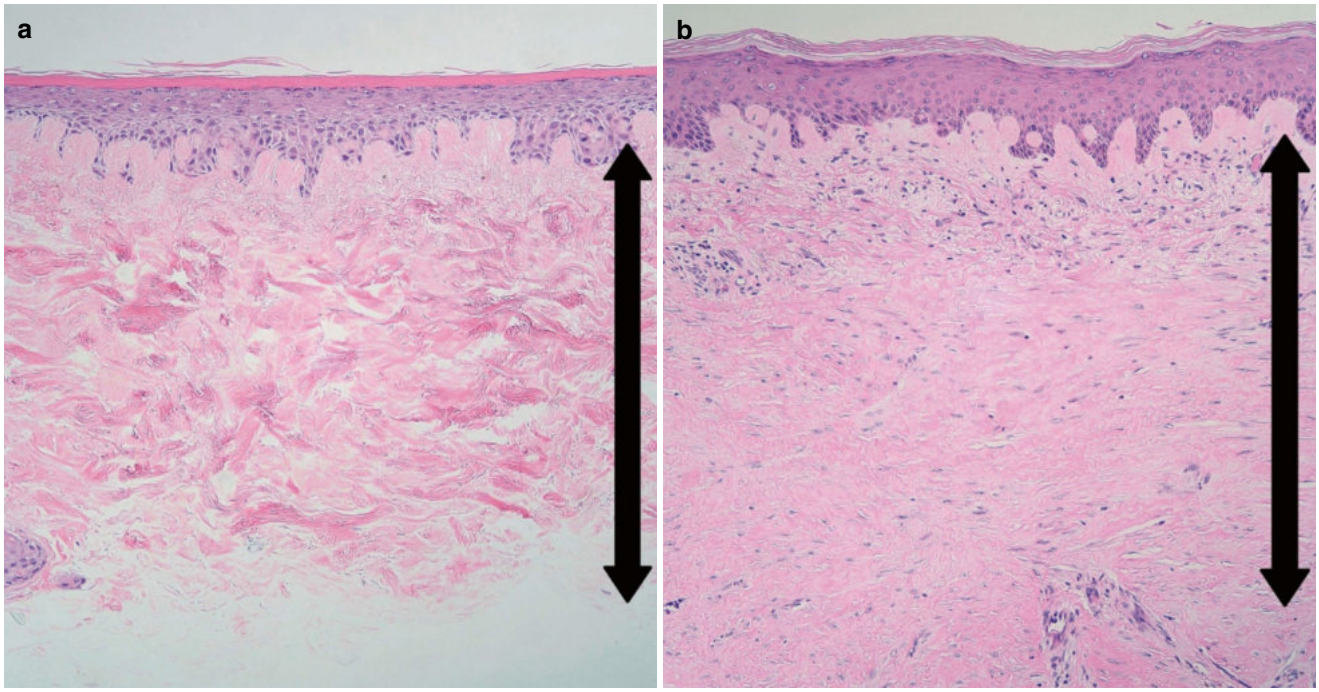


Fig. 24.10 Microscopic images of tissue samples in two panels labeled ‘a’ and ‘b’. Both panels show layers of cells with varying densities and colors, primarily in shades of pink and purple. A black double-headed arrow is present in each panel, indicating the thickness of the tissue layers. The images highlight differences in tissue structure and composition between the two samples

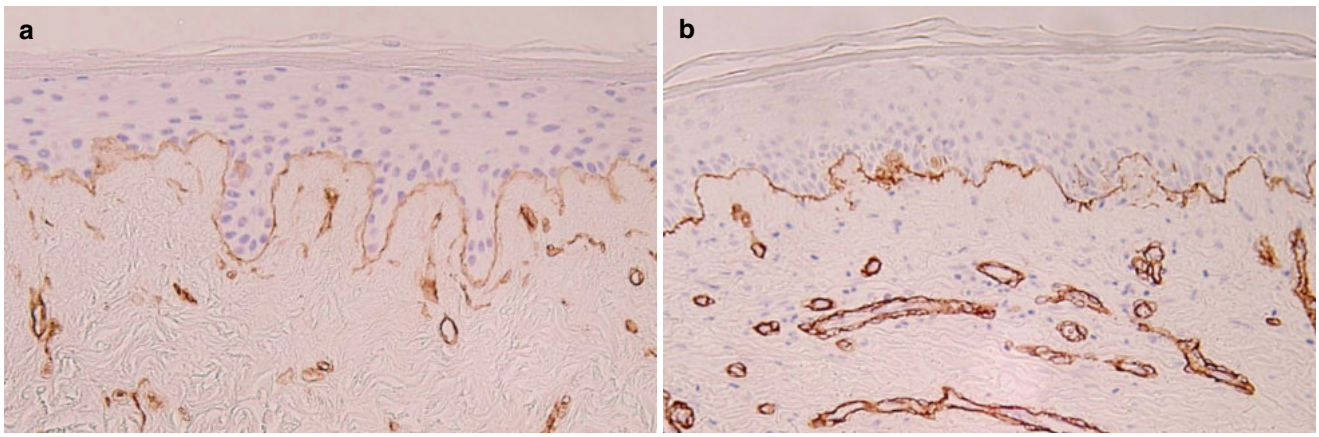


Fig. 24.11 Microscopic images of animal tissue sections. Panel (**a**) shows a section with a layer of cells stained in blue, indicating the presence of nuclei, and brown staining highlighting specific structures. Panel (**b**) displays a similar tissue section with more pronounced brown staining, suggesting increased presence or activity of the highlighted structures. Both panels illustrate the cellular and structural composition of the tissue

24.4 Effectiveness and Clinical Evidence of Acellular Allogenic Dermal Matrices (AADMs) in Burn Treatment

Emerging literature highlights the promising role of AADMs in burn treatment. Here is a summary of recent findings and advancements, which underscore the effectiveness of AADMs, particularly in combination with tissue-engineered approaches for improved outcomes in wound healing, graft survival, and aesthetic results:

Enhanced Wound Healing and Graft Survival: Research with 18 deep burn patients revealed that those treated with AADM and autologous skin grafts had significantly better graft survival (88.9%) compared to autograft-only treatments (66.7%) [8]. The AADM group also showed improved skin elasticity, reduced blistering, and greater joint mobility at 6 months post-treatment.

Long-Term Aesthetic and Functional Improvements: In a long-term study of 19 patients, the combination of AADM and split-thickness autografts demonstrated reduced scarring and contractures with a natural skin contour and better functional recovery, particularly in joint areas [9]. These improvements led to high patient satisfaction and minimal donor site complications.

Effective Joint Area Treatment: For full-thickness burns over joints, where contractures and limited mobility often result, AADM combined with ultrathin autografts (e.g., AlloDerm) reduced contracture rates significantly [10]. Patients saw high graft success (91.5%), with near-normal joint motion (95%) and rapid donor site healing within 6 days, leading to stable, trauma-resistant skin.

Innovative Tissue-Engineered Skin Equivalents (TESEs): A recent approach has used AADM as a scaffold for tissue-engineered skin equivalents (TESEs), which incorporate autologous keratinocytes and fibroblasts cultured from burn patients [11]. This process, completed in 3 weeks, achieved a 96% graft survival rate in four patients with third-degree burns. Histological analysis showed these TESEs to have characteristics similar to normal skin grafts, making them suitable for long-term repair of full-thickness skin defects.

References

1. Livesey SA, Herndon DN, Hollyyoak MA, Atkinson YH, Nag A. Transplanted acellular allograft dermal matrix: potential as a template for the reconstruction of viable dermis. Transplantation. 1995;60:1–9.
2. Takami Y, Matsuda T, Yoshitake M, Hanumadass M, Walter RJ. Dispase/detergent treated dermal matrix as a dermal substitute. Burns. 1996;22:182–90.
3. Takami Y, Tanaka H, Wada T, Takeda T, Kubota J, Ogo K, Shimazaki S. Characterization of an acellular allogenic dermal matrix and its clinical application. Jpn J Burn Injuries. 2000;26:261–7.
4. Takami Y, Shimazaki S, Yamaguchi R, Tanaka H, Harii S. Transplantation of tissue-engineered skin composed of autologous cells and acellular allogeneic dermal matrix. Jpn J Plast Reconstr Surg. 2004;47:867–73.
5. Takami Y, Yamaguchi R, Shimazaki S. Successful transplantation of tissue-engineered skin equivalent based on autologous transformation of allograft skin. Am J Transplant. 2006;82(Suppl 3):746.
6. Sahota PS, Burn JL, Heaton M, Freedlander E, Suvarna SK, Brown NJ, MacNeil S. Development of a reconstructed human skin model for angiogenesis. Wound Rep Reg. 2003;11:275–84.
7. Hernon CA, Harrison CA, Thornton DJA, MacNeil S. Enhancement of keratinocyte performance in the production of tissue-engineered skin using a low calcium medium. Wound Rep Reg. 2007;15:718–26.
8. Tan J. Clinical research of early allogeneic acellular dermal matrix on deep burn wound. China Med Herald. 2014;
9. Pan YC, Liang Z, Yuan S, Xu J, Wang J, Chen S. A long-term follow-up study of acellular dermal matrix with thin autograft in burns patients. Ann Plast Surg. 2011;67:346–51.
10. Tsai C, Lin SD, Lai C, Lin T. The use of composite acellular allodermis-ultrathin autograft on joint area in major burn patients—one year follow-up. Kaohsiung J Med Sci. 1999;15(11):651–8.
11. Takami Y, Yamaguchi R, Ono S, Hyakusoku H. Clinical application and histological properties of autologous tissue-engineered skin equivalents using an acellular dermal matrix. J Nippon Med Sch. 2014;81(6):356–63.

Cultured Epithelial Autograft Transplantation on Dermal Reconstructions with Artificial Dermis

25

Minoru Hayashi

Abstract

Skin grafting cannot be used sometimes in patients with severe burns because of insufficient skin. One way of solving this problem is to use cultured epithelial autografts (CEAs): here, the cells from a small piece of epidermis are grown in vitro into sheets that resemble conventional split-thickness skin grafts. This tissue-engineering approach was first used clinically in the early 1980s by the Green group. In 1984, they then reported that CEAs enabled the recovery of extensively burned children (O'Connor NE, Mulliken JB, Banks-Schlegel S, et al. Lancet 1:75–78, 1981; Gallico GG 3rd, O'Connor NE, Compton CC, et al. N Engl J Med 311:448–451, 1984; Gallico GG 3rd, O'Connor NE. Clin Plast Surg 12:149–157, 1985). Thereafter, the usefulness of Green-type CEAs became widely known, and CEAs are now a common treatment for extensive burn wounds (Munster AM, Weiner SH, Spence RJ. Ann Surg 211:676–679, 1990; Sood R, Balledux J, Koumanis DJ, et al. J Burn Care Res 30:576–586, 2009; Cirodde A, Leclerc T, Jault P, et al. Burns 37:964–972, 2011; Yim H, Yang HT, Cho YS, et al. Burns 37:1067–1071, 2011; Lee H. Burns 38:931–936, 2012). Another important early development in the field related to the fact that the wound bed must be prepared for successful CEA transplantation: in 1986, Cuono et al. showed that the dermal layer of allografts can be used to prepare burn wounds for CEAs (Cuono C, Langdon R, McGuire J. Lancet 1:1123–1124, 1986).

Keywords

Cultured epithelial autografts · Wound bed preparation · Allograft · Artificial dermis · Trafermin · Hydrosurgery system · Split-thickness skin graft · Meshed skin graft

25.1 Introduction

Skin grafting cannot be used sometimes in patients with severe burns because of insufficient skin. One way of solving this problem is to use cultured epithelial autografts (CEAs): here, the cells from a small piece of epidermis are grown in vitro into sheets that resemble conventional split-thickness skin grafts. This tissue-engineering approach was first used clinically in the early 1980s by the Green group. In 1984, they then reported that CEAs enabled the recovery of extensively burned children [1–3]. Thereafter, the usefulness of Green-type CEAs became widely known, and CEAs are now a common treatment for extensive burn wounds [4–8]. Another important early development in the field related to the fact that the wound bed must be prepared for successful CEA transplantation: in 1986, Cuono et al. showed that the dermal layer of allografts can be used to prepare burn wounds for CEAs [9].

In terms of the commercial availability of CEAs, the first product was a Green-type CEA called EPICEL, which was first marketed in the United States in 1988 [10]. In 2009, a similar Green-type autologous cultured epidermis called JACE was covered by the national health insurance scheme of Japan (Fig. 25.1). JACE involves a distinct manufacturing process and thus is different from EPICEL. Since JACE also requires wound-bed preparation, and there are insufficient cryopreserved cadaver allografts in Japan, the wound bed is often managed with artificial dermis instead of allografts. This chapter describes the way CEA transplantations are performed in Japan.

M. Hayashi (✉)
Department of Plastic and Reconstructive Surgery, St. Mary's Hospital, Fukuoka, Japan

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_25

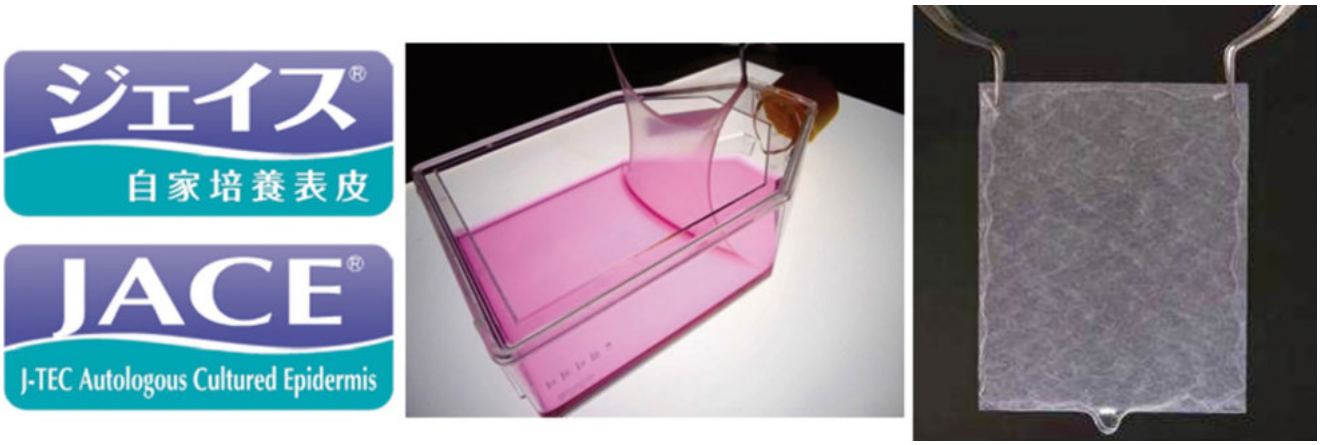


Fig. 25.1 Cultured epithelial autografts are commercially available in Japan in the form of JACE. The company is called J-TEC (left). The cells are grown in large flasks on culture media (middle) and form sheets of epithelial cells (right)

25.2 Clinical Course

The health regulations in Japan state that CEAs can be used for deep second-degree and third-degree burn wounds that affect a total body surface area (TBSA) of at least 30%. To obtain the JACE CEAs, a 1–12 cm^2 area of full-thickness skin is harvested early from the patient and cultured by Japan Tissue Engineering Co., Ltd. (J-TEC) (Aichi, Japan). The wide variation in sampled skin area reflects variables such as projected culture duration, patient age, and the number of CEA sheets that are required. Consequently, to determine the skin area, J-TEC employees should be consulted.

In this section, we will assume that the patient has extensive burns. After the primary survey of the burn is completed, the secondary survey is conducted and the burn area and depth are determined. If the burn area exceeds 30% TBSA, the use of CEAs is discussed with the emergency department and the patient's family within 1 day of admission. After consent is obtained from the family, the CEAs are ordered from J-TEC, and 1–12 cm^2 full-thickness normal skin is harvested from unburned skin areas within 48 h of the burn. The CEAs can be used 3 weeks later. While waiting, the wound beds are prepared for transplanting, as follows.

A good wound bed is created by constructing good-quality, dermal-like tissue. We usually achieve this by implanting artificial dermis after completing debridement. It is generally considered safe to perform a single debridement if it takes less than 2 h and involves crusted resection over less than 20% of TBSA. Thus, multiple debridements over a couple of weeks may be needed [11]. However, if the emergency department agrees, the entire debridement can be completed in a single operation, even if the crusted-resection TBSA is ≥20%. In cases where multiple debridements are necessary, they are often divided according to the required body position. For example, all debridements that can be conducted with the patient in the supine and prone positions are conducted in separate operations. This reflects the fact that intraoperative position changes are a risk factor for poor outcomes.

The debridement is completed in the first week after ordering the CEAs, and the wound bed is prepared in the remaining 2 weeks. Artificial dermis is implanted immediately after finishing the debridement. Dressings with Vaseline petroleum jelly and Trafermin (Fibrast Spray; Kaken Pharmaceutical Co., Ltd., Japan) are applied immediately and changed daily. This promotes the early construction of the wound bed [12, 13]. Since the use of artificial dermis is a risk factor for infection, the patient and wound bed are monitored closely for fever and other signs/symptoms. If infection is suspected, the infected artificial dermis area is removed as soon as possible. The date of the operation must be set two weeks in advance, as CEA starts culture two weeks in advance and cannot be rescheduled. If there is more than a week before the CEAs will be implanted, new artificial dermis is applied in the operating room.

During the wait for the CEAs, the skin grafts that are needed are completed. For example, since hand function is very important, we apply skin grafts to hand burns at the time of the initial debridement, if possible. Hand rehabilitation can then begin one week after this skin grafting. Similarly, if a tracheostomy is necessary due to an inhalation injury, skin grafting of the neck is also performed at the time of the initial debridement; this allows early placement of a tracheal tube over the grafted skin. In addition, if the burns cover 30–40% TBSA, there is sufficient area of normal skin for skin grafting on the back and other areas when CEA grafting is complicated; thus, these skin grafts are also applied while waiting for the CEAs to arrive.

Once the CEAs arrive, the prepared wound bed is first washed with saline solution and the wound surface is

refreshed using a sharp curette, an electrodermatome, or a hydrosurgery system (VERSAJETII; Smith & Nephew Medical Ltd., UK). Autologous healthy skin is then harvested to a thickness of 2–3/10 mm with an electrodermatome. The split-thickness skin graft is subjected to 6:1 meshing, applied to the wound bed, and then covered with a CEA. Care is taken to avoid air bubbles under the CEA. A dressing of non-adherent silicone gauze is then applied. Gauze is placed over the silicone gauze, and the CEA-grafted wounds are compressed with bandages.

After implanting the CEAs, we follow the dressing protocol described by Sood et al. [14]. Thus, in the first week, the gauze and bandages are removed daily, and the grafted areas bearing the silicone gauze are left open to the air for 4 h/day to allow the CEAs to dry. Takedown, namely, the removal of the silicone gauze from the CEAs, generally occurs 1 week after the CEAs were placed. This removal should occur in the shower room, where a foam wash is applied gently so that the CEAs do not peel off.

After takedown, dressings with Vaseline petroleum jelly are applied daily. The grafted areas are exposed to air daily for 1 more week. Trafermin is used on the other burn wound areas while raw surfaces are rested. Almost all wounds close within 3–4 weeks of applying the CEAs.

Rehabilitation of the CEA-implanted areas should begin 1 week after surgery, namely, after takedown. The rehabilitation staff are invited to the takedown so that they learn which parts of the affected area can be touched.

25.3 Case Presentations

25.3.1 Case 1

A 45-year-old woman injured herself with fire and kerosene. She had deep second- and third-degree burn wounds on the head, thorax, abdomen, back, both upper extremities, and both thighs (45% TBSA; 2% deep second-degree and 43% third-degree) (Fig. 25.2). Inhalation injury was also observed.

On admission, a full circumferential burn was noted on the trunk and both upper extremities. An escharotomy was performed at the bedside in the emergency department under sedation (Fig. 25.3). After discussing the treatment plan with the emergency department, consent for CEA transplantation was obtained from the family.

On day 2 after the injury, normal skin in the groin was harvested and sent to J-TEC for epidermal cell culturing. On post-injury day 5, debridement of the trunk and both upper extremities was conducted, and the right hand underwent split-thickness skin grafting. On post-injury day 7, the face was debrided and the neck was subjected to segmental skin grafting to prepare the area for tracheostomy. On post-injury day 12, some infected artificial dermis on the chest was removed in a bedside procedure (Fig. 25.4). After debriding the affected areas and applying new artificial dermis in the operating room, the date of CEA implantation was set at post-injury day 26. On post-injury day 21, the back and face underwent split-thickness skin grafting, and a tracheotomy was performed over the neck graft. On post-injury day 26, the CEA grafts arrived and were transplanted. Thus, the wound beds were first covered with meshed 6:1 split-thickness autografts and then with CEAs (Fig. 25.5). The wounds were managed as described above. On postoperative day 95 (post-injury day 121), the patient was transferred for rehabilitation with the goal of discharge home. At 1 postoperative year, the CEAs were viable (Fig. 25.6) and soft enough to be pinched (Fig. 25.7).

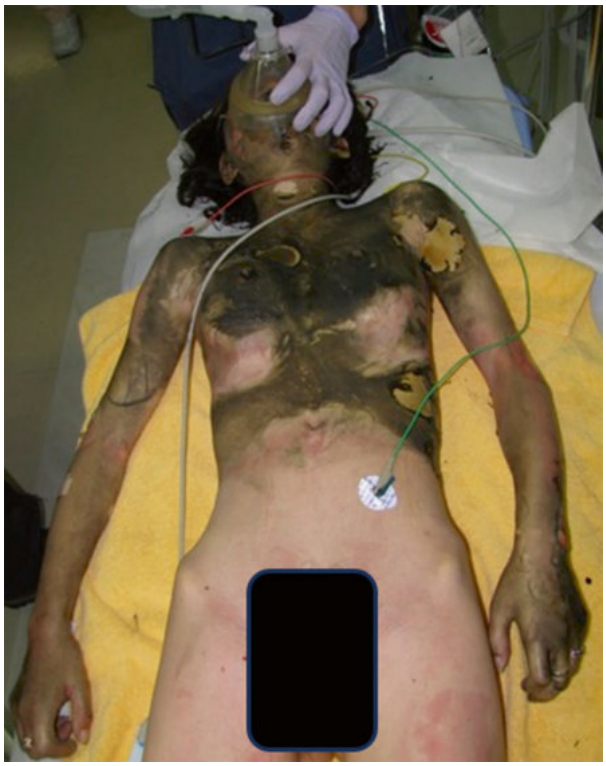


Fig. 25.2 Initial examination of Case 1. The patient had deep second- and third-degree burn wounds on the head, thorax, abdomen, back, both upper extremities, and both thighs (45% TBSA; 2% deep second-degree and 43% third-degree)

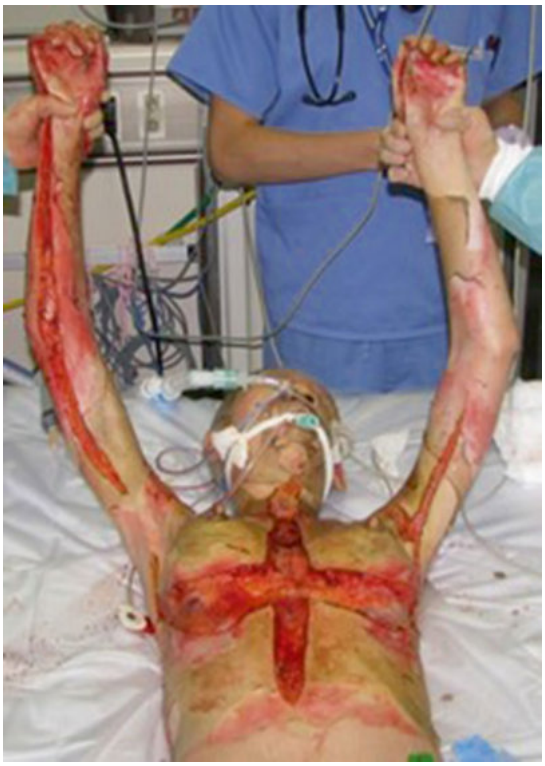


Fig. 25.3 Case 1 underwent escharotomy at the bedside in the emergency department under sedation

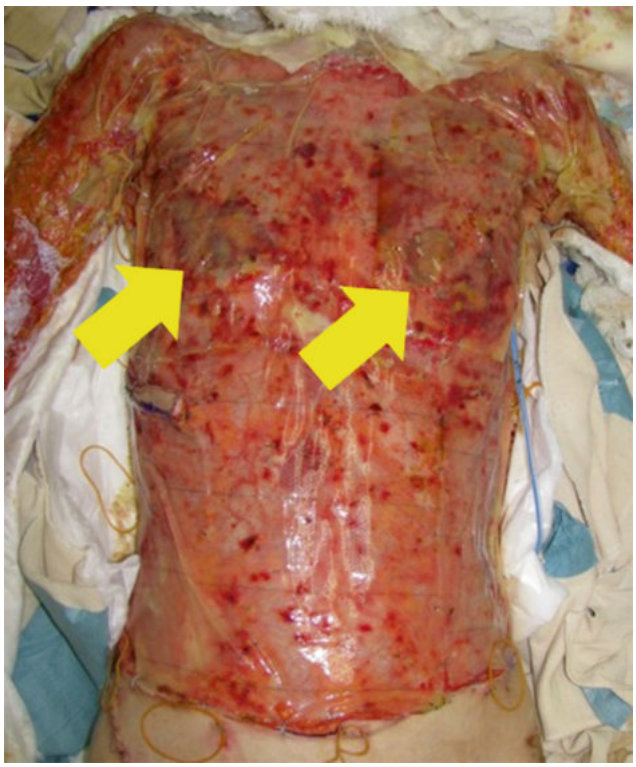


Fig. 25.4 Case 1 developed infections of the artificial dermis on the chest (arrows) on post-injury day 12. The infected dermis was removed in a bedside procedure

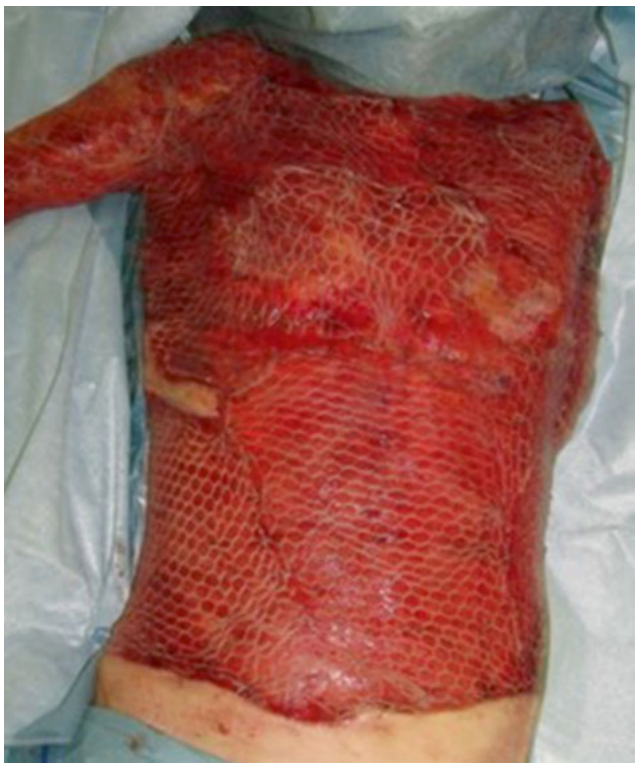


Fig. 25.5 The prepared wound beds of Case 1 were covered with first meshed 6:1 split-thickness autografts and then CEAs on post-injury day 26

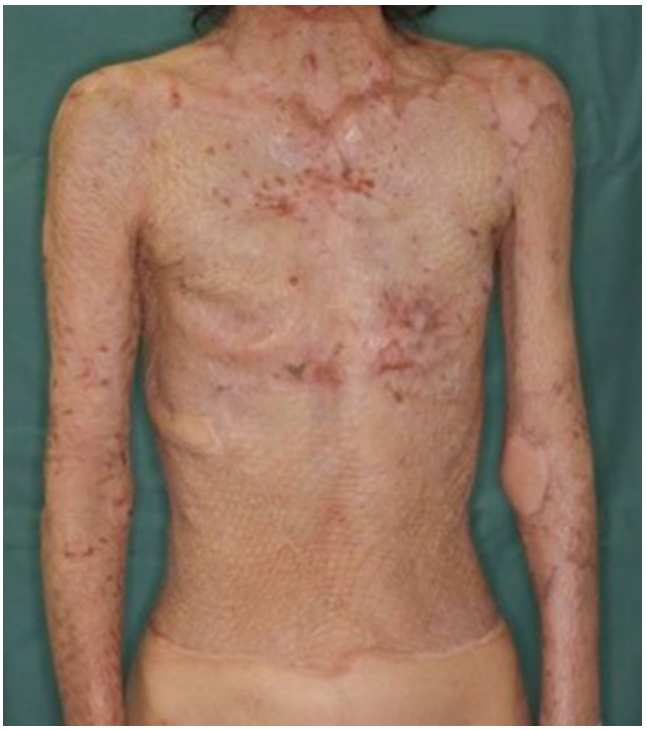


Fig. 25.6 Case 1 at 1 year after CEA implantation. The CEAs were viable

25.3.2 Case 2

A 50-year-old man injured himself with fire and kerosene. He had deep second- and third-degree burn wounds on the head, thorax, abdomen, back, both upper extremities, and both thighs (44% TBSA; 34% deep second-degree and 10% third-degree) (Fig. 25.8). Inhalation injury was also observed.

Normal skin in the groin was harvested on day 2 after the injury and sent to J-TEC for epidermal cell culturing. On post-injury day 3, the debridement of all burned areas was completed, and artificial dermis was implanted (Fig. 25.9). On post-injury day 24, CEA grafting was performed. Thus, the wound beds were covered with first meshed 6:1 split-thickness autografts and then CEAs (Fig. 25.10). The wounds were managed as described above. On postoperative day 77 (post-injury day 101), the patient was transferred for rehabilitation with the goal of discharge home. Six months after CEA implantation, the CEAs were viable (Fig. 25.11) and soft enough to be pinched (Fig. 25.12).

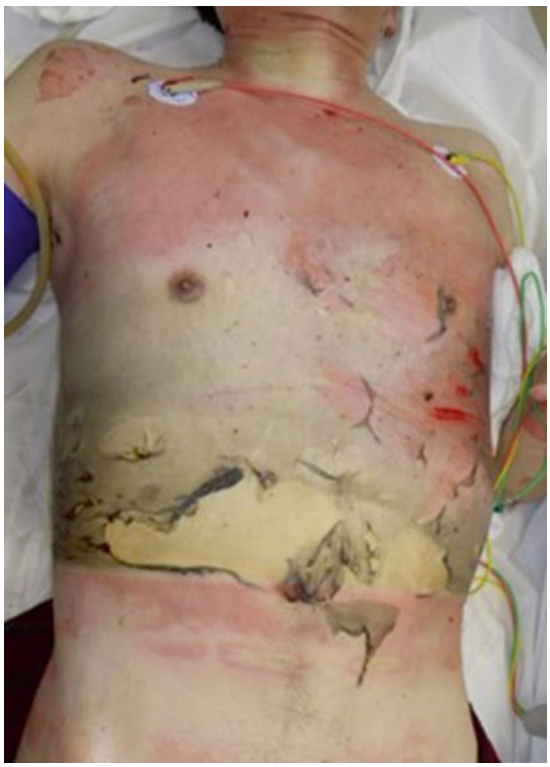


Fig. 25.8 Initial examination findings of Case 2. The patient had deep second- and third-degree burn wounds on the head, thorax, abdomen, back, both upper extremities, and both thighs (44% TBSA; 34% deep second-degree and 10% third-degree)

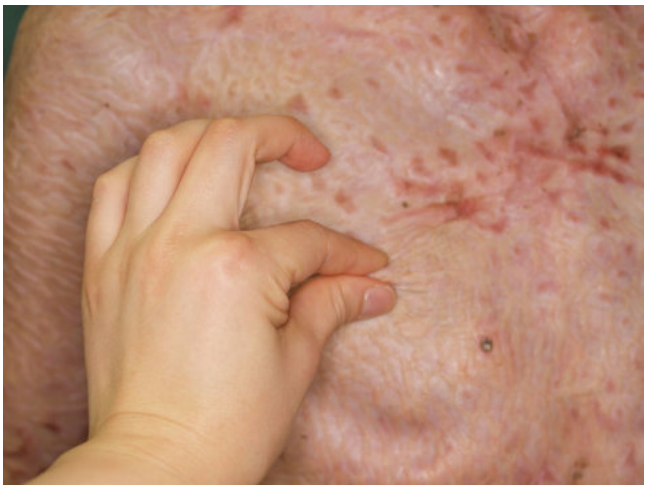


Fig. 25.7 Case 1 at 1 postoperative year. The CEAs were soft enough to be pinched

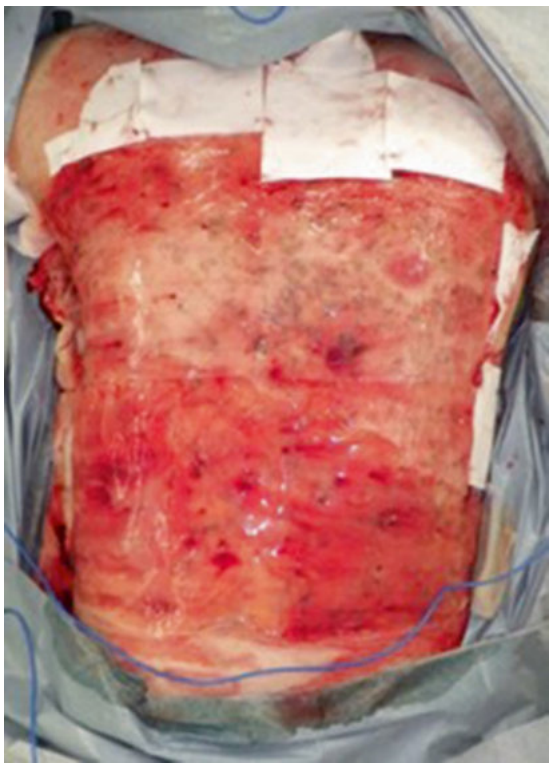


Fig. 25.9 Case 2 after debridement of all burned areas was completed and the wounds were implanted with artificial dermis

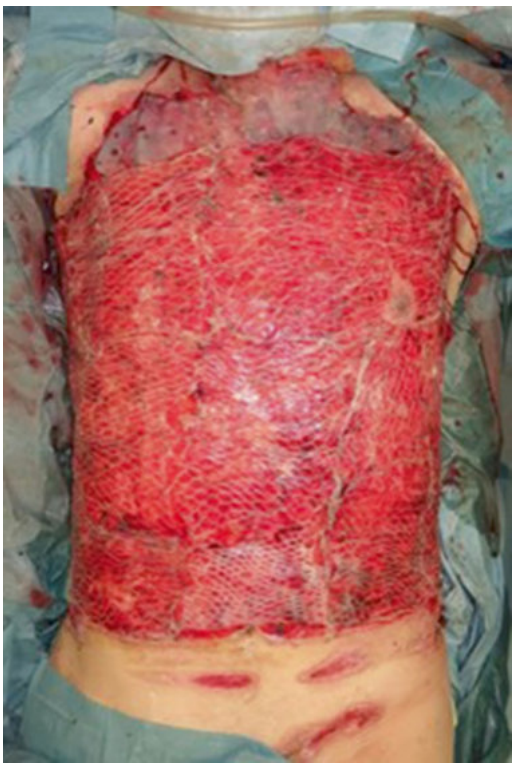


Fig. 25.10 The prepared wound beds of Case 2 were covered with first meshed 6:1 split-thickness autografts and then CEAs on post-injury day 24

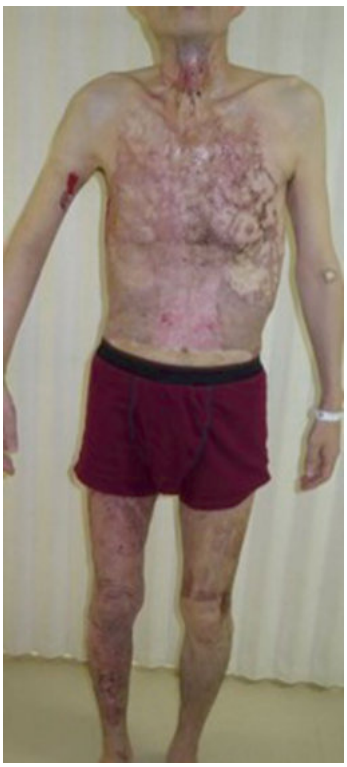


Fig. 25.11 Case 2 at 6 months after CEA transplantation. The CEAs were viable

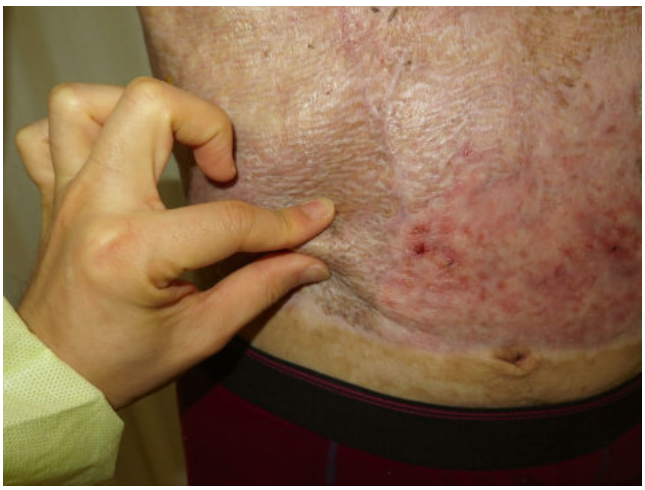


Fig. 25.12 Case 2 at 6 months after CEA transplantation. The CEAs were soft enough to be pinched

25.4 Discussion

In Japan, cultured epithelial autografting is conducted with JACE after wound-bed preparation with either allograft or artificial dermis. While allograft dermis from the Japan Skin Bank System is preferred, it is not always available in sufficient quantities. This reflects the fact that although this system was established in Japan in 1991 and has now expanded into the nationwide Japan Skin Bank Network, there remains a shortage of cryopreserved allograft cadaver donors. Thus, wound beds are often prepared with artificial dermis [15]. In such cases, JACE is combined with meshed split-thickness autografts because the collagen of JACE implants has a poor architecture. Moreover, combining JACE with meshed autografts yields a better uptake rate: a 6-year surveillance of the use of JACE in Japan shows that such combined treatment is associated with an average graft-uptake rate of 77 ± 29% [16]. The better engraftment rate reflects the fact that the autograft dermis extends, thereby filling the mesh and strongly binding to JACE [17]. This is supported by our previous study, where skin biopsies taken at various timepoints after JACE/meshed 6:1 split-thickness autograft transplantation were subjected to scanning electron microscopy. Analysis of the JACE-autograft boundary showed that the papillary dermis moved toward the central region and associated closely with JACE.

In our experience, as shown by the cases reported here, grafting with JACE/autografts yields good flexibility and texture over time. This is likely due to the use of artificial dermis and Trafermin. While patients with JACE/autograft transplants often do experience scar contractures in other areas of the body, the CEA-implanted areas generally do not require further surgery, and the patients are able to lead comfortable daily lives.

References

1. O'Connor NE, Mulliken JB, Banks-Schlegel S, et al. Grafting of burns with cultured epithelium prepared from autologous epidermal cells. Lancet. 1981;1:75–8.
2. Gallico GG 3rd, O'Connor NE, Compton CC, et al. Permanent coverage of large burn wounds with autologous cultured human epithelium. N Engl J Med. 1984;311:448–51.
3. Gallico GG 3rd, O'Connor NE. Cultured epithelium as a skin substitute. Clin Plast Surg. 1985;12:149–57.
4. Munster AM, Weiner SH, Spence RJ. Cultured epidermis for the coverage of massive burn wounds. A single center experience. Ann Surg. 1990;211:676–9.
5. Sood R, Balledux J, Koumanis DJ, et al. Coverage of large pediatric wounds with cultured epithelial autografts in congenital nevi and burns: results and technique. J Burn Care Res. 2009;30:576–86.
6. Cirodde A, Leclerc T, Jault P, et al. Cultured epithelial autografts in massive burns: a single-center retrospective study with 63 patients. Burns. 2011;37:964–72.
7. Yim H, Yang HT, Cho YS, et al. Clinical study of cultured epithelial autografts in liquid suspension in severe burn patients. Burns. 2011;37:1067–71.
8. Lee H. Outcomes of sprayed cultured epithelial autografts for full-thickness wounds: a single-centre experience. Burns. 2012;38:931–6.
9. Cuono C, Langdon R, McGuire J. Use of cultured epidermal autografts and dermal allografts as skin replacement after burn injury. Lancet. 1986;1:1123–4.
10. https://www.fda.gov/media/134119/download.
11. Cancio LC, et al. Guidelines for burn care under austere conditions: surgical and nonsurgical wound management. J Burn Care Res. 2017;38:203–14.
12. Akita S, Akino K, Imaizumi T, et al. The quality of pediatric burn scars is improved by early administration of basic fibroblast growth factor. J Burn Care Res. 2006;27:333–8.
13. Akita S, Akino K, Imaizumi T, et al. A basic fibroblast growth factor improved the quality of skin grafting in burn patient. Burns. 2005;31:855–8.
14. Sood R, Roggy D, Zieger M, et al. Cultured epithelial autografts for coverage of large burn wounds in eighty-eight patients: the Indiana University experience. J Burn Care Res. 2010;31:559–68.
15. Hayashi M, Muramatsu H, Nakano M, et al. Experience of using cultured epithelial autografts for the extensive burn wounds in eight patients. Ann Plast Surg. 2014;73:25–9.
16. Matsumura H, Matsushima A, Ueyama M, et al. Application of the cultured epidermal autograft "JACE®" for treatment of severe burns: results of a 6-year multicenter surveillance in Japan. Burns. 2016;42:769–76.
17. Hayashi M, Muramatsu H, Nakano M, et al. Changes in the dermal structure during cultured epidermal autograft engraftment process. Plast Reconstr Surg Glob Open. 2016;4:e870.

ReCell

26

Fiona M. Wood

Abstract

The aim of burn care is the timely restoration of skin integrity (Brown TL, Muller MJ. Burns 29(3):197–198, 2003). The skin has a capacity for regeneration in superficial injuries, which is overwhelmed as the burn injury extends deeper into the hypodermis and the time to healing extends (Finlay V et al. Scars Burns Heal 3:1–10, 2017). The longer the time taken to heal, the greater the risk of healing by scarring, with the lifelong loss of some skin functions (Wallace HJ et al. Burns 43(6):1271–1283, 2017). The most frequently used technique to heal a burn wound is autologous split-thickness skin grafting (STSG) (Ozhathil HJ et al. Medicina (Kaunas, Lithuania) 57(4):380, 2021). There are limitations with the potential for both the recipient and donor site to leave a scarred area; site matching of the skin characteristics is challenging. The donor site may also leave a scar, and in larger injuries, the size of the donor site is inadequate (Bache SE et al. Burns, 2023).

Keywords

Skin regeneration · Burn injury · Autologous cells · Split-thickness graft · ReCell device · Cell suspension · Dermal junction · Epithelial repair · Donor site · Wound healing · Scar reduction · Enzymatic dissociation

The aim of burn care is the timely restoration of skin integrity [1]. The skin has a capacity for regeneration in superficial injuries, which is overwhelmed as the burn injury extends deeper into the hypodermis and the time to healing extends [2]. The longer the time taken to heal, the greater the risk of healing by scarring, with the lifelong loss of some skin functions [3]. The most frequently used technique to heal a burn wound is autologous split-thickness skin grafting (STSG) [4]. There are limitations with the potential for both the recipient and donor site to leave a scarred area; site matching of the skin characteristics is challenging. The donor site may also leave a scar, and in larger injuries, the size of the donor site is inadequate [5].

There have been many innovations around skin regeneration, specifically over the last few decades [6]. The exploration of cell-based therapies is one area of increasing interest, initially as cultured epithelial autograft sheets as a method of laboratory-based skin expansion [7]. Cell therapies have expanded to include allograft and autograft cells from skin and other sources, such as fat and mesenchymal stem cells [8]. The majority of cell therapies are laboratory-based, requiring access to and coordination of the facilities with the burns centres [9]. The ReCell™ device was developed to harvest autologous skin cells at the time of intervention, providing a source of cells for immediate use. The dissociation of the skin structure to harvest the cells allows the cells to be delivered to a larger area than the donor site [10]. The capacity to expand the area of wound cover reduces the size of the donor site required and can also reduce the number of surgical procedures by covering larger areas [11]. This chapter will focus on the opportunities of the autologous skin cell suspension in clinical burn wound care.

26.1 Background of the Technique

ReCell is a medical device used for harvesting cells from the dermal-epidermal junction of the skin for delivery to the wound as a cellular suspension. It is a non-cultured, mixed-cell suspension consisting predominantly of keratinocytes, along with papillary dermal fibroblasts and melanocytes [12]. Delivered as an aerosol to the prepared wound bed, it is used to facilitate rapid epithelialisation. In wounds with viable dermal elements, such as paediatric scald injuries, it is applied to a prepared wound bed in isolation [13, 14]. In

F. M. Wood (✉)
Burns Service of Western Australia, Burn Injury Research Unit, University of Western Australia, Perth, WA, Australia
e-mail: fiona.wood@health.wa.gov.au

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_26

deeper wounds, it is applied in association with standard and advanced wound repair techniques [15, 16]. The ReCell kit is a medical device used to harvest skin cells using a thin STSG from a non-injured site. These cells are programmed for regeneration. The suspension of cells is then delivered as an aerosol to the prepared wounded site to enhance repair. A 1 cm^2 area of donor site will produce 1 mL of suspension, which can cover up to 80 cm^2. The reduction of donor site morbidity is significant as the STSG used is just in the papillary dermis to include the dermal-epidermal junction, and a smaller surface area [17]. The smaller donor site allows for flexibility—the goal is to achieve wound healing through a tailored approach matching the donor site with the recipient defect as closely as possible.

Treatment of the acute burn wound is directed by the knowledge that rapid wound closure is essential for survival and quality of outcomes. Understanding the natural history of the burn wound is pivotal in planning the timing the interventions [18]. The clinical outcome will be a result of the extent of the injury, the patient's ability to heal and the technologies available for use [19]. Tailored wound care is bringing together the knowledge, experience and technology to meet the patient's needs. To achieve rapid wound closure, clinical interventions must be tailored to the wound and directed by the assessment of the extent of the injury, which requires information on the area of skin involved, the depth of the injury and the body site affected [20].

In all but minor burn injuries, the ability of the skin to regenerate is overwhelmed. Every intervention from the time of injury influences the scar worn for life. Therefore, the first steps in the healing process, to achieve the best quality of outcome, must be to pay attention to tissue preservation, limiting the extent of injury and reducing the extent of surgical intervention required by accurate resuscitation, oedema and infection control, focused on dermal salvage [21].

If the wound involves the superficial dermis,, healing is expected in less than 10 days with a risk of hypertrophic scar incidence less than 4% [22]. As wounds extend into the mid and deep dermal zones, a conservative, non-surgical approach is associated with an increasing risk of poor scar outcome. The challenge is in wound assessment to proceed to surgery in a timely fashion to improve the scar outcome. When all the dermis is lost, surgical intervention is necessary to reduce the risk of contracture and poor scarring. The donor site tissue available is a key factor in designing the surgical plan for repair of both the dermis and epidermis.

Several methods have been used to increase the coverage from a given skin donor site, including meshing of split thickness skin grafts, the Meek or Chinese method and laboratory-based tissue expansion with cultured epithelial autografts [23].

ReCell has been developed as a perioperative technique that harvests cells from the dermal-epidermal junction. The ability to expand the coverage at a 1:80 ratio has several advantages [10]:

- A small donor site with a proportional reduction in donor site morbidity.
- Recipient and donor sites can be matched due to the small donor site size.
- The process takes approximately 30 min and is available for immediate use.

26.2 Characteristics and Indications for Use

Cells are harvested by a combination of enzymatic and physical dissociation. The suspension is a mixed population of cells including basal keratinocytes, papillary dermal fibroblasts, melanocytes and Langerhans giant cells [12]. The cells are in a suspension for delivery onto the prepared wound bed either via an aerosol or a dripping technique. The initial kit was designed to process a 4 cm^2 piece of skin into a 5 mL suspension to cover an area of 320 cm^2. Kits with larger capacity are in development.

Cells can be used in isolation to facilitate rapid wound closure in wounds with salvageable dermal remnants. For example, in paediatric scalds, minimal debridement techniques, such as dermabrasion, preserve the dermis, and the cells delivered facilitate rapid epithelisation with minimal donor site morbidity [13, 24].

In deeper wounds, cells are used in association with thin expanded meshed SSGs, to assist in closure of the interstices, promoting rapid healing and less scarring [16, 17].

In full-thickness wounds treated with a dermal substitute, cells can again be used with the meshed graft during second stage of repair to speed the rate of epithelisation with the aim of improving the quality of the scar outcome.

In extensive burns, the SSG donor sites will need repeated harvest; some of the cell suspension may be sprayed onto the donor sites to speed the rate of epithelisation for more rapid secondary STSG harvesting [5].

In areas where the donor site tissue is limited, cells can be used to achieve a site-matched repair. For example, the sole of the foot or palm of the hand and the use of post-auricular skin for repair of the skin on the face.

In post-burn scars, the technique can be used for resurfacing, to improve the surface quality of the scar, the colour and the pigment load, blending the scar with the surrounding skin [25, 26].

26.3 Specific Skill of the Method

The ReCell kit contains a trypsin-based enzyme, a balanced salt solution for cell suspension, a cell filter and a nozzle for delivering the cell suspension to the wound.

A thin split-thickness piece of skin is harvested from a site-matched donor site. The biopsy needs to be thin enough to allow enzyme penetration to dissociate the skin at the dermal-epidermal junction. After a period of 15–30 min in the enzyme, the skin is removed from the enzyme and placed on a Petri dish in balanced salt solution. It is then scraped to release the cells, which can be seen as a plume moving into the surrounding fluid. The cell-bearing fluid is aspirated into a syringe and filtered to remove keratin debris prior to collection in a clean syringe for delivery to the wound bed. The volume of fluid is matched to the area requiring coverage, with smaller volumes being preferable, reducing the fluid run off from the surface.

The cells will adhere to the wound surface and proliferate and migrate under favourable conditions [27]. The wound bed preparation is an essential element to the success of cell function and hence wound healing. The wound should be prepared to remove all necrotic tissue and establish haemostasis. Wound infection must be treated aggressively and controlled prior to using cell-based therapies.

The surface is fragile and requires protection whilst the cells proliferate, migrate and then differentiate on the wound surface [28]. The primary dressing on the wound interface remains in place for the first week, with protective secondary dressings, which can be changed. Subsequently, the surface needs protection as it matures for approximately another 2 weeks. The dressing systems can and should allow movement; no splinting is required, and the rapid restoration of function is important to minimise the impact on long-term functional outcome.

The ReCell device affords a technique that is flexible, providing an autologous skin cell suspension for immediate use. It can provide the definitive epidermal repair and can be used with a range of other wound healing strategies. Surgical timing should also be considered as a strategy to reduce the overall time to healing and therefore reducing scar risk. ReCell can be used at any stage along the clinical journey of burn wound repair (Figs. 26.1 and 26.2) [29].

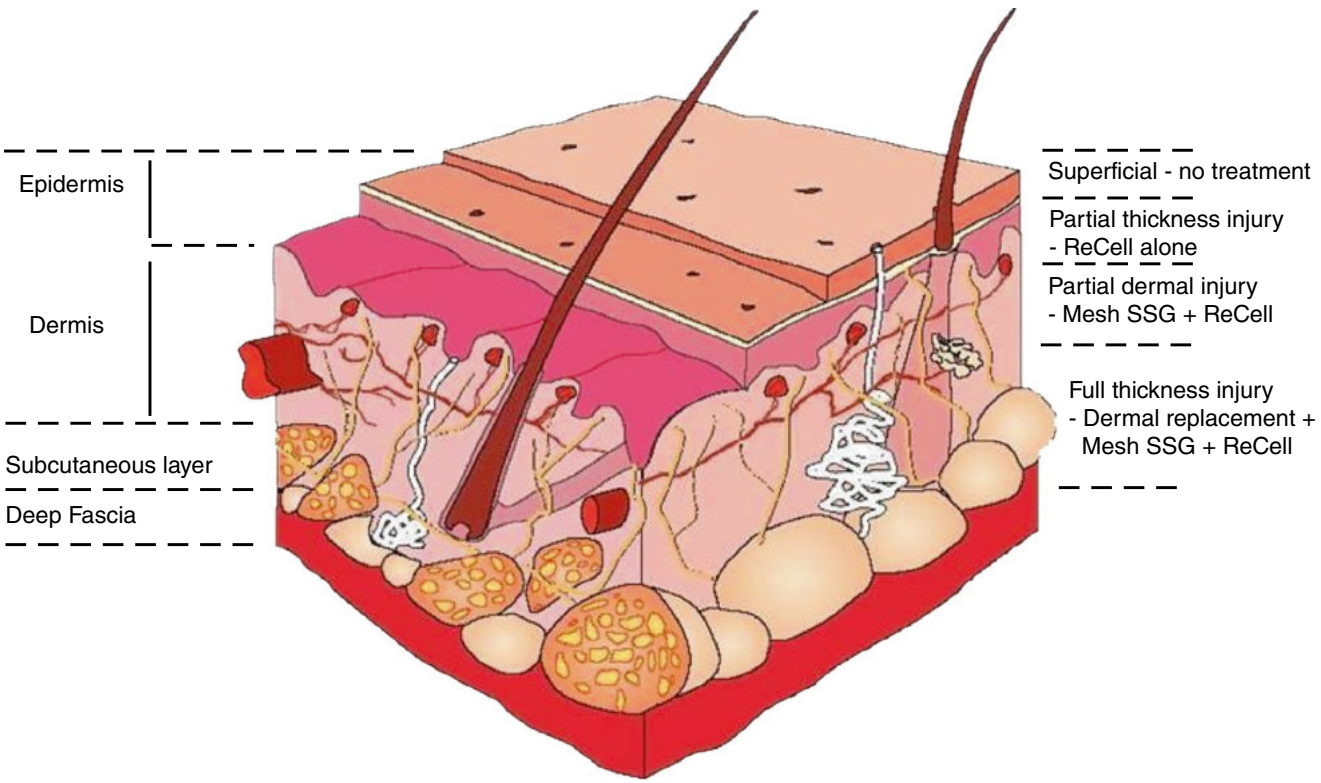


Fig. 26.1 Example of tailoring the wound repair to the injury using ReCell to facilitate epidermal repair

Fig. 26.2 ReCell cell autologous cell suspension harvesting kit

26.4 Clinical Cases

26.4.1 Case 1

An acute burn injury in a toddler who had fallen into a campfire, resulting in a complex skin defect. The area requires specialised epidermis for the palm of the hand and epidermal repair over the dorsum (Fig. 26.3a). In addition, dermis is lost on the ulnar palmer surface and on the dorsum of the hand (Fig. 26.3b).

Repair was tailored to the defect using:

- A thin split-thickness skin graft meshed 1:1.5, harvested from the buttock to the dorsum of the hand over the ulnar deeper area to introduce the dermis.
- Cell suspension harvested using the ReCell kit was applied over the expanded meshed graft and the surrounding area, where dermis was preserved.
- A split-thickness dermal graft was harvested from the same donor site, meshed 1:1.5 and expanded to the deep areas of the palm.
- Cell suspension was applied to the donor site.
- Cells were harvested from a split-thickness biopsy (1 cm^2) from the sole of the foot and applied to the palm.

As the scar matures, there is no evidence of a meshed pattern, and the surface appears site appropriate (Fig. 26.3c, d).

26.4.2 Case 2

A 1-year-old patient. Four days post scald from boiling water (Fig. 26.4a, b).

Seven days post-burn, the wound was debrided using predominantly dermabrasion to ensure the removal of necrotic, contaminated tissue (Fig. 26.4c). Autologous cell suspension was used as the repair technique, reseeding the retained dermal elements with cells harvested from the dermal-epidermal junction. Surfasoft®, Jelonet®, Betadine®, dry gauze and Fixomull® were applied in layered dressings.

Thirteen days post-burn and 6 days post-theatre, small areas remained moist and were treated with Algisite® and Fixomull® dressings (Fig. 26.4d). Massage was commenced to all healed areas and protected with a soft hydrophobic fabric vest tailor-made by Second Skin.

At 16 days post-burn, 8 days post-theatre, all areas were massaged with oily glycerol twice a day and protected with the hydrophobic garment (Fig. 26.4e).

At 7 weeks post-burn, the areas were fading rapidly with no evidence of developing hypertrophic scar (Fig. 26.4f).

26.4.3 Case 3

An 80% total body surface area (TBSA) burn injury in a road traffic accident with full thickness injury to the limbs and sparing of the back. The area on the abdomen was cleaned and an escharotomy performed due to respiratory compromise in the resuscitation phase (Fig. 26.5a).

Four days post-injury, all the burn wounds were debrided to viable tissue, and the skin on the back was harvested as STSG, including thin STSG for ReCell (Fig. 26.5b). The arms were treated using meshed split-thickness skin graft and autologous cell suspension. The wounds on the legs were covered with Integra as a staged repair. The abdomen was debrided to retain the dermal elements and repaired using autologous cell suspension harvested from the dermal-epidermal junction using the ReCell technique. The primary dressing used to protect the cells in this case was Biobrane™. Cell suspension was also applied to the donor site.

Fourteen days post-surgery, the wounds treated with cell suspension under Biobrane™ were 90% healed, with donor site on the back healed prior to the second stage Integra procedure (Fig. 26.5c).

26.4.4 Case 4

An established scar from a flame injury. Years post-flame burn, the scar persisted as an area of uneven texture and irregular pigmentation (Fig. 26.6a). One year post-

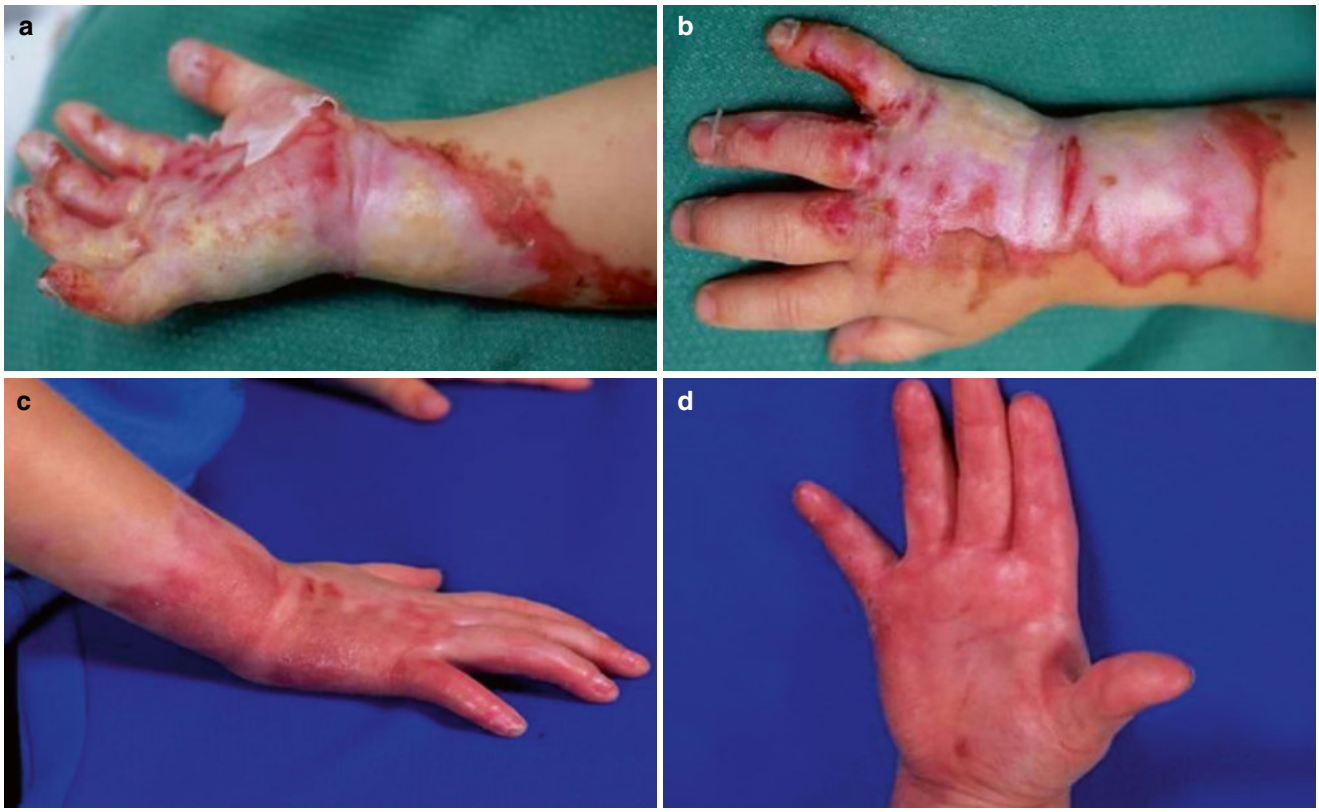


Fig. 26.3 (**a**–**d**) Case 1

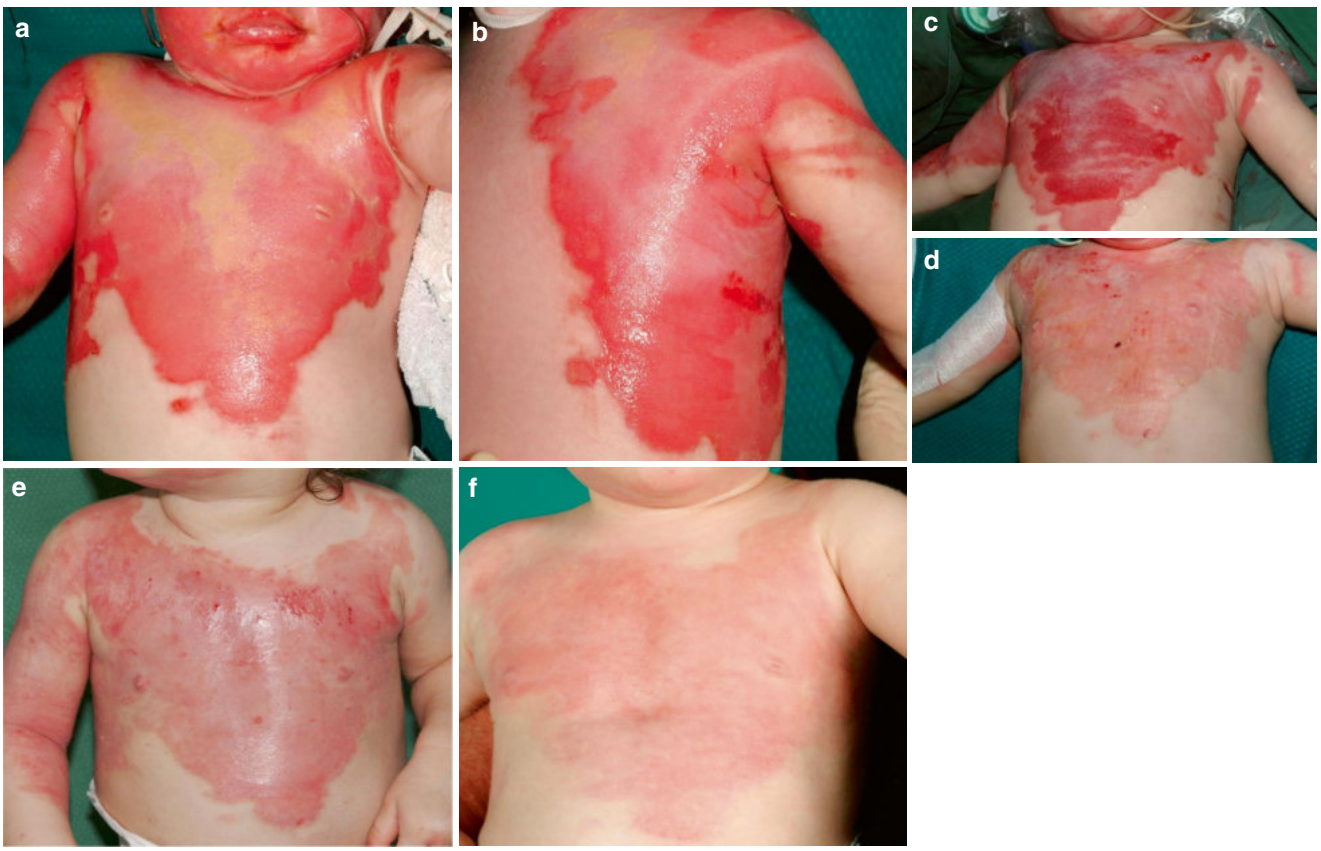


Fig. 26.4 (**a**–**f**) Case 2

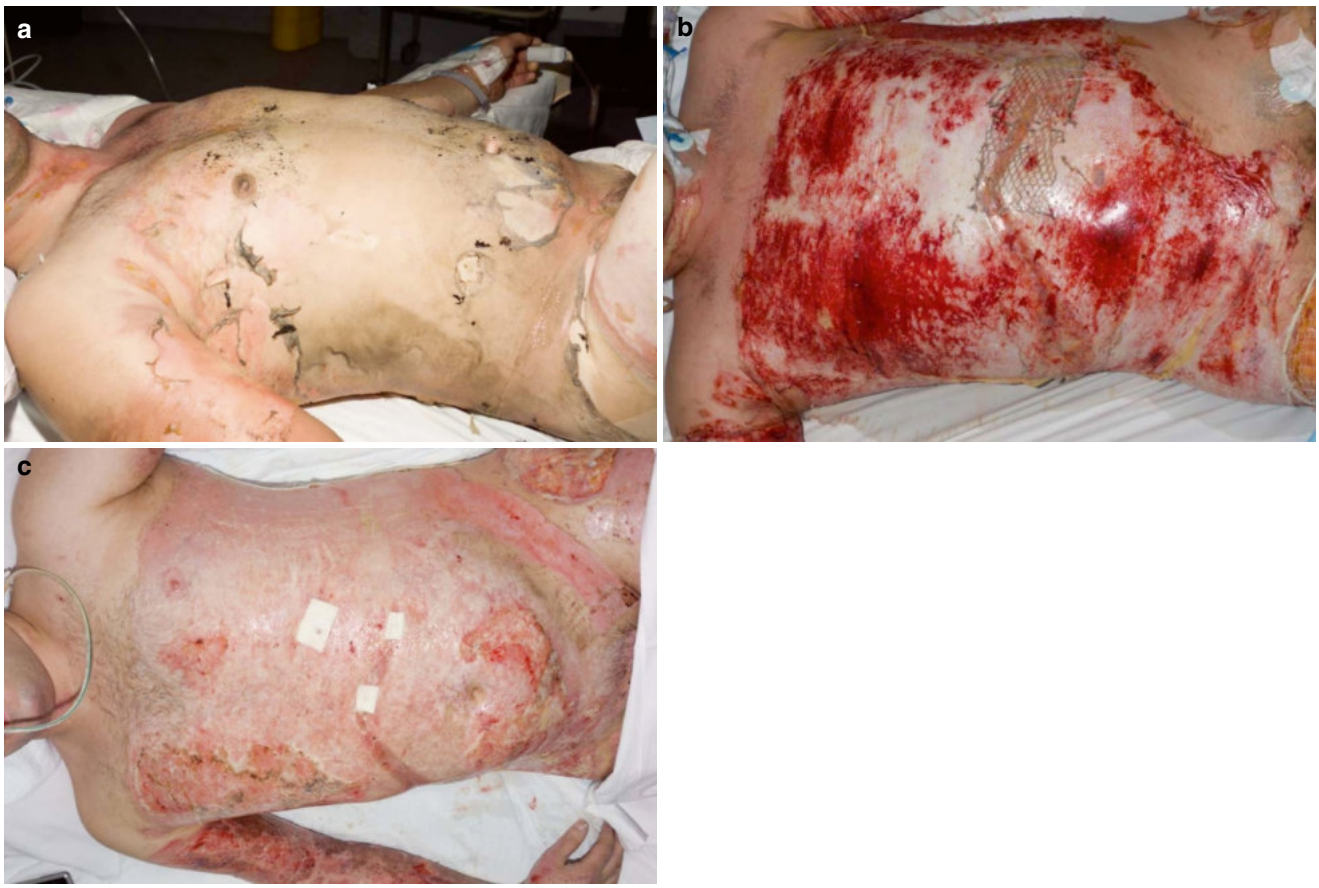


Fig. 26.5 (**a**–**c**) Case 3

dermabrasion and resurfacing with cells harvested using the ReCell kit from a post-auricular donor site, scar modulation of the surface and pigment distribution is demonstrated (Fig. 26.6b).

26.4.5 Case 5

A 39-year-old male with a flame injury, treated with a focus on dermal salvage such that debridement was at the level of the deep dermis. The skin was repaired using a very thin split-thickness skin graft to introduce the papillary dermal element. The graft was meshed 1:1.5 and spread widely onto the wound, and the cells harvested with ReCell were sprayed over the entire wound. The scar matured over time with fading of the meshed pattern (Fig. 26.7).

26.4.6 Case 6

A 27-year-old male with a chemical injury, surgically debrided with dermabrasion and repaired with ReCell alone to the preserved dermis (Fig. 26.8).

26.4.7 Case 7

A 41-year-old male involved in a light aircraft incident, suffering a 60-degree TBSA full-thickness injury. The focus is on the full-thickness injury of the sole of the foot, which was debrided with Integra as the primary repair. At 3 weeks after integration of the dermal scaffold, the sole of the foot was repaired using a thin meshed split-thickness skin graft and ReCell harvested from the hypothenar palmer region of the hand to provide a site-matched glabrous skin repair (Fig. 26.9).

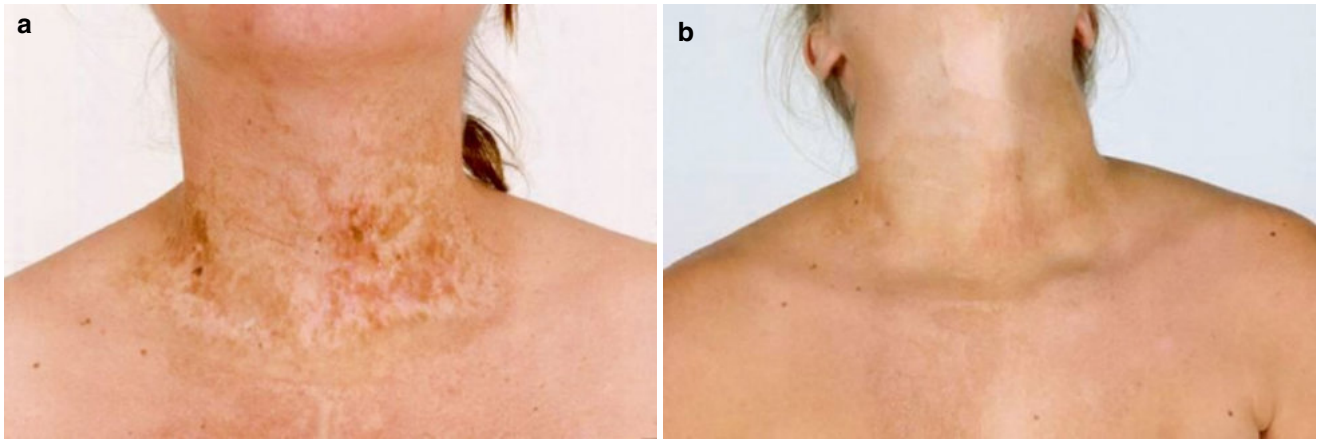


Fig. 26.6 (**a** and **B**) Case 4

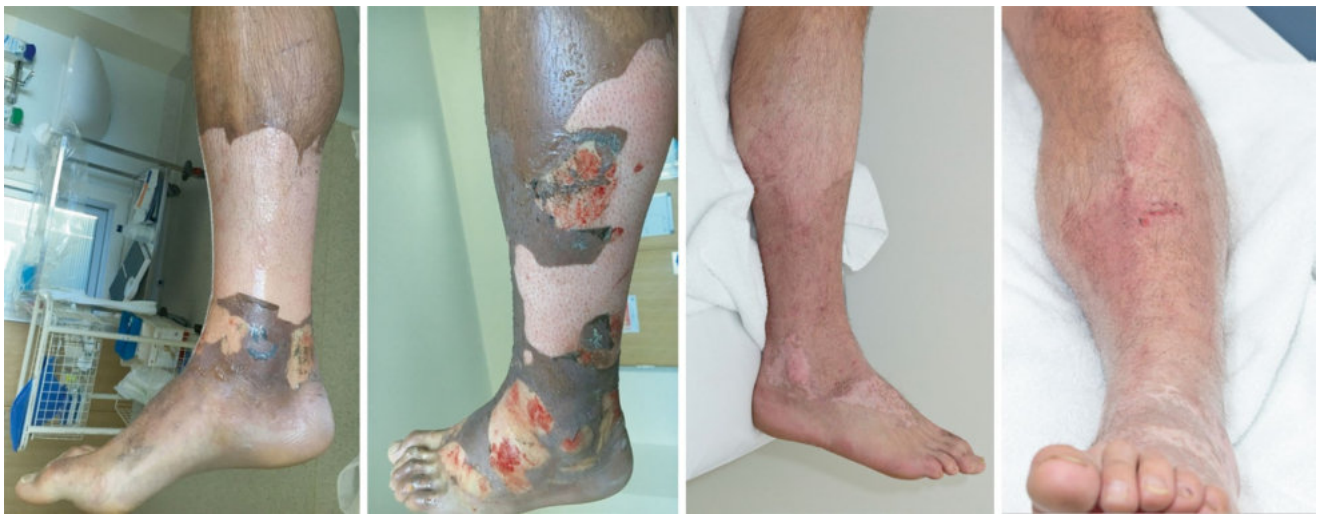


Fig. 26.7 Flame burns 3 months STSG and ReCell

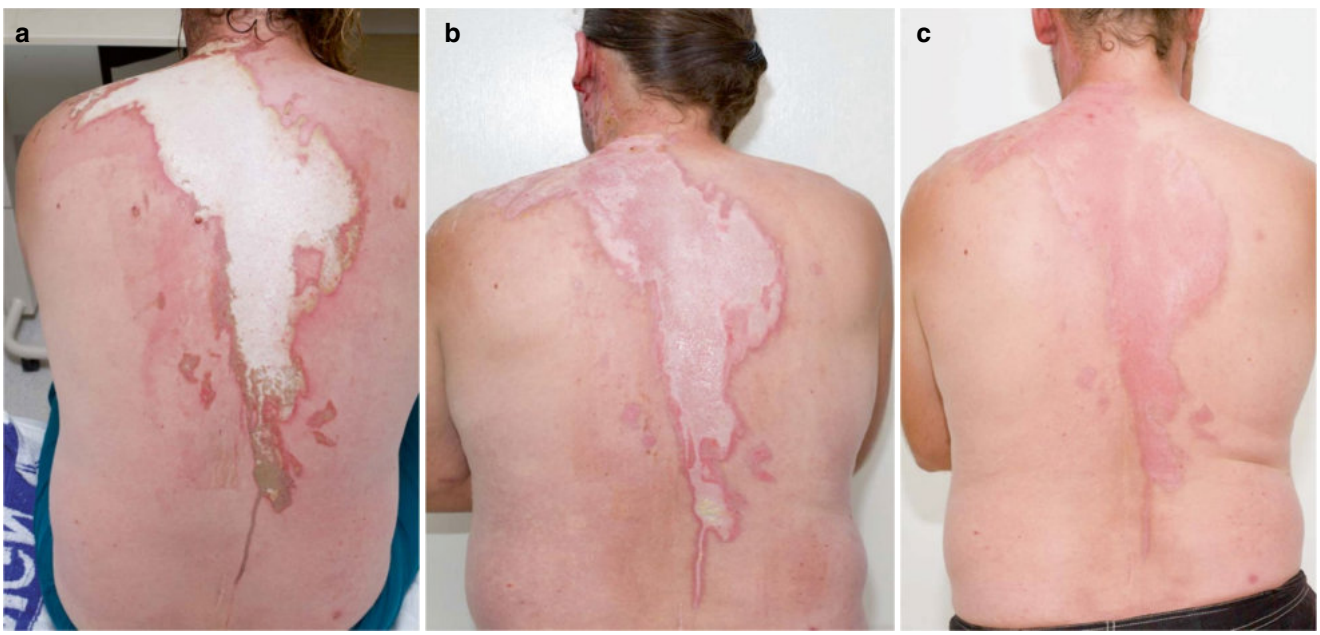


Fig. 26.8 Deep dermal injury treated with dermabrasion and resurfacing with autologous spray-on cells. (**a**) 1 week after injury; (**b**) 10 days after surgery; (**c**) 3 months after injury

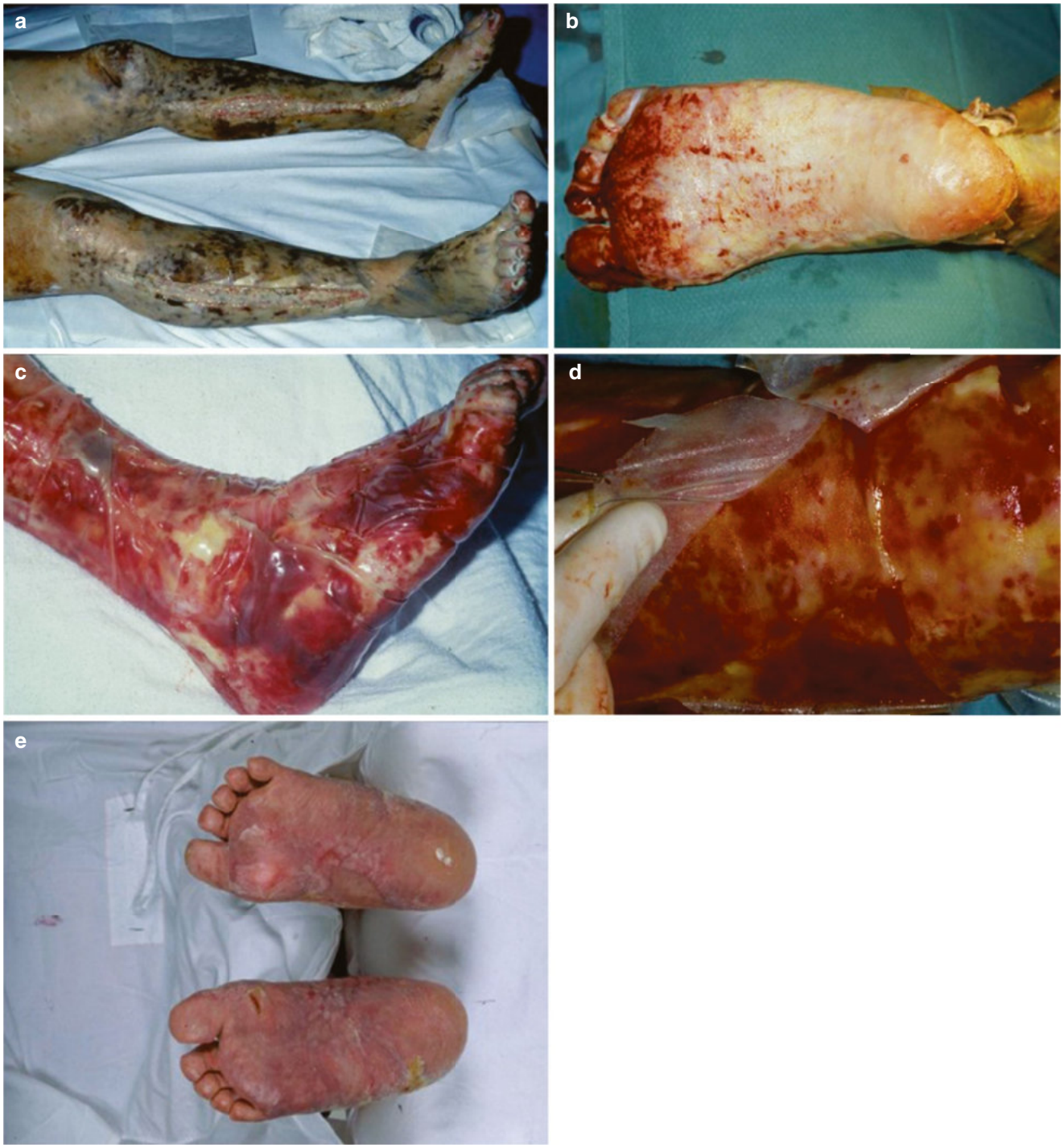


Fig. 26.9 (**a**–**e**) Integra dermal regeneration template with cells from the palm of the hand to repair the epithelium

References

1. Brown TL, Muller MJ. Parsimony, simplicity and survival in burn care. Burns. 2003;29(3):197–8. https://doi.org/10.1016/s0305-4179(03)00015-9.
2. Finlay V, Burrows SA, Burmaz M, Yawary H, Lee J, Edgar DW, Wood FM. Increased burn healing time is associated with higher Vancouver Scar Scale score. Scars, Burns & Healing. 2017;3:1–10. https://doi.org/10.1177/2059513117696324.
3. Wallace HJ, Fear MW, Crowe MM, Martin LJ, Wood FM. Identification of factors predicting scar outcome after burn in adults: a prospective case–control study. Burns. 2017;43(6):1271–83. https://doi.org/10.1016/j.burns.2017.03.017.
4. Ozhathil DK, Tay MW, Wolf SE, Branski LK. A narrative review of the history of skin grafting in burn care. Medicina

(Kaunas, Lithuania). 2021;57(4):380. https://doi.org/10.3390/medicina57040380.
5. Bache SE, Martin L, Malatzky D, Nessler M, Frank A, Douglas H, Rea S, Wood F. First do no harm: a patient-reported survey of split skin graft donor site morbidities following thin and super-thin graft harvest. Burns. 2023; https://doi.org/10.1016/j.burns.2023.10.016.
6. Wood F. Advances in isolation and expansion of human cells for clinical applications. In: Albanna MZ, Holmes IV JH, editors. Skin tissue engineering and regeneration medicine. Academic; 2016. p. 299–315. https://doi.org/10.1016/B978-0-12-801654-1.00015-2.
7. Rheinwald JG, Green H. Serial cultivation of strains of human epidermal keratinocytes: the formation of keratinizing colonies from single cells. Cell. 1975;6(3):331–43. https://doi.org/10.1016/s0092-8674(75)80001-8.
8. Chogan F, Chen Y, Wood F, Jeschke MG. Skin tissue engineering advances in burns: a brief introduction to the past, the present, and the future potential. J Burn Care Res. 2023;44(1):S1–4. https://doi.org/10.1093/jbcr/irac127.
9. Wood F. Skin regeneration: The complexities of translation into clinical practise. Int J Biochem Cell Biol. 2014;56:133–40. https://doi.org/10.1016/j.biocel.2014.10.025.
10. Wood FM. The role of cell-based therapies in acute burn wound skin repair: a review. J Burn Care Res. 2023;44(1):S42–7. https://doi.org/10.1093/jbcr/irac146.
11. Wood F. Clinical potential of autologous epithelial suspension. Wounds. 2003;15(1):16–22.
12. Wood F, Giles N, Stevenson A, Rea S, Fear M. Characterisation of the cell suspension harvested from the dermal epidermal junction using a ReCell kit. Burns. 2012a;38:44–51. https://doi.org/10.1016/j.burns.2011.03.001.
13. Wood F, Martin L, Lewis D, Rawlins J, McWilliams TL, Burrows S, Rea S. A prospective randomised clinical pilot study to compare the effectiveness of Biobrane® synthetic wound dressing, with or without autologous cell suspension, to the local standard treatment regimen in paediatric scald injuries. Burns. 2012b;38:830–9. https://doi.org/10.1016/j.burns.2011.12.020.
14. Wala SJ, Patterson K, Scoville S, Srinivas S, Noffsinger D, Fabia R, Thakkar RK, Schwartz DM. A single institution case series of ReCell® use in treating pediatric burns. Int J Burns Trauma. 2023;13(2):78–88.
15. Holmes Iv JH, Molnar JA, Carter JE, Hwang J, Cairns BA, King BT, Smith DJ, Cruse CW, Foster KN, Peck MD, Sood R, Feldman MJ, Jordan MH, Mozingo DW, Greenhalgh DG, Palmieri TL, Griswold JA, Dissanaike S, Hickerson WL. A comparative study of the ReCell® device and autologous spit-thickness meshed skin graft in the treatment of acute burn injuries. J Burn Care Res. 2018;39(5):694–702. https://doi.org/10.1093/jbcr/iry029.
16. Sood R, Roggy DE, Zieger MJ, Nazim M, Hartman BC, Gibbs JT. A comparative study of spray keratinocytes and autologous meshed split-thickness skin graft in the treatment of acute burn injuries. Wounds. 2015;27(2):31–40.
17. Holmes JH 4th, Molnar JA, Shupp JW, Hickerson WL, King BT, Foster KN, Cairns BA, Carter JE. Demonstration of the safety and effectiveness of the RECELL® System combined with split-thickness meshed autografts for the reduction of donor skin to treat mixed-depth burn injuries. Burns. 2019;45(4):772–82. https://doi.org/10.1016/j.burns.2018.11.002.
18. Ramsey WA, O'Neil CF, Corona AM, Cohen BL, Lyons NB, Meece MS, Saberi RA, Gilna GP, Satahoo SS, Kaufman JI, Schulman CI, Namias N, Proctor KG, Pizano LR. Burn excision within 48 hours portends better outcomes than standard management: a nationwide analysis. J Trauma Acute Care Surg. 2023;95(1):111–5. https://doi.org/10.1097/TA.0000000000003951.
19. Wood F. Alternative delivery of keratinocytes for epidermal replacement. In: Biomaterials for treating skin loss: a volume in Woodhead Publishing series in biomaterials. Pergamon; 2009. p. 115–23. https://doi.org/10.1533/9781845695545.2.115.
20. Wood F, Kolybaba ML, Allen P. The use of cultured epithelial autograft in the treatment of acute burn wounds: eleven years of clinical experience. Burns. 2006;32(5):538–44. https://doi.org/10.1016/j.burns.2006.02.025.
21. Palackic A, Jay JW, Duggan RP, Branski LK, Wolf SE, Ansari N, El Ayadi A. Therapeutic strategies to reduce burn wound conversion. Medicina (Kaunas, Lithuania). 2022;58(7):922. https://doi.org/10.3390/medicina58070922.
22. Chiang RS, Borovikova AA, King K, Banyard DA, Lalezari S, Toranto JD, Paydar KZ, Wirth GA, Evans GR, Widgerow AD. Current concepts related to hypertrophic scarring in burn injuries. Wound Repair Regen. 2016;24(3):466–77. https://doi.org/10.1111/wrr.12432.
23. Leon-Villapalos J, Barret JP. Surgical repair of the acute burn wound: who, when, what techniques? What is the future? J Burn Care Res. 2023;44(Issue Supplement_1):S5–S12. https://doi.org/10.1093/jbcr/irac145.
24. Bairagi A, Griffin B, Tyack Z, Vagenas D, McPhail SM, Kimble R. Comparative effectiveness of Biobrane®, RECELL® autologous skin cell suspension and Silver dressings in partial thickness paediatric burns: BRACS randomised trial protocol. Burns Trauma. 2019;7:33. https://doi.org/10.1186/s41038-019-0165-0.
25. Chen Q, Yu N, Liu Z, Zhang W, Long F, Zeng A, Zhu L, Wang X. The clinical efficacy of ReCell® autologous cell regeneration techniques combined with dermabrasion treatment in acne scars. Aesthet Plast Surg. 2020;44(2):535–42. https://doi.org/10.1007/s00266-019-01481-8.
26. Navarro FA, Stoner ML, Lee HB, Park CS, Wood FM, Orgill DP. Melanocyte repopulation in full-thickness wounds using a cell spray apparatus. J Burn Care Rehabil. 2001;22(1):41–6. https://doi.org/10.1097/00004630-200101000-00009.
27. Wood FM, Stoner M. Implication of basement membrane development on the underlying scar in partial thickness burn injury. Burns. 1996;22(6):459–62. https://doi.org/10.1016/0305-4179(95)00178-6.
28. Wood F, Liddiard K, Skinner A, Ballentyne J. Scar management of cultured epithelial autograft. Burns. 1996;22(6):451–4. https://doi.org/10.1016/0305-4179(95)00177-8.
29. Kowal S, Kruger E, Bilir P, Holmes JH, Hickerson W, Foster K, Nystrom S, Sparks J, Iyer N, Bush K, Quick A. Cost-effectiveness of the use of autologous cell harvesting device compared to standard of care for treatment of severe burns in the United States. Adv Ther. 2019;36(7):1715–29. https://doi.org/10.1007/s12325-019-00961-2.

MEEK Micrografting

27

Junya Oshima and Mitsuru Sekido

Abstract

When performing split-thickness skin grafting on extensive burn wounds, it is common to expand the area covered by meshing with a mesh dermatome or by patch grafting. The Meek micrografting technique uses a dedicated system to create small grafts, allowing for efficient expansion of the coverage area, and there have been several reports on its effectiveness (Oshima J et al. Jpn J Burn Inj 47:29–34, 2021; Oshima J and Sekido M. Jpn J Acute Med 45:1410–1414, 2021; Oshima J. PEPARS 211:81–88, 2024). This chapter explains the surgical procedure, characteristics, and indications, including descriptions of clinical cases of Meek micrografting.

Keywords

MEEK · Micrograft · Clinical cases

27.1 Background of the Technique

When performing split-thickness skin grafting on extensive burn wounds, it is common to expand the area covered by meshing with a mesh dermatome or by patch grafting. The Meek micrografting technique uses a dedicated system to create small grafts, allowing for efficient expansion of the coverage area, and there have been several reports on its effectiveness [1–3]. This chapter explains the surgical procedure, characteristics, and indications, including descriptions of clinical cases of Meek micrografting.

The first mention of micrografting was by Dr. Meek in 1958. It is a procedure in which a split-thickness skin graft is cut into pieces of several square millimeters using a dedicated cutter and then expanded using a dedicated expander [4]. In 1993, Kreis et al. reported a modified Meek graft technique using adhesives, and this method is now widely used [5]. The dedicated cutter (MEEK machine), expander (MEEK gauze), and spray-type adhesive used for Meek micrografting are collectively referred to as the MEEK system (Humeca, the Netherlands) (Fig. 27.1).

J. Oshima (✉) · M. Sekido
Department of Plastic, Reconstructive, and Hand Surgery,
University of Tsukuba, Tsukuba, Japan

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_27

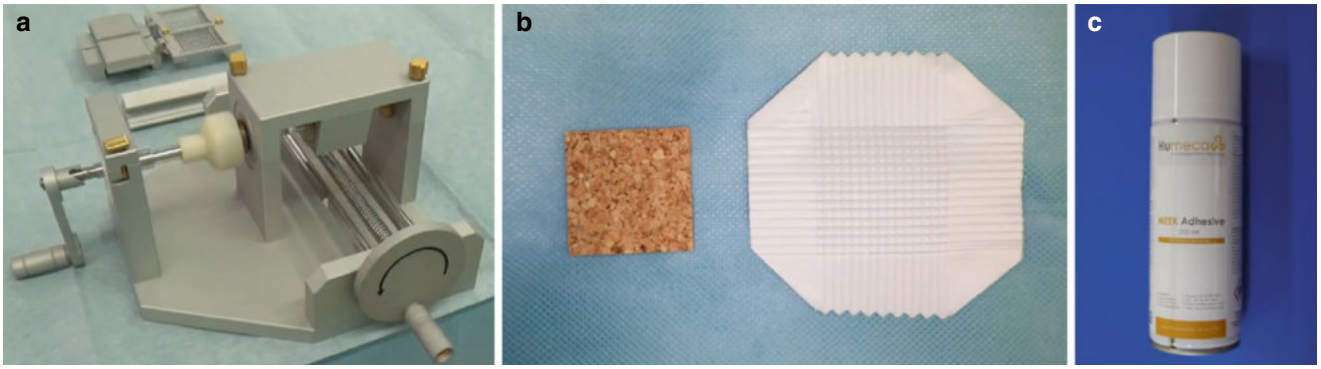


Fig. 27.1 Equipment. (**a**) MEEK machine. (**b**) MEEK gauze. (**c**) Spray adhesive. (*Reprinted from* Oshima [3]; *with permission*)

27.2 Procedure

Skin grafts are harvested using an electric dermatome at a thickness of 8–12/1000 inches. The MEEK™ system is used to process the skin grafts. The skin graft is cut to the same size as a 42 × 42 mm cork plate, and the dermal side is attached to the cork (Fig. 27.2a, b). The skin graft is then cut into 196 skin graft pieces measuring 3 × 3 mm using the MEEK machine (Fig. 27.2c, d). After spraying adhesive onto the cut skin pieces, the epidermal side is attached to the MEEK gauze (Fig. 27.2e, f). After removing the cork, the MEEK gauze is manually expanded (Fig. 27.2g–i). The MEEK gauze is applied to the skin defect, the foil backing is peeled off, and the edges are stapled (Fig. 27.2j–l).

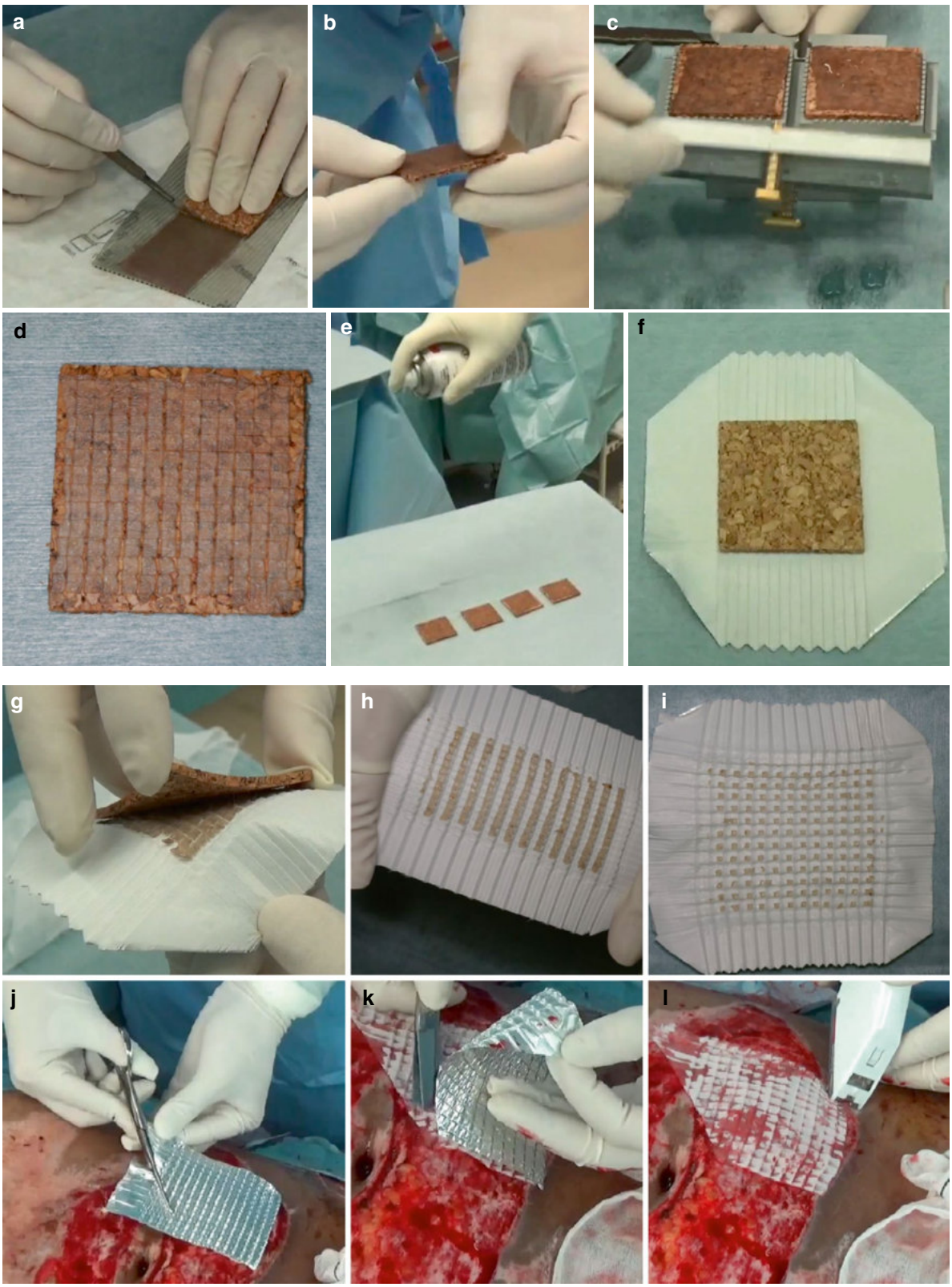


Fig. 27.2 Procedure. (**a**) Cut the sheet of harvested skin graft with a scalpel to fit the size of the cork plate. (**b**) Spread it evenly over the cork plate to avoid wrinkles. (**c**) Place the cork plate in the MEEK machine. (**d**) After cutting into 196 pieces of 3 × 3 mm skin grafts using a MEEK machine. (**e**) Spray the adhesive. (**f**) After the adhesive has dried, attach it to the MEEK gauze. (**g**) When the cork is removed, the skin pieces adhere from the cork to the gauze. (**h**) Manually pull and expand the finely folded MEEK gauze. (**i**) After expansion. (**j**) Trim to fit the burn wound. (**k**) Remove the foil backing. (**l**) Staple the edges of the gauze. (*Reprinted from* Oshima et al. [1], Oshima and Sekido [2], and Oshima [3]; *with permission*)

27.3 Characteristics and Indications

One key feature of the MEEK system is that it can expand a limited amount of skin graft efficiently and at a high expansion rate. Although it is possible to expand skin grafts using a mesh dermatome, the expansion rate is not as expected, and the accuracy decreases as the expansion rate increases [6, 7]. On the other hand, with the MEEK system, the area after expansion is precisely determined by the expander, making it easier to plan the surgery (Fig. 27.3a). The MEEK gauze serves as a backing, making it easy to handle small, highly expanded skin pieces. Furthermore, small skin grafts remaining during processing can be combined and placed on a cork mount, then cut into 3 × 3 mm pieces, allowing for effective use of limited skin grafts (Fig. 27.3b).

Skin pieces created with the MEEK system also have the advantage of being small patch grafts. Small, individual patch grafts are more resistant to microbial invasion than interconnected mesh grafts [8, 9]. In addition, because small skin grafts have low tissue metabolic demands, it has been reported that they have a high survival rate even in situations where the underlying bed has poor blood flow [10]. Furthermore, there are reports that MEEK requires less time to complete epithelialization than mesh grafts with the same expansion rate [1, 9].

Because this technique allows for efficient skin expansion, we believe that it is well suited to the trunk and limbs of patients with extensive burns who have limited areas to donate skin. In addition, the MEEK gauze can be easily handled with one hand, and since it allows the application of skin pieces and dressing to be performed simultaneously, it is useful for the undersides of limbs and the sides of the chest. On the other hand, since the skin pieces are fixed to the MEEK gauze with adhesive, effective contact between the wound surface and the skin graft may not be achieved in areas with fine irregularities or in movable areas such as those around the joints. The disadvantages of the MEEK system are that it may result in a polka-dot appearance after epithelialization and that the work process is complicated [7].

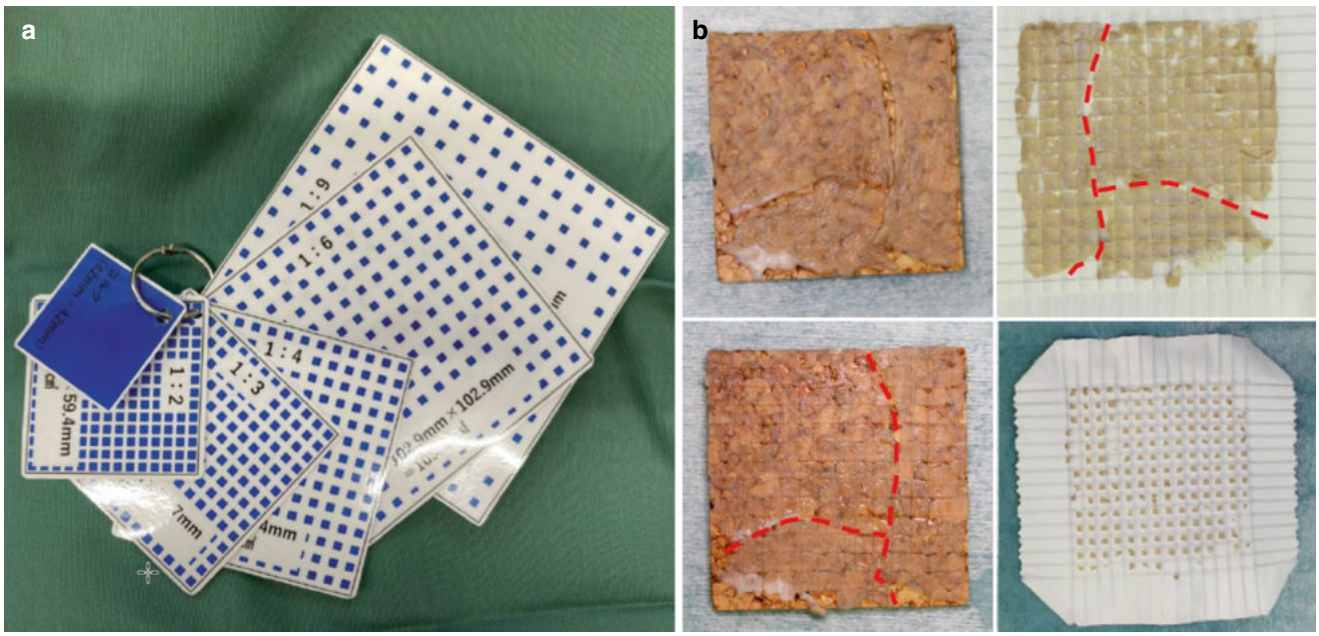


Fig. 27.3 Characteristics. (**a**) Template of pre- and post-expansion area. Expansion is possible according to the template. (**b**) Small skin grafts remaining during processing can be combined and placed on a cork mount, then cut into 3 × 3 mm pieces. (Upper left: Three small pieces of skin attached to the cork. Lower left: After cutting. Upper right: After sheet attachment. Lower right: After expansion). (*Reprinted from* Oshima [3]; *with permission*)

27.4 Clinical Cases

27.4.1 Case 1

A 44-year-old woman suffered burns after kerosene was poured on her and her clothes were set on fire. Deep dermal (DDB) and deep burns (DB) of 52% of the total body surface area (TBSA) were observed on the chest, abdomen, back, both upper limbs, and both anterior thighs (Fig. 27.4a). For the chest and abdominal burns, debridement and application of artificial dermis were performed on Day 5 after the injury (Fig. 27.4b) and then 1:6 MEEK micrografting was performed on Day 30 after the injury (Fig. 27.4c, d). The skin graft took well (Fig. 27.4e). Four weeks after grafting, epithelialization was mostly achieved, and the patient was transferred to a general hospital (Fig. 27.4f).

27.4.2 Case 2

A 60-year-old man suffered burns when his clothes accidentally caught fire while burning cardboard. DDB and DB of 40% TBSA were observed mainly on the back, anterior chest, and both upper limbs (Fig. 27.5a). For the back burn, debridement and application of artificial dermis were performed on Day 7 after the injury (Fig. 27.5b), and then 1:6 MEEK micrografting was performed on Day 24 after the injury (Fig. 27.5c, d). The skin graft took well (Fig. 27.5e). On Day 45 after the injury, during surgery on other areas, a patch graft was performed on the remaining skin defect on the back. The postoperative course was uneventful (Fig. 27.5f) and the patient was discharged 12 weeks after MEEK micrografting.

27.4.3 Case 3

A 25-year-old man suffered burns when his clothing caught fire while working at an automobile factory. DDB and DB with 24% TBSA were observed mainly on the posterior aspect of both lower limbs. For the lower limb burns, debridement and application of artificial dermis were performed on Day 3 after the injury (Fig. 27.6a, b), and then 1:6 MEEK micrografting was performed on both lower legs with deep damage on Day 14 after the injury (Fig. 27.6c, d). The skin graft took well, and the patient's postoperative course was uneventful (Fig. 27.6e). Eight weeks after surgery, there was no inflammation or thickening of the wound (Fig. 27.6f).

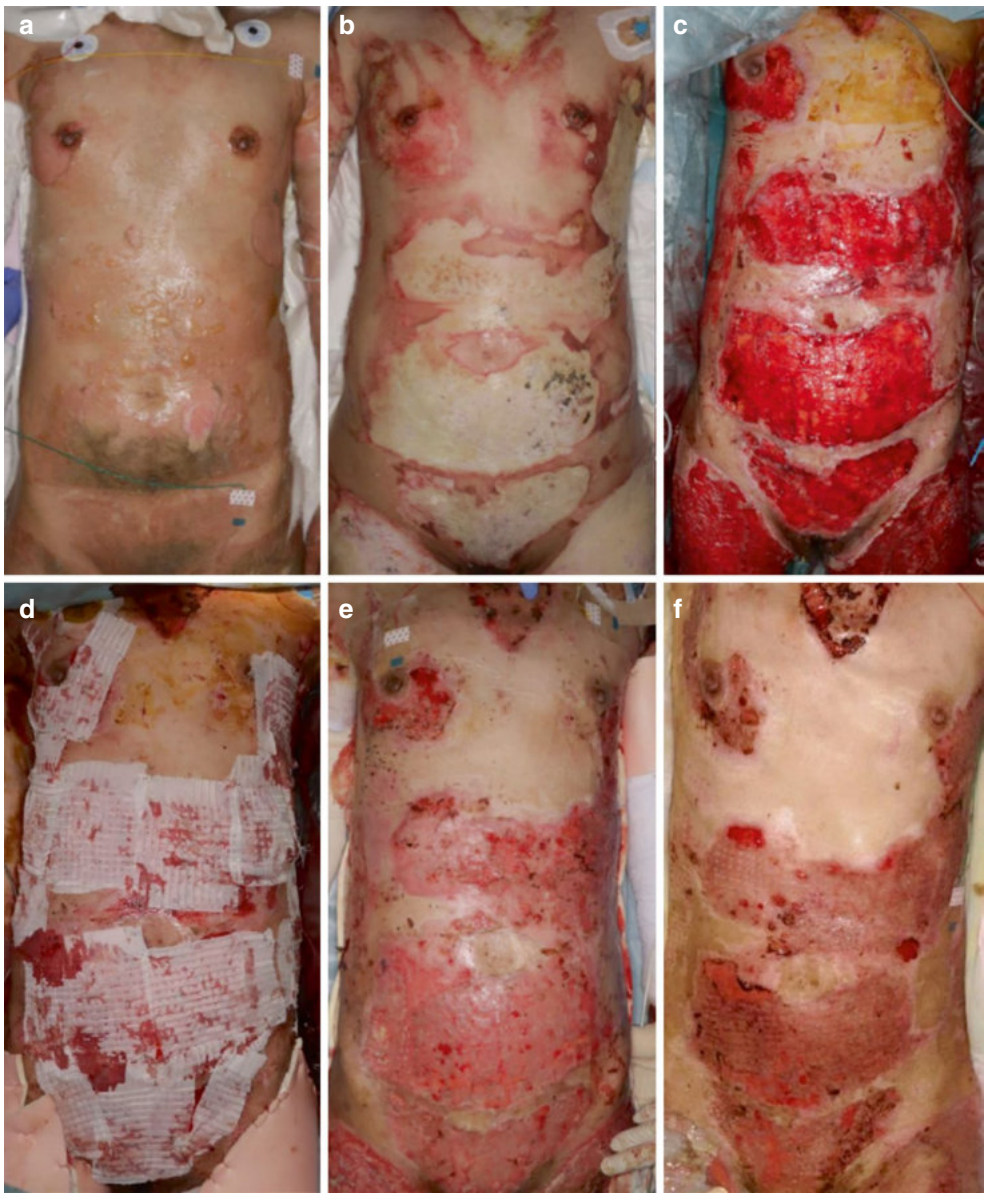


Fig. 27.4 Case 1: Chest and abdominal burns. (**a**) On the day of injury, at the time of transport. (**b**) Day 5 after injury, before debridement. (**c**) Day 30 after injury, at the time of MEEK grafting. After artificial dermal film removal. (**d**) Day 30 after injury, immediately after MEEK graft was performed. (**e**) Day 14 after MEEK grafting. MEEK skin survival was good. (**f**) Four weeks after MEEK grafting, epithelialization was mostly achieved. (*Reprinted from* Oshima and Sekido [2] and Oshima [3]; *with permission*)

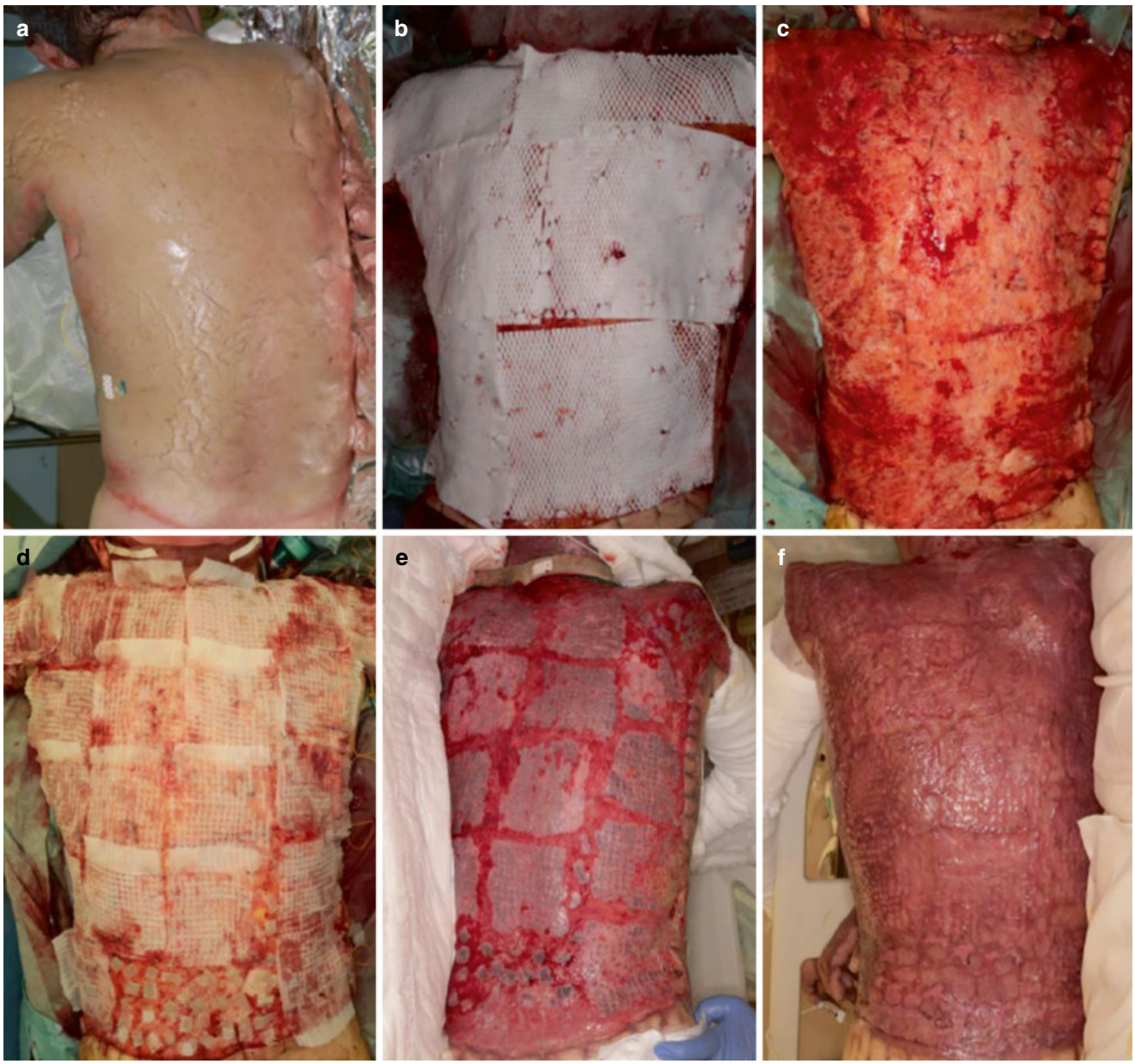


Fig. 27.5 Case 2: Back burns. (**a**) On the day of injury, at the time of transport. (**b**) Day 7 after injury. Debridement was performed, and artificial dermis was applied. (**c**) Day 24 after injury, at the time of MEEK grafting. After artificial dermal film removal. (**d**) Day 24 after injury, immediately after MEEK graft was performed. Patch skin grafting was also used in some areas. (**e**) Day 18 after MEEK grafting. The gap in the MEEK graft has almost completely epithelialized. (**f**) Nine weeks after MEEK grafting, there was no inflammation or thickening of the wound. (*Reprinted from* Oshima and Sekido [2] and Oshima [3]; *with permission*)

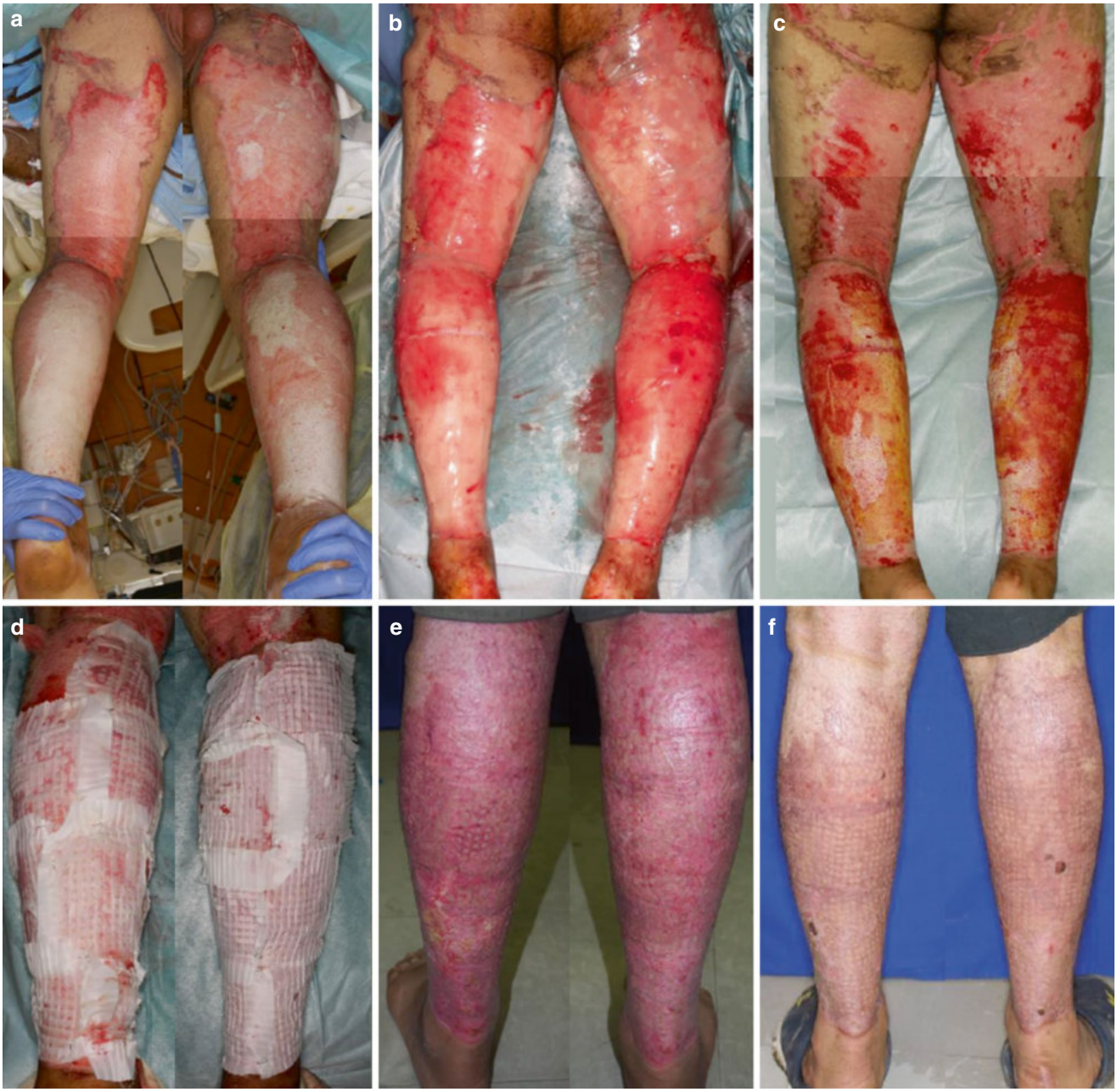


Fig. 27.6 Case 3: Bilateral lower limb burns. (**a**) Day 3 after injury, findings at surgery. Before debridement. (**b**) Day 3 after injury. Debridement was performed, and artificial dermis was applied. (**c**) Day 14 after injury, at the time of MEEK grafting. After artificial dermal film removal. (**d**) Day 14 after injury, immediately after MEEK graft was performed. (**e**) Four weeks after MEEK grafting, epithelialization has been achieved. (**f**) Eight weeks after MEEK grafting, there was no inflammation or thickening of the wound. (*Reprinted from* Oshima and Sekido [2] and Oshima [3]; *with permission*)

References

1. Oshima J, Inoue Y, Aihara Y, Sasaki M, Sasaki K, Sekido M. Use of MEEK system for skin graft expansion in split-thickness skin grafting. Jpn J Burn Inj. 2021;47:29–34.
2. Oshima J, Sekido M. MEEK system. Jpn J Acute Med. 2021;45:1410–4.
3. Oshima J. MEEK skin graft. PEPARS. 2024;211:81–8.
4. Meek CP. Successful microdermagrafting using the Meek-Wall microdermatome. Am J Surg. 1958;96:557–8.
5. Kreis RW, Mackie DP, Vloemans AW, Hermans RP, Hoekstra MJ. Widely expanded postage stamp skin grafts using a modified Meek technique in combination with an allograft overlay. Burns. 1993;19:142–5.
6. Peeters R, Hubens A. The mesh skin graft–true expansion rate. Burns Incl Therm Inj. 1988;14:239–40.
7. Quintero EC, Machado JFE, Robles RAD. Meek micrografting history, indications, technique, physiology and experience: a review article. J Wound Care. 2018;27:S12–8.
8. Hsieh CS, Schuong JY, Huang WS, Huang TT. Five years' experience of the modified Meek technique in the management of extensive burns. Burns. 2008;34:350–4.
9. Noureldin MA, Said TA, Makeen K, Kadry HM. Comparative study between skin micrografting (Meek technique) and meshed skin grafts in paediatric burns. Burns. 2022;48:1632–44.
10. Kok YO, Chong SJ, Liang WH, Tan BK, Tan KC. Revolutionizing major burns management with micrografting – improved healthcare costs, time and burns resources. Plast Reconstr Surg. 2015;136:64.

Tsukada's Graft: A Preserved Subcutaneous Vascular Network Skin Graft

28

Toru Miyanaga and Kenichi Shimada

Abstract

Tsukada's graft is a full-thickness skin grafting technique that preserves the subcutaneous vascular network (SVN). Unlike a standard full-thickness skin graft, this graft completely preserves the dermis, hair follicles, and sweat glands, and includes some fat. The survival process is similar to that of full-thickness grafts, but the vascular anastomosis from the wound bed to the graft depends on the SVN. The number of vessels anastomosed to the graft is more prominent, and because the deep dermis and skin appendages are preserved, postoperative contractures are less likely to occur, and the skin can be reconstructed to resemble normal skin. This makes the graft suitable for reconstructing areas that are important cosmetically and functionally, such as the face and hands.

Keywords

Tsukada's graft · Preserved subcutaneous vascular network · Full-thickness skin graft · Face and limb reconstruction

28.1 Indication

Tsukada's graft is a full-thickness skin grafting technique that preserves the subcutaneous vascular network (SVN) [1]. The full-thickness graft technique was devised by Wolfe (1885) and Krause (1893), and in principle, the subcutaneous fatty tissue of the graft is completely removed [2]. Tsukada's graft preserves the SVN with a small amount of fat remaining. Because the dermis, hair follicles, and sweat glands are not damaged, the graft is less prone to secondary shrinkage than a full-thickness skin graft and can reconstruct a softer, more natural contour. Therefore, it is suitable for cosmetically and functionally significant facial and limb skin defects (Figs. 28.1 and 28.2). Three hundred ninety-eight of Tsukada's grafts were performed in 376 patients, and Tsukada et al. reported a 96% survival. The largest graft area was 25 × 10 cm [1]. The survival of Tsukada's graft depends primarily on anastomosis between its vascular network and the vessels of the graft bed, which increases the probability of success [3]. Thus, the success of this graft depends on adequate blood flow to the graft bed [3].

The skin grafting area is also limited. The thicker the graft tissue, the lower the success rate of skin grafts and dermal fat grafts [4]. Therefore, thick skin from the back or buttocks cannot be used as a donor and is limited to areas with thin skin [3]. Generally, the groin, periclavicular area, periauricular area, medial side of the upper arm, and medial side of the thigh are selected. Since the characteristics of the grafted skin are inherited from the harvested area to the grafted area, the harvested area with a good color match and texture match should be selected. If a large graft is needed, it should be taken from the groin. The maximum width of the graft can be up to 10 cm, and even larger grafts can be obtained using a tissue expander (Fig. 28.3).

T. Miyanaga · K. Shimada (✉)
Department of Plastic Surgery, Kanazawa Medical University, Kahoku, Ishikawa, Japan
e-mail: miyanaga@kanazawa-med.ac.jp; shimaken@kanazawa-med.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_28

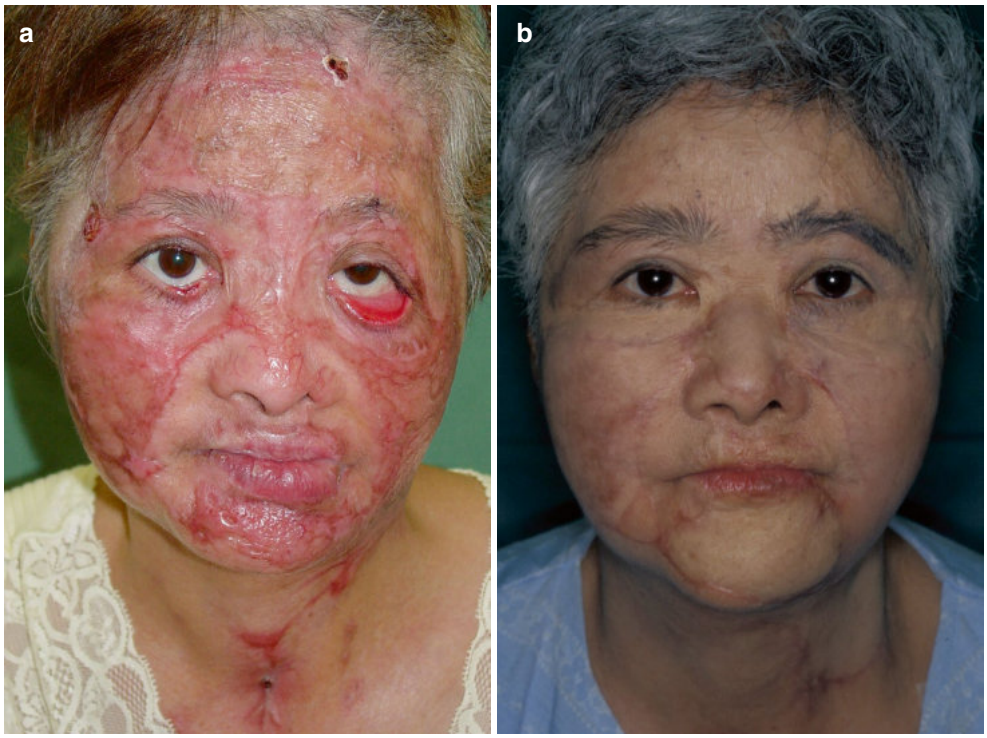


Fig. 28.1 A case of burn scar contracture of the face and neck reconstructed with Tshukada's graft. (**a**) Preoperative image. (**b**) Clinical images 2 years after the initial surgery. Five Tsukada grafts were performed on both the lower eyelids and nasal root, the left lower eyelid and marsupial, the left neck, the right cheek, and the left cheek. Donor sites were subclavian, inguinal, medial thigh, and medial humerus

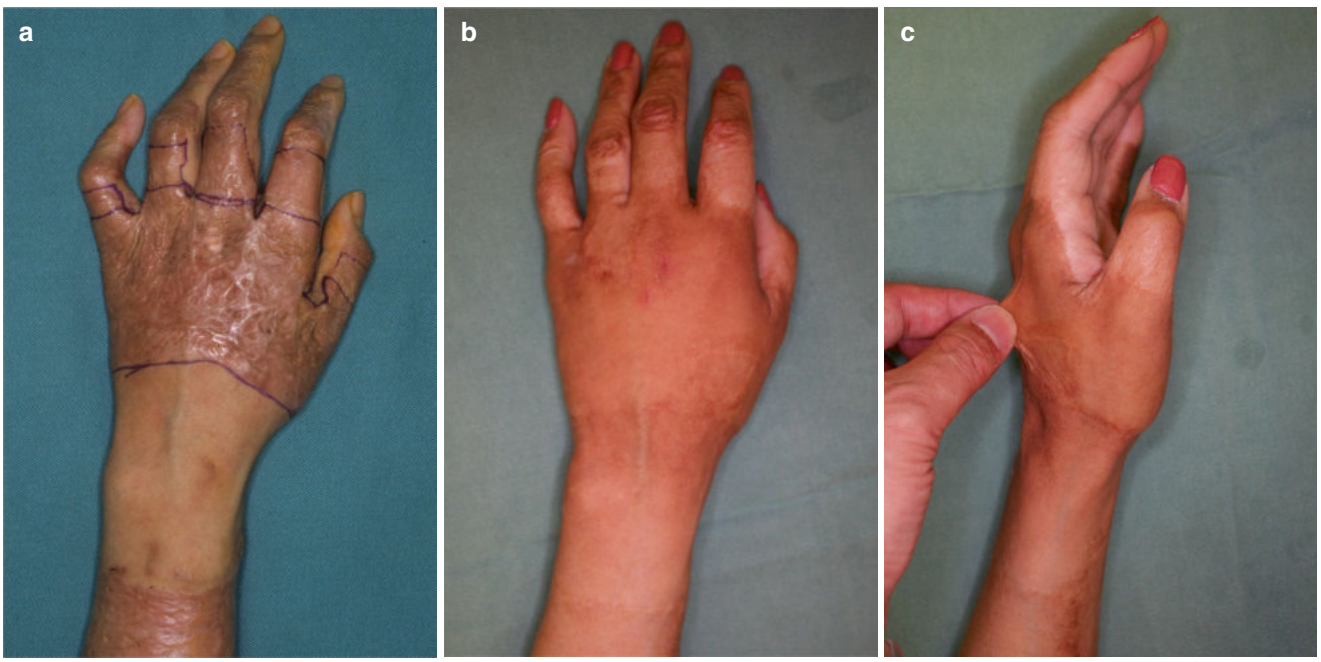


Fig. 28.2 A case of burn scar contracture of the hand reconstructed with Tsukada's graft. (**a**) Excisional design of burn scar contracture on the left dorsal hand. (**b**) Clinical image 8 years after reconstruction with Tsukada's graft

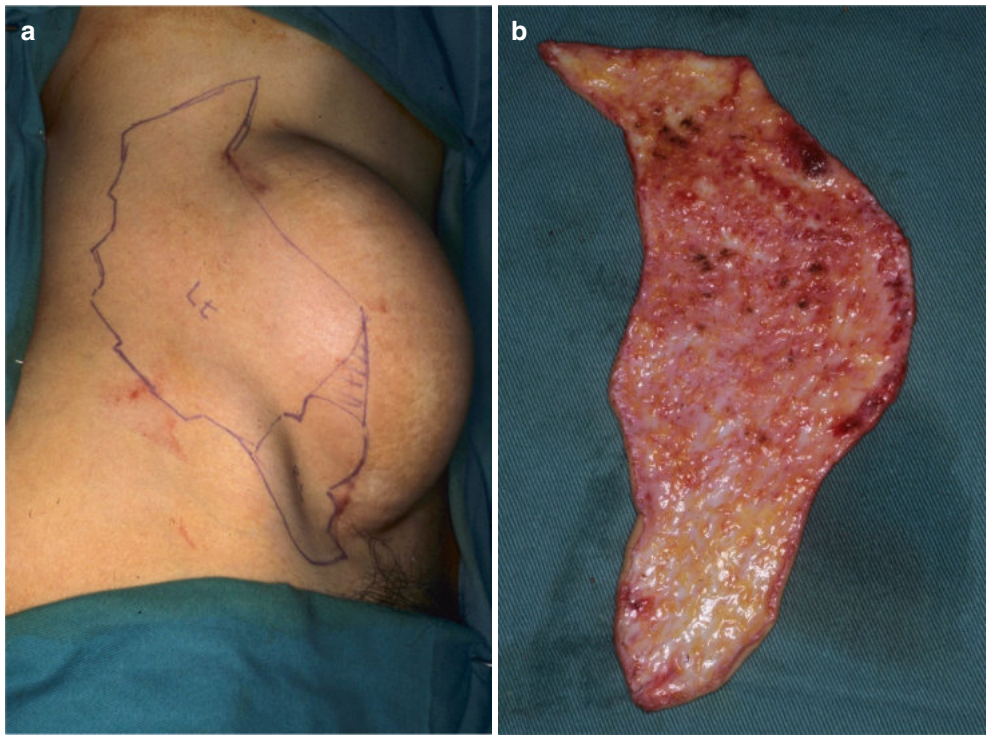


Fig. 28.3 Inguinal skin expansion and skin harvesting using a tissue expander. (**a**) Design of right inguinal skin expansion with tissue expander and skin harvesting. (**b**) Backside of grafted skin after harvesting and subcutaneous fat excision

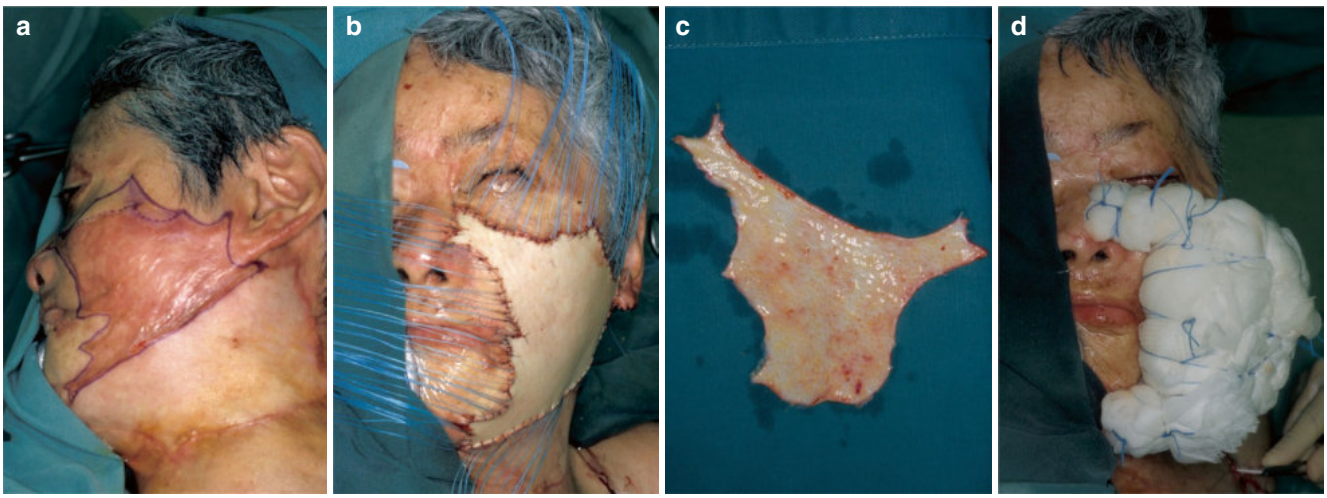


Fig. 28.4 Intraoperative view of the case in Fig. 28.1. (**a**) Excision of the scar on the left cheek and reduction of surrounding skin. (**b**) Tsukada's graft was performed. (**c**) Grafted skin graft with sparing of the subcutaneous vascular network and surrounding sparse connective tissue. Some adipose tissue was adhered. (**d**) Tie-over dressing was performed

28.2 Surgical Technique

The graft bed must be prepared with a healthy wound free of contamination or infection, and with complete hemostasis. The graft should be harvested, including all skin and subcutaneous adipose tissue layers. The donor site is closed directly. The graft fat is excised with shears [1, 2]. The layer in which the vascular network is present contains visible microvessels and many invisible vessels, so care should be taken not to injure this layer. The best grafts are those in which the vascular network is exposed, and a small layer of adherent fat remains. The graft is sutured to the skin defect, and a tie-over dressing is performed (Fig. 28.4). Restrict movement around the graft, if necessary, to prevent the development of a subgraft hematoma. The dressing is removed after 1 week, and the mobility restrictions are lifted.

Postoperative compression and immobilization with a sponge for 3–6 months may cause epidermal necrosis, which often improves with saline compresses.

28.3 Survival

The process of angiogenesis to the full-thickness skin grafts begins with passive absorption of serum into the graft vessels 24–48 h after transplantation. On day 3, angiogenesis begins in the reticular dermis in the center of the graft and the graft bed [5, 6]. On day 7, the new vessels in the graft bed that have entered the graft begin to connect with the vessels in the graft [7]. This allows blood to reperfuse the graft through the graft's existing blood vessels [6]. At the same time, existing blood vessels in the graft regress, and neovascularization is performed by bone marrow-derived vascular endothelial cells induced from the graft bed [6]. By day 14, vascular connection and neovascularization spread to the margins of the graft [7]. On day 21, when neovascularization is complete to the periphery of the graft, this process ceases [7].

On the other hand, the vascularization process of Tsukada's graft was observed by scraping the epidermis and scanning the capillaries in the dermis under a microscope [1]. At 24 to 36 hours after transplantation, some blood vessels were found to contain stationary, non-coagulated blood. By day 3, all vessels were dilated and congested. Seven days after transplantation, active blood flow was observed. After 10–14 days following transplantation, the vessels became smaller and thinner. On day 21, numerous capillaries had developed from the graft bed.

Thus, the grafting process of Tsukada's graft is similar to that of allograft grafting. The difference between Tsukada's graft and a full-thickness skin graft is in the structure of the vessels anastomosed at an early stage [8]. Human skin microcirculation is composed of two horizontal vascular plexuses. One is located 1–2 mm below the skin surface in the subpapillary dermis (subpapillary microvascular network), and the other is at the dermal-subcutaneous interface (deep dermal microvascular plexus). The SVN to be preserved in Tsukada's graft is the deep dermal microvascular plexus, which plays a significant role in blood supply and distribution to the skin appendages [8]. The ascending microvascular arteries pass through the pilosebaceous and sweat glands to reach the subpapillary microvascular plexus from this deep plexus [8]. The SVN exposed on the undersurface of Tsukada's graft runs horizontally. Therefore, the area of vessels in direct contact with the graft bed is significant, and it is believed that more vessels are anastomosed than in full-thickness skin grafts [1, 4]. Furthermore, blood from the anastomosed vascular network can quickly spread peripherally, nourish hair matrix cells and sweat glands, and feed the skin surface layer from the shallow subpapillary microvascular plexus. This vascular structure of the grafted skin, along with the preservation of the deep dermis and skin appendages, accounts for the reduced contracture and the ability to reconstruct softer, more natural skin compared to full-thickness skin grafts [1].

References

1. Tsukada S. Transfer of free skin grafts with a preserved subcutaneous vascular network. Ann Plast Surg. 1980;4(6):500–6.
2. Scherer-Pietramaggiori SS PG, Orgill DP. Skin graft. 3 ed. Peter C N, editor: Elsevier Inc; 2013. 319–38 p.
3. Hihara M, Kakudo N, Mitsui T, Kuro A, Kusumoto K. Functional reconstruction for severe heat press injury of the proper digits using immediate preserved subdermal vascular network skin graft: a case report. J Burn Care Res. 2022;43(5):1207–10.
4. Smahel J, Clodius L. The blood vessel system of free human skin grafts. Plast Reconstr Surg. 1971;47(1):61–6.
5. Abdelhakim M, Dohi T, Yamato M, Takada H, Sakai A, Suzuki H, et al. A new model for specific visualization of skin graft neoangiogenesis using Flt1-tdsRed BAC transgenic mice. Plast Reconstr Surg. 2021;148(1):89–99.
6. Lindenblatt N, Platz U, Althaus M, Hegland N, Schmidt CA, Contaldo C, et al. Temporary angiogenic transformation of the skin graft vasculature after reperfusion. Plast Reconstr Surg. 2010;126(1):61–70.
7. Capla JM, Ceradini DJ, Tepper OM, Callaghan MJ, Bhatt KA, Galiano RD, et al. Skin graft vascularization involves precisely regulated regression and replacement of endothelial cells through both angiogenesis and vasculogenesis. Plast Reconstr Surg. 2006;117(3):836–44.
8. Parsi K, Partsch H, Rabe E, Ramelet AA. Reticulate eruptions. Part 1: vascular networks and physiology. Australas J Dermatol. 2011;52(3):159–66.

Pediatric Burn Reconstruction

29

Martin R. Buta, Branko Bojovic, and Matthias B. Donelan

Abstract

Pediatric burn reconstruction has made significant progress in the past 75 years. Advances in acute burn care have greatly improved patient survival, particularly in children, resulting in a large number of pediatric burn survivors who require reconstructive surgery for a wide range of deformities. These deformities can range from small areas of superficial scarring with no associated contractures to the most extensive and complicated deformities imaginable following massive burns. The goal for all these patients should be to restore them as closely as possible to their pre-injury state. Keeping this goal in mind from the first presentation of a burned child is essential to achieving the best possible outcome. The best outcomes require choosing the best reconstructive options while minimizing iatrogenic deformities. The goal of this chapter is to describe an overall reconstructive strategy and present selected examples that will emphasize what is possible today.

Keywords

Burns · Pediatric burn reconstruction · Burn surgery · Hypertrophic scar · Donor site morbidity · Local tissue rearrangement · Z-plasty · Laser therapy

29.1 Introduction

Pediatric burn reconstruction has made significant progress in the past 75 years. Advances in acute care, including wound assessment, fluid resuscitation, infection control, pathophysiology, inhalation injury management, nutritional support, superficial dressings, and burn surgery, contributed to less morbid interventions [1–3]. Greatly improved patient survival, particularly in children, has given plastic and burn surgeons the opportunity to reconstruct an infinite number of deformities in pediatric burn survivors and return them as closely as possible to their pre-injury state [4–6]. Achieving the best possible outcomes requires choosing the best reconstructive options with the minimal iatrogenic deformities. In ideal circumstances, restoring severely burned areas close to a normal state is possible, as shown in Fig. 29.1. This chapter describes our current approach to pediatric burn reconstruction, with selected cases highlighting what is possible.

A deeper appreciation of modern pediatric burn reconstruction emerges by briefly reflecting on a few key historical developments. Over 150 years ago, the introduction of general anesthesia in 1846 and local anesthesia in 1884 made the surgical reconstruction of burn deformities using local tissue rearrangement more accessible, leading to the proliferation of various surgical techniques [7, 8]. Before these innovations, burn scars and contractures were rarely addressed surgically due to pain and the challenges of mobilizing tissues without anesthesia. Burn survivors lived with little hope of their deformities and disabilities being treated. Anesthesia and local tissue rearrangement transformed the surgical options and patients benefited with progressively better outcomes. Techniques were developed that built upon the work of J.C. Fricke, Thomas Mutter, Stewart McCurdy, and other pioneers during the nineteenth century, many of whom believed in preserving scar tissue [9–11].

A notable shift in managing burn scars and contractures occurred approximately 100 years ago. The seminal work of Sir Harold Gillies, and his advocacy for scar excision, influenced the surgical approach to scars for most of the twentieth century [5, 6]. For many burn survivors, burn reconstruction focused on scar excision and resurfacing with either flaps or grafts. Unfortunately, those patients were frequently left with a grotesque appearance as well as donor sites that had their own morbidities and complications (Fig. 29.2).

M. R. Buta · B. Bojovic · M. B. Donelan (✉)
Department of Plastic, Reconstructive, and Laser Surgery, Shriners Children's, Division of Plastic and Reconstructive Surgery, Massachusetts General Hospital, Boston, MA, USA
e-mail: mbuta@mgh.harvard.edu; bbojovic@mgb.org; mdonelan@mgh.harvard.edu

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_29

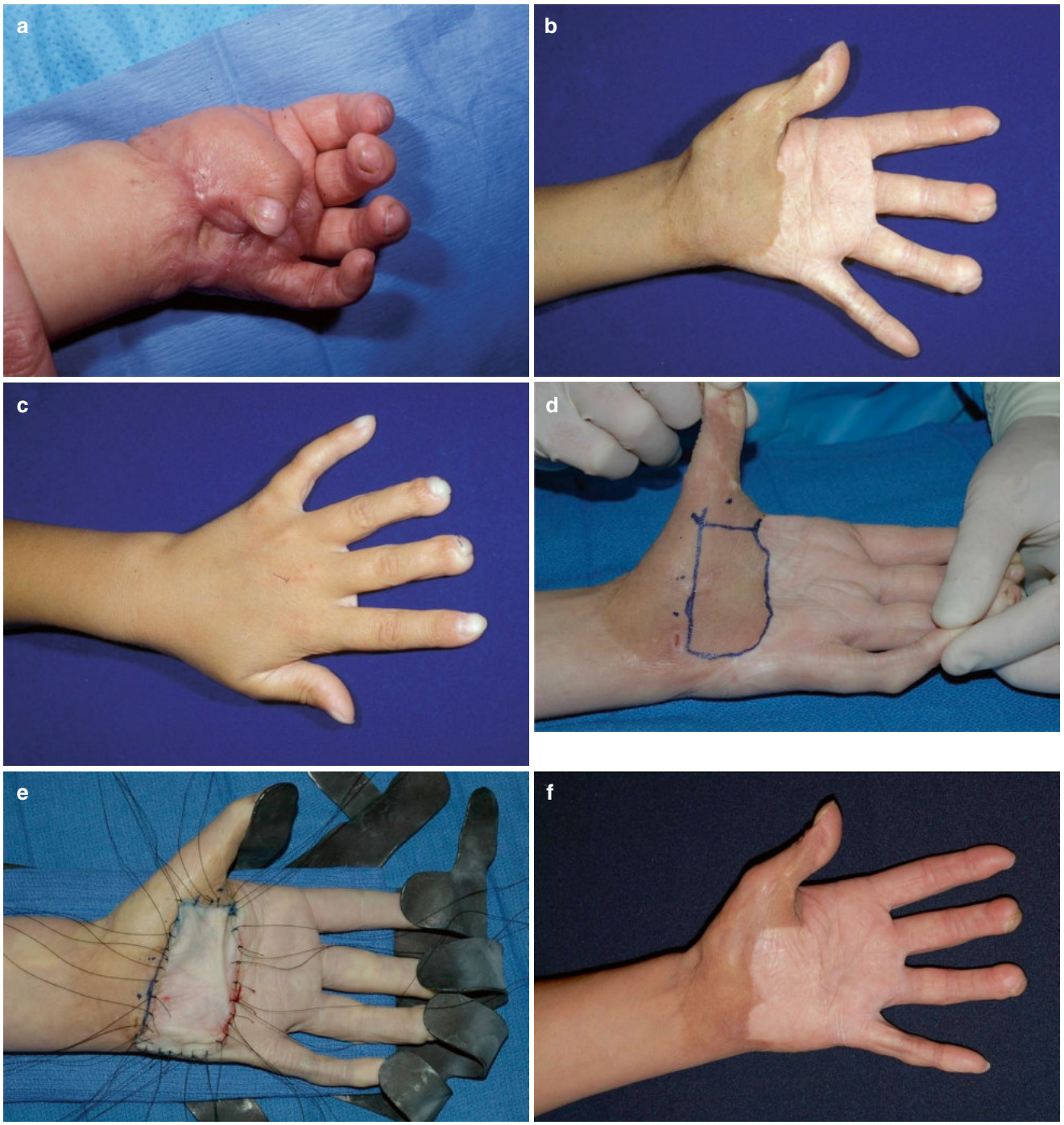


Fig. 29.1 (**a**) A 1-year-old child with extensive hand burn scars and contractures to the hand. (**b**, **c**) After 9 years of undergoing acute post-burn reconstruction, she had essentially normal hand function but a sub-optimal aesthetic result with palmar hyperpigmentation. (**d**–**f**) At age 18, 17 years after the burn, the patient underwent excision of the hyper-pigmented grafts and replacement with split-thickness skin grafts from the plantar insteps (**g**, **h**). Each donor site was harvested twice. (**i**) Final result. (*From* Donelan and Buta [20]; *with permission*)

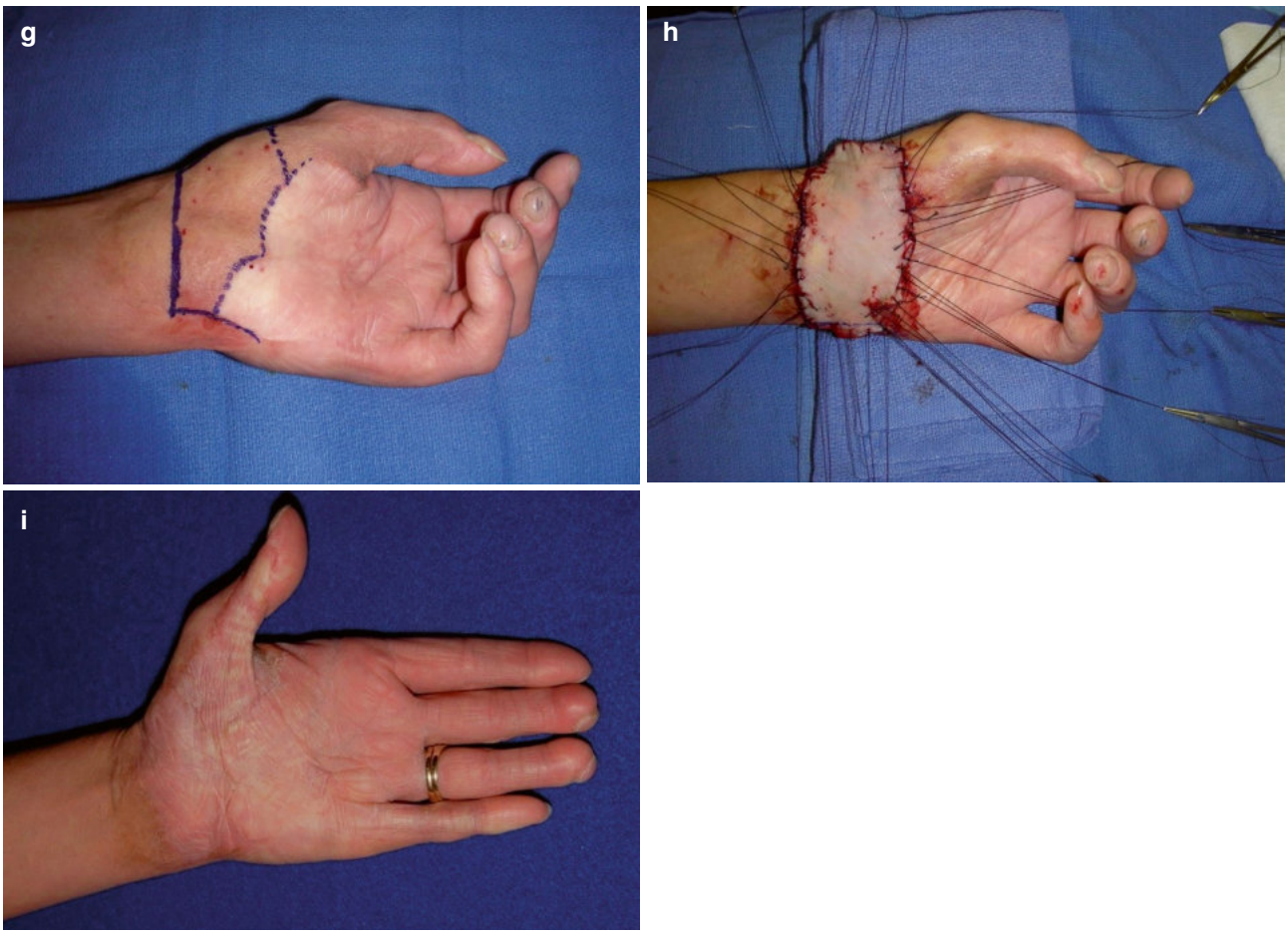


Fig. 29.1 (continued)

Improved patient survival today has given plastic surgeons new opportunities to reconstruct burn scar deformities and optimally restore form, function, and appearance in ideal circumstances. A paradigm shift in how we think about burn scars has developed in the past 40 years because of technological and pharmaceutical innovations. Early excision and grafting of burns greatly improved survival, particularly in children, and is now the gold standard of acute care. It may be that today the morbidities associated with early excision and grafting should decrease its use for non-life-threatening burn injuries because of the ways that laser technology has transformed what is possible for scar rehabilitation (Fig. 29.3).

With current technology, tissue preservation should be a goal of reconstruction, contrary to Sir Gillies' entrenched ideas. Scars are autologous tissue, already in the right place, and with the potential to be valuable reconstructive material. Using classic plastic surgery techniques such as Z-plasty and other types of local tissue rearrangement, scars can often be remodeled and rehabilitated to improve elasticity and morphology and blend them with adjacent normal tissue. These local rearrangements avoid the morbidities often encountered with scar excisions requiring skin grafts and regional or distant flaps to close the resulting defects (Figs. 29.4, 29.5, and 29.6). Figure 29.4 shows a severe burn contracture involving the entire right lower extremity, including the buttock, thigh, knee, ankle, and foot. All of the patient's contractures and hypertrophy were corrected with only local tissue rearrangement and without laser therapy. Her result would have been even better had her surgery been coupled with modern laser treatment.

Laser therapy with laser-assisted drug delivery (LADD), introduced in the past 20 years, has significantly improved scar rehabilitation and can further enhance results achieved from surgery (Fig. 29.7) [13–19]. When laser therapy is combined with local tissue rearrangement, as shown in Fig. 29.7, an almost completely normal appearance and function can be restored. This combination of synergistic modalities can be very effective in all areas of the body, as demonstrated in Figs. 29.8, 29.9, 29.10, 29.11, and 29.12.

Despite an abundance of clinical and experimental evidence demonstrating the efficacy of laser therapy in rehabilitating burn scars, it has not yet been widely adopted as standard of care [19]. At present, laser therapy should be considered when putting together a reconstructive plan for

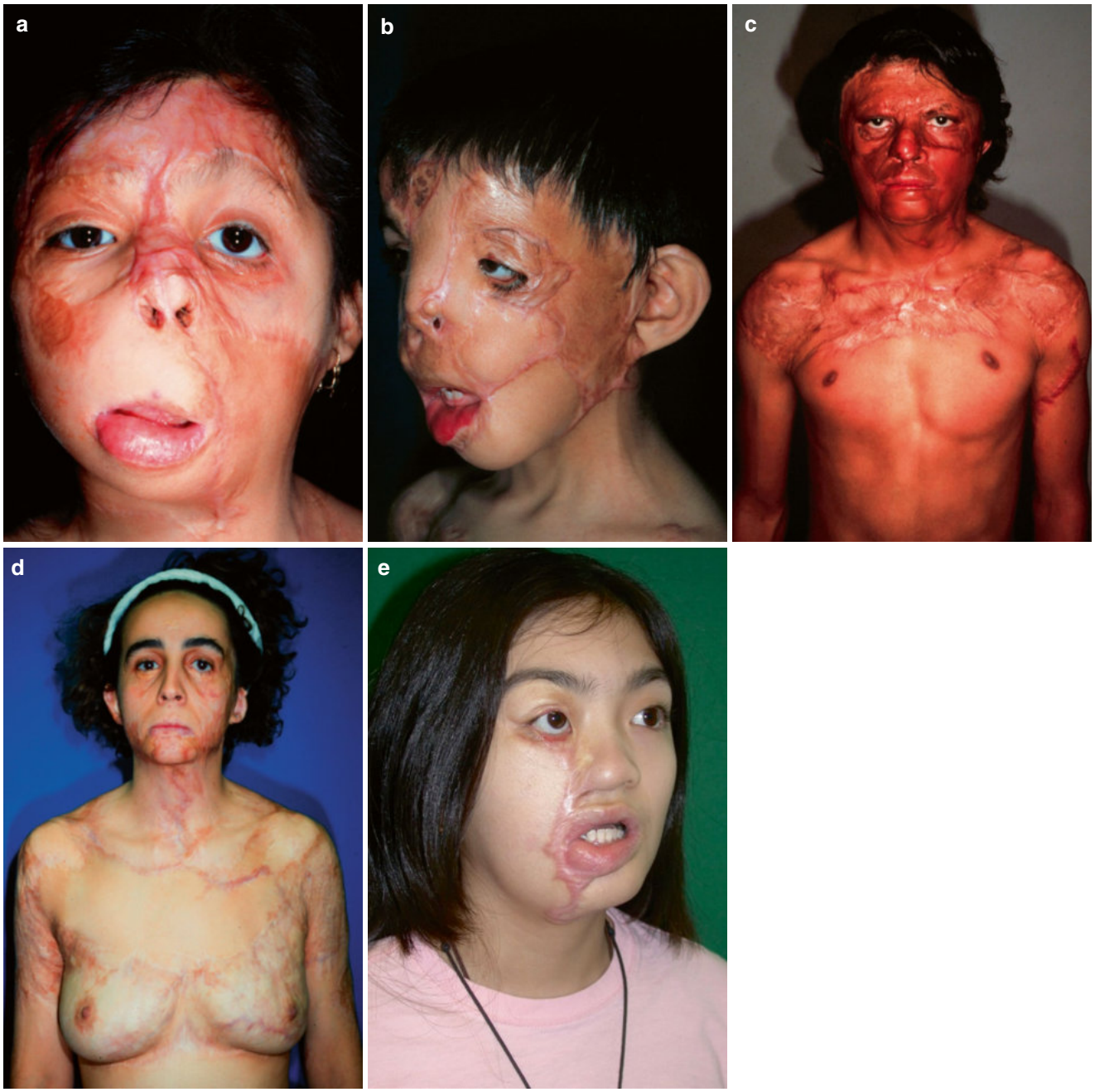


Fig. 29.2 (**a**–**e**) Burn scar excisions and flap closures frequently result in a grotesque appearance. (*From* Donelan and Buta [20]; *with permission*)

essentially all burn scars, particularly in children, when appropriate laser technology is available. Scar excision should only be used when other options are unavailable or suboptimal. This current approach to treating scars and contractures is especially well-suited to highly sensitive and exposed areas of the body, such as the face, where deformities can lead to significant long-term physical and psychosocial impairment. Ironically, hypertrophic and contracted burn scars have become burn patients' most valuable reconstructive anatomy. Rehabilitated and rearranged burn scar tissue can be superior to reconstructive results obtained by scar excision with closure under tension and/or replacement with flaps or grafts. At present, in our pediatric burn reconstructive practice, burn scars are rarely excised.

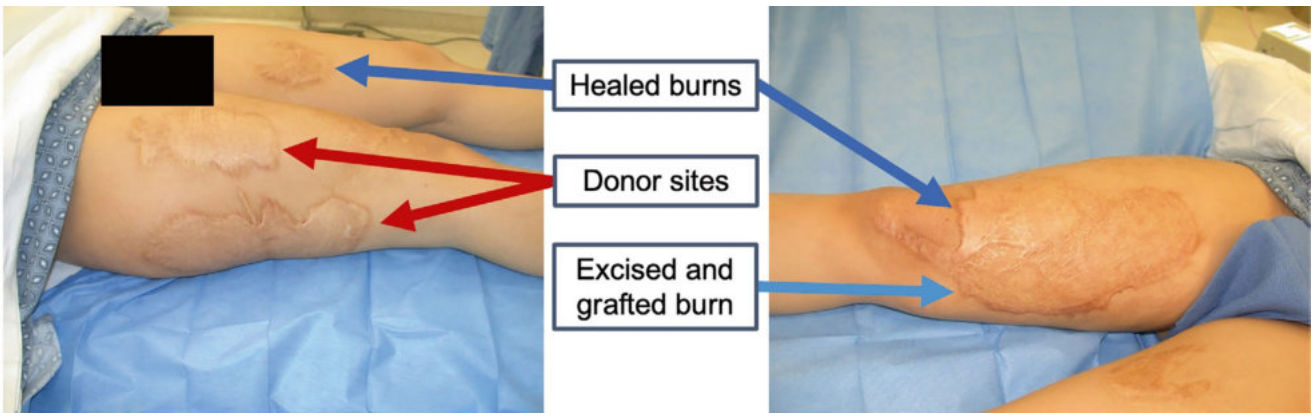


Fig. 29.3 Donor site morbidity. This patient's non-life-threatening burn injury was treated by elective surgical excision and skin grafting. The treatment created two permanent donor site deformities. The case raises important questions: Is the excised and grafted burn significantly better than the nonexcised healed burns? Are the donor scars on this patient worth the alleged improved outcome?

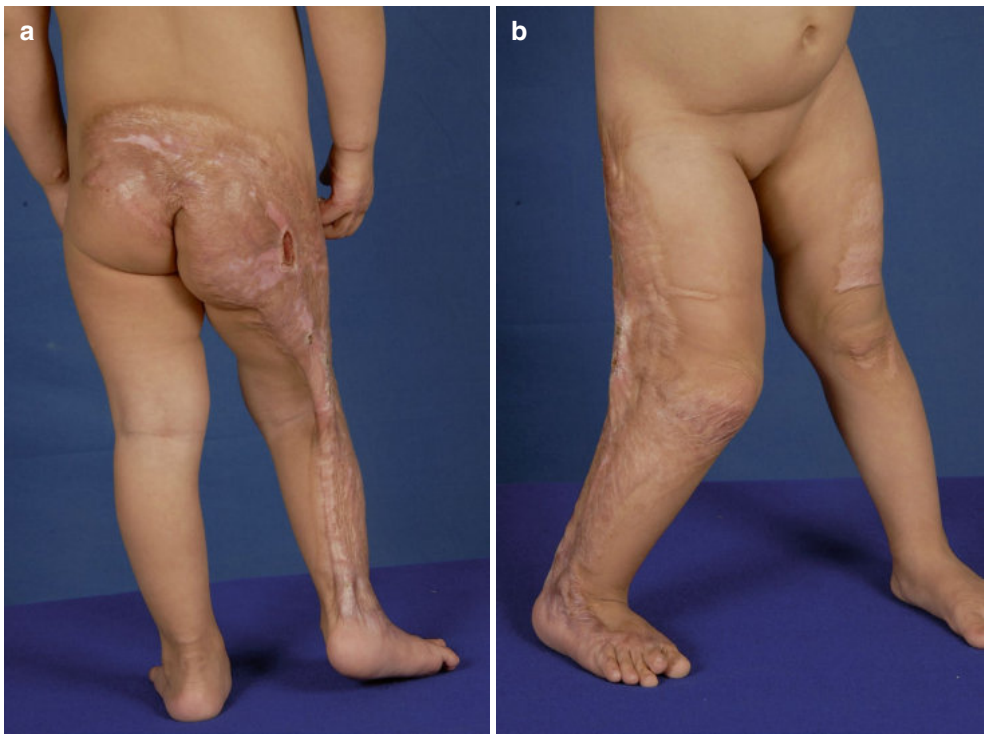


Fig. 29.4 (**a**, **b**) Young female patient with massive thick burn scars and contractures on the right leg. Note the downward displacement of the right buttock. The patient was unable to place her right heel on the ground and extend her knee normally. (*From* Donelan and Buta [20]; *with permission*)

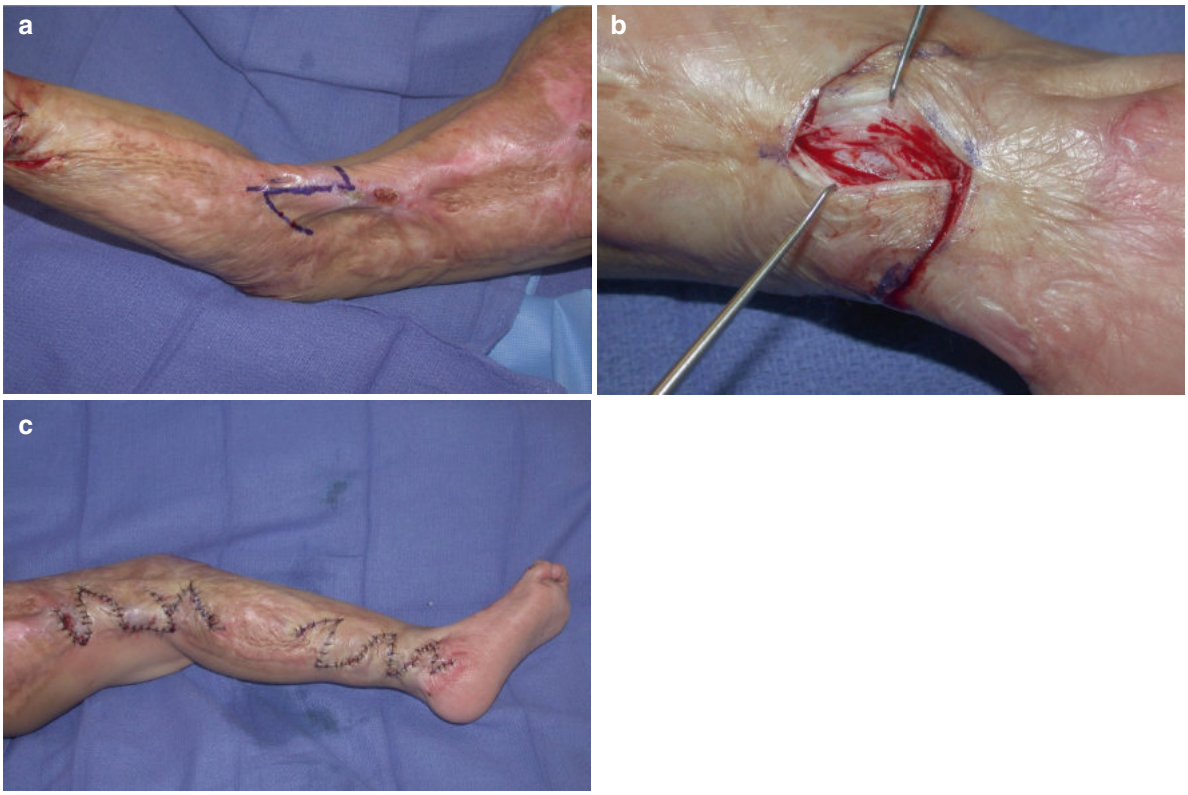


Fig. 29.5 (**a**–**c**) Thickened contractures along the lateral aspect of the leg and the popliteal fossa were released with multiple Z-plasties. (*From* Donelan and Buta [20]; *with permission*)

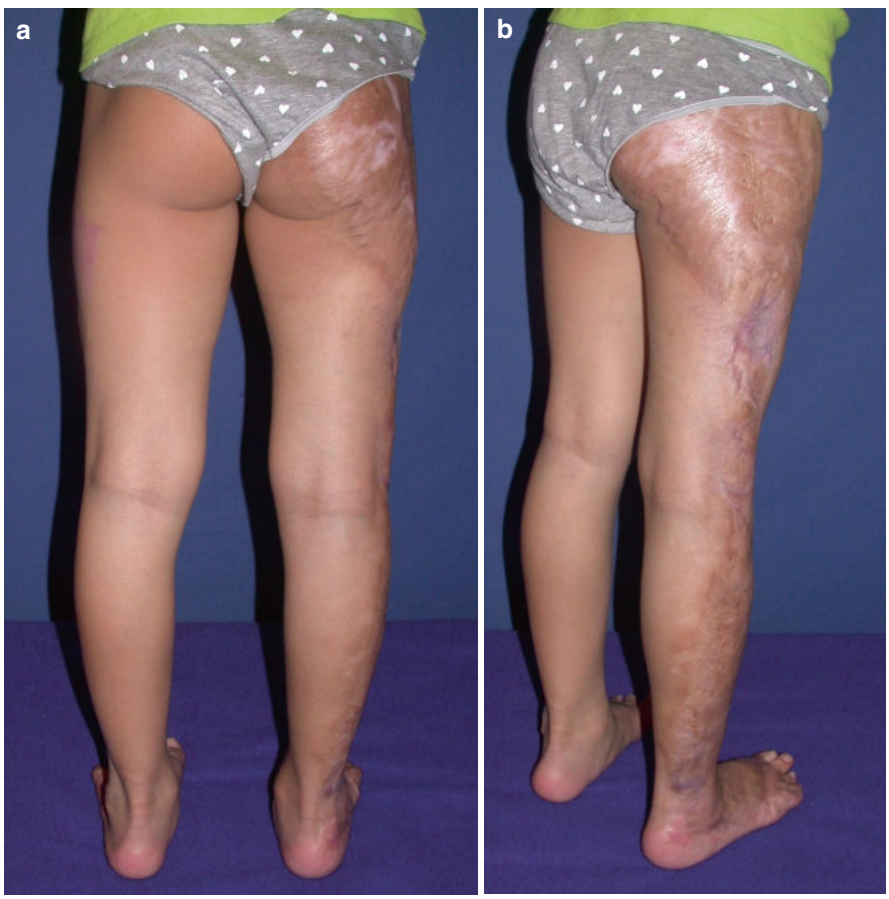


Fig. 29.6 (**a**, **b**) Four years after her first Z-plasty, the patient had a normal range of motion in her right knee, and she was able to place her foot flat on the ground. The scar's appearance and skin tension were close to normal. Her buttock was restored to a normal position. No laser therapy was used. (*From* Donelan and Buta [20]; *with permission*)

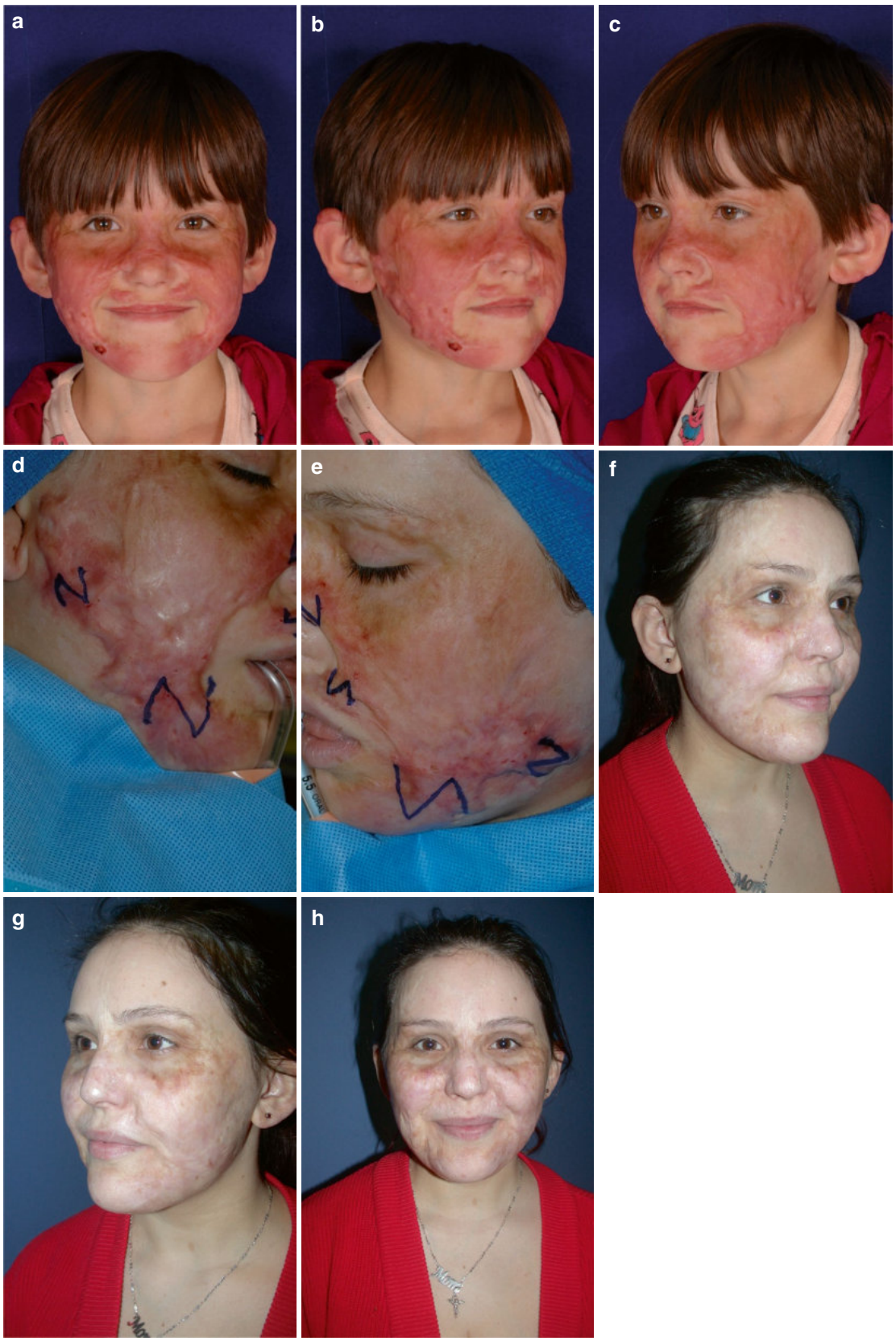


Fig. 29.7 (**a**–**h**) An 11-year-old girl who suffered a flash burn to her face, resulting in diffuse erythematous, ulcerated, and hypertrophic scars. Over 7 years, she underwent four Z-plasty procedures, nine treatments with pulsed dye laser, and ten treatments with a CO_2 ablative fractional laser. No scars were ever excised; only dyspigmentation remained. Her face has a much more normal appearance and expression. (*From* Donelan and Buta [20]; *with permission*)

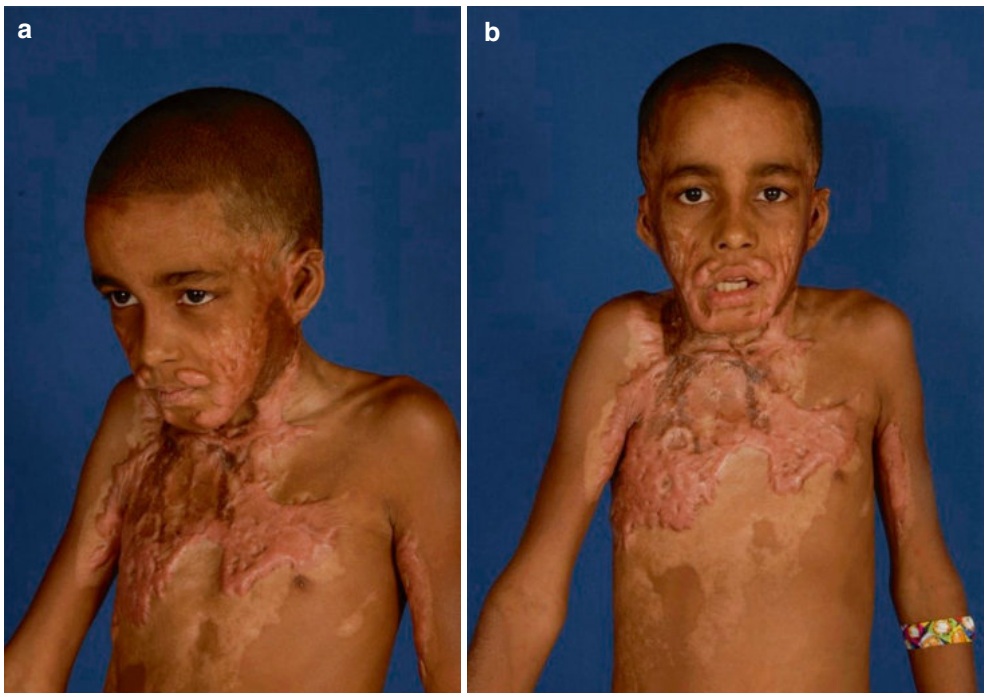


Fig. 29.8 (**a**, **b**) Young male with extensive third-degree burns with diffuse scarring and a severe linear contracture with a chronic ulcer in the right axilla. Right shoulder abduction was limited to 30 degrees. (*From* Donelan and Buta [20]; *with permission*)

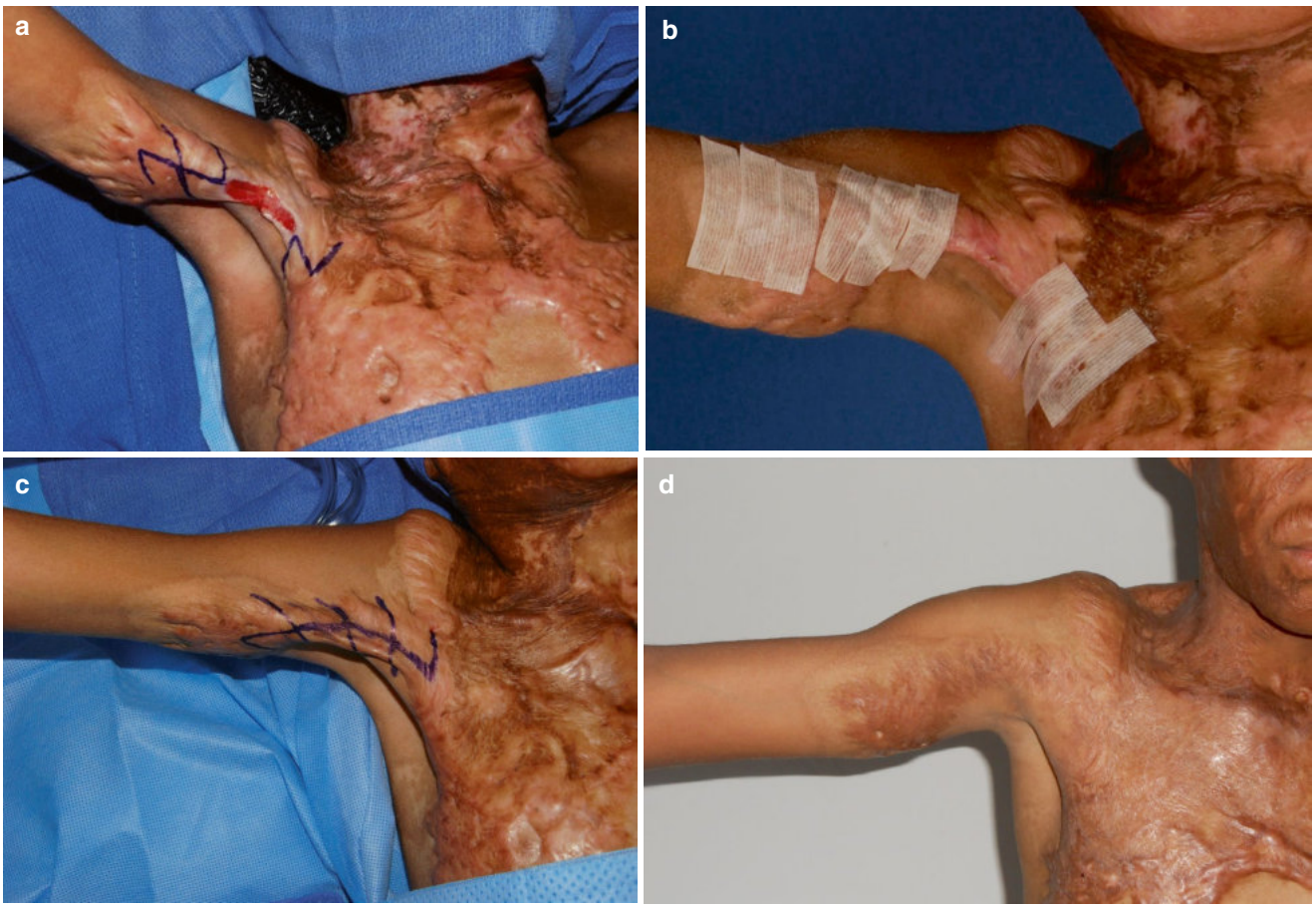


Fig. 29.9 (**a**) Z-plasties were done on the linear contracture on 1/24/2011. (**b**) By 2/9/2011, 2 weeks later, the ulcer had healed. (**c**) Serial Z-plasties were carried out on 9/12/2011. (**d**) By 3/24/2014, the contracture had been eliminated. (*From* Donelan and Buta [20]; *with permission*)

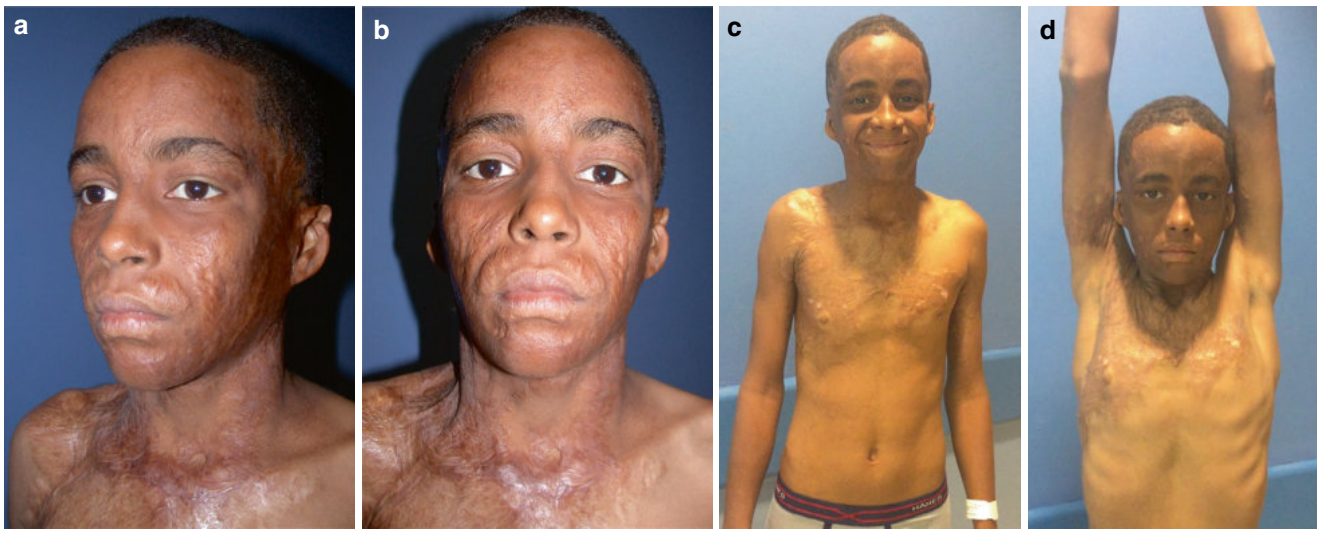


Fig. 29.10 (**a**–**d**) After 3 years, the first Z-plasties and five CO_2 ablative fractional laser treatments, the appearance, elasticity, and sensation of the rehabilitated scars approximate normal. (*From* Donelan and Buta [20]; *with permission*)

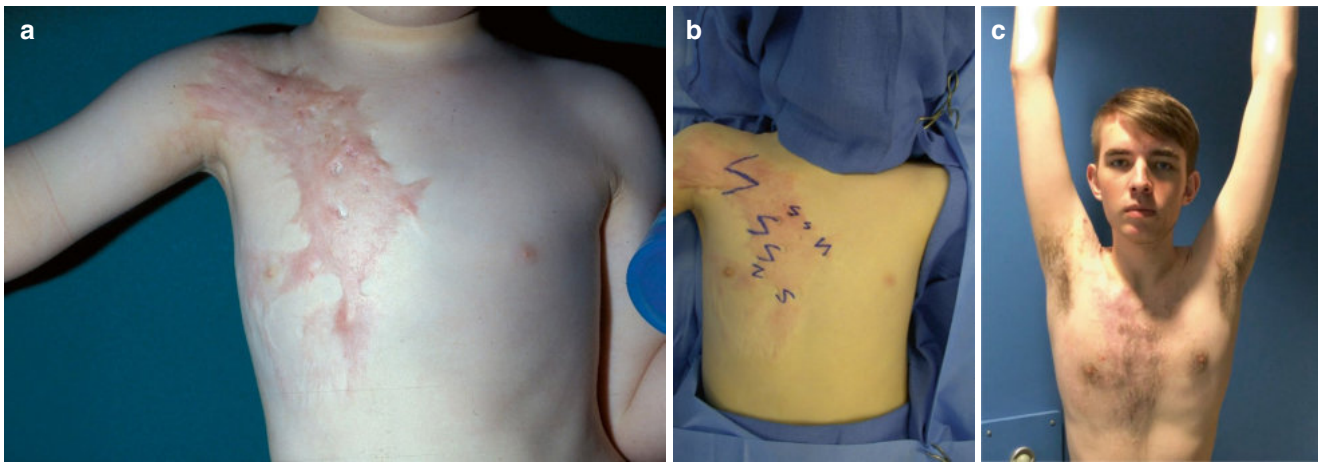


Fig. 29.11 (**a**–**c**) Young male with diffuse hypertrophic burn scars and contractures on the right chest. After undergoing Z-plasties within the scar tissue and ablative fractional CO_2 laser treatments, full range of motion was restored, and the scar's appearance was near normal. (*From* Donelan and Buta [20]; *with permission*)

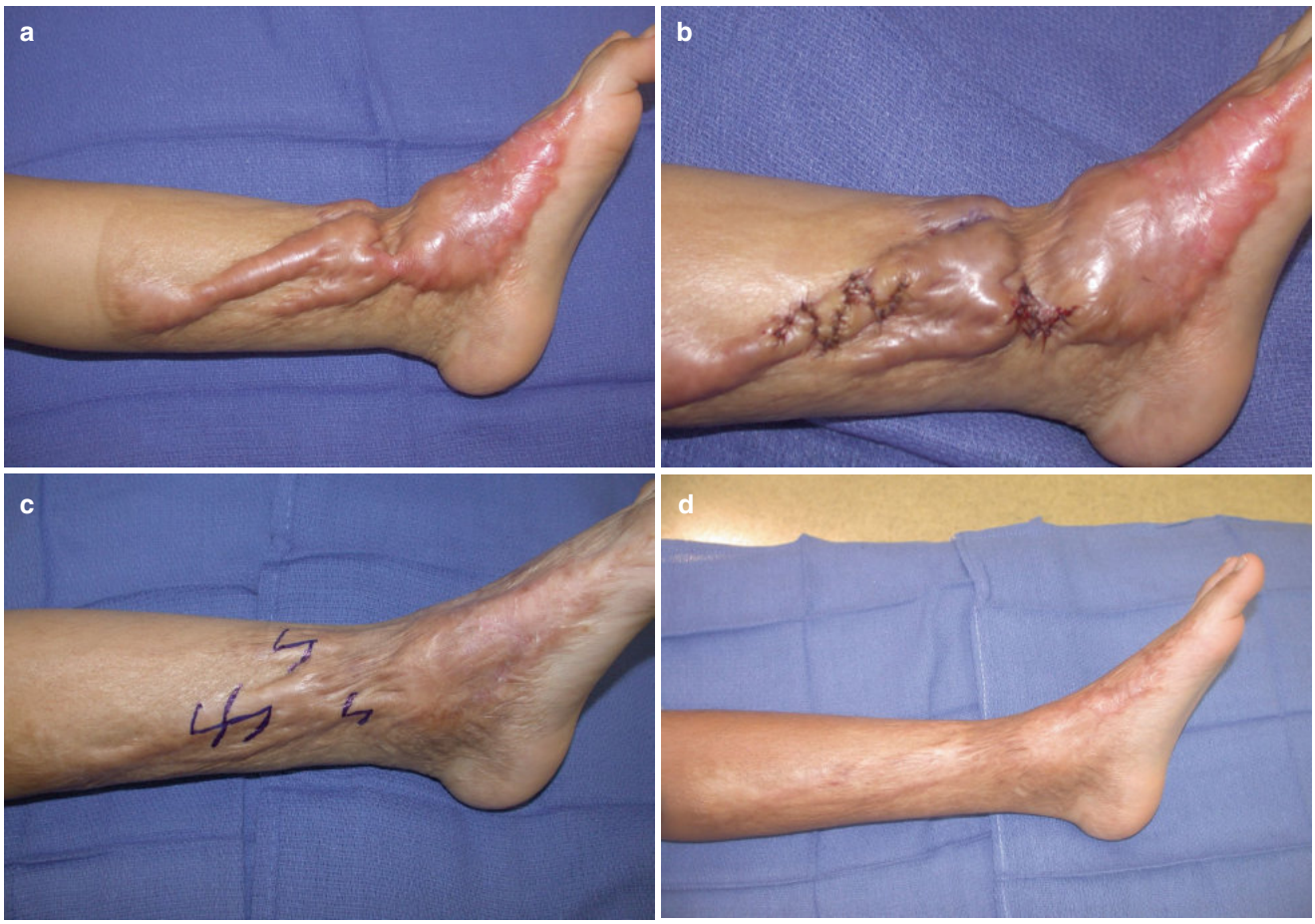


Fig. 29.12 (**a**) Young patient with severe hypertrophic scarring and contractures following a scald injury to the lower left leg and foot, limiting range of motion in the ankle. (**b**, **c**) Z-plasties were done in 2012 and 2014. (**d**) After 6 years, in 2018, the hypertrophic scarring had resolved, and the patient's left leg and foot had a markedly improved appearance. Normal ankle function was restored. (*From* Donelan and Buta [20]; *with permission*)

29.2 Key Points

- Approximately 150 years ago, burn reconstruction consisted of local tissue rearrangement including the local scar tissue.
- Approximately 100 years ago, burn reconstruction focused on scar excision and resurfacing with either flaps or grafts.
- Approximately 40 years ago, scar rehabilitation was greatly improved by laser technology combined with local tissue rearrangement.
- Approximately 20 years ago, laser-assisted drug delivery (LADD) further advanced scar rehabilitation.
- Today, hypertrophic and contracted burn scars can be a patient's most valuable reconstructive anatomy.

References

1. Buta MR, Donelan MB. Evolution of burn care. Clin Plast Surg. 2023;51:191.
2. Branski LK, Herndon DN, Barrow RE. A brief history of acute burn care management. In: Herndon DN, editor. Total burn care. 5th ed. Saunders; 2018. p. 1–7.
3. Lee KC, Joory K, Moiemen NS. History of burns: the past, present and the future. Burns Trauma. 2014;2(4):169–80.
4. Burke JF, Bondoc CC, Quinby WC. Primary burn excision and immediate grafting: a method shortening illness. J Trauma. 1974;14(5):389–95.
5. Tompkins RG, Remensnyder JP, Burke JF, et al. Significant reductions in mortality for children with burn injuries through the use of prompt eschar excision. Ann Surg. 1988;208(5):577–85.
6. Herndon DN, Barrow RE, Rutan RL, et al. A comparison of conservative versus early excision. Therapies in severely burned patients. Ann Surg. 1989;209(5):547–52; discussion 552–3.

7. Robinson DH, Toledo AH. Historical development of modern anesthesia. J Investig Surg. 2012;25(3):141–9.
8. Eger EI, Saidman LJ, Westhorpe R. The wondrous story of anesthesia. Springer; 2014. p. xviii, 944 pages.
9. Borges AF. Elective incisions and scar revision. Little Brown & Co. Inc; 1973.
10. McCurdy SL. Manual of orthopedic surgery. Nicholson Press; 1898.
11. McCurdy SL. Z-plastic surgery: plastic operation to elongate cicatricial contraction of the neck, lips and eyelids and across joints. Surg Gynecol Obstet. 1913;16:209–12.
12. Asuku M, Yu TC, Yan Q, et al. Split-thickness skin graft donor-site morbidity: a systematic literature review. Burns. 2021;47(7):1525–46.
13. Manstein D, Herron GS, Sink RK, et al. Fractional photothermolysis: a new concept for cutaneous remodeling using microscopic patterns of thermal injury. Lasers Surg Med. 2004;34(5):426–38.
14. Donelan MB, Parrett BM, Sheridan RL. Pulsed dye laser therapy and Z-plasty for facial burn scars: the alternative to excision. Ann Plast Surg. 2008;60(5):480–6.
15. Wenande E, Anderson RR, Haedersdal M. Fundamentals of fractional laser-assisted drug delivery: an in-depth guide to experimental methodology and data interpretation. Adv Drug Deliv Rev. 2020;153:169–84.
16. Issler-Fisher AC, Waibel JS, Donelan MB. Laser modulation of hypertrophic scars: technique and practice. Clin Plast Surg. 2017;44(4):757–66.
17. Choi KJ, Williams EA, Pham CH, et al. Fractional CO(2) laser treatment for burn scar improvement: a systematic review and meta-analysis. Burns. 2021;47(2):259–69.
18. Klifto KM, Asif M, Hultman CS. Laser management of hypertrophic burn scars: a comprehensive review. Burns Trauma. 2020;8:tkz002.
19. Miletta N, Siwy K, Hivnor C, et al. Fractional ablative laser therapy is an effective treatment for hypertrophic burn scars: a prospective study of objective and subjective outcomes. Ann Surg. 2021;274(6):e574–80.
20. Donelan MB, Buta MR. The art of local tissue rearrangements in burn reconstruction: Z-Plasty and more. Clin Plast Surg. 2024;51(3):329–47. https://doi.org/10.1016/j.cps.2024.02.010. Epub 2024 Apr 6. PMID: 38789143.

Skin Grafts for Hand and Digital Scar Contractures

30

Rei Ogawa

Abstract

While skin grafting is a common initial treatment for burns, we here describe its use in secondary reconstruction of scar contractures of the hands and fingers. Hypertrophic scars are the result of chronic inflammation at the wound/scar site, which is promoted by stretch stimuli and joint movement. Such stimuli and movements are abundant in the hand/digit area, which is why these sites are particularly prone to hypertrophic scarring and contracture formation after burn injury.

Keywords

Skin grafting · Hypertrophic scars · Contractures · Corticosteroid tapes · Surgical techniques · Postoperative management · Reconstruction

While skin grafting is a common initial treatment for burns, we here describe its use in secondary reconstruction of scar contractures of the hands and fingers. Hypertrophic scars are the result of chronic inflammation at the wound/scar site, which is promoted by stretch stimuli and joint movement. Such stimuli and movements are abundant in the hand/digit area, which is why these sites are particularly prone to hypertrophic scarring and contracture formation after burn injury.

Given the predilection of the hands/digits to develop contractures, it is important to try to prevent hypertrophic scarring after deep burns in these areas. This can be achieved by simply immobilizing the area. However, over the long term, this treatment can lead to disuse atrophy of the intrinsic muscles and tendons of the hand and joints. Consequently, it is preferred to maintain extension fixation on the hand/fingers only at night and to apply 24-h corticosteroid-tape fixation when the first signs of hypertrophic scarring emerge. Corticosteroid tapes can also be used to treat existing hypertrophic scars/contractures. Indeed, in Japan, corticosteroid tapes are considered a first-line therapy for hand/finger burn wounds/scars [1, 2], since they often limit or eliminate the need for surgery (Fig. 30.1). This reflects the fact that corticosteroids can block the emergence of the chronic wound/scar inflammation that drives hypertrophic scarring. If the contractures worsen during the first 3 months, reconstructive surgery is advisable. Nonetheless, before considering surgery, conservative measures should be tried first.

R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery,
Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_30

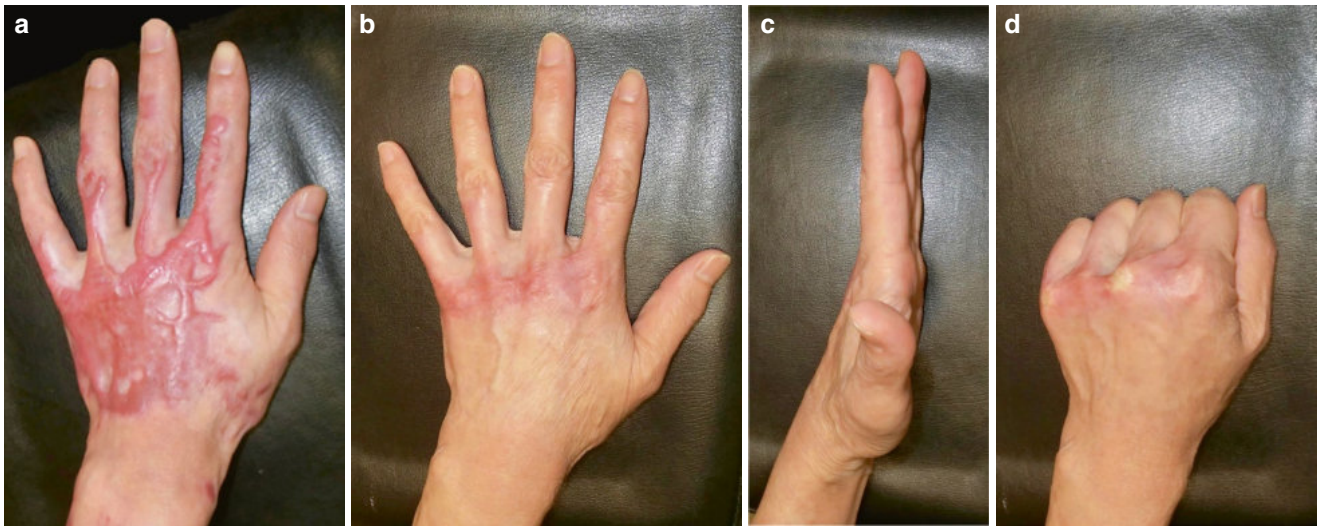


Fig. 30.1 Treatment of a post-burn scar contracture on the dorsal hand and fingers with deprodone propionate tape (Eclar® plaster). A woman in her 50 s presented with hypertrophic scars on the dorsal hand and fingers following a burn. The contractures were mild (**a** and **b**). Treatment with deprodone propionate tape (Eclar® Plaster) was initiated. After 4 years, the scars continued to exhibit some redness, but the hypertrophic scarring and contractures had improved significantly. Consequently, the patient could avoid reconstructive surgery (**b** and **c**)

30.1 Preoperative Evaluation

When a patient presents with contractures for the first time, it is essential to determine the type of contracture that is involved by preoperative assessments. There are several contracture types, including connective-tissue contractures caused by tendons and tendon sheaths, muscular contractures resulting from Volkmann's contracture or disuse atrophy, neurological contractures due to spastic paralysis or reflex-muscle tension, and joint contractures caused by intra-articular heterotopic ossification. In addition, conditions that are not directly related to trauma, such as Dupuytren's contracture and scleroderma, must be considered in the differential diagnosis. To make the differential diagnosis, X-rays, magnetic-resonance imaging scans, blood tests, and detailed medical history taking should be conducted as necessary. However, most burn-induced scar contractures generally involve the skin only.

30.2 Selection of Surgical Technique

When conservative treatment of the hand/digit scar contracture has failed, contracture resection and reconstructive surgery can be considered. A variety of surgical techniques can be used. It is important to ensure that the scars left after resection and closure are themselves not exposed to repetitive/sustained postoperative skin tension, since this greatly increases the risk of re-contracture. Relatively thin scars can be treated with resection followed by Z-plasty or local-flap surgery. However, wider scars should be treated with skin grafting. To prevent secondary contracture of the graft, full-thickness skin grafting is the first choice. For children, the medial malleolus is the preferred donor site (Fig. 30.2), because it is at the transition between the plantar and lower-leg skin. Consequently, its texture and color closely match those of the palmar skin, thus yielding superior aesthetic and functional outcomes. However, if the recipient area in children is large, the groin is more preferable (Fig. 30.3). For adults, whose burn areas tend to be larger, the medial malleolus is rarely used as the donor site; instead, the groin or the inner upper arm are better choices. While the inner upper arm provides the best thickness, texture, and color (Fig. 30.4), donor-site morbidity can be high. Consequently, the groin is often chosen (Fig. 30.5); the cosmetic outcomes are still good, even though the groin skin is slightly thinner than dorsal-hand skin. Note that the non-weight-bearing area of the sole is not suitable for transplantation to the fingers or palms because it often results in complaints of hyperkeratosis and texture discomfort.

Notably, when the scar contractures extend to the interdigital spaces, the area can still be reconstructed with a skin graft, but the interdigital spaces should be reconstructed with local flaps. This is because the interdigital spaces are highly mobile and prone to secondary re-contracture after grafting. A suitable donor site for the local flaps is the dorsal hand or palm; if this skin remains healthy, it can be harvested as rectangular local flaps to reconstruct each affected interdigital space (Fig. 30.6). Local flaps with a skin pedicle are best for

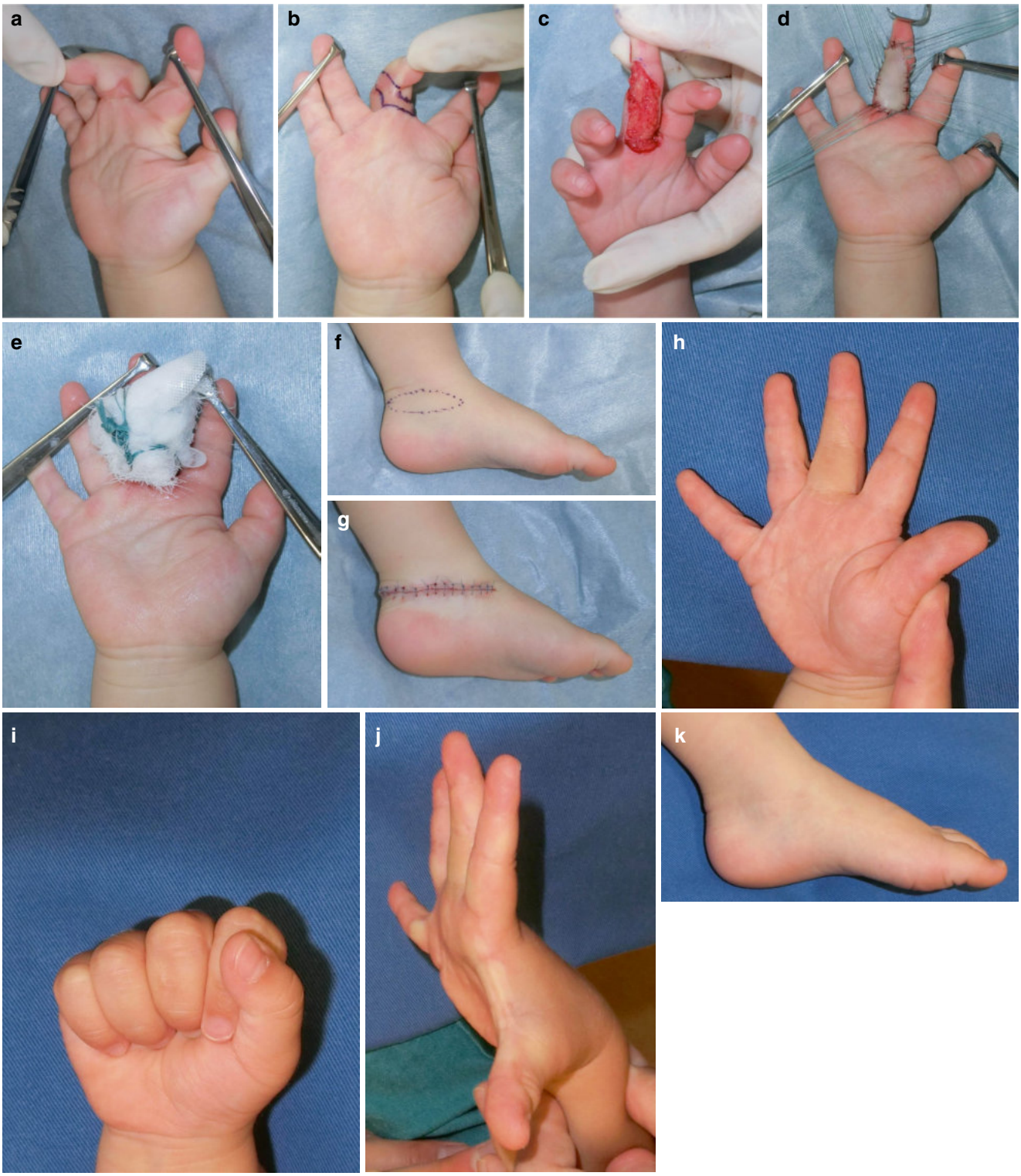


Fig. 30.2 Reconstruction of a middle-finger contracture in a child by using a full-thickness skin graft from the medial malleolus. A 2-year-old boy had a burn-induced scar contracture on his right middle finger (**a**). (**b**–**g**) All fibrous tissue masses were excised and reconstruction was performed with a full-thickness skin graft harvested from the medial malleolus of the left foot. (**b**) Scar removal design. (**c**) After removing the scars. (**d**) After applying the skin graft. (**e**) Tie-over fixation. (**f**) Marking of the donor site. (**g**) The donor site after primary skin closure. (**h**–**k**) The view 18 months after surgery. The contracture was completely released, resulting in both functional and cosmetic improvement. The donor site scar was also inconspicuous

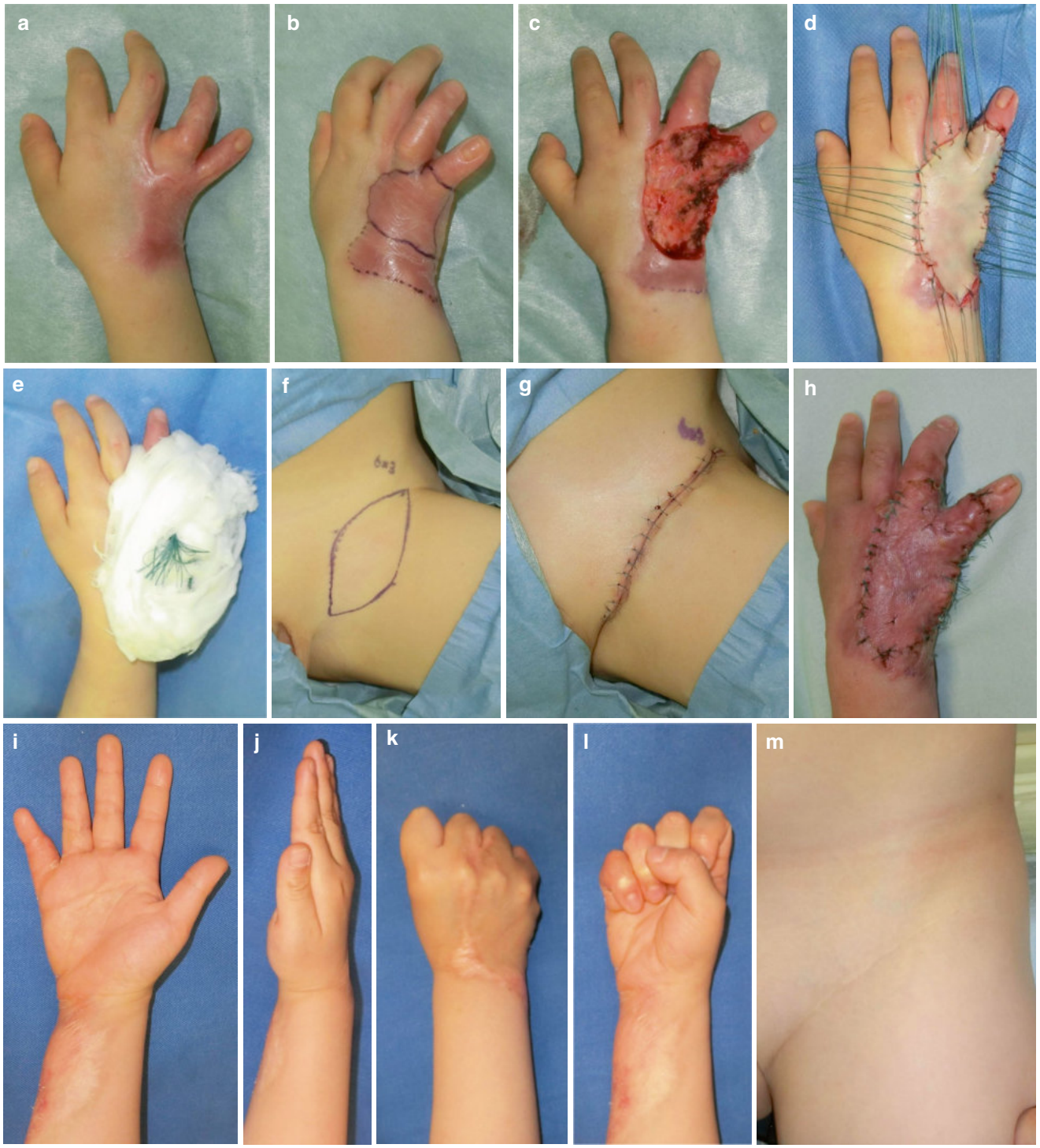


Fig. 30.3 Reconstruction of a little-finger contracture in a child by using a full-thickness skin graft from the groin. A 1-year-old boy had a burn-induced scar contracture on the right hand that led to dislocation of the little finger (**a**). (**b**–**h**) All fibrous tissue masses were excised, and reconstruction was performed with a full-thickness skin graft harvested from the groin area. (**b**) Scar removal design. (**c**) After removing the scars. (**d**) After applying the skin graft. (**e**) Tie-over fixation. (**f**) Marking of the donor site. (**g**) The donor site after primary skin closure. (**h**) The hand immediately after skin closure. (**i**–**m**) The view 2 years after surgery. The contracture was completely released, resulting in both functional and cosmetic improvement. The donor-site scar was also inconspicuous

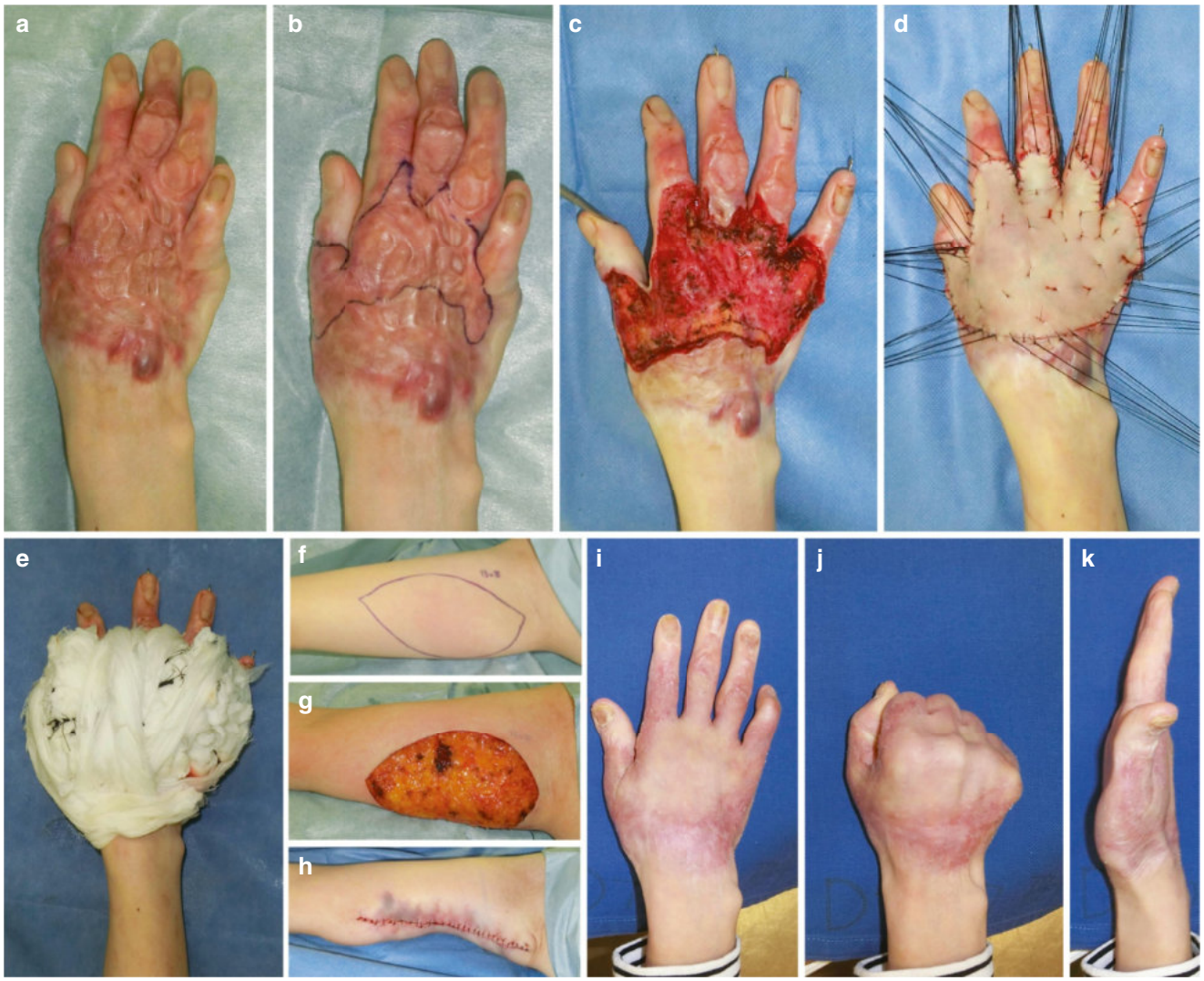


Fig. 30.4 Reconstruction of dorsal-hand contractures in an adult using a full-thickness skin graft from the inner upper arm. A woman in her 30 s had hypertrophic scars and scar contractures on her dorsal hand (**a**). (**b**–**h**) Only the thickest part of the scar was completely excised, and reconstruction was performed with skin harvested from the inner upper arm. (**b**) Scar removal design. (**c**) After removing the scars. (**d**) After applying the skin graft. (**e**) After tie-over fixation. (**f**) Marking of the donor site. (**g**) Design of the donor site. (**h**) After primary closure of the donor site. (**i**–**k**) The view 2 years after surgery. The contractures were released, and the texture, color, and thickness of the skin from the inner upper arm matched the dorsal hand well

this purpose because the skin extends after surgery, thus helping to release the contracture and dissipate skin tension.

When grafting pediatric fingers, pinning is not necessary because the flexion force is not strong. Instead, a wire frame should be created to fix the finger joints and grafts simultaneously [3] (refer to Chap. 31).

When suturing the graft to the recipient bed, ensure meticulous hemostasis and use fine sutures to sew the graft without gaps. Whenever possible, a single large graft should be used because if the graft is split into two pieces over a single finger, the junction will form a scar. Thus, it is best to take a large graft and start suturing from the edges while adjusting the shape with scissors as needed, until the entire area is covered. After suturing all around, perform anchor sutures if necessary to prevent the graft from floating. Subsequently, ensure even pressure with tie-over dressings. Very careful and meticulous surgery from beginning to end will ensure 100% graft take.

If multiple grafts must be used, the recipient-site shape can be split into two equally sized pieces and then slotted into each other to form a long, thin shape, as shown in Fig. 30.7; this means that only a single narrow strip of skin is taken from the donor site, and it can be closed primarily.

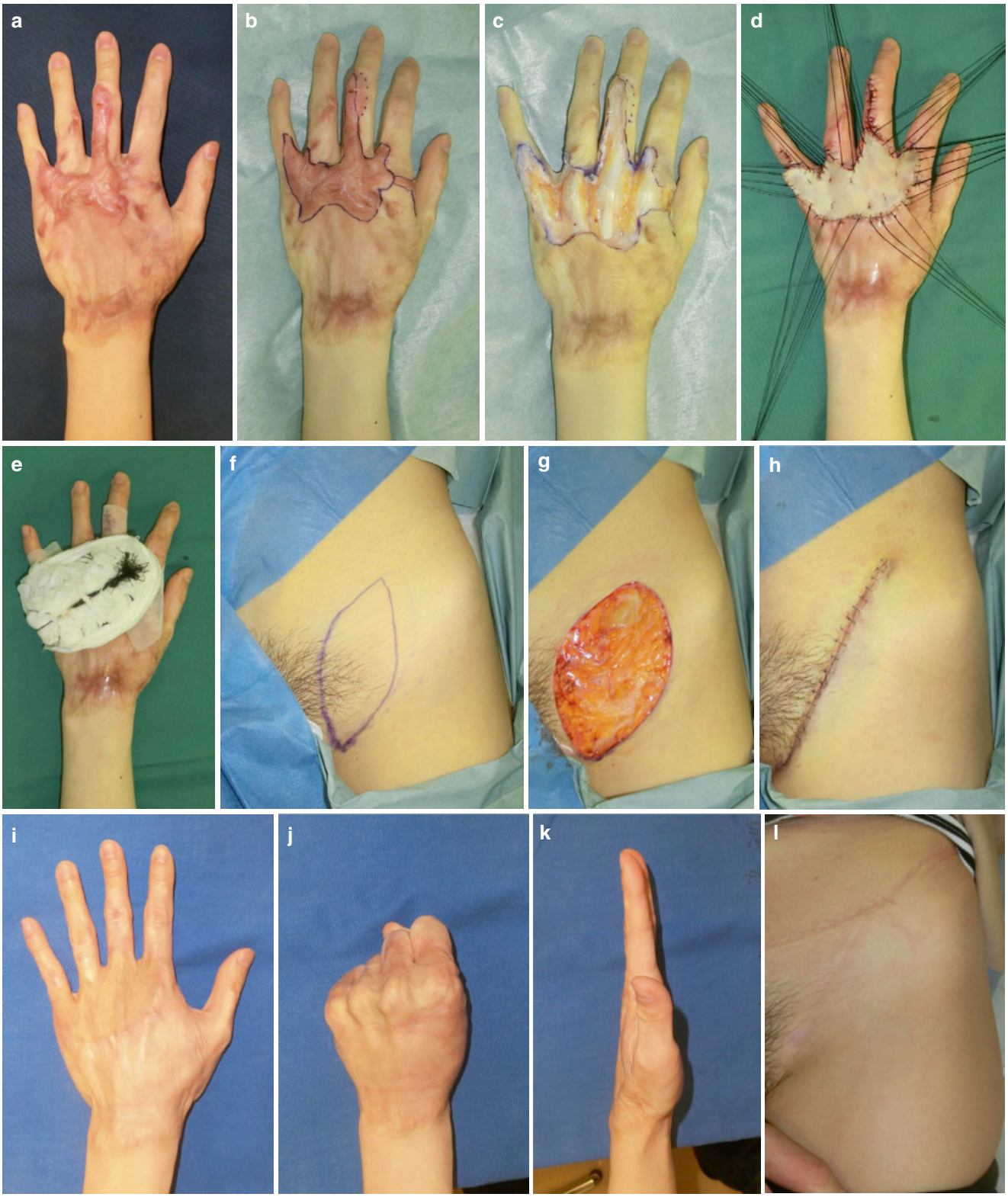


Fig. 30.5 Reconstruction of dorsal-hand contractures in an adult by using a full-thickness skin graft from the groin. A woman in her 30 s had hypertrophic scars and scar contractures on the dorsal hand (**a**). (**b**–**h**) Only the thickest part of the scar was completely excised, and reconstruction was performed with skin harvested from the groin area. (**b**) Scar removal design. (**c**) After removing the scars. (**d**) After applying the skin graft. (**e**) After tie-over fixation. (**f**) Marking of the donor site. (**g**) The donor site after harvesting the graft. (**h**) After primary closure of the donor site. (**i**–**l**) The view 2 years after surgery. The contractures were released. Although the groin skin is slightly thinner than the dorsal-hand skin, its texture and color matched the hand dorsum well. The donor-site scar was also inconspicuous

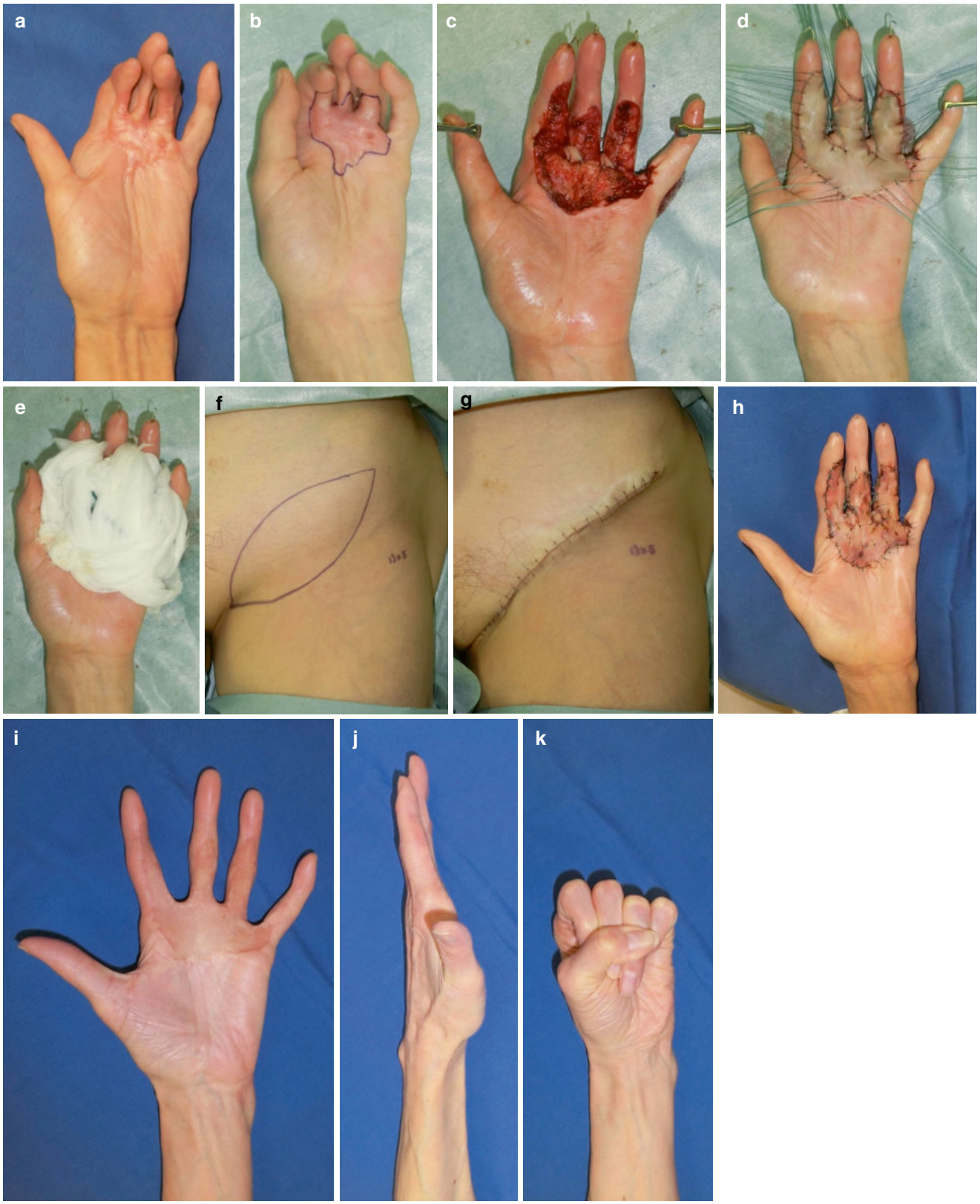


Fig. 30.6 Reconstruction of palmar-hand contractures in an adult using a full-thickness skin graft from the groin and interdigital flaps from the hand dorsum. A woman in her 50 s had hypertrophic scars and scar contractures on the palmar side of her hand (**a**). (**b**–**h**) The scars were completely excised, and reconstruction was performed with skin harvested from the groin area. The second and third interdigital spaces were reconstructed with rectangular flaps from the dorsal side of the hand. (**b**) Scar removal design. (**c**) After removing the scars. (**d**) After applying the skin graft and using the rectangular flaps to reconstruct the finger webs. (**e**) After tie-over fixation. (**f**) Marking of the donor site. (**g**) After primary closure of the graft-donor site. (**h**) View immediately after removing the tie-over, 10 days after surgery. (**i**–**k**) The view 2 years after surgery. The interdigital areas were well reconstructed and contractures were not observed

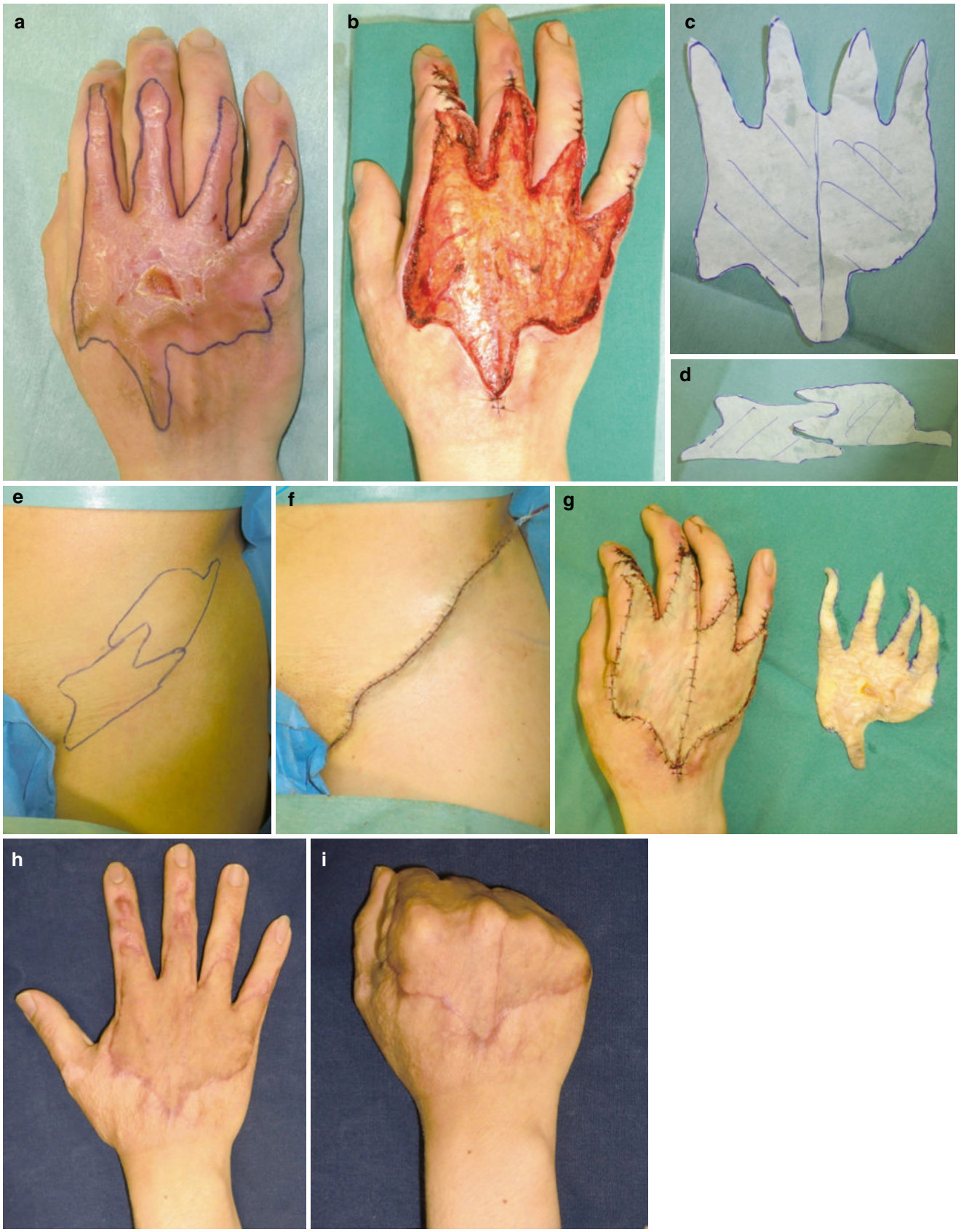


Fig. 30.7 Reconstruction of dorsal-hand contractures in an adult using a large full-thickness skin graft from the groin that was split in half after harvest. A woman in her 50 s had hypertrophic scars and scar contractures on the palmar side of her hand (**a**). (**b**) The scars were completely excised. (**c** and **d**) A template of the required skin graft was created by tracing the size and shape of the recipient site. The template was then split in half, and the two pieces were reoriented to design the long and narrow donor-site area. (**e**) The graft design was retraced on the groin area. (**f**) After primary closure of the donor site. (**g**) Photograph of the grafted skin and excised scars immediately after surgery. (**h** and **i**) View 6 months after surgery. The contractures were fully released

30.3 Postoperative Management

Re-contracture can be prevented by keeping the fingers immobilized and fixed, but this conflicts with the goal of functional recovery through rehabilitation. Therefore, during the day, patients should engage in active movements while applying a corticosteroid tape agent. We use deprodone propionate plaster (Eclar® plaster), which has a strong steroid. At night, instead of creating an expensive splint, a simple splint can be made with wooden tongue depressors or ice-cream spoons to maintain extension fixation.

30.4 Summary

With regard to burn-induced scar contractures of the hands and fingers, the primary objective is to prevent them from arising after burn-wound epithelialization. This can be achieved by maintaining extension fixation at night and appropriately using corticosteroid tape. However, if surgery is or becomes necessary, it is crucial to select the surgical technique that both releases the contractures and prevents postoperative re-contracture. Full-thickness skin grafting is preferred, although it is best to reconstruct interdigital spaces with local flaps, particularly skin-pedicle flaps. Single grafts are also preferred.

References

1. Ogawa R, Akita S, Akaishi S, Aramaki-Hattori N, Dohi T, Hayashi T, et al. Diagnosis and treatment of keloids and hypertrophic scars-Japan scar workshop consensus document 2018. Burns Trauma. 2019;7:39.
2. Ogawa R. Effectiveness of Corticosteroid Tapes and Plasters for Keloids and Hypertrophic Scars. 2020 Dec 8. In: Téot L, Mustoe TA, Middelkoop E, Gauglitz GG, editors. Textbook on scar management: state of the art Management and emerging technologies [Internet]. Cham: Springer. p. 2020. Chapter 56.
3. Huang C, Ogawa R, Hyakusoku H. External wire-frame fixation of digital skin grafts: a non-invasive alternative to the K-wire insertion method. Burns. 2014;40(5):981–6.

Uses of External Wire-Frame Fixation After Skin Grafting

31

Rei Ogawa, Chenyu Huang, Masahiro Murakami, and Hiko Hyakusoku

Abstract

We have used external wire frames to fix skin grafts since 1986. In 1991, we reported this method and described two advantages: (1) It secures the graft to the wound bed, and (2) it prevents the graft edges from lifting (Hirai T et al. Br J Plast Surg 44:69–70, 1991). We also showed that this technique is useful for skin grafts in regions with free borders. These regions include the lips and eyelids (Murakami M et al. Br J Plast Surg 56:312–313, 2003). The eyelids are particularly suited to external wire-frame fixation because it obviates the need for tarsorrhaphy (Murakami M et al. Br J Plast Surg 56:312–313, 2003). Moreover, three-dimensional external wire frames are also useful for preventing joint movement in digits that have undergone skin grafting (Ogawa R et al. Plast Reconstr Surg 119(1):440–442, 2007). This obviates the need for invasive digital-joint pinning. This is particularly helpful when grafting the palmar surfaces of fingers.

Keywords

External wire-frame fixation · Skin grafting · Reconstruction · Postoperative bone stabilization · Soft tissue management · Graft integration · Tissue perfusion

We have used external wire frames to fix skin grafts since 1986. In 1991, we reported this method and described two advantages: (1) It secures the graft to the wound bed, and (2) it prevents the graft edges from lifting [1]. We also showed that this technique is useful for skin grafts in regions with free borders. These regions include the lips and eyelids [2]. The eyelids are particularly suited to external wire-frame fixation because it obviates the need for tarsorrhaphy [2]. Moreover, three-dimensional external wire frames are also useful for preventing joint movement in digits that have undergone skin grafting [3]. This obviates the need for invasive digital-joint pinning. This is particularly helpful when grafting the palmar surfaces of fingers.

During surgery, the usual method is used to fix the skin graft to the wound bed with sutures. A wire frame consisting of 0.7–1.0 mm-diameter Kirschner wire is then made in the shape of the graft itself. It is placed onto the graft and attached with the sutures that were used to stitch the graft to the wound bed. Tie-over fixation is then performed in the usual way. The skin graft then covers the entire site, even if it involves application to a free edge (Fig. 31.1).

As a precautionary note, if the wire frame tightly compresses the skin, pressure ulcers could develop. This issue is less problematic in the case of secondary graft reconstruction because postoperative edema rarely occurs after this procedure. However, in the case of skin grafting during the initial treatment of burns, caution is required because postoperative edema is more likely to arise.

Below, we describe the graft reconstruction techniques in different body parts that involve external wire-frame fixation.

R. Ogawa (✉) · M. Murakami · H. Hyakusoku
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp; masa2@nms.ac.jp; hyakusok@nms.ac.jp

C. Huang
Department of Dermatology, Beijing Tsinghua Changgung Hospital, School of Clinical Medicine, Tsinghua University, Beijing, China

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_31

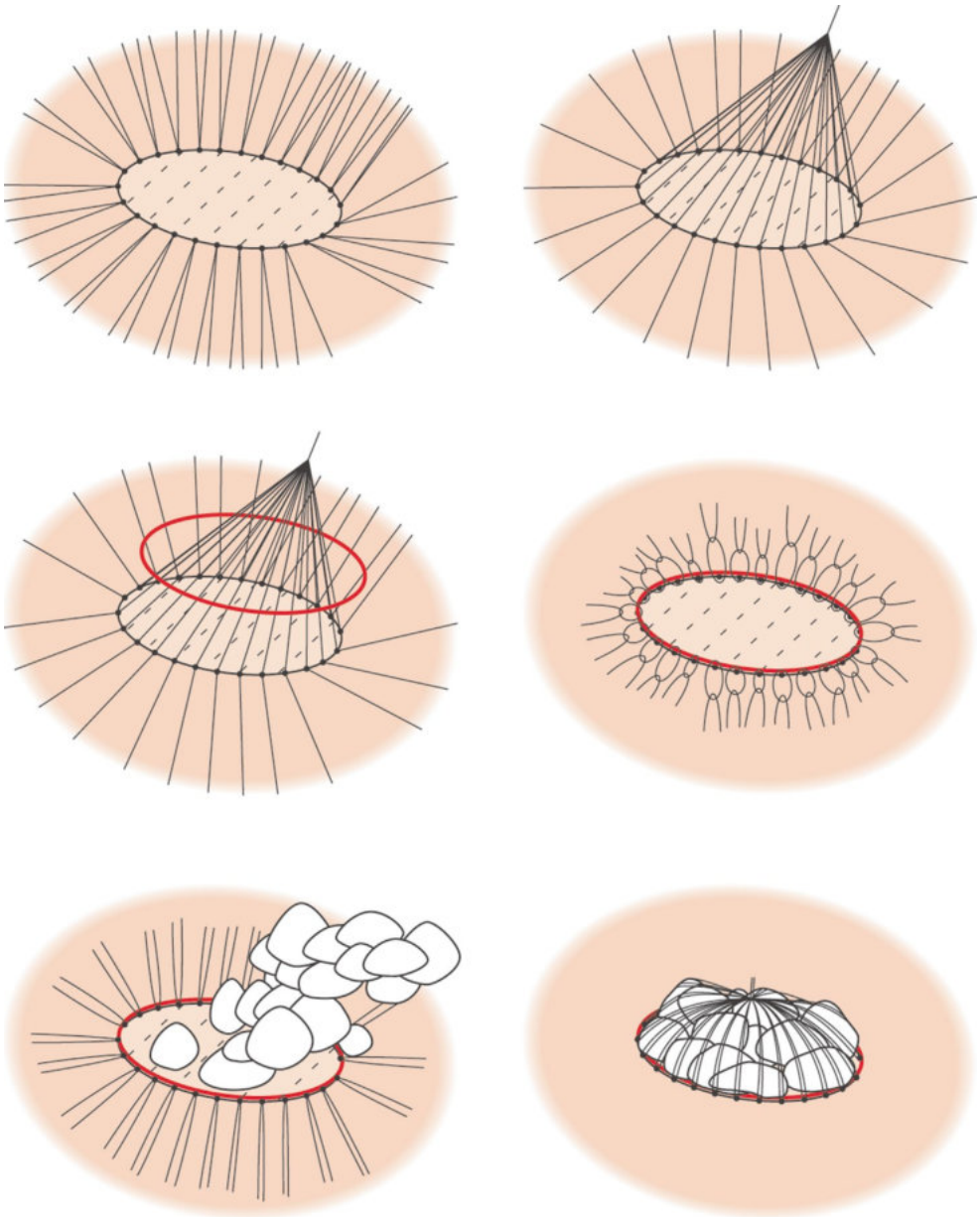


Fig. 31.1 Schematic depiction of the procedure used to fix the skin graft with an external wire frame. The skin graft is fixed to the wound bed with sutures. A wire frame consisting of 0.7–1.0 mm-diameter Kirschner wire is then created in the shape of the graft, laid on the graft, and attached with the same sutures used for stitching the graft. Tie-over fixation is then completed

31.1 Eyelid

For the lower eyelid, a relatively thick split-thickness or full-thickness skin graft is generally suitable. However, for the upper eyelid, a split-thickness skin graft is preferable. Since these areas are highly movable and have free margins, an external wire frame is needed to fix these grafts. Thus, a thinner Kirschner wire (~0.7 mm) is used to create the frame. Its shape should match the contours of the graft bed as closely as possible. The entire perimeter of the graft is then sutured to the wound bed, the wire frame is secured to the graft, and tie-over fixation is completed (Fig. 31.1). This fixes the graft firmly to the eyelid without requiring tarsorrhaphy. Consequently, the patient can open their eyes immediately after the operation (Figs. 31.2 and 31.3). The wire frame is generally removed when the tie over is released, but it can be left in place for about a month after surgery to prevent secondary contracture.

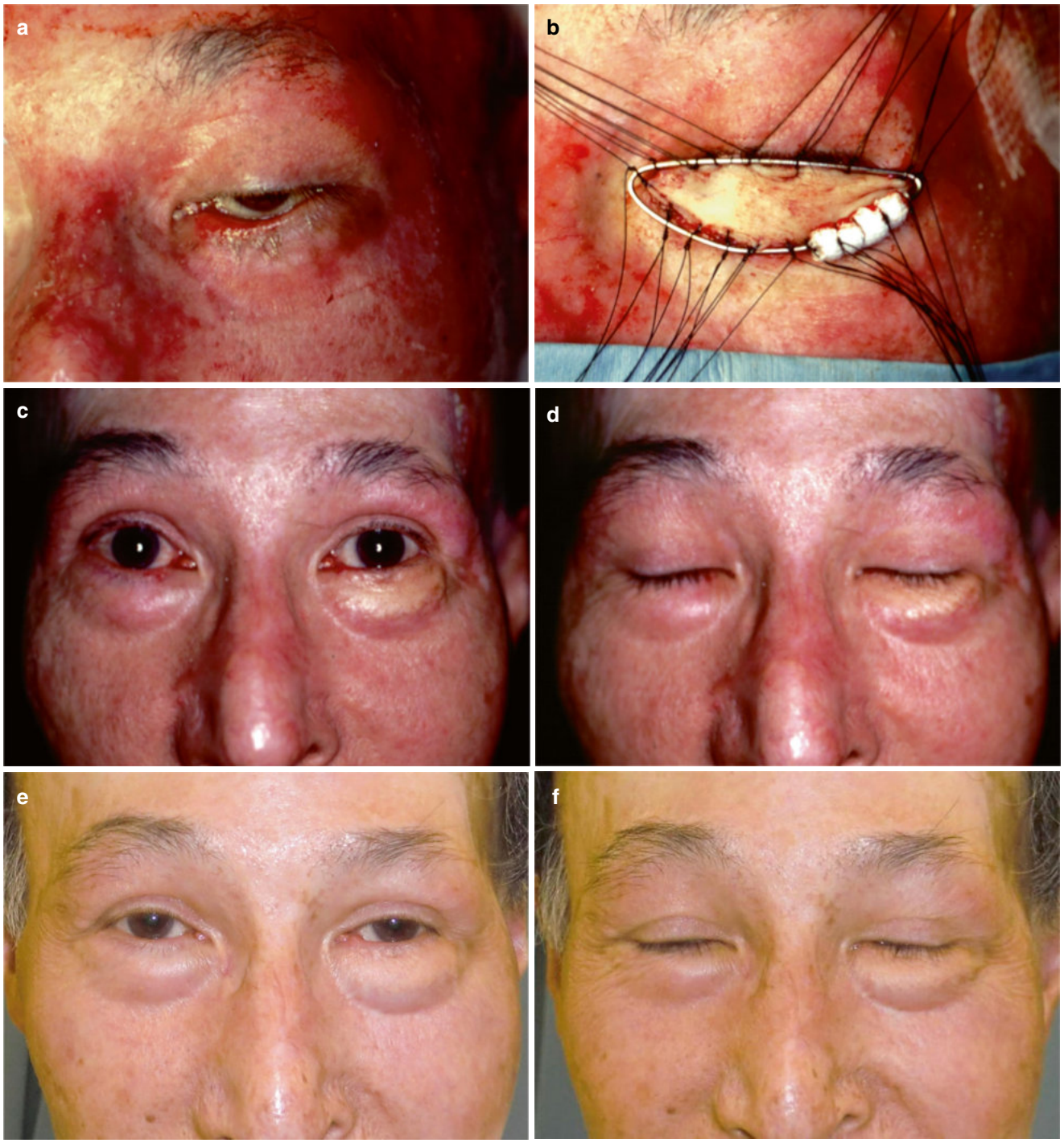


Fig. 31.2 Use of an external wire frame to fix a lower eyelid graft. A man in his 50 s sustained facial burns in an accident. He developed left lower eyelid ectropion after 2 months of conservative treatment (**a**). (**b**) The left lower eyelid was excised and a full-thickness skin graft was harvested from the supraclavicular area and sutured to the wound bed. The graft was fixed with an external wire frame to prevent displacement of the graft edge even when the mouth is opened. (**c**, **d**) View 6 months after the operation. The postoperative course was uneventful. (**e**, **f**) View 5 years after the operation. No contracture of the lower eyelid has been observed

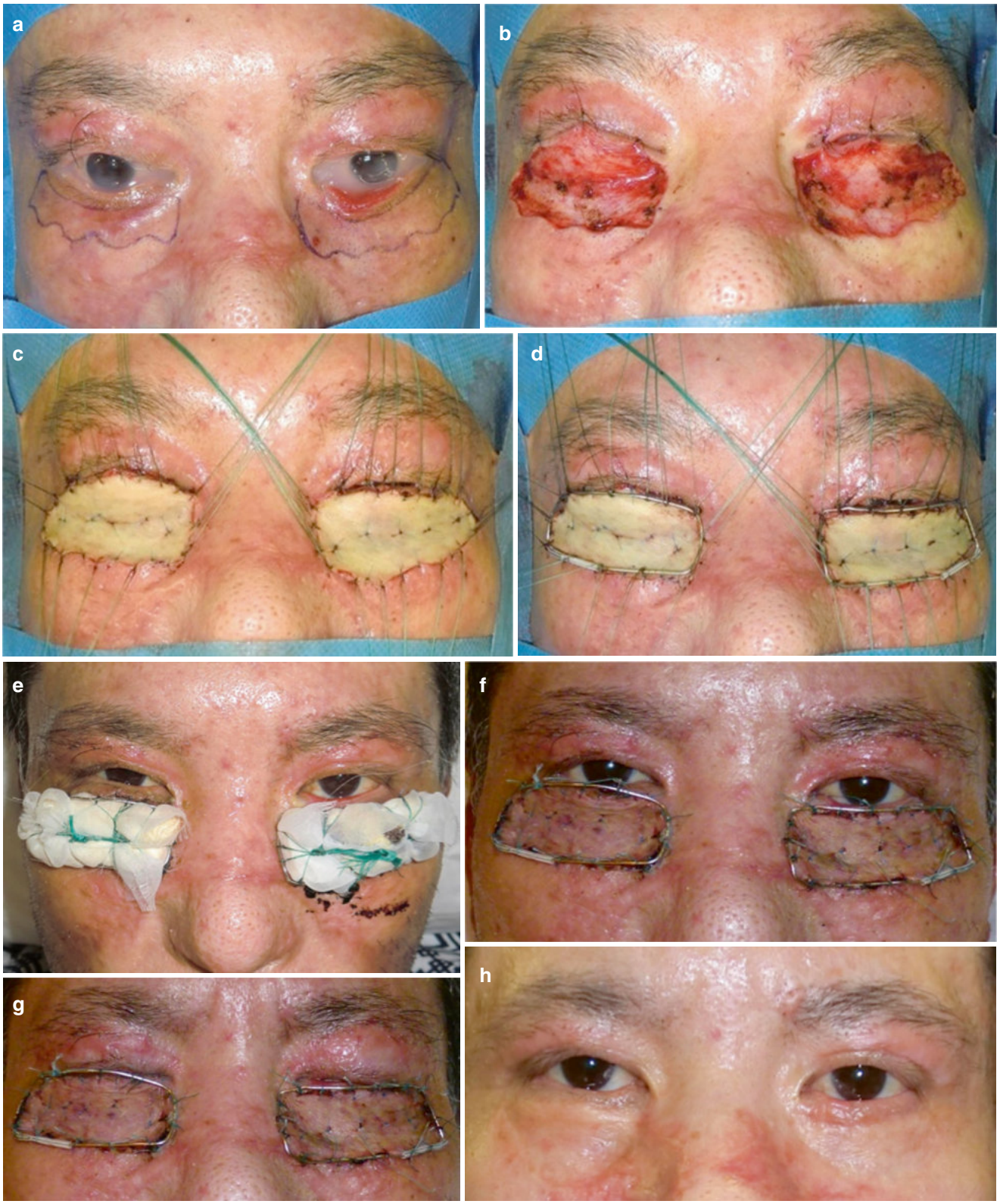


Fig. 31.3 Use of external wire frames to fix bilateral lower eyelid grafts. A man in his 60 s sustained facial burns in an accident. He developed bilateral lower eyelid ectropion after 3 months of conservative treatment (**a**). (**b**) Both lower eyelids were resected. (**c**) Full-thickness skin grafts were harvested from the groin area and fixed to the wound beds. (**d**) External wire frames were fixed to the grafts without tarsorrhaphy. (**e**) View 3 days after the operation. The patient was able to open and use both eyes. (**f**, **g**) View 7 days after the operation. The postoperative course was uneventful. (**h**) View 12 months after the operation. No contracture of the lower eyelid has been observed. (*From* Yoshino et al. [4]; *with permission*)

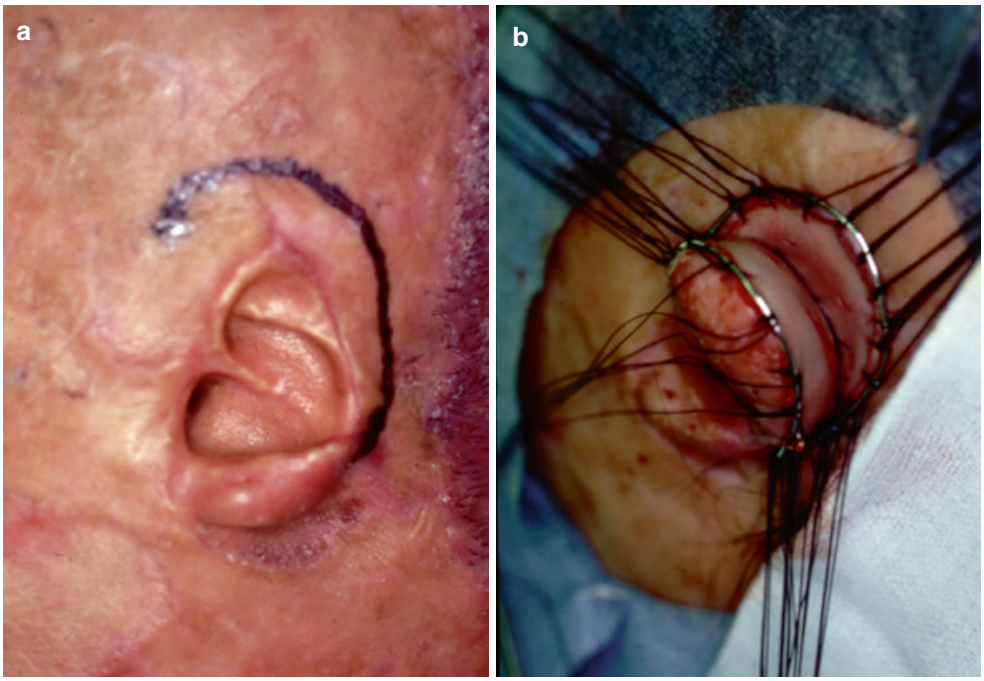


Fig. 31.4 Use of an external wire frame to fix an auricle graft. A 42-year-old man sustained burns to his entire face in a suicide attempt. The left auricle was damaged. To support the arm of a pair of spectacles, auricle reconstruction without cartilage was planned to create a sulcus. (**a**) Incision design. A full-thickness skin graft was harvested from the lower abdomen and sutured to the head. (**b**) It was then fixed with a three-dimensional external wire frame that had been constructed from 1.0-mm-diameter Kirschner wire. Tight fixation of the grafted skin was achieved, and the postoperative course was uneventful

31.2 Auricle

External wire-frame fixation of grafts is often used when the ear is reconstructed after burn injury. It is relatively easy to fix the skin graft because it can be secured by packing gauze along the groove behind the ear. Nonetheless, to ensure that the ear maintains a sufficient angle of projection, the external wire-frame fixation method can be employed (Fig. 31.4).

31.3 Lips

Similar to the eyelids, the external wire-frame fixation method is well suited to lip reconstruction. It can be applied to the upper lip (Fig. 31.5), lower lip (Fig. 31.6), and the cheek area near the corner of the mouth (Fig. 31.7). It permits patients to open their mouth and resume oral intake immediately after the operation. When the graft is adjacent to the lips, care should be taken to prevent contamination of the tie-over gauze during meals. To prevent secondary contracture, the wire frame can be left in place for about a month after surgery.

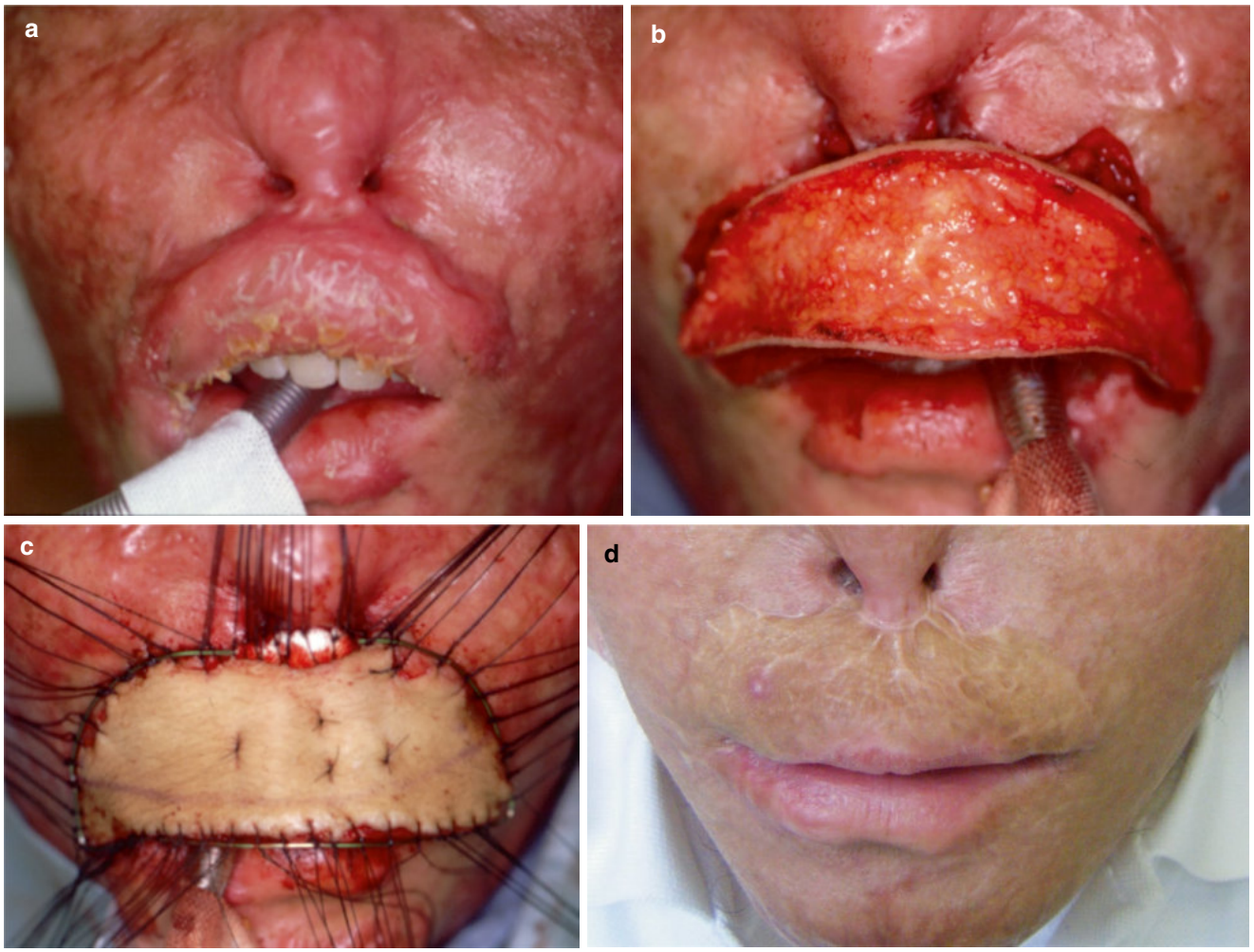


Fig. 31.5 Use of an external wire frame to fix an upper-lip graft. A 13-year-old boy sustained burns to his entire face in a house fire and developed severe upper-lip contracture after 2 months of conservative treatment (**a**). (**b**) The contracted area was resected. (**c**) A full-thickness skin graft from the upper arm was sutured to the wound bed, after which an external wire frame was fixed to the skin graft. Tight fixation of the grafted skin was achieved, and the patient was able to open his mouth and eat normally soon after the operation. The postoperative course was uneventful. (**d**) View 1 year after surgery. No contracture of the upper lip has been observed

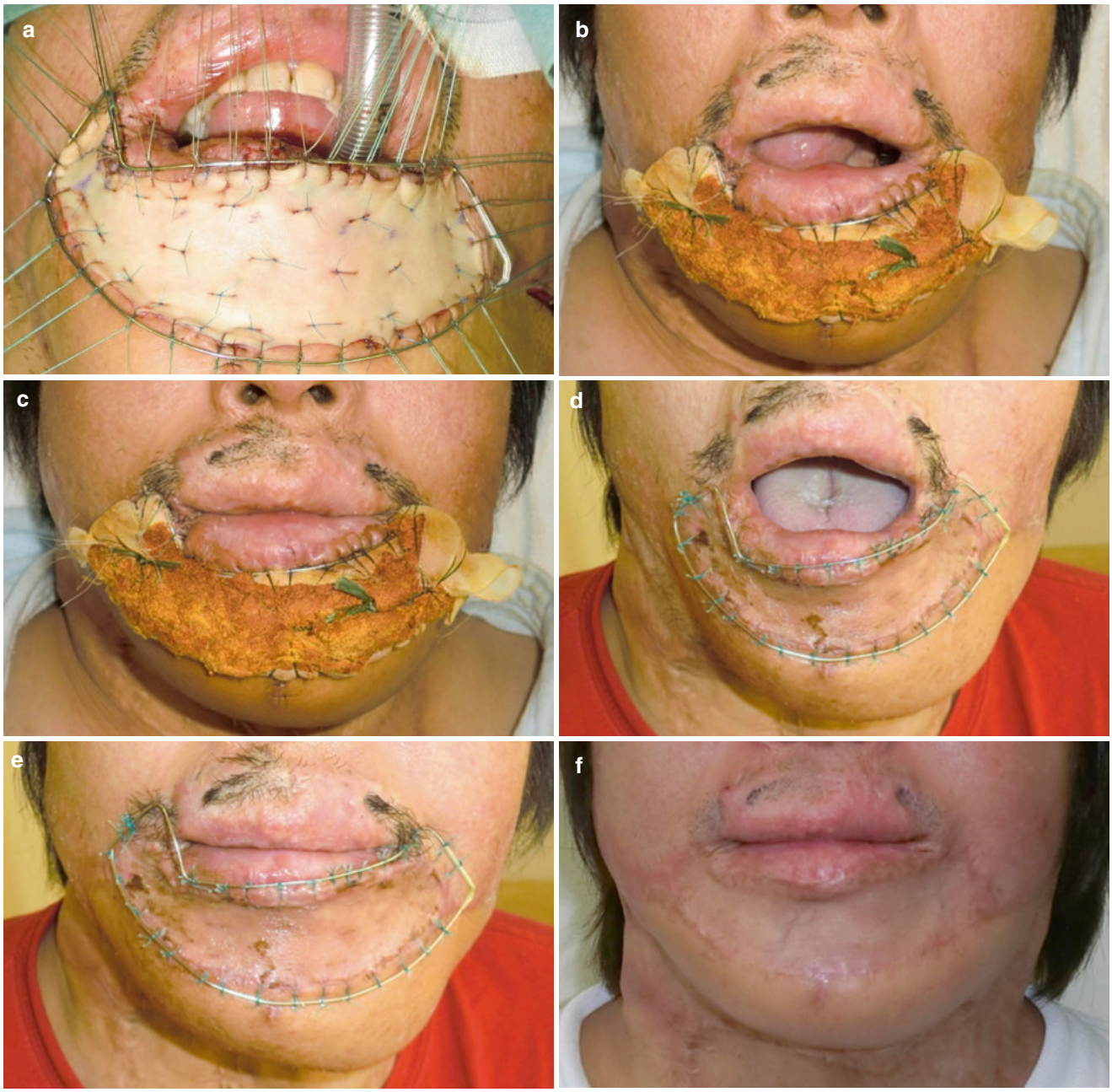


Fig. 31.6 Use of an external wire frame to fix a lower lip graft. A 20-year-old man sustained burn injuries to the lower part of his face and developed severe contractures of the lower lip after 2 months of noninvasive medical therapy. (**a**) The contractures were resected and a full-thickness skin graft was harvested from the upper arm and fixed to the wound bed. An external wire frame was then used to tightly fix the skin graft. (**b**, **c**) One day after the operation, the patient could open and close his mouth and eat normally. (**d**, **e**) View after removing the tie-over fixation 7 days after surgery. (**f**) View 12 months postoperatively. No postoperative complications had been reported and lower lip contractures were not observed. (*From* Yoshino et al. [4]; *with permission*)

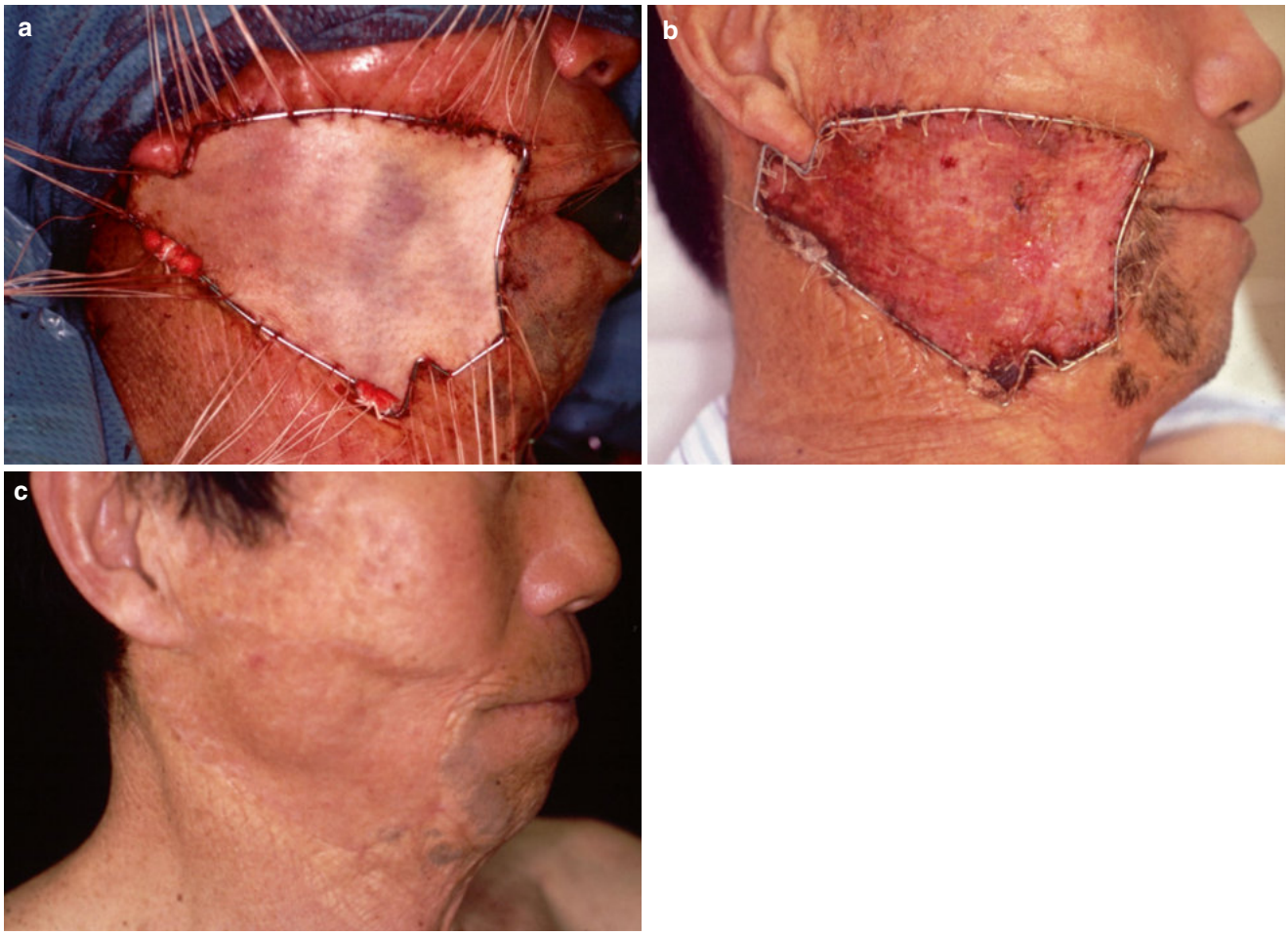


Fig. 31.7 Use of an external wire frame to fix a cheek graft. A 61-year-old man who had previous burn injuries developed squamous-cell carcinoma in the burned scar on the right cheek. (**a**) The carcinoma was excised along with the surrounding scar tissue and fatty tissue, and the skin defect was reconstructed with a full-thickness skin graft from the supraclavicular area. The graft was fixed with an external wire frame to prevent displacement of the graft edge even when the mouth is opened. (**b**) View after removing the tie-over fixation 7 days after surgery. The grafting was completely successful and the postoperative course was uneventful. (**c**) View 12 months postoperatively

31.4 Fingers and Toes

Kirschner wire can also be used to create a three-dimensional external wire frame that prevents joint motion in fingers/toes that undergo skin grafting. This is particularly useful when grafting skin to the fingers of children, since it is noninvasive and reduces the risk of inhibiting bone growth (Figs. 31.8 and 31.9). Thus, in this case, the external frame does not fix the graft to the wound bed, it only prevents the affected joints from flexing. This approach is also useful when multiple fingers/toes are involved. This is true for both children (Fig. 31.9) and adults (Fig. 31.10). In this case, a single wire frame can be used to fix all the involved fingers/toes: There is no need to shape the frame to fit each individual wound (Figs. 31.9 and 31.10). Since fingers must be allowed to move for rehabilitation, the wire frame is typically removed from grafted fingers when the tie-over fixation is released. During the day, patients are encouraged to move their fingers freely. At night, a simple splint made from tongue depressors or a finger splint is used to maintain extension for about a month. This effectively prevents recontracture.

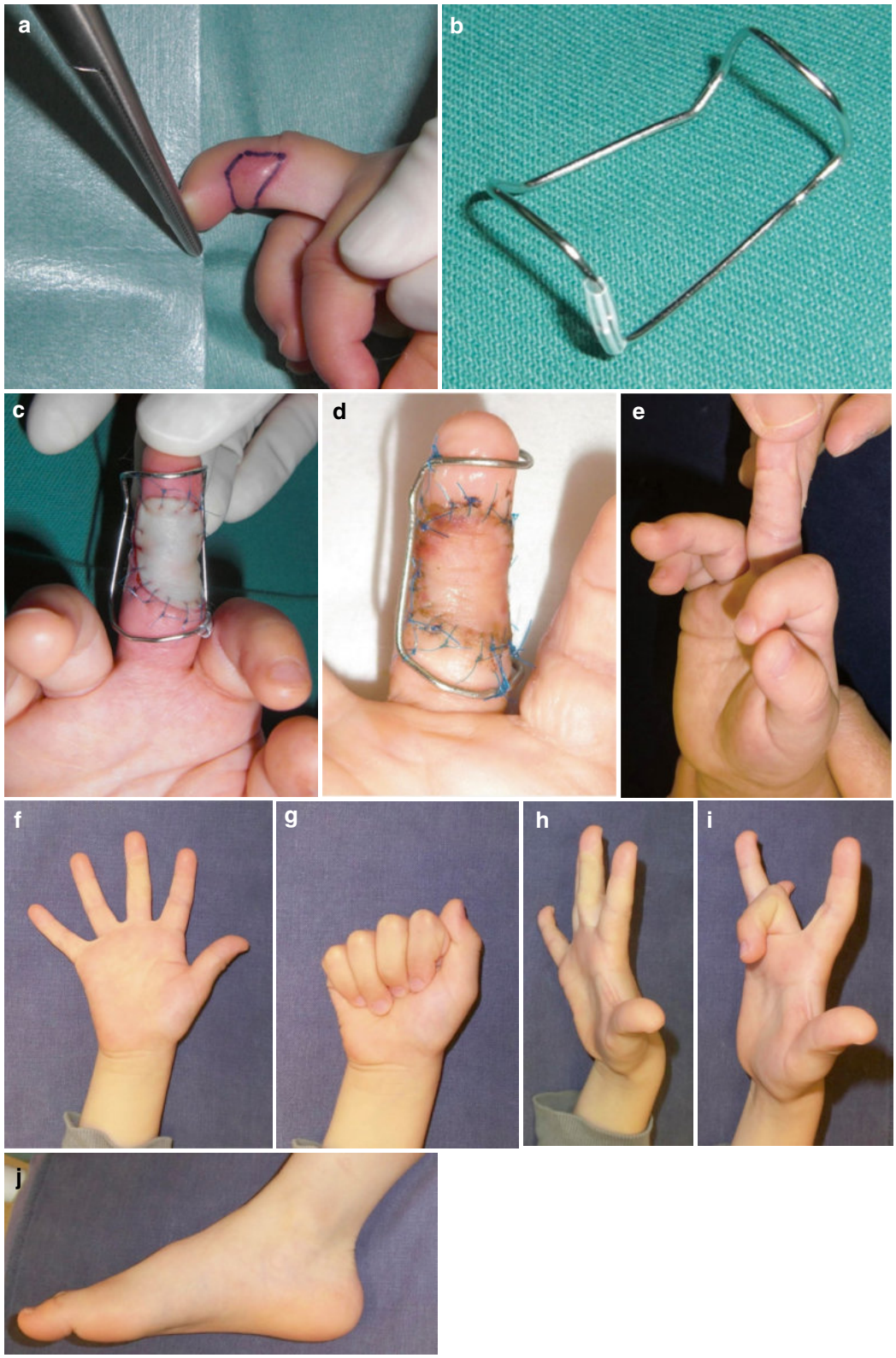


Fig. 31.8 Use of an external wire frame to prevent joint movement in the skin-grafted middle finger of a child. The 2-year-old boy developed burn-scar contractures on the palmar side of his right middle finger. The distal and proximal interphalangeal joints were involved. (**a**) Preoperative design of the contracture-releasing incisions. (**b**) An external wire frame that would prevent joint motion in the grafted finger was constructed. (**c**) After the contractures were released, a full-thickness skin graft was harvested from the medial malleolus and sutured to the wound bed. The skin-grafted joint was then splinted with the external wire frame. (**d**) After removing the tie-over fixation at 7 postoperative days. The graft take was 100%. (**e**) View 18 months after surgery. (**f–j**) View 4 years after surgery. Scar contractures were not observed on the affected finger. The donor-site scar was inconspicuous. (*From* Huang et al. [5]; *with permission*)

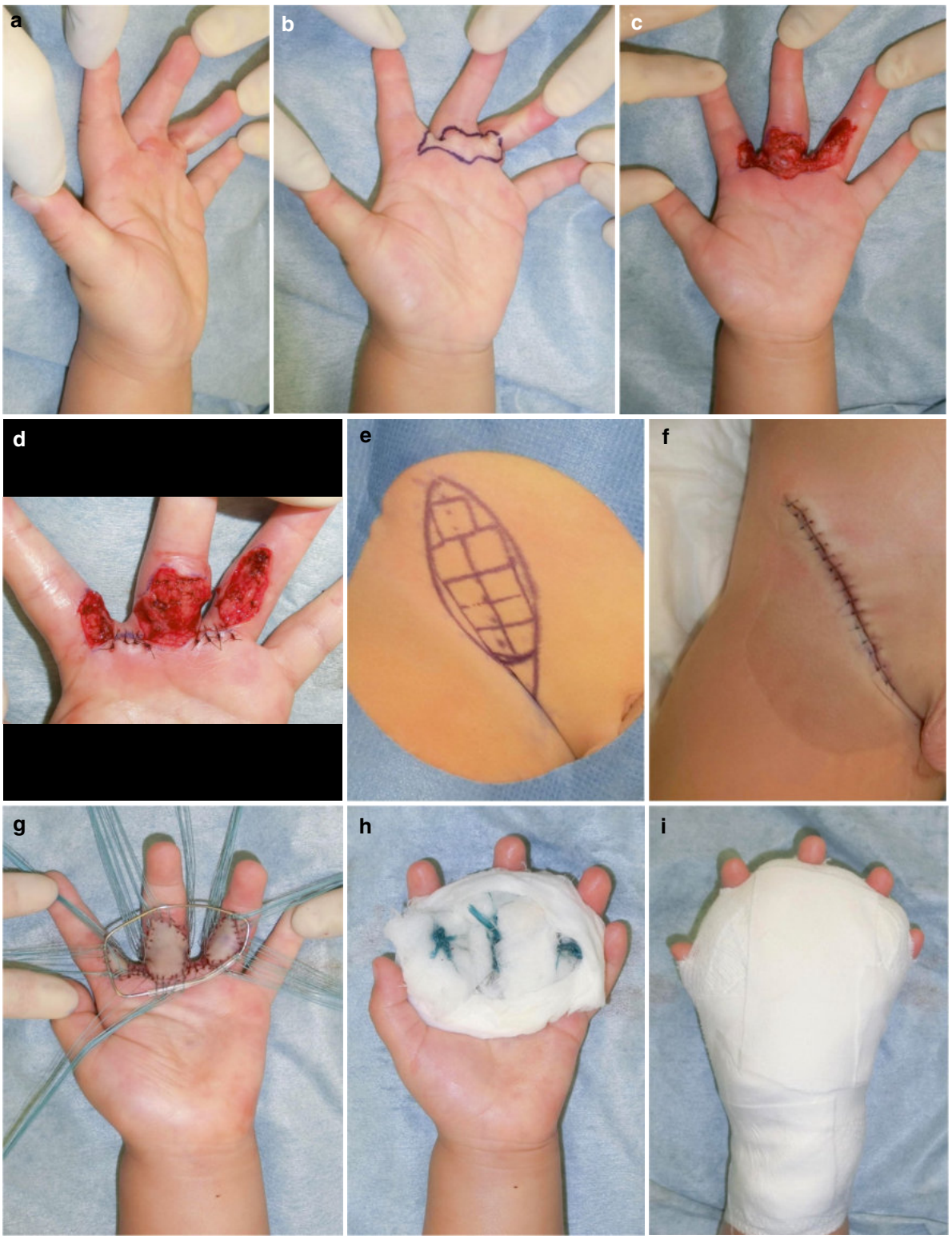


Fig. 31.9 Use of an external wire frame to fix three fingers of a child that underwent reconstruction with skin grafts. A 2-year-old boy had burn-scar contractures that spanned three fingers and involved the interdigital spaces (**a**). (**b**) Scar removal design. (**c**) After excising the scar, the raw surface area was calculated to determine the size of the skin graft that would be harvested from the groin. (**d**) The interdigital spaces were reconstructed with rectangular flaps from the hand dorsum. (**e**) Design of the skin graft on the groin. (**f**) After harvesting the skin graft. (**g**) To fix the proximal interphalangeal and metacarpophalangeal joints, a wire frame that was slightly larger than the grafted area was secured to the general grafted area with some of the sutures used to fix the skin graft to the wound bed. (**h**) After tie-over fixation. (**i**) After bandaging the hand. (**j**) After removing the tie-over gauze at 7 postoperative days. The graft achieved complete take. (**k**, **l**) View 2 years after surgery. There were no functional issues and the donor-site scar was inconspicuous

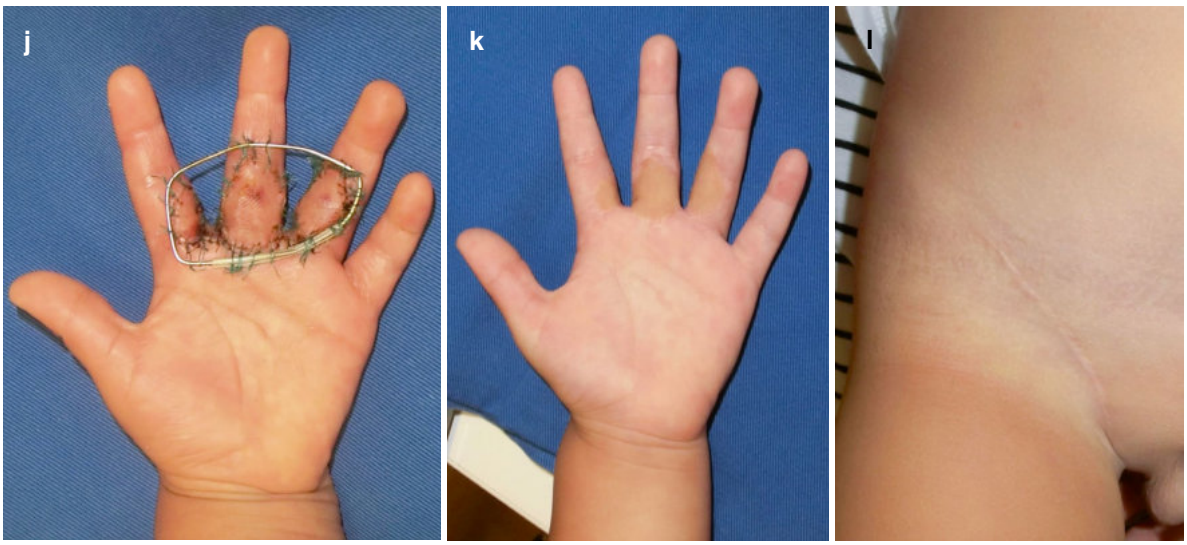


Fig. 31.9 (continued)

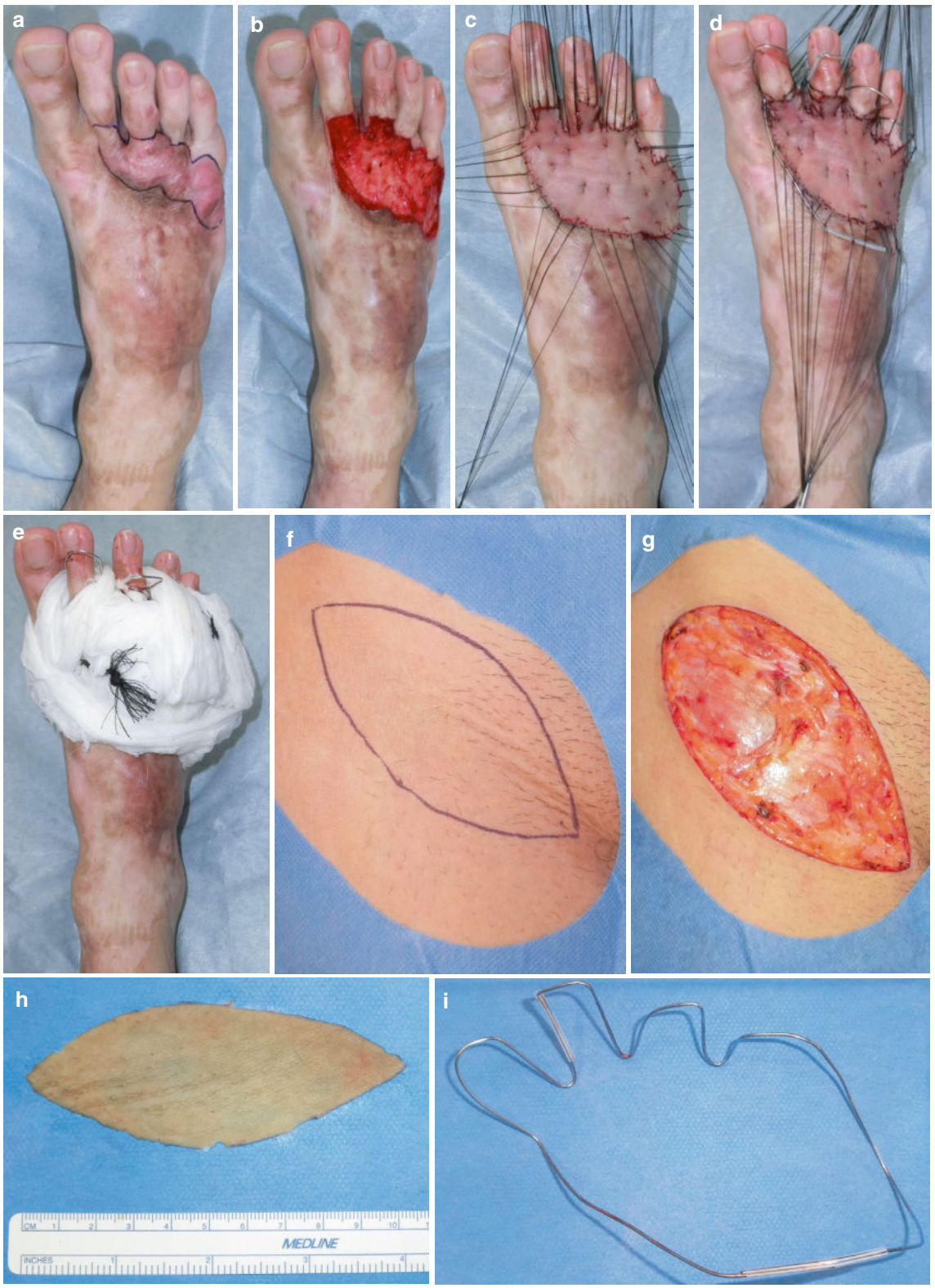


Fig. 31.10 Use of an external wire frame to splint four skin-grafted toes of an adult. A male patient in his 20 s presented with postburn scar contractures on the dorsum of his foot. Contractures were observed on the third, fourth, and fifth toes. (**a**) Scar removal design. (**b**) All of the scar tissue was excised. (**c**) A skin graft from the inguinal region was grafted to the wound bed. (**d**) A wire frame was used to splint the second to fifth toes. It was held in place with some of the sutures emanating from the skin graft. (**e**) After tie-over fixation. (**f**) The design on the graft donor site. (**g**) After harvesting the skin graft. (**h**) The harvested skin graft. (**i**) The wire frame, which conformed to the shape of the recipient site. (**j**) At 6 postoperative months, the donor-site scar was satisfactory. (**k**) At 6 months, the patient's foot demonstrated functional and aesthetic recovery

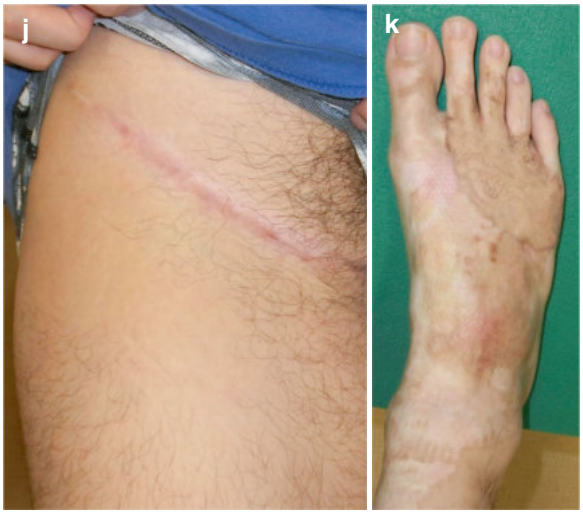


Fig. 31.10 (continued)

References

1. Hirai T, Hyakusoku H, Fumiiri M. The use of a wire frame to fix grafts externally. Br J Plast Surg. 1991;44:69–70.
2. Murakami M, Hyakusoku H, Ishimaru S. External wire frame fixation of eyelid graft. Br J Plast Surg. 2003;56:312–3.
3. Ogawa R, Aoki S, Aoki M, Oki K, Hyakusoku H. Three-dimensional external skin graft fixation of digital skin graft. Plast Reconstr Surg. 2007;119(1):440–2.
4. Yoshino Y, Ueda H, Ono S, Ogawa R. An external wire frame fixation method of skin grafting for burn reconstruction. J Burn Care Res. 2018;39(1):60–4.
5. Huang C, Ogawa R, Hyakusoku H. External wire-frame fixation of digital skin grafts: a non-invasive alternative to the K-wire insertion method. Burns. 2014;40(5):981–6.

Z-Plasties and V-Y Flaps

32

Shigehiko Suzuki and Naoki Morimoto

Abstract

A localized scar contracture is usually repaired by using Z-plasties or V-Y flaps. However, the scar itself remains even if the contracture is released. Therefore, it would be useful to reduce any unsightly scarring at the time of release of contractures. The application of modified planimetric Z-plasties and comprehensive classification of V-Y flaps (V-Y plasties) and their analogs is effective for this purpose.

Keywords

Z-plasty · Planimetric Z-plasty · V-Y flap · V-Y plasty · Scar contracture

A localized scar contracture is usually repaired by using Z-plasties or V-Y flaps. However, the scar itself remains even if the contracture is released. Therefore, it would be useful to reduce any unsightly scarring at the time of release of contractures. The application of modified planimetric Z-plasties and comprehensive classification of V-Y flaps (V-Y plasties) and their analogs is effective for this purpose.

32.1 Z-Plasties

32.1.1 Conventional Z-Plasties

A linear scar contracture is repaired by using conventional Z-plasty (Fig. 32.1a). The execution of a conventional Z-plasty produces stereometric elongation of a cutaneous contracture (Fig. 32.1b). The scar ridge becomes a dent after the Z flaps are exchanged. Therefore, large Z-plasty is effective especially in concave linear longitudinal contractures.

32.1.2 Modified Planimetric Z-Plasties (Fig. 32.2)

Planimetric Z-plasty was first reported by Roggendorf [1, 2]. In his method, the longer lateral limb A is as long as the longer central limb D, and the vertical angle is 75°. The shaded portions are excised when the flaps are transferred (Fig. 32.2a). Planimetric Z-plasty is useful for irregular scarring with slight contracture, but when the contracture is severe, the longer lateral limb shrinks immediately after incision (Fig. 32.2b). Therefore, the central limb should be designed to be longer than the lateral limb. In other words, the vertical angle should be more acute than 75° (Fig. 32.2c) [3]. In practice, it is safer to prepare triangular flaps with slightly sharper angles than estimated. The excess tissue can then be trimmed after the flaps have been transferred. When the scar is wider and the skin tension in the transverse direction is lower, more tissue can be excised (Fig. 32.2d).

32.1.3 Continuous Modified Planimetric Z-Plasties (Fig. 32.2)

Planimetric Z-plasties can be connected obliquely to elongate an oblique contracture in the longitudinal direction. Angles sharper than 75° are required as described above (Fig. 32.2e). When the scar is wider and the skin tension in the transverse direction is lower, more tissue can be excised as extended oblique continuous planimetric Z-plasties (Fig. 32.2f). The shaded portions should be designed to excise unsightly scars as much as possible. Planimetric Z-plasties can be connected

S. Suzuki (✉)
Hamamatsu Rosai Hospital, Shizuoka, Japan
e-mail: ssuzuk@kuhp.kyoto-u.ac.jp

N. Morimoto
Department of Plastic and Reconstructive Surgery, Graduate School of Medicine, Kyoto University, Kyoto, Japan
e-mail: prs_info@kuhp.kyoto-u.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_32

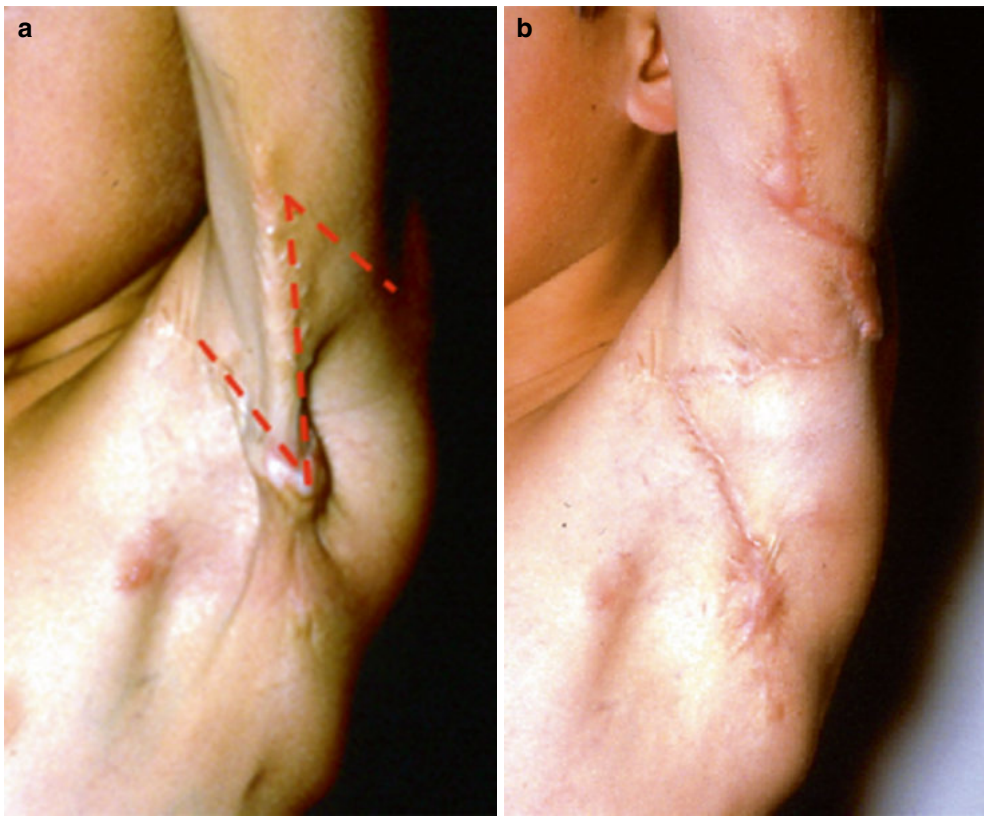


Fig. 32.1 (**a**) Design of conventional Z-plasty. (**b**) Fifteen-month postoperative appearance after the execution of a conventional Z-plasty

in an alternative direction according to the shape of the scar (Fig. 32.2g). It is possible to combine oblique and alternative continuous planimetric Z-plasties.

32.1.4 Case 1

A 10-year-old boy presented with a hypertrophic scar with contracture on his left foot (Fig. 32.3a). Extended oblique continuous planimetric Z-plasties were designed (Fig. 32.3b). After skin excision, the contracture was released and the hypertrophic scar was partially excised (Fig. 32.3c). Then, the flaps were transferred and sutured (Fig. 32.3d). The remaining hypertrophic scar gradually flattened. Fifteen months after the second operation, both the functional and cosmetic improvements were excellent (Fig. 32.3e).

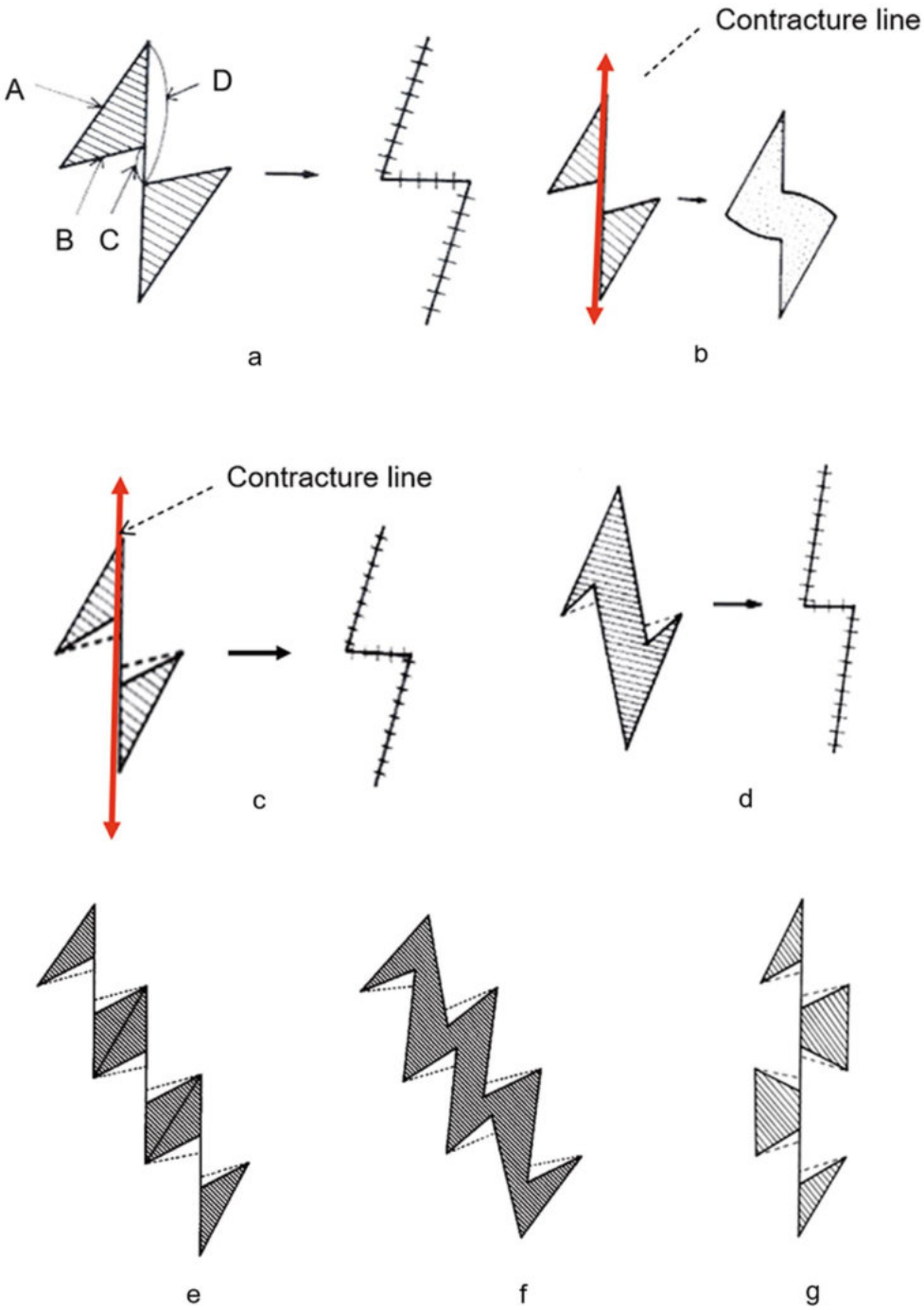


Fig. 32.2 Planimetric Z-plasties and modified planimetric Z-plasties

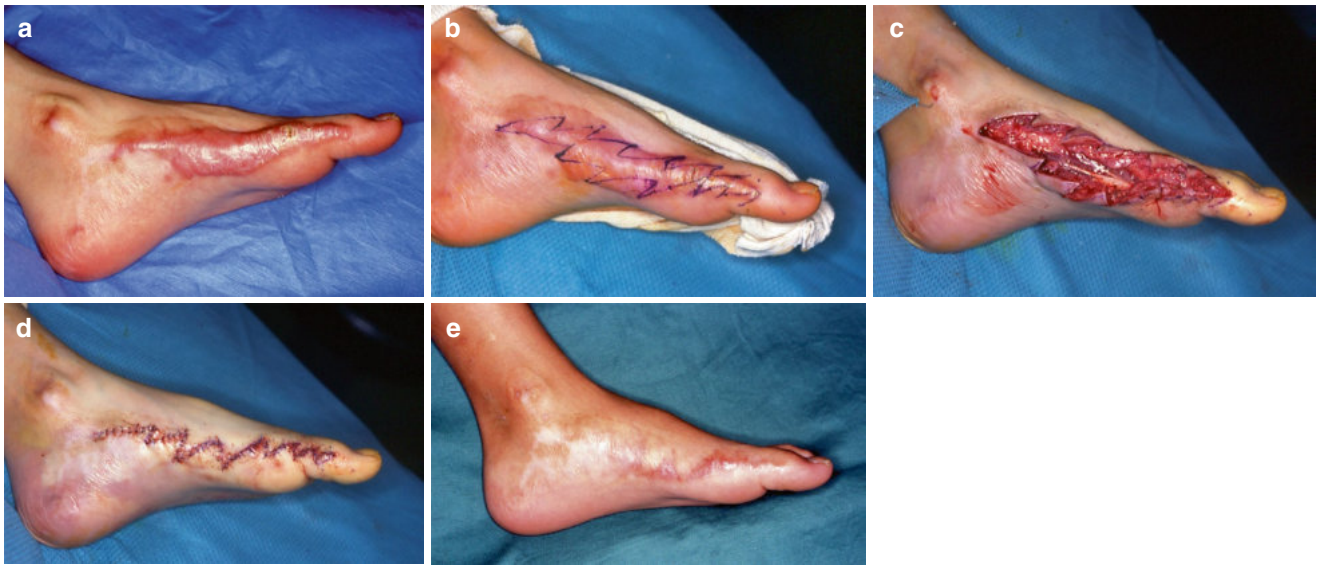


Fig. 32.3 (**a**) Hypertrophic scar with contracture on the left foot of a 10-year-old boy. (**b**) Operative design. (**c**) Appearance during operation. (**d**) Immediate postoperative appearance. (**e**) 15-month postoperative appearance

32.2 V-Y Flaps and Their Analogs

32.2.1 Comprehensive Classification of V-Y Plasties and their Analogs

There are various kinds of V-Y flaps and their analogs. To make the selection of an appropriate method easier for the treatment of scars and scar contractures, we proposed a comprehensive classification of V-Y plasties and their analogs (Fig. 32.4) [4].

32.2.2 V-Y Flaps with Burow's and Inverted Burow's Triangle Excisions

Burow's triangle excisions are commonly applied in V-Y flaps to facilitate skin closure (Fig. 32.4a). We devised an alternative to the Burow's triangle excision, namely an inverted Burow's triangle excision. This procedure results in a zigzag line of suturing (Fig. 32.4c). The zigzag is longer but less conspicuous, and it contracts less than the straight scar produced by a conventional Burow's triangle excision. Although we describe a triangle excision, the base of the triangle should be incised along the arch line of the central convex according to the degree of contracture. More practically, we recommend that a cut is made along the radial lines first before the excess tissue is trimmed after releasing the contractures.

32.2.3 Double V-Y Flaps

The division of a wide V flap into two V flaps in the V-Y flap is named a double V-Y advancement flap. Double V-Y flaps with a pair of Burow's triangle flaps (Fig. 32.4b) result in V-W plasty as reported by Koyama [5], and double V-Y flaps with a pair of inverted Burow's triangle flaps (Fig. 32.4d) resemble V-M plasty reported by Alexander [6]. Turning the design of the double V-Y flap with Burow's triangle excisions upside down results in the V-Y flap with inverted Burow's triangle excisions.

32.2.4 V-Y Flaps with Transposition Flaps

In severe contracture, transposition flaps can be used instead of triangle excisions. You may notice that the V-Y flap with a pair of transposition flaps (Fig. 32.4e) results in a five-flap plasty [7] and that double V-Y flap with a pair of transposition flaps (Fig. 32.4f) results in a seven-flap plasty [8].

32.2.5 Application of the Comprehensive Classification of V-Y Flaps and Their Analogs

Separate maneuvers can be used in each arm of the V-Y or double V-Y flap. For example, a Burow's triangle excision can be performed in one arm, and an inverted Burow's triangle excision can be performed in the other arm (Fig. 32.4g, h). On the basis of the abovementioned concepts, V-Y advancement flaps and their analogs can be classified comprehensively. With reference to the classification, an appropriate design can be determined according to the degree of contracture and the shape of the scar in each case. Therefore, we can easily design V-Y flaps

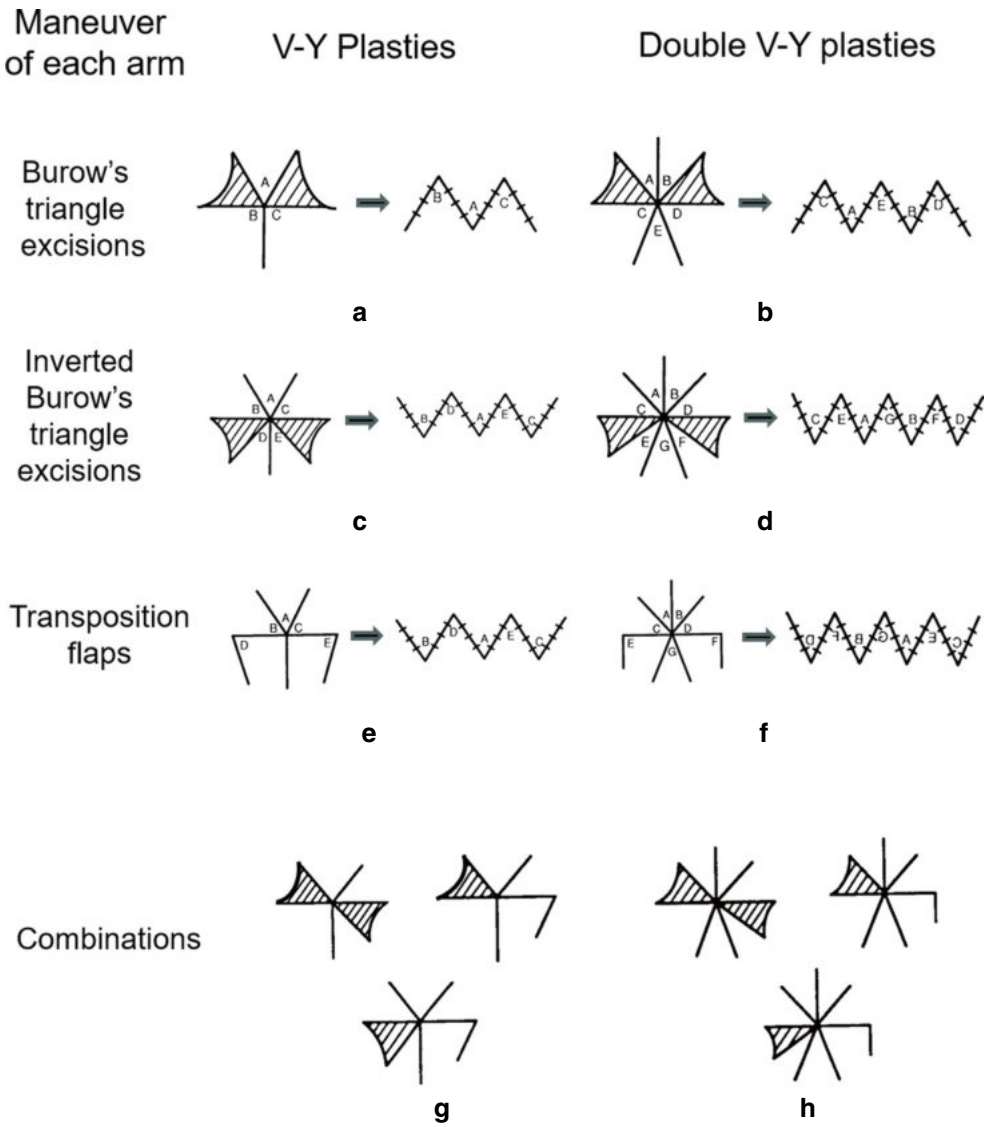


Fig. 32.4 Comprehensive classification of V-Y plasties and their analogs

according to the degree of contracture and the shape of the scar. It is also useful to combine V-Y flaps with planimetric Z-plasties.

32.2.6 Case 2

A 22-year-old woman presented with a hypertrophic scar on her right elbow (Fig. 32.5a). Taking the degree of the contracture and the shape of the scar into consideration, we designed a V-Y flap with a Burow's triangle excision and performed planimetric Z-plasty (Fig. 32.5b). After a skin incision along the violet mark, an additional skin incision was made along the green dotted line to further advance the V flap. Before skin closure, another Z-plasty was executed along the blue dotted lines. The hypertrophic scar was excised as much as possible. The transferred flaps were sutured (Fig. 32.5c). The remaining hypertrophic scar gradually flattened, and the 4-month postoperative appearance showed both functional and cosmetic improvements (Fig. 32.5d).

32.2.7 Case 3

A 74-year-old man presented with a postburn scar contracture between the right thumb and the index finger. A double V-Y flap with transposition flaps, namely a seven-flap plasty, was planned. Double V flaps were designed on the dorsal side, and transposition flaps were designed for the palmar side (Fig. 32.6a). After the skin incisions, dissection of the flaps on the dorsal side was minimized, and the flaps on the

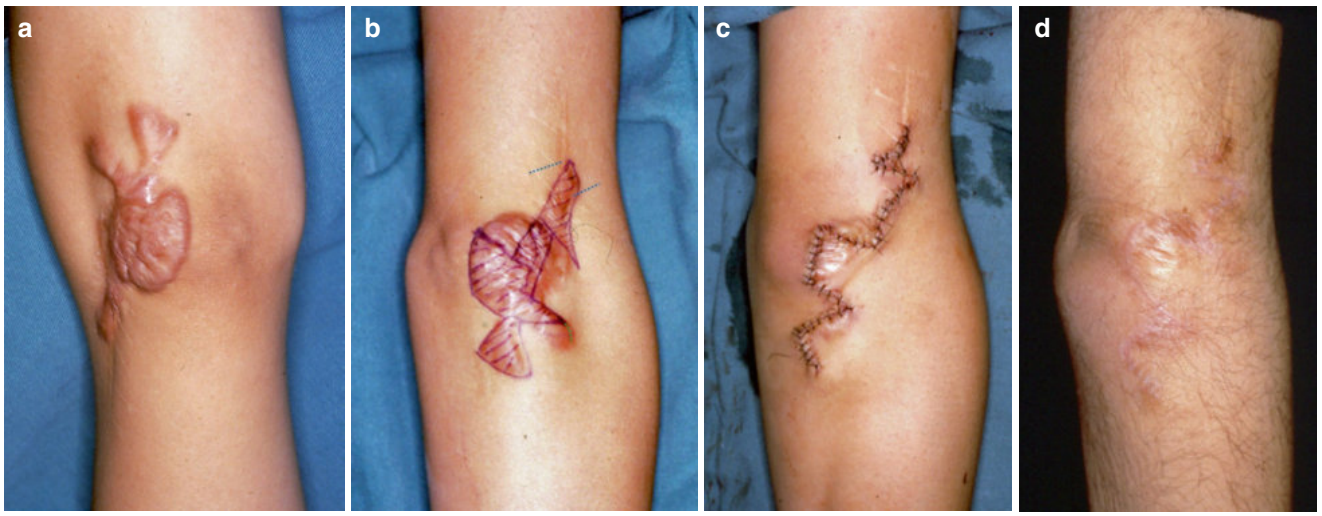


Fig. 32.5 (**a**) Hypertrophic scar on the right elbow of a 22-year-old woman. (**b**) Operative design. (**c**) Immediate postoperative appearance. (**d**) 4-month postoperative appearance

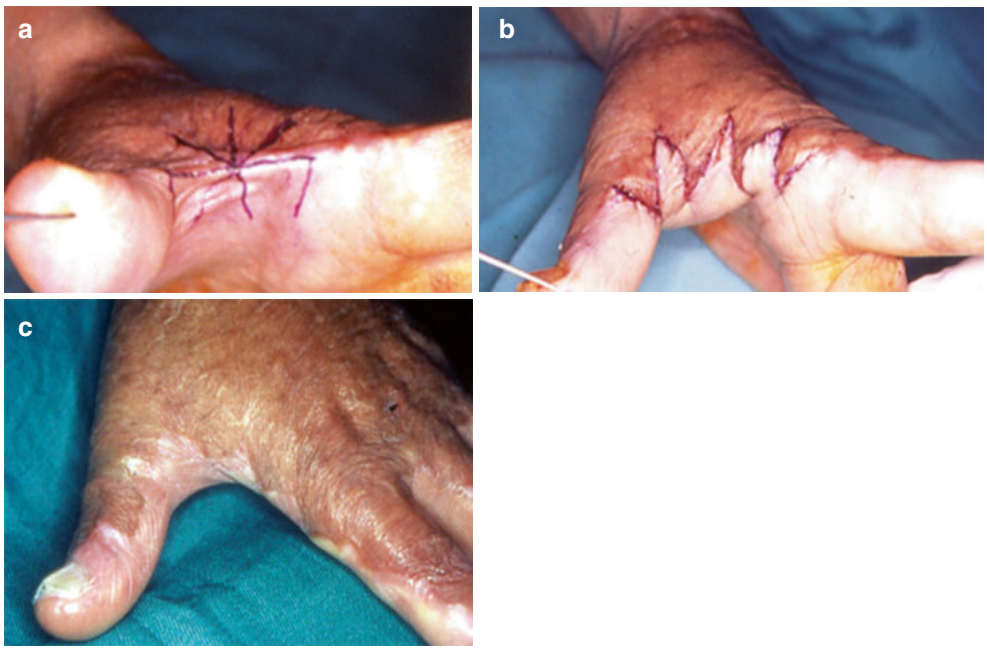


Fig. 32.6 (**a**) Double V flaps with transposition flaps were designed for the palmar side scar contracture between the right thumb and the index finger of a 74-year-old man. (**b**) Operative design. (**c**) 1-year postoperative appearance

palmar sides were mainly transferred (Fig. 32.6b). All flaps survived, and 1 year postoperatively, both the functional and cosmetic improvements were impressive (Fig. 32.6c).

Acknowledgments The authors gratefully acknowledge the contribution of Katsuya Kawai to this chapter as it appeared in the first edition of the book.

References

1. Roggendorf E. Planimetric elongation of skin by Z-plasty. Plast Reconstr Surg. 1982;69:306–16.
2. Roggendorf E. The planimetric Z-plasty. Plast Reconstr Surg. 1983;71:834–42.
3. Suzuki S, Um SC, Kim BM, Sin-ya K, Kawai K, Nishimura Y. Versatility of modified planimetric Z-plasties in the treatment of scar with contracture. Br J Plast Surg. 1998;51:363–9.
4. Suzuki S, Matsuda K, Nishimura Y. Proposal for a new comprehensive classification of V-Y plasty and its analogues: the pros and cons of inverted versus ordinary Burow's triangle excision. Plast Reconstr Surg. 1996;98:1016–22.
5. Koyama H, Fujimori R. V-W plasty. Ann Plast Surg. 1982;9:216–9.
6. Alexander JW, MacMillan BG, Martel L. Correction of post-burn syndactyly: an analysis of children with introduction of the VM-plasty and postoperative pressure inserts. Plast Reconstr Surg. 1982;70:345–52.
7. Hirshowitz B, Karev A, Rousso M. Combined double Z-plasty and Y-V advancement for thumb web contracture. Hand. 1975;7:291–3.
8. Karacaoglan N, Uysal A. The seven flap-plasty. Br J Plast Surg. 1994;47:372–4.

Part IV

Local Flap Method

Essential Aspects of Transposition Flaps, Particularly Z-Plasties

33

Loelita Marcelia Lumintang and Rei Ogawa

Abstract

The most important objective of burn reconstruction is the release of contractures. Local skin flaps are particularly useful for this purpose. These flaps can be classified into three types based on how they are moved, namely advancement, rotation, and transposition flaps. For example, Z-plasty and W-plasty are categorized as transposition and advancement flaps, respectively. Transposition flaps, particularly Z-plasty, are frequently used to release contractures in burn reconstruction. Numerous variations in local skin flaps, especially in Z-plasties, have been reported. This chapter will describe these variations and provide tips to help the surgeon select the optimal transposition flap techniques on a case-by-case basis.

Keywords

Local flap · Transposition flap · Z-plasty · Contracture · Scars

33.1 Introduction

To obtain good functional outcomes after burn reconstruction, it is essential to fully release contractures. This can often be achieved with local skin flaps such as Z-plasty and W-plasty. These flaps also provide good aesthetic outcomes because the flap tissues come from the skin surrounding the scar and thus bear the correct textural and color properties. Local skin flap surgery is also a simpler surgical intervention compared to skin grafting and distant flap options [1].

Local skin flaps can be classified into three types based on how they are moved, namely advancement, rotation, and transposition flaps. For example, Z-plasty and W-plasty are categorized as transposition and advancement flaps, respectively.

Skin-pedicled local flaps release contractures better than island and free flaps because the healthy skin pedicle gradually expands after surgery, thus effectively releasing tension in the area [2] (Fig. 33.1). This is clearly demonstrated by a case series study of 40 patients who received an island flap (n = 20) or a skin-pedicled flap (n = 20) to reconstruct burn scars on the anterior chest, axilla, cubital fossa, lateral chest, abdomen, thigh, or popliteal fossa: By 6 months, the skin-pedicled and island flaps had extended on average by 1.53-fold and 1.28-fold, respectively [2]. Consequently, skin-pedicled flaps such as rotation and transposition flaps are preferred over island flaps such as the V-Y advancement flap. Transposition flaps are also preferred over rotation flaps for burn reconstruction because although the rotation flap covers skin defects better, it does not release wide and extensive contractures or linear contractures.

L. M. Lumintang
Department of Surgery, Faculty of Medical and Health Sciences, Warmadewa University/Sanjiwani General Hospital, Denpasar City, Bali, Indonesia

R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_33

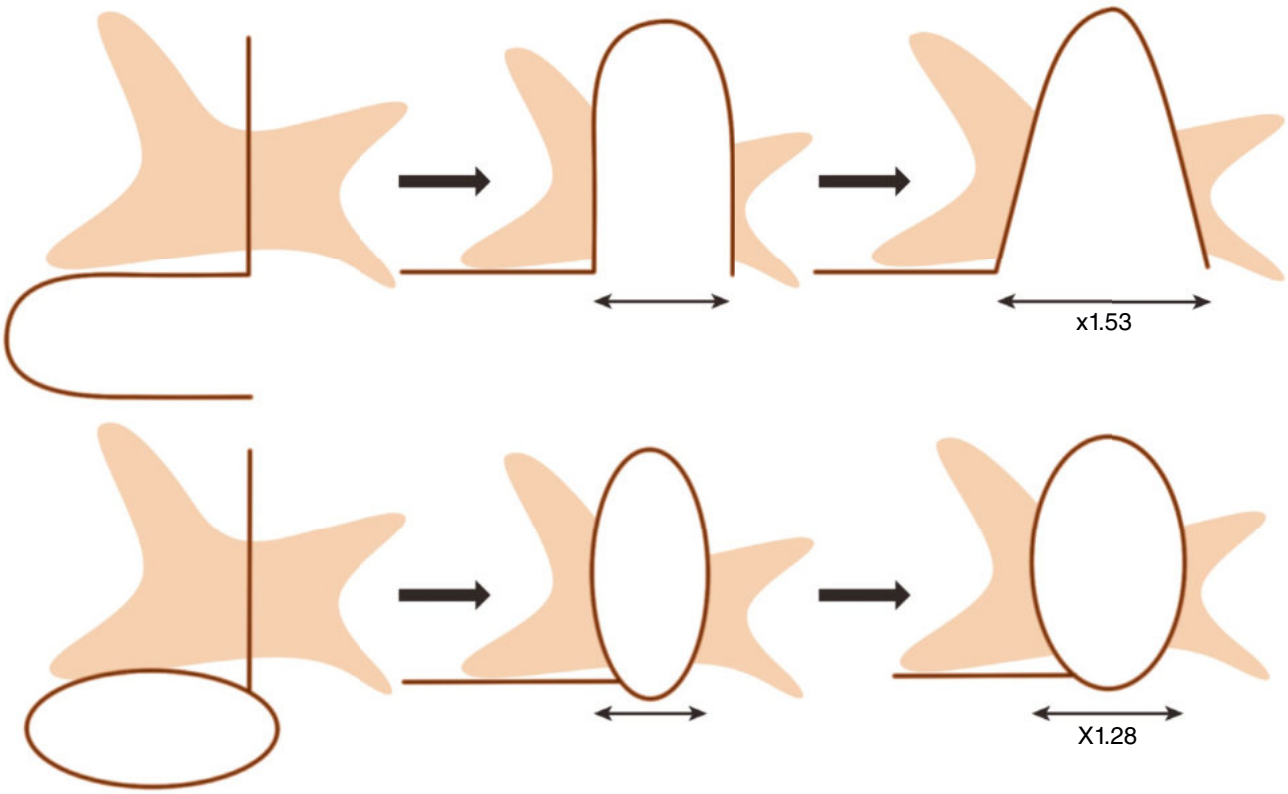


Fig. 33.1 Skin-pedicled flaps expand strongly after surgery, unlike island flaps

33.2 History of Local Skin Flaps

The earliest report of a flap being used to rebuild a complicated skin defect was in India in 700 BC. This report was unknown to Western medicine until the late 1700s. In the mid-1800s, Fricke, Horner, Serre, and Denonvilliers separately described repairing facial defects with single transpositional flaps; these flaps can be seen as early Z-plasty predecessors [3]. Of these flaps, the methods of Horner (1837) and Denonvilliers (1854) involved transposing triangular flaps and thus more closely resembled modern-day Z-plasty (Fig. 33.2a) [4]. Subsequently, Berger (1904) reported transposing triangular flaps of equal size and angles (Fig. 33.2b) [4, 5]. McCurdy then coined the term "Z-plasty" in 1913 [5], and in 1967, McGregor published a highly cited paper on the role of Z-plasty in hand surgery [4].

Local skin flaps were refined in the 1950s, mostly in Europe and the United States. In 1973, McGregor and Morgan classified them as random or axial flaps [6]. Daniel and Williams (1973) [7], Webster (1937) [8], Kunert (1991) [9], and Cormack and Lamberty (1984) [10] have also contributed to local flap techniques. Consequently, a local flap is defined as skin and subcutaneous tissue harvested from a random site near the defect and that maintains its intrinsic blood supply. Rhomboid flaps and Z-plasties are variants of the transposition flap.

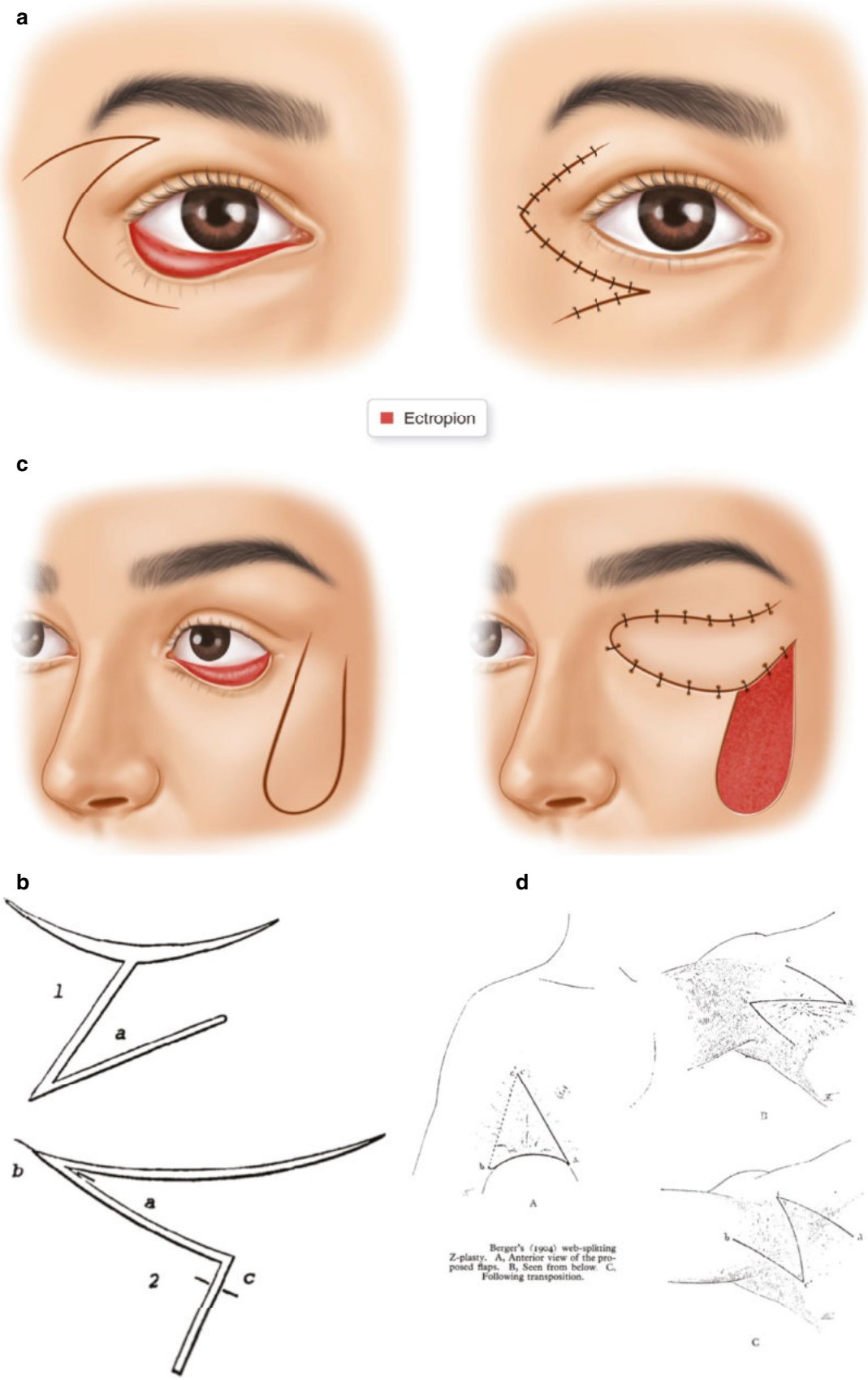


Fig. 33.2 Horner (1837) described a single transpositional flap (**a**), while Berger (1904) reported transposition of triangular flaps of equal size and angles (**b**). The term "Z-plasty" was coined in 1913. (From Borges and Gibson [5] with permission)

33.3 Transposition Flap

Many powerful transposition flap techniques have been discovered. They include one or more Z-plasties (Fig. 33.3a), the 3/4 Z-plasty of Huang (Fig. 33.3b), the trapezoidal flap of Grishkevich (Fig. 33.3c), square-flap methods (Fig. 33.2d), the V-Y/Y-V plasty (Fig. 33.3e), and the Limberg flap (Fig. 33.3f).

The advantage of the transposition flap is that it divides contractures with a wide skin pedicle. Because the flap divides the contracture site, it is not necessary to excise all scar tissues to alleviate the contracture and restore function.

To conduct safe and effective transposition flap surgery, it is essential to realize that it involves exchanging the main flap (flap A) and the minor flap (flap B). Thus, both flap A and flap B should be identified and exchanged, after which the dissection and elevation of the flaps should be stopped. This maintains the blood flow to the flaps. Focusing solely on flap A and elevating it could lead to excessive dissection, which could compromise the peripheral blood flow to the flap (Fig. 33.4).

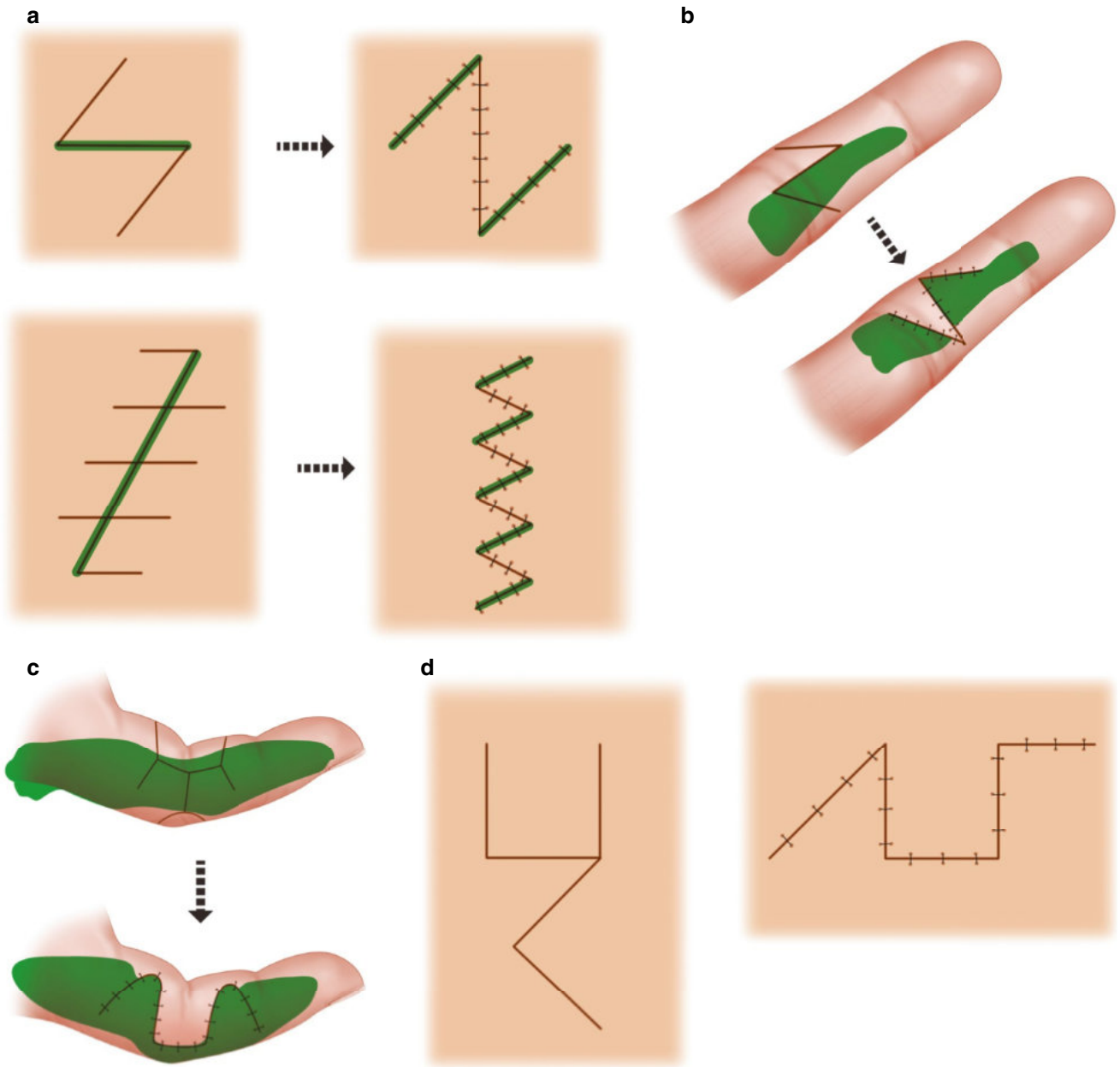


Fig. 33.3 Transposition flap techniques include (**a**) one or more Z-plasties, (**b**) the 3/4 Z-plasty of Huang, (**c**) the trapezoidal flap of Grishkevich, (**d**) square-flap methods, (**e**) the V-Y/Y-V plasty, and (**f**) the Limberg flap

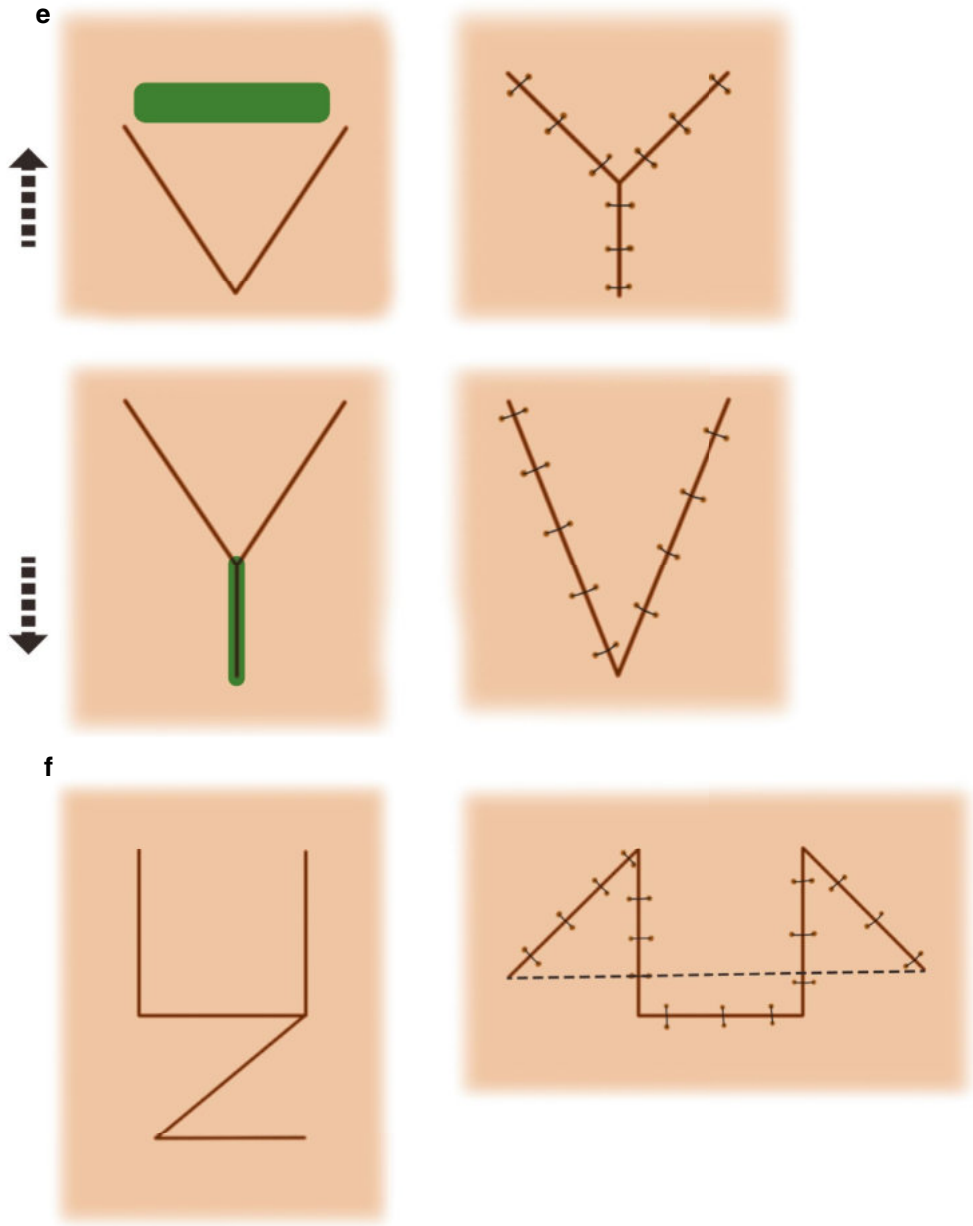


Fig. 33.3 (continued)

33.3.1 Transposition Surgery Tips

1. When choosing or creating a transpositional flap, several factors should be considered: the conditions and structures in the surrounding skin; the amount of flap needed and its direction; the length of the lateral arms; the angle involved in the flap; the direction of the relaxed skin tension line (RSTL); and patients' age and genetics.
2. The new incision should not be perpendicular to the RSTL. If the scar is less than 40° from the RSTL, it is best managed with simple excision [11].
3. If the area demonstrates vascular impairment, it is recommended to create a transposition flap with a bigger base.
4. To prevent secondary scar contracture, the transposition should be conducted with full-thickness skin containing the dermis. Thus, the ideal plane for flap elevation is situated between the subdermal and subcutaneous tissues.
5. To ensure proper flap mobilization and tension-free flap transposition, it is necessary to undermine the surrounding subcutaneous tissue sufficiently [12].

To demonstrate these tips, we show the following four cases:

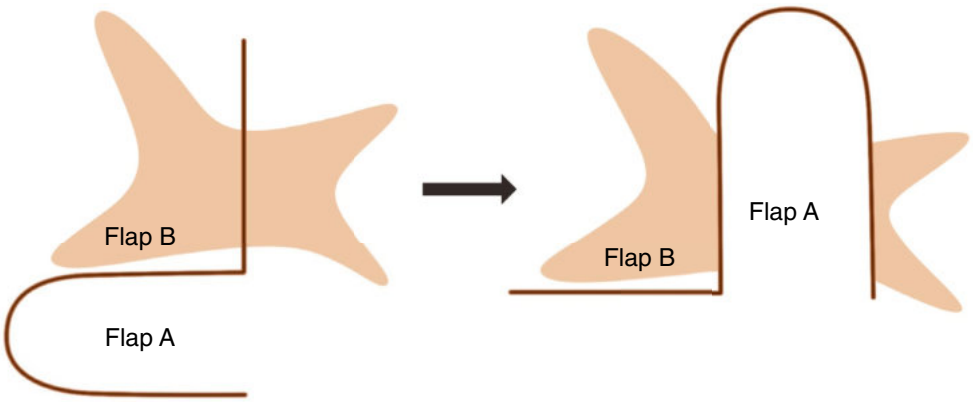


Fig. 33.4 Transposition flap surgery involves exchanging flap A and flap B

Case 1: A 76-year-old woman presented with a postburn diffuse flexion contracture at the left elbow. Double transposition flap procedures were planned (Fig. 33.5a). After releasing the contracture, flaps A and B were exchanged and the undermining was stopped (Fig. 33.5b–e). Two years postoperatively, the functional and cosmetic improvements were excellent (Fig. 33.5f–i). Note that the surrounding area was scarred. Consequently, stopping undermining after flap A/B exchange maintained strong blood flow to the distal end of the flap. This was also aided by elevating the flaps at the plane between the subdermal and subcutaneous tissues. The latter approach also prevented secondary scar contracture.

Case 2: A 44-year-old man presented with a linear flexion contracture at the posterior axillary fold of the left axilla region due to a previous burn injury (Fig. 33.6a). To release the linear contracture, incisional releases were designed. A transposition flap was used to segment the linear incision. The flap was transposed and sutured (Fig. 33.6b). Twelve months after the operation, the scars appeared soft and supple. Moreover, the contractures were completely corrected (Fig. 33.6c). Note that when the flap includes scarred and vascularly impaired tissue, it is necessary to use a sufficiently large flap. This approach promoted early primary healing and rehabilitation of the shoulder function in this case.

Case 3: A 28-year-old woman presented with a scar contracture in the popliteal area. Only the thickest part of the scar was excised and reconstructed with a transposition flap. Postoperatively, the skin pedicle gradually extended and the patient's complaint about contracture disappeared. In this case, the scar area appeared to be scattered, which suggests that a transposition flap with a larger base would yield the best results (Fig. 33.7).

Case 4: A 10-year-old girl presented with a scar contracture in the elbow area. A transposition flap and a square flap were used to release the contractures and to reposition healthy skin. One year post-surgery, the elbow contracture was completely released.

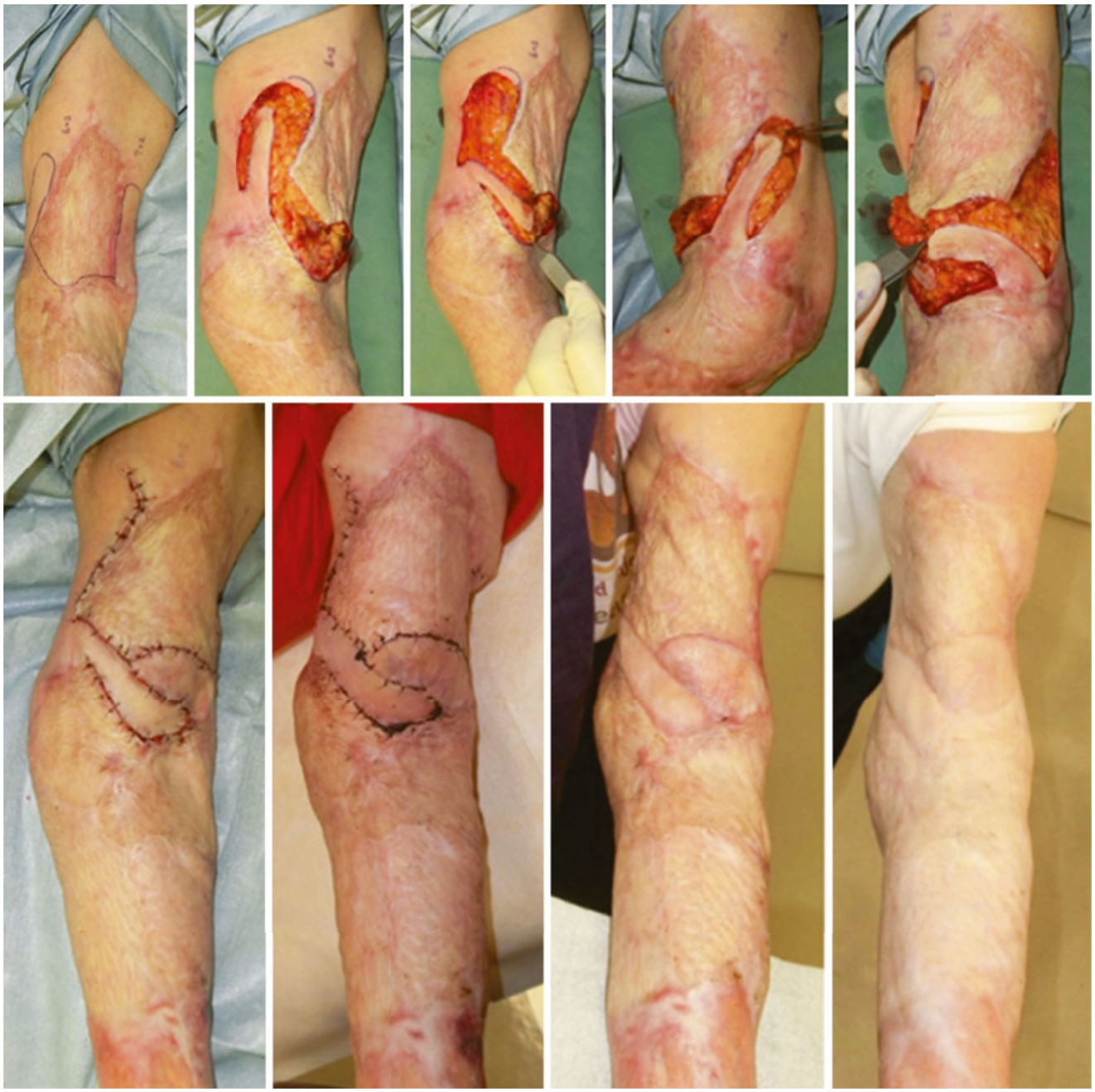


Fig. 33.5 Use of a transposition flap to release an elbow joint contracture

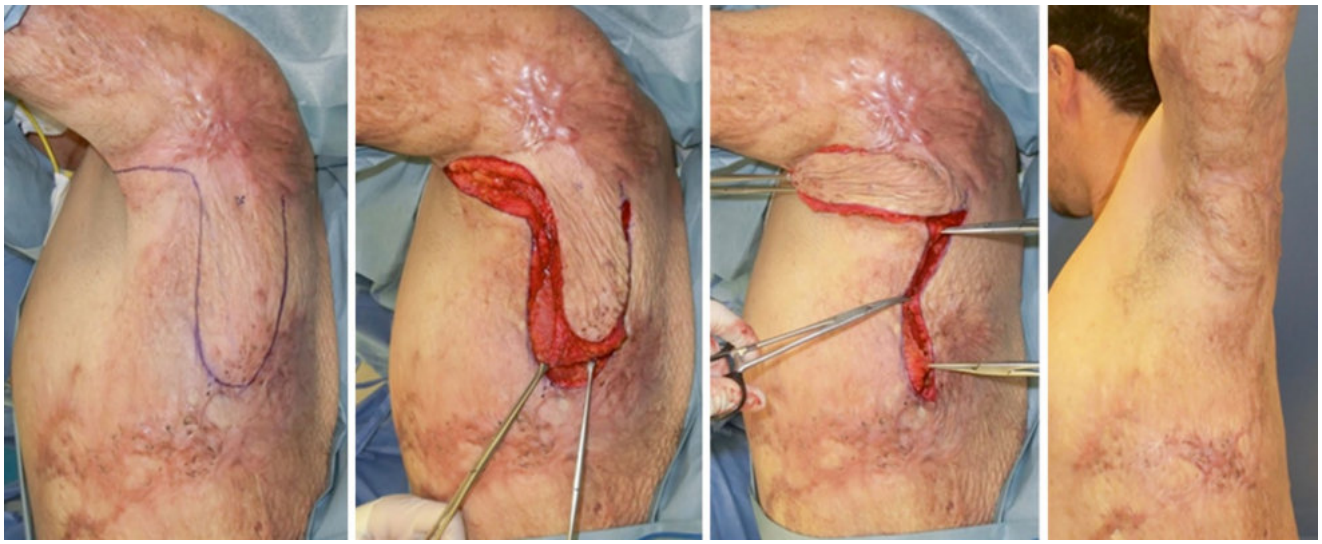


Fig. 33.6 Use of a large, single-limb, pedicled skin transposition flap to release a posterior axillary contracture in a scarred area

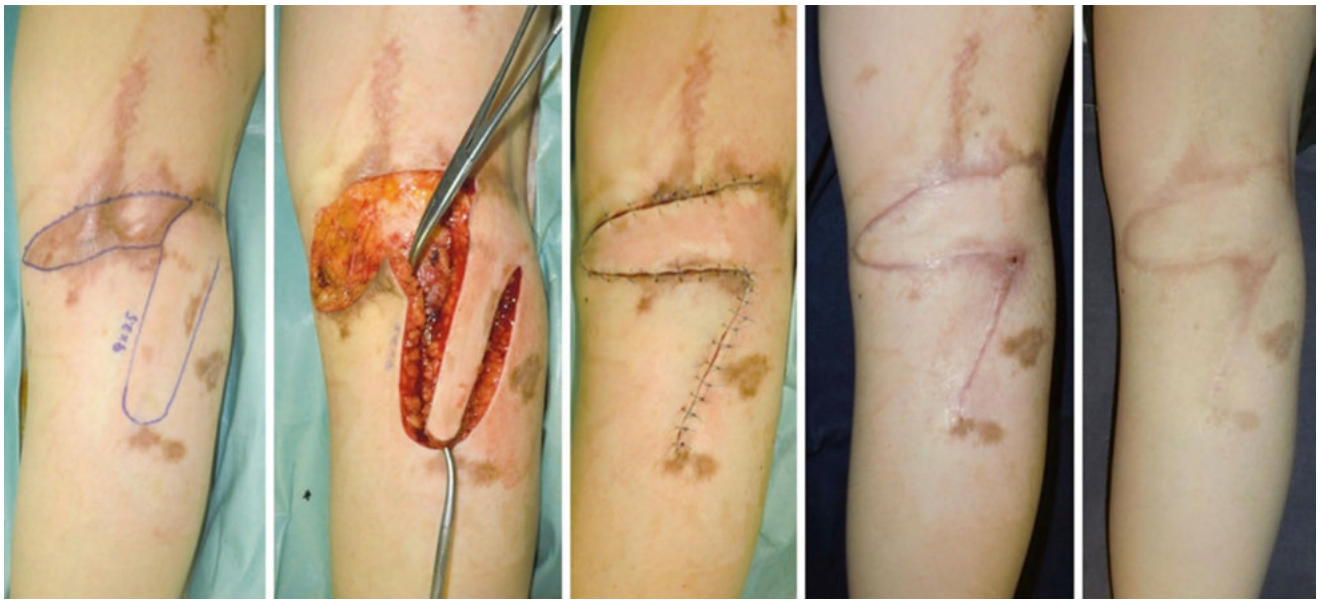


Fig. 33.7 Use of a transposition flap with a large base to release a popliteal contracture

33.4 Z-Plasty

Z-plasty is considered the oldest transposition method in plastic and reconstructive surgery [3, 13], but textbooks often fail to discuss this procedure adequately or provide guidelines for selecting the most appropriate method. Moreover, burn reconstructive surgeons sometimes appear to focus more on learning new methods, which can leave little time for understanding the mechanics of each procedure. To obtain successful outcomes with Z-plasty, it is important that surgeons assess the degree of laxity of the adjacent skin, understand the mechanics of Z-plasty, and select the best technique [14].

One of the key advantages of Z-plasty is that the incisions can be closed primarily. This decreases healing time, which is particularly useful in cases that need functional rehabilitation. It also prevents contracture of linear scars and improves both functional and cosmetic appearance [15, 16]. Another key advantage is that it redirects the scar so that it aligns better with the line of least skin tension or a natural skin fold. This permits closure of a large scar without the risk of recontracture. Z-plasty does not necessarily require complete removal of the scar, since the surgery can promote the disruption and degradation of scar collagen fibers [15, 17] (Fig. 33.8).

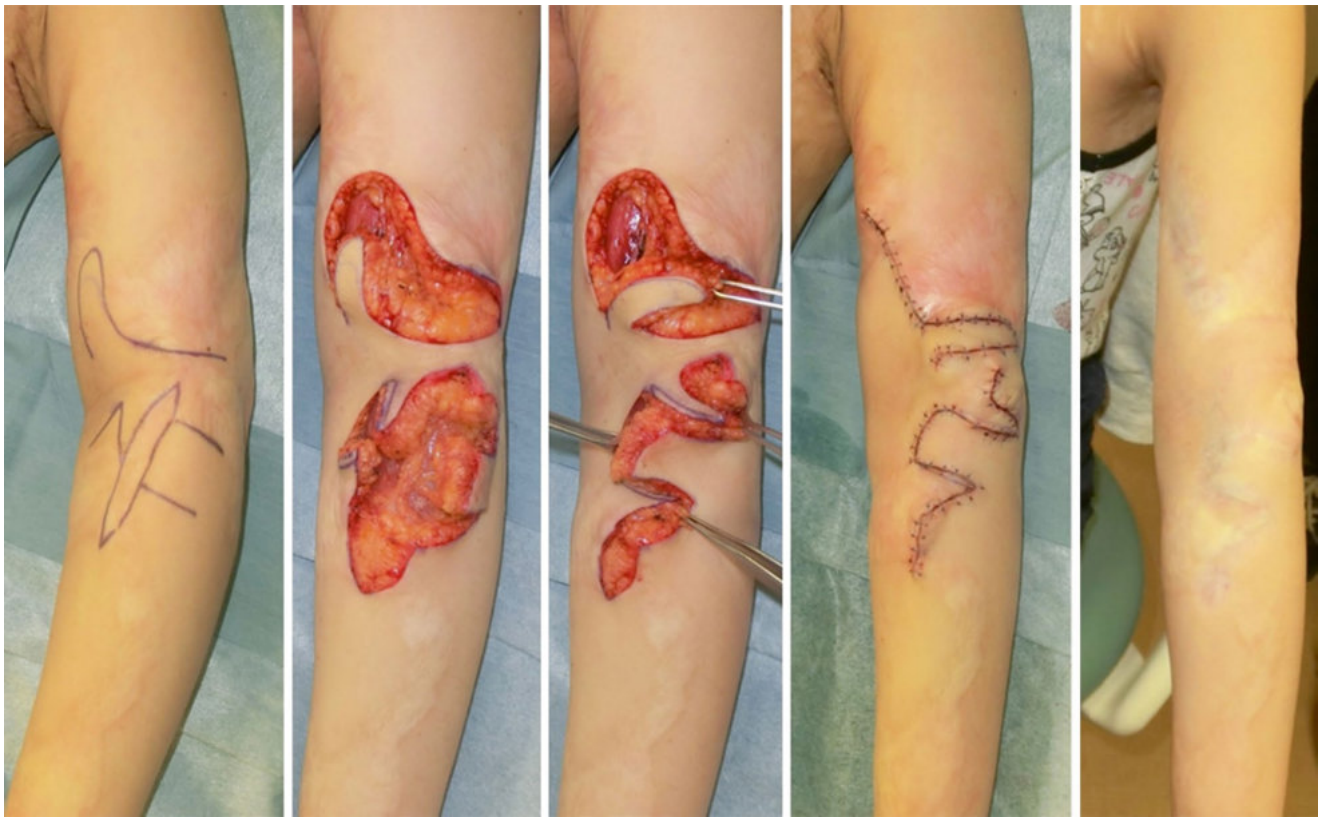


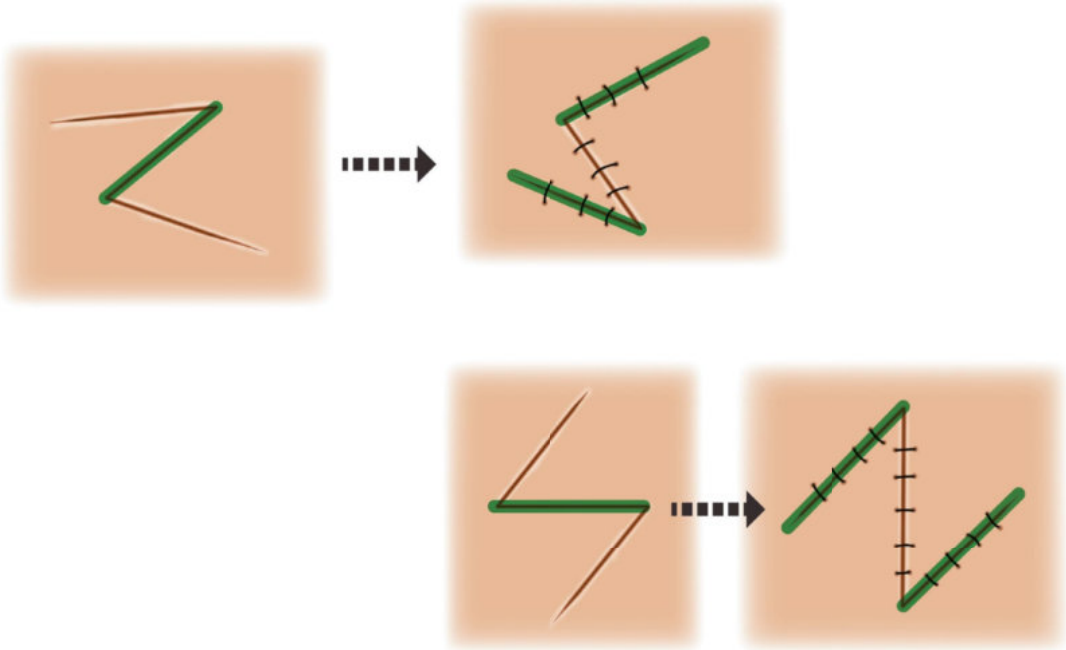
Fig. 33.8 Combined use of a square flap and a transposition flap to release an elbow contracture

33.4.1 Z-Plasty Variations

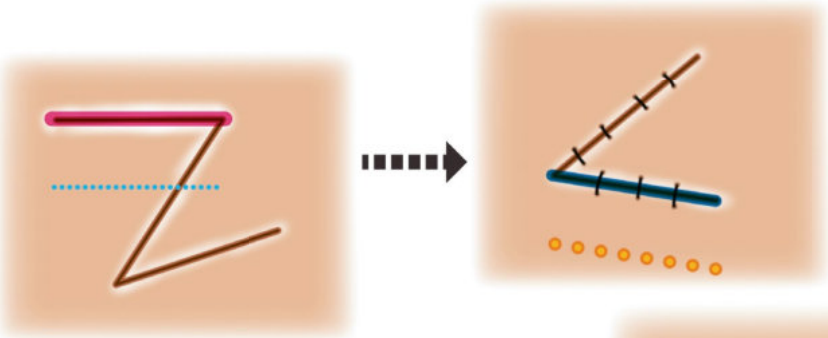
Z-plasty can be modified into many variations in several ways. While the angle is usually 60°, it can be changed to >60° or <60°, and the angles can be similar or dissimilar (Fig. 33.9a). The number of Z-plasties used can vary from one (Fig. 33.9b) to many (Fig. 33.9c) [4, 11, 14, 18]. The direction of double Z-plasties can be opposing and nonopposing (Fig. 33.9d) [7, 9, 11]. Conventional/planimetric Z-plasty can preserve tissue (Fig. 33.9e) [14]. Z-plasty can also be combined with other local flaps. For example, double opposing Z-plasties can be combined with a Y-V advancement flap to yield Jumping Man (Fig. 33.9f) [4]. Z-plasty can also be combined with a rhomboid-shaped flap. Moreover, it can vary in thickness, leading to skin flap Z-plasty, fasciocutaneous Z-plasty, and musculocutaneous Z-plasty [3]. X-shaped incision can also be used: This is termed "X-plasty" (Fig. 33.9g) [3]. Double opposing Z-plasty combined with V-plasty is denoted as "K-M-N plasty." Other Z-plasty variants include star-plasty, which is used to reconstruct the web space after burn injury (Fig. 33.9h) [3], and the Spider Procedure, where the defect is surgically converted to a triangular shape and five flaps are outlined and transposed in a Z-plasty manner(Fig. 33.9i) [18].

33.4.2 Z-Plasty Surgery Tips

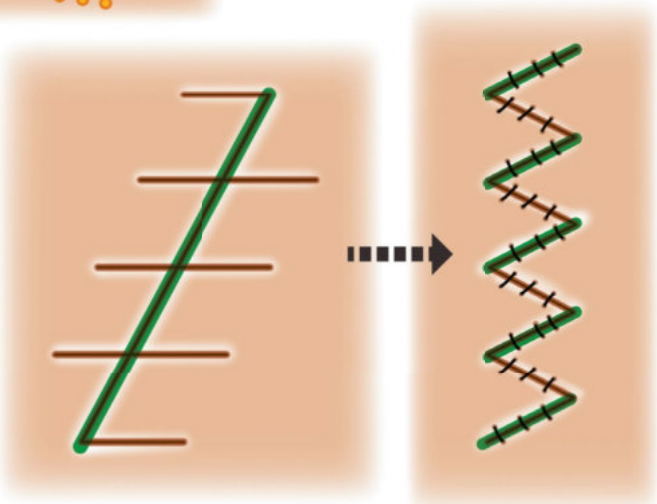
1. As with transposition flaps in general, the surrounding skin conditions and structures must be considered carefully when choosing or creating Z-plasty. Z-plasty outcomes also depend on the number of Z-plasties, the length of the lateral arm, the angle, the Z-plasty direction, and the RSTL direction. It also depends on the location, which shapes skin elasticity and biomechanical forces, and patients' age and genetics.
2. Z-plasty is commonly designed at 60° because this increases the scar length by 1.73-fold and thus effectively releases contractures. A 45° design can also be chosen to minimize scar length. However, a 30° design can lead to ischemia in burn reconstruction. Thus, to minimize scar length and reduce dog ears, it is recommended to use a 45° design.
3. For the face and neck, it is better to use multiple small Z-plasties than fewer Z-plasties with large limbs [19]. This is because, to effect closure, a larger Z-plasty requires 7–10 times more tension than that of smaller Z-plasties [5, 14] and can thus result in a larger dog ear. It should be noted that a computer simulation study of one, two, four, and eight Z-plasties has shown that while a



a The similarity of angles (similar/unsimilar)

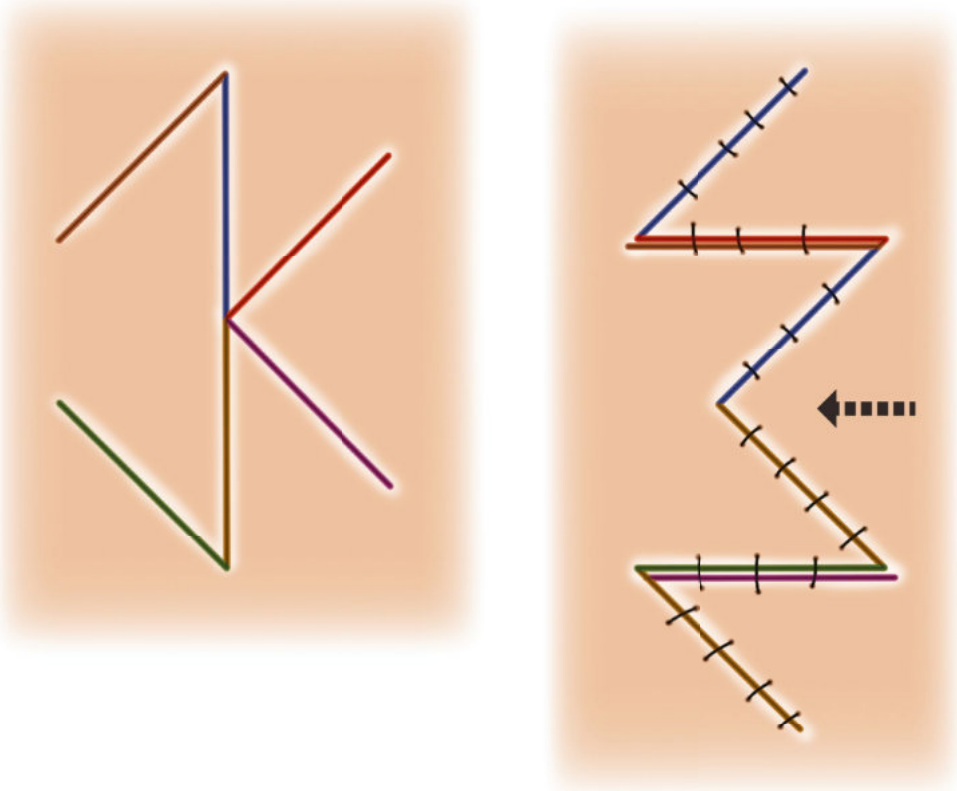


b Single

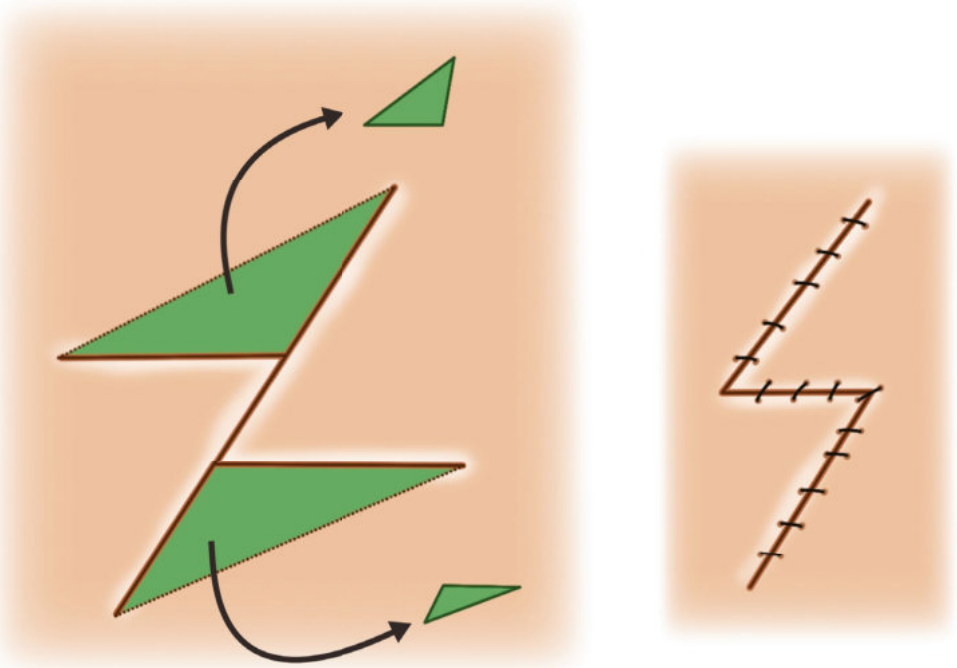


c Multiple

Fig. 33.9 Z-plasty variations

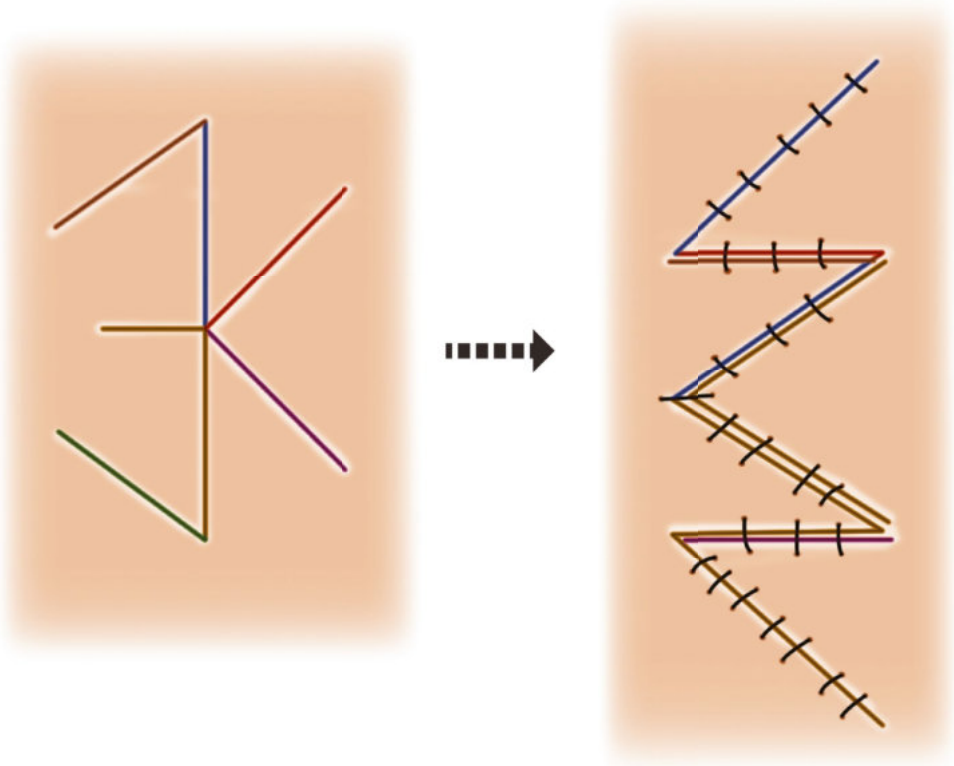


d Direction (opposing/non-opposing)

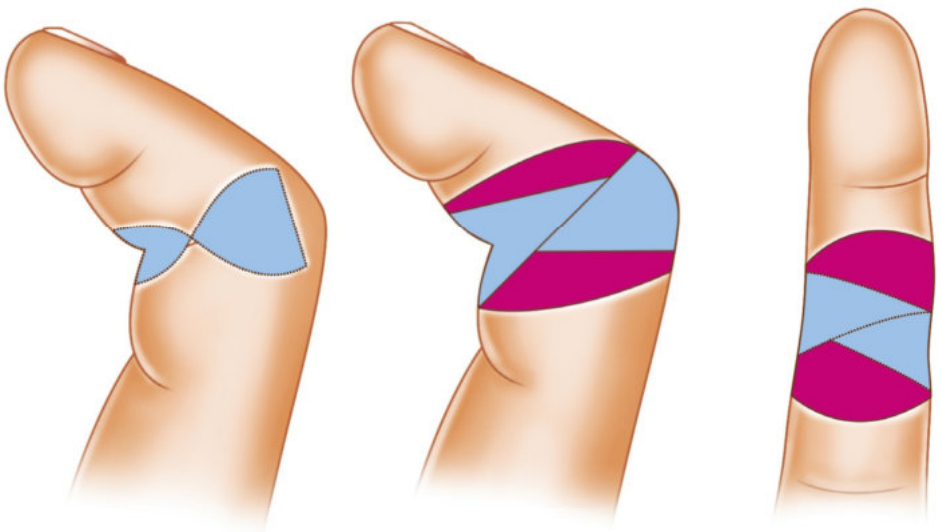


e Preserve tissues (conventional/planimetric)

Fig. 33.9 (continued)

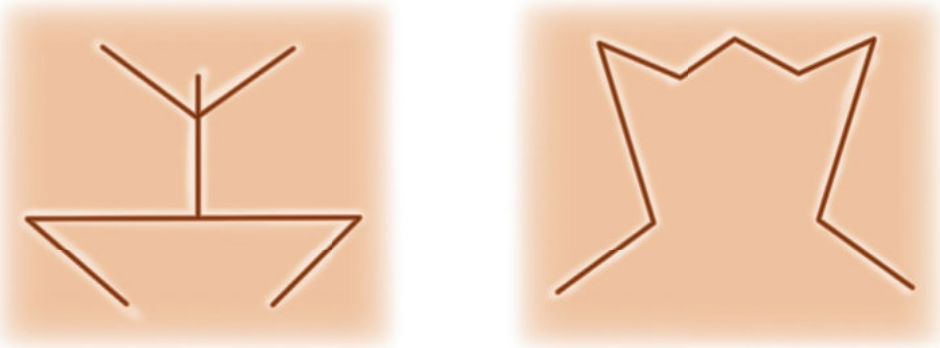


f Combination (jumping man)

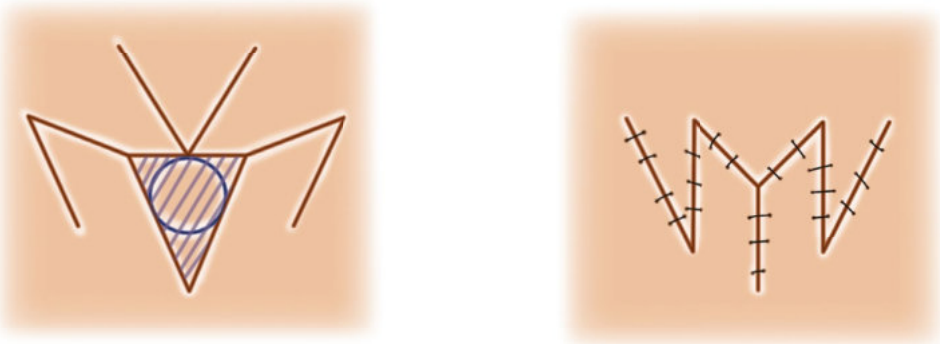


g X-Plasty

Fig. 33.9 (continued)



h K-M-N Plasty, Star Plasty



i Spider Procedure

Fig. 33.9 (continued)

single 8-cm Z-plasty lengthens the scar by 73%, two Z-plasties of the same total length (i.e., 4 cm each) achieve less gain in length, and this worsens with increasing numbers of total Z-plasties. Nonetheless, the study also showed that eight Z-plasties produced both the least tension and area of distortion after relocation and that these beneficial effects declined with diminishing numbers of Z-plasties [20]. Thus, these relative advantages and disadvantages of single/multiple Z-plasties should be considered when choosing the Z-plasty approach.

4. Several possible Z-plasties are available; unfortunately, only one is ideal (Fig. 33.10a, b) [21]. To determine the optimal locations of the Z-plasty incisions, the lateral limbs of the Z-plasty should align with the RSTL; this means that the new central incision will not run perpendicular to the line of decreased skin tension. If the long axis of the scar lies less than 40° from the RSTL, simple excision is preferred over Z-plasty [11].
5. Z-plasty is a local flap that has random vascularization. For vascularly impaired areas, Z-plasty can be combined with muscle or fascia [3].
6. Z-plasty is particularly beneficial in joint areas because scars that cross them can become hypertrophic due to constant stretching in these mobile areas [13].
7. Small areas with less tissue laxity such as the finger webs should not be treated with simple Z-plasty. Rather, Z-plasty should be performed in the Dancing Man/Jumping Man mode, which combines double opposing Z-plasty with Y-V advancement. The "V" component is marked on the side with lax skin, and the lengths of the lateral limbs depend on the desired deepening, which is often equal to half the length of the central limb. This leads to a total gain in length of 125% [4].
8. As with transposition flaps in general, the ideal plane for flap elevation is located between the subdermal and subcutaneous tissues. This means that the flap contains full-thickness skin, including the dermis. This prevents

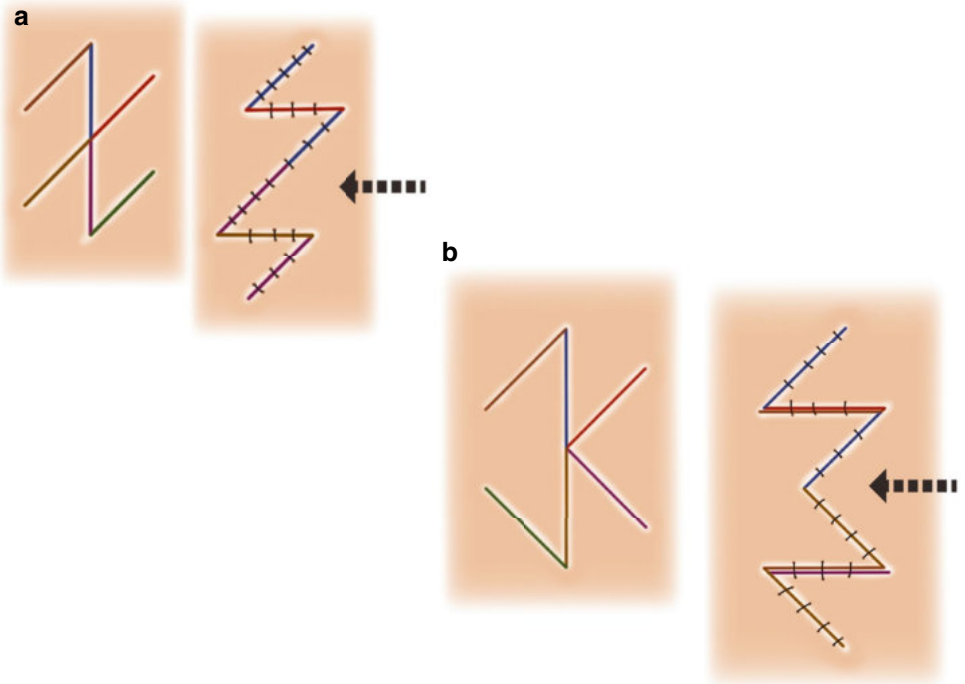


Fig. 33.10 Transposition in different directions leads to disparate results. (**a**) Double nonopposing Z-plasties, (**b**) Double opposing Z-plasties

secondary scar contracture. Moreover, to properly mobilize the flap in a tension-free manner, the surrounding subcutaneous tissue must be undermined sufficiently [12].

9. The Z-plasty design must be reevaluated and perhaps even remodeled after deep and superficial fascia suturing. The resulting wounds are stitched with dermal and superficial sutures, respectively [13]. The long limbs of each Z-plasty should be divided in a "cut as you go" manner at the midpoint vertically [1].

The following four cases illustrate these tips:

Case 5: A 12-year-old girl presented with two linear hypertrophic scars of differing lengths and with contracture on her left foot due to a traffic injury (Fig. 33.11a). Extended continuous Z-plasties with different triangle sizes were designed (Fig. 33.11b). The contracture was released, and the hypertrophic scar was totally excised. The flaps were then transferred and sutured (Fig. 33.11c). At 18 postoperative months, the leg exhibited excellent functional and cosmetic improvements (Fig. 33.11d).

Case 6: A 14-year-old boy presented with multiple linear contractures at the webs and at a finger of the right hand (Fig. 33.12a). On the basis of the contracture severity and the scar shape, it was planned to conduct a conventional multiple Z-plasty on the finger and three-flap modifications of Z-plasties (i.e., square flaps) on the webs (Fig. 33.12b). After a skin incision was conducted along the mark, an additional skin incision was created throughout the dotted line to transpose the flaps further. The transferred flaps were then sutured (Fig. 33.12c). The 18-month postoperative evaluation showed functional and cosmetic improvements (Fig. 33.12e–g). Thus, this case was characterized by multiple small areas with specific needs, namely optimal web indentation and width. While skin graft and simple Z-plasty could have been chosen, a square flap was selected because it could best deliver smooth indentation at the web groove. It also provided enough but not too much width. By contrast, a Jumping Man would have yielded too much width and is thus more suitable for reconstructing the first web, which was not affected in this case. Finally, the square flap did not leave a scar in the web indentation area, whereas this would have occurred if simple Z-plasty had been used. These advantages promoted early rehabilitation of the hand.

Case 7: A 15-year-old girl presented with a postburn linear scar contracture that ran from the first to the third webs and then down the palm of the left hand (Fig. 33.13a). Multiple Z-plasties were planned to release the palm, while three-flap modifications of Z-plasties (square flaps) were planned for the first to the third webs (Fig. 33.13b). After contracture release, the flaps on the palmar sides were transferred (Fig. 33.13c). Eighteen months postoperatively, impressive functional and cosmetic improvements were observed (Fig. 33.13e–g).

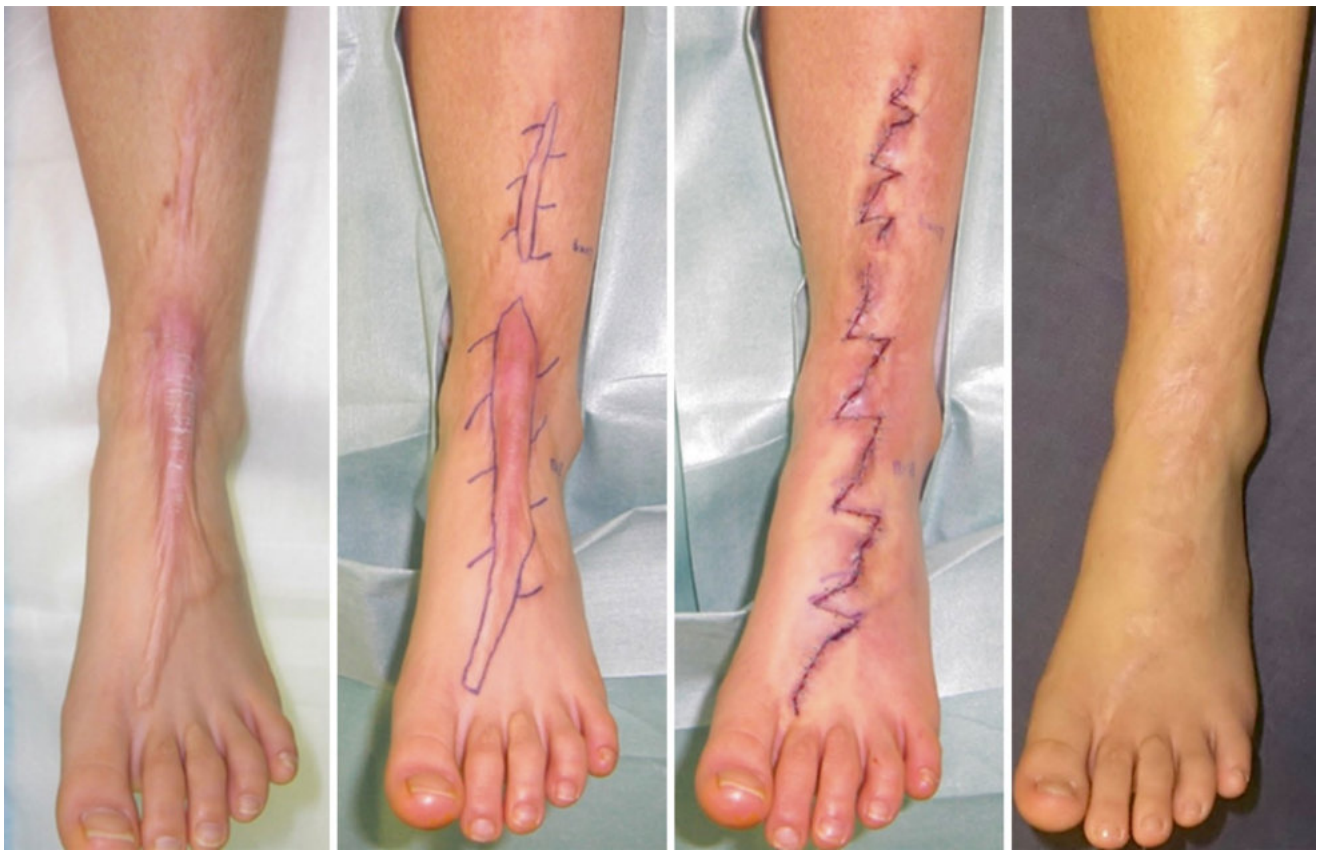


Fig. 33.11 Use of continuous Z-plasties with differently sized triangles to release a contracture on the inferior extremity

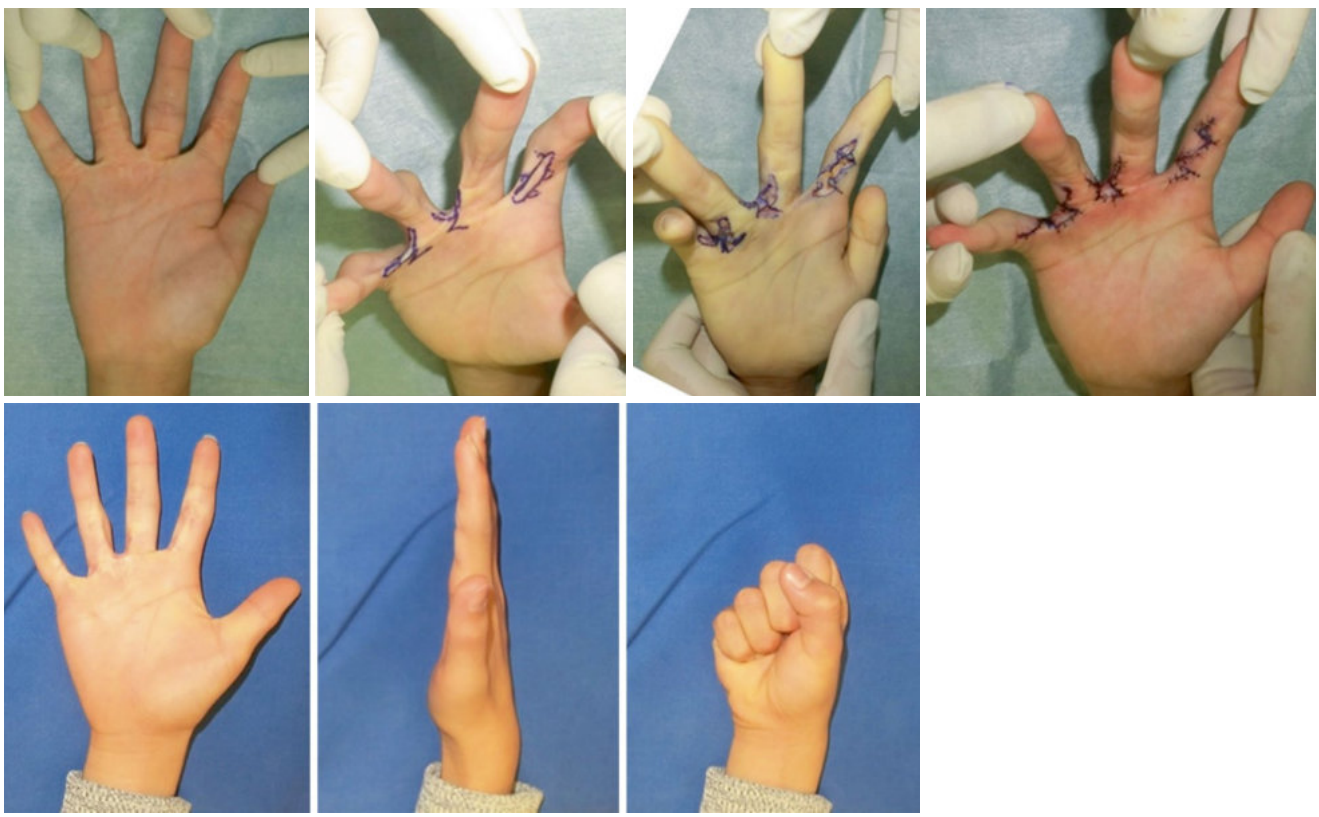


Fig. 33.12 Use of square flaps and continuous Z-plasties to release linear contractures at the webs and a finger of the hand, thereby restoring full function

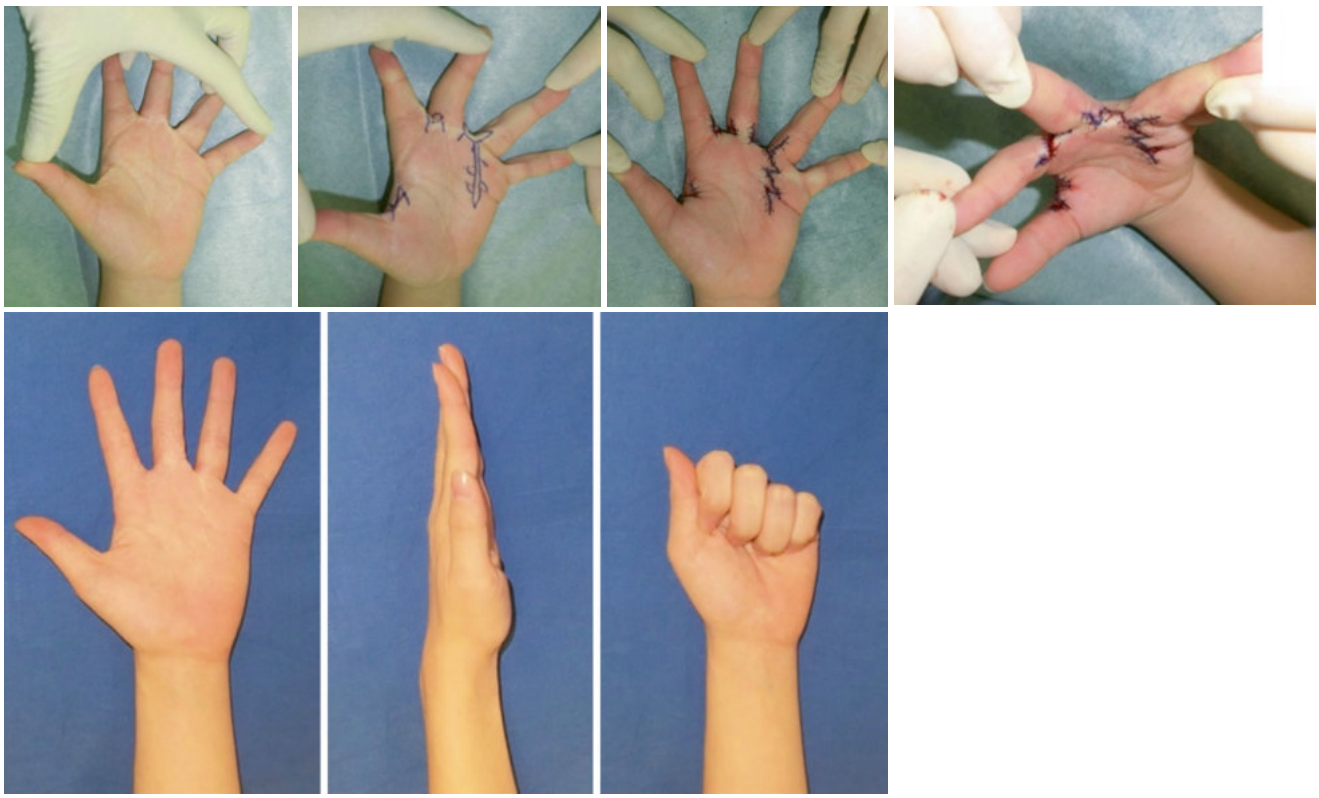


Fig. 33.13 Use of square flaps and continuous Z-plasties to release contractures and to restore function of the hand

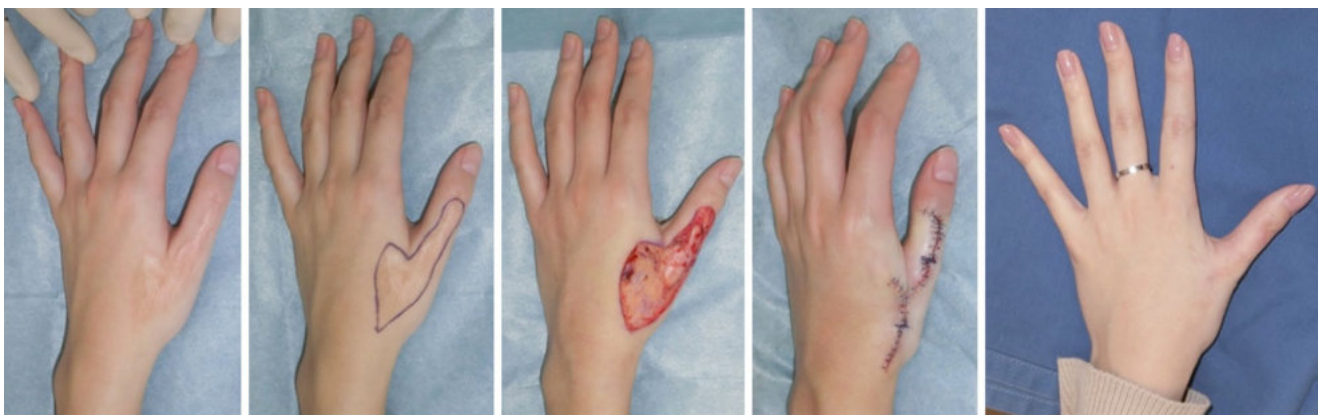


Fig. 33.14 Use of Z-plasty for scar revision of the hand

Case 8: A 20-year-old woman presented with a widening scar with an irregular shape, uneven pigmentation, and variable thickness on her left hand due to a previous traffic injury (Fig. 33.14a). Z-plasties were used to segment the linear wound. The flaps were then transferred and sutured (Fig. 33.14d). The evaluation 18 months after the operation revealed excellent functional and cosmetic improvements (Fig. 33.14e). Geometric methods such as Z-plasty or W-plasty are better than straight-line closure for camouflaging and preventing scar contractures.

33.5 Summary

This chapter delineates the essential aspects of reconstruction with local flaps, particularly transposition flap and Z-plasty. To choose the best procedure for each case, surgeons should carefully assess the nearby skin and comprehensively understand the mechanics of the various flap possibilities. This fundamental understanding will allow the local flap to become a powerful tool in the surgeon's armamentarium.

References

1. Ersoy B. A new flap design for release of parallel contracture bands: dual opposing five-flap z-plasty. Burns. 2014;40(8):e69–71.
2. Yoshino Y, Kubomura K, Ueda H, Tsuge T, Ogawa R. Extension of flaps associated with burn scar reconstruction: a key difference between Island and skin-pedicled flaps. Burns. 2018;44(3):683–91.
3. Hundeshagen G, Zapata-Sirvent R, Goverman J, Branski LK. Tissue rearrangements. Clin Plast Surg. 2017;44(4):805–12.
4. 2020 Z- plasty. The twin transposing symmetrical flaps.pdf.
5. Borges AF, Gibson T. The original Z-plasty. Br J Plast Surg. 1973;26(3):237–46.
6. McGregor IA, Morgan G. Axial and random pattern flaps. Br J Plast Surg. 1973;26:202–13.
7. Daniel RK, Williams HB. The free transfer of skin flaps by microvascular anastomoses: an experimental study and a reappraisal. Part I: the vascular supply of the skin. Plast Reconstr Surg. 1973;52:16–31.
8. Webster JP. Thoraco-epigastric tubed pedicles. Surg Clin North Am. 1937;17:145.
9. Kunert P. Structure and construction: the system of skin flaps. Ann Plast Surg. 1991;27:509–16.
10. Cormack GC, Lamberty BGH. A classification of fasciocutaneous flaps according to their patterns of vascularization. Br J Plast Surg. 1984;37:80–7.
11. Hove CR, Williams IEF, Rodgers BJ. Z-Plasty: a concise review. Facial Plast Surg. 2001;17(04):289–94.
12. Nguyen. How to Address Scar Pincushioning and Webbing of the Nasal Dorsum Using Surgical Defatting and Z-plasty. Cutis (Internet). 2022 Aug (cited 2023 Aug 13);110(2). Available from: https://www.mdedge.com/dermatology/article/256903/nonmelanoma-skin-cancer/how-address-scar-pincushioning-and-webbing-nasal.
13. Ogawa R, editor. Total scar management: from lasers to surgery for scars, keloids, and scar contractures (Internet). Singapore: Springer Singapore; 2020. (cited 2023 Oct 9). Available from: http://link.springer.com/10.1007/978-981-32-9791-3
14. Hudson DA. Some thoughts on choosing a Z-Plasty: the Z made simple. Plast Reconstr Surg. 2000;106(3)
15. Jindal R, Schultz BE, Ruane EJ, Spiess AM. Cadaveric study of a Z-Plasty modification to the moberg flap for increased advancement and decreased morbidity. Plast Reconstr Surg. 2016;137(3):897–904.
16. Asif M, Khan MA, Bokhari SG, Abbas G, Sajid M, Ijaz M, et al. Angular effects of Z-Plasty technique on extent of relaxation of contracted scar, cosmetic appearance and tip necrosis in dogs. Adv wZool Bot. 2017 Oct;5(4):45–9.
17. Li N, Yang L, Cheng J, Han J, Hu D. Early intervention by Z-plasty combined with fractional CO_2 laser therapy as a potential treatment for hypertrophic burn scars. J Plast Reconstr Aesthet Surg. 2021;74(11):3087–93.
18. Mutaf M, Temel M, Günal E. A new Z-Plasty–based local flap procedure for closure of lateral canthal skin defects. Plast Reconstr Surg. 2012;129(2):372e–4e.
19. Shockley WW. Scar revision techniques: Z-Plasty, W-Plasty, and geometric broken line closure. Facial Plast Surg Clin N Am. 2011;19(3):455–63.
20. Kitta E, Akimoto M. Biomechanics and computer simulation of the Z-Plasty. J Nippon Med Sch. 2013;80(3):218–23.
21. Aasi SZ. Z-Plasty made simple. Dermatol Res Pract. 2010;2010:1–5.

Use of Z-Plasty in Burn Reconstruction

34

Rodney K. Chan and Matthias B. Donelan

Abstract

Z-plasty is a fundamental concept in surgery, plastic surgery, and burn reconstruction. While it is simple to conceptualize, proper execution requires experience and finesse. The original concept of a Z-plasty has not changed since the early 1900s, but emerging scar management modalities using the pulsed dye laser, fractionated ablative lasers, and laser-assisted drug delivery (LADD), have helped expand its indications.

Keywords

Hypertrophic scar · Laser scar resurfacing · Scar contracture · Common limb · Soft tissue rearrangement

34.1 Background of the Technique

Burn scars are frequently described as undesirable consequences that follow burn injury. However, while the incident that resulted in the burn scars was unfortunate and undesirable, the scarring itself is a necessary part of normal wound healing and can often become the patient's most valuable anatomy for their reconstruction and rehabilitation. The scar tissue is autologous, already in the right location, blends well into the surrounding tissue, and using it for a patient's reconstruction can often equal or surpass the results obtained with scar excision followed by reconstruction with distant flaps and grafts. Burn scar excision today is less frequently indicated and decreases the need for creating iatrogenic injuries in the form of donor site deformities [1]. Hypertrophic scars are frequently the result of tension. The tension results in scar proliferation with erythema, pain, irregularity, contractures, and a visually disturbing appearance. The solution to hypertrophic scarring is tension relief. Z-plasty is a well-described, tension-relieving operation for hypertrophic burn scars. Its indications have expanded as new laser modalities for burn scar rehabilitation have gained popularity.

Denonvilliers, often credited with the first description of Z-plasty, used it for the treatment of lower lid ectropion in 1856. The first reference to the term "Z-plasty" in American literature, however, was not found until 1913, when McCurdy used it for an oral commissure contracture release. Limberg, in 1929, provided a more detailed geometric description, and Davis subsequently popularized the technique with a better definition of angles and theoretically achievable length relationships [2].

34.2 Characteristics and Indications of the Method

Z-plasty involves transposing two interdigitating triangular flaps arranged in the shape of a "Z" or reversed "Z," which results in lengthening and altering the direction of the common limb. This technique is versatile and can be used to lengthen scar contractures, narrow scars, change scar direction, break up scars, flatten raised or depressed scars, and correct contour deformities such as the creation of a web space.

In burn survivors, Z-plasty is often used to lengthen contracted scars and camouflage hypertrophic scars. A classic application involves releasing a "scar band" that "bowstrings" across a hollow, borrowing tissue from either side to lengthen the scar and improve the visual outcome. Even in cases where the scar is diffuse and lacks transverse skin laxity, Z-plasty can still be effective if the limbs of the "Z" can reach a more lax area of skin and scar. In extreme cases,

R. K. Chan
US Army Burn Center, US Army Institute of Surgical Research, San Antonio, TX, USA
e-mail: chan@metisfoundationusa.org

M. B. Donelan (✉)
Division of Plastic Surgery, Shriners Hospital for Children, Boston, MA, USA
e-mail: mdonelan@partners.org

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_34

where transverse skin laxity is absent, autografting following transverse scar release may be necessary. Infrequently, a Z-plastied hypertrophic scar might develop a secondary area of banding, which may require additional Z-plasties or skin graft releases at a later date.

Clinically, it is remarkable that hypertrophic scars soften and thin following Z-plasty even without the removal of any scar tissue. Part of this is mechanical, as the previously protuberant scar has been halved and redistributed into a different location and direction. Reorientation of the fibers and relief of tension also have biochemical consequences. Longacre et al. performed histochemical studies of tissue before and after Z-plasty and showed that abnormally sulfated mucopolysaccharides were replaced by normal acid mucopolysaccharides within 14 days [3]. Collagen that appeared in nodules in hypertrophic scars is decreased in quantity and reoriented into bundles at right angles to each other, resembling normal skin. Hydroxyproline and hydroxylysine, molecules unique to collagen degradation, were found in higher concentrations in urine following Z-plasty. All these findings indicate that biochemical scar degradation and remodeling occur following Z-plasty, leading to a clinically more inconspicuous scar.

34.3 Specific Skill of the Methods

The most important determining factor of Z-plasty success is patient selection, followed by design and execution. For the most part, each limb of the Z-plasty should be equal. A 60° angle between the common limb and the side limbs results in a theoretical 75% gain in length of the common axis [4]. In practice, most surgeons maintain a 60° angle but vary the length of the common limb, as determined by the amount of transverse skin laxity. When the scar is long, it might be necessary to make tandem Z-plasties, thereby limiting the required transverse length. In a properly designed and executed Z-plasty, the flaps transpose into their intended positions with ease.

The correct way to cut a Z-plasty is to first incise the central limb, then releasing the side limbs of the Z-plasty by cutting toward the middle and rounding out the corners toward the end, almost orthogonal at the junction with the common limb. Tissue tends to retract as one cuts away from the corner, leading to flaps that are smaller than intended. It is important to incise deep enough beyond the scar plane down to healthy subcutaneous tissue. Undermining is minimized to only what is necessary for flap transposition. The corner stitches bear the most tension during closure; additional closure stitches to take tension off that point should respect the blood supply to the distal flap ends.

34.4 Combining Surgical and Nonsurgical Scar Rehabilitation

There is mounting evidence supporting the use of lasers to improve scar appearance and symptoms. While the fractionated ablative laser's primary mode of action is still up for some debate, studies have reported objective improvement in scar thickness and elasticity, equating to a type of microscopic tension relief [6, 7]. It stands to reason that macroscopic tension relief in the form of a Z-plasty, together with microscopic tension relief using lasers, may augment one another's effectiveness. Indeed, scars that were previously deemed too broad or diffuse to warrant a Z-plasty have become candidates after several laser treatments. Similarly, secondary banding following Z-plasties has also been treated successfully using lasers, negating the need for a skin graft.

34.5 Summary

Z-plasty is an essential tool in every plastic surgeon's armamentarium, and it is also a tool that evolves and grows over a plastic surgeon's career. The lack of a donor site is an attractive option for burn survivors with little donor skin left to give. With experience, proper documentation, and a willingness to experiment, surgeons will grow their internal comfort and expand their indications. Combining Z-plasty with lasers can have synergistic effects on scar rehabilitation.

34.6 Clinical Cases

34.6.1 Case 1: Face and Ear Hypertrophic Scar

A hypertrophic scar extends from the anterior ear down toward the neck. The scar is thick and raised and also obliterates the normal lobule–neck relationship (Fig 34.1a). Tandem Z-plasties were designed to break up the linear scar inferior to the ear. A separate Z-plasty was designed to release the tethered lobule (Fig 34.1b). An immediate postoperative photo shows successful flap transposition and skin closure (Fig 34.1c). Nine months after surgery and three pulsed dye laser treatments, the transposed flaps are barely visible, and the lobule is free from the neck skin (Fig. 34.1d).

34.6.2 Case 2: Axillary Contracture

This postburn axillary contracture involves both the anterior and posterior axillary folds (Fig. 34.2a). This is typical of the hypertrophy seen with constant tension, which in severe cases can even lead to ulceration (Fig. 34.2b). Incisional

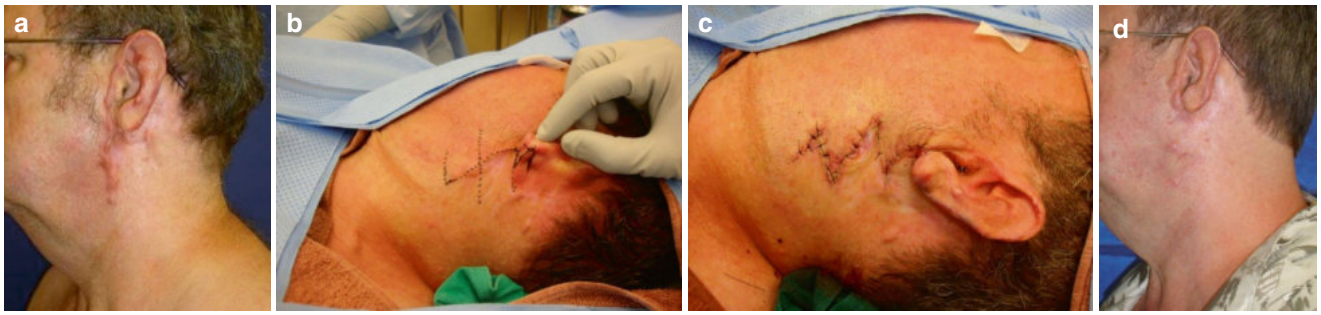


Fig. 34.1 A–D: Case 1

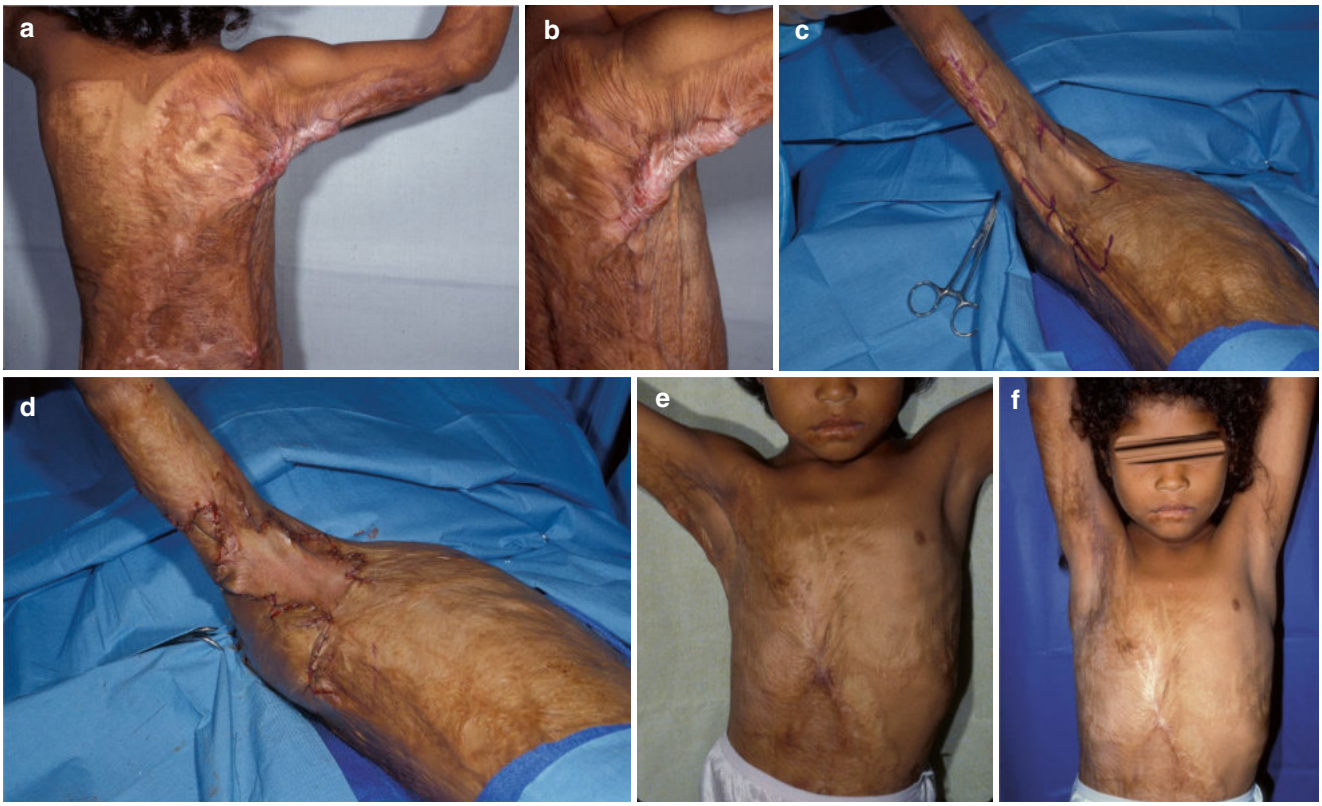


Fig. 34.2 A–F: Case 2

releases were designed using tandem Z-plasties within the hypertrophic scar (Fig. 34.2c). This achieves tension relief and reorientation of the collagen fibers, allowing the scars to favorably remodel. The central limb of the Z-plasty was designed over the hypertrophic band, with the lateral limbs extending into adjacent normal, supple skin. Note immediate relief of the scar contracture without need for additional skin grafting or scar excision (Fig. 34.2d). After Z-plasty release, there is minimal need for therapy and no need for splinting. Three years after release, the scars are soft and supple, and the contractures are completely corrected (Fig. 34.2e, f [before, after]).

34.6.3 Case 3: Neck Contracture

Neck contracture developed following a partial-thickness flame burn, acutely treated with tangential excision and split-thickness skin grafting. The contracture resulted in loss of a normal chin-neck angle (Fig. 34.3a). She underwent two separate Z-plasty procedures to release the contracture and improve neck contour. The initial procedure used two large Z-plasties which included the entire area of graft and scar (Fig. 34.3b). This lengthened the vertical contracture, narrowed the scarred area transversely, and deepened the chin-neck angle by appropriate placement of the Z-plasty flaps

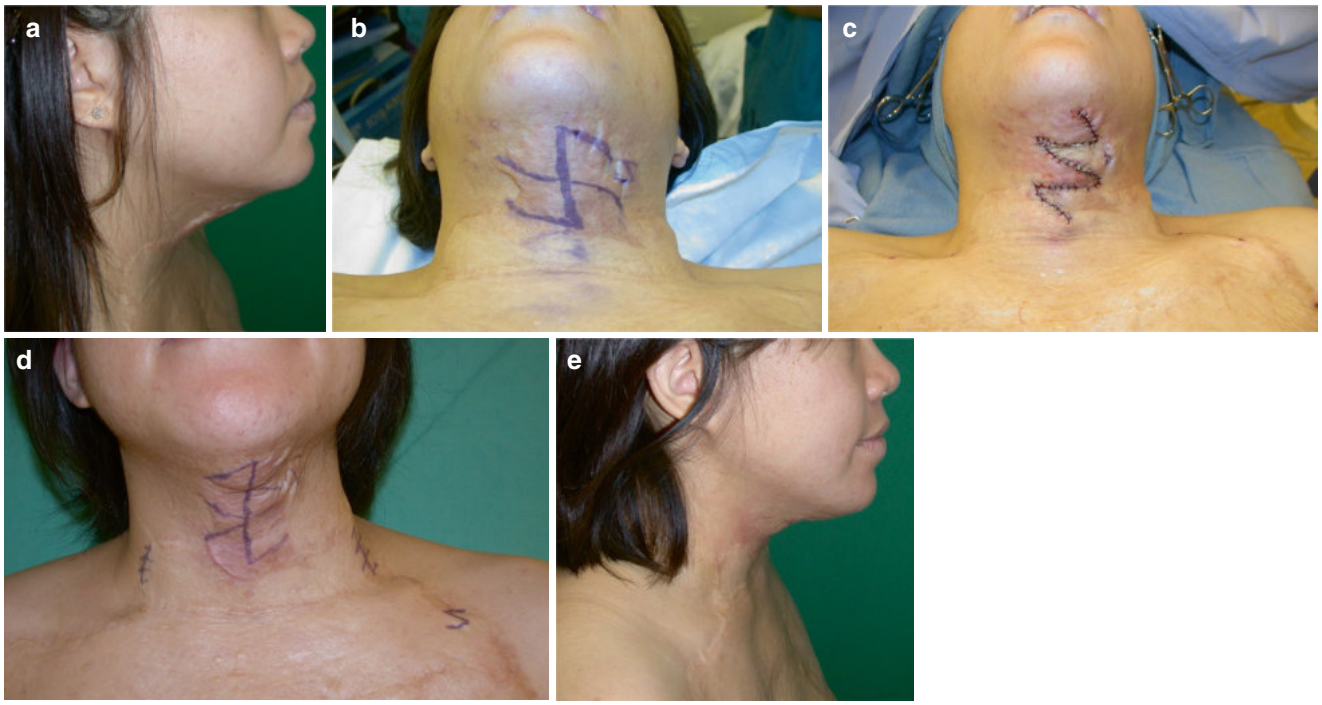


Fig. 34.3 A–E: Case 3. Note the patient's appearance 3 years after his first Z-plasties and four CO_2 lasers. Scar rehabilitation of this sort, with improved function and appearance, as well as restoration of normal skin qualities, was not possible before laser therapy

(Fig. 34.3c). The second procedure used more focal Z-plasties to further narrow and lengthen the contracted tissues (Fig. 34.3d). One year following the two procedures, tension has been eliminated, and the neck contour is normal (Fig. 34.3e).

34.6.4 Case 4: Axillary Contracture

A young man sustained extensive third-degree burns with a severe linear contracture of the right axilla (Fig 34.4a, b). The tension is so severe that a chronic ulcer has developed at the center of the contracture, where repeated auto-scar releases had occurred (Fig 34.4c). Tandem Z-plasties were performed in two separate operative encounters, six months apart, with progressive improvement in tension and spontaneous closure of the chronic ulcer (Fig 34.4d, e). Long-term appearance at 3 years is shown. The patient also underwent five ablative CO_2 laser treatments to this area during the same period (Fig 34.4f).

34.6.5 Case 5: Leg and Buttock Contracture

A young female patient with massive thick burn scars and contractures on the right leg had downward displacement of the buttock. She was unable to place her right foot flat on the ground or extend her knee fully (Fig 34.5a). Thickened contractures along the lateral aspect of the leg and popliteal fossa were released with multiple Z-plasties (Fig 34.5b). Four years after her first Z-plasty, she had a normal range of motion in the right knee and ankle. She was able to place her foot flat on the ground with improved scar appearance and skin tension. The anatomic buttock position and proportion are also restored (Fig 34.5c).

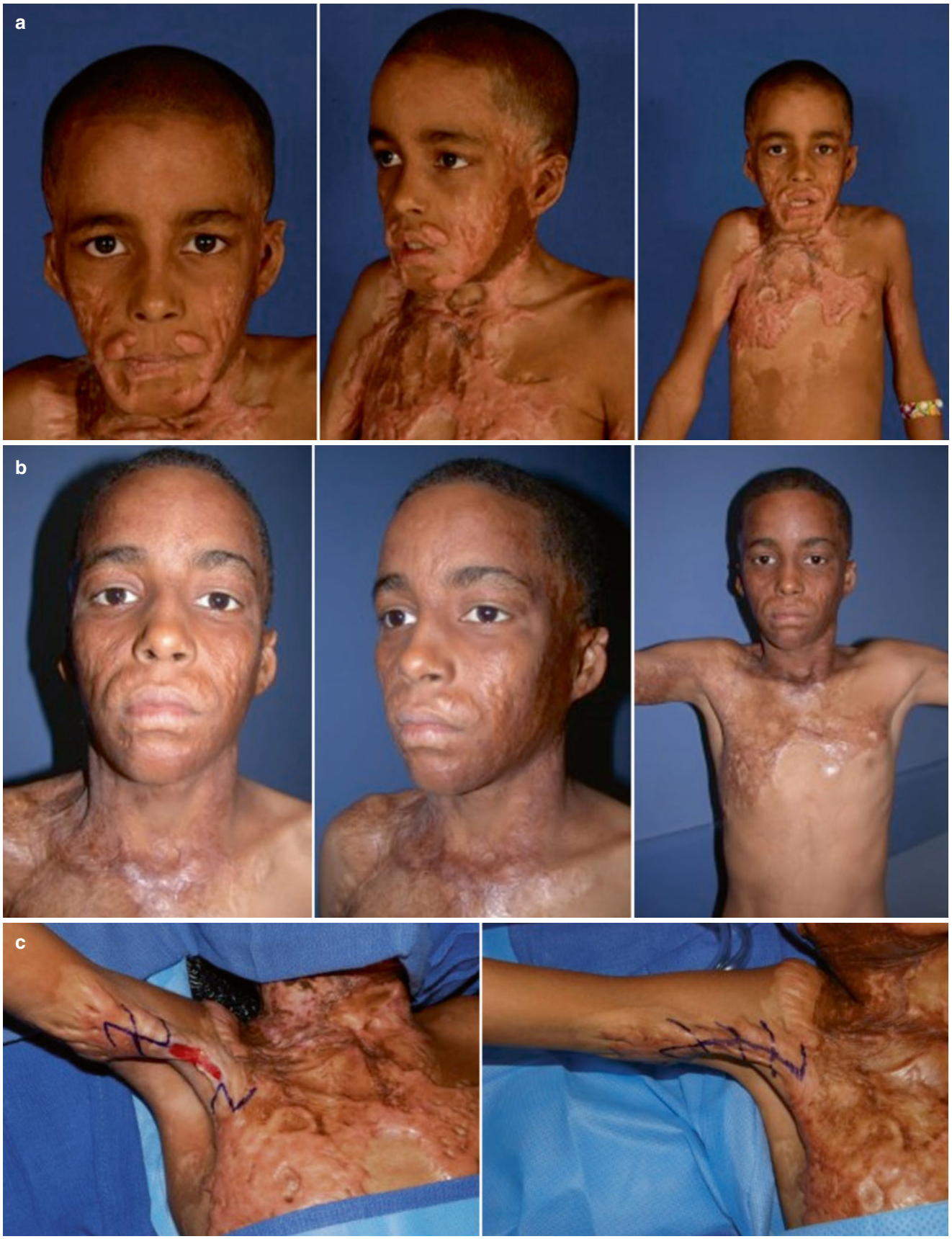


Fig. 34.4 A–E: Case 4

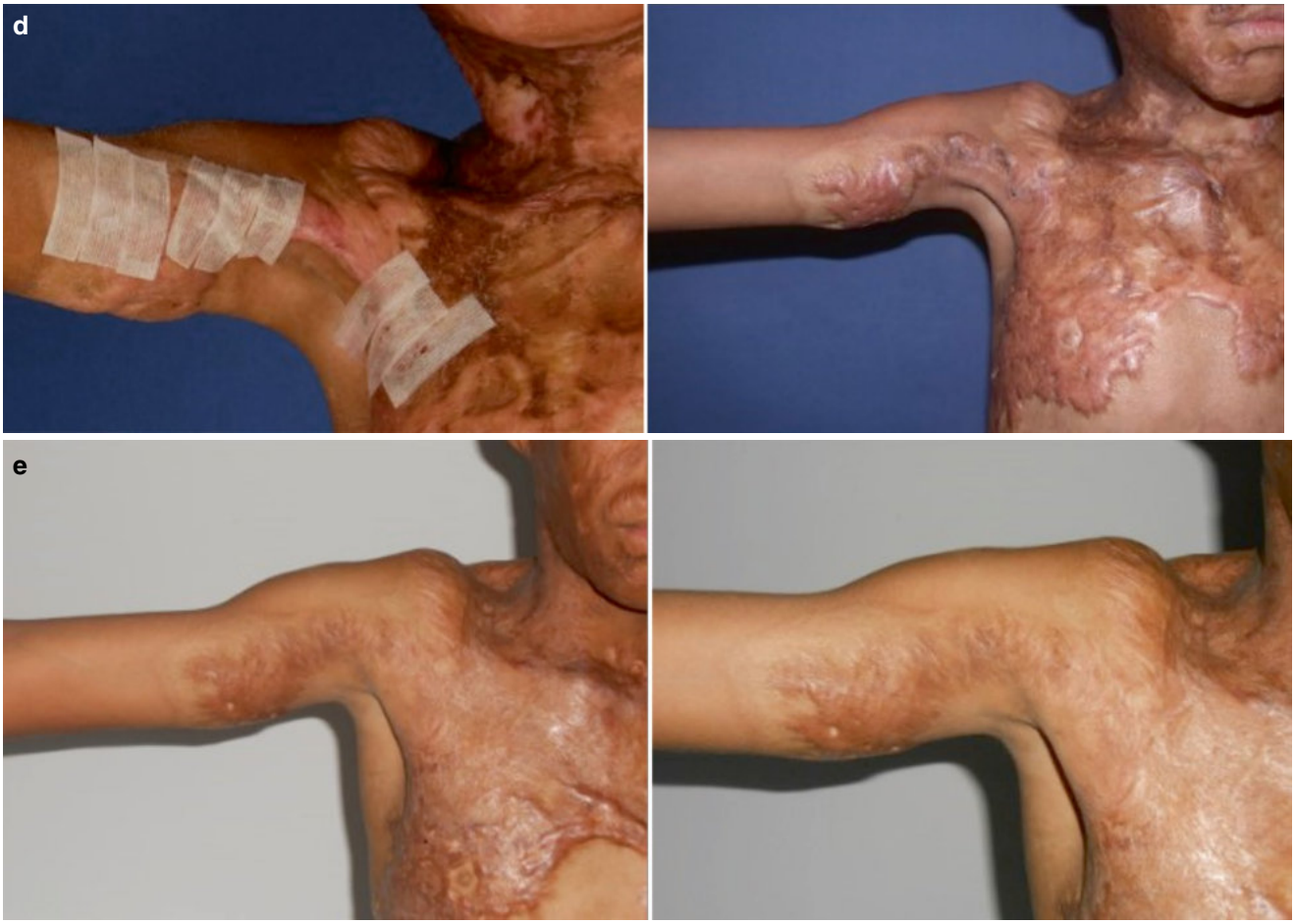


Fig. 34.4 (continued)

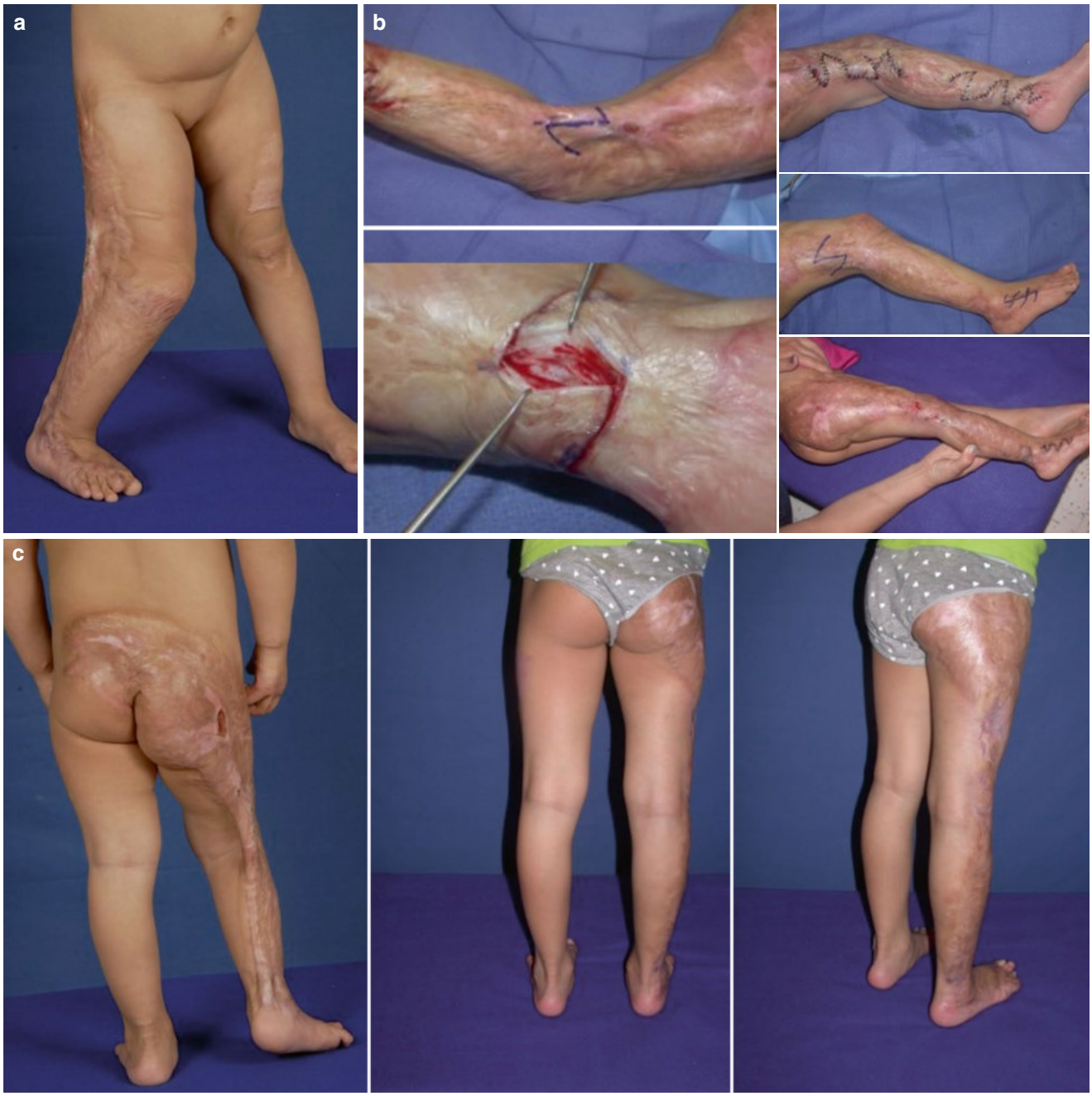


Fig. 34.5 A–C: Case 5

References

1. Parrett BM, Donelan MB. Pulsed dye laser in burn scars: current concepts and future directions. Burns. 2010;36(4):443–9. https://doi.org/10.1016/j.burns.2009.08.015. Epub 2009 Dec 21. PMID: 20022430
2. Macgregor AD (2000) Fundamental techniques of plastic surgery, 10th edn
3. Davis JS. The relaxation of scar contracture by means of z-, or reversed z-type incision: stressing the use of scar infiltrated tissue. Ann Surg. 1931;94:871–84.
4. Longacre JJ, Berry HK, Basom CR, Townsend SF. The effects of Z-plasty on hypertrophic scars. Scand J Plast Reconstr Surg. 1976;10(2):113–28.
5. Donelan MB, Buta MR. The Art of Local Tissue Rearrangements in Burn Reconstruction: Z-Plasty and More. Clin Plast Surg. 2024;51(3):329–47. https://doi.org/10.1016/j.cps.2024.02.010. Epub 2024 Apr 6. PMID: 38789143
6. Cooper LE, Nuutila K, Kemp Bohan PM, Diaz V, Batchinsky M, Carlsson AH, Cancio LC, Chan RK. Analysis of the Utility of CO2 and Pulse-Dye Lasers Together and Separately in the Treatment of Hypertrophic Burn Scars. Ann Plast Surg. 2022;89(2):166–72. https://doi.org/10.1097/SAP.0000000000003240. PMID: 35943226
7. Miletta N, Siwy K, Hivnor C, Clark J, Shofner J, Zurakowski D, Anderson RR, Lee K, Donelan M. Fractional ablative laser therapy is an effective treatment for hypertrophic burn scars: a prospective study of objective and subjective outcomes. Ann Surg. 2021;274(6):e574–80. https://doi.org/10.1097/SLA.0000000000003576. PMID: 31469749

Local Flaps for Burned Face

35

Jake Laun, Allen Liu, and Julian J. Pribaz

Abstract

A person's face serves as the principal focal point for social interactions, communication with one another, as well as an integral aspect of expressing emotion and functioning in everyday life. Traumatic insults can leave the face deformed and sometimes significantly distorted, causing the victim to withdraw from society and affecting everyday interactions and social events. Burns are one such traumatic event that can cause significant functional as well as aesthetic changes to the face. Reconstruction of the burned face poses a difficult and complex challenge, as local flap options that may be present and available in nonburned faces for reconstructing trauma or skin cancer resection defects are often not available in burned faces. This chapter presents and elucidates various options available for local flap reconstruction in the burned face.

Keywords

Free flap · Advancement flap · Superficial temporal artery · Local flap · Free tissue transfer

35.1 Principles in Facial Burn Reconstructions

The face serves as the pivotal point of expression and conveyance of emotion in social interactions. Traumatic events, such as burns, can often lead to distortion, deformation, and destruction of not only the aesthetic features of the face but also its functions, affecting sight, smell, speech, sleep, breathing, and eating. These functional limitations and facial distortions can lead to social stigmas and disruption of the burn patient's self-confidence and even self-worth, sometimes driving them into seclusion or withdrawal from society. These functional issues depend upon the location of the contracture. For example, in the periorbital region, a cicatricial ectropion can lead to corneal irritation and even abrasions. Lower lip and perioral contractures can lead to significant drooling, impaired oral competence with eating, as well as dental-related complications. Perinasal and alar contractures can lead to issues with breathing and significant congestion. [1] Local flaps in the burned face pose a reconstructive challenge, yet remain a great tool in our armamentarium to reconstruct and improve the burned face.

Facial burns, due to the significant vasculature, heal very well, with partial-thickness burns often left to heal by secondary intention. However, scars can still develop and affect the general contour and function of the face. As with other scars, revision should be delayed until scar maturation is complete, which often takes 6–18 months postburn. Mature scars are more pale, flat, soft, and less irritated compared to the itchy, raised, and erythematous immature scars and are much more suitable for reconstructive measures [2]. This chapter discusses various local flaps and reconstructive approaches in the burned face, including the following problems: (1) resurfacing, (2) contracture release, (3) contour restoration, (4) restoration of hair-bearing tissue, and (5) secondary sculpting of free tissue transfers with local flaps.

J. Laun · J. J. Pribaz (✉)
Department of Plastic Surgery, University of South Florida, Tampa, FL, USA
e-mail: jlaun@usf.edu

A. Liu
Division of Plastic Surgery, Brigham and Women's Hospital, Boston, MA, USA
e-mail: aliu@mgh.harvard.edu

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_35

35.2 Resurfacing

Resurfacing of the face is often approached in a subunit fashion. Local advancement flaps and rotation flaps can be used, but are limited due to a lack of skin laxity. However, in burned skin, full-thickness or thick split-thickness grafts can be used to reconstruct entire subunits. Tissue expansion is an often-utilized approach for subunit reconstruction in the face, including the lateral cheek and forehead for central and nasal defects (Fig. 35.1). The unburned neck and supraclavicular area can also be used for facial resurfacing, but these flaps are discussed in other chapters.

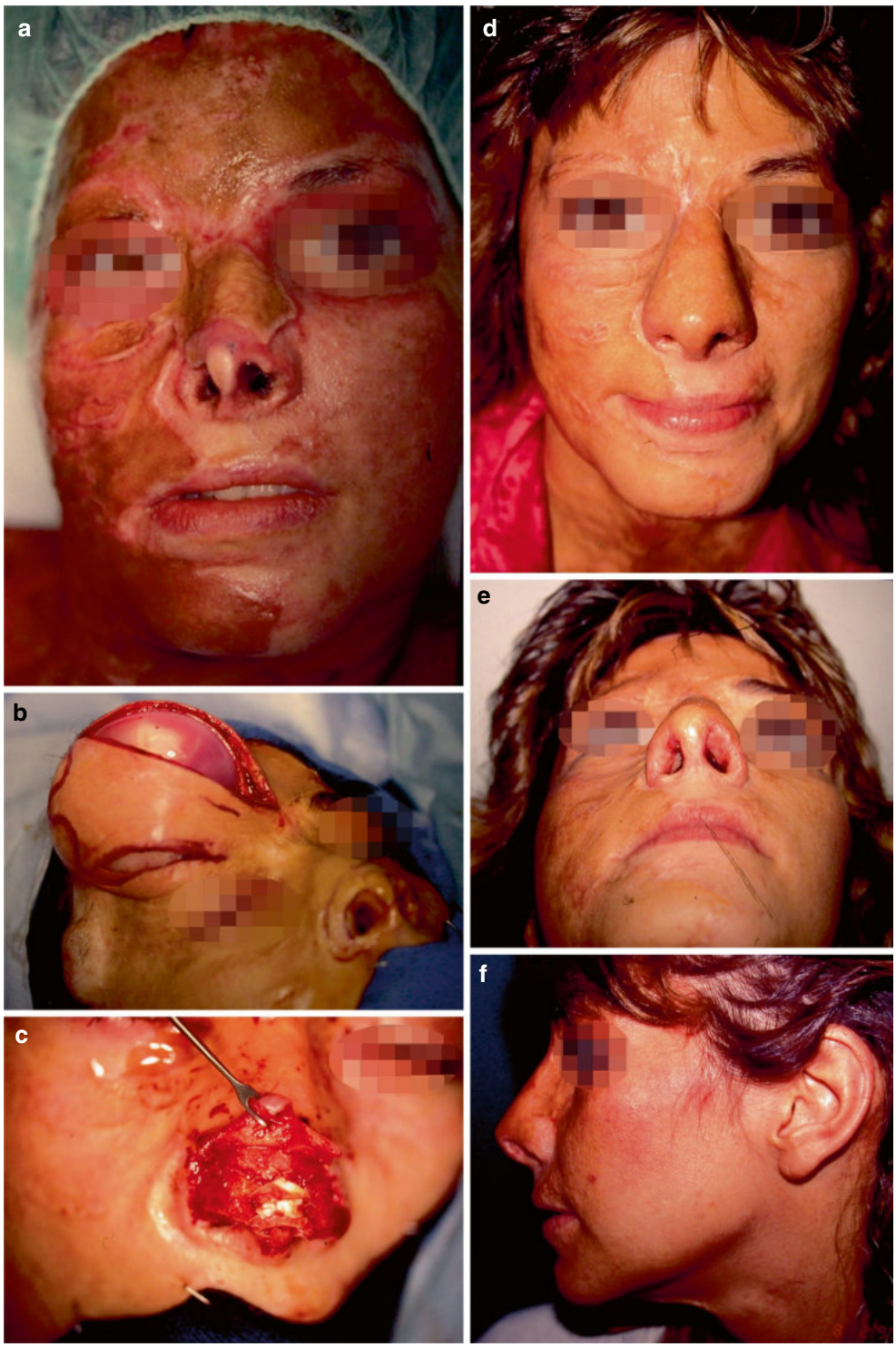


Fig. 35.1 A middle-aged woman suffered thermal burns to the right side of her face. She had superficial burns to the majority of her forehead, right cheek, dorsum of the nose, nasal tip, upper and lower eyelids, and chin. The burn injury to her nasal alars was full-thickness, leading to a full-thickness defect of her entire right ala and almost a 90% defect of her left ala (**a**). Burn scarring and contracture also led to loss of projection and abnormal contour of her nasal tip. Tissue expansion of right forehead skin was performed for reconstruction of her nasal alar defects and also to resurface her nasal dorsum and tip (**b**). She also had local turnover flaps of healed burn scar on the distal end of the nose for nasal lining, and cartilage grafts were used for support of alar rim and tip projection (**c**). Appearance of the patient after reconstruction (**d**–**f**). Superficial burn scars of the nasal dorsum and nasal tip had been excised and resurfaced with the forehead flap

35.3 Contracture Release

Contractures can develop in many areas of the face; however, they are principally located in and around the most mobile areas, such as the perioral (lips and commissure), periorbital (mainly eyelids), nose, and chin. As with any scar or contracture release, it involves the incisional release of the scar, restoration of normal tissues, and filling of the defect with either another skin graft or local flap. Local flaps can include both nonburned skin as well as previously grafted burn skin, as long as the previous scar has matured and softened and can be based on a subcutaneous vascularized pedicle [4]. Local flaps can be in the form of Z-plasties in webbed or straight-line contractures, local transposition flaps as in upper and lower eyelid contractures, as well as the perinasal area. Cicatricial ectropion of the lower eyelid can lead to eye irritation, and release, either with skin grafting or by utilizing a local transposition flap to fill the resultant defect, can restore form and function. The same can be done in the nasolabial region to release a contracture of the ala.

The perioral region is particularly important in scar contracture release, as circumoral and commissure burns and subsequent contractures can significantly limit opening and closing of the mouth, eating as well as speaking (Fig. 35.2). Burn etiology around the mouth can range from thermal injuries to electrical burns, especially in children who may place a live wire in their mouths, causing burns to their bilateral commissures. As with other areas, contracture release

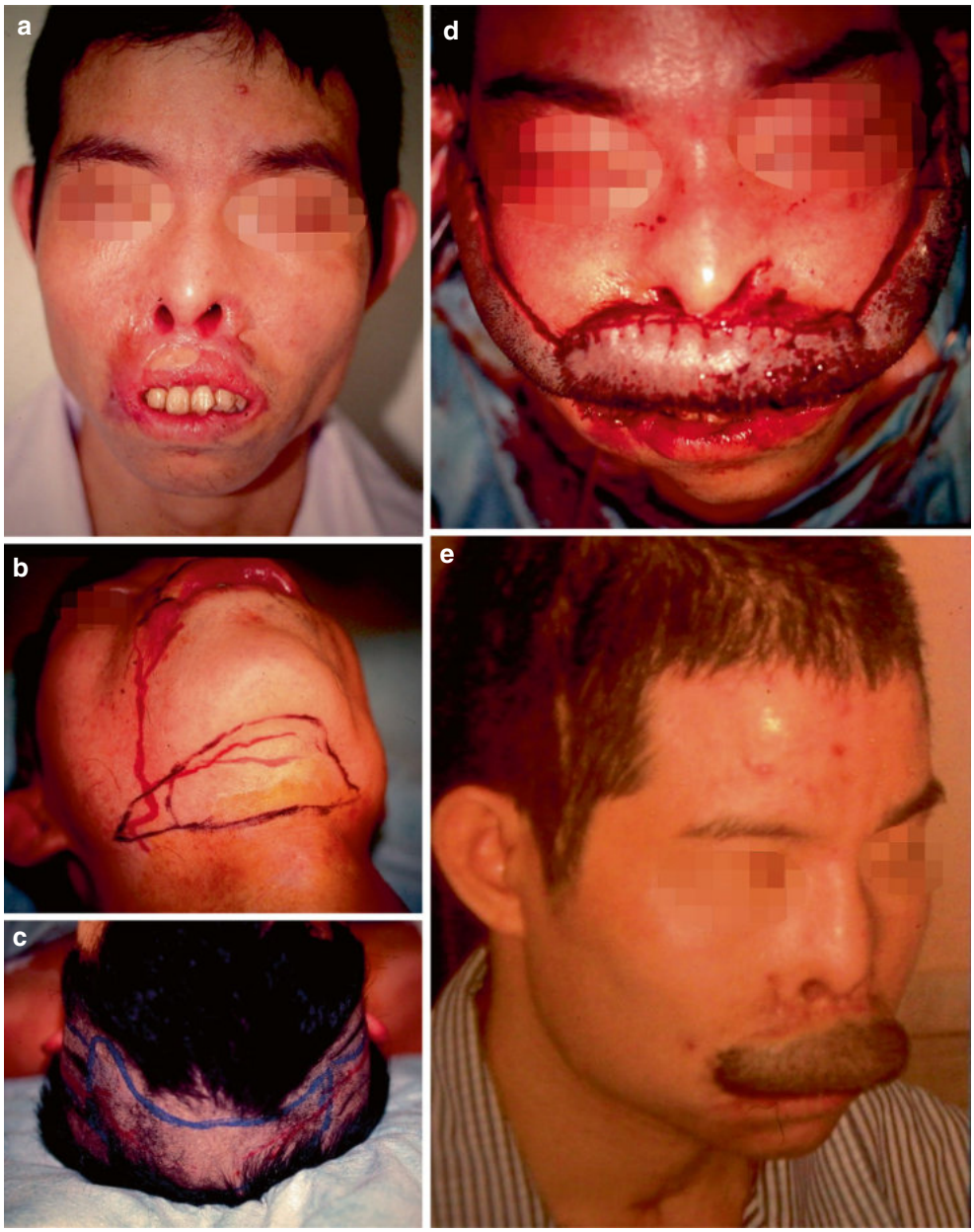


Fig. 35.2 This middle-aged man suffered acid burns to his eyes, nasal tip, nasal alae, cutaneous upper lip, as well as oral mucosa on the right side (**a**). He developed blindness and upper lip incompetence due to scar contracture of the cutaneous upper lip. In addition, the contracture of his oral mucosal scarring on the right side limited his mouth opening on that side. Submental flap was designed based on the submental artery, which is a branch of the facial artery, to resurface the intraoral defect created after release of oral mucosal contracture on the right side (**b**). To store the hair-bearing cutaneous upper lip after burn scar excision, a bipedicled hair-bearing scalp flap, based on the superficial temporal arteries on both sides, was used (**c**, **d**). The scalp flap was rotated down like a "bucket handle" and inset. The pedicles were divided a few weeks later. Appearance of the patient 1 year after reconstruction (**e**)

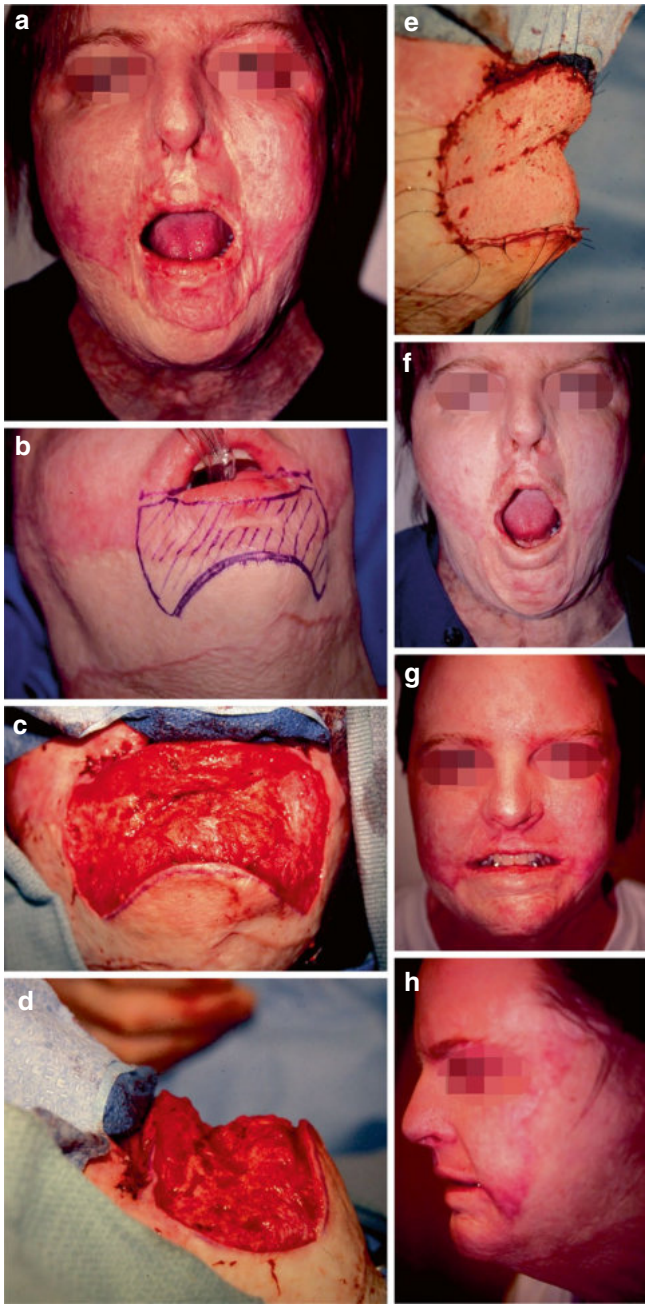


Fig. 35.3 This middle-aged man suffered circumferential oral burns, as well as burns to his bilateral cheeks and nasal alars. Scar contractures of his cutaneous lower lip and chin area produced lower lip ectropion, oral incompetence, and limitation of mouth opening (**a**). The contour of his lower lip and chin area was also abnormal due to the absence of a supramental crease (**b**). The burn scar was first excised to release the contracture. To give his lower lip and chin area a more normal contour, local turnover flaps of subcutaneous tissue were moved from the region of the supramental crease, where an indentation is desired, to the area immediately above (in the lower lip), and immediately below (the chin prominence) (**c**). Note the supramental indentation after flap transposition (**d**). A full-thickness skin graft from the lower abdomen was used to resurface the cutaneous defect, and bilateral commissuroplasties were performed (**e**). Appearance of the patient after reconstruction. Note the increased mouth opening and also the more natural contour of the lower lip and chin, imparted by the supramental crease and chin prominence (**f**–**h**)

often involves release of the burn scar contracture, with local tissue rearrangement, mucosal advancement flap into the apex of the commissure, and vermillion advancement. Other regional flaps, such as a facial artery myomucosal flap or a tongue flap, may also provide enough bulk and extra tissue after contracture release. [9] The underlying mucosal surface of the tongue is best suited for reconstruction, given its similar surface and texture to the lip. [6] Lower lip ectropion and chin scar contractures usually are released and reconstructed with a full-thickness skin graft with part of the underlying dermis, even being able to be utilized for a turnover chin augmentation if there is a lack of bulk (Fig. 35.3).

35.4 Contour Restoration

Not only are scarring and contractures sequelae to facial burns, but the loss of the normal facial contours also occurs and can be divided into intrinsic as well as extrinsic factors. Intrinsic contractures are inherent to the scar itself and produce functional deformities as has already been described, as well as contour irregularities. These can be exacerbated by extrinsic contractures, such as neck contractures exacerbating a lower lip contracture and midface contractures affecting a lower eyelid contracture. Extrinsic contractures like those in the neck, midface, or lower eyelids should be released prior to releasing the lower lip or eyelids [7, 8]. Lower lip contractures can affect the upper lip as well and should be released first [8].

It is often said that contour restoration supersedes scars, and this also applies to the face, where scars can be camouflaged, but the contour must be restored [5]. As is described elsewhere in this book, burned skin still maintains a deeper blood supply and can be used in local fasciocutaneous flaps, such as forehead and nasolabial flaps, and can be recruited to reconstruct defects created by scar contracture release and help restore the contour in prominent facial structures like the nose. These flaps can be raised with a thicker fatty subdermal plexus intact and can also be delayed 1–2 weeks if needed [4].

All tissue surrounding the burns and contractures should be saved and can be used to recruit into the defect created and should not be discarded until the full reconstruction and release is performed and closed, while always respecting aesthetic subunits [2]. An example is reconstructing the nose and upper lip in the setting of extensive other facial and forehead scarring. While resurfacing and reconstructing the upper lip, any tissue may be used to augment and reconstruct the nose [3, 4]. Utilizing a combination of local flaps and skin grafts can help in many areas, especially the lower lip and chin, where local turnover flaps can be used to augment these regions while creating a supramental crease with the resultant defects being able to be covered with a full thickness skin graft (Fig. 35.3).

35.5 Restoration of Hair-Bearing Tissue

Another aspect that must be considered in facial burns is deep burns that damage the hair follicles, leading to loss of hair on the scalp, eyebrows, eyelids, and sideburn/beard region in men. Local flaps that can include hair-bearing skin are very useful in reconstructing these areas. The scalp hair-bearing area can be tissue-expanded and used to reconstruct the sideburns as well as the eyebrows. Restoring hair-bearing skin in prominent regions can significantly improve the overall aesthetics of the face. These scalp flaps are often based on the superficial temporal artery and, in reconstructing the eyebrows, can be tunneled under the temporal skin and into place, making sure to be similar in size, shape, and hair follicle direction to the contralateral eyebrow [2].

Beard reconstruction can be done WITH a local flap reconstruction - such as V-Y flap can be used (Fig. 35.4). For larger areas, superficial temporal artery pedicle or bipedicle staged island flaps from the scalp or the hair-bearing submental region can be used to help in reconstructing the bearded area, though donor site scarring may be more prominent [4] (Fig. 35.2).

35.6 Secondary Sculpting of Free Tissue Transfer with Local Flaps

With large facial burn defects, free flaps often are needed; however, in the initial stages after free flap reconstruction, there is often a lack of normal shape and contour. In secondary burn scar revision, thinning the bulk of the flap by trimming the deeper subcutaneous tissue and even scoring the nasolabial crease, supramental crease, and the philtrim can lead to significantly improved and restored contours (Fig. 35.4).

Local flaps provide the ideal tissue for facial burn reconstruction in terms of tissue color and texture match. Despite the challenges posed by facial burn reconstruction, the following general principles can be applied to optimize outcomes: (1) delay of reconstruction until after scar maturation, (2) release of contractures and extrinsic sources of distortion, (3) the primacy of contour restoration over scarring, (4) conservation of tissues, even scarred ones, for reconstruction, and (5) use of hair-bearing flap to restore normal hairlines in hair-bearing areas.

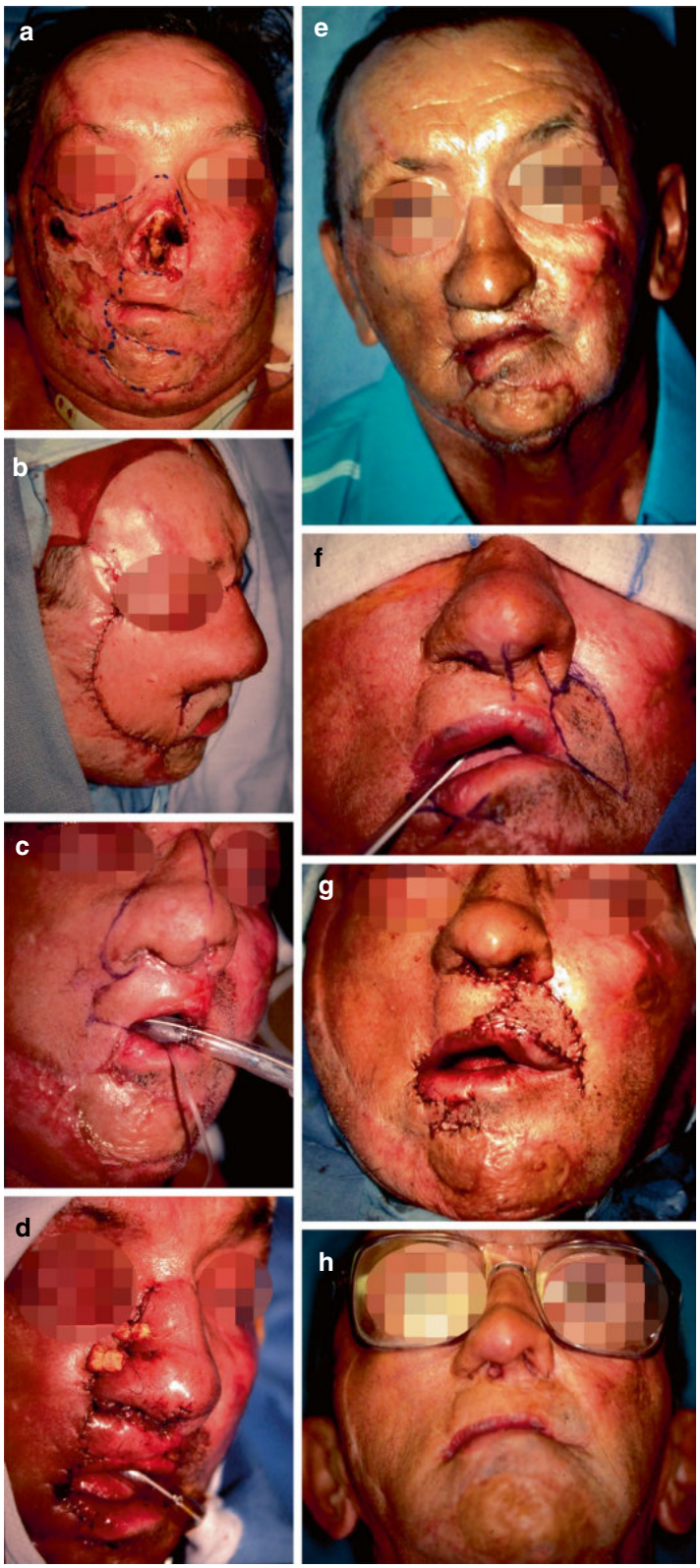


Fig. 35.4 This middle-aged man suffered thermal burns to his face, leaving him with a full-thickness defect of the lower third of his nose, scar contractures of his right central cheek and malar region, as well as a nonhealing ulcer over his right zygomatic prominence (**a**). He underwent a prelaminated free radial forearm flap for reconstruction of the lower third of his nose and to resurface his right central cheek and malar region (**b**). The area reconstructed by the prelaminated free flap lacked natural contours, with no clear boundary between the right cheek and the nasal sidewall, as well as an absent right nasolabial fold. The flap was sculpted to create these natural landmarks. Incisions were made along where the cheek is expected to border on the nasal sidewall and the nasal ala. The expected location of the nasolabial fold was also incised (**c**, **d**). Underlying soft tissue was trimmed, and the incisional edges were tacked down to the deep fascial layer to further enhance the definition of the subunit borders. More natural contour of patient's right face, with more defined cheek–nasal sidewall–ala borders and nasolabial fold (**e**). This patient also had a V-Y advancement of left upper lip hair-bearing tissue to reconstruct an area of burn alopecia centrally (**f**–**h**)

References

1. Goverman J, He W, Martello G, Whalen A, Bittner E, Schulz J, Gibran N, Herndon D, Suman O, Kowalske K, Meyer WJ, Ryan C, Schneider J. The presence of scarring and associated morbidity in the burn model system national database. Ann Plast Surg. 2019;82(3 Suppl 2):S162–8.
2. Achauer B. Burn reconstruction. 1st ed. Stuttgart: Thieme; 1991.
3. Achauer B. Reconstructing the burned face. Clin Plast Surg. 1992;19:623–36.
4. Feldman J. Secondary repair of the burned upper lip. Perspectives Plast Surg. 1987;1:31–72.
5. Guo L, Pribaz JR, Pribaz JJ. Nasal reconstruction with local flaps: a simple algorithm for management of small defects. Plast Reconstr Surg. 2008;122:130e–9e.
6. Jackson I. Local flaps in head and neck reconstruction. 2nd ed. St. Louis: Quality Medical; 2007.
7. MacLennan SE, Corcoran JF, Neale HW. Tissue expansion in head and neck burn reconstruction. Clin Plast Surg. 2000;27:121–32.
8. Neale HW, Billmire DA, Carey JP. Reconstruction following head and neck burns. Clin Plast Surg. 1986;13:119–36.
9. Pribaz JJ, Meara JG, Wright S, Smith JD, Stephens W, Breuing KH. Lip and vermilion reconstruction with the facial artery musculomucosal flap. Plast Reconstr Surg. 2000;105:864–72.

The Square Flap Method

36

Chenyu Huang and Rei Ogawa

Abstract

The square flap method refers to the modified three-flap Z-plasty that combines one square-advancement flap with two triangular transposed flaps. It is mainly used to reconstruct single linear or band scar contractures in web spaces such as the axilla and elbow, but can also be used to correct clefts, cryptotia, and epicanthal folds. Its function is to increase the length between two points on the skin surface (i.e., the commissure) by up to 2.825-fold. This greatly reduces the biomechanical skin tension on the scar, which in turn decreases postsurgical recurrence. Moreover, the commissure is not only lengthened by the square flap; it also forms a three-dimensional trough that is sufficiently deep and wide and has the required shape. The square flap method offers superior lengthening capacity and restoration of function and aesthetics compared to the single-, four-, and five-flap Z-plasties. It also does not divide the hairy regions in the axilla, thus futhre promoting good aesthetics. Thus, the square flap achieves good outcomes without requiring skin excisions.

Keywords

Square flap · Web reconstruction · Commisure lengthening; Stereometric geometrical modeling · Finite element analysis

36.1 Definition and History

The square flap method combines three local flaps, namely, a square-advancement flap and two triangular transposed flaps, as shown in Fig. 36.1.

The standard square flap method was first proposed by Hyakusoku and Fumiiri in 1987 for treating burn contractures and correcting cryptotia and clefts [1]. This reconstruction method was a modification of the square flap proposed by Limberg in 1963. Specifically, while the angle of the first triangular flap (α) remained at 45°, the angle of the seconde triangular flap (β) was changed to 90°. This improved the lengthening achieved by the flap. It also meant the suture line was not parallel to the line of lengthening. It should be noted, however, that the α and β angles can be varied [1, 2], albeit with the proviso that the angles of the triangular flaps should be as blunt as possible to prevent acute tip necrosis. This flexibility makes the square flap method highly versatile. Consequently, it has been used to reconstruct many defects [1]. In particular, it has been used to release linear band con-

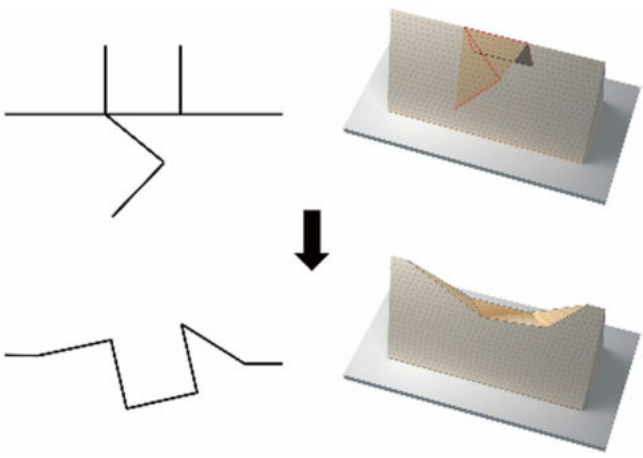


Fig. 36.1 Schematic depiction of the standard square flap method (α = 45°and β = 90°). The figure shows the linear (left) and three-dimensional (right) design before (top) and after surgery (bottom). (From Huang and Ogawa [9] with permission)

C. Huang (✉)
Department of Dermatology, Beijing Tsinghua Changgung Hospital, School of Clinical Medicine, Tsinghua University, Beijing, China
e-mail: huangchenyu@mail.tsinghua.edu.cn

R. Ogawa
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_36

tractures and to reconstruct the web spaces in the axilla [3], neck, elbow [1], and 1–4 palmar/dorsal digital web spaces [4, 5]. It has also been used to correct various clefts (cleft palate [6] and cleft earlobe [1]), cryptotia [7], and epicanthal folds [8].

36.2 Indications

The square flap is indicated for single linear or band contractures in the web spaces at various locations. Examples include the following: (1) single-band scar contractures on the anterior (Type IIa) or posterior axillary line (Type IIb) of the axillary web; (2) single digital joint contractures on the palmar or dorsal side (Type I); (3) linear or band scar contractures at the chin/anterior neck web; (4) linear or band contractures on the flexor/palmar or dorsal surface of the cubital and wrist joints (Type I) [9]; and (5) clefts, cryptotia, and epicanthal folds. Larger and deeper tissue defects should be treated with choices further up the reconstructive ladder (e.g., skin grafts, pedicled flaps, or free flaps).

36.3 Effects and Efficacy

The square flap lengthens the commissure. This reduces the local biomechanical skin tension and thus prevents postsurgical recurrence. Its three-dimensional shaping effect means that it also aesthetically restores commissural anatomy.

36.3.1 Functional Reconstruction

To permanently restore the anatomical function of web spaces impeded by pathological scar contractures, the linear band should be substantially lengthened along its long axis. This objective is perfectly met by the square flap method. Our stereometric geometrical modeling analyses indicate that the standard square flap yields better maximum stereometric commissure lengthening (2.825-fold) than the single (60°, 1.732-fold), four-flap (45°, 2.239-fold), and five-flap (60°, 1.366-fold) Z-plasty methods (Figs. 36.1, 36.2, 36.3 and 36.4) [9].

Moreover, the gain in geometrical length does not require additional skin excision, nor does it come at the expense of the physiological blood supply. Compared to the other three Z-plasties, the square flap yields the largest nourishable flap area ($1.854a^2$) and the longest incision/contact length (5a). Moreover, the minimal width of the square flap is equal to that of the four-flap Z-plasty (0.765a), despite the fact that the two methods have identical maximum length-to-width ratio (1.207) [9]. In addition, the length achieved by the square flap means that it imposes the least physiological tension on the adjacent skin. This minimizes adjacent skin deformity and also means that the square flap is the least reliant of the Z-plasties on the laxity of the adjacent healthy skin [9].

The efficient lengthening of the square flap means that the resulting skin tension is low. This, together with the sufficient blood supply and the fact that the suture lines are not parallel to the direction of lengthening, means that full functional reconstruction can be achieved with low recurrence. Moreover, if the contracture recurs, the square flap method can be repeated, as it reliably corrects such recurrences [5].

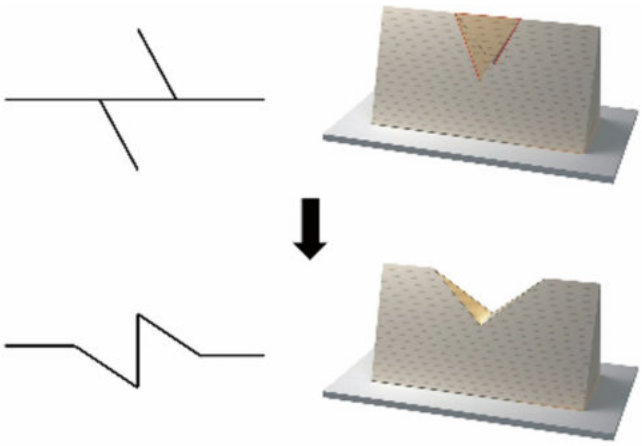


Fig. 36.2 Schematic depiction of the single Z-plasty method (60°). The figure shows the linear (left) and three-dimensional (right) design before (top) and after surgery (bottom). (From Huang and Ogawa [9] with permission)

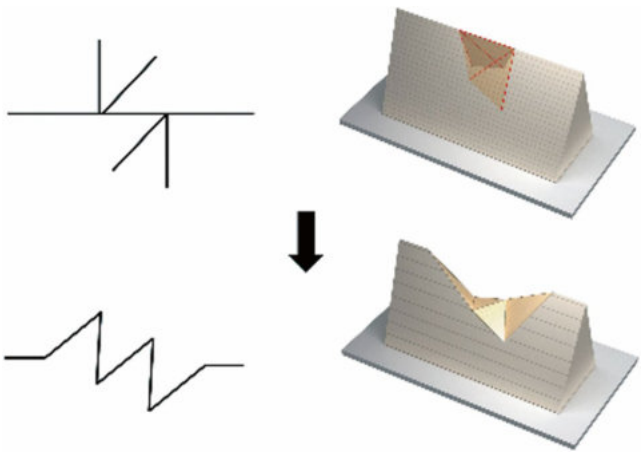


Fig. 36.3 Schematic depiction of the four-flap Z-plasty (45°). The figure shows the linear (left) and three-dimensional (right) design before (top) and after surgery (bottom). (From Huang and Ogawa [9] with permission)

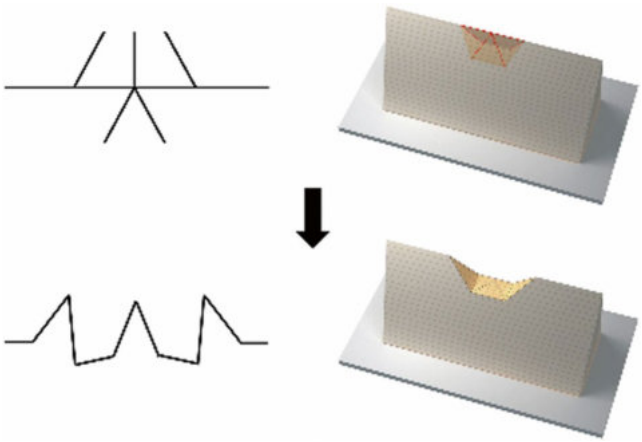


Fig. 36.4 Schematic depiction of the five-flap Z-plasty (60°). The figure shows the linear (left) and three-dimensional (right) design before (top) and after surgery (bottom). (From Huang and Ogawa [9] with permission)

36.3.2 Aesthetic Restoration

To restore the basic functions of the web bearing a pathological scar contracture, it is sufficient to increase the length of the commissure. However, this will not restore the delicate aesthetics of the web, which requires reconstruction of the width, depth, and shape of the web. This can be effectively achieved with the square flap. Specifically, the centrally located square-advancement flap in this method serves as the floor of the web space and controls its width, while the two lateral triangular transposed flaps determine the depth of the commissure. Thus, combining the three flaps generates a natural slope with a flat palm surface and palmar inclination of the dorsal surface, thus reestablishing the anatomy of the original web space [5, 9].

The square flap also has an advantage over the other Z-plasties with regard to the axilla. While other Z-plasties divide this hair-bearing region by cutting across it, the square flap preserves it. This maintains the natural hair direction, thus promoting good aesthetic outcomes [1].

36.3.3 Flexibility in Theoretical Design and Practical Applications

The square flap method is also highly flexible in terms of design and can be combined with other local flaps, as follows.

First, the angles of the square and triangular flaps can be modified to fit the reconstructive requirements. For example, the angles of the two triangular flaps can be modified from the standard 45° and 90° to 45° and 45°, or 45° and 60°, based on the morphology and location of surrounding scars and pliability of the adjacent healthy skins [10]. This permits flexible transposition and ensures an efficient blood supply and easy donor-site closure.

Second, the square flap can be combined with itself to reconstruct complex deformities. One example of using two square flaps in a parallel fashion is also known as the two-facing square flap method [10]. To use this approach to lengthen a contracture, which generally takes an ovoid shape, two square flaps are placed on opposite sides of the long axis of the contracture such that the bottoms of the square-advancement flaps run along the edge of the ovoid. The square flap designs mirror each other and the square-advancement flap lies either outside (Pattern 1) or inside (Pattern 2) the contracture (Sects. 36.4.5 and 36.4.6). Such two-facing square flaps are particularly helpful for reconstructing highly complex web contractures that involve both the anterior and posterior axillary lines.

Third, the square flap can be combined with other local flaps. An example is when not only the pathological contracture must be broken but also vulnerable tissues near the joints must be protected. These combinations effectively release the scar contracture while guaranteeing sufficient blood supply.

This flexibility of the square flap means it has many practical applications.

36.4 Application Examples

36.4.1 Case 1: Burn Contracture in the Axilla

A 53-year-old man had a scar contracture in his right axilla after flame burns (Fig 36.5).

36.4.2 Case 2: Burn Contracture in the Elbow

A 20-year-old woman had a severe scar contracture on her elbow after a burn injury (Fig 36.6).

36.4.3 Case 3: Burn Contracture in the Digital Web

A 30-year-old man had a scar contracture on the first web of his right hand due to flame burns, resulting in a 60° range motion of right thumb abduction (Fig 36.7).

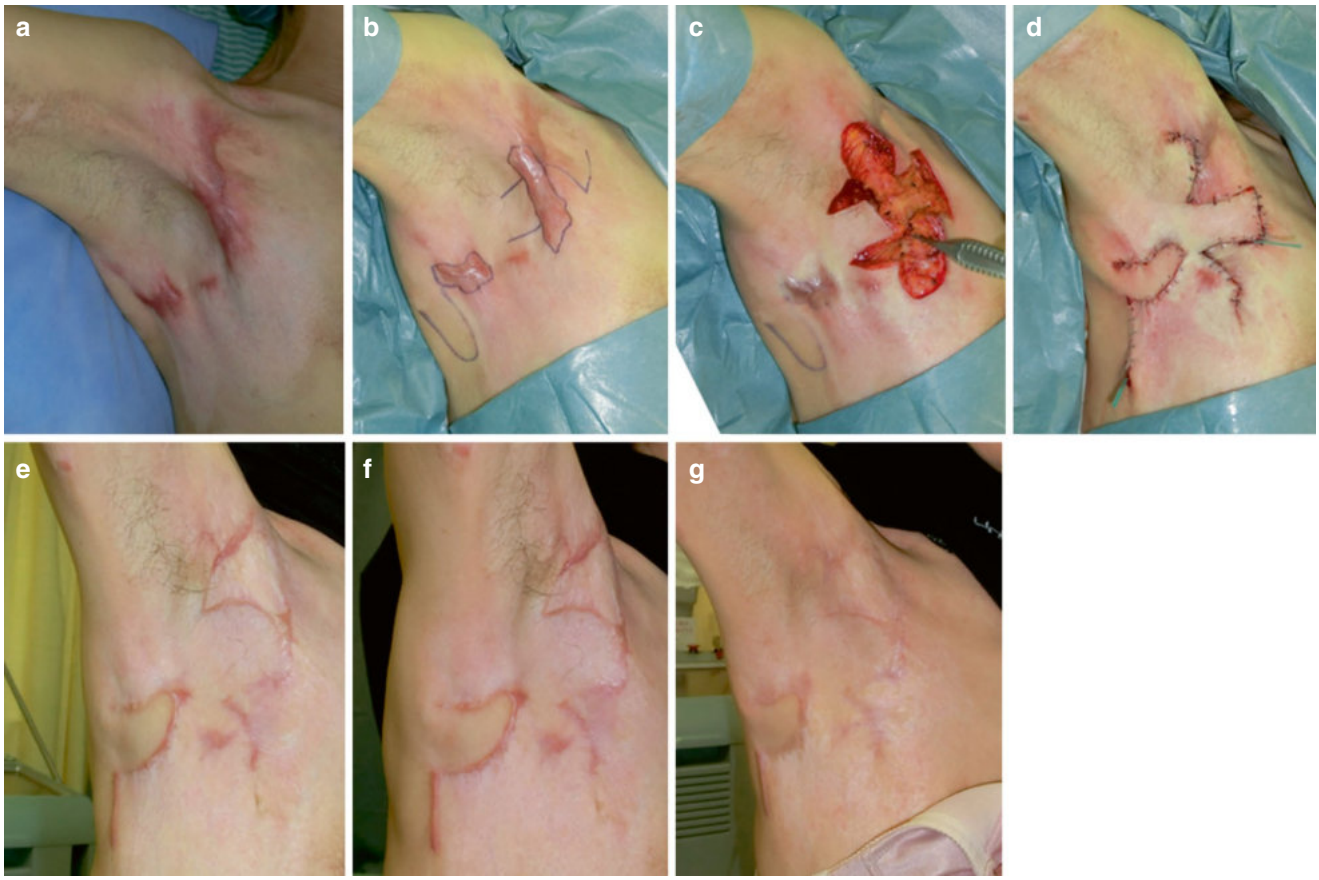


Fig. 36.5 A 53-year-old man had a scar contracture in his right axilla after flame burns. (**a**) Original contracture. (**b**) Incision design. (**c**) After flap elevation. (**d**) Immediately after surgery. (**e**) At the 3-month follow-up. (**f**) At the 6-month follow-up. (**g**) At the 12-month follow-up [9]. (From Huang and Ogawa [9] with permission)

36.4.4 Case 4: The Square Flap Combined with Other Local Flaps for Burn Contracture in the Elbow

A 10-year-old girl had a severe scar contracture on her elbow after a burn injury (Fig 36.8).

36.4.5 Case 5: Releasing Complex Axillary Linear Burn Contractures with the Pattern 1 Two-Facing Square Flap Method

A 74-year-old man had limited shoulder abduction due to right-sided axillary contracture that involved both the anterior and posterior axillary lines 1 year after flame burns (Fig 36.9) .

36.4.6 Case 6: Releasing Complex Axillary Linear Burn Contractures with the Pattern 2 Two-Facing Square Flap Method

A 73-year-old woman had limited shoulder abduction due to left-sided axillary contracture that involved both the anterior and posterior axillary lines 1 year after flame burns (Fig 36.10).

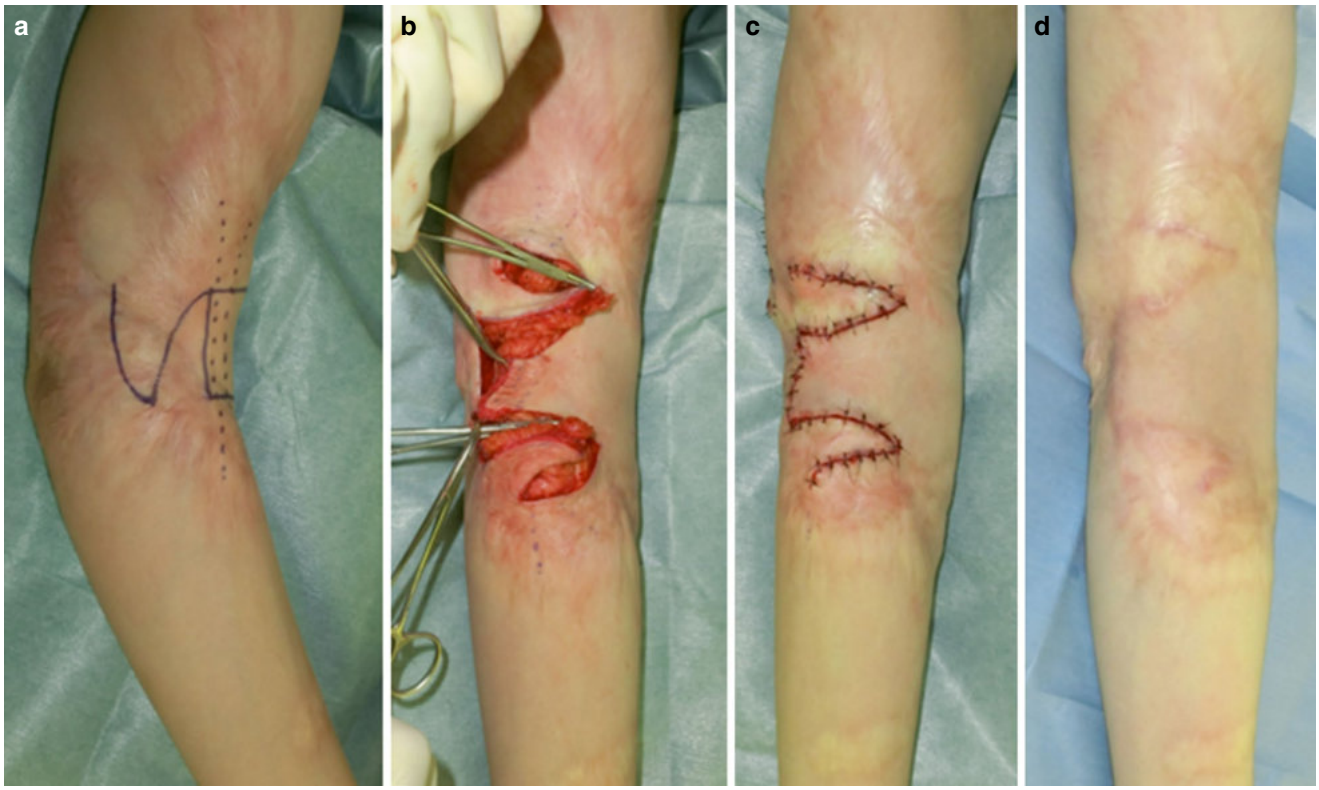


Fig. 36.6 A 20-year-old woman had a severe scar contracture on her elbow after burn injury. (**a**) Design of the square flap. (**b**) Intraoperative view. (**c**) Flap transfer and the outcomes immediately after surgery. (**d**) At the 18-month follow-up. (From Ogawa [11]; Creative Commons CC BY; https://creativecommons.org/licenses/by/4.0/)

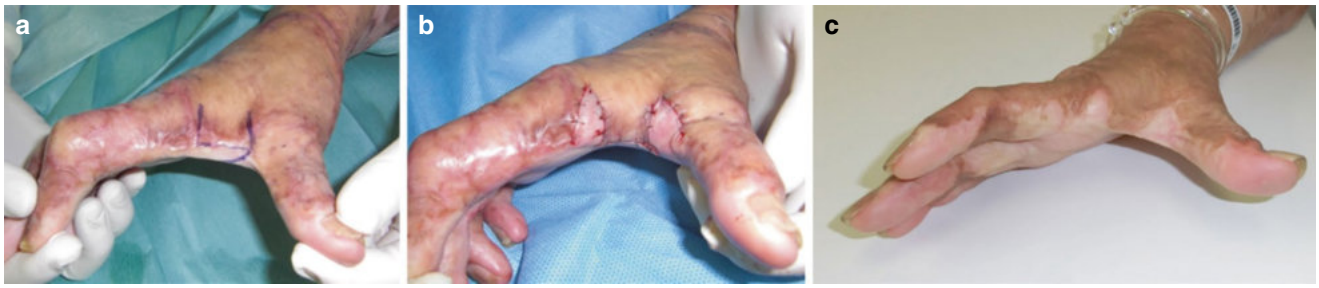


Fig. 36.7 A 30-year-old man had a scar contracture on the first web of his right hand due to flame burns, resulting in a 60° range motion of right thumb abduction. (**a**) Original contracture and incision design. (**b**) Flap transfer and the outcomes immediately after surgery. (**c**) At the 1-year follow-up (From Huang and Ogawa [9] with permission)

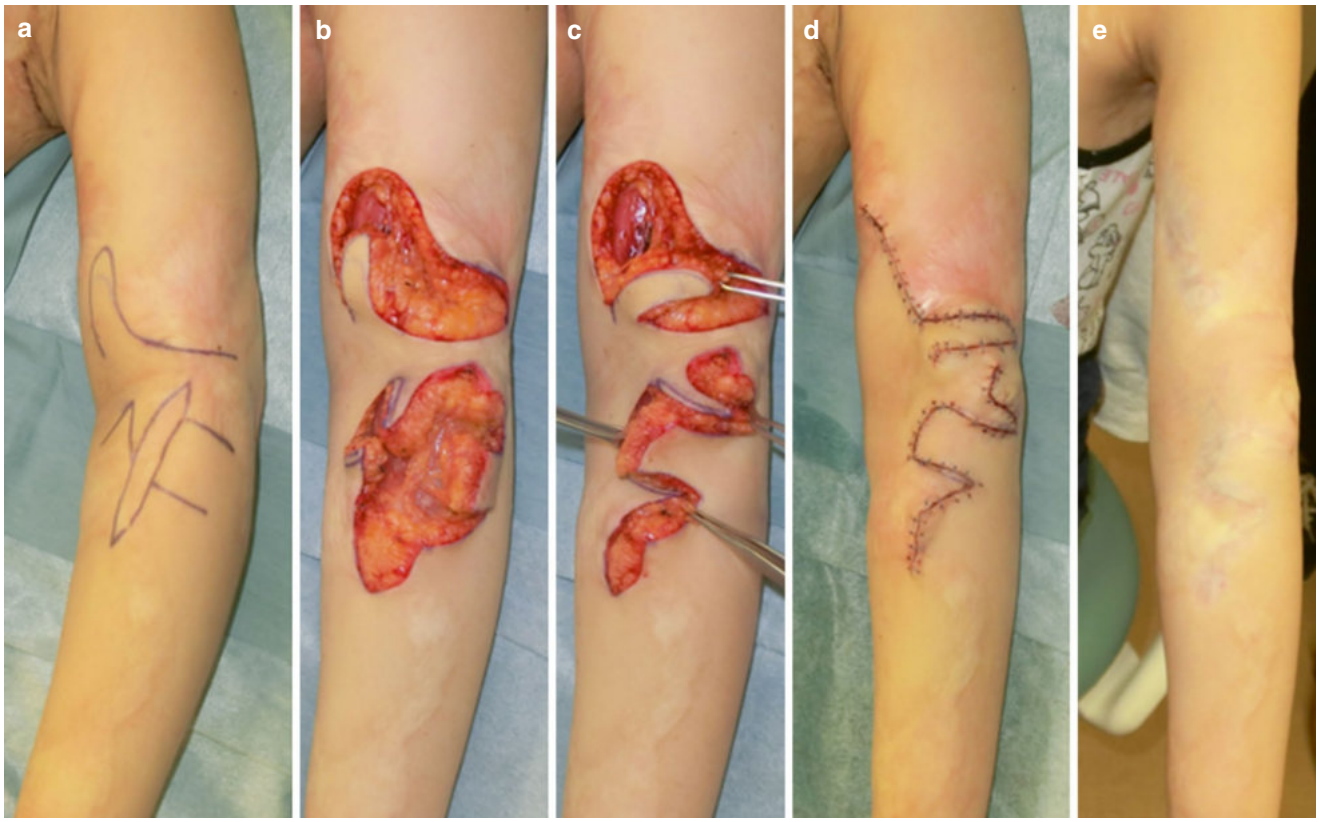


Fig. 36.8 A 10-year-old girl had a severe scar contracture on her elbow after a burn injury. (**a**) Design of the square flap and other local flaps. (**b**) Flap formation. (**c**) Flap transfer. (**d**) The outcomes immediately after surgery. (**e**) At the 2-year follow-up

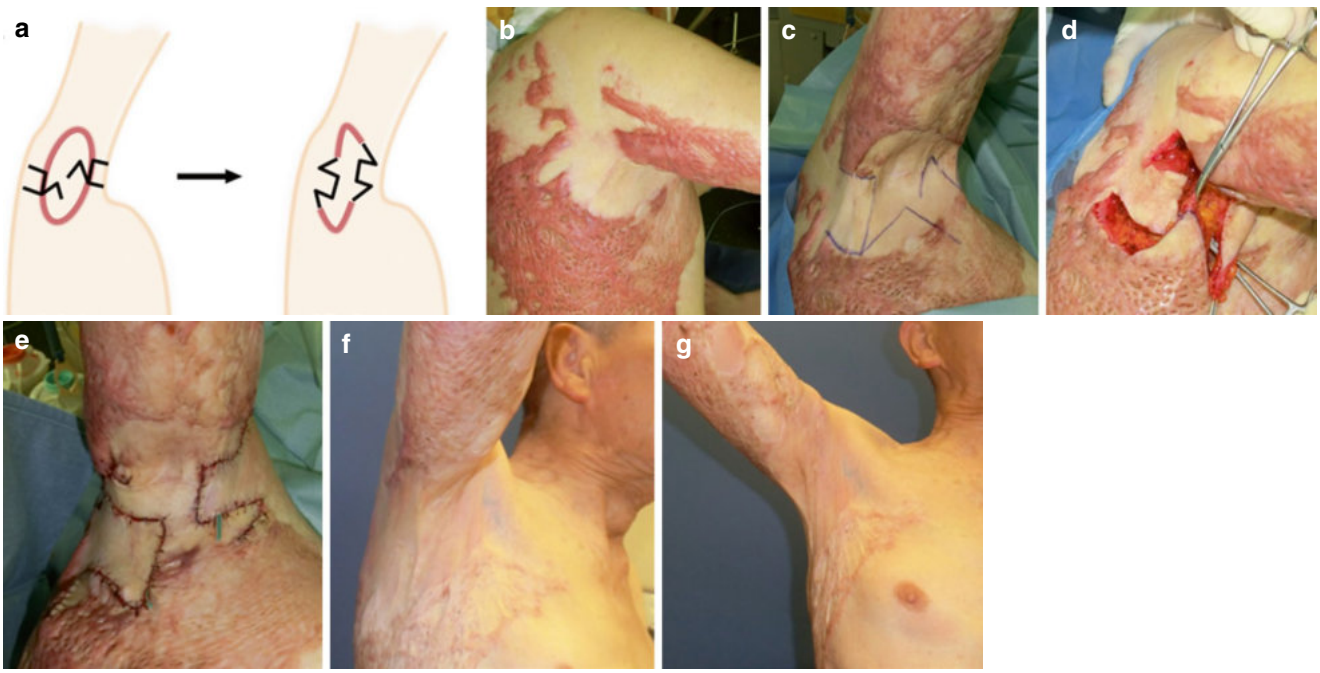


Fig. 36.9 A 74-year-old man had limited shoulder abduction due to right-sided axillary contracture that involved both the anterior and posterior axillary lines 1 year after flame burns. (**a**) Schematic depiction of Pattern 1 two-facing square flaps. (**b**) Preoperative view from the posterior side showing significant contracture and restriction of the shoulder range of motion. (**c**) Design of the Pattern 1 two-facing square flaps. (**d**) Flap elevation and advancement. (**e**) The outcomes immediately after surgery. (f) and (**g**) At the 1-year follow-up. Adequate range of motion was achieved. (From Quong and Ogawa [10]; Creative Commons Attribution (CC BY) License; https://creativecommons.org/licenses/by/4.0/)

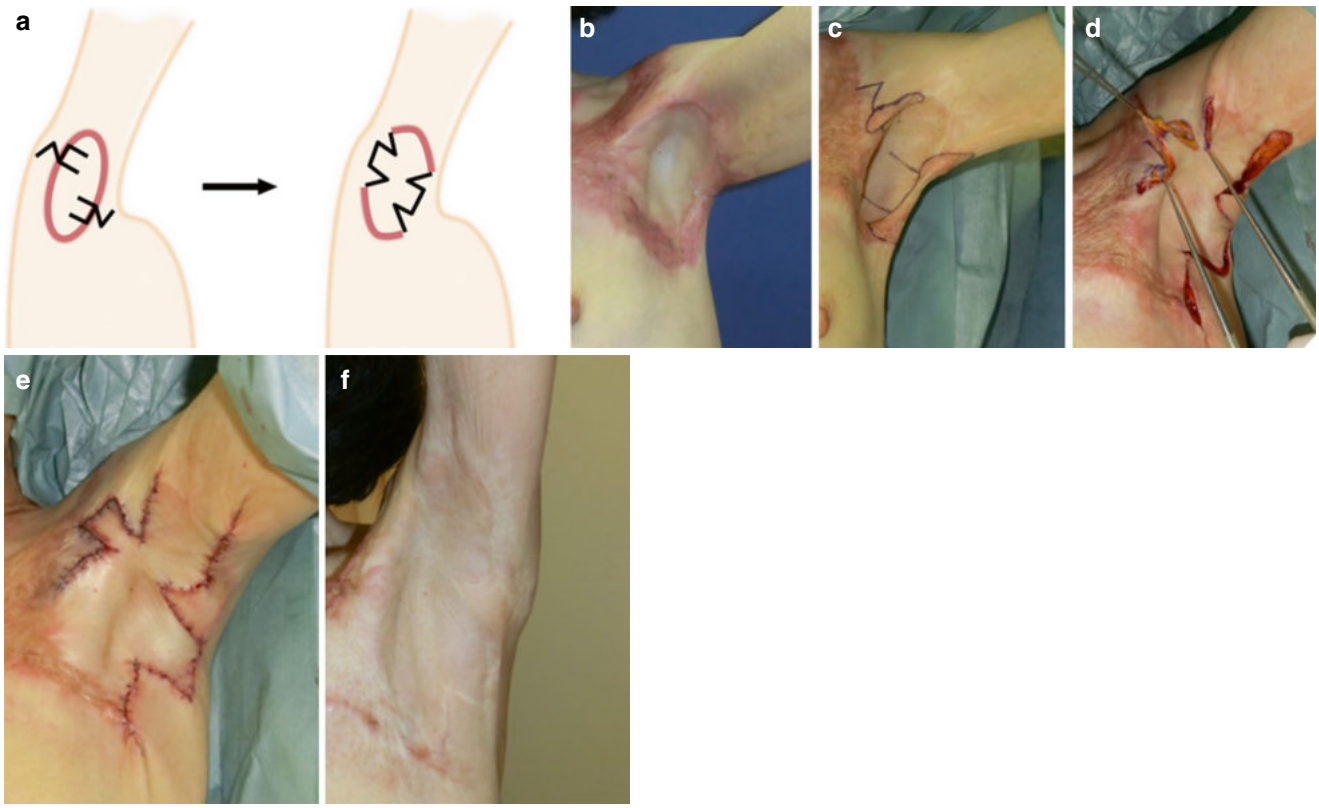


Fig. 36.10 A 73-year-old woman had limited shoulder abduction due to left-sided axillary contracture that involved both the anterior and posterior axillary lines 1 year after flame burns. (**a**) Depiction of Pattern 2 two-facing square flaps. (**b**) Preoperative view showing significant contracture and restriction of shoulder range of motion. (**c**) Design of the Pattern 2 two-facing square flaps. (**d**) Flap elevation and advancement. (**e**) The outcomes immediately after surgery. (**f**) At the 1-year follow-up. Nearly complete range of motion was achieved. (From Quong and Ogawa [10]; Creative Commons Attribution (CC BY) License; https://creativecommons.org/licenses/by/4.0/)

36.5 Summary

The square flap method is a modified three-flap Z-plasty that combines one square advancement-flap and two triangular transposed flaps. It has widely been applied to release linear band contractures and for reconstructing web spaces, as well as correcting various clefts, cryptotia, and epicanthal folds. It can lengthen the commissure by 2.825-fold and aesthetically recreates the web space. When used for contractures in the axilla, it does not disrupt the natural hair flow, thus promoting good aesthetic outcomes. It is highly flexible, as the triangular flaps can take different angles, it can be paired with itself, and it can be combined with other local flaps. The satisfactory performance and safety of this flap mean that it has enjoyed widespread use. Further studies with larger case numbers and longer follow-up periods are expected to broaden the indications, thus allowing this approach to benefit more patients.

Acknowledgment The authors gratefully acknowledge the contributions of Hiko Hyakusoku and Masataka Akimoto to this chapter, as it appeared in the first edition of the book.

References

1. Hyakusoku H, Fumiiri M. The square flap method. Br J Plast Surg. 1987;40:40–6.
2. Karki D, Narayan RP. Role of square flap in post burn axillary contractures. World J Plast Surg. 2017;6(3):285–91.
3. Ogawa R, Hyakusoku H, Murakami M, Koike S. Reconstruction of axillary scar contractures--retrospective study of 124 cases over 25 years. Br J Plast Surg. 2003;56(2):100–5.
4. Balakrishnan G, Vijayaragavan S, Somesh B. Symbrachydactyly. Indian J Plast Surg. 2021;55(1):7–17.
5. Hifny MA, Ogawa R. Square flap method for reconstruction of palmar and dorsal web space burn contractures. Ann Plast Surg. 2022;88(5):496–9.
6. Xu JH, Chen H, Tan WQ, Lin J, Wu WH. The Square flap method for cleft palate repair. Cleft Palate Craniofac J. 2007;44(6):579–84.

7. Xu JH, Wu WH, Tan WQ. Surgical correction of cryptotia with the square flap method: a preliminary report. Scand J Plast Reconstr Surg Hand Surg. 2009;43(1):29–35.
8. Wu W, Xu J, Yan S, He B. Correction of severe congenital epicanthus using the modified square-flap method. Br J Plast Surg. 2000;53:667–8.
9. Huang C, Ogawa R. Three-dimensional reconstruction of scar contracture-bearing axilla and digital webs using the square flap method. Plast Reconstr Surg Glob Open. 2014;2(5):e149.
10. Quong WL, Ogawa R. The two facing square flaps method for release of anterior and posterior axillary line burn contractures. Eur Burn J. 2023;4:529–36.
11. Ogawa R. Surgery for scar revision and reduction: from primary closure to flap surgery. Burns Trauma. 2019;7:7.

Propeller Flap

37

Shimpei Ono, Hiko Hyakusoku, and Rei Ogawa

Keywords

Propeller flap · Skin grafts · Burn injuries · Local tissue · Subcutaneous pedicle · Scar contractures · Flap rotation · Multilobed flap · Pedicled flaps · Color match · Functional recovery · Joint regions · Donor-site defects · Clockwise rotation · Vertical tension · Critical care medicine

37.1 Background of the Technique

Extensively burned patients often lack ample healthy skin for skin grafts. We developed a method using several novel flaps composed of healthy skin left around recipient sites. In 1991, Hyakusoku et al. presented a propeller flap with a subcutaneous pedicle [1]. The original propeller flap was used in intact fossae to reconstruct the axilla or cubitus. The flaps were designed in the center of the fossa and elevated as island flaps. Hyakusoku et al. indicated that perforating vessels are often constant in their pedicles [1]. After this report, improvements such as the multilobed propeller flap [2] and scar band rotation flap [3] were introduced. A subcutaneous pedicle is located under the center of every flap, categorizing these methods as “central axis flap methods.” [4] Nowadays, the subcutaneous pedicle has been refined, and vascular (perforator) pedicle propeller (PPP) flaps [5] are now widely used. This PPP flap is discussed in another chapter of this book.

S. Ono (✉) · R. Ogawa · H. Hyakusoku
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: s-ono@nms.ac.jp

37.2 Ideas and Inspirations for Devising Propeller Flaps

Nippon Medical School Hospital in Tokyo, Japan, where the authors practice, is renowned for establishing Japan's first critical care medicine center in 1977. We have treated numerous patients with extensive burn injuries and post-burn contractures and devised several original flaps using the skin left around the recipient sites. Our focus was on developing pedicled flaps using adjacent local tissue, as the advantage of local tissue transfer lies in its color and texture matching with the missing skin.

Post-burn scar contracture release defects are often covered with skin grafts; however, secondary contraction of the grafted skin can cause recurrence of scar contractures, particularly over joints. Therefore, we preferred using local flaps as much as possible over skin grafts for defect coverage after contracture release. Based on our clinical experience, the flexor side of joint regions (such as the axilla, cubital fossa, or popliteal fossa) of extensively burned patients is often spared from burns due to the defensive posture taken during injury. We frequently find areas of healthy skin between scars when both sides of a joint are involved in contracture. For reconstructing such regions, we considered that the intact healthy skin at the fossa could be useful for releasing neighboring scar contractures.

In 1991, the coauthor of this chapter, Hiko Hyakusoku, reported two cases where propeller flaps were applied to the cubital and axillary regions [1]. The flaps were designed in the center of the fossa and harvested as island flaps, with subcutaneous pedicles allowing approximately 90-degree rotation to release longitudinal scar contractures. The donor-site defects after rotation were closed with skin grafts. The blade-shaped flaps, resembling a helicopter propeller, led to the naming of the "propeller flap." We believe that a straightforward and descriptive name helps to spread the idea. We defined the original propeller flap as an "island skin flap with a propeller-like shape that undergoes axial rotation around its vascular pedicle." After this report, modifications such as the multilobed propeller flap were introduced to address the

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_37

need for donor-site grafting [2]. These variations involved attaching small lobules to the sides of the flap to reduce the requirement for grafting.

37.3 Characteristics and Specific Skills of the Method

37.3.1 Propeller Flap Method (Fig. 37.1a)

Flaps are vascularized from the subcutaneous pedicle in the central portion. Generally, there is no need to identify a central perforator using Doppler. Scar contractures are released by flap rotation. The flaps can be rotated easily, and two scar bands can be released simultaneously. However, covering the donor sites can be difficult, and small skin grafts may be needed.

37.3.2 Multilobed Propeller Flap Method (Fig. 37.1b)

The multilobed propeller flap method was developed to overcome the disadvantages of the original propeller flap method. Small lobules attached to the propeller flaps reduce the need for free skin grafts. We have applied the method to various shapes according to the shape of the scar. The flaps are designed as bilobed, trilobed, or quadrilobed, and the pedicle is made as thick as possible to maintain the rotation angle and minimize tension. Rotation can be in the clockwise or counterclockwise direction. Generally, the donor site can be closed primarily after flap elevation and rotation at an angle of 90 degrees.

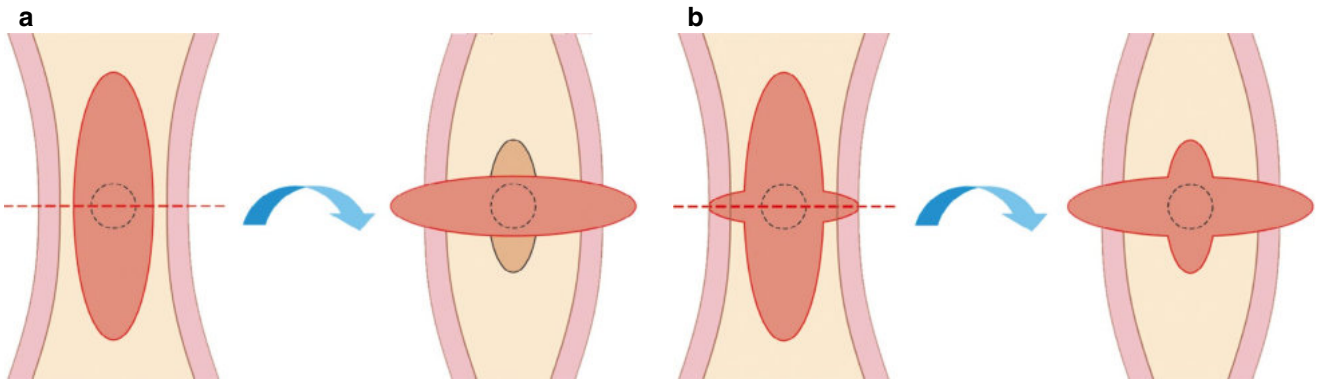


Fig. 37.1 (**a**) Propeller flap method. (**b**) Multilobed propeller flap method

37.4 Case Reports

37.4.1 Case 1

A 17-year-old boy had a scar contracture of the left elbow after severe flame burns due to a traffic accident (Fig. 37.2).

37.4.2 Case 2

A 25-year-old man had scar contractures on his left axilla following an extensive burn (Fig. 37.3).

37.4.3 Case 3

A 13-year-old boy suffered from an extensive flame burn (Fig. 37.4).

37.4.4 Case 4

A 17-year-old boy suffered from extensive burns (Fig. 37.5).

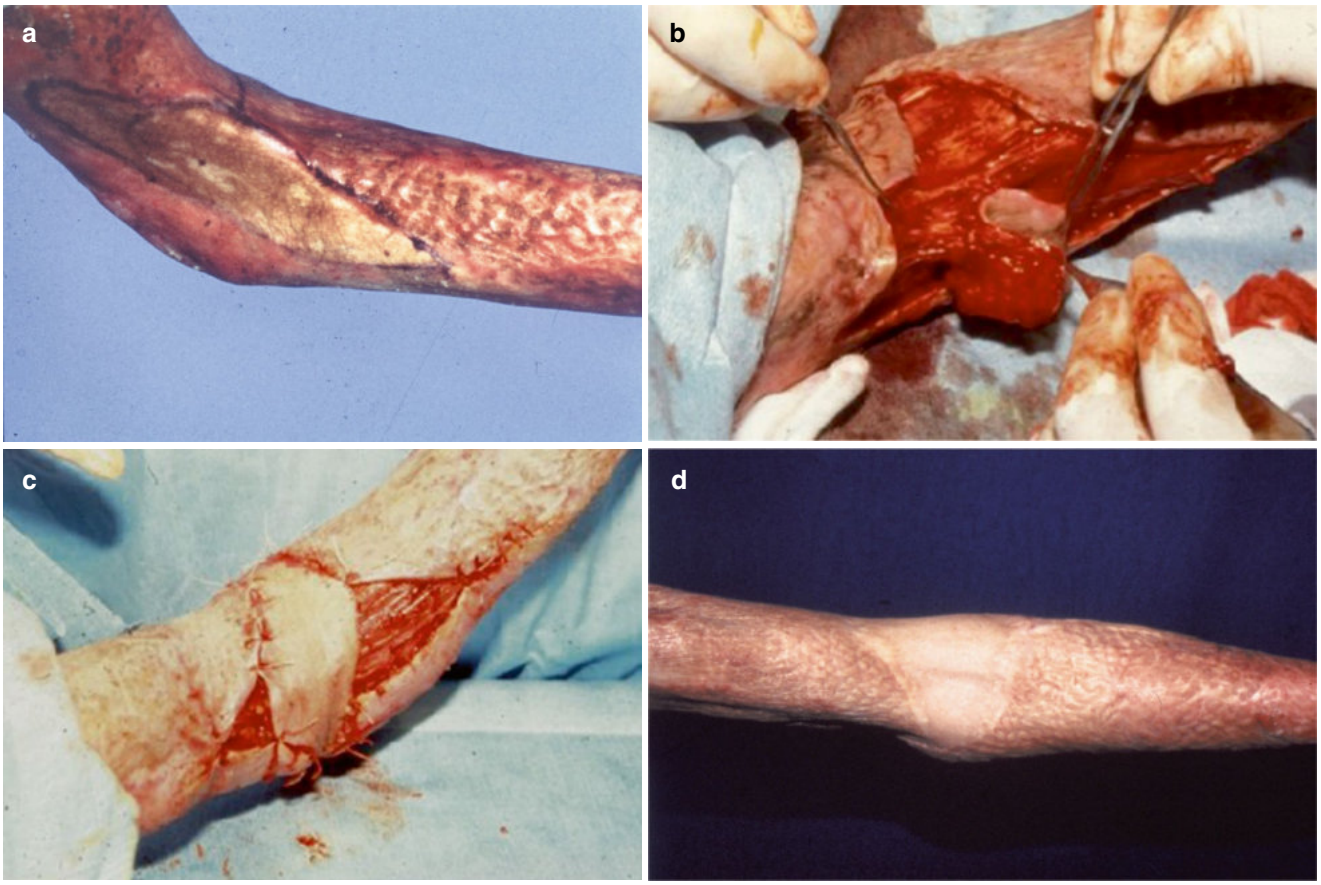


Fig. 37.2 Case 1: A 17-year-old boy had a scar contracture of the left elbow after severe flame burns due to a traffic accident (**a**). A propeller flap was planned to release the contracture. After a 90-degree rotation (**b**, **c**), the skin defects were epithelialized within a month without requiring skin grafts. After a year, the functional recovery of the elbow joint was perfect (**d**)

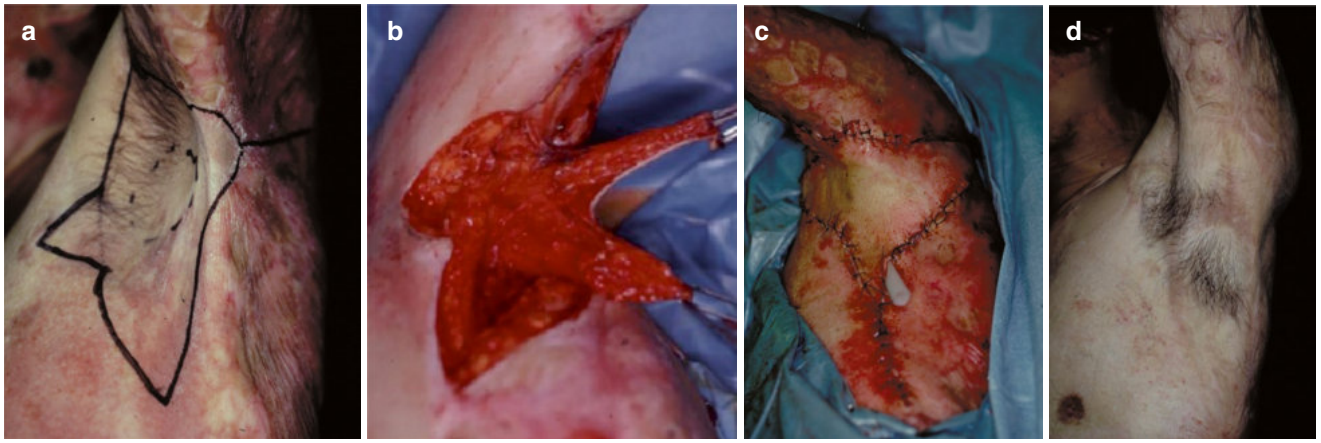


Fig. 37.3 Case 2: A 25-year-old man had scar contractures on his left axilla following an extensive burn. A quadrilobed propeller flap was used to release the contracture (**a**). The flap was rotated 90 degrees, releasing the contracture completely (**b**, **c**). Functionally and cosmetically, the result was excellent, and the axillary hair area was preserved (**d**)

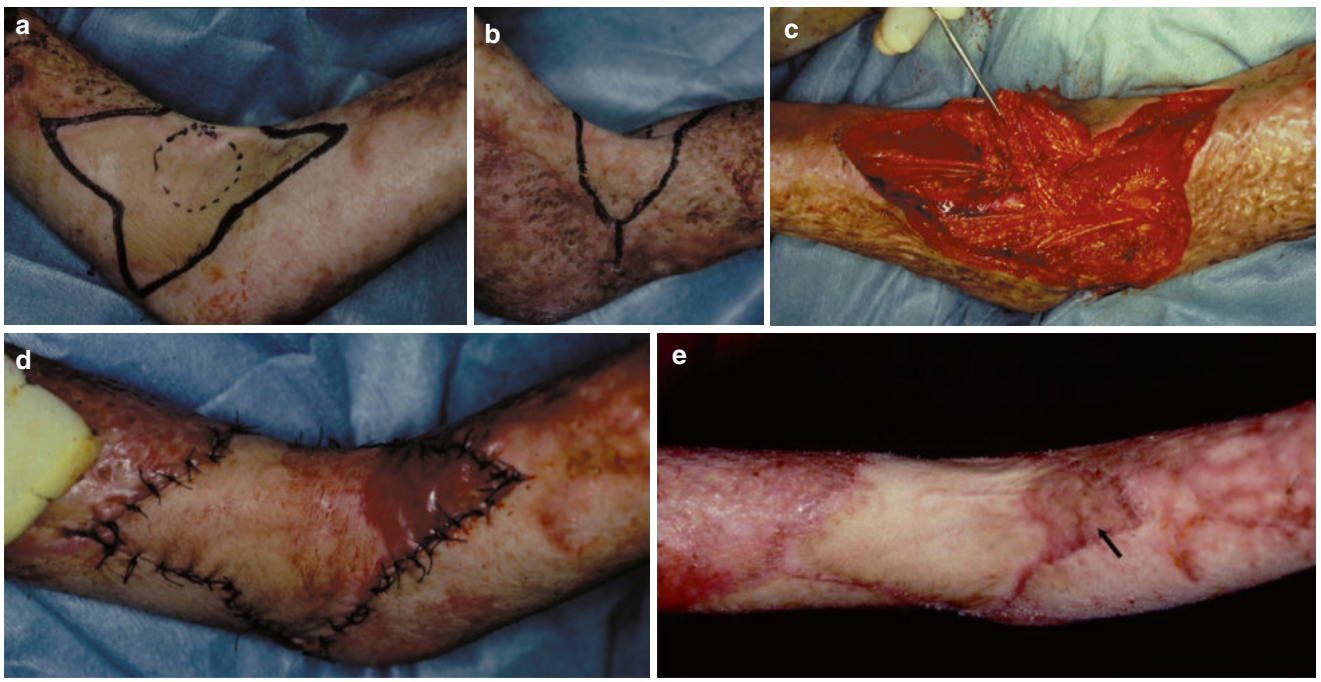


Fig. 37.4 Case 3. A 13-year-old boy suffered from an extensive flame burn. After skin grafting, severe contractures occurred in the cubital fossae of both upper limbs. In the right limb, some normal skin remained in the cubital fossa, allowing a quadrilobed propeller flap to be designed (**a**, **b**). The flap was rotated clockwise, and the donor site was closed primarily (**c**, **d**). Although the release was initially insufficient, full elbow extension was achieved after 3 years due to flap expansion (**e**)

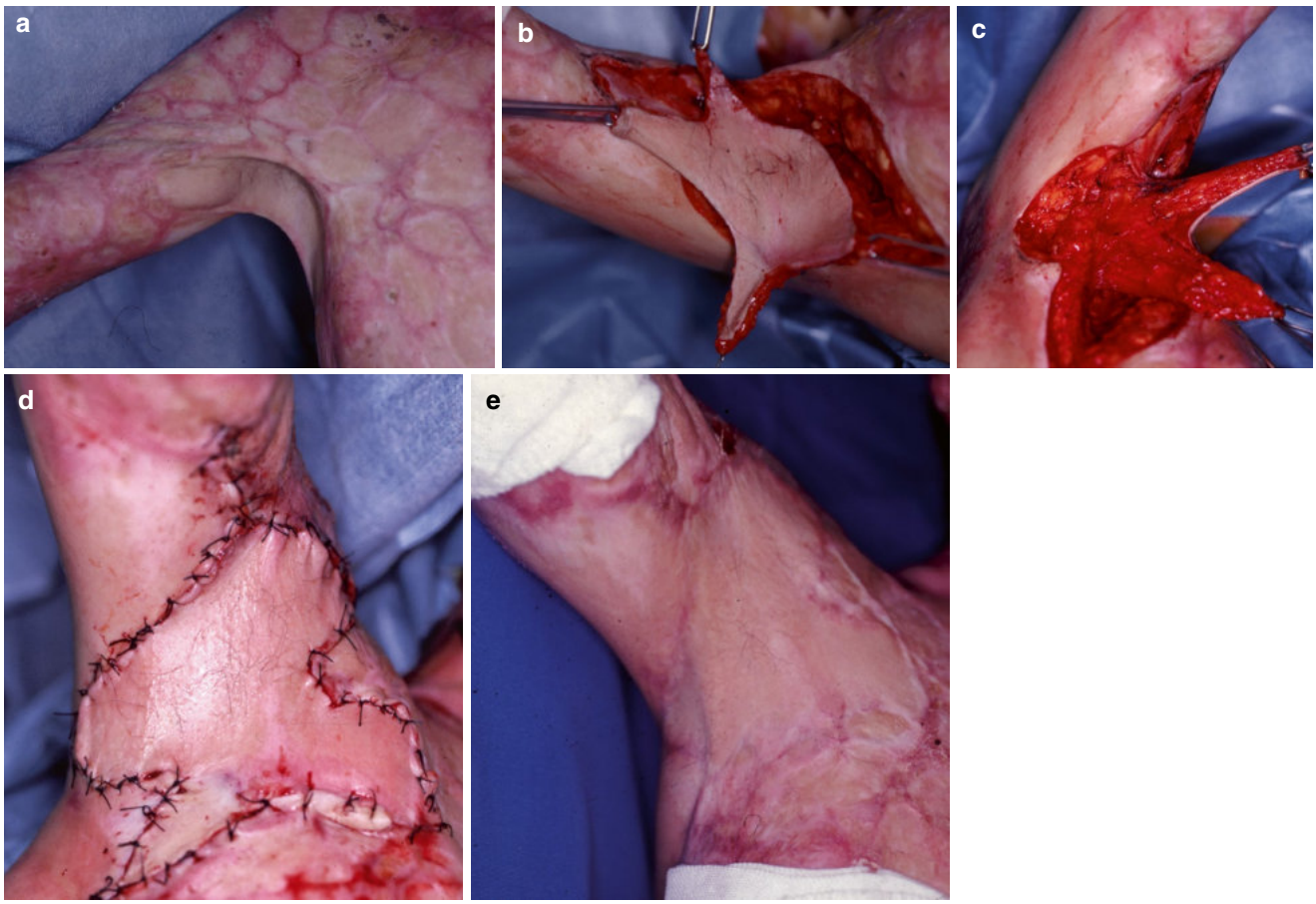


Fig. 37.5 Case 4. A 17-year-old boy suffered from extensive burns. A right axillary scar contracture developed after a skin graft was performed. Healthy skin remained in the center of the right axilla between scar bands (**a**). The multilobed propeller flap method was used (**b**–**d**), and the range of motion (ROM) improved from 60 to 120 degrees. The contracture has not recurred in the 3 years since the operation (**e**)

References

1. Hyakusoku H, Yamamoto T, Fumiiri M. The propeller flap method. Br J Plast Surg. 1991;44:53–4.
2. Murakami M, Hyakusoku H, Ogawa R. The multi-lobed propeller flap method. Plast Reconstr Surg. 2005;116:599–604.
3. Murakami M, Hyakusoku H, Ogawa R. The scar band rotation flap. Burns. 2005;31:220–2.
4. Hyakusoku H, Iwakiri I, Murakami M, Ogawa R. Central axis flap methods. Burns. 2006;32:891–6.
5. Hyakusoku H, Ogawa R, Oki K, Ishii N. The perforator pedicled propeller (PPP) flap method: a report of two cases. J Nippon Med Sch. 2007;74:367–71.

Facial Reconstruction

38

Viola A. Stögner, Sam Boroumand, and Bohdan Pomahac

Abstract

Facial burn reconstruction is one of the most challenging problems a plastic surgeon encounters. As much as 80% of the morbidity of burn injuries results from burns to the face and hands. Head and neck burns affect approximately 50% of the patients admitted to burn centers, the majority of which are partial thickness, and they heal well without surgical intervention [1, 2]. Facial reconstruction should be an integral part of the acute management of facial burns and should continue throughout the patient's hospital stay and the rehabilitation process. The goal of this chapter is to provide an overview of the assessment, management, and ultimately reconstructive principles and approaches involved with facial burns.

Keywords

Facial reconstruction · Burn injuries · Wound management · Skin grafts · Reconstruction principles · Aesthetic units · Scar contracture · Biobrane · Dermabrasion · Local flaps · Free tissue transfers · Eyelid deformity

38.1 Assessment of Burns

The most important initial step in the management of facial burns is a systematic evaluation and execution of advanced trauma life support (ATLS) protocols in particular assessing for inhalational injury, ensuring airway patency, and considering the need for intubation. Depending on the severity of the burns and the presence of concomitant injuries, a thorough medical plan must be implemented. This should include appropriate debridement of necrotic or nonviable burned tissue—such as escharotomies as clinically necessary—along with metabolic support, fluid resuscitation of the patient, antimicrobial wound care and prophylaxis, and adequate sedation and/or pain management [3]. Once the patient has been medically stabilized and cleared by the trauma service of other life-threatening injuries, a thorough survey of facial burn regions is warranted to determine the most appropriate wound management and, if necessary, reconstructive approaches. Specifically, an assessment must be made to evaluate burn depth, including consideration of neurovascular damage inflicted, extent of burn across facial regions, and involvement of critical functional and aesthetic units of the face including eyelids, lips, ears, and nose.

38.2 Management of Burns

38.2.1 Superficial to Mid-Dermal Burns

In light of the dynamic nature of burn wounds, initial management of superficial to mid-dermal facial burns should focus on preventing progression to deeper injuries and achieving early wound closure. Adequate fluid resuscitation, prevention of wound sepsis, and providing a wet/moist environment are key elements to minimize the conversion of areas of partial-thickness burn injuries that would heal spontaneously, to areas of deep dermal to full-thickness injuries that would require surgical intervention.

Attempts must be made to accelerate skin regeneration by providing an optimal environment where keratinocytes can proliferate, migrate, and subsequently re-epithelialize the burn wound. Such an environment can be provided by frequent hydrotherapy, topical antimicrobial agents, and occlusive dressing. Alternatively, in superficial and mid-dermal facial burns, the use of Biobrane, a biosynthetic dressing, offers a number of advantages [4]. It adheres to the wound bed, prevents evaporative water loss and desiccation, and serves as a barrier against the invasion of microorganisms. In the facial region, it is particularly useful as it obviates the need for frequent painful debridement and hydrotherapy after the initial application and minimizes patient discom-

V. A. Stögner · S. Boroumand · B. Pomahac (✉)
Department of Surgery, Division of Plastic and Reconstructive Surgery, Yale New Haven Hospital, Yale School of Medicine, New Haven, CT, USA
e-mail: viola.stogner@yale.edu; sam.boroumand@yale.edu; Bohdan.pomahac@yale.edu

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_38

fort. It allows for frequent inspection without the need for being removed.

38.2.2 Deep Dermal and Full-Thickness Burns

Superficial to mid-dermal burns would typically heal within 2–3 weeks. Healing that takes longer than 3 weeks is an indicator of a deep dermal or full-thickness injury. The distinction between these two groups of patients may not always be clear, necessitating a period of expectant management, in which the indeterminate burn injuries are given the opportunity to declare their true depth and regenerative capacity. Wound following 3 weeks is associated with ongoing inflammation, proliferation of granulation tissue, and scar formation prone to hypertrophy [5, 6]. Depending on location, scars can lead to contractures and secondary deformities. In small burns and certain locations, for example, where the concavities and flexion creases of the face are not crossed, this process favoring healing by contraction and epithelial migration from the wound periphery may lead to superior results compared to grafting (forehead, dorsum of the nose).

Mid to deep dermal burns develop by the end of tenth day a thin, superficial debris typically of a white shiny appearance that is avascular and prone to bacterial contamination and infection. We find surgical debridement of this debris highly valuable in managing facial burns. Using dermabrasion or Hydrocision (Versajet™, Smith & Nephew), this necrotic debris is removed in a very controlled fashion to punctuate diffuse dermal bleeding. Occlusive dressings are often applied afterward.

Tangential excision of the facial burns is reserved for extensive full-thickness injuries. It may not be easily applicable, particularly in the complex central facial regions. Lack of delicate control over the level of excision makes it less than ideal when it comes to dealing with facial burns, where it is vital to avoid over excision of the burned skin. In addition, bleedings of the well-perfused facial skin can substantially threaten the take of autografts. For this reason, we have often staged the excision of facial full-thickness burns, and covered the excised bed with allografts or synthetic acellular dermal matrices such as Biobrane®, Integra®, or NovoSorb® BTM, followed by autografts several days later.

38.3 Reconstruction of Facial Burns

38.3.1 General Principles

The reconstructive goals comprise restoration and preservation of function; contour and shape of individual facial structures; and achieving good color and texture match, whenever possible. Except for unique circumstances, no skin graft will ever look as natural as preserved facial skin. The quality of reconstruction (aesthetics, mobility, and late complications) seems to correlate to the thickness of preserved or added dermis by the thickness of the graft. Preservation of the dermis is therefore critical. We have adopted an aggressive removal of the superficial debris in mid to deep dermal burns to minimize inflammation and the chance of superficial infection. Extensive third-degree burns should be excised early after injury, while small third-degree burns can occasionally be managed following the principles of facial reconstruction similar to cancer or trauma defects.

Wherever possible, aesthetic units of the face must be respected to guide both excision and grafting or other reconstructive procedures [7]. The grafts and flaps should be designed in such a way that scars are located within the lines of facial expression (e.g., nasolabial fold), relaxed skin tension lines, or lines of contour (e.g., mandibular margin). It is imperative to use thick skin grafts, as thin skin grafts frequently lead to the development of contractures. When resurfacing only part of the face, the graft should be taken from an area that closely matches the color of unburned skin, usually from the scalp, neck, or supraclavicular area. In resurfacing the entire face, the issue of color match becomes much less relevant.

The timing of facial reconstruction following burns can generally be divided into acute, intermediate, and later stages [8]. Acute reconstruction typically occurs sometime in the first few months following burn injury. The initial delay is to allow appropriate closure of burn wounds and endogenous inflammation and swelling to subside, thereby minimizing the risk of infection, related complications, and the subsequent formation of contractures. The main purpose of reconstruction in the acute time frame is primarily to address any functional deficits resulting from the burn injury, including damage to the eyelid, perioral, or cervical regions to restore quality of life and mitigate lasting damage that acute contractures can have on these facial functional units. Intermediate facial reconstruction typically occurs on the spans of many months to a few years following the initial

burn with the surgical goal of scar modification. The delay is to provide burn scars adequate time to mature and thus only intervene when their natural maturation process is concluded. Late-phase reconstructions can be completed many years following the initial burn injury to address stable deformities and achieve more optimal comfort and aesthetic outcomes for patients.

38.3.2 Reconstructive Options for Burn Scars

The reconstructive repertoire comprises a number of interventions along the plastic reconstructive ladder, all aiming to reduce aesthetic and functional morbidity associated with scar contracture and formation. Minimally invasive procedures such as repeated medical needling (or percutaneous collagen induction) can often already achieve significant softening of thickened and tense burn scars. The utilization of Z-, W-, or V-Y plasties, as well as many other local flap techniques, facilitate the excision or lengthening of linear scars by recruiting unscarred adjacent lateral tissue [8]. This approach helps to break down the collagen build-up and relieve the accumulated tension from scars and contractures. Following the release of scar contractures, skin grafting can be used as an initial reconstructive approach. Full-thickness skin grafts are preferred over split-thickness skin grafts, especially over facial units, due to several prevailing factors including the reduced rate of scar contracture recurrence, reduced folding/wrinkling of the skin graft, and improved stability and color match and ultimately aesthetic outcomes. If matching donor sites for facial skin grafts are inadequate, rectangular or oval tissue expanders can be placed in adjacent healthy tissue to provide excess tissue for rotation, transposition, and advancement flaps. Note that the latter flap type is typically avoided with facial burns if they cross aesthetic features as advancement flaps are prone to retract in this context. It is important to be mindful that excessive skin stretching with tissue expanders is associated with an increased complication rate. Adequate growth of tissue during expansion must be achieved to avoid thinning the skin inappropriately with rapid expansion.

Whenever possible, utilization of local flaps for the reconstruction of facial burns is preferred due to optimized color match, skin thickness, and texture relative to the face. Historically, this has primarily included cervicopectoral flaps such as the pedicled supraclavicular artery (SCA) fasciocutaneous flap, a reliable local flap providing coverage for lower thirds of the face and neck [9]. However, in severe panfacial burns, it is not uncommon for the burn trauma to extend to neighboring regions, such as scalp, neck, and chest, thus significantly mitigating availability of local flap options. In this case, free tissue transfers are often the only remaining reconstructive option outside of facial transplantation. Well-established free flap options for facial soft-tissue reconstruction include the radial forearm free flap (RFFF), parascapular free flaps, and the anterolateral thigh (ALT) free flap [10, 11].

38.3.3 Specific Reconstructive Considerations of Facial Features

38.3.3.1 Eyelids

Eyelid deformity from facial burns is typically a result of either direct burn trauma to the eyelids themselves or scarring of periocular tissue including the cheeks and forehead that can result in cicatricial ectropion of the eyelids [8, 12]. The biggest concern for eyelid burn injuries is ensuring the patient can fully close the lids to adequately protect the globe and prevent exposure keratopathy. Inability to protect the globe and surrounding ocular conjunctivae is one of the few indications for early reconstructive surgery. Management of the ectropion requires surgical release of the scar tethering the lid, allowing it to relax to its normal anatomical position. This is followed by skin grafts—preferably full thickness—for the eyelids, selected from donor sites with similar color and texture, such as the contralateral eyelid (if unburned), or skin from postauricular, preauricular, supraclavicular, inner arm, or groin regions.

38.3.3.2 Nose

The nose stands as one of the most challenging facial units to reconstruct as full-thickness burn injury requires reconstruction of not only the skin but also the skeletal or cartilaginous support and mucosal lining. The most common burn deformity of the nose is alar retraction when scar contracture encroaches on the alar rim [8, 12]. Amelioration of this deformity often necessitates grafting of skin and cartilage to recreate the ala. Local tissue advancement or adjacent tissue transfer, such as a dorsal nasal or nasolabial flap, can allow sufficient skin coverage of minor nasal defects. More extensive nasal defects can be addressed with regional flaps, if available, such as a forehead flap or a nasal turndown flap, possibly in combination with a conchal cartilage graft if needed. Microvascular free flaps can also be utilized to provide appropriate nasal lining and skin cover in the likely event of a lack of healthy tissue for locoregional flaps.

38.3.3.3 Lips

The two most common deformities of the lips and perioral region following severe burn injury are microstomia and upper/lower lip ectropion [8, 12]. Lip ectropion is treated with surgical scar release in conjunction with full-thickness skin grafts. Further reconstruction of aesthetic facial landmarks including the philtrum and Cupid's bow can be accomplished at later stages. Microstomia is treated with a

commissuroplasty. This approach involves identifying the appropriate anatomical location of the commissure by following a line down from the medial limbus to the lip. A triangular excision of the scar in this region can be taken followed by mucosal V-Y advancement flaps to close the defect and reform the commissure.

38.3.3.4 Ears

Like the nose, the protruding position of the ears makes them particularly susceptible to burn injuries of the face. The helix and antihelix are frequently affected. During the acute phase of the burn injury, prevention as well as early detection and treatment of chondritis is crucial to avoid additional cartilage loss. Minor defects of the helical rim can be addressed with wedge excision and primary closure or local flaps, such as a tubed flap, or full-thickness skin grafts if the perichondrium is preserved. In cases of adhesion-related projection deficits of the ear, autologous full-thickness skin grafts can be used to restore the postauricular angle. The reconstruction of more complex thermal injuries of the ear may require cartilage grafts (e.g., conchal or costal) for structural support, as well as soft tissue coverage with regional flaps. The postauricular skin, if available, is most favored for ear reconstruction and is frequently used to create a subcutaneous pocket for ear coverage. If healthy postauricular skin is not available, an ipsilateral or even contralateral temporoparietal fascial flap, or radial forearm flap, can represent reconstructive alternatives. In extensive cases with significant periauricular soft tissue destruction, a partial or complete ear prosthesis should be considered [12, 13].

38.4 Clinical Cases

38.4.1 Case 1: Superficial burn with Biobrane

A 38-year-old man sustained second-degree burns including facial burn in a house fire. He underwent fluid resuscitation and mid-dermal burns were managed with Biobrane™ on admission (Fig. 38.1a). Two weeks later, the Biobrane completely came off the patient's face and healed without further complications (Fig. 38.1b).

38.4.2 Case 2: Deep Dermal Burn—Dermabrasion and Biobrane

A 53-year-old woman with a history of depression suffered from extensive facial burns following a cooking accident when a pot of oil caught on fire (Fig. 38.2a, b). Due to her past medical problems, facial burns were managed with conservative moisturization protocol until day 10 when she was taken to the operating room for dermabrasion and application of Biobrane. Same patient 4 months following her accident (Fig. 38.2c, d).

38.4.3 Case 3: Full-Thickness Small Area Burn

A 41-year-old woman suffering from epilepsy fell on a heat radiator during a seizure attack and sustained a contact burn to the right side of her face while unconscious. The resulting

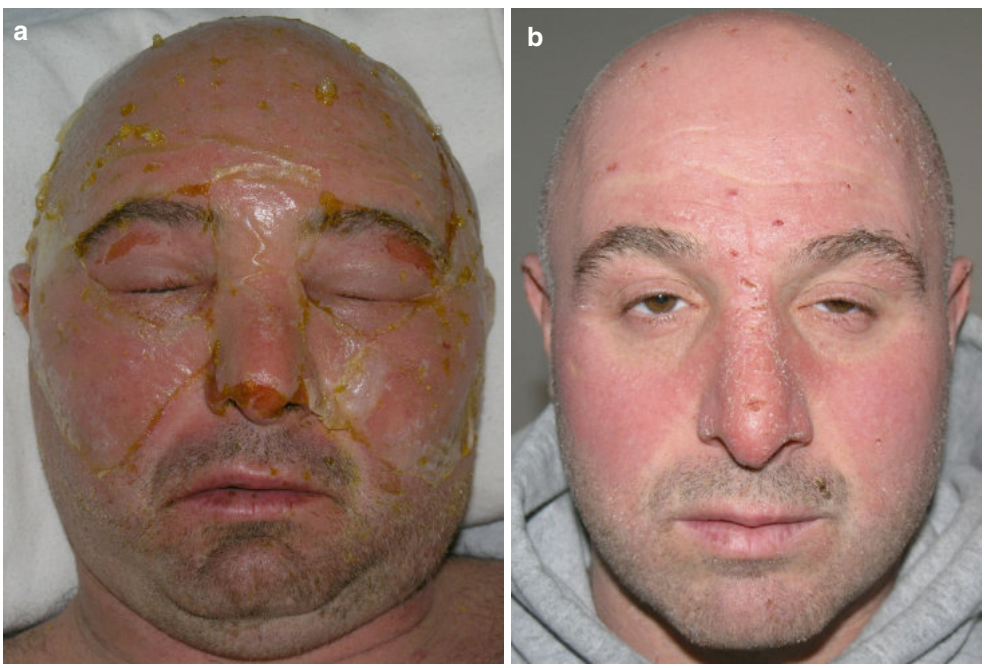


Fig. 38.1 Case 1

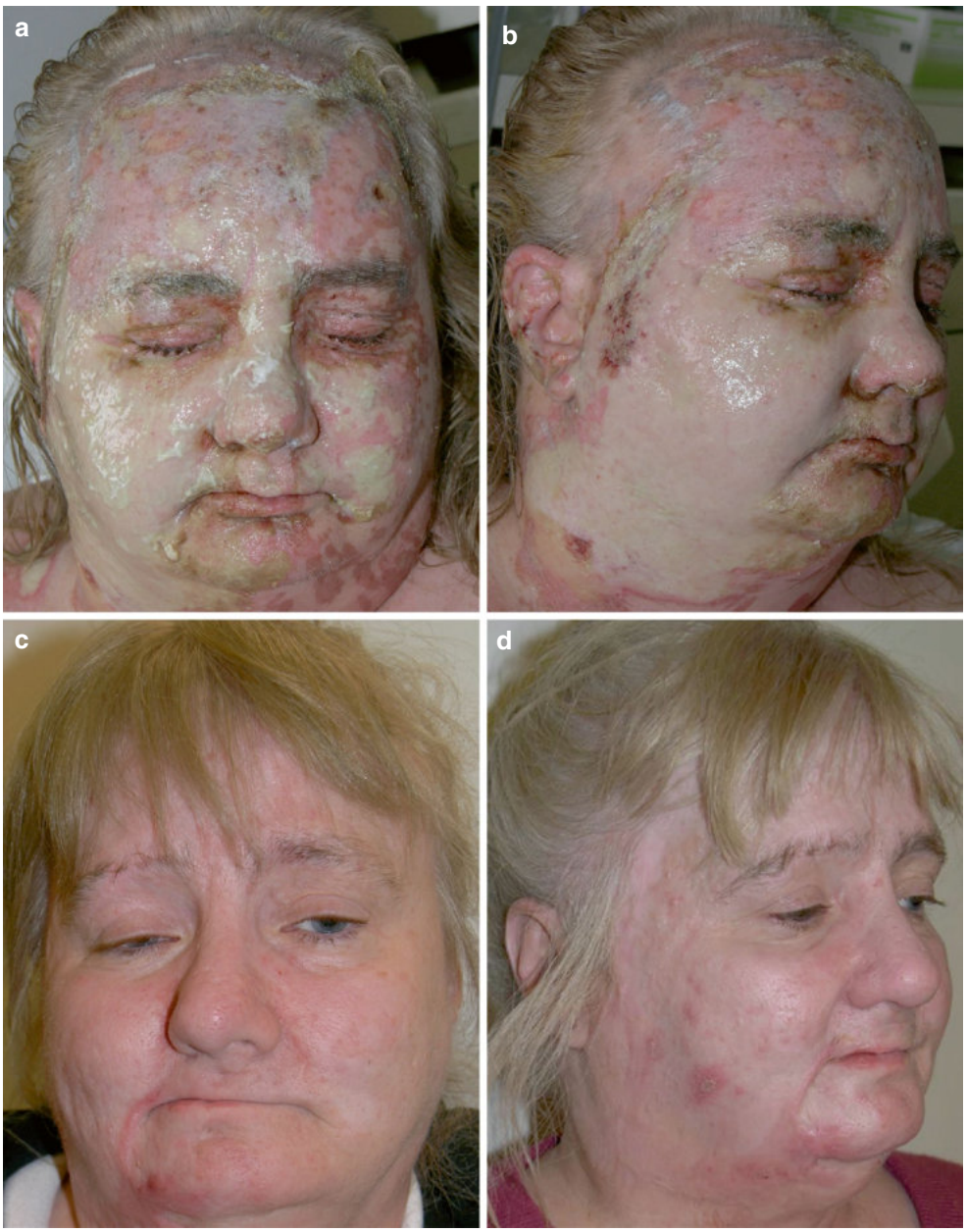


Fig. 38.2 Case 2

contact burn was managed in an outside institution for 3 weeks prior to her presentation to our clinic (Fig. 38.3a, b). She was taken to the operating room and underwent local tissue undermining, rearrangement, and neck advancement flap. Small skin graft was used behind the ear from a supraclavicular location. Healed face 3 months postoperatively is shown (Fig. 38.3c, d).

38.4.4 Case 4: Full-Thickness Extensive Burn

A 47-year-old man was involved in a motor vehicle accident. A car caught on fire and caused deep head and neck and other deep third-degree burns; 35% total body surface area (TBSA). Facial, scalp, and neck burns were clearly deep third-degree (Fig. 38.4a, b) and sequentially excised once the

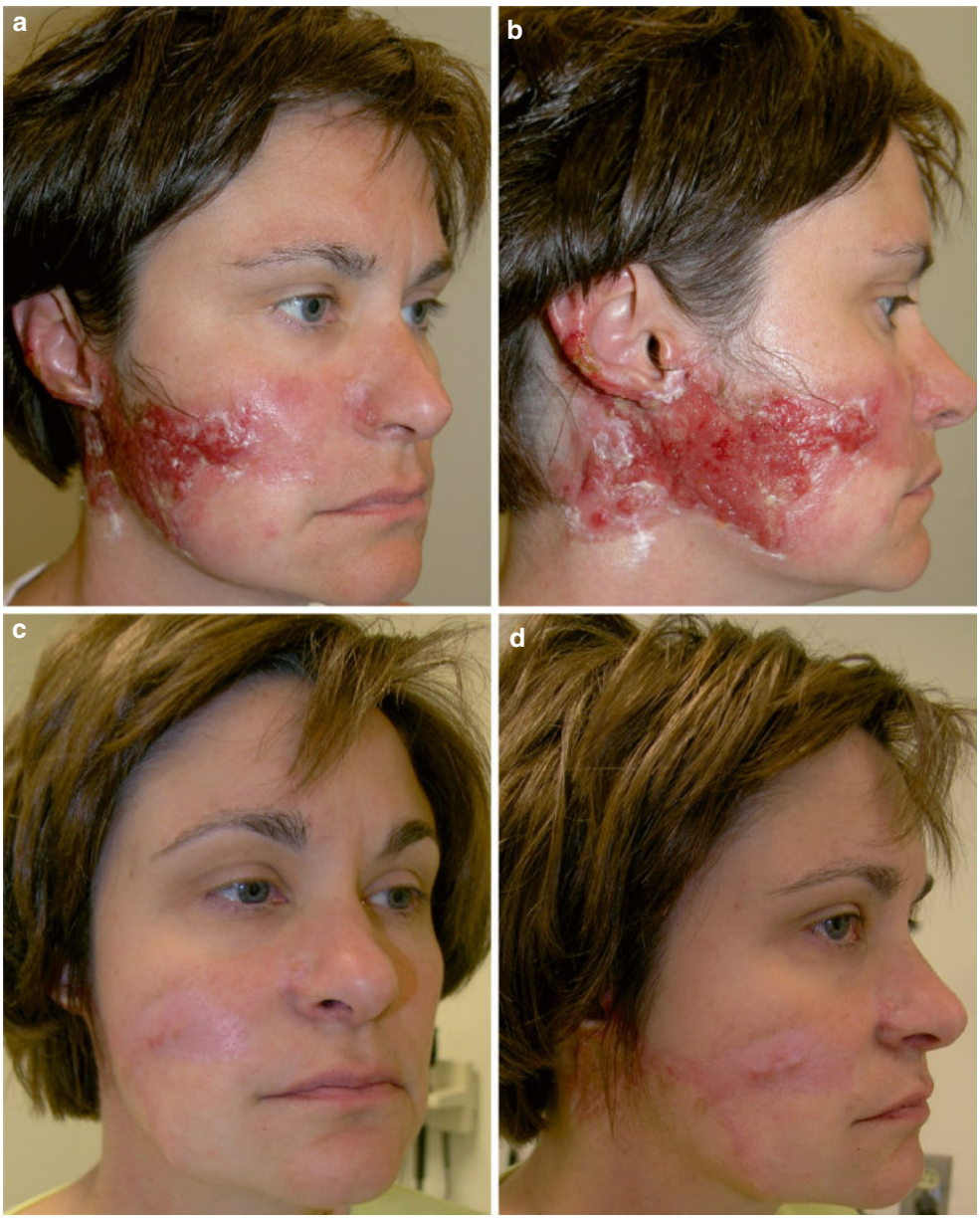


Fig. 38.3 Case 3

Fig. 38.4 Case 4

patient's overall condition allowed. The grafting continued with autografts and ultimately the exposed calvarium and nasal structures were reconstructed with two free tissue transfers, latissimus dorsi and radial forearm flap, respectively (Fig. 38.4c–e).

References

1. Fraulin FO, Illmayer SJ, Tredget EE. Assessment of cosmetic and functional results of conservative versus surgical management of facial burns. J Burn Care Rehabil. 1996;17(1):19–29.
2. Cole JK, et al. Early excision and grafting of face and neck burns in patients over 20 years. Plast Reconstr Surg. 2002;109(4):1266–73.
3. Tejiram S, Romanowski KS, Palmieri TL. Initial management of severe burn injury. Curr Opin Crit Care. 2019;25(6):647–52.
4. Hansbrough JF, et al. Clinical experience with Biobrane biosynthetic dressing in the treatment of partial thickness burns. Burns Incl Therm Inj. 1984;10(6):415–9.
5. Ghahary A, et al. Enhanced expression of mRNA for transforming growth factor-beta, type I and type III procollagen in human post-burn hypertrophic scar tissues. J Lab Clin Med. 1993;122(4):465–73.
6. Deitch EA, et al. Hypertrophic burn scars: analysis of variables. J Trauma. 1983;23(10):895–8.
7. Gonzalez-Ulloa M. Restoration of the face covering by means of selected skin in regional aesthetic units. Br J Plast Surg. 1956;9(3):212–21.

8. Wong S, Melin A, Reilly D. Head and neck reconstruction. Clin Plast Surg. 2017;44(4):845–56.
9. Granzow JW, et al. Supraclavicular artery island flap (SCAIF) vs free fasciocutaneous flaps for head and neck reconstruction. Otolaryngol Head Neck Surg. 2013;148(6):941–8.
10. Zeiderman MR, Pu LLQ. Contemporary reconstruction after complex facial trauma. Burns. Trauma. 2020;8:tkaa003.
11. Seth AK, et al. Microsurgical burn reconstruction. Clinic Plastic Surg. 2017;44(4):823–32.
12. Klein MB. Burn reconstruction. Phys Med Rehabil Clin N Am. 2011;22(2):311–25.
13. Bos EJ, Doerga P, Breugem CC, van Zuijlen PP. The burned ear; possibilities and challenges in framework reconstruction and coverage. Burns. 2016;42(7):1387–95.

Part V

Expanded Flab, Prefabricated Flap, and Secondary Vascularized Flap

Expanded Thin Perforator Flaps

39

Chunmei Wang and Yang Sifen

Abstract

Expanded thin perforator flaps are an innovative surgical technique, designed to address the need for more precise and efficient tissue reconstruction. These flaps, thin layers of tissue that retain their blood supply through perforating vessels, offer several advantages over traditional flap techniques, including reduced donor site morbidity, enhanced aesthetic outcomes, and more predictable survival rates. This chapter explores the principles and applications of expanded thin perforator flaps, discussing their role in modern surgical reconstruction. In the field of reconstructive surgery, the expanded thin perforator flap has emerged as a promising technique for achieving both functional and aesthetic outcomes, with extremely large and thin flaps for reconstructing, especially in contour-sensitive areas such as the facial, cervical parts, and extremities.

Keywords

Expanded flap · Perforator flap · Animal experiment · Flap graft · Thin flaps

39.1 Introduction of Expanded Thin Perforator Flap

Extremely large and thin flaps are the first choice for reconstructing postburn scars in wide contour-sensitive areas such as the facial, cervical parts, and extremities. In 1996, Colson [1] initially repaired dorsal of hands with the thinned flap, which is now called "the graft flap." After 1980, thin flaps with very narrow pedicles were developed in China [2], and Koshima [3] developed the free super-thin flap in Japan. In 1994, Hyakusoku [4] reported the perforator-supercharged subdermal vascular network (SVN) flap, which is the so-called perforator-supercharged super-thin flap. Thereafter, perforator-supercharged flaps were made much larger and that made thinner flaps possible [5–7].

Based on our animal experimental study on mini-pigs [8], in the tissue expansion group, the bridging effect during the soft tissue expansion is related to the neovascularization between the neighboring axial vessels with enlargement of choke anastomosis into real anastomosis. Target vessels are fully perfused with abundant anastomoses of considerable size and caliber. These experiments have established the model for the flap with crossing areas of perfusion, which establishes the clinical basis and provides new ideas for the axial flap.

According to Nakajuma's theory of layered blood supply by vessels [9], the authors found that the expanded thin flap, which is just under the subdermal vascular network layer, may lead to the best aesthetic appearance in the recipient regions, especially where have only a minimal fat layer with thin surface contours.

Thus, based on the above theory, we have used expanded random-pattern flaps, perforator flaps, and prefabricated flaps to repair large areas of postburn scars, severe jaw and neck contractures, and scars in the dorsal area of hands that are highly required for the shape and function of the hand. As a result, the limitation of the donor site, the difficult reconstruction of large area defects, and the poor postoperative appearance have been resolved simultaneously.

39.2 Characteristics and Indication of the Method

1. Tissue expansion is a common way to harvest extra skin, especially for patients who have small amounts of normal skin around scars.
2. Tissue expansion has been applied to many kinds of flaps, such as random-pattern flaps, free flaps, perforator flaps, and prefabricated flaps.

C. Wang (✉)
Department of Plastic Surgery, Dongguan Kanghua Hospital, Guangdong Province, China

Y. Sifen
Department of Plastic and Cosmetic Surgery, The Sixth People's Hospital of Dongguan, Guangdong Province, China

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_39

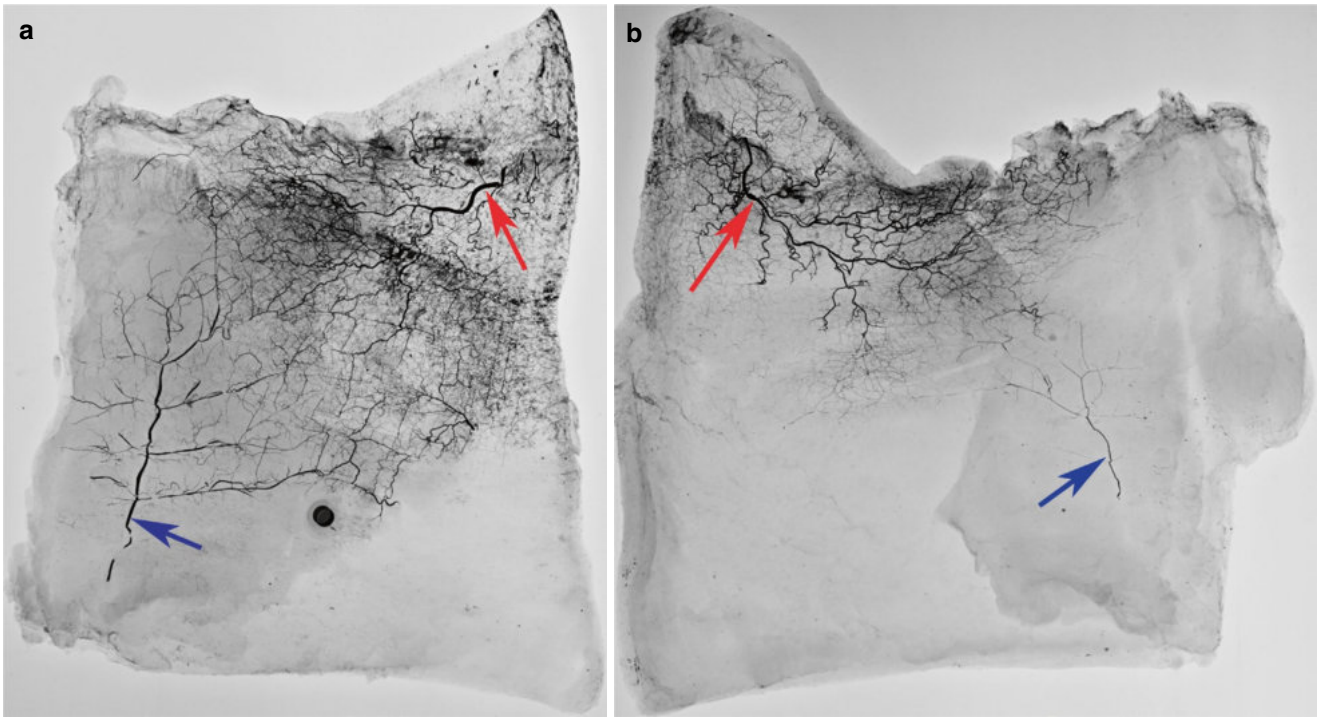


Fig. 39.1 Angiograms of expanded flap in mini-pigs. (**a**) Expansion group. (**b**) Control group. The area between two large cutaneous perforators (red and blue arrows) was expanded for 2 weeks. In the results, the neoangiogenesis of vessels was significant in the expansion group

3. Expansion includes a delay procedure and a "pass-bridge" effect [8]. After implanting the expander, the flap loses connection with the bed. This effect stimulates the neogenesis of vessels and facilitates the formation of vessel networks. From the animal experiments, we found the "pass-bridge" effect, because, during the expansion, the skin perforator connected with others through neogenetic vessels to supply more areas (Fig. 39.1a) compared to the control side (Fig. 39.1b).
4. In the early stage, the blood supply of the expanded and prefabricated thin flaps depends on the pedicle. Later, it quickly connects to the bed by the newly formed vessels. After being cut off from the pedicle, the flap depends on the blood supply from the bed. It is suggested that there is no ischemic phase during the time the flap is transferred to the recipient site. Moreover, the flap becomes thinner.

39.3 Specific Skills of the Methods

1. To expand the random-pattern flap, the expander is usually placed above the superficial fascia of the adjacent normal skin. To expand the perforator flap, the perforator artery should be detected by Doppler such as the superficial abdominal artery, intercostal artery, and descending branch of transverse cervical artery [10], after which the expander is put in the area dominated by the perforator at 2 cm away from the perforating point.
2. Design the flap according to the wound surface. After removing the expander, the flap will become thinner, and portions of the capsule should be excised. The SVN must then be preserved.
3. As the course and territory of perforators are quite different in each region, careful preoperative assessment using a variety of methods to map the perforators is necessary to ensure the success of flap dissection sometimes. Multidetector row computed tomography (MD-CT) angiography has been used clinically to aid reconstructive surgeons for more precise preoperative planning for a perforator flap [11]. A narrow skin pedicle is also available. Venous drainage through the skin pedicle is strong and will therefore facilitate safer harvesting of thin or large flaps.
4. As for the expanded prefabricated flap, because it takes at least 7 days to reconstruct the blood supply of the flap, the pedicle of the flap should be usually cut off 9–14 days postoperation.

39.4 Cases

39.4.1 Case 1: Expanded Random-Pattern Flap

A 27-year-old woman suffered from flame burns more than 20 years ago. An expanded random-pattern cervical flap was designed to reconstruct the face (Fig. 39.2a). The expanded cervical flap was advanced to cover the wound surface of the middle and lower face (Fig. 39.2b). The entire middle and lower face is formed in one stage (Fig. 39.2c). In the follow-up after 8 months, the flap is thin enough to visualize the contour clearly even while smiling (Fig. 39.2d).

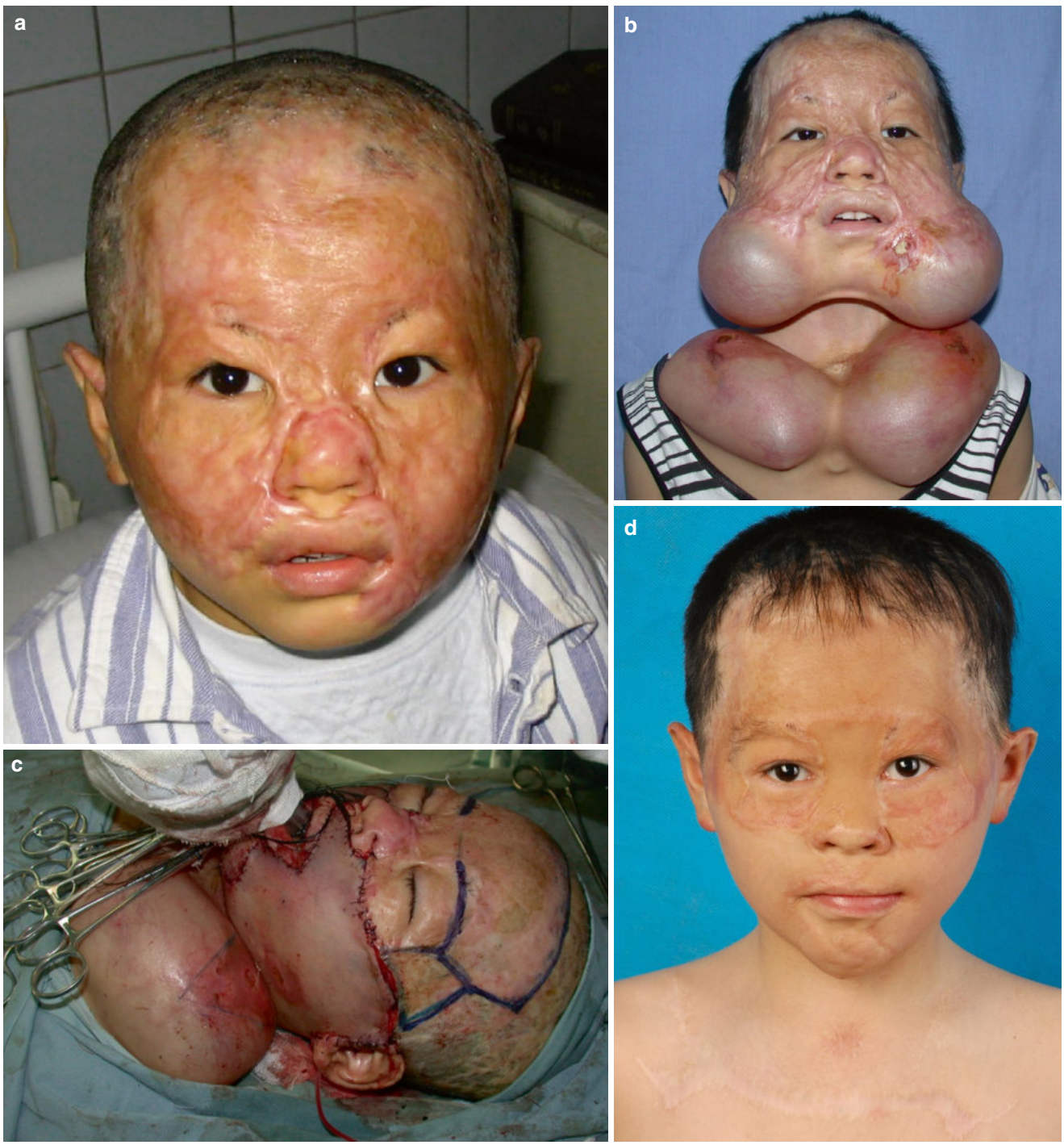


Fig. 39.2 Case 1 (**a**–**d**) Expanded random-pattern flap

39.4.2 Case 2: Expanded Perforator Flap

A 29-year-old man developed severe cervical contracture after extensive burns to the neck, shoulder, chest, and upper limbs (Fig. 39.3a). We designed an expanded super-thin flap that was transferred from the back with the help of two perforators by "pass-bridge" (the descending branch of the transverse cervical artery and the circumflex scapular artery) (Fig. 39.3b). We rotated the left back flap (3 × 16 cm) with a 4-cm-wide pedicle to cover the neck wound surface and advanced the right back flap to the front to cover the shoulder wound surface. The flap is thin enough to visualize the contour clearly (Fig. 39.3c–f). The closure of the back donor site was free of tension and no hypertrophic scar was left (Fig. 39.3g). No shrinking of the flap was observed after 2 years (Fig. 39.3h).

39.4.3 Case 3: Expanded Perforator Flap

A 19-year-old woman had a right face deformity secondary to burn scars when she was 8 months old. She developed significant scar contracture leading to right facial narrowing, which shifted her mouth outward (Fig. 39.4a). A 300-mL

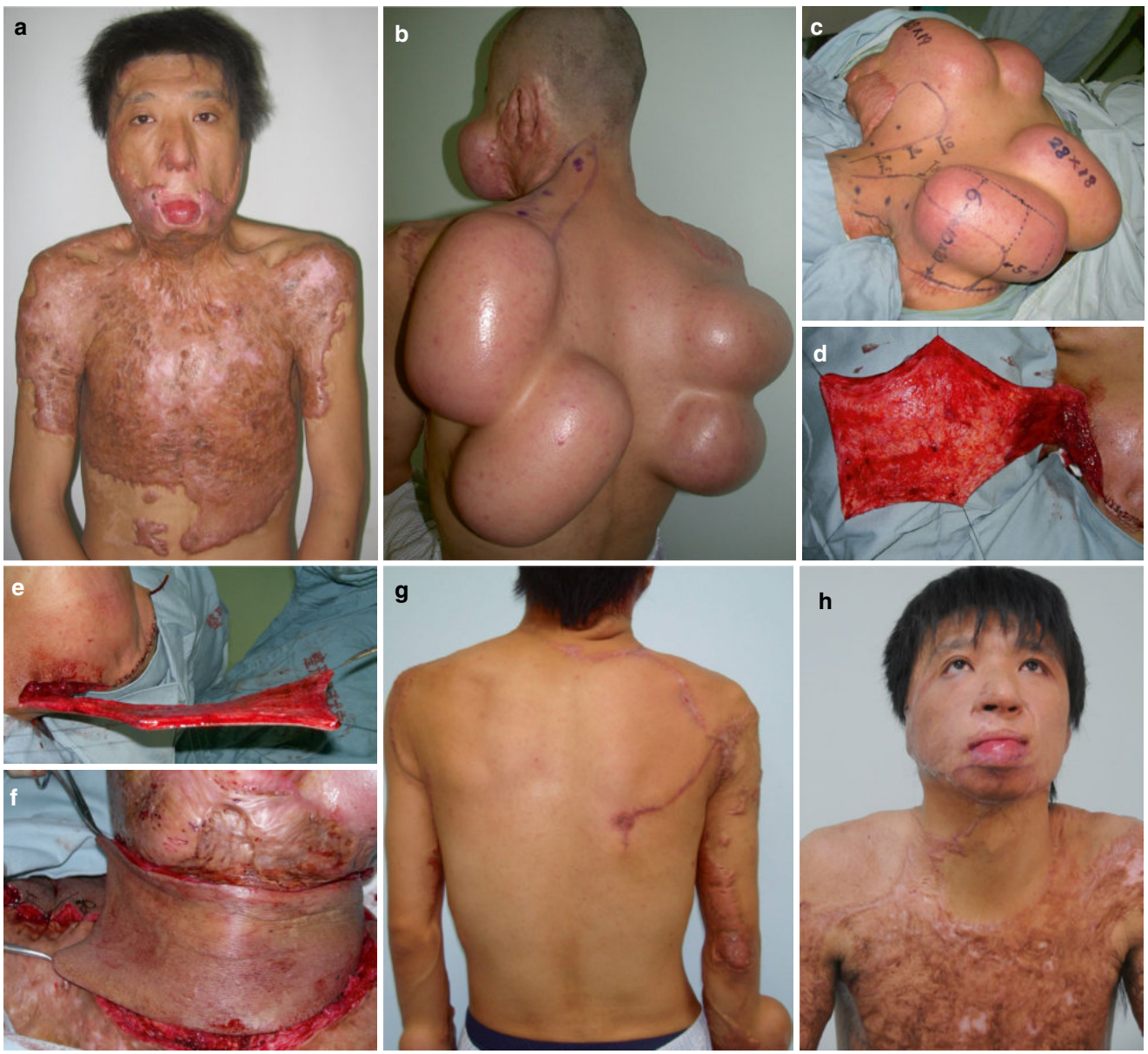


Fig. 39.3 Case 2 (**a**–**h**) Expanded perforator flap

expander was implanted in her right neck under the perforator that was identified by MD-CT Three months later, the same perforator was identified again on the surface of the expanded perforator flap (Fig. 39.4b, c). A 12 × 14 cm expanded perforator flap was elevated based on this perforator and was transferred to resurface her right face (Fig. 39.4d). The flap survived completely giving the patient an excellent cosmetic outcome (Fig. 39.4e).

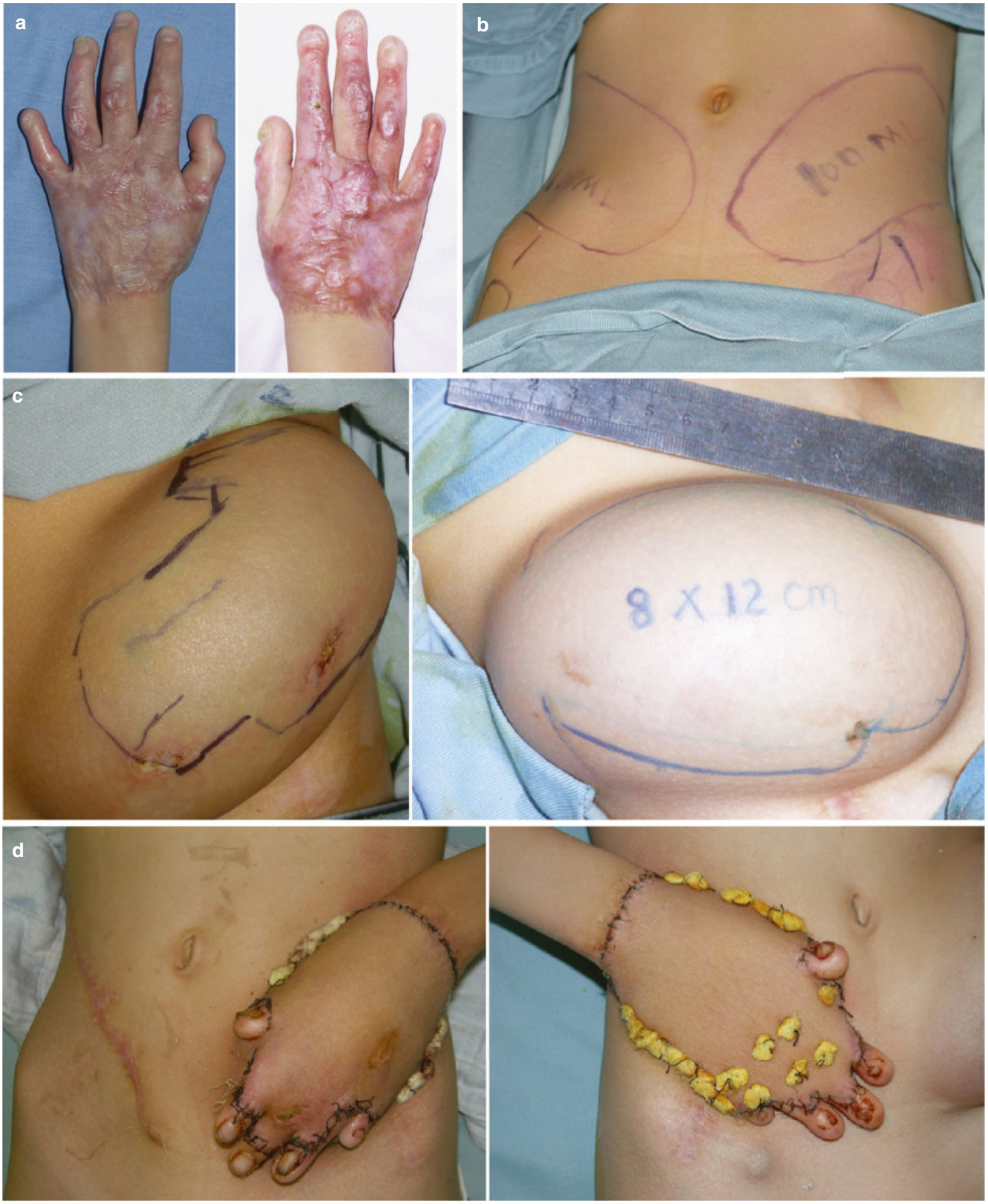


Fig. 39.4 Case 3 (**a**–**h**) Expanded prefabricated flap

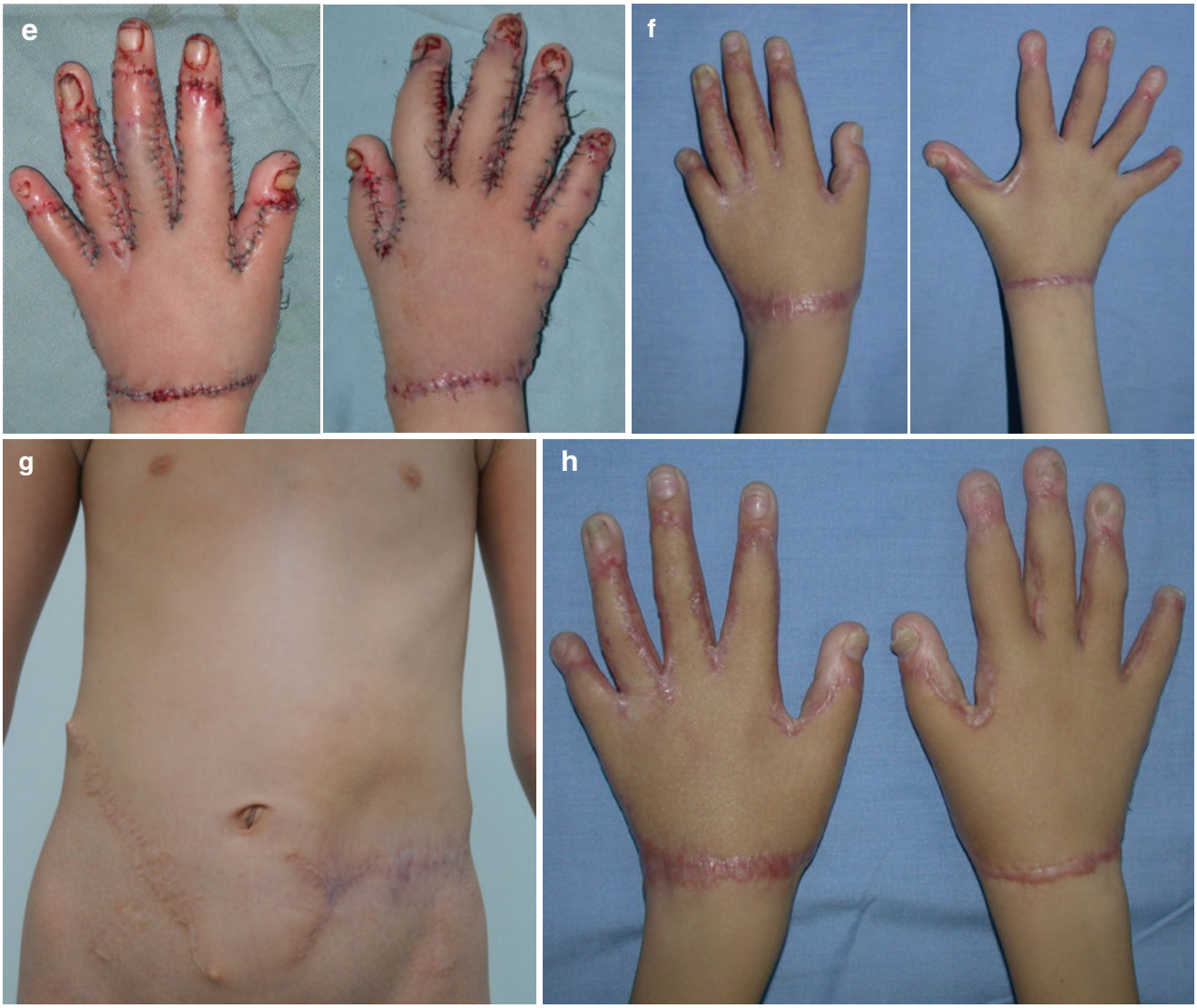


Fig. 39.4 (continued)

39.4.4 Case 4: Expanded Prefabricated Flap

A 4-year-old girl suffering from a fire burn had hypertrophic scars on the dorsal side of her hands (Fig. 39.4a). We prefabricated an abdominal perforator pass-bridge superthin flap by expansion (Fig. 39.4b). The procedure included three steps. The first was to implant the expander (Fig. 39.4c). The next was to remove the scar and take out the expander forming the bipedicle flap to resurface the wound (Fig. 39.4d). The last was to cut off the pedicles and form the finger webs (Fig. 39.4e). The result after 1 year is shown in (Fig. 39.4f). The donor site had no hypertrophic scar left (Fig. 39.4g). In the follow-up after 10 years, both the contour and the function of hand were satisfactory (Fig. 39.4h, i).

39.5 Summary

The expanded perforator thin flap represents a significant advancement in reconstructive surgery. By combining the principles of tissue expansion with the precision of perforator vessel utilization, this technique offers a reliable and effective means of achieving both functional and aesthetic reconstruction. While it has its limitations, the expanded perforator flap remains a valuable tool in the armamentarium of reconstructive surgeons. With ongoing research and technological advancements, the expanded perforator thin flap technique is expected to continue to evolve. Future developments may include improved surgical techniques, and the application of regenerative medicine principles to further enhance flap viability and outcomes.

Acknowledgment The authors gratefully acknowledge the contributions of Junyi Zhang and Qian Luo to this chapter as it appeared in the first edition of the book.

References

1. Colson P, Janvier H. Le degraissage primaire et total des lambeaux d'autoplastic a distance. Ann Chir Plast. 1966;11:11–20.
2. Situ P. Pedicled flap with subdermal vascular network. Acad J First Medical Coll PLA (Chinese). 1986;6:60.
3. Koshima I, Higaki H, Kyou J, Yamasaki M. Free or pedicled rectus abdominis muscle perforating artery flap. Jpn J Plast Reconstr Surg. 1989;32:715–9.
4. Hyakusoku H, Pennington DG, Gao JH. Microvascular augmentation of the super-thin occipito-cervico-dorsal lap. Br J Plast Surg. 1994;47:465–9.
5. Ogawa R, Hyakusoku H, Murakami M, Aoki R, Tanuma K, Pennington DG. An anatomical and clinical study of the dorsal intercostal cutaneous perforators—its application to free microvascular augmented subdermal vascular network (ma-SVN) laps. Br J Plast Surg. 2002;55:396–401.
6. Ogawa R, Hyakusoku H, Murakami M, Gao JH. Clinical and basic research on occipito-cervico-dorsal flaps including a study of the anatomical territories of dorsal trunk vessels. Plast Reconstr Surg. 2004;113:1923–33.
7. Chin T, Ogawa R, Murakami M, Hyakusoku H. An anatomical study and clinical cases of "super-thin laps" with transverse cervical perforator. Br J Plast Surg. 2005;58:550–5.
8. Zhang J, Wang C, Gui L, et al. The effect of expansion prefabrication on crossing area supply axial pattern flap: an experimental study on pigs. J Rep Reconstr Surg (Chinese). 2008;5:554–7.
9. Nakajima H, Imanishi N, Minabe T, et al. Anatomical study of subcutaneous adipofascial tissue: a concept of the protective adipofascial system(PAFS) and lubricant adipofascial system(LAFS). Scand J Plast Reconstr Surg Hand Surg. 2004;38(5):261–6.
10. Ogawa R, Hyakusoku H. Color Doppler ultrasonography in the planning of microvascular augmented super-thin (SVN: subdermal vascular network) flaps. Plast Reconstr Surg. 2003;112:822–8.
11. Yang SF, Wang CM, Ono S, et al. The value of multidetector row computed tomography angiography for preoperative planning of freestyle pedicled perforator flaps. Ann Plast Surg. 2016;77:669–73.
12. Gao JH, Hyakusoku H, Inoue S, et al. Usefulness of narrow pedicled intercostal perforator flap for coverage of the burned hand. Burns. 1994;20:65–70.

Tissue Expansion for Burn Reconstruction

40

Cagri A. Uysal and Abbas Albayati

Keywords

Burn reconstruction · Contracture · Expander · Scar · Postburn surgery

40.1 Background

Tissue expansion was initially described by Neumann in the late 1950s, employing a rubber balloon placed in the subcutaneous plane of the scalp for ear reconstruction [1]. Neumann utilized a subcutaneous rubber balloon to expand a specific scalp area for ear reconstruction. Subsequently, Radovan [2] employed a sophisticated silicone implant for breast reconstruction. Following various clinical and experimental studies [3, 4], tissue expansion has become an established procedure in reconstructive surgery.

40.2 Basic Principles of Tissue Expansion in Burn Reconstruction

The reconstructive ladder in burn reconstruction comprises direct closure, adjacent tissue transfer, skin grafts, flaps, and tissue expansion [5–9]. Advances in microsurgery have diminished the role of tissue expanders in burn reconstruction. Nevertheless, tissue expansion remains an integral part of the reconstructive ladder for addressing chronic sequelae of burns. Replacing scar tissue with adjacent healthy skin offers advantages in terms of color, texture, thickness, and sensation, with low morbidity [10–16], especially in situations where access to microsurgery is limited. However, drawbacks include the necessity for at least two operations and the extended time required for total expansion, which may take up to 3 months. Complications may involve exposure or infection of the tissue expander, pain, and discomfort.

Basic principles of tissue expansion in burn reconstruction can be outlined as follows:

- The technique should be employed after all burns have healed, and scars have matured.
- Preoperative planning is crucial to ensure that suture lines, once flaps are rotated or advanced, do not parallel previous scars. Planning varies according to the location, with the head and neck, trunk, and extremities being the three main areas where planning and procedures may differ.
- All incisions should be vertical to the expansion plane.
- Incisions can be placed over previous scars, but the scar should be mature and sufficiently thick to prevent extrusion (Fig. 40.1).
- The use of multiple tissue expanders of smaller volume is preferable to one large tissue expander.
- Perioperative antibiotics are always employed due to the higher incidence of infection in these patients.
- The amount of expansion should be monitored to prevent necrosis of the expanded tissue and exposure of the expander.
- Planning for expansion should consider the localization:
  - Head and neck: Caution is needed when advancing expanded neck skin beyond the borders of the mandible. Risks of scar widening and possible lip or eyelid ectropion need consideration. Multiple and serial small expanders are preferable to one large expander, especially when placed in the cheek region. Expansion should be continued as much as possible, considering the immobility of expanded scalp flaps compared to other skin flaps. Galeal scoring is a valuable method for increasing skin advancement through tissue expansion. Pre-expansion galeal scoring can be applied to allow for more rapid expansion of the scalp and reduce pain during expander inflation.

C. A. Uysal (✉) · A. Albayati
Department of Plastic, Reconstructive and Aesthetic Surgery, Baskent University Faculty of Medicine, Ankara, Turkey

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_40

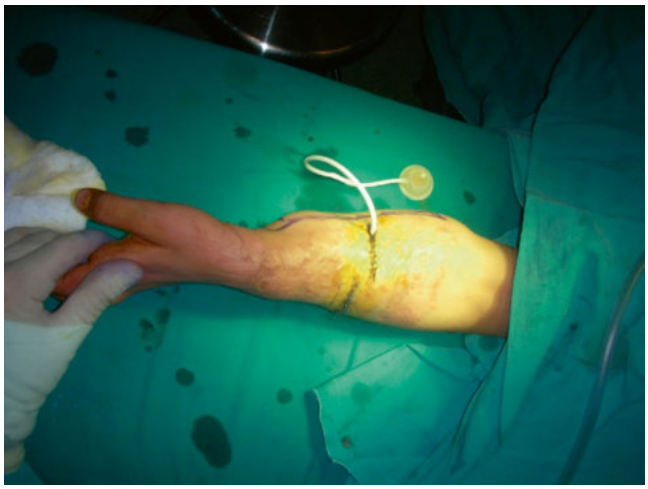


Fig. 40.1 An illustration depicting the recommended orientation of the incision for expander placement, emphasizing the importance of a vertical alignment to the expansion plane. Incisions are strategically positioned over areas of previous scars, which will be excised during the subsequent session

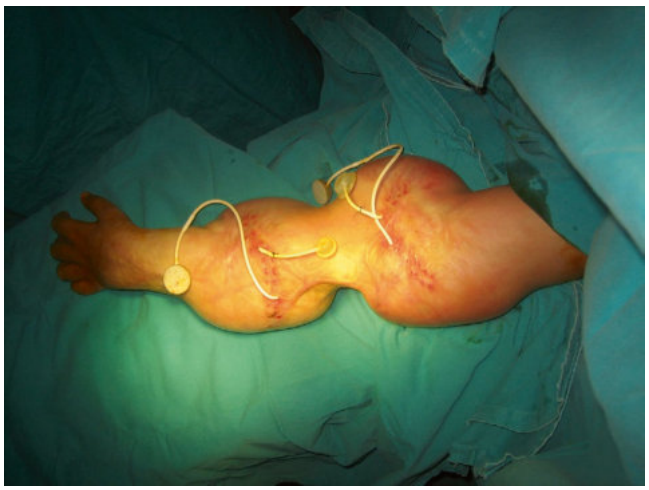


Fig. 40.2 An intraoperative photograph capturing the patient immediately before expander explantation. External port expanders were chosen for this case, considering the patient's residence in a rural area, where self-inflation convenience influenced the selection

- A novel method has been implemented in our department for scalp flap dissection during tissue expander placement. A balloon trocar is inserted through a small incision far from the expander pocket, and visualization is achieved through an endoscopic light source. The main advantage of this method is controlling dissection-related complications such as dehiscence and expander exposure [17].
- Trunk: The abdominal region differs from the dorsal and costal regions. Expanders should be placed to avoid hindering visceral functions. Abdominal expansion may not be as feasible and predictable due to insufficient pressure for thorough tissue expansion. Multiple small expanders may help overcome gravity issues in long-term trunk expansions.
- Extremities: Expanders implanted on extremities are more prone to complications than those on other body parts. Small, serial, and multiple expansions should be planned, with caution due to the mobility of extremities.

40.3 Clinical Cases

40.3.1 Case 1

A 13-year-old male patient presented with complaints of scar tissue on his right arm and forearm due to a flame burn. Both areas healed by secondary intention after the burn, with scars measuring 9 x 7 cm and 10 x 7 cm, respectively. Four expanders were inserted on both the medial and lateral sides of both the left forearm and arm (Fig. 40.2). All expanders were inflated up to 120 % of their original size. After 2.5 months, the expanders were removed alongside scar excision and flap advancement (Fig. 40.3). The wound was primarily closed with expanded skin flaps (Fig. 40.4). A 6-month follow-up demonstrated successful release of scar tissues (Figs. 40.5 and 40.6).

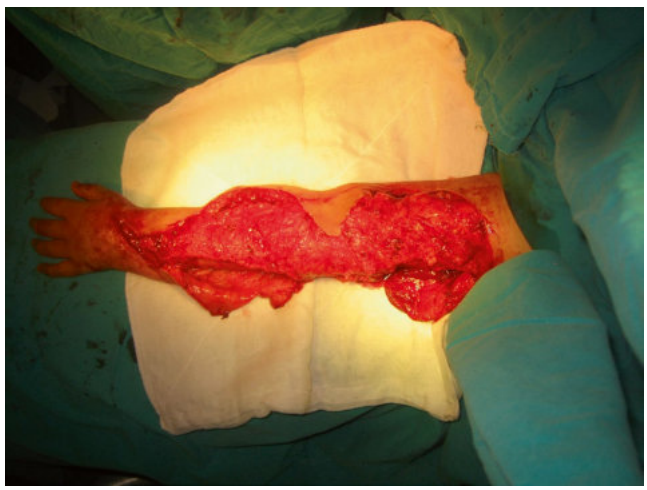


Fig. 40.3 Intraoperative perspective showcasing the expanded flaps following the removal of scar tissues

40.3.2 Case 2

A 29-year-old male patient was referred to our department with scar tissue on the lateral aspect of the antecubital fossa causing flexion deformity of the left elbow joint. The wound,

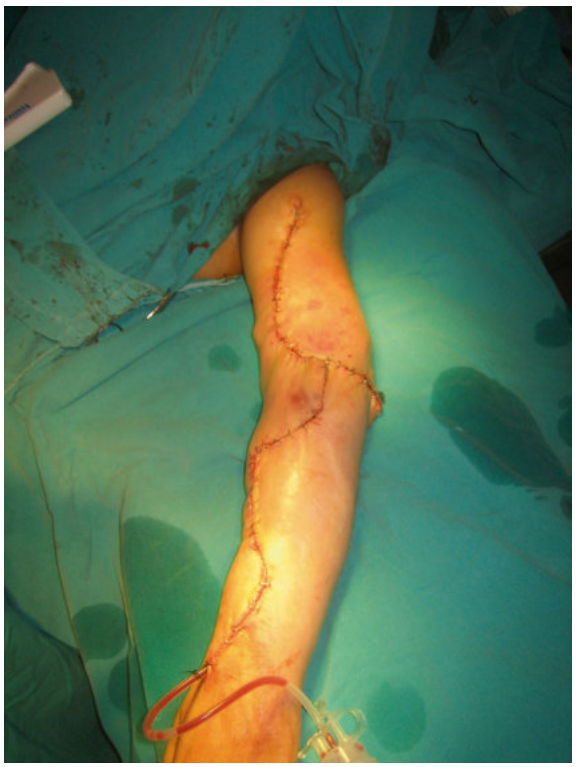


Fig. 40.4 Immediate postoperative view presenting the inset of expanded flaps with minimal tension on suture lines. The drain was removed 2 days after the surgery

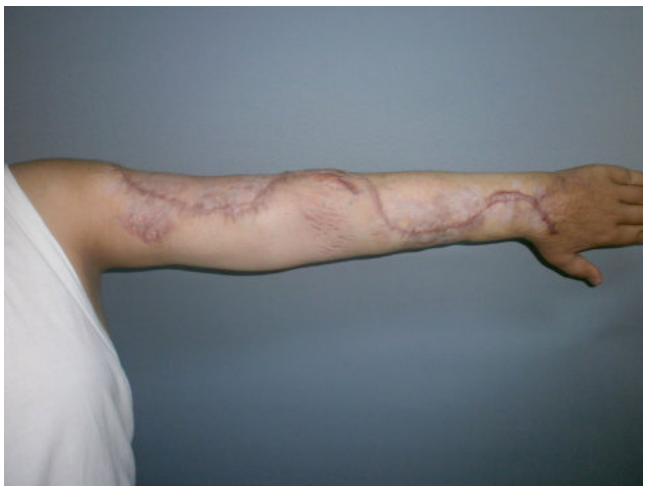


Fig. 40.5 A 6-month postoperative view of the patient, demonstrating the successful treatment of scar tissues

secondary to a scald burn injury, was initially treated with secondary intention 2 years ago. A 240 cc silicone expander was placed on the volar aspect of the left arm superior to the

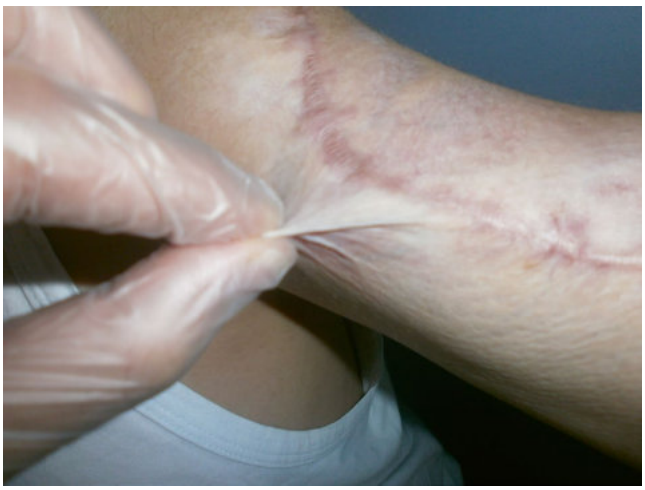


Fig. 40.6 Visual representation of the expanded skin 6 months after surgery, highlighting the dermal thinning resulting from tissue expansion

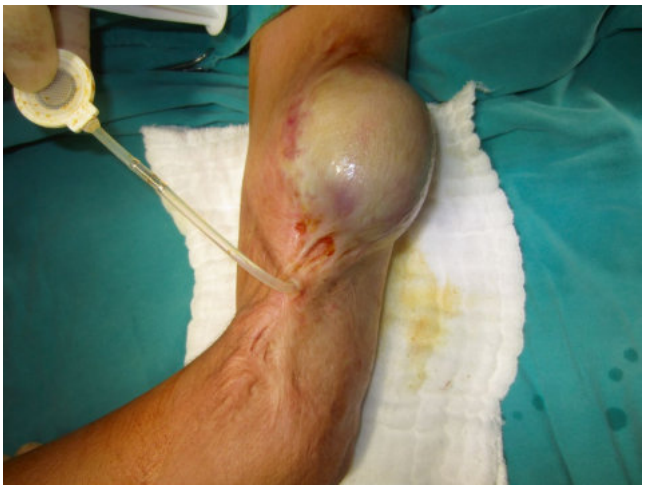


Fig. 40.7 Intraoperative image displaying the scar contracture and the expander equipped with an external port. Observe the skin's whitening above the expander due to the rapid over-inflation immediately before expander explantation. This technique is employed to counteract the primary contraction witnessed in the flap after expander removal

contracture (Fig. 40.7). After 7 weeks of weekly expansion with saline injections, the expander was removed, the scar tissue was excised, and the expanded flaps were adapted as planned. No complications were encountered throughout the treatment, except for a hypertrophic scar at the incision site that did not restrict movement. A 6-month follow-up showed a release of the contracture with normal range of motion (Fig. 40.8).

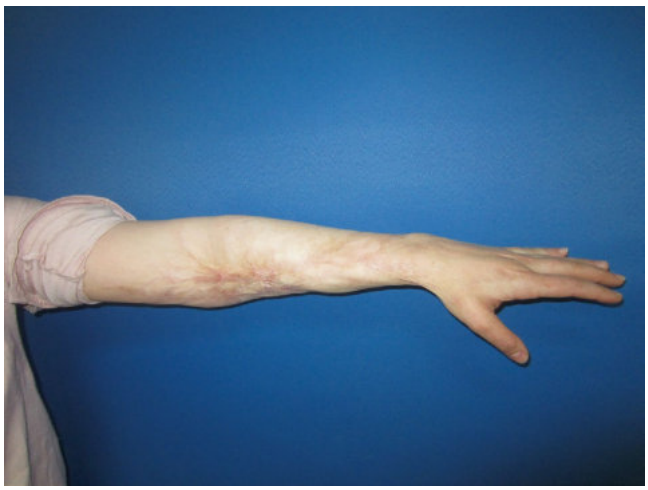


Fig. 40.8 A 6-month postoperative view of the same patient, showcasing the complete release of contracture with restored normal range of motion

Acknowledgment The authors gratefully acknowledge the contribution of Huseyin Borman to this chapter as it appeared in the first edition of the book.

References

1. Neumann CG. The expansion of an area of skin by Progressive distention of a subcutaneous balloon. Plast Reconstr Surg. 1957;19:124.
2. Radovan C. Breast reconstruction after mastectomy using the temporary expander. Plast Reconstr Surg. 1982;69:195.
3. Radovan C. Tissue expansion in soft tissue reconstruction. Plast Reconstr Surg. 1984;74:482.
4. Argenta LC, Marks MW, Pasyk KA. Advances in tissue expansion. Clin Plast Surg. 1985;12:159.
5. Chun JT, Rodrich RJ. Versatility of tissue expansion in head and neck reconstruction. Ann Plast Surg. 1998;40:226.
6. Spence RJ. Experience with novel uses of tissue expanders in burn reconstruction of the face and neck. Ann Plast Surg. 1992;28:453.
7. Hallock GG. Tissue expansion techniques in burn reconstruction. Ann Plast Surg. 1987;81:274.
8. Borman H, Maral T, Demirhan B, Haberal M. Skin flap survival after superficial and deep partial-thickness burn injury. Ann Plast Surg. 1999;43(5):513.
9. Borman H, Maral T, Demirhan B, Haberal M. Reliability of island flaps raised from superficial and deep burn injury. Ann Plast Surg. 2000;45(4):395.
10. Spence RJ. An algorithm for total and subtotal facial reconstruction using an expanded transposition flap: a 20-year experience. Plast Reconstr. 2008;121(3):795.
11. Gao JH, Ogawa R, Hyakusoku H, Lu F, Hu ZQ, Jiang P, et al. Reconstruction of the face and neck scar contractures using staged transfer of expanded "Super-thin flaps". Burns. 2007;33(6):760.
12. Lu F, Gao JH, Ogawa R, Hykusoku H. Preexpanded distant "super-thin" intercostal perforator flaps for facial reconstruction without the need for microsurgery. J Plast Reconstr Aesthet Surg. 2006;59(11):1203.
13. Unlu RE, Sensöz O, Uysal AC. Re: The use of serial tissue expansion in pediatric plastic surgery. Ann Plast Surg. 2001;47(6):679.
14. Lozano S, Drucker M. Use of tissue expanders with external ports. Ann Plast Surg. 2000;44(1):14.
15. Hudson DA, Grob M. Optimising results with tissue expansion: 10 simple rules for successful tissue expander insertion. Burns. 2005;31(1):1.
16. Acarturk TO, Glaser DP, Newton ED. Reconstruction of difficult wounds with tissue-expanded free flaps. Ann Plast Surg. 2004;52(5):493.
17. Özkan B, Savran S, Uysal AC. Novel scalp flap elevation with balloon trocar dissection device. J Craniofac Surg. 2023;34(7):2185–6.

Local Flaps for Facial Burn Reconstruction

41

Szu-Han Wang, Victor Bong-Hang Shyu, Jui-Yung Yang, Shih-Yi Yang, and Chia-Hsuan Tsai

Keywords

Local flaps · Facial reconstruction · Burn patients · Functional outcome · Aesthetic appearance · Scar contracture · Reconstruction timing · Skin grafting · Tissue expanders · Free tissue transfer · Psychosocial impact · Eyelid reconstruction

Facial reconstruction in burn patients remains challenging, requiring the restoration of both functional and aesthetic appearance. It is challenging to achieve good functional and cosmetic outcomes at the same time in any head and neck patient, and this is especially true for the face. Any functional impairment in visual acuity, visual field, smell, speech function, nutritional intake or even respiratory exchange can result in severe discomfort and inconvenience of daily living. Slight asymmetries or deviations from the norm are also poorly tolerated. The face is exposed and not easily concealed with makeup. Moreover, deformities caused by either the initial trauma or subsequent scarring and scar contractures often lead to difficulties in burn victims' social relationships and have severe negative psychosocial consequences leading to withdrawal of the victim from society [1].

After adequate resuscitation and stabilization of the patient, comprehensive assessment and accurate wound care management are the next priority. This will influence the final scar formation, reconstruction timing, and sequence. Debridement and skin grafting are infrequently performed on the facial region unless deep burns occur. This chapter will review the general principles of facial burn reconstruction and the local flap options for post-burn facial reconstruction in different facial subunits and regions. The application of free tissue transfer and facial transplantation is also described in this chapter.

S.-H. Wang · V. B.-H. Shyu · C.-H. Tsai (✉)
Division of Plastic and Reconstructive Surgery, Department of Surgery, Chang Gung Memorial Hospital, Keelung branch, Keelung City. College of Medicine, Chang Gung University, Chang Gung Memorial Hospital, Keelung branch, Taoyuan City, Taiwan

J.-Y. Yang · S.-Y. Yang
Division of General Plastic Surgery and Burn Care, Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Linkou Branch. College of Medicine, Chang Gung University, Taoyuan City, Taiwan

41.1 Principles of Facial Burn Reconstruction

The principles of facial subunits and comprehensive face shaping should be considered during reconstruction planning. For the patient, it is difficult to conceal any facial burn scars by clothing or makeup. In general, nearly all superficial burn wounds can heal via secondary intention with minimal scarring, and most full-thickness (deep second degree and third degree) burn injuries will lead to scar formation and contracture. When suboptimal scarring occurs, adequate contracture release and resurfacing then plays an important role in facial contour restoration. The timing of reconstructive surgery is also an important concern in the management sequence. The ideal condition is to wait until there is no red, raised, pruritic, and tight scarring, which often means waiting at least 6, and up to 35 months after the initial burn [2, 3]. Mature scars are usually white, soft, and relatively flat, indicating resolution of the local inflammatory process, which will allow for reconstruction in a suitable wound bed.

On the other hand, distinct facial structures such as the ear and ocular region demonstrate unique characteristics that should be addressed with specific reconstructive concepts. Burned ear reconstruction may involve skin and cartilage defects, which require structural support from rib cartilage grafts or alloplastic materials. Ocular region burn injuries may involve the upper and lower eyelids, periorbital region, and structures of the globe such as sclera, conjunctiva, and cornea, which may require prompt reconstruction to prevent visual impairment. The perioral region and nose also possess specialized considerations during reconstruction, such as avoidance of microstomia, prevention of stenotic airways, or necessity of mucosal lining replacement.

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_41

In summary, reconstruction of the burned face should follow the general principles mentioned below. First, replace like tissue with like tissue if available. Second, consider function over cosmesis during the reconstruction but attempt to balance both. For example, periorbital area reconstruction should prioritize over-narrowing of visual field, over-exposure of conjunctiva and sclera, and cicatricial ectropion. Mouth and lip reconstruction should avoid the possibility of drooling, microstomia, and sphincter contracture. Third, have multiple options and planning for the reconstruction, and discuss the primary goals of each stage with patients and their family members. Last but not least, consider tissue expanders, local flaps, full- thickness skin grafts (FTSG), or even free tissue transfer over split-thickness skin grafts if there is not enough pliable autologous skin and soft tissue available.

41.2 Contracture Release and Resurfacing

Hypertrophic scar and scar contracture are the most common complications after burn injury if the burned wound was not managed adequately or the depth and severity of burn were critical. Poor scarring often leads to distortion of anatomical landmarks and restrictive movement of key facial structures. There are several non-surgical methods that may decrease scar contracture during various stages of scar formation, including antihistamines, hydrotherapy, dynamic or static splinting, compression garment therapy, skin tension release therapy, intra-lesional corticosteroid injection, corticosteroid taping, and laser therapy. However, one of the most efficient methods to deal with the scar contracture is surgical intervention. During scar contracture release of the eyelid, both intrinsic (eyelid itself) and extrinsic (extra-periorbital region including cheek and neck) regions should be considered. Peri-oral region can be managed based on similar principles to the peri-orbital area (Fig. 41.1). The main purpose of contracture release is to allow healthy tissue to return to its normal location.

There are several areas that should be considered carefully due to their vulnerability, including upper and lower eyelids, the nostrils and alar bases, and the oral commissure and lips. During reconstruction and resurfacing, FTSG and local flaps are utilized rather than split-thickness skin grafts to prevent secondary contracture (Fig. 41.2). Local flaps are a safe and effective method of reconstruction that demonstrate better long-term results than FTSG in resurfacing of scar contracture. In fact, the aesthetic results are also better based on our experience. Local flaps, such as transposition flaps, propeller flaps, square flaps, or V-Y advancement flaps, utilize surrounding unburned tissue or tissue from areas that have already healed. For instance, lateral cheek local flaps can be used to address medial tissue deficiencies, while forehead flaps can be designed for nasal tip and nasal dorsum reconstruction. Local turndown flaps can also be used to reconstruct the nasal lining. Local flaps from the neck and supra-clavicle area can be utilized for lower face scar contracture release and resurfacing [4].

V-Y advancement flaps and Z-plasty are two of the most commonly used local flaps for scar contracture release. V-Y flaps can be designed for alar base or peri-orbital scar contractures. Z-plasty can also be used in the contracture release and realignment of alar base, eyebrow peaking, vermilion border, and oral commissure (Fig. 41.3). Local flaps can also

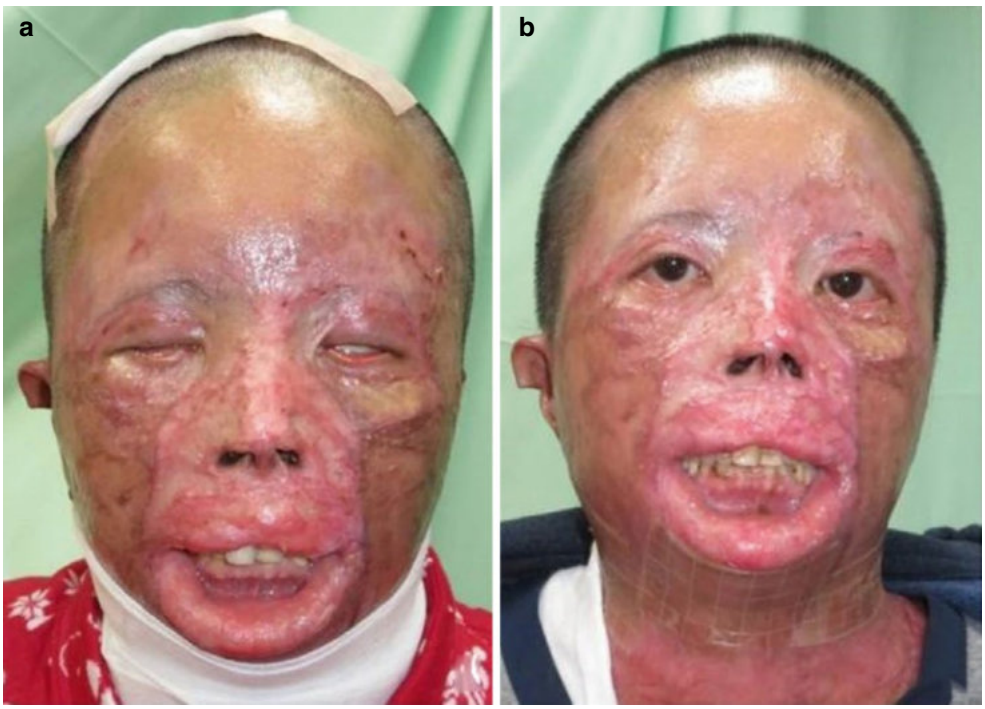


Fig. 41.1 (**a**) Facial burn with severe eyelid contracture. (**b**) Status post intrinsic and extrinsic release by local flaps and FTSG

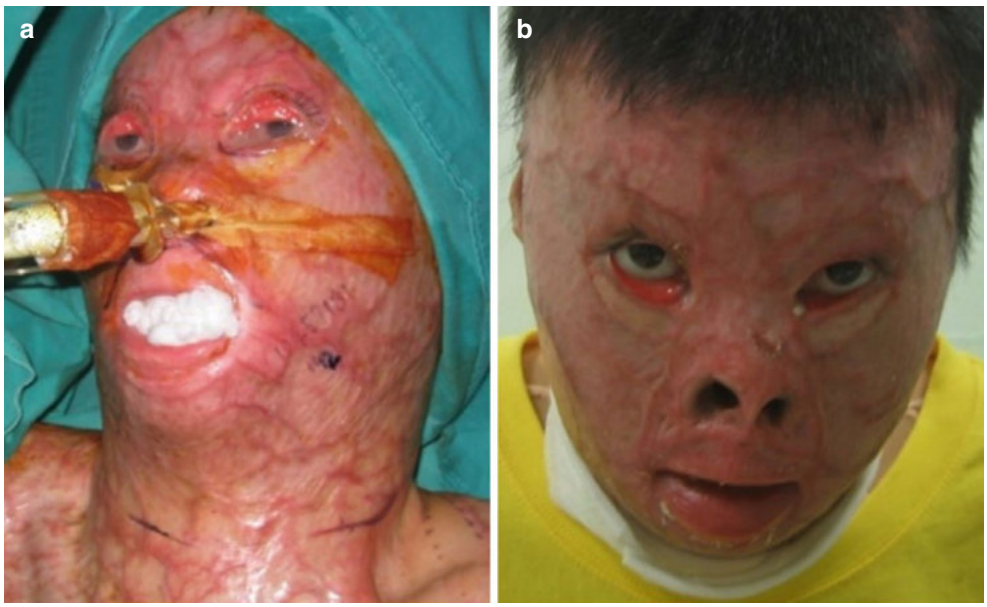


Fig. 41.2 (**a**) Facial burn with severe scar contracture. (**b**) Post scar release and FTSG

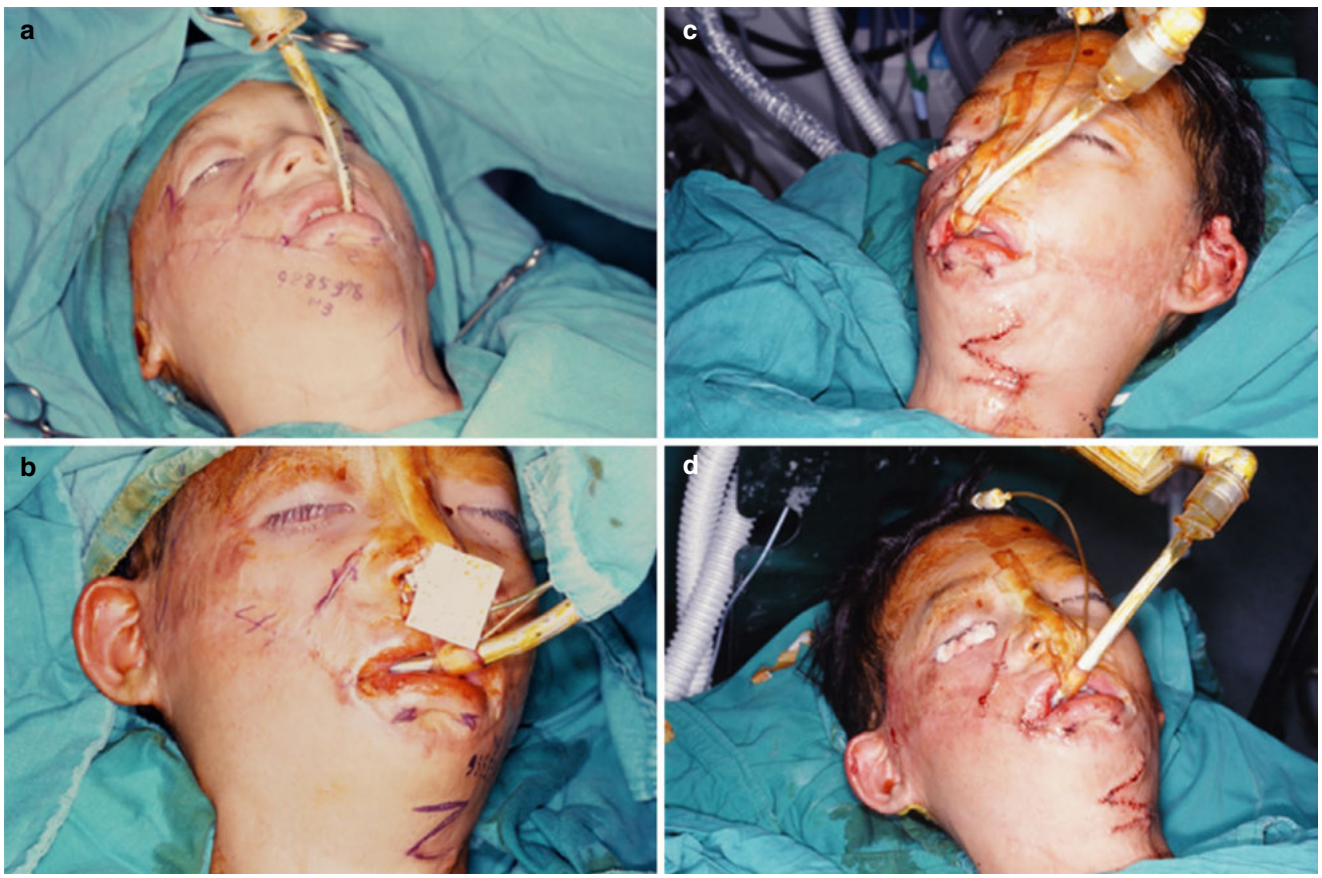


Fig. 41.3 Z-plasty for face, nasolabial fold and neck contracture. (**a**) Preoperative scar contracture. (**b**) Design of multiple Z-plasty on face, nasolabial fold and neck contracture release. (**c** and **d**) Post-operative outcome

be designed to deal with several post-burn complications, such as lower eyelid ectropion, oral commissure contracture, and microstomia caused by circumferential thermal or electric burns [5, 6]. In the situation of electric burns, the lips and oral mucosa may also be injured and present with contracture. Contracture release and resurfacing of the lip and philtrum with various local flaps is possible using Abbe flap, intra-oral mucosal flaps, vermilion advancement flap, and facial artery musculomucosal flap from the buccal area [7–9]. However, ectropion of lip vermilion should be addressed by FTSG rather than a local flap. If an intraoral contracture is released, the tongue flap serves as another choice to fulfill the defect.

41.3 Contour Restoration and Secondary Scar Revision

Contour restoration for aesthetic purpose is an important issue in facial burn reconstruction. Loss of protrusion of features on the face caused by burn and scar contracture is a major concern to patients. The most notable areas are the periorbital area, nose, lips, and bilateral ears. Adjacent scar contracture in the neck and cheek may lead to feature deformity; hence, surrounding contracture release should be addressed prior to resurfacing. The area that needs to be resurfaced may decrease after adjacent contracture release, which allows the reconstruction design to be more straightforward. Based on the concept of subunit reconstructive surgery, subunit contour restoration is prioritized over minimizing scar length during the reconstruction planning. Soft tissue and skin should both be rearranged to achieve the best post-operative outcome. Superficially scarred tissue can also be used during the design of local flaps, because the preservation of deep dermal circulation or axial circulation allows fasciocutaneous flap to be raised for regional reconstruction. Additionally, excised scar can be utilized as an augmentation source during lip or nose reconstruction to preserve volume.

In cases of extensive burn injury, combination of local flap with skin graft may also be considered. Full-thickness and sheet split-thickness skin grafts are better choices for face resurfacing compared to their meshed counterparts. In patients who received skin grafts (STSG and FTSG) in their initial burn management due to lack of healthy skin and available soft tissue, severe secondary scar contractures may develop. Local flaps should be considered as the preferable option for secondary scar revision after primary reconstruction due to less possibility of post-operative contracture.

41.4 Local Flaps for Different Facial Areas

41.4.1 Restoration of Facial Contour

Local flaps can be used to restore facial contour because they share similar texture and color with surrounding tissue. Even if the surrounding tissue has received minor concomitant damage, tension release potentially allows restoration of anatomical landmarks to original location. Skin grafts possess the possibility of secondary contracture. Local flaps can generally be categorized into three major types, including advancement flaps, rotation flaps, and transposition flaps. V-Y advancement flap and Z-plasty can also be used to restore the cheek and contour. Y-V and V-Y flaps can also be applied in epicanthus reconstruction. Five-flap can also provide significant results in the medial and lateral canthus (Fig. 41.4). Nasolabial flaps can also be designed to reconstruct the shape of nose and philtrum area with acceptable post-operative scar. Nasolabial flap with full-thickness skin graft can be designed for nasal ala and nasal tip reconstruction (Fig. 41.5). Hinge flap could also be designed to improve the contouring of lateral check and para-alar region. Median and paramedian forehead flaps can be applied for nose or midface contouring. Nasal ala contracture can also be reconstructed by septal mucoperichondrial flap combined with paramedian forehead flap [10].

If the burn injury was too severe to allow for usage of tissue in the immediate proximity, propeller flaps can occasion-

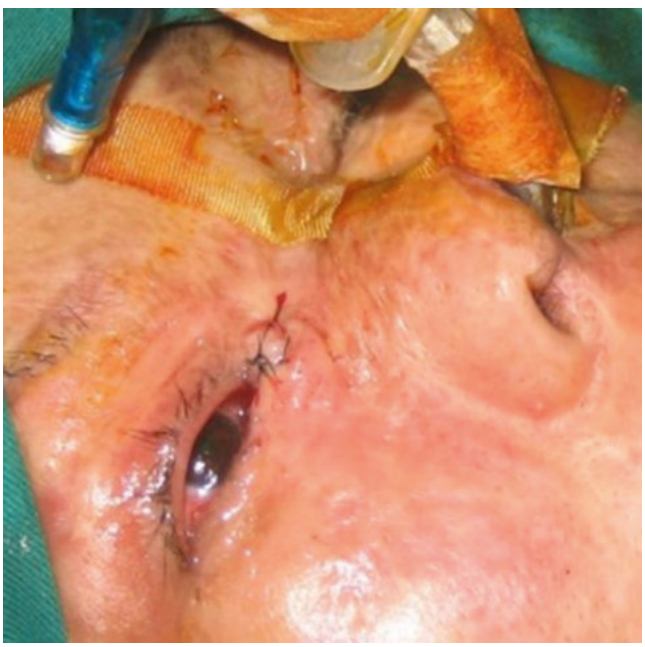


Fig. 41.4 Y-V Plasty for medial canthus reconstruction

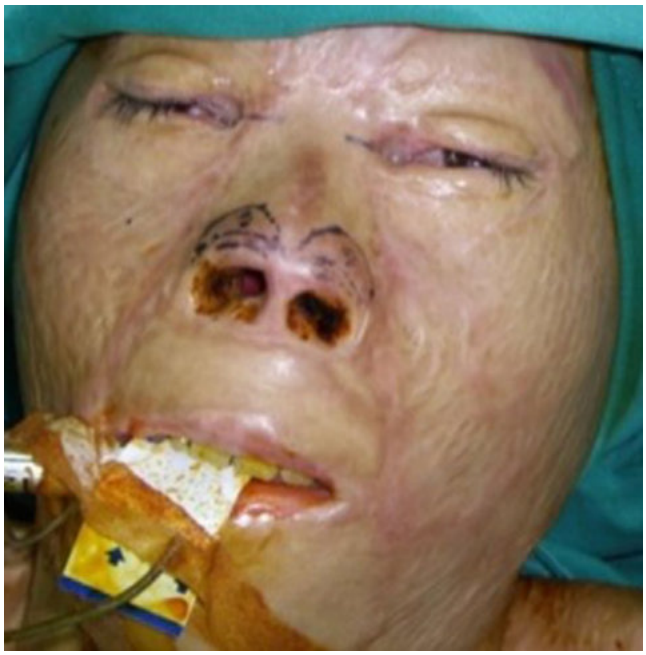


Fig. 41.5 Nasal ala reconstruction by nasolabial turnover flap and FTSG

ally be an alternative choice, such as use in lip contracture release [11, 12]. Perforator-based pedicled propeller flaps can also be designed at other facial areas based on the discovery of a suitable perforator in the vicinity of the region that needs to be resurfaced.

41.4.2 Restoration of Hair-Bearing Tissue

Deep and full-thickness thermal burn may involve the injury of hair follicles, leading to the loss of hair growth in hair-bearing areas. Loss of hair-bearing tissue causes both aesthetic and psychological issues in the burn patient. There are several hair-bearing regions that should be reconstructed for aesthetic and psychosocial reasons.

The eyebrow is one of the most important landmarks and aesthetic features on the face. During periorbital reconstruction, post-burn scar contracture should be released, and a flap such as the superficial temporal artery island flap can be designed from the lateral scalp for reconstruction of this hair-bearing region [13]. If the whole eyebrow was injured and more hair-bearing tissue is needed, tissue expander can be applied to expand the scalp hair-bearing tissue before pedicle flap reconstruction [14]. For burns that only involve the lateral eyebrow, contralateral orbicularis oculi muscle pedicled skin island flap can be harvested for reconstruction.

The beard should be divided into the preauricular zone, which includes the sideburn and the buccomandibular area, and the submental zone. Reconstruction of small alopecia in the sideburn and buccomandibular region can rely on different types of V-Y flaps, such as single V-Y flap, opposing V-Y flaps, extended V-Y flaps, and double extended V-Y flaps based on the vector and affected area [15, 16]. Scalp transposition flap based on superficial temporal artery provides hair-bearing tissue with reliable perfusion that can be designed to deal with larger defects. For the beard of the chin area, advancement of neck skin or use of submental island flap can be applied to release scar contracture. Expanded superficial temporal artery-based island flap with increased length could also resurface the chin area. However, hair transplantation should still be considered if lack of hair-bearing tissue is present.

The mustache area, including the philtrum and cupid bow, is more difficult to reconstruct with local flaps. There are limited local flaps available that can be applied in this area. Expanded scalp flap and expanded submental flaps are the two main local flap that can be utilized to resurface the mustache area.

41.5 Tissue Expander, Free Tissue Transfer, and Facial Transplantation

Tissue expanders are widely used in burn reconstruction due to lack of available skin and healthy tissue in burn victims. Staged reconstruction by application of tissue expanders allows surgeon to resurface extensive burned areas with surrounding skin based on the principle of reconstructing like-with-like. Depending on the shape of tissue expander used, at least 25% increase in calculated surface area can be achieved [17]. Expanded scalp transposition flap is one popular method to reconstruct the hair-bearing areas in the burned face. The decision of implanting tissue expander depends on the wound or scar location, shape, and size that need resurfacing, and the area of remaining healthy skin [12]. However, there are still concerns such as patient discomfort, tissue structure changes including fat atrophy and thinning of dermis, and possibility of extrusion or infection that should be considered before tissue expander placement [18] (Fig. 41.6).

Free tissue transfer is relatively less common in the burned face because of suboptimal contour outcome. Free flaps generally provide flat surfaces that do not fit well with facial features and contour. However, it can still provide the necessary tissue volume to replace tissue deficiency after burn injury or after scar contracture release [19]. Several revision surgeries for fine adjustments using liposuction, local flaps, or scar transposition may be necessary for better natural contouring.

Facial transplantation is a surgical technique that can be considered as a last resort in complex facial burn cases. Although it can provide reconstruction of the whole face, it

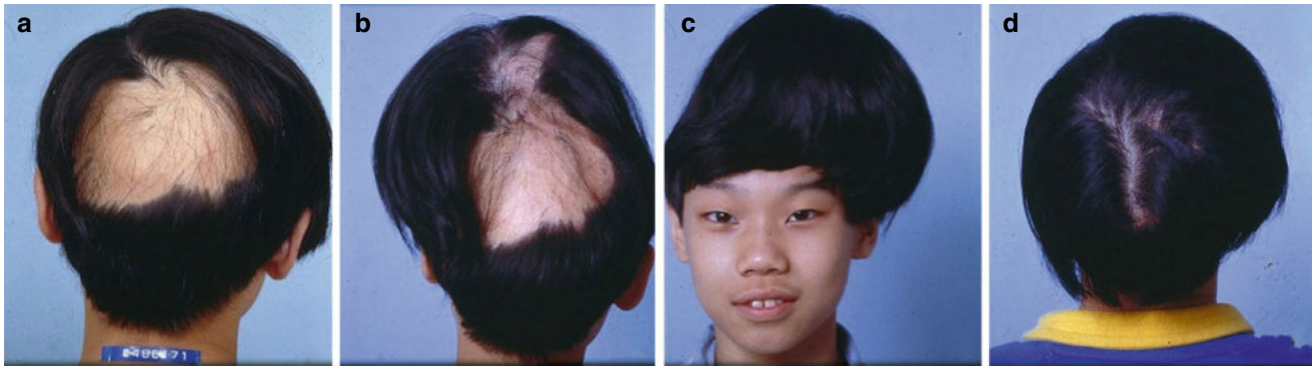


Fig. 41.6 Scalp alopecia reconstruction by tissue expander. (**a**) Preoperative photo. (**b** and **c**) After tissue expander insertion. (**d**) After alopecia area excision

is currently still an experimental surgical procedure with limitations such as limited donor facial tissue allografts, complexity and experience requirement of surgical technique, requirement of well-trained and skilled multidisciplinary surgical team, and the risk associated with lifelong immunosuppression treatment after surgery [20–22].

41.6 Summary

In conclusion, local flaps can provide excellent outcomes and ideal color, texture, and contouring in burned face reconstruction. Reconstruction and resurfacing of the face should consider both functional and aesthetic aspects to achieve desirable results. Although facial burn reconstruction remains challenging, general principles detailed in this chapter could serve as a guide for surgeons to optimize their results.

References

1. Palackic A, Franco-Mesa C, Beck I, et al. The impact of facial burns on short- and long-term quality of life and psychological distress—a prospective matched cohort study. J Clin Med. 2023;12(15)
2. Bond JS, Duncan JAL, Sattar A, et al. Maturation of the human scar: an observational study. Plast Reconstr Surg. 2008;121(5):1650–8.
3. Kant S, van den Kerckhove E, Colla C, van der Hulst R, Piatkowski de Grzymala A. Duration of scar maturation: retrospective analyses of 361 hypertrophic scars over 5 years. Adv Skin Wound Care. 2019;32(1)
4. Jerome TJ, Sabtharishi V, Sk T. Supraclavicular flap for severe post-burn neck contracture in children. Cureus. 2021;13(1):e12910.
5. Egeland B, More S, Buchman SR, Cederna PS. Management of difficult pediatric facial burns: reconstruction of burn-related lower eyelid ectropion and perioral contractures. J Craniofac Surg. 2008;19(4):960–9.
6. Mordjikian E. Severe microstomia due to burn by caustic soda. Burns. 2002;28(8):802–5.
7. Nyame TT, Pathak A, Talbot SG. The abbe flap for upper lip reconstruction. Eplasty. 2014;14:ic30.
8. Su CT, Manson PN, Hoopes JE. Electrical burns of the oral commissure: treatment results and principles of reconstruction. Ann Plast Surg. 1980;5(4):251–9.
9. Navarro Cuéllar C, Tousidonis Rial M, Antúnez-Conde R, et al. Functional outcomes with facial artery musculo-mucosal (FAMM) flap and dental implants for reconstruction of floor of the mouth and tongue defects in oncologic patients. J Clin Med. 2021;10(16):3625.
10. Lee DW, Ryu HR, Choi HJ, Kim JH. One-stage reconstruction of full-thickness alar defects with a folded nasolabial island flap. Arch Craniofac Surg. 2021;22(6):296–302.
11. Hyakusoku H, Yamamoto T, Fumiiri M. The propeller flap method. Br J Plast Surg. 1991;44(1):53–4.
12. Ogawa R. Surgery for scar revision and reduction: from primary closure to flap surgery. Burns Trauma. 2019;7:7.
13. Amouzou KS, Hissein HA, Mokako LJ, Diouri M. Aesthetic reconstruction of post-burn eyebrow alopecia with a superficial temporal island scalp flap: a case report and review of the literature. Ann Burns Fire Disasters. 2020;33(4):329–33.
14. Accardo G, Aveta A, Ambrosino E, Aceto B, Di Martino A, Schonauer F. A surgical algorithm for partial or total eyebrow flap reconstruction. J Surg Oncol. 2015;112(6):603–9.
15. Giraldo F, González C, Garnica I, Ferrón M, Rus JA. Sideburn reconstruction with an expanded supraauricular trapezoidal flap. Plast Reconstr Surg. 1997;100(1):257–61.
16. Juri J, Juri C, Colnago A. The surgical treatment of temporal and sideburn alopecia. Br J Plast Surg. 1981;34(2):186–93.
17. van Rappard JH, Sonneveld GJ, Borghouts JM. Geometric planning and the shape of the expander. Facial Plast Surg. 1988;5(4):287–90.
18. Agrawal K, Agrawal S. Tissue regeneration during tissue expansion and choosing an expander. Indian J Plast Surg. 2012;45(1):7–15.
19. De Lorenzi F, van der Hulst R, Boeckx W. Free flaps in burn reconstruction. Burns. 2001;27(6):603–12.
20. Siemionow M, Gordon CR. Overview of guidelines for establishing a face transplant program: a work in progress. Am J Transplant. 2010;10(5):1290–6.
21. Kantar RS, Alfonso AR, Diep GK, et al. Facial transplantation: principles and evolving concepts. Plast Reconstr Surg. 2021;147(6):1022e–38e.
22. Win TS, Frew Q, Taylor CJ, Peacock S, Pettigrew G, Dziewulski P. Allosensitization following skin allografts in acute burn management: Are burns patients suitable face transplant candidates? J Plast Reconstr Aesthet Surg. 2015;68(8):1155–7.

Reconstruction in Pediatric Burns

42

Jui-Yung Yang and Fu-Chan Wei

Keywords

Free flap · Fasciocutaneous flap · Scar contracture · Augmentation mammaplasty · Pediatric burn

The incidence of pediatric burns (<18 years old) in Taiwan, according to data from the Childhood Burn Foundation Taiwan ROC, was about 33.4%. The incidence of reconstruction needed for this age group was also about the same. From the data presented in Singapore in 2006, there was an average of 36.3% (patient number: 2,833/7,795) of pediatric burns (<18 years old) in the Linkou Burn Center (LBC), Chang Gung Memorial Hospital (CGMH) from 1986 to 2004 [1]. Among these, one-third of the patients needed reconstruction. This is a large reconstruction group and is of concern.

Burn scar contracture are common problems in children after deep thermal burn involving head–neck, extremities, including axilla, hands, and perineum because they are neither easily positioned initially nor easily rehabilitated later [2]. Another consideration about the needs of reconstruction is that the children will face both the functional and developmental problems as well as aesthetic issues if not reconstructed.

42.1 Hair Restoration for Scalp and Eyebrow in Pediatric Burns

The children are vulnerable to suffer from loss of hair either from flame or scald burn if the injuries are deep enough to destroy the hair follicles. If the scar area without hairs (cicatricial alopecia) is not so large, less than 15% of the surface area of the scalp, serial excision, sometimes up to six procedures, may solve the problem [3]. Various hair-bearing flaps, such as local advancement, transposition, interpolation, and island flaps may be considered as a tool for hair restoration for relatively small, 3–5 cm wide, or isolated area as described in literature and Coleman III's descriptions [4]. Tissue expander implantation to expand the hair-bearing scalp for the replacement of the cicatricial area is approved to be an effective and safe method for even scars up to 80% of the scalp area [5] or series expansion up to 4 times in the pediatric group [6]. Hair graft is an alternative method for hair restoration for spotted scars or residual scars after reconstruction. Sometimes, a combination of the above-mentioned methods is needed for both functional and aesthetic consideration [7]. For example, a girl sustained a scald burn, which resulted in cicatricial alopecia in about 80% of the scalp area (Figs. 42.1 and 42.2). Serial hair-bearing scalp expansion (3 times) with tissue expander implantation at the subgaleal plane was done (Fig. 42.3) and most of the scar tissues were replaced with hairy scalp (Fig. 42.4). Free hair follicle unit graft for the residual scar area using excised scar tissue containing hairs as donor site was done (Fig. 42.5). This girl got more than 95% of scalp hair restoration and was very happy to go to school (Figs. 42.6 and 42.7).

J.-Y. Yang (✉)
Department of Plastic and Reconstructive Surgery, Division of General Plastic Surgery and Burn Care, Chang Gung Memorial Hospital, Linkou Branch, College of Medicine, Chang Gung University, Tao-Yuan City, Taiwan

F.-C. Wei
Linkou Burn Center, Chang Gung Memorial Hospital and University, Taipei, Taiwan
e-mail: isc@cgmh.org.tw

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_42

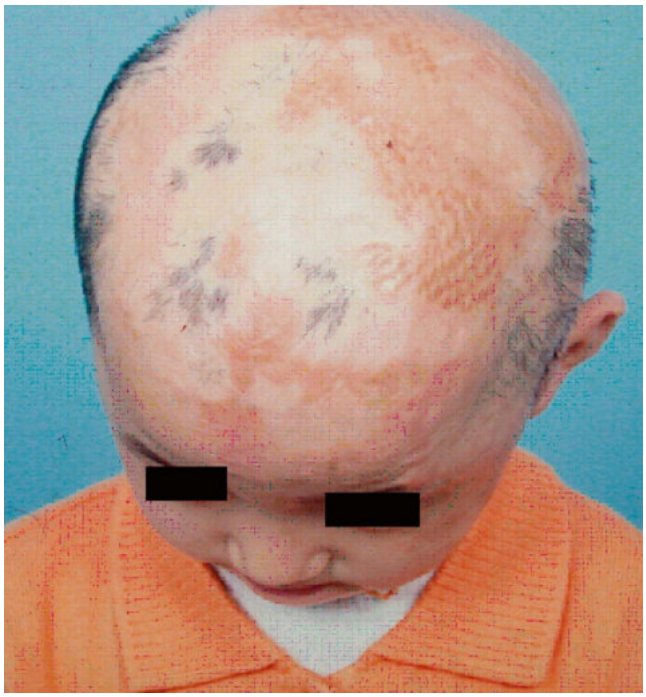


Fig. 42.1 Cicatricial alopecia with 80% hair loss over scalp of a young girl after scald burn, anterior view

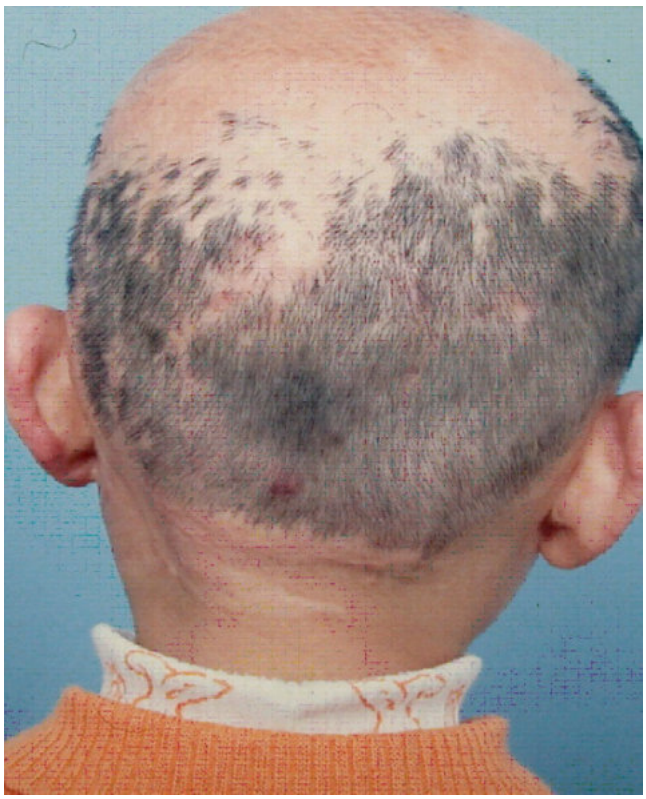


Fig. 42.2 Cicatricial alopecia with 80% hair loss over scalp of a young girl after scald burn, posterior view

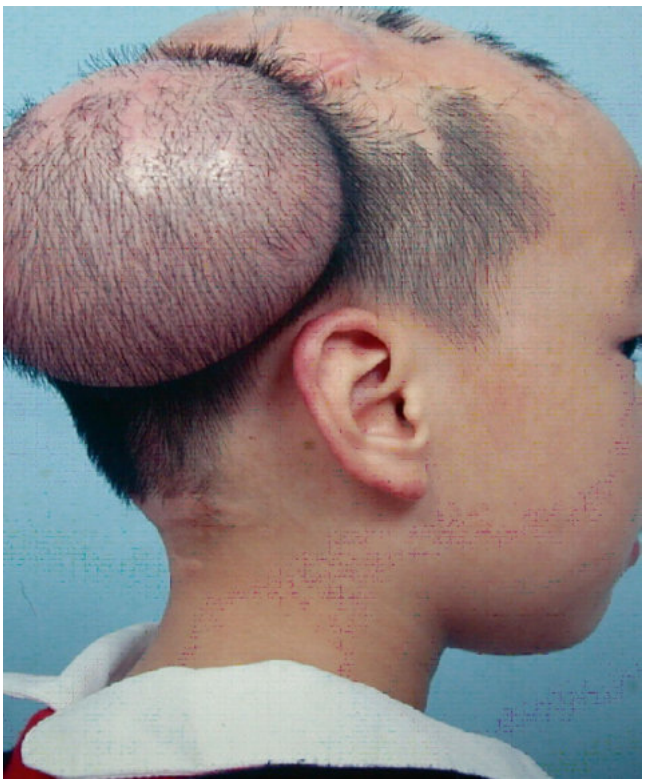


Fig. 42.3 Series tissue expander reconstruction for major alopecia area

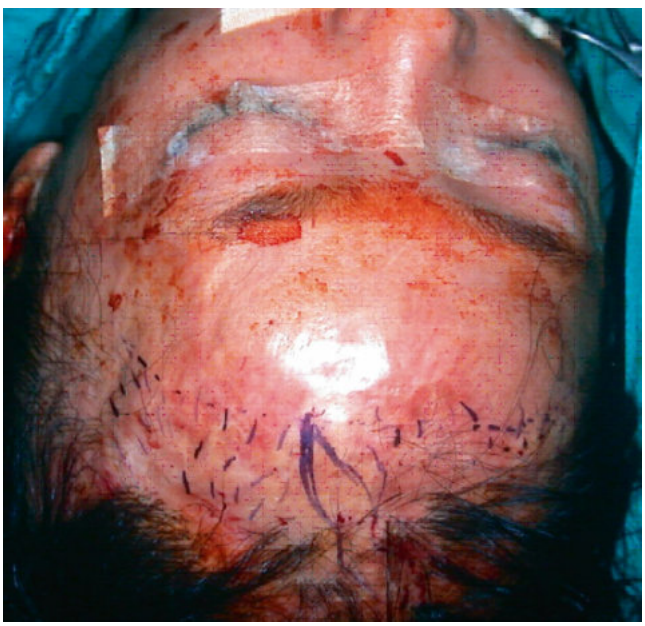


Fig. 42.4 Results of three times hair-bearing scalp expansion reconstruction

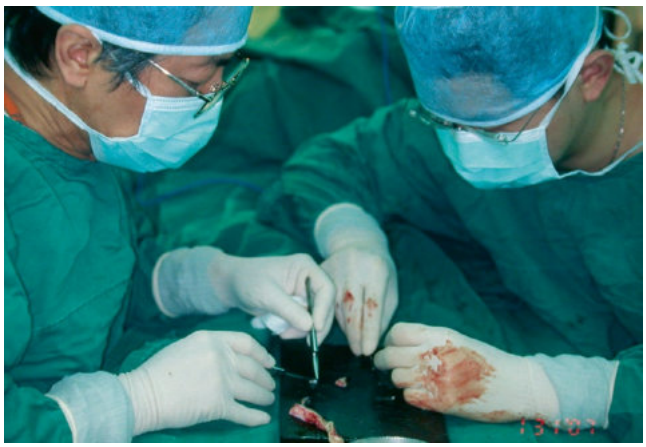


Fig. 42.5 Residual hairs in excised scar tissue may be used as a donor site of free hair unit graft

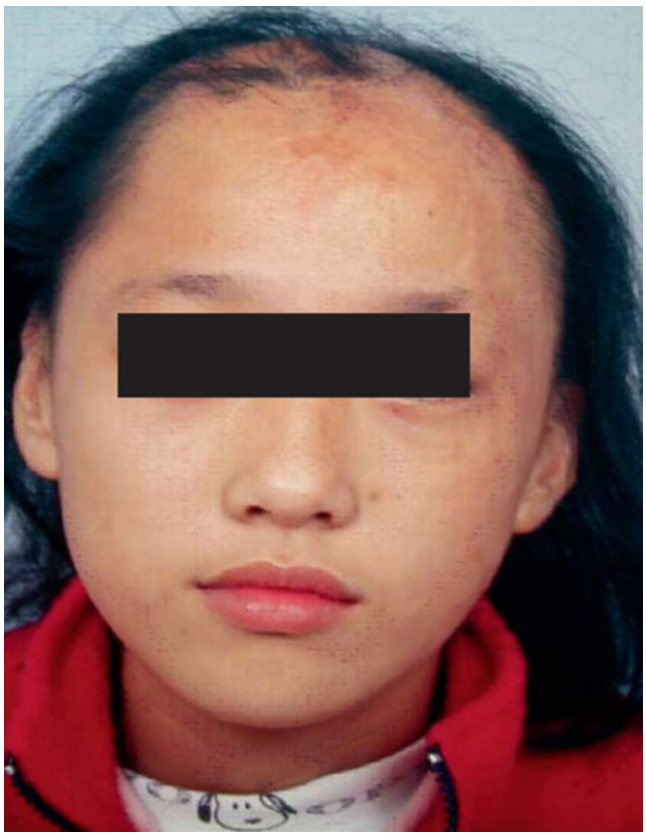


Fig. 42.6 Results of hair restoration courses, over 95% of scalp hairs restored, anterior view

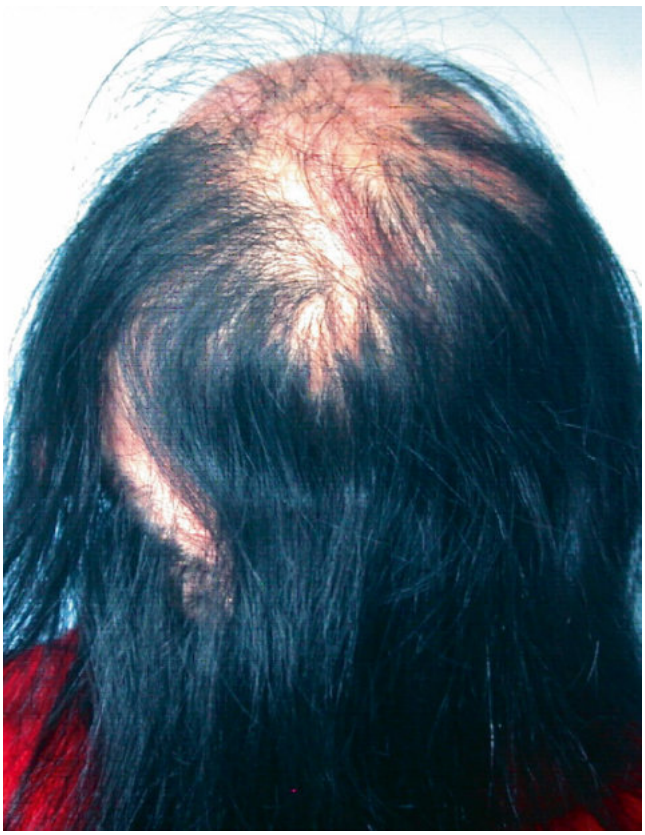


Fig. 42.7 Posterior view

42.2 Facial Reconstruction in Pediatric Burns

Small kids occasionally pull down the hot soup, tea, or coffee from the table and this results in burn injury to the head and face. Sometimes children like to play with their father's lighter and this results in ignition of clothes or something else. Isolated scar contracture or deformity of the face such as eyebrow, nose, lips, ear, or part of the cheeks can be corrected by means of scar excision, contracture release, full-thickness skin graft (FTSG), composite graft taken from ear to nasal ala or scalp to eyebrow, local flap [8] or even free flap. If the scar involved the entire or near-total face, replacement therapy using a large piece of FTSG may be considered as Feldman did [9]. Tissue expander implantation to healthy skin along the scar tissue is an alternative method

for replacement therapy, as Achauer did [10]. The example showing in Figs. 42.14–42.22 is a replacement therapy for facial scars involving nearly total face (Figs. 42.8, 42.9, and 42.10). A big tissue expander was implanted to the subcutaneous space of the healthy skin in the neck and expanded as much as possible after regular injection of normal saline for a period (Fig. 42.11). The entire scar in both cheeks, according to aesthetic units, was excised. The defects were covered with upward advancement of the expanded skin flaps after the removal of the tissue expander (Figs. 42.12 and 42.13). Periosteal fixation in between the periosteum of the zygoma bone and under surface of the skin flaps with 3-0 PDS was done. The resultant dimpling of the skin flaps after periosteal fixation will disappear about 2 months later. The final results of follow-up for 2 more years revealed good skin function, appearance, and texture (Figs. 42.14, 42.15 and 42.16).

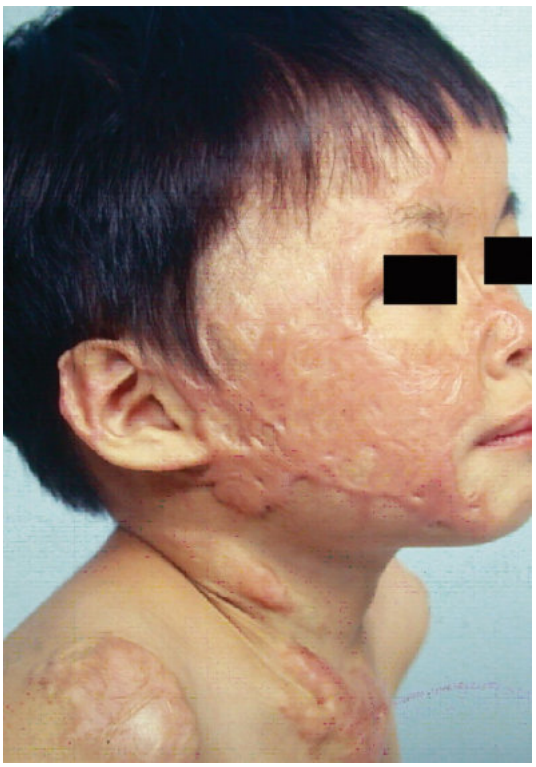


Fig. 42.8 Persistent hypertrophic scars over both cheeks of a boy after flame burn, right lateral view

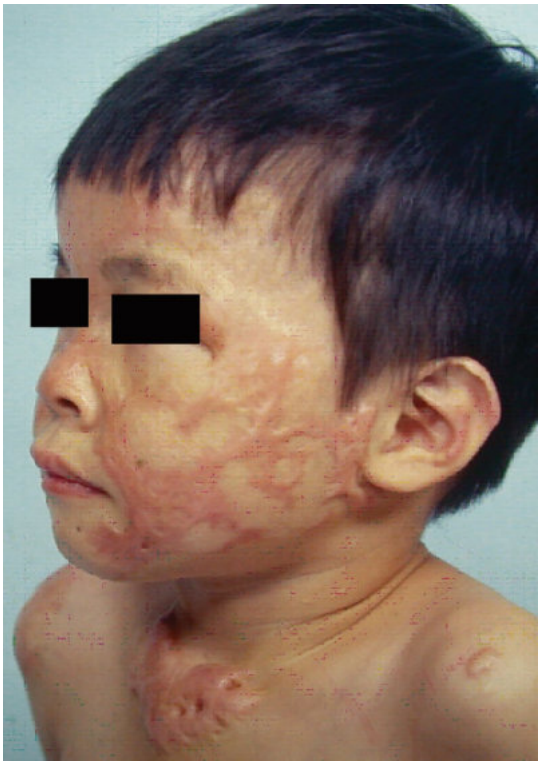


Fig. 42.9 Left lateral view

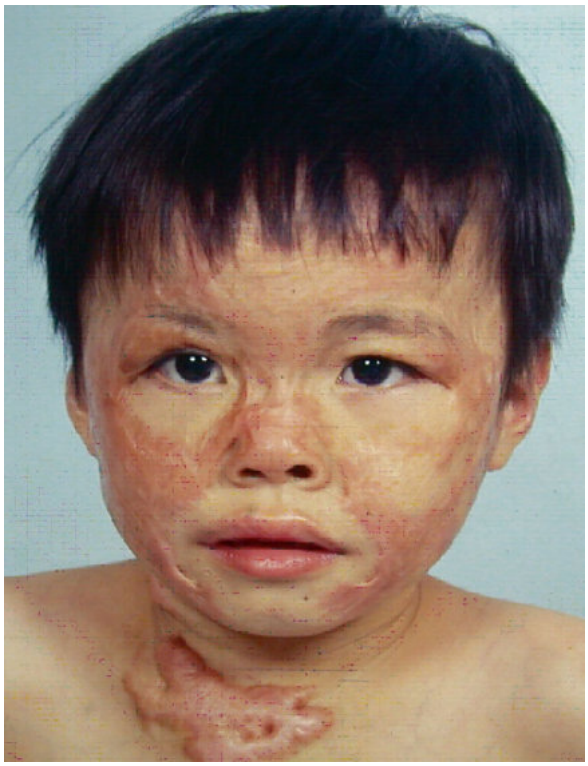


Fig. 42.10 Anterior view

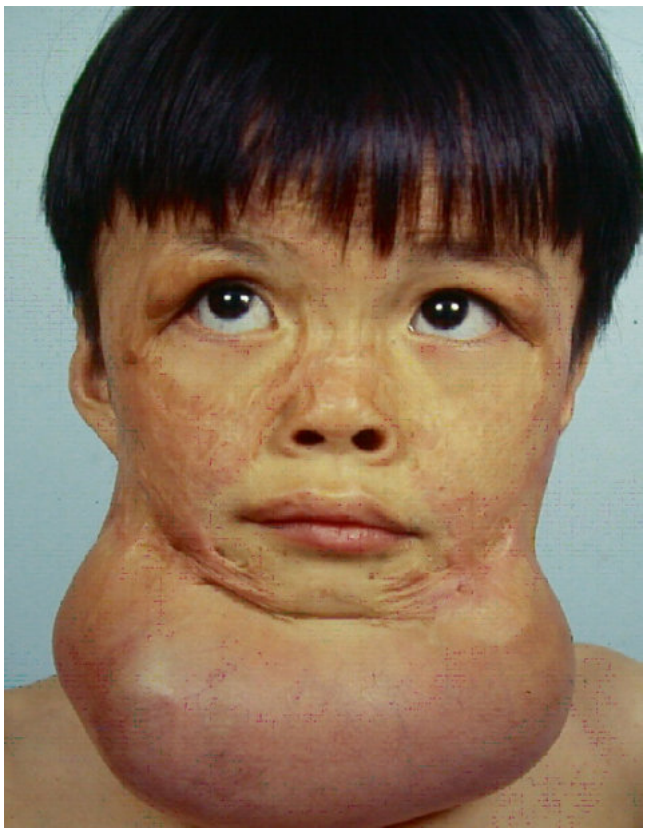


Fig. 42.11 A big tissue expander was used for expansion of healthy neck skin

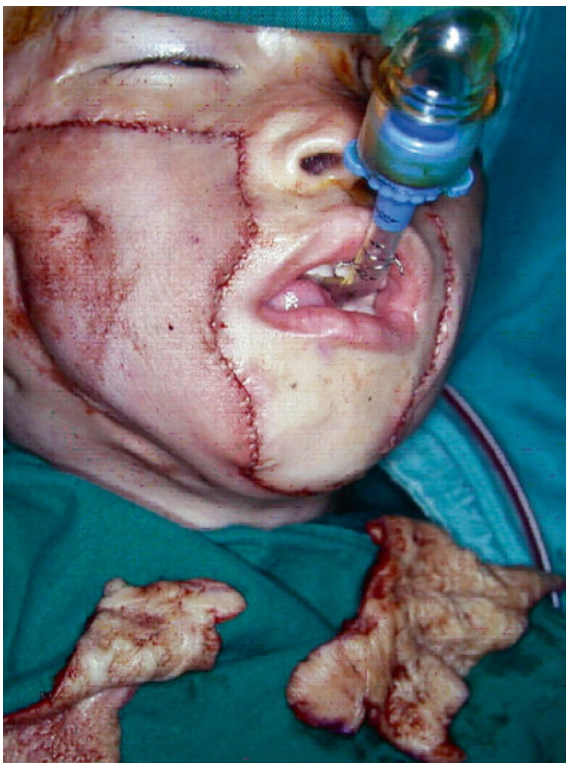


Fig. 42.12 The scars over both cheeks were all excised and replaced by expanded skin flap. Periosteal fixation using PDS in zygoma area (dimpling area) for fixation of the skin flap

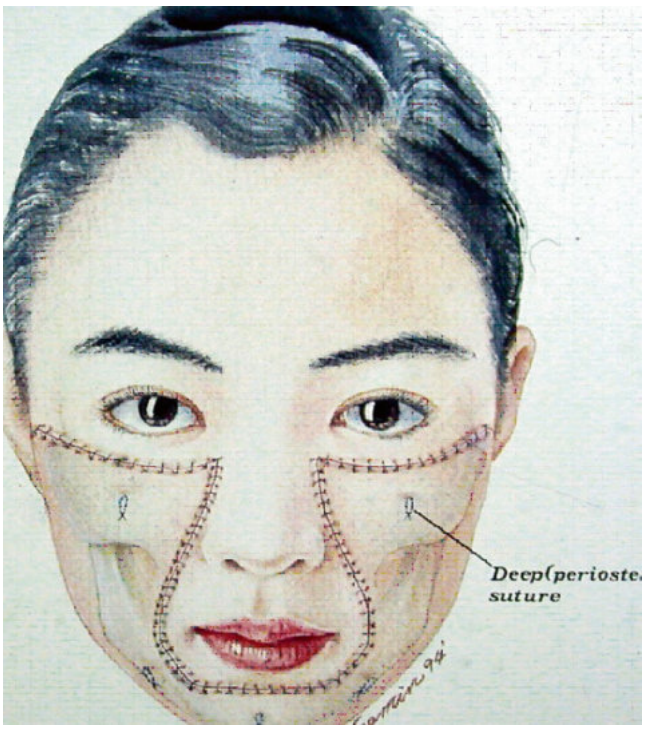


Fig. 42.13 Illustration of periosteal fixation for expanded skin flap

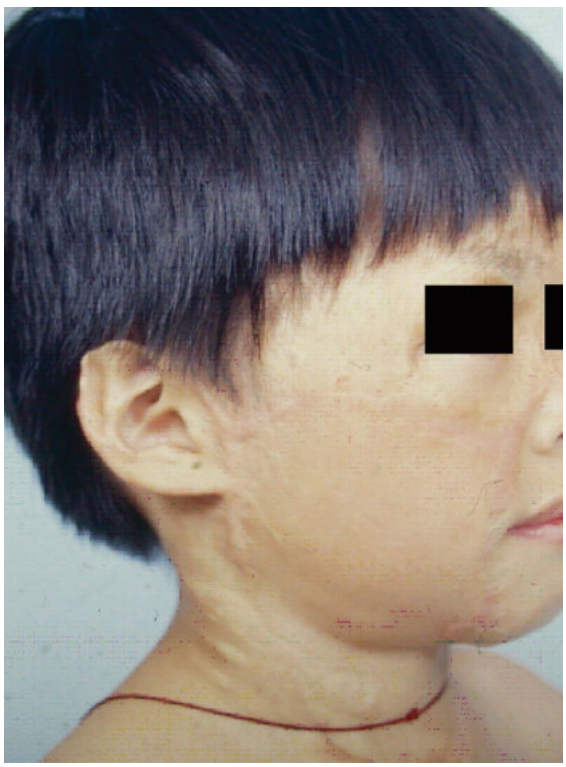


Fig. 42.14 The late results, right lateral view

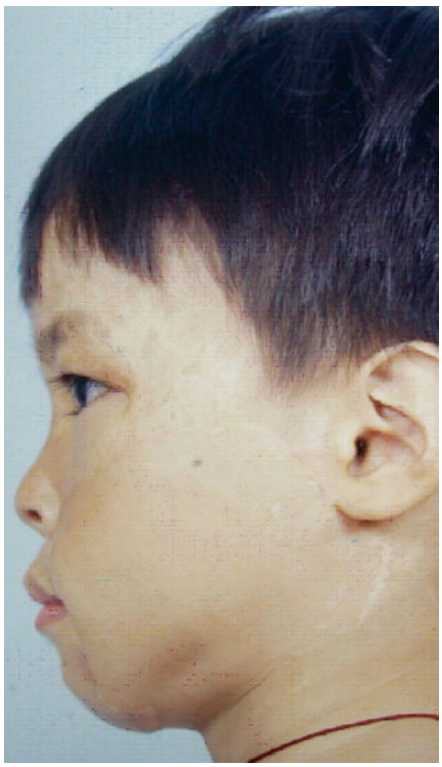


Fig. 42.15 The late results, left lateral view

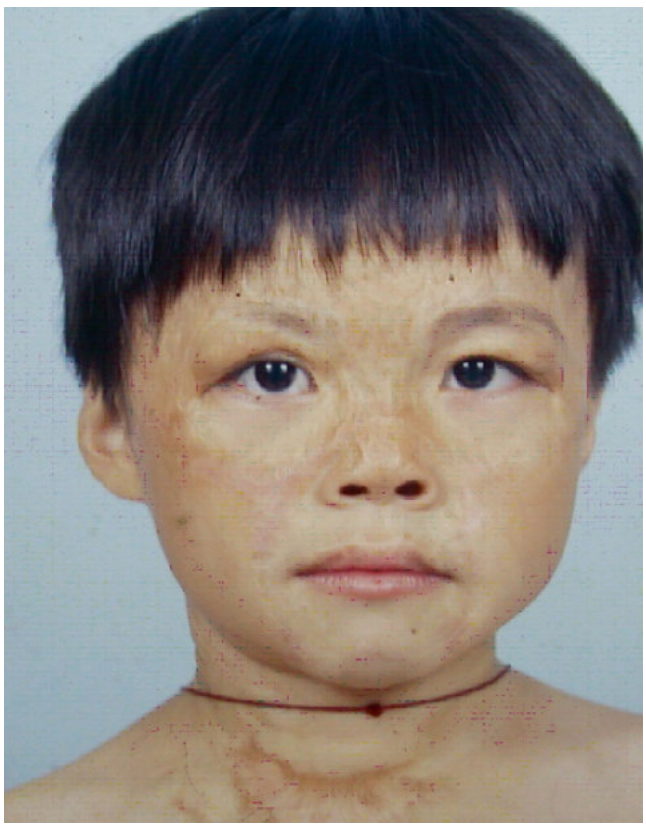


Fig. 42.16 The late results, anterior view

42.3 Axillary Reconstruction in Pediatric Burns

Axillary scar contracture is a common complication in burn survivors not only because of the fact that this area is a 3D structure including anterior, posterior folds, and upper dome, but also due to the difficulty to keep the upper limbs stretching out during the rehabilitation stage. In the pediatric burn, the added difficulties with initial positioning and aftercare in physical therapy make this complication quite common. The cooperation of the children should be taken into consideration for the choice of reconstruction modality. The skin graft procedure is not a good choice because this procedure needs about 1 of week immobilization for graft taking. The local cutaneous skin flaps, such as multiple Z, VY, or 5-flap plasties can be considered as a method for axillary contracture due to anterior and/or posterior scar band. The fasciocutaneous or square flap is a good choice for the reconstruction of the contracture involving the axillary dome, including or not including the anterior or posterior axillary fold [2, 11]. Flap surgery, although sometimes technically difficult, is easy for aftercare in the pediatric group. For example, a small kid sustained scald burn which resulted in scar contracture involving the entire axilla (Fig. 42.17). This kid did

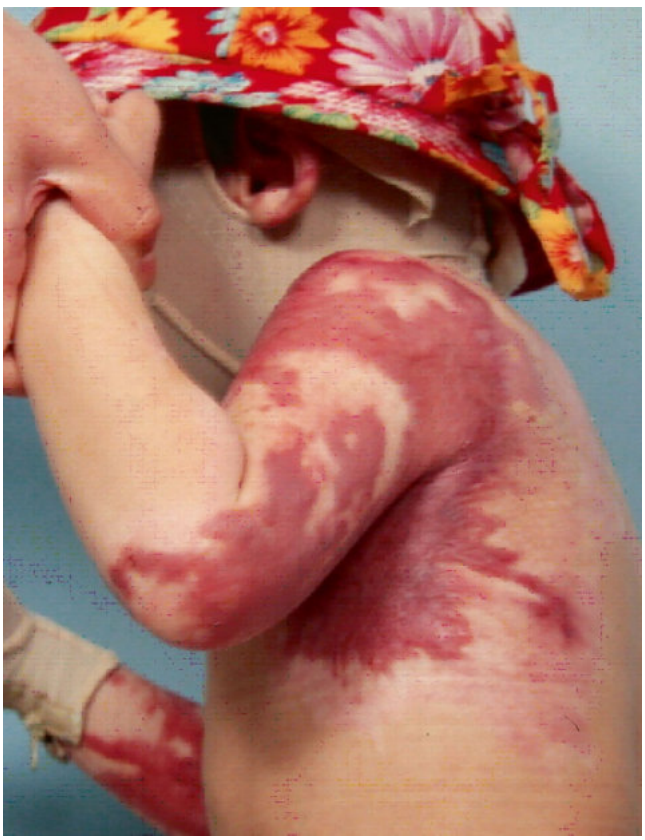


Fig. 42.17 Severe scar contracture in left axilla of a girl after scald burn

not cooperate with the physiologic therapist or even her parents. An island pedicle parascapular flap was designed and elevated from the left back (Fig. 42.18) and rotated to the left axilla along with the overlying scar tissues (Fig. 42.19). The donor site was closed primarily (Fig. 42.20). Follow-up for 1 more year showed good functional release (Fig. 42.21). An interesting finding was that not only did the overlying scars on the flap not affect the flap viability but also the surrounding scar tissues matured satisfactorily.

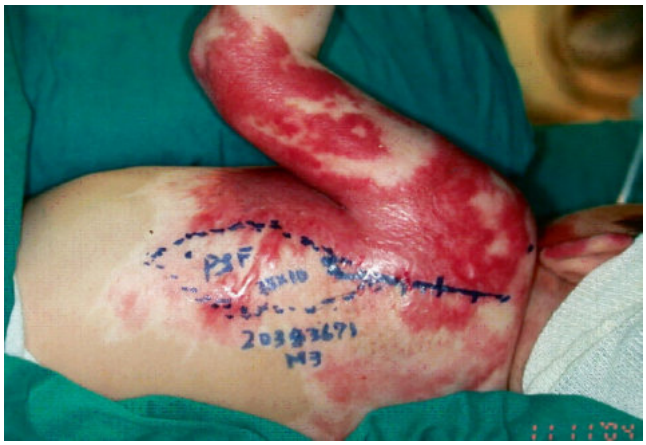


Fig. 42.18 An island pedicle parascapular flap was designed and elevated from left back

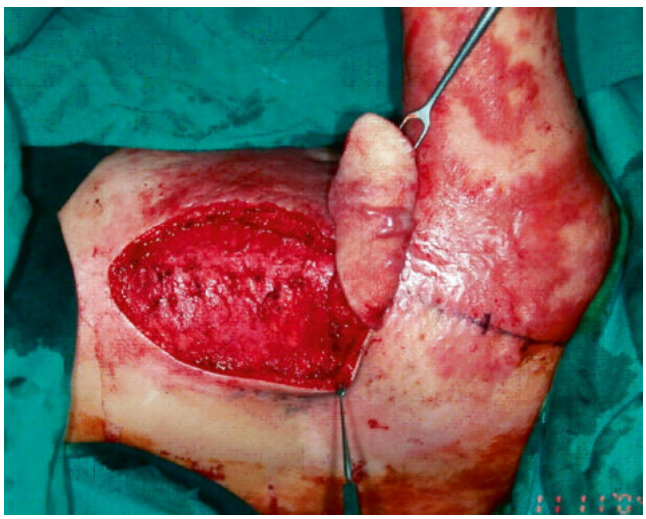


Fig. 42.19 The flap including overlying scar tissue was used for axillary reconstruction

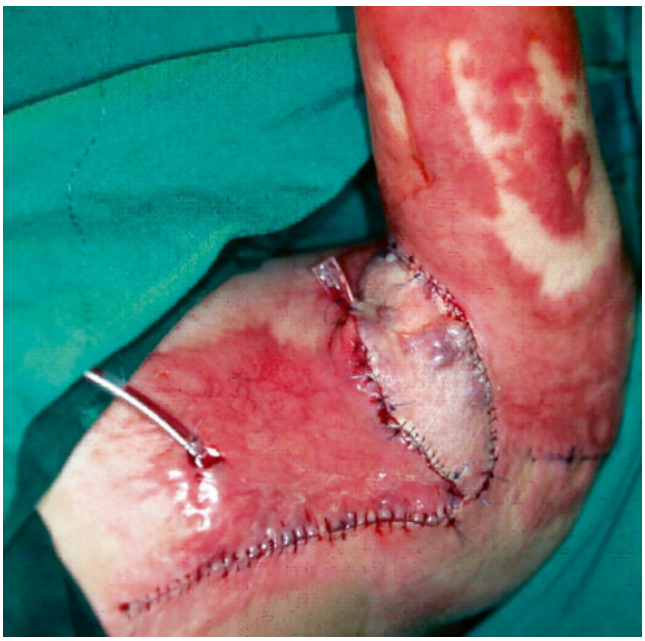


Fig. 42.20 Donor site can be closed primarily

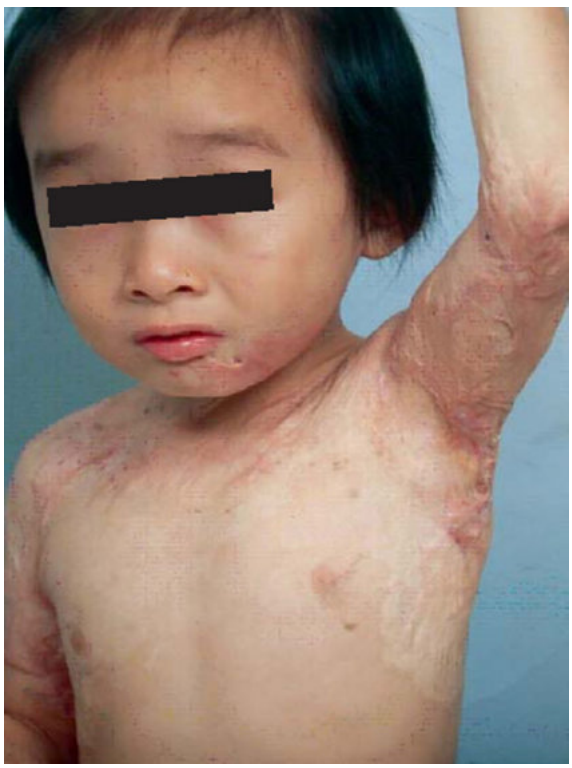


Fig. 42.21 Results of good functional correction. The scars over the flap do not affect flap viability

42.4 Chest Including Breast Reconstruction in Pediatric Burns

Deep chest injury in the pediatric group whether from scald or flame burn may be a disaster for them. Scar contracture from deep burn will affect not only the straightening function of the trunk but also the development of the breast or/and nipple-areolar complex (NAC), especially in female children. This is the reason why Dr. Foley P. et al. said that breast burns are not benign [12]. This is also the reason why most burn doctors make every effort to preserve the breast buds and/or NAC during debridement for the deep breast burn in prepuberty girls. Besides early conservative treatment for breast burns, proper release of the scar contracture, if any, too much scar tissue involvement around the axillary region or severe axillary dome contracture. Contracture release sometimes could be achieved simply by local cutaneous Z-plasty, YV advancement flap, or rotation flap. However, in more extensive scar tissue involvement or severe scar contracture, big patch of FTSG, tissue expansion, larger fasciocutaneous flap, or free flap may be considered [13, 14]. If the development of breast was compromised before puberty or breast buds and/or NAC were destroyed during the acute stage, then reconstruction of the breast volume and/or NAC should be considered. In some situations, combined reconstruction scar release with aesthetic augmentation mammaplasty may be finished simultaneously in one stage [15]. The following example is that of a 3-year-old girl who sustained scald burn, which resulted in thick scar formation in her chest and rt. axilla (Fig. 42.22). The contracture of the right axilla and most of the right breast were released before puberty. Underdevelopment of the right breast was noted at the age of 12 years. A big fasciocutaneous flap elevated from right flank was used for releasing tension and replacement of the scar tissues in the right breast (Figs. 42.23 and 42.24).

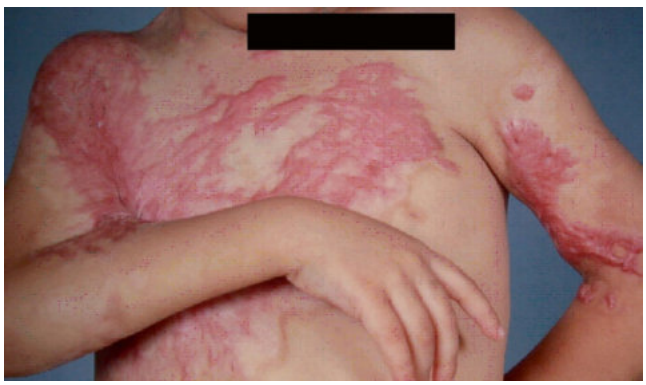


Fig. 42.22 Severe scar contracture involving right axilla and chest with loss of nipple–areolar complex in a young girl after scald burn

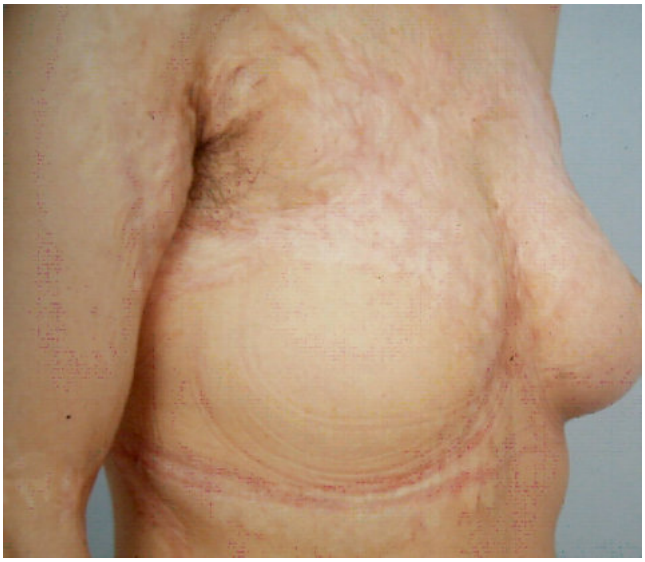


Fig. 42.23 Functional correction of right axilla and fasciocutaneous flap reconstruction of right chest were done

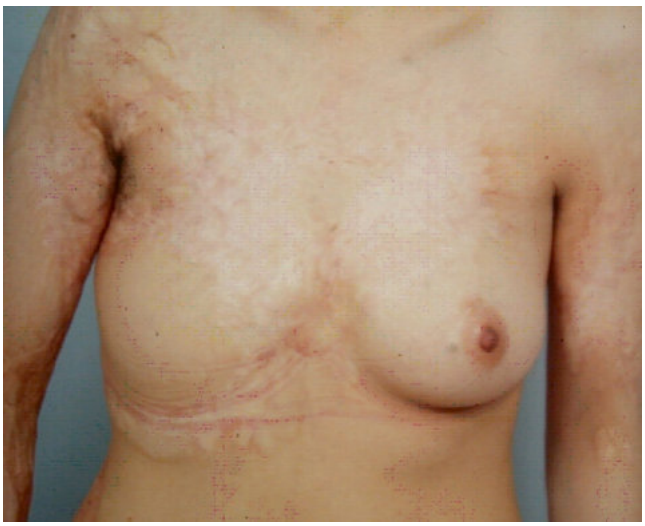


Fig. 42.24 Hypoplasia of right breast after puberty noted

However, the right breast was still smaller than the left. Reelevation and repositioning of the previous fasciocutaneous flap, release of some residual contracture with Z-plasty, and augmentation mammaplasty with implant simultaneously for her right breast were done at the age of 23 years (Fig. 42.25). Nipple reconstruction with modified star flap was done 1 year later in her right breast Fig. 42.26. The girl was satisfied with the results and gave up further reconstruction of the areolar component.

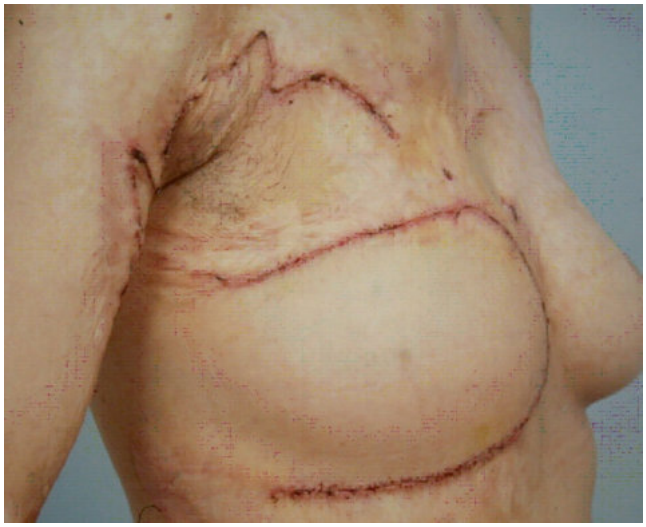


Fig. 42.25 Flap re-elevation, scar revision, and augmentation mammaplasty with implant were done simultaneously

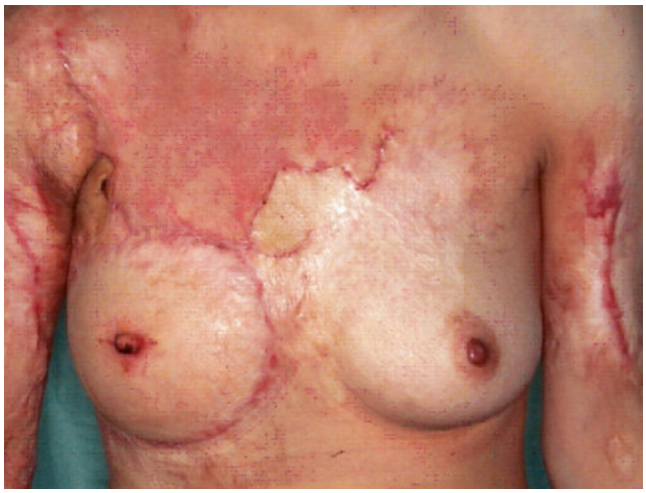


Fig. 42.26 Results of nipple reconstruction with modified star flap for right breast in an another stage

42.5 Hand Reconstruction in Pediatric Burns

Pediatric hand burn is quite common. Most are due to scald burn, including hot water, hot drinks such as tea or coffee, hot soup, and instant noodle soup.

Proper initial and after care, including physical therapy, may get good results. In some situations, the wounds are very deep especially those from contact thermal burns, such as ironer and hot pressure machine. Scar contracture more or less will occur in those situations because proper physical therapy is very difficult to do for pediatric patients. Reconstruction choice usually depends on the types of hand contractures. Some classification of burn hand scar contractures had been offered by some authors [16, 17]. The classification of contractures includes adduction contracture of the thumb, abduction contracture of the fifth finger, extensor contracture of the wrist and/or dorsal hand especially metacarpal joints (MPs), flexor contracture of fingers especially proximal phalanx joints (PIPs), palm contracture, web space contracture including syndactylism, boutonnière deformity, and digital amputation. Various reconstruction procedures and methods have been mentioned in the literature and textbooks. However, one of the methods called hour-glass flap [18] is very effective for burn web scar contracture, including two joints (PIP and MP) in the pediatric group. The design of hour-glass flap is shown in Fig. 42.27. Point 1 at PIP and Point 2 at MP should be pointed out first. The midpoint between Points 1 and 2 is Point 3, which equal to the volar distal edge of the web space. The midpoint between Points 2 and 3 is Point 4. This is lumbrical canal where the digital vessels go through and is the bottom of flap dissection. The midpoint between Points 3 and 4 is Point 5, which is the waist of the hour-glass flap. The midpoint between Points 4 and 5 is Point 6, which is the distal edge of the flap. Point 7 is the width of the flap between the dorsal central lines of two fingers. The flap is elevated from Points 6 to 4 and used to reconstruct the web space after splitting the adhesion between two fingers. There will be donor defects in finger sides and should be grafted. The example is that of a small kid with web space contracture in both hands. Hour-glass flap was designed (Fig. 42.28) and web space was reconstructed (Fig. 42.29). Follow-up for more than 1 year showed good web spaces without any recurrence (Fig. 42.30).

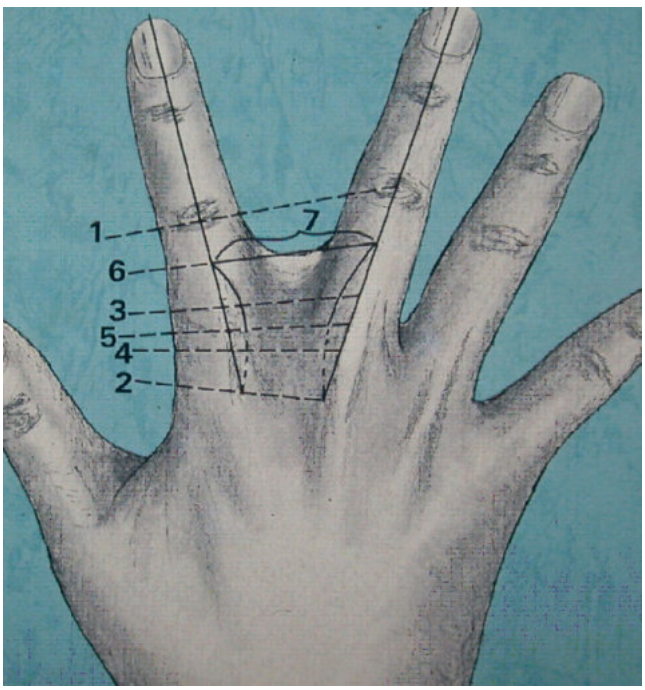


Fig. 42.27 Illustration of hour-glass flap, which is very useful for burn web space reconstruction

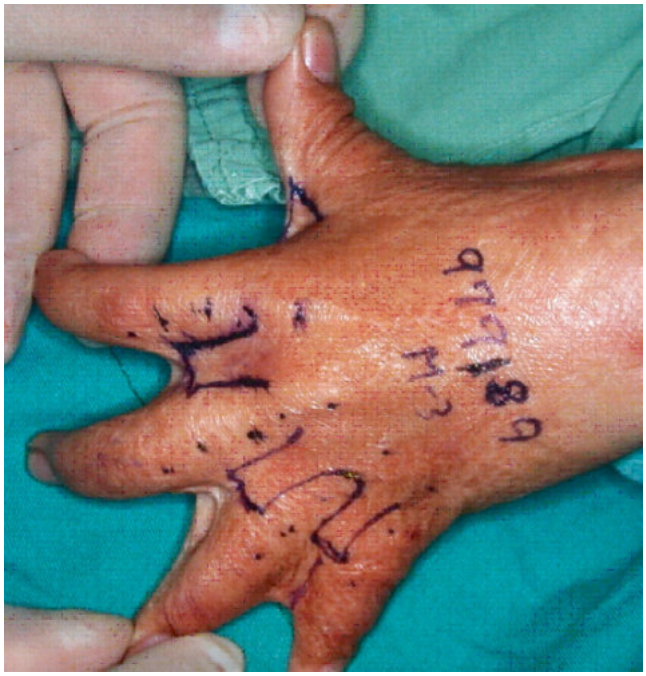


Fig. 42.28 Designs of hour-glass flap for correction of scar contracture in hand webs of a boy sustained from flap burn

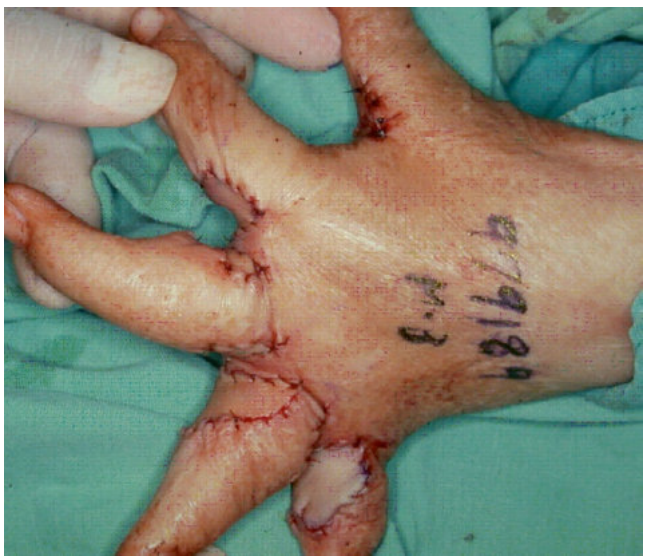


Fig. 42.29 Early results of web reconstruction. Flap in web base and skin graft in finger side

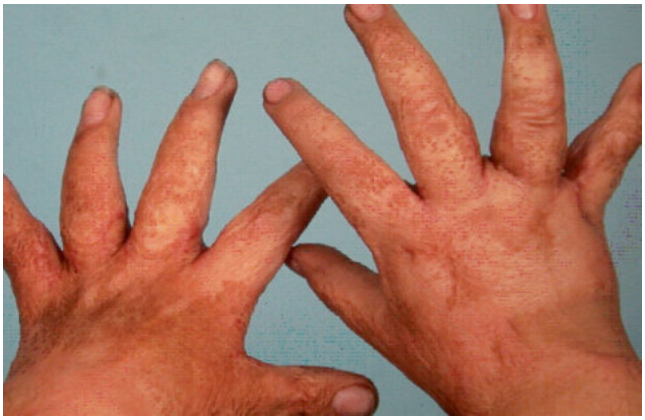


Fig. 42.30 Late results showed no recurrence of web contracture

42.6 Neck Reconstruction in Pediatric Burns

Burn neck scar contracture should be corrected as early as possible in pediatric patients. The contracture not only affects rotation and extension function of the head, but also may cause development of the mandible and result in malocclusion and distortion of the lower face. According to the severity of the contracture, it can be classified into several types, namely simple scar bands contracture, scar patches contracture occupying more or less 50% of the neck area, and cervicomandibular adhesion. Considerations about the treatment modality depend on the severity. Z-plasty or other cutaneous flaps may be used for release of contracture bands. Fasciocutaneous flap, parascapular flap, etc. may be used for the correction of contracture due to patch scars in which the area ratio is less than 50% of the neck area. Skin graft, large local flap such as latissimus dorsi (LD) flap, or free flap such as anterorolateral thigh (ALT) flap may be applied if the scar ratio is more than 50% of neck area or for cervicomandibular adhesion [19]. Among these methods, the ALT-free flap surgery is a good choice for neck reconstruction for children. Although the surgery is technique-demanding, the advantage is big enough. The postoperative care of flap surgery is easier than skin graft for severe neck contracture in children. The durability, extensibility, and less recurrence of the flap make the long-term results acceptable. The example shown in Fig. 42.31 is that of a child with neck scar contracture involv-

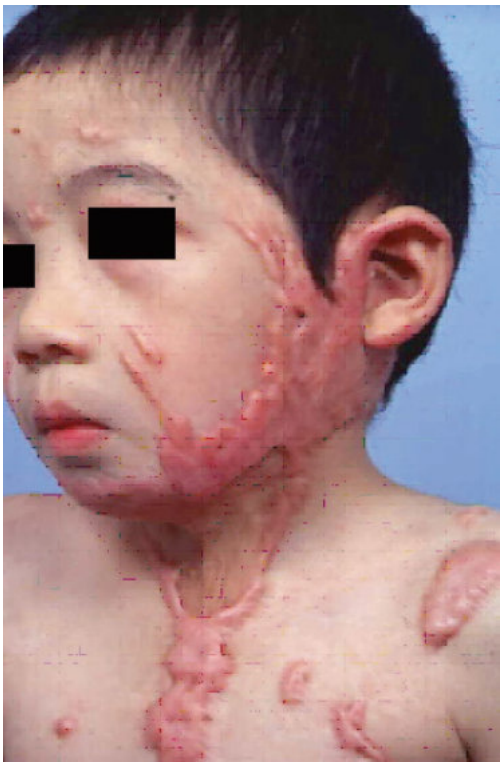


Fig. 42.31 Persistent hypertrophic scars with contracture in left face and neck of a boy after flame burn

ing the lower face. He received release contracture with FTSG from another hospital before, but the results were not satisfactory (Fig. 42.31). All the scar tissues in the neck and lower face were excised and the contracture was released as much as possible in our hospital. A big ALT flap was elevated from the patient's left thigh based on descending branch of lateral femoral artery as vascular pedicle (Fig. 42.32). The flap was split into two components to provide wide distance and fix to the defect using facial artery as recipient vessel (Fig. 42.33). No postoperative neck splint was needed for this child.

Follow-up for nearly 2 years showed good functional (including head extension and rotation) and aesthetic (including cervicomandibular angle) results (Figs. 42.34 and 42.35). The perforator flap, because of easy harvesting, possible spitting, and thin out, has been emphasized by Professor Wei et al. [20] and is proved to be an excellent flap for neck scar reconstruction for children by some authors [21].

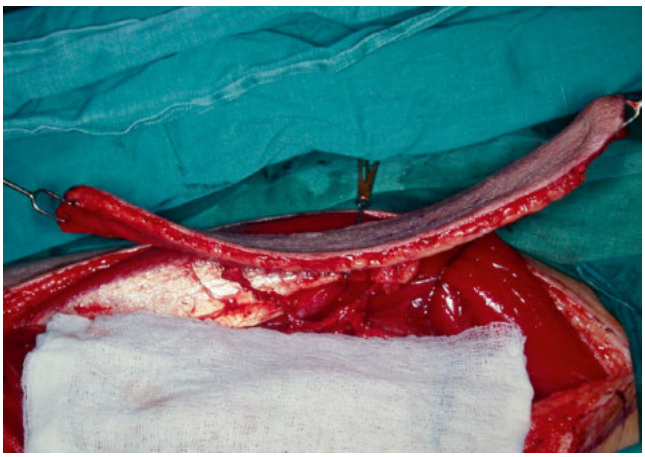


Fig. 42.32 Thin anterior lateral thigh (ALT) flap elevated from left thigh was used for reconstruction. Several perforators can be used as vascular pedicles for flap split

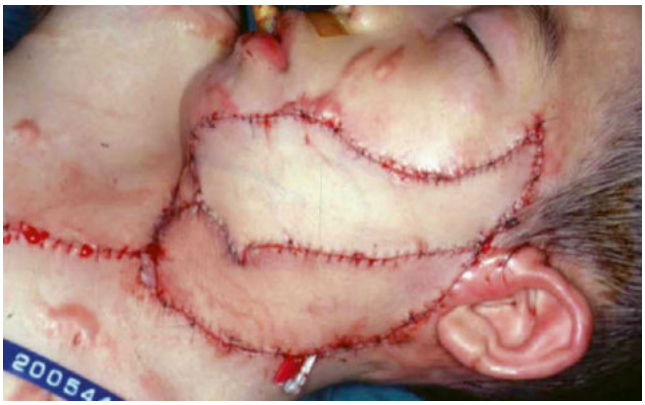


Fig. 42.33 Immediate results of split ALT flap with Z-plasty in flap edge for scar replacement and functional release of scar contracture in face–neck area

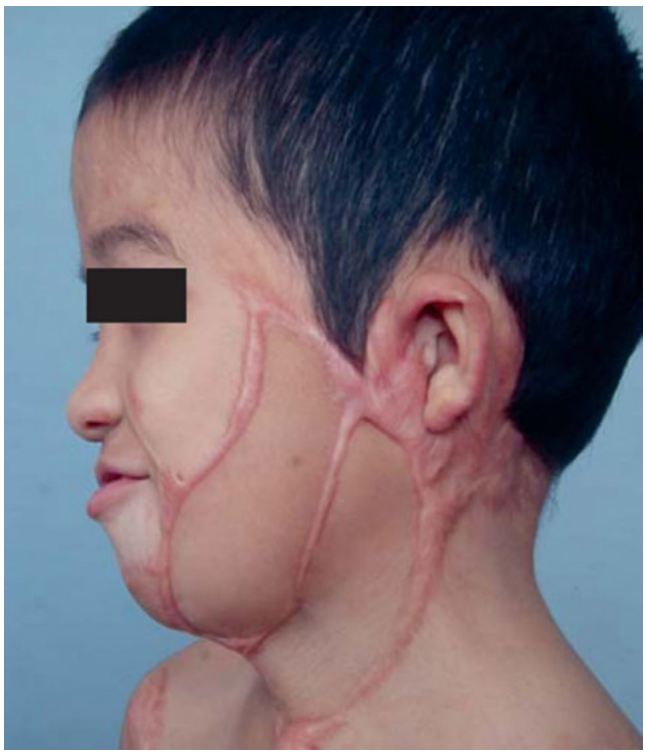


Fig. 42.34 Early results of split ALT flap reconstruction

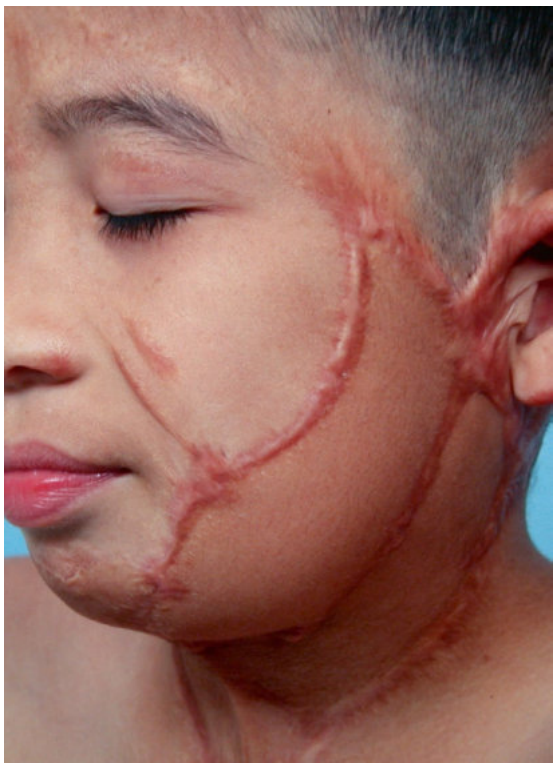


Fig. 42.35 Late results and closed-up view. Scars in incision wounds softer day by day

42.7 Aftercare Including Nursing and Physiological Therapy (PT) in Pediatric Burn Reconstruction

Preoperative prevention from scar contracture in pediatric burns, including antideformity positioning, proper dressing, adequate splinting, and patient physical therapy, are mentioned in the previous introduction and sections in this chapter. If reconstruction is inevitable, postoperative aftercare, including nursing and PT, is also very important. The nurse should keep an eye and make sure that the dressings and/or postoperative splint are in adequate place. During dressing change, enough man-power is usually needed to keep the proper anatomic position, such as hand, neck, or axilla, especially when there is tie-over dressing, K-pin, or splint in the operative fields.

After wound healing, aggressive and patient PT is also overemphasized to maintain the operation achievement and prevent recurrence. This usually needs education and cooperation of parents. Regular follow-up for those children after reconstruction is advised because of the fact that the results may change after the growth of the children, especially in hand and breast surgery. Because the development rate in reconstruction area is sometimes not as fast as the normal site, residual contracture may occur after the growth of the child, even if there was adequate reconstruction initially. In this situation, usually simple procedure such as Z-plasty. may solve the problem or the minor contracture will result in major complications such as scar bands in fingers or breast. Sometimes, long-term follow-up until full growth of the children with burn injuries is needed.

42.8 Summary

Children are not small-sized adults. This is also true in the reconstruction of pediatric burns. Although the treatment principles are almost the same as adults, the key points are different. The cooperation from children and their parents, development problems of the children, proper treatment modality for easy aftercare, possibility of postoperative follow-up, PT, etc. need to be taken into consideration. These are the key points for successful reconstruction in pediatric burns.

References

1. Yang JY, Chuang SS, Huang CY. Burn epidemiology in Taiwan and Chang Gung Memorial Hospital (CGMH). Present at 3rd meeting of Asian Wound Healing Society, Singapore, Aug; 2005.
2. Yang JY. Reconstruction of axillary contractures. In: McCauley RL, editor. Functional and aesthetic reconstruction of burned patients, Chapt. 27. Taylor & Francis; 2005. p. 367–78.
3. Huang TT, Larson DL, Lewis SR. Burn alopecia. Plast Reconstr Surg. 1977;60:763–7.
4. Coleman JJ III, Matthew K. Reconstruction of the burned scalp. In: Sood R, editor. Achauer and Sood's burn surgery, reconstruction and rehabilitation, Chapt. 9. Saunders; 2006. p. 149–67.
5. Buhrer DP, Huang TT, Yee HW, et al. Treatment of burn alopecia with tissue expanders in children. Plast Reconstr Surg. 1988;81:512–5.
6. Hudson DA, Lazarus D, Silfen R. The use of serial tissue expansion in pediatric plastic surgery. Ann Plast Surg. 2000;45:589–93.
7. Graravito E, McCauley RL. Reconstruction of the burned scalp. In: McCauley RL, editor. Functional and aesthetic reconstruction of burned patients, Chapt. 16. Taylor & Francis; 2005. p. 217–26.
8. Dougherty WR, Spence RJ. Reconstruction of the burned face/neck: acute and delayed. In: Sood R, editor. Achauer and Sood's burn surgery, reconstruction and rehabilitation, Chapt. 14. Saunders; 2006. p. 234–53.
9. Feldman J. Reconstruction of the burned face in children. In: Serafin D, Georgiade NG, editors. Pediatric plastic surgery. St. Louis: CV Mosby; 1984. p. 552–632.
10. Achauer BM. Burn of the face. In: Achauer BM, editor. Burn reconstruction, Chapt. 3. Thieme; 1991. p. 23–30.
11. Asuku ME, Ibrahim A, Ijekeye FO. Post-burn axillary contractures in pediatric patients: a retrospective survey of management and outcome. Burns. 2008;34:412–7.
12. Foley P, Jeeves A, Davey RB, et al. Breast burns are not benign: long-term outcomes of burns to the breast in pre-pubertal girls. Burns. 2008;34(3):412–7.
13. McCauley RL. Reconstruction of the burned breast. In: Herndon DN, editor. Total burn care, 3rd edn, Chapt 57. Saunders; 2007. p. 741–8.
14. Yang JY. Reconstruction of chest contractures. In: McCauley RL, editor. Functional and aesthetic reconstruction of burned patients, Chapt. 29. Taylor & Francis; 2005. p. 393–410.
15. Huang T. Overview of burn reconstruction. In: Herndon DN, editor. Total burn care, 3rd edn, Chapt. 52. Saunders; 2007. p. 674–86.
16. McCauley RL, Asuku ME. Upper extremity burn reconstruction. In: Mathes's plastic surgery, 2nd edn, Vol VII, Chapt. 186. Saunders; 2006. p. 605–46.
17. Sood R, Brenner K, Achauer BM. Reconstruction of he burned hand. In: Sood R, editor. Achauer and Sood's burn surgery, reconstruction and rehabilitation, Chapt. 20. Saunders; 2006. p. 307–23.
18. Salisbury RE, Bevin AG. Burn syndactyly the "hour-glass" procedure. In: Salisburn RE, Bevin AG, editors. Atlas of reconstructive burn surgery, Chapt. 38. Saunders; 1981. p. 180–5.
19. Tsai FC, Mardini S, Chen DJ, Yang JY, et al. The classification and treatment algorithm for post-burn cervical contractures reconstructed with free flaps. Burns. 2006;32:626–33.
20. Wei FC, Celik N. Perforator flap entity. Clin Plast Surg (Ed. Wei FC). 2003;30(3):325–9.
21. Yang JY, Tsai FC, Jagdeep Chana S, Chuang SS, Chang SY, Huang WC. Use of the free thin anterolateral thigh Flaps combined with cervicoplasty for reconstruction of postburn anterior cervical contractures. Plast Reconstr Surg. 2002;110(1):39–46.

Secondary Vascularized Flaps

43

Hiko Hyakusoku, Hiroshi Mizuno, and Rei Ogawa

Keywords

Secondary vascularized flaps · Free vascular bundle · Blood flow · Angiogenesis · Hair-bearing flaps · Reconstruction · Pedicled flap · Superficial temporal vessels · Deep inferior epigastric vessels · Tissue transplantation · Prefabricated flaps · Clinical cases

43.1 Background of the Technique

Due to the development of perforator flaps, free flaps can now increasingly be elevated in smaller sizes. In fact, if the perforator flap is completely minimized, it would consist of only the vascular pedicle. We have succeeded in transplanting only the vascular pedicle with blood flow and have used this to create flaps in areas that lack vascular pedicles. These flaps are termed "secondary vascularized flaps," and it is likely that they are successful because of the blood flow, which feeds the cells that constitute the transplanted vessels; after being transplanted, these cells then induce angiogenesis in the surrounding tissue, thereby establishing new blood flow to the area. This hypothesis is supported by the fact that when major vessels are extensively dissected during surgery and their ends are then ligated, the vessels do not necrotize.

The first report of a secondary vascularized flap was published in 1980 by a Chinese burn surgeon called Shen Tzu Yao in 1981 [1]. Thus, he elevated the vascular bundle, implanted it in the proximal subcutaneous region, and 2 weeks later elevated the neovascularized flap as a pedicled flap for facial and helical reconstruction.

Conversely, we elevate a free vascular bundle and transfer it to the recipient site (Fig. 43.1). Two weeks later, the pedicled secondary vascularized flap is elevated for transposition [2]. This method was described by Hyakusoku et al. in 1987 [2, 8]. We have found that this technique is particularly suitable for creating hair--bearing flaps that reconstruct eyebrows or beards [3].

It should be noted that secondary vascularized flaps are a form of "prefabricated flaps" since prefabricated flaps involve introducing secondary tissue such as cartilage or bone before the flap is transplanted [4]. Notably, Washio [5] and Orticochea [6] reported creating and using prefabricated flaps in 1971. These articles likely contributed to the development of the concept of flap prefabrication.

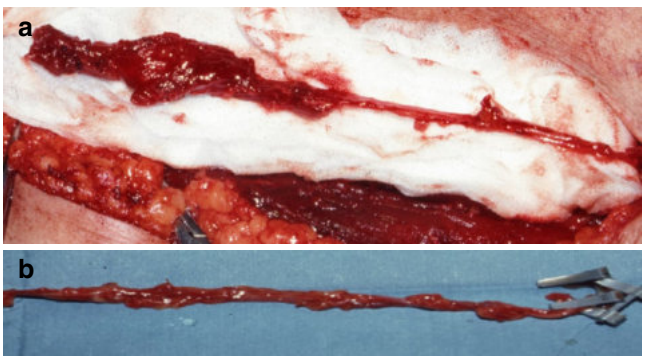


Fig. 43.1 Free vascular bundle transfer. (**a**) The vascular bundle of the deep inferior epigastric vessels is shown. A small piece of muscle is attached at the distal portion. Of the bundle, about 15 cm of length could be harvested. (**b**) The vascular bundle of the superficial temporal artery and vein is shown after it was harvested. Of the bundle, about 12 cm of length could be harvested. It should be noted that sometimes the arteries and veins can become separated. Thus, it is important to maintain the superficial fascia between the vessels, since this preserves the shunt circulation

H. Hyakusoku
Nippon Medical School, Tokyo, Japan
e-mail: hyakusok@nms.ac.jp

H. Mizuno
Department of Plastic and Reconstructive Surgery, Juntendo University School of Medicine, Tokyo, Japan
e-mail: hmizuno@juntendo.ac.jp

R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_43

43.2 Characteristics and Indications of the Method

43.2.1 Characteristics

Three procedures for creating secondary vascularized flaps have been reported. The methods are classified as free vascular bundle transfer or pedicled vascular bundle transposition in the first and second operations. The pedicle-to-pedicle type was presented by Shen [1], the pedicle-to-free type by Shintomi and Oura [7], and the free-to-pedicle type by Hyakusoku et al. [2, 8].

43.2.2 Indications

A secondary vascularized flap is useful when a tissue with specific characteristics is needed for reconstruction, and it lacks a vascular pedicle. However, if another reconstructive procedure that only involves a single operation can be used, it is generally preferred over the secondary vascularized flap method. Therefore, the indications for secondary vascularized flaps are limited. We apply this method to hairy-skin flap transposition because it offers a flexible choice in terms of hair thickness and/or orientation.

43.3 Specific Steps of the Method

43.3.1 Selection of the Vascular Bundle

To date, we have used superficial temporal vessels or deep inferior epigastric vessels to serve as the free vascular bundle. These vessels are sufficiently long for this purpose, and the donor scars are hidden by hair or underwear. The major vessels of the extremities should be avoided when harvesting vascular bundles.

43.3.2 Wrapping of the Vascular Bundle

It is often said that it is very difficult to reelevate buried vascular bundles in the second operation. We reduce this difficulty by wrapping the vascular bundle with a Penrose drain so that the bundle resembles a Norimaki or sushi roll.

43.3.3 Using the Free Vascular Bundle to Engineer Transplantable Tissue

The role of the vascular bundle is temporary: It does not have to maintain a permanent blood flow. Thus, it is only needed for 2–3 weeks after the first operation to neovascularize the intended flap skin. This means that an allogeneic vascular bundle could be used instead, since this would avoid creating a donor-site scar [9]. Notably, free vascular bundles may be useful when transplanting engineered tissues in the future [10].

43.4 Clinical Cases

43.4.1 Case 1

A 33-year-old man had a flame burn on his face (Fig. 43.2a). After receiving a full-face free skin graft, the patient asked for bilateral eyebrows. Simultaneous reconstruction of the eyebrows with a secondarily vascularized tandem-island hair-bearing flap was therefore planned. Since the flap had to be 20 cm long, the deep inferior epigastric vessels were harvested as a free vascular bundle and transplanted in the first operation. Three weeks later, the tandem-island flap was transferred (Fig. 43.2b). The outcomes were good (Fig. 43.2c).

43.4.2 Case 2

A 32-year-old man had an electrical burn on his face that had been caused by 400 volts of electricity at his work. A skin ulcer arose on his upper lip and left cheek and persisted for 3 months (Fig. 43.3a). To reconstruct the affected area cosmetically, we planned to reconstruct a bearded upper lip with hairy skin from the chin. In the first operation, a superficial temporal vascular bundle was anastomosed to the facial arteries and veins. Two weeks later, the hairy skin was elevated as a skin flap and transposed to reconstruct the upper lip and left cheek (Fig. 43.3b, c).

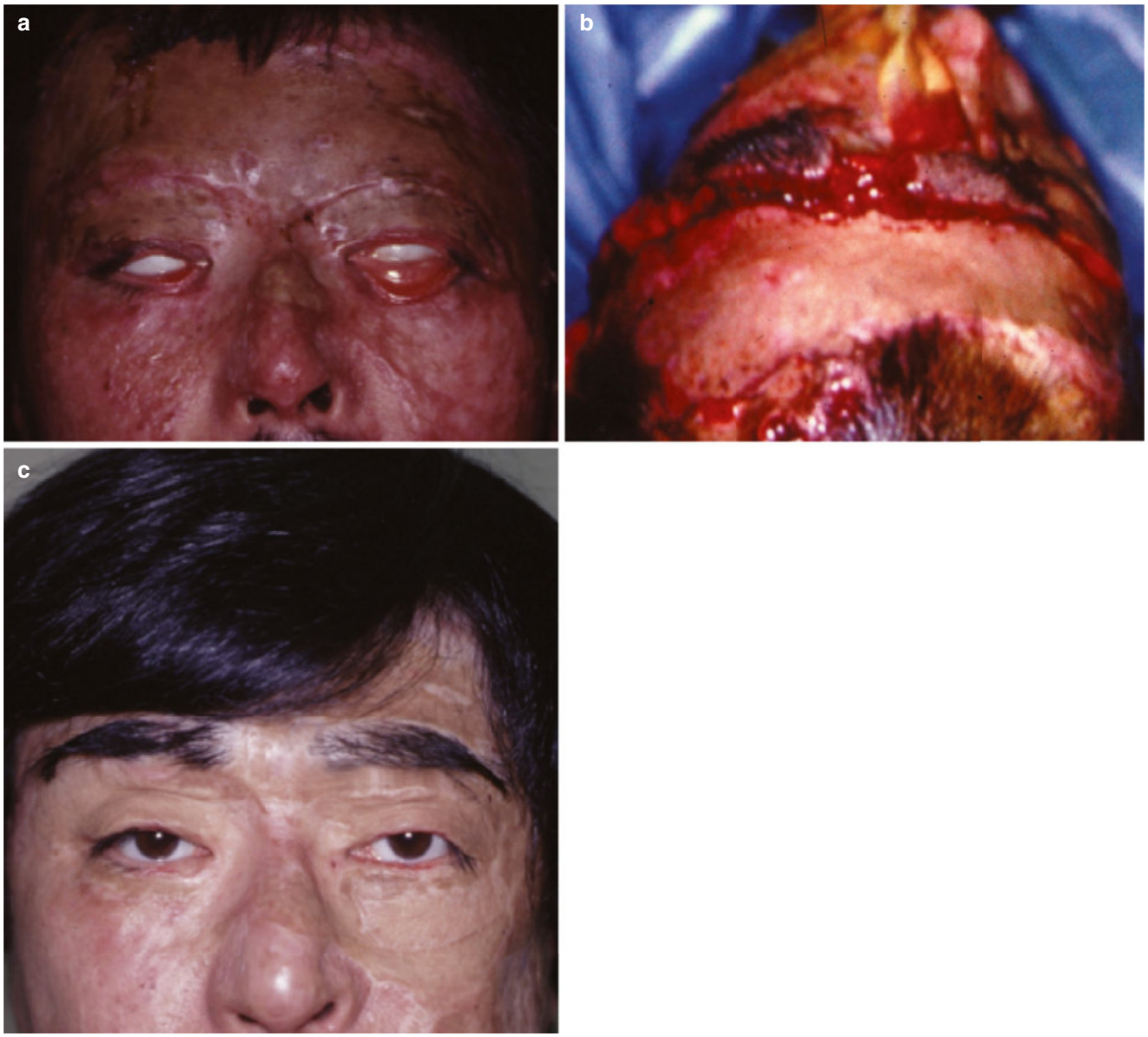


Fig. 43.2 Case 1. Bilateral eyebrow reconstruction in a man

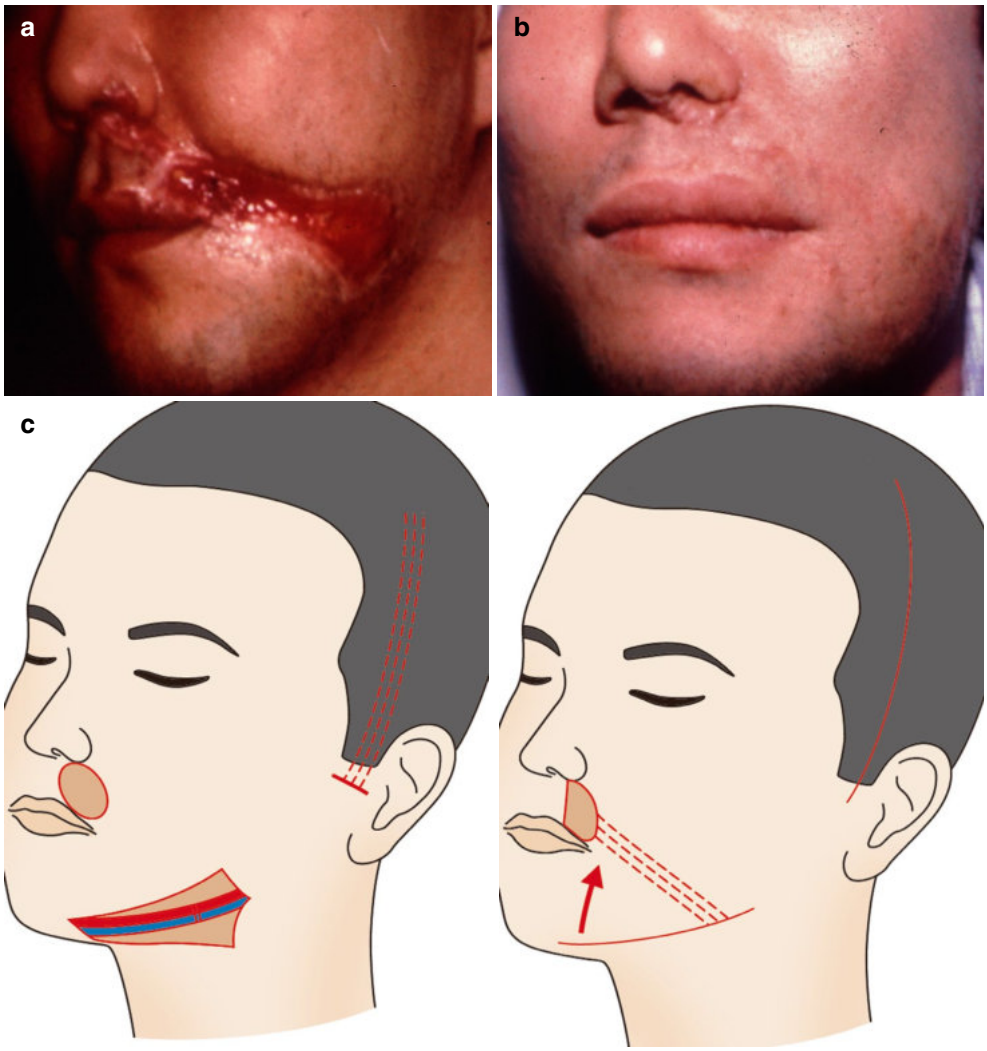


Fig. 43.3 Case 2. Upper lip reconstruction in a man

43.4.3 Case 3

A 40-year-old woman with a flame burn scar had a right eyebrow defect (Fig. 43.4a). The secondary vascularized flap method was selected for the safe transplantation of ipsilateral retroauricular hair. This region was chosen because the hair in this area possessed the necessary qualities and density needed to repair female eyebrows. In the first operation, a 13-cm-long vascular bundle composed of left deep inferior epigastric vessels was harvested and anastomosed to the superficial temporal arteries and veins. The bundle was buried in the subcutaneous tissue along the retroauricular hair border. Two weeks later, the bundle was elevated with the hairy skin island attached to the top of the buried bundle (Fig. 43.4b). The island flap was transposed to reconstruct the right eyebrow. The flap survived perfectly with growing hairs (Fig. 43.4c).

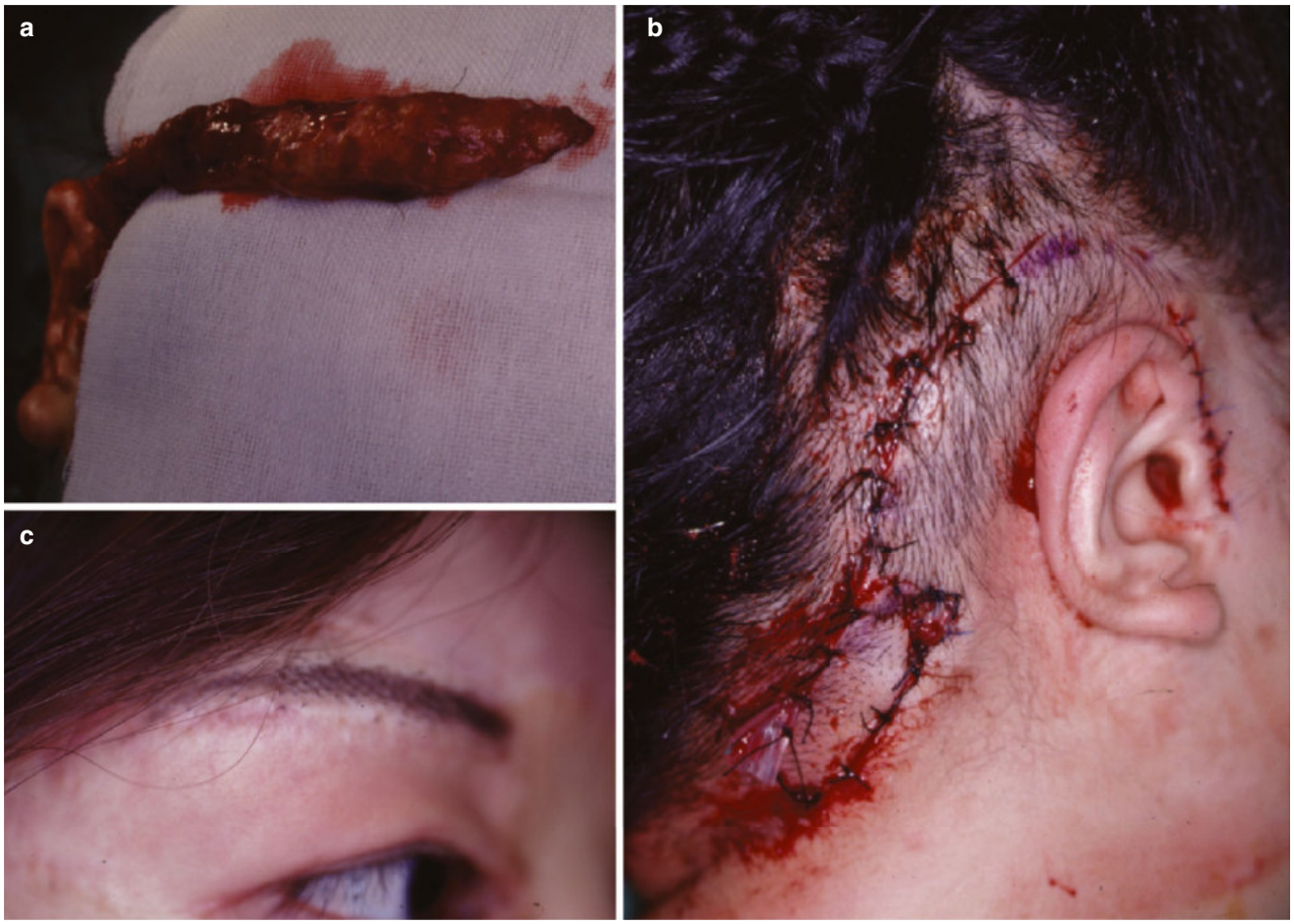


Fig. 43.4 Case 3. Hemilateral eyebrow reconstruction in a woman

43.4.4 Case 4

A 45-year-old man with scar contracture of the upper lip caused by a flame burn asked for upper lip reconstruction (Fig. 43.5a). Therefore, we planned to transpose a secondary vascularized flap from the chin (Fig. 43.5b). A deep inferior epigastric vascular bundle was harvested and implanted in the subcutaneous tissue of the chin via microvascular anastomoses. Two weeks later, the hair-bearing skin-island flap was elevated secondarily and transposed to the upper lip (Fig. 43.5c). The flap survived completely and reconstructed a bearded upper lip (Fig. 43.5d).

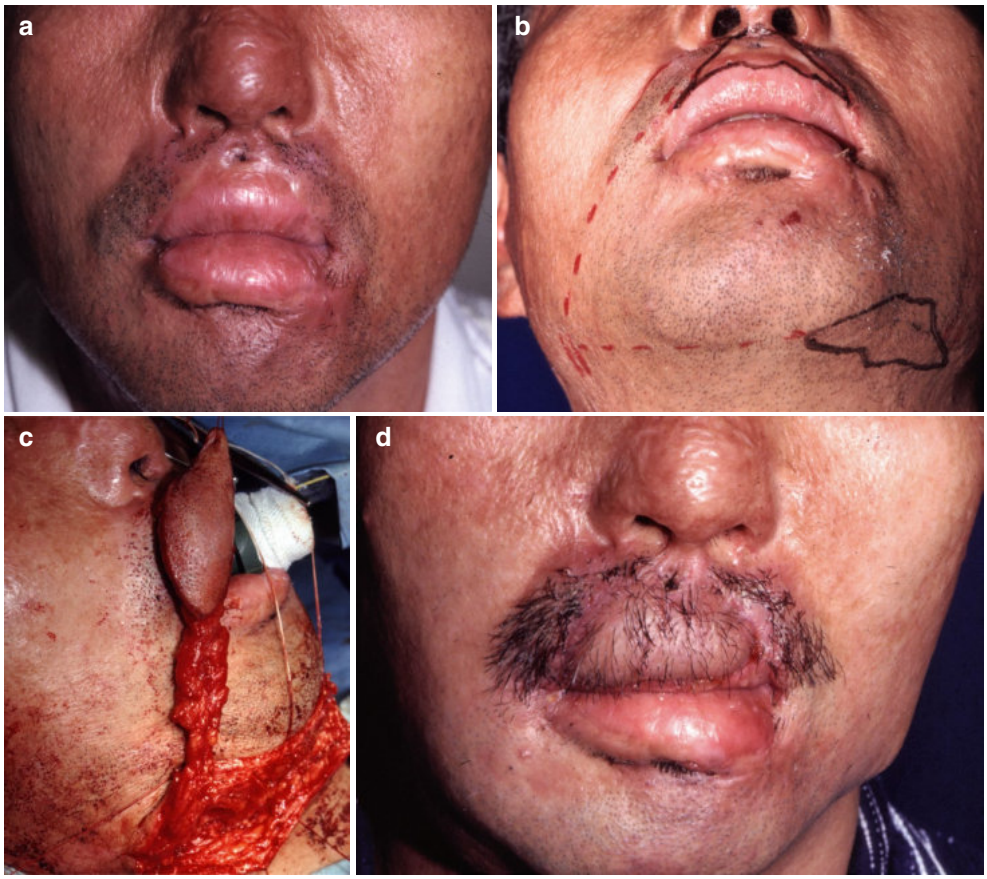


Fig. 43.5 Case 4. Upper lip reconstruction in a man

43.4.5 Case 5

A 27-year-old man underwent an acid injury in his workplace that affected his left scalp, hemiface, and upper extremity. Although the entire injured area was repaired by skin grafting, the patient eventually suffered severe scar contracture around his neck and wrist joint that affected the functions of these areas. He also exhibited mesh scarring, external auricular loss, and eyebrow hair loss (Fig. 43.6a). After the functional repair of his neck and wrist joint with a cervicopectoral flap and an intercostal perforator "super-thin" flap, respectively, eyebrow reconstruction was scheduled at his request. His deep inferior epigastric artery and vein, which were 12 cm in length, were harvested and anastomosed, respectively, to the contralateral side of his superficial temporal artery and vein. This was because his ipsilateral superficial temporal artery and vein appeared to be damaged or absent due to the initial injury or the subsequent skin grafting. The distal part of the deep inferior epigastric vascular bundle was buried beneath the temporal galea along the retroauricular hair border (Fig. 43.6b). Three weeks later, the secondary vascularized hairy flap was elevated as an island flap, transferred through the subcutaneous tunnel, and placed above the supraorbital rim. All wounds were closed primarily. The whole flap subsequently exhibited congestion, especially in the distal area. However, the congestion improved gradually over a few weeks. During this period, a topical steroid ointment was administered to avoid necrosis of the hair follicles. The secondary vascularized hairy flap survived in its entirety with little hair loss. An almost symmetrical appearance was achieved (Fig. 43.6c).

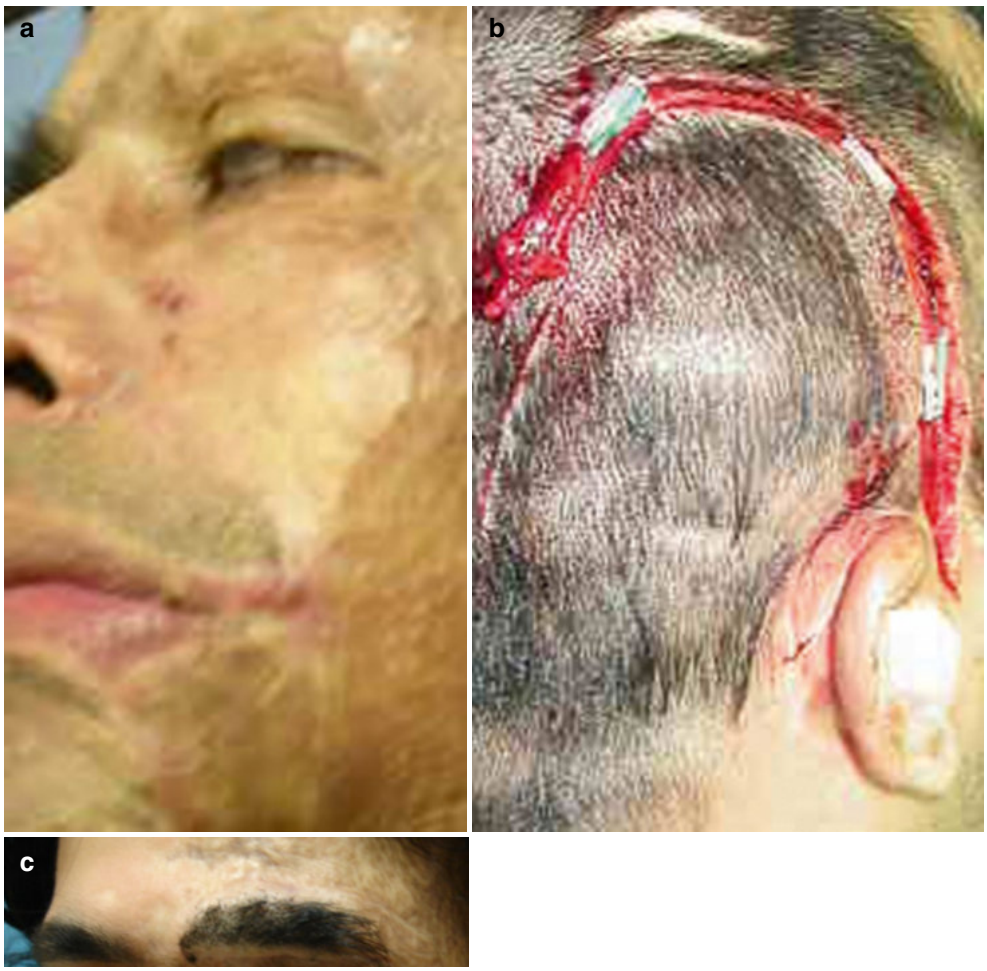


Fig. 43.6 Case 5. Contralateral eyebrow reconstruction in a man

References

1. Shen T. Vascular implantation into skin flap: experimental study and clinical application; a preliminary report. Plast Reconstr Surg. 1981;68:404–9.
2. Hyakusoku H, Okubo M, Umeda T, Fumiiri M. A prefabricated hair-bearing island flap for lip reconstruction. Br J Plast Surg. 1987;40:37–9.
3. Mizuno H, Akaishi S, Kobe K, Hyakusoku H. Secondary vascularized hairy flap transfer for eyebrow reconstruction. J Plast Reconstr Aesthet Surg. (in press)
4. Erol OO, Parsa FD, Spira M. The use of secondary island graft-flap in reconstruction of the burned ear. Br Plast Surg. 1981;34:417.
5. Wasio H. An intestinal conduit for free transplantation of other tissues. Plast Reconstr Surg. 1971;48:48.
6. Orticochea M. A new method for total reconstruction of the nose: the ears as donor areas. Br J Plast Surg. 1971;24:225.
7. Shintomi Y, Oura T. The use of muscle vascularized pedicle flaps. Plast Reconstr Surg. 1982;70:725–32.
8. Hyakusoku H. Secondary vascularized hair-bearing island flaps for eye-braw reconstruction. Br J Plast Surg. 1993;46:45–7.
9. Hirai T, Manders EK, Huges K, Oki K, Hyakusoku H. Experimental study of allogeneically vascularized prefabricated flaps. Ann Plast Surg. 1996;37:394–9.
10. Ogawa R, Oki K, Hyakusoku H. Vascular tissue engineering and vascularized3D tissue regeneration. Regen Med. 2007;2:831–7.

Prefabricated and Prelaminated Flaps

44

Jake Laun, Brian M. Parrett, and Julian J. Pribaz

Abstract

Burn reconstruction often requires innovative and more complex approaches to reconstruction, especially when there is a paucity of local tissue and typical flap reconstruction is unable to be performed. One such method is utilizing flap prefabrication and prelamination [3, 6, 8, 9, 11, 16, 17]. Prefabrication was first introduced by Shen [14] in 1982 and describes the implantation of a vascular pedicle into a new territory, followed by a period of maturation and neovascularization, and then the subsequent transfer of tissue based on its implanted pedicle allowing a significant amount of tissue to be transferred from one location to the area being reconstructed, greatly expanding our reconstructive options [11]. Flap prelamination, first defined by Pribaz and Fine in 1994 [8], describes the process of implanting either tissues or devices into a vascularized region, which can subsequently be transferred on its own axial blood supply but now with added support, lining, and structural components for layered reconstruction [9, 12]. In this chapter, we present the techniques of flap prelamination and the prefabrication as well as their usage in burn reconstruction.

Keywords

Vascular pedicle · Cartilage graft · Recipient site · Facial defect · Flap transfer

J. Laun · J. J. Pribaz (✉)
Department of Plastic Surgery, University of South Florida, Tampa, FL, USA
e-mail: jlaun@usf.edu

B. M. Parrett
Division of Plastic Surgery and Microsurgery, The Buncke Clinic, California Pacific Medical Center, San Francisco, CA, USA

44.1 Background of the Technique

Burn reconstruction often requires innovative and more complex approaches to reconstruction, especially when there is a paucity of local tissue and typical flap reconstruction is unable to be performed. One such method is utilizing flap prefabrication and prelamination [3, 6, 8, 9, 11, 16, 17]. Prefabrication was first introduced by Shen [14] in 1982 and describes the implantation of a vascular pedicle into a new territory, followed by a period of maturation and neovascularization, and then the subsequent transfer of tissue based on its implanted pedicle allowing a significant amount of tissue to be transferred from one location to the area being reconstructed, greatly expanding our reconstructive options [11]. Flap prelamination, first defined by Pribaz and Fine in 1994 [8], describes the process of implanting either tissues or devices into a vascularized region, which can subsequently be transferred on its own axial blood supply but now with added support, lining, and structural components for layered reconstruction [9, 12]. In this chapter, we present the techniques of flap prelamination and prefabrication as well as their usage in burn reconstruction.

44.1.1 Indications

In head and neck burn reconstruction, the goal of reconstruction is to replace like with like. Often this is hindered by the lack of availability of like tissue characteristics such as hair-bearing skin and thin, pliable skin with similar skin texture and tone. Flap prefabrication allows the transfer of a vascularized pedicle into a region of similar tissue characteristics that does not have its own axial blood supply. After allowing for neovascularization of that region, the newly vascularized tissue can then be mobilized based on the new pedicle to the areas of reconstruction. This method can be especially useful in those burn patients with significantly scarred areas of the face and neck, which require reconstruction after excisional or incisional scar contracture release [6].

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_44

Prelamination allows the fashioning of multilayered, composite flaps for the reconstruction of complex defects after significant facial burns, often electrical in nature. Prelamination is particularly useful for patients with central facial defects, especially of the nose, lips, and palate that have layers of skin, cartilage, and mucosa that need to be reconstructed.

44.2 Operative Technique for Prefabrication

44.2.1 Stage 1: Implantation of Vascular Pedicle

First, one must define the defect, requirements for reconstruction, and available donor sites with a plan and timeline for reconstruction as the prefabrication process takes at least 8 weeks and is performed in two stages. A vascular pedicle (which includes at least the artery and its venae comitantes surrounded by adventitial tissue and may also include fascia or a cuff of muscle) is dissected out, transferred to the new area of tissue, and implanted. The distal end is ligated, and no vascular anastomoses are performed (Fig. 44.1a, b). Vascular connections occur spontaneously between the implanted pedicle and the surrounding tissue to create a new vascular territory (Fig. 44.1c). We wrap Gore-Tex® (polytetrafluoroethylene tubing) (W.L. Gore & Associates, Flagstaff, AZ) or silicone sheeting around the pedicle to facilitate later flap harvest and pedicle dissection and identification (Fig. 44.1b).

Flaps may be prefabricated at a distant site in cases where there is no local tissue available, with the aim of creating a thin flap for head and neck reconstruction by transferring the pedicle superficially (Table 44.1). After the maturation period, which is often around 8 weeks, the flap is transferred as a free flap. One example is in resurfacing the neck after burn scar excision using a prefabricated thigh flap. The descending branch of the lateral femoral circumflex vascular pedicle is transferred from deep to the vastus lateralis muscle to the subcutaneous plane to vascularize the overlying tissue creating a thin, supple flap.

We preferentially perform prefabrication locally in patients who have nonburned areas adjacent to the face; regions near the recipient site provide excellent color and texture match. Common donor sites are the anterior and posterior neck, supraclavicular region, postauricular area, and scalp (Table 44.1). In these cases where a local pedicle is used, no microsurgery is involved. During the first stage, a local vascular pedicle is rerouted into the new area, and this neovascularized tissue is subsequently transferred into the defect in the second stage as a pedicled flap. Most commonly, the superficial temporal vascular pedicle is dissected, ligated distally, and transferred into the upper neck usually above a tissue expander, allowing prefabrication of the neck for later transfer to the face. This process is useful for cheek or jaw reconstruction. Another benefit of prefabrication near the recipient site is the possibility of using multiple sequential prefabricated flaps for reconstructions of multiple facial subunits, transferred sequentially by the same vascular pedicle in a process called the "vascular crane" principle [10].

Occasionally, the native pedicles are too short to reach the area to be vascularized. In these cases, a vascular pedicle can be transferred as a mini-free flap from a distant area to the neck or another chosen area. Any long pedicle is suitable, but most commonly, the descending branch of the lateral femoral circumflex vascular pedicle or the radial forearm vascular pedicle with surrounding fascia is used. The base of the

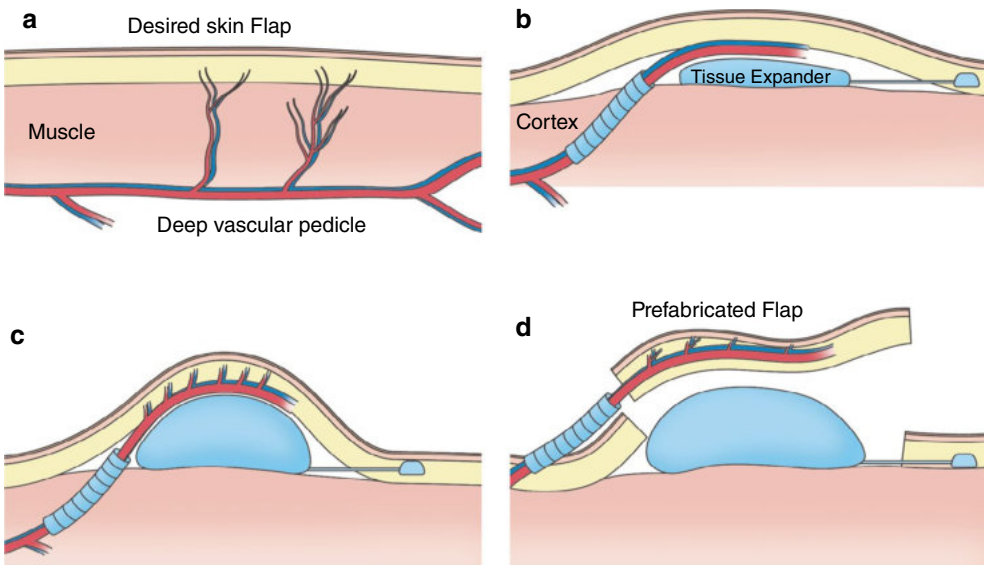


Fig. 44.1 Technique of flap prefabrication. (**a**) A deep vascular pedicle is shown and will be dissected out with a cuff of fascia or muscle around it. (**b**) The vascular pedicle is placed between the underside of the skin flap to be prefabricated and a tissue expander. Gore-Tex® tubing is placed around the proximal pedicle to facilitate later flap harvest. (**c**) Tissue expansion starts in 1 week. (**d**) After at least 8 weeks, the prefabricated flap is raised off the tissue expander (the capsule is included within the flap) and then transferred to the recipient site

Table 44.1 Common anatomic locations for flap prefabrication in head and neck reconstruction

Anatomic location	Vascular pedicle	Technical points
Distal site		
Medial thigh	Descending branch of lateral femoral circumflex vessels	Incorporate greater saphenous vein for drainage
Lateral thigh	Descending branch of lateral femoral circumflex vessels	Place tissue expander below pedicle to thin flap and increase flap size
Inner upper arm	Thoracodorsal vessels to latissimus and serratus muscles	
Near recipient site		
Upper cervical	Superficial temporal vessels	Include temporoparietal fascia in pedicle
Retroauricular or mastoid region	Superficial temporal vessels	Include temporoparietal fascia in pedicle
Supraclavicular	Thoracoacromial vessels	Transfer pedicle over the clavicle and above a tissue expander

pedicle is anastomosed to the nearby main pedicle, and the distal ligated end is tunneled beneath the area to be prefabricated. Assure that the vascular pedicle is long enough and appropriately based to allow second-stage transfer without detaching the anastomosis.

Tissue expansion is often used in conjunction with prefabrication as it stimulates angiogenesis and neovascularization, thins the flap, and allows primary closure of the future donor site and the transfer of a greater amount of tissue. The implanted pedicle is placed directly underneath the skin and on top of the expander (Fig. 44.1b, c). Expansion begins approximately 1–2 weeks postoperatively and lasts until flap transfer. A hand-held Doppler may be used to assure patency of the pedicle at the time of expander fill. If a signal disappears, removing the fluid from the expander will restore flow.

44.2.2 Stage 2: Transfer of Flap

After maturation, the neovascularized tissue is harvested and transferred based on the implanted pedicle after at least 8 weeks of maturation (Fig. 44.1d). The flap is transferred as a local or free flap depending upon the nature of the flap and the pedicle transferred. The flap after transfer usually has some degree of transient venous congestion that can last as long as 48 h. Including a native subcutaneous vein in the flap and performing an additional anastomosis or waiting longer before flap transfer is effective in decreasing congestion. It is mandatory that the flap not be folded as prefabricated flaps cannot tolerate manipulation and folding as well as axial flaps can. The donor site, especially if tissue expansion has been used, can usually be closed primarily.

Flap size can be rather large, but in clinical cases, we commonly use a conservative 2:1 ratio (the length of the flap vs. extent of pedicle length within the flap) [5, 15]. Flap delay may also be used to enhance neovascularization and increase the size of the transferred flap. Delay is accomplished by progressively raising the flap off its axial blood supply [5]. Tissue expansion also increases the size of the flap that can be transferred.

44.3 Operative Technique for Prelamination

44.3.1 Stage 1: Introduction of Tissue

Prelamination involves a two-stage procedure and begins by defining the defect and the layers that need to be reconstructed. Stage 1 involves introducing the appropriate graft material, such as cartilage, bone, mucosa, or bioengineered materials [1, 2, 4, 7, 12, 13]. Skin or mucosal grafts can provide lining, and costochondral, auricular, or septal cartilage can provide structural support.

Prelamination is most often employed at a distant site as reconstruction in a remote unscarred territory will allow the best chance for healing and graft incorporation. The forearm provides abundant and thin tissue for nasal, cheek, and upper lip reconstruction. The radial artery territory is most commonly used for prelamination as it has a reliable vascularity that facilitates incorporation of skin, mucosal, and cartilage grafts to construct a complex, three-dimensional flap.

Generally, the fasciocutaneous flap is partially raised, the grafts sutured onto the forearm fascia, and the flap reinserted. With mucosa, the graft is meshed or cut into small pieces, sutured onto the fascia, and then, a 1-mm silastic sheet is placed over the grafts to avoid adhesions and promote spreading. A tissue expander can be placed under the lining and allows the grafts to better adhere to the underlying flap.

Flaps may also be prelaminated in close proximity to the facial defect, such as a prelaminated forehead flap for nasal reconstruction. We have used the submental flap, based on the facial artery submental branch, as a prelaminated flap for full-thickness lip and cheek reconstruction.

44.3.2 Stage 2: Flap Transfer

After a period of 3–4 weeks to allow for graft incorporation into the flap, the composite flap is transferred to the face. This can be performed as a free-tissue transfer if prelamination occurs distally or as a pedicled flap transfer if prelamination occurs in the head and neck.

44.4 Later Stages: Secondary Refinements

With this two-stage procedure, edema, scarring, and contraction may result at the donor site before transfer and at the recipient site after transfer. Revisions are necessary to achieve an aesthetically pleasing result. For instance, in complex cheek and nasal reconstruction, prelaminated flaps may need to be debulked, sculptured, and nasal anatomic subunits separated to enhance the full aesthetic result.

44.5 Clinical Cases

44.5.1 Case 1

A 32-year-old man sustained extensive burns to his head, neck, and torso and presented with a diffuse burn scar contracture of his neck (Fig. 44.2a). The usual flap donor sites were unavailable because of the burn injury. Thus, a flap was prefabricated over the anterolateral thigh (Fig. 44.2b). The descending branch of the lateral femoral circumflex vessel with some surrounding muscle and fascia was dissected and transferred subcutaneously, where it was placed directly underneath the skin (Fig. 44.2c). Gore-Tex® tubing was placed around the base of the pedicle. Eight weeks later, the thin prefabricated flap was ready for transfer (Fig. 44.2d, e). The neck burn scar contracture was released, and the prefabricated flap was microsurgically transferred to the neck (Fig. 44.2f). The flap survived completely, and 3 months later, a minimal debulking was performed. The patient now has excellent neck extension (Fig. 44.2g).

44.5.2 Case 2

A 45-year-old man with 80% total body surface area burns with extensive facial burns resulting in an absent nose (Fig. 44.3a). A prefabricated flap was designed using a section of unburned skin in the left neck region (Fig. 44.3b). A free transfer of lateral femoral circumflex vessels to the superficial temporal vessels was performed, and this vascular pedicle was rotated into the nonburned neck area (Fig. 44.3c). Nine weeks later, nasal reconstruction was performed with nasal turn-down flaps from local scarred tissues for lining and cartilage grafts for support. Simultaneously, the newly prefabricated flap was transferred as a pedicled flap to the nose (Fig. 44.3d). Six weeks later, using the "vascular crane" principle, the same pedicle was transferred to the hair-bearing scalp region to prefabricate a hair-bearing flap (Fig. 44.3e). Eight weeks later, his upper lip was reconstructed with the prefabricated scalp flap, again using the lateral femoral circumflex pedicle (Fig. 44.3f). He is shown 1 year postoperatively after two nasal revisions (Fig. 44.3g).

44.5.3 Case 3: Prelamination

A 62-year-old man sustained full-thickness facial burns, and debridement resulted in loss of the distal subunits of his nose and full-thickness cutaneous loss of the nasal dorsum, right cheek, and upper lip, with exposed bone and cartilage (Fig. 44.4a). During the first stage of reconstruction, skin and cartilage grafts were placed beneath a radial forearm flap to serve as nasal vestibular lining and nostril rim support, respectively (Fig. 44.4b). After 3 weeks, the grafts had taken and the prelaminated flap was transferred as a single unit for reconstruction of the nose, cheek, and upper lip (Fig. 44.4c, d). One month later, a revision was performed to define the lip, nasal subunits, and cheek (Fig. 44.4e).

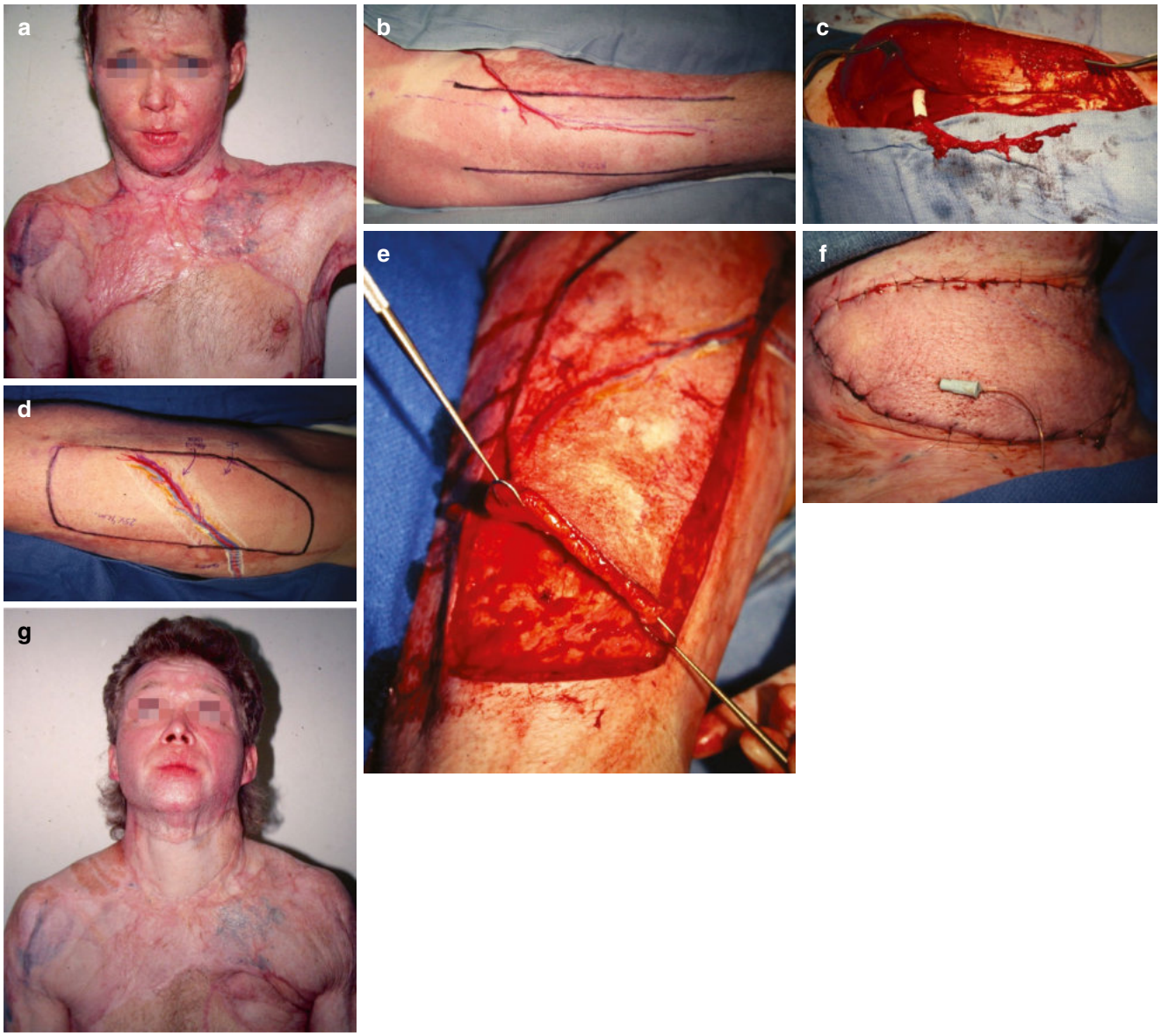


Fig. 44.2 (**a**–**g**), Patient photographs for Case 1 showing the prefabrication of a thigh flap with the lateral femoral circumflex pedicle for neck burn contracture release and flap coverage

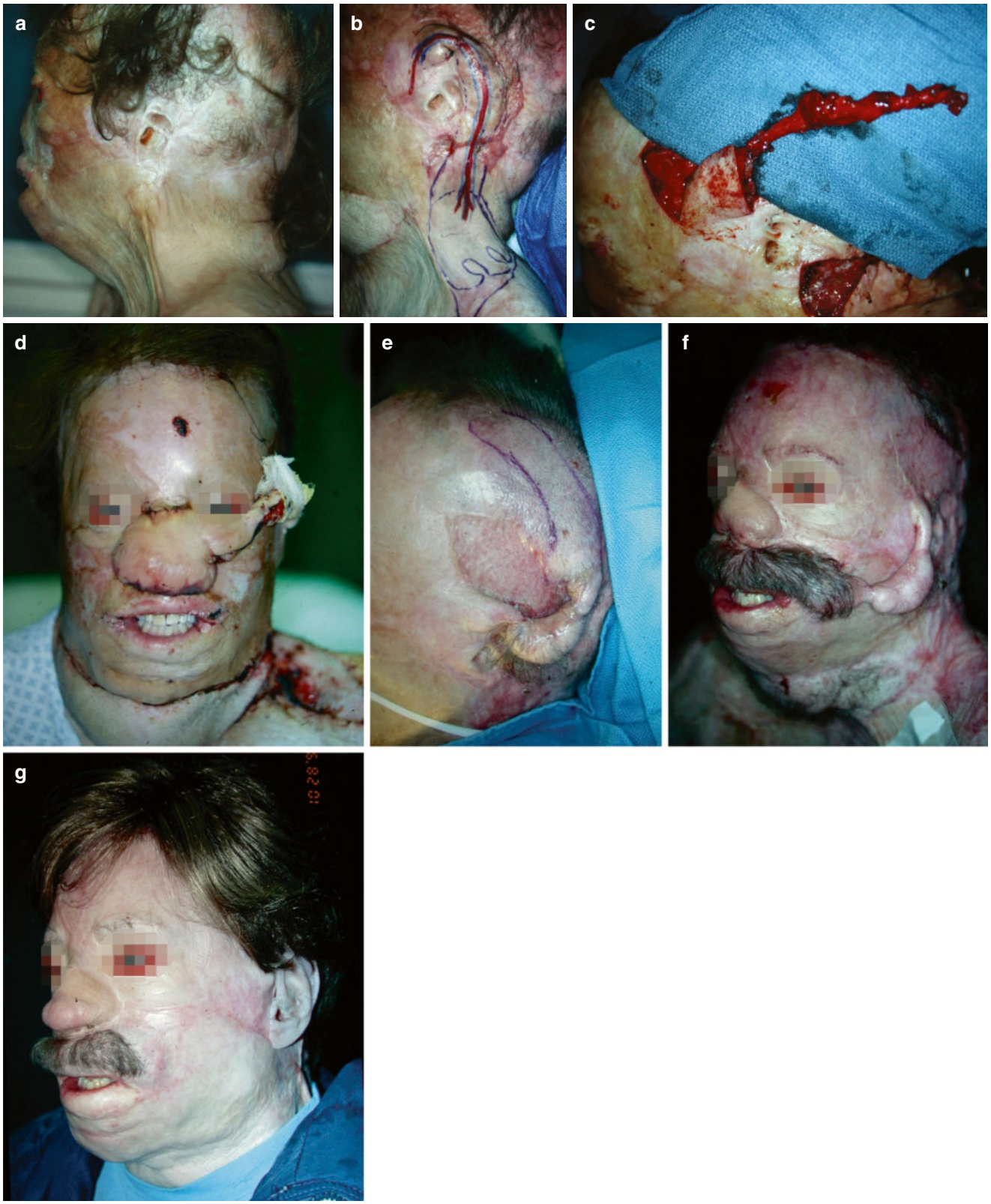


Fig. 44.3 (**a**–**g**), Patient photographs for Case 2 showing prefabrication near the recipient site for facial burns. The "vascular crane" principle is demonstrated using a single pedicle to prefabricate two separate flaps for nasal reconstruction and for the formation of a hair-bearing flap for mustache reconstruction

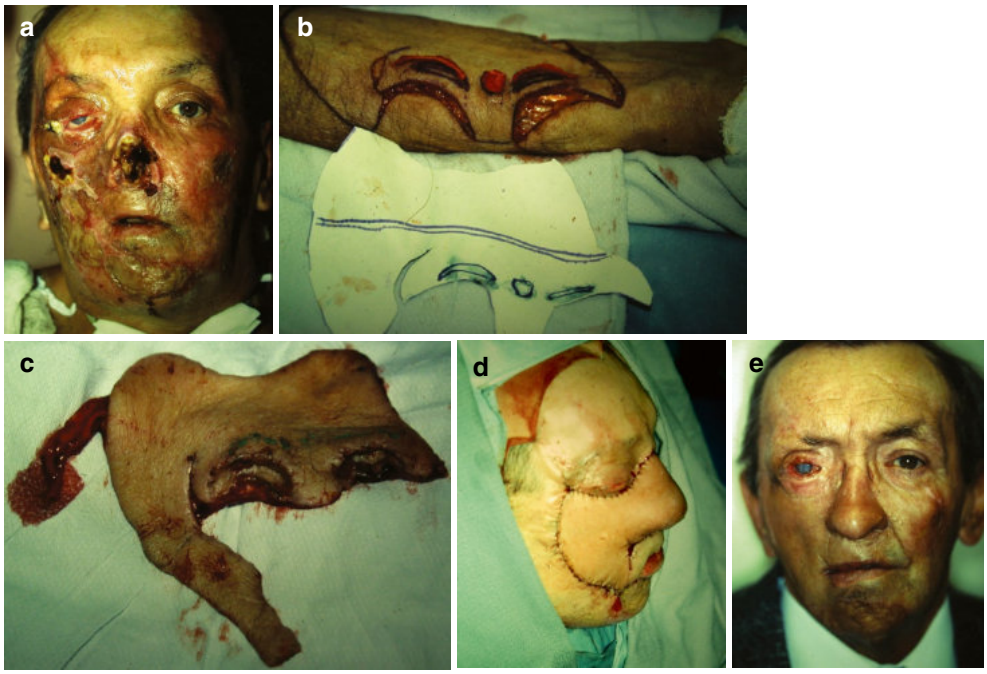


Fig. 44.4 (**a**–**e**), Patient photographs for Case 3 showing a severe central facial burn reconstructed with a radial forearm flap prelaminated with cartilage grafts for nasal support and skin grafts for nasal lining

References

1. Costa H, Cunha C, Guimaraes I, et al. Prefabricated flaps for the head and neck: a preliminary report. Br J Plast Surg. 1993;46:223–7.
2. Holle J, Vinzenz K, Wuringer E, et al. The prefabricated combined scapula flap for bony and soft-tissue reconstruction in maxillofacial defects–a new method. Plast Reconstr Surg. 1996;98:542–52.
3. Khouri RK, Upton J, Shaw WW. Principles of flap prefabrication. Clin Plast Surg. 1992;19:763–71.
4. Lauer G, Schimming R, Gellrich NC, et al. Prelaminating the fascial radial forearm flap by using tissue-engineered mucosa: improvement of donor and recipient sites. Plast Reconstr Surg. 2001;108:1564–72.
5. Maitz PK, Pribaz JJ, Hergrueter CA. Impact of tissue expansion on flap prefabrication: an experimental study in rabbits. Microsurgery. 1996;17:35–40.
6. Parrett BM, Pomahac B, Orgill DP, et al. The role of free-tissue transfer for head and neck burn reconstruction. Plast Reconstr Surg. 2007;120:1871–8.
7. Pribaz JJ, Guo L. Flap prefabrication and prelamination in head and neck reconstruction. Semin Plast Surg. 2003;17:351–62.
8. Pribaz JJ, Fine N. Prelamination: defining the prefabricated flap—a case report and review. Microsurgery. 1994;15:618–23.
9. Pribaz JJ, Fine NA. Prefabricated and prelaminated flaps for head and neck reconstruction. Clin Plast Surg. 2001;28:261–72.
10. Pribaz JJ, Maitz PK, Fine NA. Flap prefabrication using the "vascular crane" principle: an experimental study and clinical application. Br J Plast Surg. 1994;47:250–6.
11. Pribaz JJ, Fine N, Orgill DP. Flap prefabrication in the head and neck: a 10-year experience. Plast Reconstr Surg. 1999;103:808–20.
12. Pribaz JJ, Weiss DD, Mulliken JB, et al. Prelaminated free flap reconstruction of complex central facial defects. Plast Reconstr Surg. 1999;104:357–65.
13. Rath T, Tairych GV, Frey M, et al. Neuromucosal prelaminated flaps for reconstruction of intraoral lining defects after radical tumor resection. Plast Reconstr Surg. 1999;103:821–8.
14. Shen TY. Microvascular transplantation of prefabricated free thigh flap (Letter). Plast Reconstr Surg. 1982;69:568.
15. Tark KC, Shaw WW. The revascularization interface in flap prefabrication: a quantitative and morphologic study of the relationship between carrier size and surviving area. J Reconstr Microsurg. 1996;12:325–30.
16. Daugherty THF, Pribaz JJ, Neumeister MW. The Use of Prefabricated Flaps in Burn Reconstruction. Clinic Plastic Surg. 2017;44(4):813–21.
17. Guo L, Pribaz JJ. Clinical flap prefabrication. Plastic Reconst Surg. 2009;124(6 Suppl):e340–50.

Prefabricated Facial Flaps

45

Luc Téot

Keywords

Prefabricated facial flaps · Skin expansion · Angiogenesis · Vascular carrier · Flap reconstruction · Postburn scarring · Microvascular anastomosis · Axial flap · Aesthetic improvement · Surgical procedure · Case studies · Facial scars

Prefabrication was proposed in 1998 by Khouri et al. [1] as a solution for the prefabrication when anatomy could not provide an adapted tissue for a specific surgical procedure, after seminal works done by Erol [2] and Pribaz [3]. The author developed a technique [4] using a vascular carrier placed above a large skin expansion device. This system induces an important angiogenetic process, allowing the expanded skin surface to be progressively vascularized by newly formed capillaries developed from the carrier. This technique may be used anywhere on the body, in particular for extensive scars of the face, to provide aesthetic improvement and a better quality of life.

45.1 Technique

We have designed a technique for the prefabrication of large flaps to cover whole face reconstruction for cervicocephalic postburn scarring. This technique, based on modifications of the normal skin flap vascular anatomy, is called prefabrication and aims to provide the surgeon with larger flaps than normal anatomy would allow.

This two-stage procedure creates, after skin expansion, a cutaneous axial flap large enough to cover the whole face. During the first stage, an antebrachial fascial flap, including the radial artery and vein, is harvested and connected to the facial pedicle artery and vein. The fascia is then inserted under the supraclavicular skin, and 2 liters contenance skin expander is placed below the fascia. Skin expansion is then carried out, creating a very large flap, with a surface area large enough to cover a 22 × 23 cm skin defect.

The second stage is realized 3 months later, when skin expansion is completed. Once the total facial scar is excised, the flap is drawn over the expanded skin surface to the size of the defect. This flap is dissected along the carrier pedicle until the previously realized microvascular anastomosis is visualized. The flap is then turned around its axial flap. Dissection should continue until the facial vessels are exposed and show the microanastomoses previously realized.

45.2 Results

Seven patients presenting extensive facial scars after burns were offered this technique. Burn sequellae extended over the neck, cheeks, nose, and mandibular area.

45.3 Clinical Cases

45.3.1 Case 1

A 27-year-old woman presented with a complete facial scar with retracted eyelids, destruction of the cartilaginous portion of the nose, retraction of the mouth commissures, and scars over the front and the neck (Fig. 45.1a, b). The antebrachial fascia was harvested prior to dissection of the facial artery and vein, and a large undermining of the supraclavicular area was achieved. The antebrachial fascial flap was inserted under the skin and microanastomosed to the facial vessels. A 2000-cc skin expander was inserted deep into the antebrachial fascia.

L. Téot (✉)
Burns and Plastic Surgery Unit, Montpellier University Hospital, Montpellier, France
e-mail: l-teot@chu-montpellier.fr

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_45

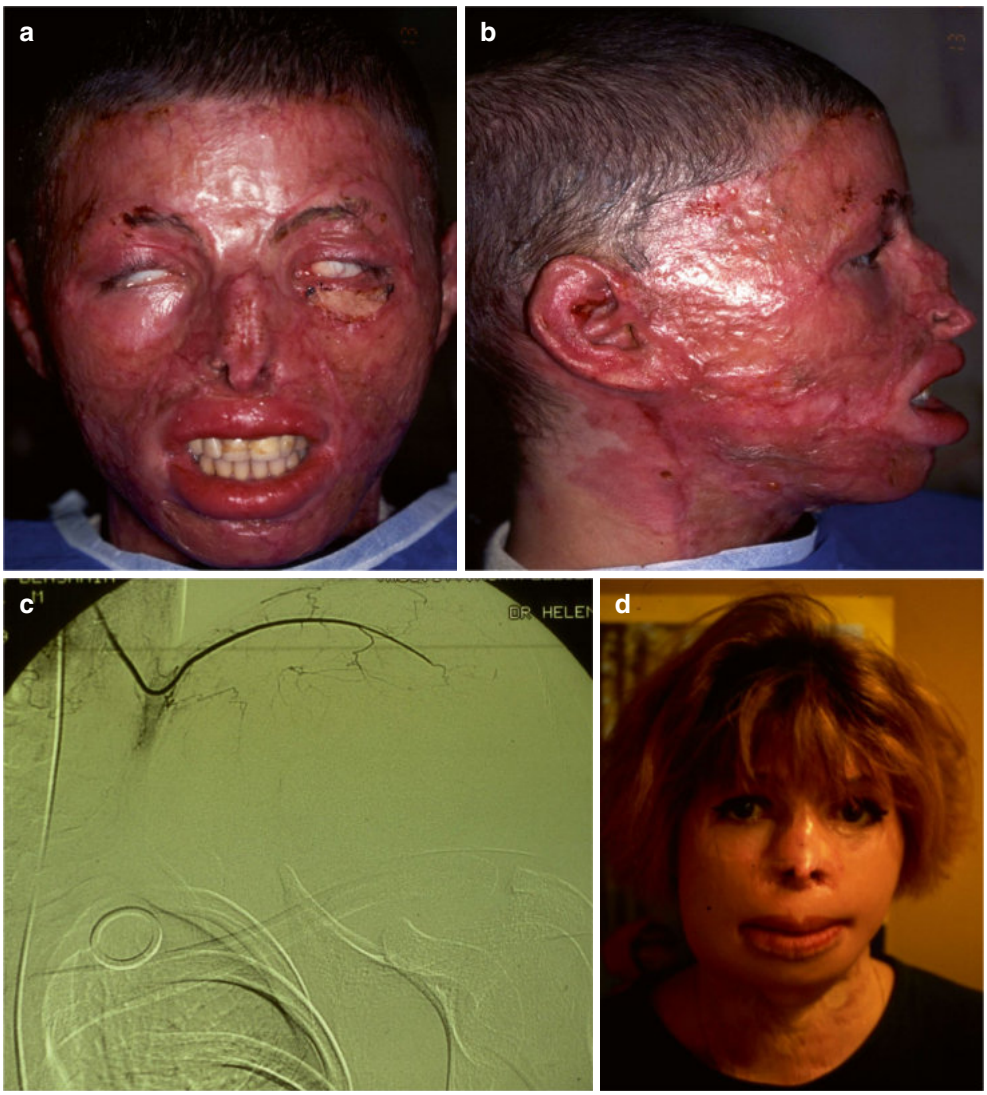


Fig. 45.1 (**a**–**d**) Case 1

After a period of 3 months of expansion using saline, an angiogram of the facial vessels was performed (Fig. 45.1c). It showed new vessels extending largely around the expanded skin and coming from the vascular carrier. The radiologist's evaluation was that an intense neoangiogenesis was induced.

During the second operative stage, the facial scars are completely removed. As usual in these types of postburn lesions, a few underlying structures are severed. Underlying muscles and nerves of the scars are atrophied but present. To reconstruct the face, a 25 × 25 cm flap was designed over the expanded area, on the left shoulder. Vessels of the carrier pedicle are retrodissected until the previously done microanastomosis could be exposed. The flap is turned over its axial pedicle to fill the surgical defect.

The opening of the mouth and realization of the commissures are performed, and the adaptation of the flap to reconstruct the lower eyebrows was also performed.

The postoperative period was marked by a progressive reappearance of facial mimics, due to the remodeling of the transplanted skin (folds around the commissure). The patient could then have a normal social life, be married, and have children (Fig. 45.1d).

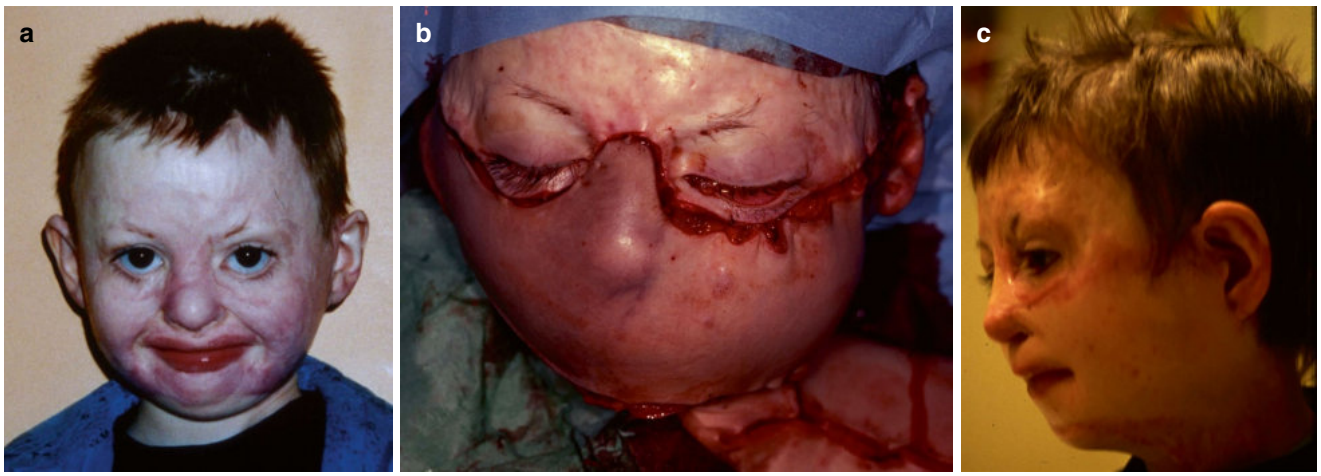


Fig. 45.2 (**a**–**c**) Case 2

45.3.2 Case 2

A 5-year-old boy was involved in a domestic accident resulting in burns of 85%. The face was involved. After resuscitation, skin grafts, and rehabilitation, the face presented extensive scars over the cheeks, the neck, and the mandibular areas. The chin was severely scarred with hypertrophic zones, as well as the commissures of the mouth (Fig. 45.2a).

The patient underwent the two-step procedure, similar to Case 1. The total scarred area was removed, and the prefabricated supraclavicular axial flap was dissected and rotated to cover the skin defect. The size of the flap was 20 × 17 cm. The mouth had to be reopened in the middle of the rotated flap (Fig. 45.2b). No postoperative problem was noted, except a transient edema of the face.

During the following years, as the child grew, a defatting procedure had to be done on the lateral part of the flap, on the side of the pedicle, without damaging the flap viability (Fig. 45.2c).

45.4 Case 3

A 17-year-old boy presented an extensive postburn scar over the lower portion of the face, the chin, and the anterior part of the neck, with a variety of hypertrophic scars and wrinkles. Irregularities were visible, despite a trial of resurfacing using a skin graft (Fig. 45.3a, b)

The flap was designed over the left shoulder, which presented a less scarred surface than the right one. However, some scarred areas were present over the expanded skin (Fig. 45.3c).

After flap rotation, the oval of the face could be restored. Results at 6 months showed a good remodeling of the contour. The skin was flat and did not present the commonly encountered bulky aspect. This was probably due to the extensive mechanical stress during the expansion period, where the fat is somehow crushed between the skin and the expander, preventing fat edema after the second surgical procedure (Fig. 45.3d, e).

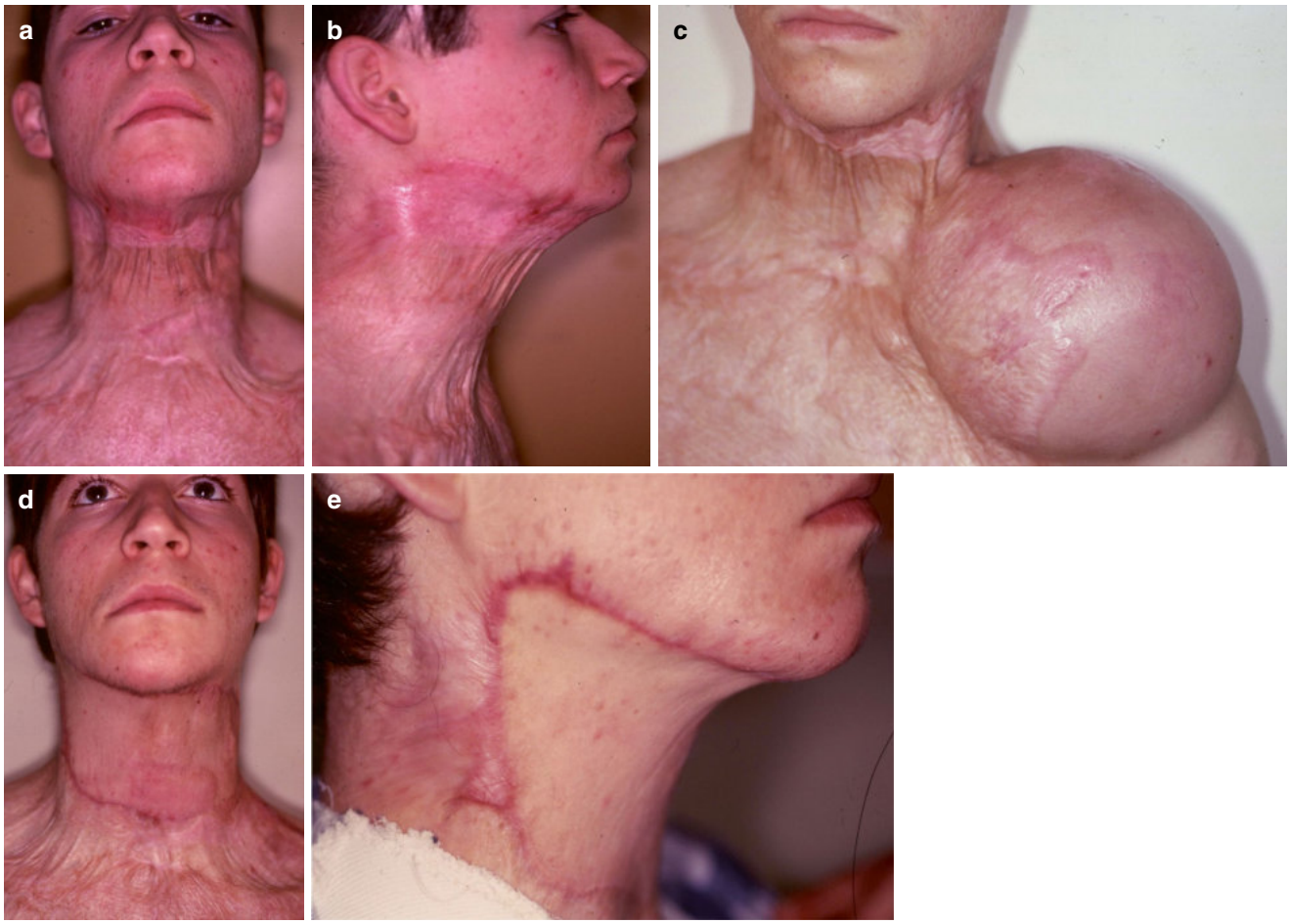


Fig. 45.3 (**a**–**e**) Case 3

References

1. Khouri RK, Ozbeck MR, Hruza GJ, Young VL. Facial reconstruction with prefabricated induced expanded (PIE) supraclavicular skin flaps. Plast Reconstr Surg. 1996;95:1007–15.
2. Erol OO. The transformation of a free skin graft into a vascularized pedicled flap. Plast Reconstr Surg. 1976;58:470–7.
3. Pribaz JJ, Fine N, Orgill DR. Flap prefabrication in the head and neck: a 10 year experience. Plast Reconstr Surg. 1999;103:808–20.
4. Téot L, Cherenfant E, Otman S, Giovannini UM. Prefabricated vascularised supraclavicular flaps for face resurfacing after postburns scarring. Lancet. 2000;355(9216):1695–6.

Part VI

Regional Flap and Thin Flap

Scarred Flap

46

Hiko Hyakusoku and Rei Ogawa

Keywords

Vascularity · Elasticity · Skin grafts · Musculocutaneous flap · Fasciocutaneous flap · Burn reconstruction · Epithelial necrosis · Doppler ultrasound · Case studies · Scar contracture · Surgical technique

46.1 Background of the Technique

When functionally reconstructing extensive burns, particularly in mobile areas such as the joints and neck, it is desirable to use flaps that can stretch adequately. However, sometimes there is insufficient healthy donor skin. In such cases, skin that bears scars due to epidermal burn (EB), superficial dermal burn (SDB), or even deep dermal burn (DDB) can be used as local or regional flaps. Skin-grafted areas can also serve as scarred flaps. When using scarred flaps, two concerns must be kept in mind: the vascularity and elasticity of the flap. About vascularity, scarred flaps may experience poorer blood flow in the epidermis than normal, which can lead to epithelial necrosis. However, this can be obviated by the fact that scarred flaps can have stronger blood flow in the dermis, similar to the mechanism observed in delayed flaps, where the blood flow in the flap increases when the surrounding blood flow is obstructed. This means that if the dermis survives, it will epithelialize over time, thus repairing any epithelial necrosis. Another issue related to scarred flap vascularity is that the scarring can significantly alter the course of the vessels in the flap; this should be assessed before surgery. The second issue regarding scarred flap stretching is a major concern: scarred flaps stretch less after surgery than flaps with normal skin. However, this can be resolved by elevating a sufficiently large flap, such as one that is 120% the size that would normally be needed. Thus, scarred flaps can be successful if the surgeon ensures that the design is appropriate and carefully assesses the scarred skin preoperatively and intraoperatively. In 1981, Hyakusoku and colleagues reported on the effectiveness of scarred flaps that included the musculocutaneous vascular system [1]. Later, they reported a number of cases of scarred flap use [2–4].

46.2 Characteristics of the Method and Specific Skills

1. Scars due to EB and SDB can generally serve as flaps with normal vascularity. By contrast, scars due to DB will display abnormal vascularity. Nonetheless, these scars can be used if they are assessed preoperatively with Doppler ultrasound, color Doppler ultrasound, or MD-CT, and these analyses reveal adequate collateral circulation in the flap.
2. Skin-grafted scars can also be used as scarred flaps. However, it is more difficult to assess the scar thickness of skin-grafted scars compared to primary scars.
3. Intraoperatively, it is necessary to carefully observe whether there is bleeding from the edge of the flap. It is also important to evaluate the scar thickness. While surgery may lead to epithelial necrosis, this can be limited by careful moisturizing and avoiding tension on the flap postoperatively.
4. There are a number of different scarred flap types, and they should be selected on a case-by-case basis. They include the (1) scarred random-pattern flap, (2) scarred axial-pattern flap, (3) scarred musculocutaneous flap, and (4) scarred fasciocutaneous flap. The vascularity of the scarred musculocutaneous flap is the most reliable.

H. Hyakusoku · R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: hyakusok@nms.ac.jp; r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_46

46.3 Clinical Cases

46.3.1 Case 1

A 60-year-old woman had flame burns of DDB and DB in her upper extremity (Fig. 46.1). After life-saving treatments, including early skin graft, the patient developed a scar contracture in her right axilla. Thus, a latissimus dorsi musculocutaneous flap was designed in the scarred lesion. The flap survived completely, and the scar contracture was released.

46.3.2 Case 2

A 38-year-old man had flame burns covering 42% of his total body surface area (Fig. 46.2). A scar contracture affecting the right axillary region was reconstructed with a scarred fasciocutaneous flap (24 × 8 cm). It was designed like a bilobed flap in the dorsal area to decrease the raw surface area after transposing the flap.

46.3.3 Case 3

A 46-year-old woman had an extensive flame burn over 70% of her total body surface area due to a suicide attempt (Fig. 46.3). After lifesaving therapy, the patient developed a scar contracture on the left foot. Thus, a free rectus abdominis musculocutaneous flap was applied to reconstruct the tissue defect after removing the scar. Since the abdominal area had previously undergone lifesaving facial excision and patch grafting, only a scarred flap was available. We thought that the survival area of the flap must be smaller than a flap in the healthy skin area, so the design of the flap was limited to the muscle area. The flap survived perfectly, and the scar contracture was removed.

46.3.4 Case 4

A 23-year-old man had a flame burn on his lower extremities and underwent mesh skin grafting (Fig. 46.4). However, the Achilles tendon of the right leg was exposed. A free flap was

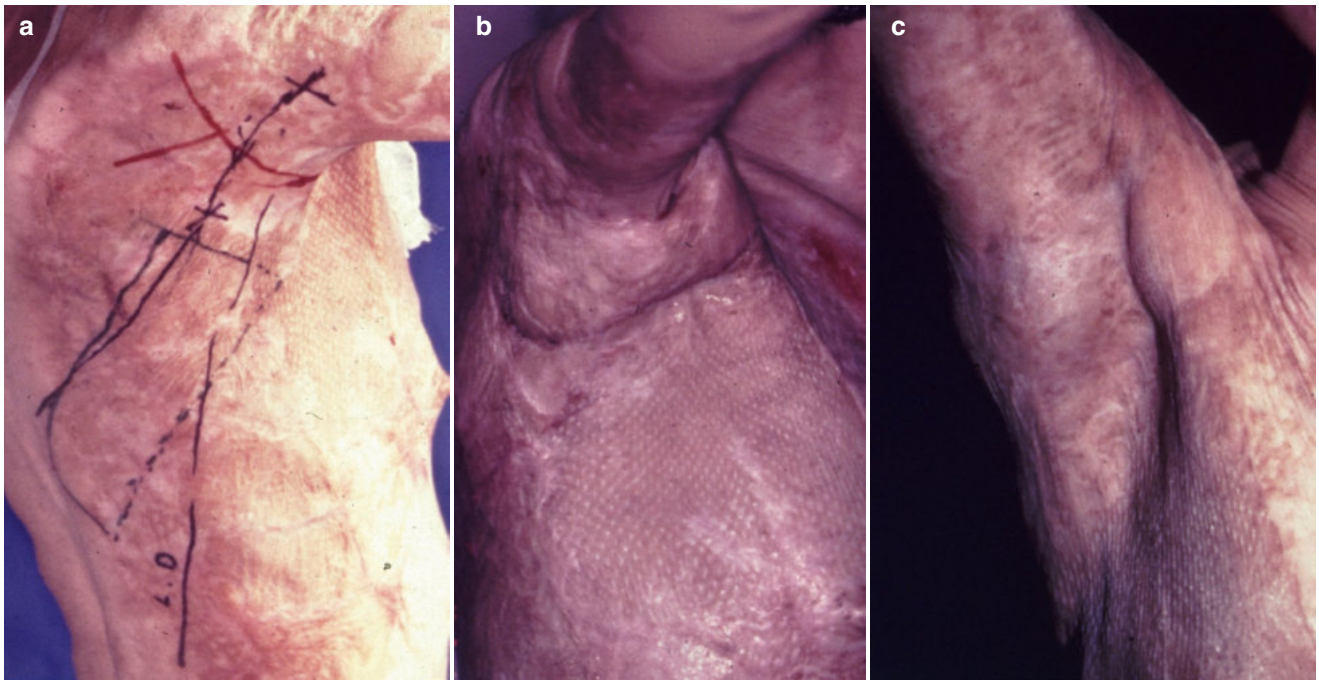


Fig. 46.1 (**a**–**c**) Case 1

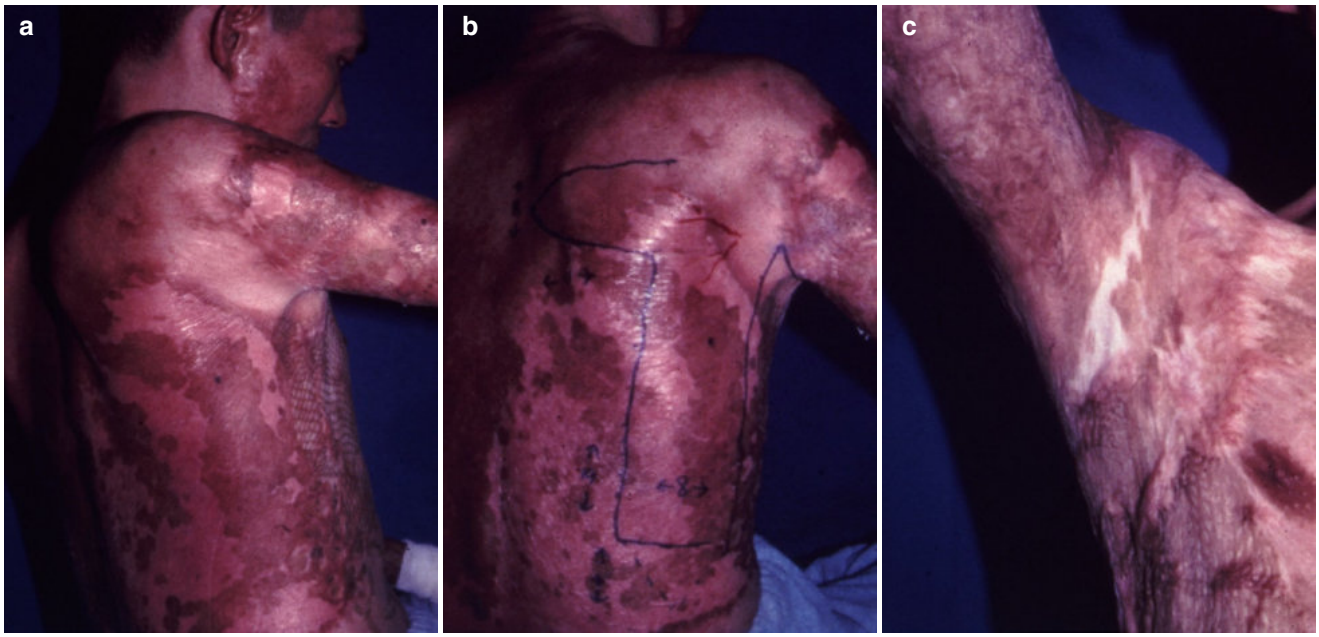


Fig. 46.2 (**a**–**c**) Case 2

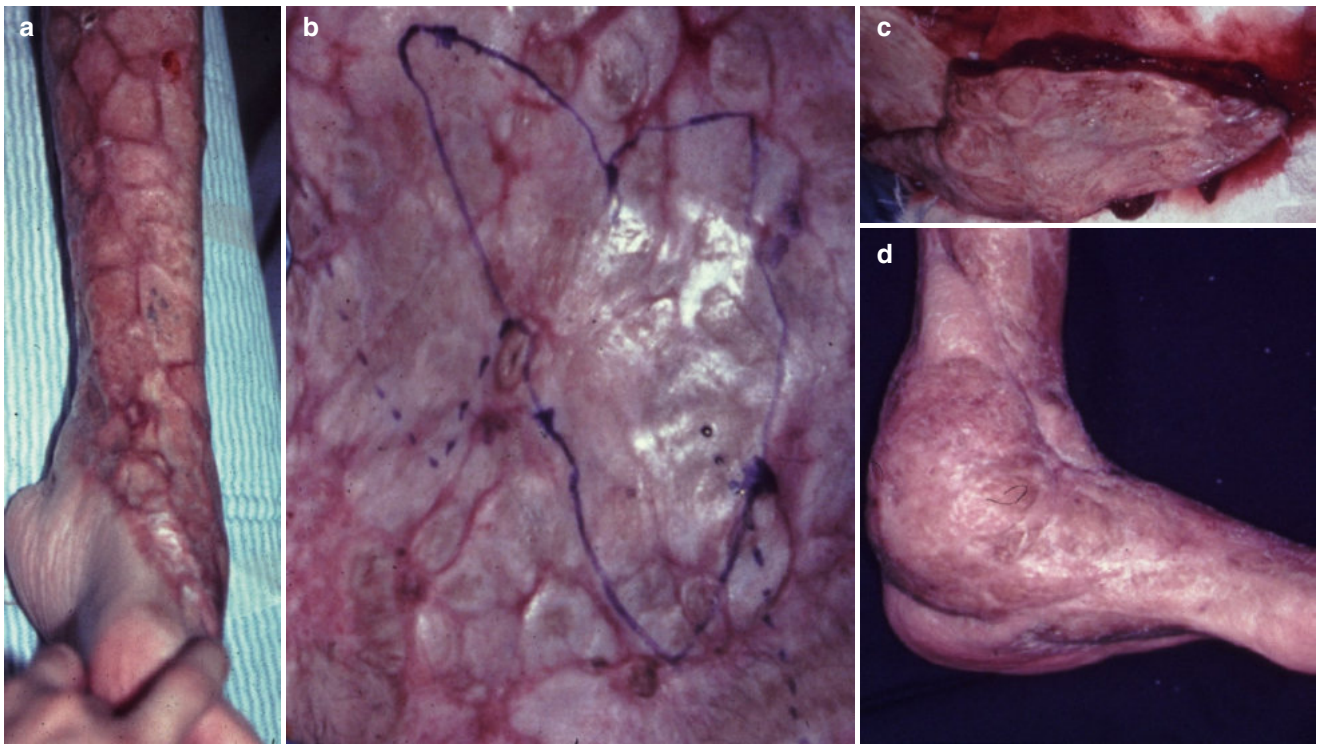


Fig. 46.3 (**a**–**d**) Case 3

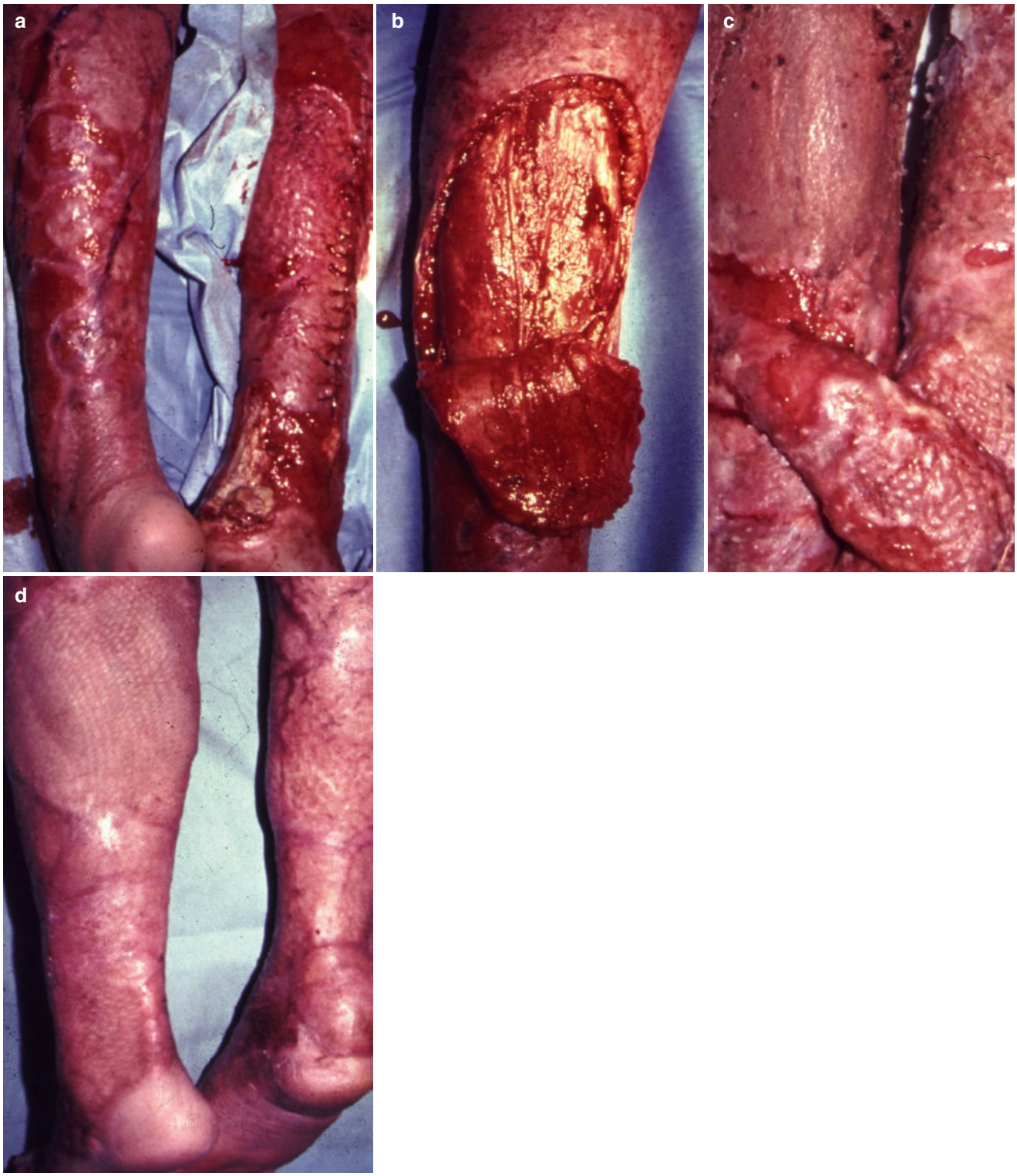


Fig. 46.4 (**a**–**d**) Case 4

planned, but the patient was admitted to a local hospital, which meant we could not perform microsurgery. Thus, the exposed tendon was reconstructed by using a cross-leg distally based scarred fasciocutaneous flap method. The flap size was 20 × 8 cm. Flap division was performed 14 days after the first operation. The tendon was adequately reconstructed.

References

1. Fumiiri M, Ishii K, Hyakusoku H, et al. Scarred flap-including musculocutaneous vascular system. Jpn J PRS. 1981;24:470–5.
2. Hyakusoku H, Ishii K, Fumiiri M. The use of skin flaps containing scar tissue for extensive burn scar contractures. Trans 8th IPRAS. 1983;8:210–2.
3. Hyakusoku H, Okubo M, Suenobu J, Fumiiri M. Use of scarred flaps and secondary flaps for reconstructive surgery of extensive burns. Burns. 1986;12:470–4.
4. Hyakusoku H, Tonegawa H, Fumiiri M. Heel coverage with a T-shaped distally based sural Island fasciocutaneous flap. Plast Reconstr Surg. 1994;93:872–6.

Use of Previously Burnt Skin in Local Fasciocutaneous Flaps

47

Jake Laun, Rodney Chan, and Julian J. Pribaz

Abstract

Burn reconstruction can be very challenging, especially when there are exposed structures such as bone, tendons, and joints that require flap reconstruction and closure. Local or regional flaps can be very helpful, given the sometimes lack of surrounding skin. It has long been said that burned skin or skin that has been previously reconstructed with a skin graft cannot be used; however, since the initial thermal injury is generally limited to the skin and subcutaneous fat, the underlying fascia and its vasculature are usually spared. Therefore, lending previously burned skin that has been reconstructed can be a viable option for local fasciocutaneous flaps. We present this idea as well as some case examples below.

Keywords

Fasciocutaneous flap · Radial forearm flap · Flap coverage · Regional flap · Anterolateral thigh flap

47.1 Background of the Technique

Burn reconstruction continues to be a very complex part of burn care, especially in wounds with exposed vital structures such as bone, tendons, vessels, and joints. Often, due to the extent and nature of the initial burn trauma, there may be little normal, nonburned skin that can be used to assist in reconstruction of the burned areas. It has been previously thought that burned skin reconstructed with a skin graft cannot be used. However, due to the usual presence and maintenance of the underlying well-vascularized fascia, these tissues can be used. Tolhurst was the first to observe that small areas of grafted skin remained viable when included in various parts of fasciocutaneous flaps in the trunk [1]. Cherup described the use of a radial forearm skin graft-fascial flap for hand reconstruction [2]. Pribaz published the first large series of 40 fasciocutaneous flaps using previously burned skin for upper extremity reconstruction [3]. Since then, Barret compared 238 previously burned skin flaps with 115 controls in the pediatric population and concluded that there were no significant differences in the rate of flap necrosis [4].

47.2 Characteristic and Indication of the Method

Whether the area in need of reconstruction is in the upper extremity or elsewhere, the need for coverage of important structures such as bone, tendon, or vasculature remains the same.

J. Laun
Department of Plastic Surgery, University of South Florida, Tampa, FL, USA
e-mail: jlaun@usf.edu

R. Chan
Department of Surgery, Division of Plastic Surgery, Brigham and Women's Hospital, Boston, MA, USA

J. J. Pribaz (✉)
Department of Plastic Surgery, Morsani College of Medicine, University of South Florida, Tampa, FL, USA
e-mail: jpribaz@usf.edu

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_47

One area especially prone to breakdown and requiring flap coverage, particularly in the setting of large contracture releases, is the elbow, both in the area of the olecranon, its underlying olecranon bursa, as well as the antecubital fossa. Often, bony prominences and aponeurotic origins of the extrinsic forearm muscles become exposed due to the thin nature of the area and subsequently need well-vascularized tissue coverage. Local options for coverage include a distally based flap from the arm or a proximally based forearm flap. In our experience, the reverse lateral arm flap, based on the anterior or posterior radial recurrent arteries, is an excellent option for elbow and proximal forearm coverage. The use of the ulnar recurrent upper arm flap is also possible but not ideal, based on the proximity to the ulnar nerve. The posterior interosseous flap, radial forearm, or the ulnar forearm flaps have also been used, but these might need to act as distally based flaps to surface the hand and wrist. Whichever flap is utilized, the principle of "not burning bridges" is crucial in maintaining bailout or additional flap options.

The wrist and hand are other potential areas requiring flap coverage, again due to the thin skin and increased propensity to exposure of important structures such as bone, joints, and tendons. In addition, contracture of the first webspace is particularly problematic, and if local Z-plasty releases are unable to significantly improve and release the contracture, we have had great success with the reverse posterior interosseous flap. Coverage over the dorsum of the hand with exposed tendons can be achieved with either reverse radial forearm or reverse ulnar forearm flaps. For smaller defects, the use of the proximally based metacarpal and axial digital flaps can also be helpful, all of which, even though the surrounding skin may have been burned, still maintain viable subcutaneous and fascial vasculature.

Digital reconstruction requiring flaps is also common and mainly involves coverage of the dorsal surface of the proximal interphalangeal joint (PIP) joint or PIP joint contracture release, which can either be extensor- or flexor-based. Local flaps, either based proximally or distally from the metacarpal or digital areas, have been used for reconstruction. Digital artery perforator flaps based upon perforators from the radial or ulnar artery, as well as first dorsal metacarpal artery perforator flaps, can be excellent options for PIP joint coverage.

While our experience has been mostly focused on the upper extremities, the use of previously burned adjacent skin as fasciocutaneous flaps can be applied throughout the body. Haddock has used previously burnt tissue in the reconstruction of the upper lip and nasal tip [5]. In Barret's series, while the majority of flaps were in the upper extremities, 11% were used in the lower extremities, 13% in the face, and 5.5% in the neck and trunk [4].

47.3 Specific Skill of the Methods

Doppler ultrasound is a valuable tool in marking out the main axial artery as well as any local perforators for flap planning and elevation. When using any radial-based forearm flaps, an Allen's test must be performed. The flaps can be based either proximally (orthograde flow) or distally (retrograde flow). The resulting donor site defects often need to be skin-grafted or covered with a wound matrix and grafted in a staged fashion, with often minimal morbidity at the donor site. The new donor defect, consisting of skin graft on muscle, has very little perceptible difference from the previous skin-grafted donor site. Often, these burn patients have multiple areas that will need reconstruction and flap planning. This emphasizes the importance of having a global and long-term reconstructive plan for these patients, making sure to not "burn any bridges" for future flap options.

When raising the flap, it is imperative to raise the skin-grafted fascia, together with the underlying vessels. Rough handling of these flaps, elevation at the wrong level, indiscriminate use of coagulation, and tension during closure can cause overlying skin necrosis and flap compromise. Some authors have also emphasized the need to maximize the time interval between the acute grafting procedure and the raising of the flap for reconstruction. Over time, the quality of the skin improves, with better pliability and improved "contourability" after scar maturation. However, more urgent flap coverage may be needed if important structures are exposed.

47.4 Clinical Cases

47.4.1 Case 1: Elbow

A 23-year-old man with extensive contracture of his left elbow, with radiograph showing ossification of the posterior

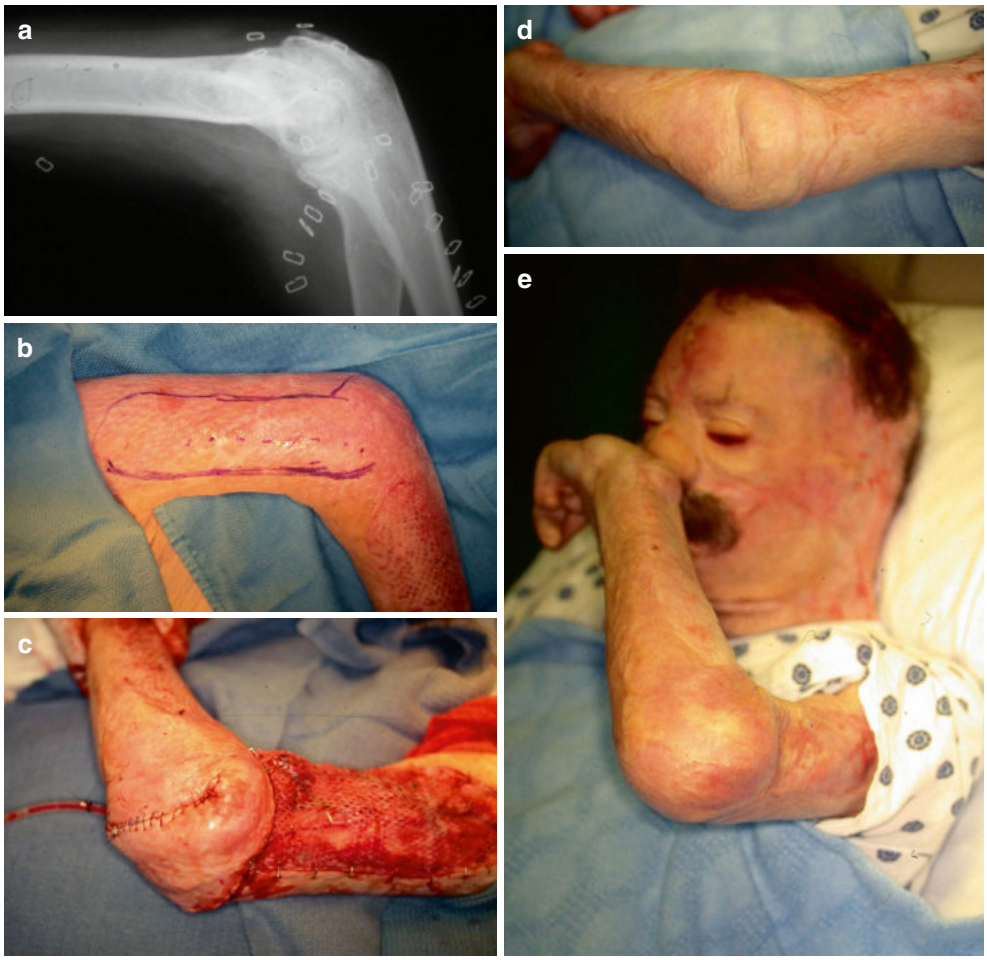


Fig. 47.1 (**a**–**e**) Case 1: Elbow

joint capsule (Fig. 47.1a). After release of soft tissue and bony ankylosis, a reversed lateral arm flap was marked on the skin-grafted upper arm (Fig. 47.1b). The flap is well-perfused and inset over the elbow release, and a skin graft was placed on the lateral arm donor site (Fig. 47.1c). At 3 months, there was excellent coverage and a healed donor site (Fig. 47.1d). The patient was able to flex his elbow and bring his hand up to his mouth (Fig. 47.1e).

47.4.2 Case 2: Wrist and Hand

A 23-year-old man with multilevel injuries of his upper extremity with contracture of his first webspace (Fig. 47.2a). The first webspace was released, and the subluxed phalanx was repositioned. A defect encompassing the first webspace and dorsum of his hand was present (Fig. 47.2b). A reverse posterior interosseous flap was raised from the skin-grafted

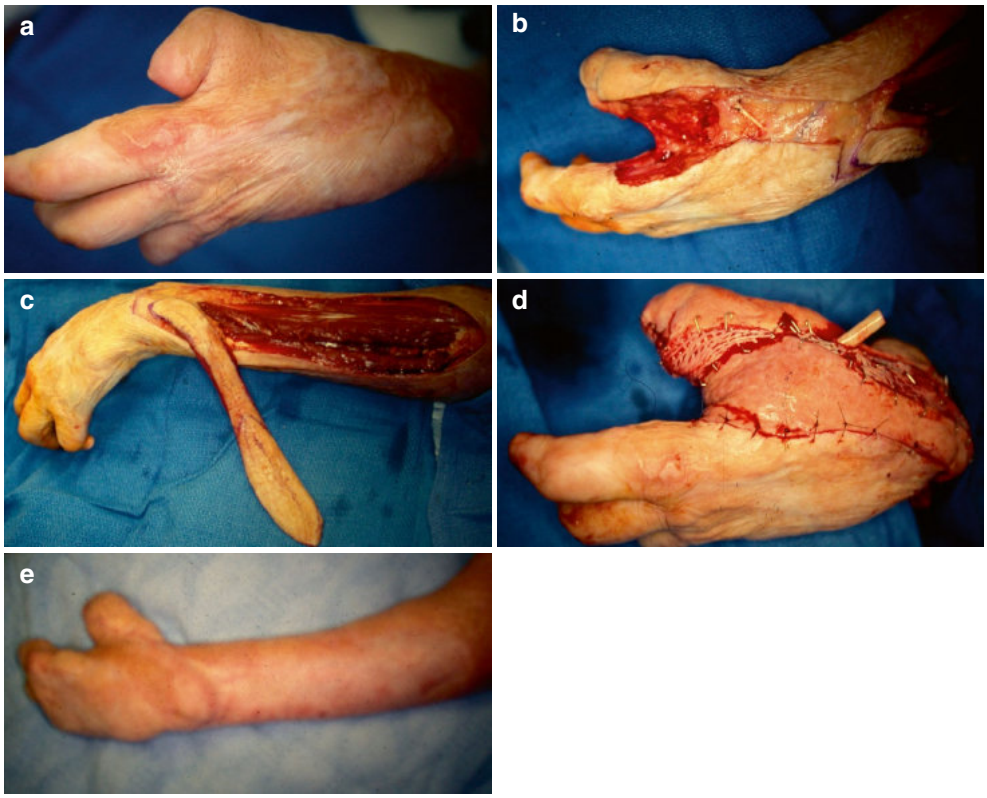


Fig. 47.2 (**a**–**e**) Case 2: Wrist and hand

forearm, with an intraoperative picture depicting a well-perfused flap (Fig. 47.2c). This was inset into the defect over a Penrose drain (Fig. 47.2d). He had a satisfactory long-term outcome with a functioning webspace (Fig. 47.2e).

47.4.3 Case 3: Digital

A 34-year-old man with full-thickness dorsal burns to the thumb and index stumps, without a functional webspace (Fig. 47.3a). "Spare part" pollicization of the injured index stump was performed based on the digital vessels, with the palmar aspect of the index stump used to reconstruct the dorsal aspect of the thumb. A ray amputation of the proximal ray of the index digit was also performed to open up the webspace (Fig. 47.3b), with its accompanying radiograph (Fig. 47.3c). This resulted in a functional webspace. The thumb is shown in both abduction and adduction. An anterolateral thigh flap was eventually performed to resurface his dorsum as well (Fig. 47.3d, e).

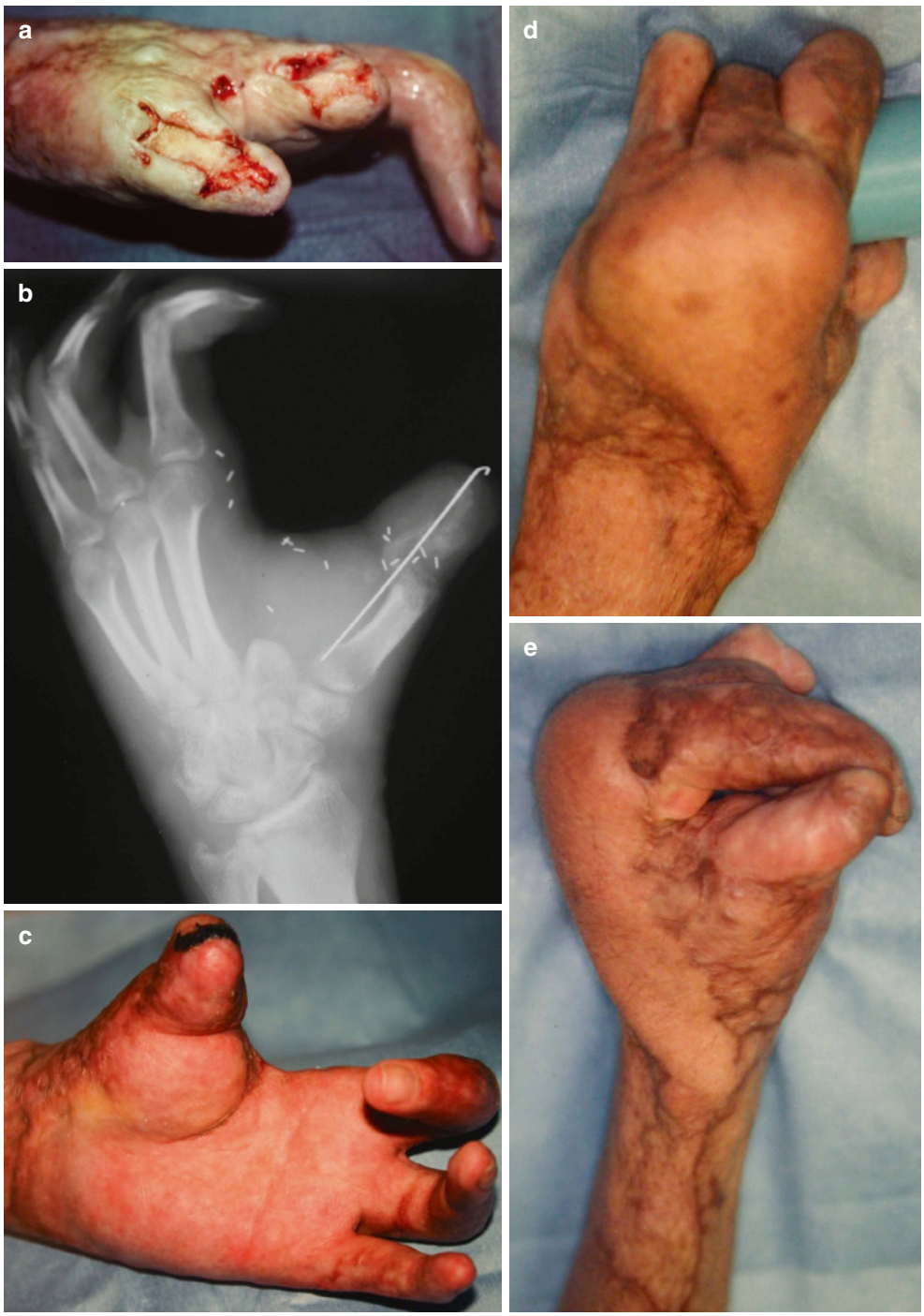


Fig. 47.3 (**a**–**e**) Case 3: Digital

References

1. Tolhurst D, Haeseker B, Zeeman R. The development of the fasciocutaneous flap. PRS. 1983;71:597–605.
2. Cherup L, Zachary L, Gottlieb L, Petti C. The radial forearm skin graft-Fascial Flap. PRS. 1990;85:898–902.
3. Pribaz J, Pelham J. Use of previously burned skin in local fasciocutaneous flaps for upper extremity reconstruction. Ann Plast Surg. 1994;33:272–80.
4. Barret J, Herndon D, McCauley R. Use of previously burned skin as random cutaneous local flaps in pediatric burn reconstruction. Burns. 2002;28:500–2.
5. Hallock GG. The random fasciocutaneous flap for upper extremity coverage. J Hand Surg. 1992;17A:93–101.

Supercharged Supraclavicular Flap

48

V. Q. Vinh

Keywords

Supercharged flap · Supraclavicular artery · Reconstruction · Scar contracture · Island flap · Perforator vessels · Anatomical territory · Vascular anatomy · Flap design · Clinical outcomes · Aesthetic results · Surgical technique

48.1 Background of the Technique

In 1979, Lamberty [1] described the supraclavicular flap on the basis of illustrations taken from Toldt's anatomical atlas, which was published in 1903 [2]. The author showed a vessel that emerged between the sternomastoid and trapezius in the lower part of the posterior triangle and passed over the acromion. After that, Pallua et al. [3] reported in 1997 that they had used this flap successfully in eight cases of neck contracture reconstruction. Since then, the supraclavicular flap has been employed widely. Of the various flap techniques that are available, the supraclavicular flap is excellent in terms of its match with the color and texture of the recipient area, and the simplicity of the operative procedure [4–11]. The author has also successfully applied this flap in the clinic in numerous cases.

The flaps that we employed clinically included not only conventional supraclavicular flaps but also tunnel island flaps, bilateral supraclavicular flaps, and supercharged flaps.

48.2 Anatomical Characteristics and Indication (Fig. 48.1)

1. Ninety percent of the supraclavicular artery can be found from the middle third of the clavicle (Type I) [12]. Ten percent of that can be found from the lateral third of the clavicle (Type II) [12].
2. The supraclavicular artery is usually derived from the transverse cervical artery [12]. Ninety-five percent of the transverse cervical artery arises from the thyrocervical trunk and 5% from the subclavian artery [12].
3. On the body surface, the transverse cervical artery can be identified under the skin as being on average 3.77 cm (3–4.5 cm) from the sternoclavicular joint [12]. The external diameter of the transverse cervical artery is on average 2.9 mm, while the external diameter of the supraclavicular artery is on average 1.17 mm [12].
4. Supraclavicular is indicated for postburn scar contracture in the neck, where a large and thin flap is required and needs to be pliable and match the color for the

V. Q. Vinh (✉)
Department of Plastic and Reconstructive Surgery, Vietnam
National Institute of Burn, Thanh-Tri, Hanoi, Vietnam

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_48

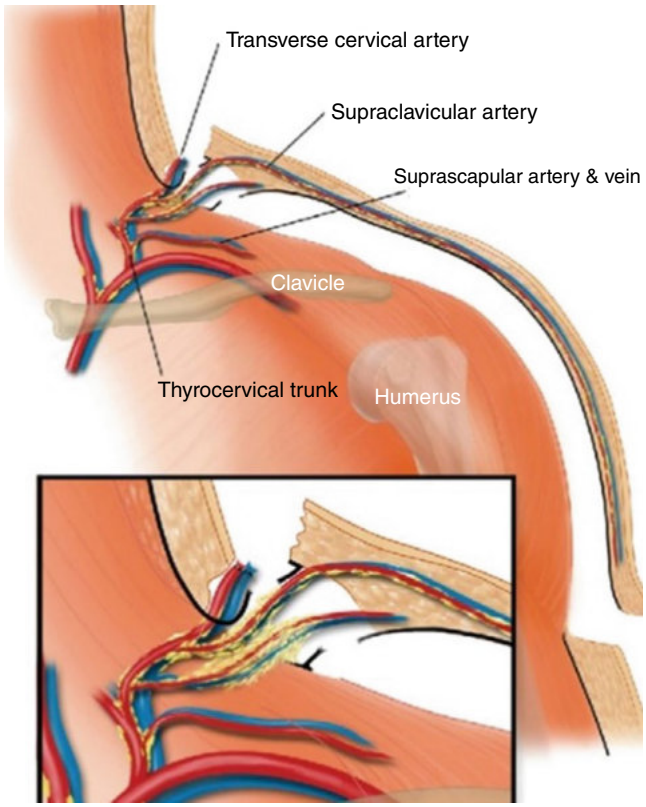


Fig. 48.1 Schematic cross section of the supraclavicular artery flap

reconstruction of contour-sensitive areas. Perforator supercharging can be employed if a much larger flap is needed.

48.3 Supercharged Supraclavicular Flap

The scientific background of expanding the size of skin flaps is based on the classical theory of vascular territory by Cormack G.C. et al. in 1986. According to Cormack and Lamberty [10], vascular territory can be classified into anatomical, dynamic, and potential territory. Anatomical territories are linked with each other through choke vessels. Thus, an anatomical territory, including the main blood flow into a flap, is linked to the next anatomical territory through choke vessels, and these two anatomical territories, including the choke vessels, are the basic flap survival area.

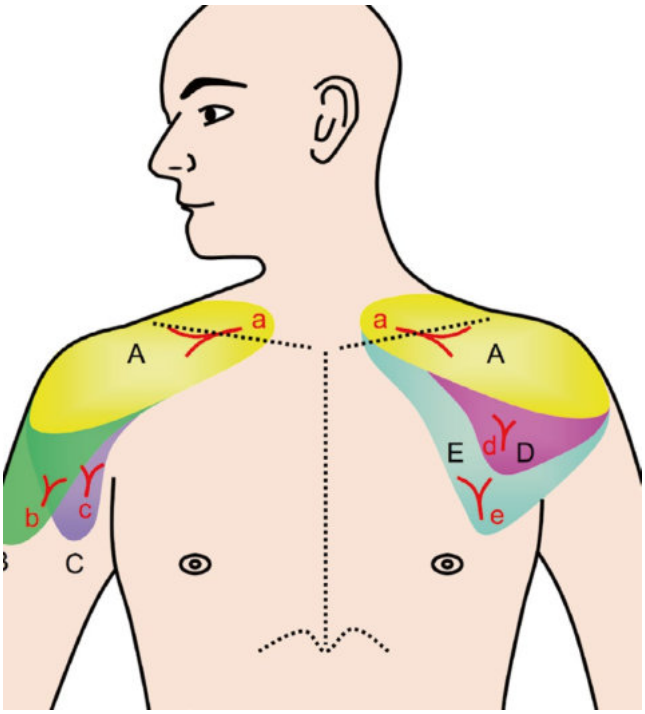


Fig. 48.2 Depiction of the supraclavicular flap and its supercharged versions. (**a**) Supraclavicular flap. (**a**, **b**) Supraclavicular flap supercharged with the posterior circumflex humeral vessel. (**a**, **c**) Supraclavicular flap supercharged with the anterior circumflex humeral vessel. (**a**, **d**) Supraclavicular flap supercharged with the thoracoacromial artery perforator (TAAP). A and E: Supraclavicular flap supercharged with the lateral thoracic artery perforator (LTAP). (**a**) supraclavicular artery. (**b**) posterior circumflex humeral artery. (**c**) anterior circumflex humeral artery. (**d**) TAAP. (**e**) LTAP

For the supraclavicular fasciocutaneous flap, when its main vascular anatomy is regarded as an anatomical territory, to extend the flap size, it is necessary to connect this anatomical territory to potential ones supplied from adjacent arteries such as thoracoacromial artery (TAA), external thoracic artery, and anterior (posterior) circumflex scapular artery (Fig. 48.2).

48.4 Flap Design

Flap size is determined according to the size of the recipient site, and the flap is designed on the patient's shoulder. In clinical practice, we design the flap before scar excision

to define the vascular location of the flap. Following scar excision and release of scar contracture, redetermination of defect size and shape is made to measure the actual shape. The flap is subsequently designed according to this shape and size. The type of design is called "made-to-order."

Identification of the exact location of preoperative axial vessels helps surgeons select and design the flap type with appropriate size and location of lesions, and facilitates the surgery. To define the location and dimension of axial vessels, there are a number of imaging modalities, including handheld Doppler ultrasound, color ultrasound, computed tomographic angiography, digital subtraction angiography, and magnetic resonance angiography. Although computed tomographic angiography and magnetic resonance angiography allow the accurate identification of vascular axis and perforators, handheld Doppler ultrasound is still the first-line option because of its convenience and high efficiency.

48.5 Advantages and Disadvantages of DIEP "Thin" Flap

The supercharged supraclavicular fasciocutaneous flap has proved a powerful option for resurfacing cervical scar with high reliability, rehabilitation of cervicomental movement, and aesthetics. Cervical function returns to normal after the surgery and restores the cervicomental region anatomically. This flap has several benefits:

- Its region is adjacent to the neck area, and it is almost similar in thickness, color, and skin properties (a great advantage in resurfacing the cervicomental area).
- The flap is highly reliable because of supplying from two ends of flap. The blood vessels nourish primarily the constant flap.
- It is used as an island flap, so it has a wide arc of rotation and a large size, offering a large amount of skin for defect coverage.
- Its thickness matches that of the cervicomental region, which helps reconstruct the natural contour of the neck, such as the cervicomental angle.
- Besides its benefits, it also has some drawbacks:
- Limitations in aesthetic outcome at the recipient site.
- A large flap size requires a skin graft at the donor site.
- Normally, for grafted skin to match with the cervicomental skin, many patients agree to have their scar left behind at the donor site. However, for patients with great demand for aesthetics, especially women, indication for using this flap should be taken into consideration carefully.

48.6 Clinical Cases

48.6.1 Case 1

A 33-year-old woman sustained severe flame burns on the neck and chest (Fig. 48.3). Emergency split-thickness skin grafts were applied, but neck scar contractures developed postoperatively. Neck reconstruction using a supercharged supraclavicular flap measuring 28 × 19 cm was designed. The perforator of the thoracoacromial artery (TAA) was chosen to expand the size of the supraclavicular flap. The flap was elevated as an island flap and transferred to cover the defect after removal of the scar. The thoracoacromial vessels were anastomosed with ipsilateral facial vessels. It survived completely, and the functional and aesthetic results were good. The donor site was closed with a split-thickness skin graft.

48.6.2 Case 2

A 25-year-old woman suffered a flame burn and developed hypertrophic scars and scar contractures on the chin and neck 2 years after the wounds had healed (Fig. 48.4). To reconstruct her neck, a supercharged supraclavicular island flap (20 × 16 cm) was planned. The perforator of the posterior circumflex humeral vessel was chosen to expand the size of the supraclavicular flap. After removing the scars, the perforator was dissected carefully. The flap was elevated as an island flap and rotated 180° to cover the defect. The flap survived completely. The donor site was closed with a split-thickness skin graft. The texture and color match of the flap were good, and the patient was satisfied with the cosmetic and functional outcomes.

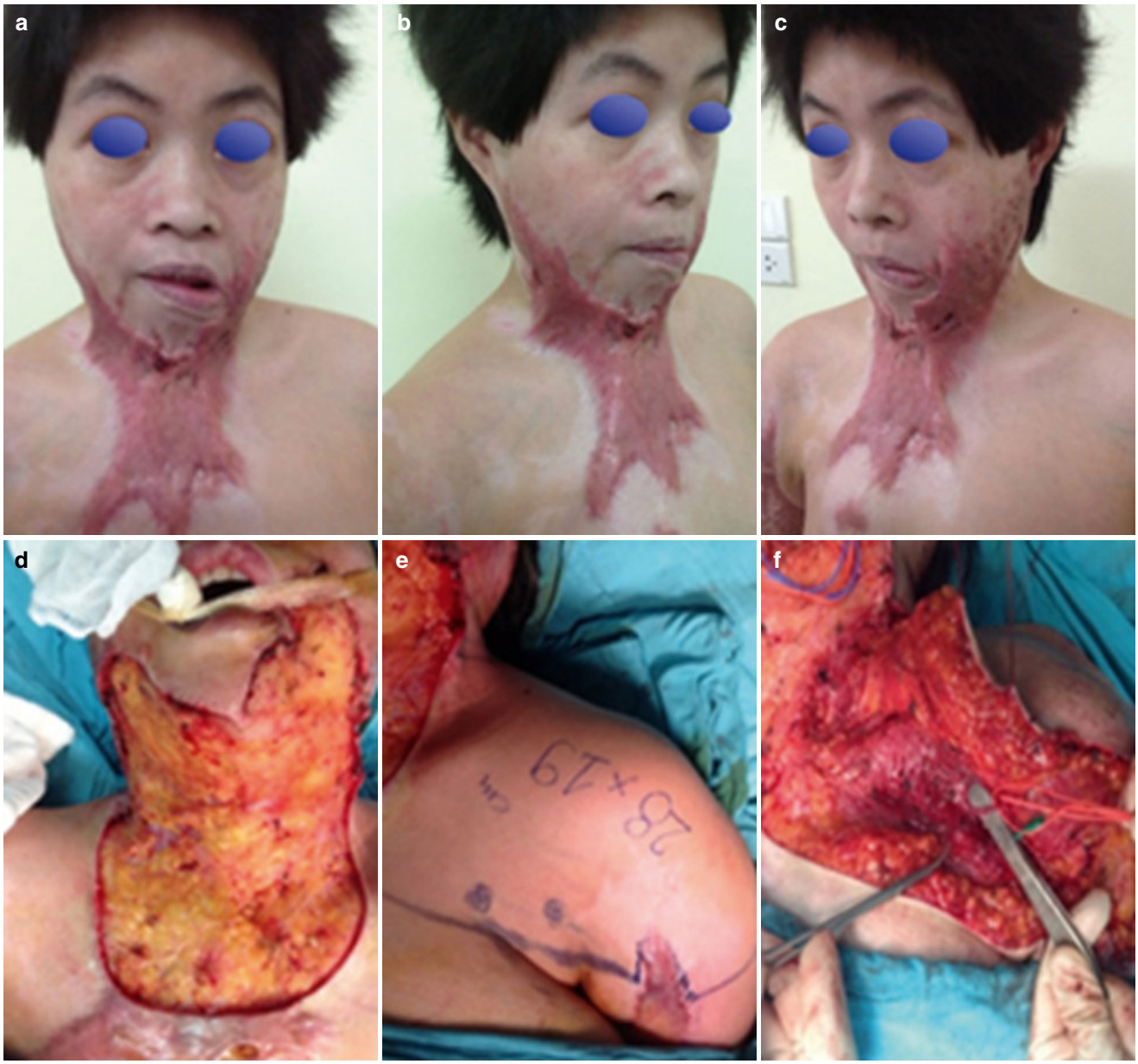


Fig. 48.3 Case 1. Neck reconstruction was carried out with a supercharged supraclavicular island flap measuring 28 × 19 cm. The perforator of the thoracoacromial artery (TAA) was chosen to expand the size of the supraclavicular flap. (**a**–**c**) Preoperative view. (**d**) Removing the neck scar. (**e**) Flap design. (f) Dissecting the perforator of TAA. (**g**–**i**) Immediately after the operation. (**j**–**l**) One-year post-surgery

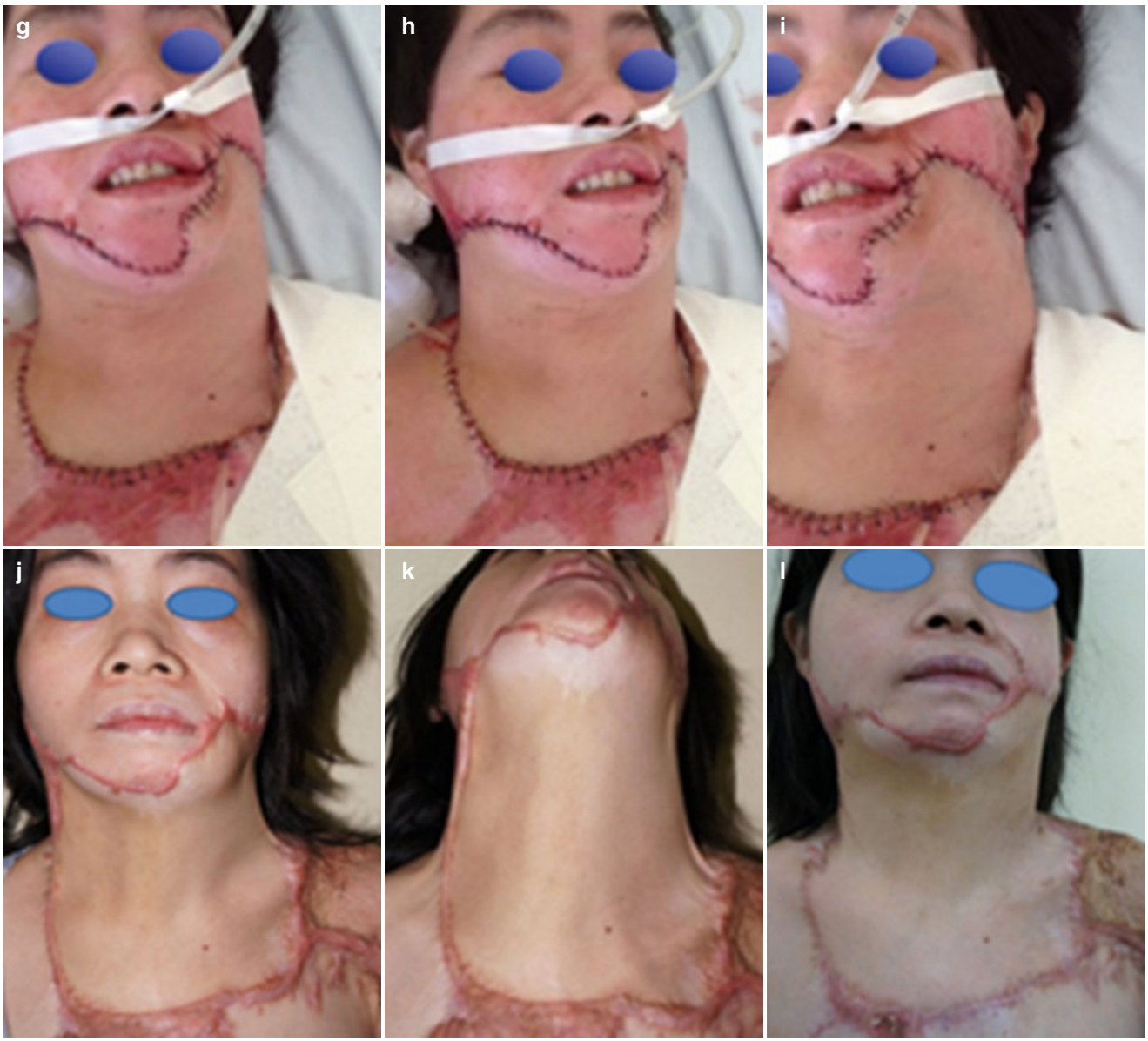


Fig. 48.3 (continued)

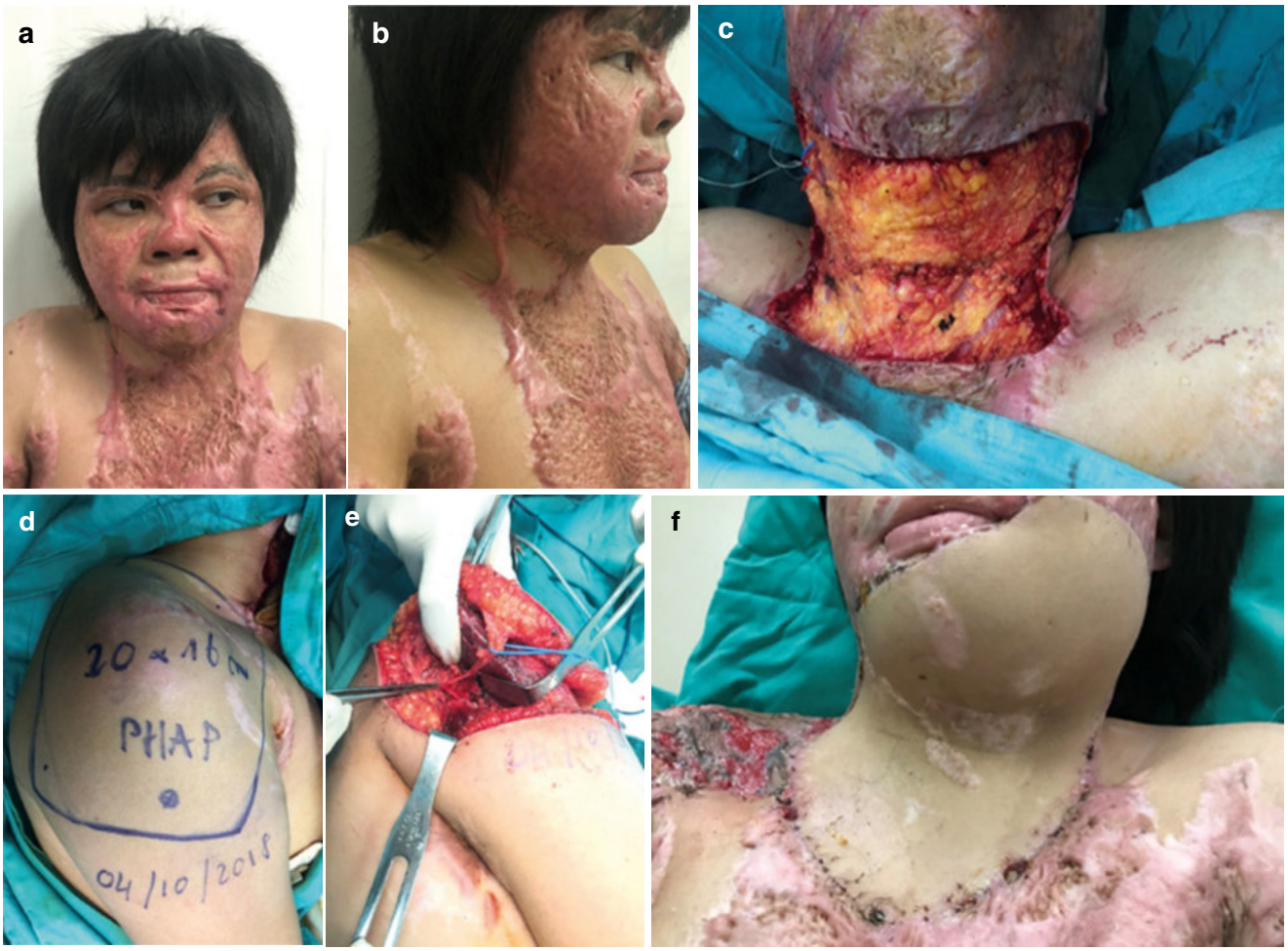


Fig. 48.4 Case 2. Neck reconstruction was carried out with a supercharged supraclavicular island flap measuring 20 x 16 cm. The perforator of the posterior circumflex humeral vessel was chosen to expand the size of the supraclavicular flap. (**a**, **b**) Preoperative view. (**c**) Removing the scar. (**d**) Flap design. (**e**) Dissecting the perforator. (**f**, **g**) View 1 week after the operation. (**h**) View 1 year after the operation

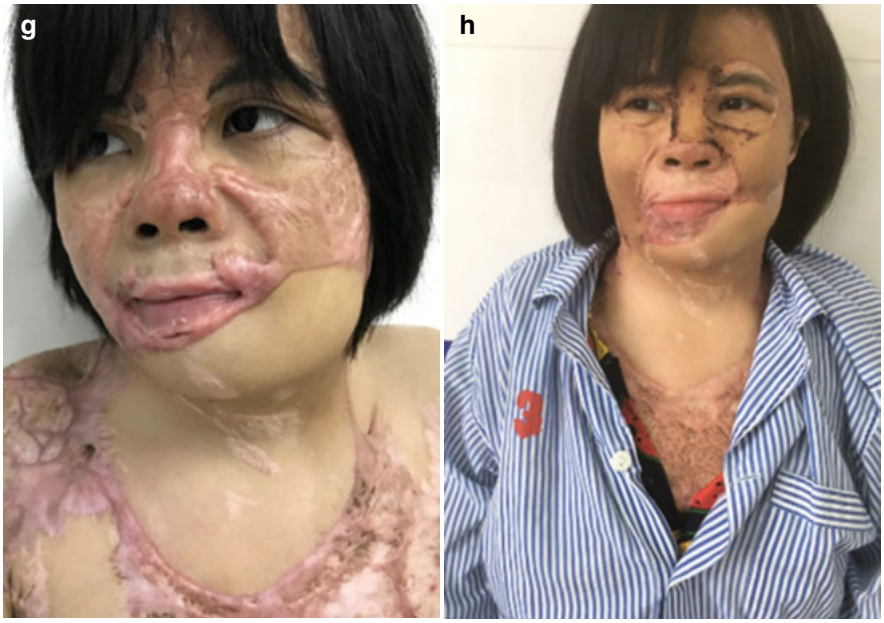


Fig. 48.4 (continued)

References

1. Lamberty BG. The supra-clavicular axial patterned flap. Br J Plast Surg. 1979;32:207.
2. Toldt C. Anatomischer atlas. 3rd ed. Berlin: Urban & Schwarzenberg; 1903.
3. Pallua N, Machens HG. The fasciocutaneous supraclavicular artery Island flap for releasing postburn mentosternal contractures. Plast Reconstr Surg. 1997;99:1878.
4. Hyakusoku H, Gao JH. The "super-thin" flap. Br J Plast Surg. 1994;47:457.
5. Ogawa R, Hyakusoku H. Color Doppler ultrasonography in the planning of microvascular augmented super-thin (SVN: subdermal vascular network) flaps. Plast Reconstr Surg. 2003;112:822.
6. Lamberty BG, Cormack GC. Misconceptions regarding the cervicohumeral flap. Br J Plast Surg. 1983;36:60.
7. Reid CD, Taylor GI. The vascular territory of the acromiothoracic axis. J Plast Surg. 1984;37:194.
8. Baudet J, Martin D. The supraclavicular neurovascular free flap: anatomy and clinical application. In: Brunelli G, editor. Textbook of microsurgery. Milan: Masson; 1988.
9. Pallua N, Noah ME. The tunneled supraclavicular Island flap: an optimized technique for head and neck reconstruction. Plast Reconstr Surg. 2000;105:842.
10. Cormack CG, Lamberty BG. The arterial anatomy of skin flaps. 2nd ed. New York: Churchill Livingstone; 1994.
11. Abe M, Murakami G, Abe S, Sakakura Y, Yajima T. Supraclavicular artery in Japanese: an anatomical basis for the flap using a pedicle containing a cervical, nonperforating cutaneous branch of the superficial cervical artery. Okajimas Folia Anat Jpn. 2000;77:149.
12. Vinh VQ, Van Anh T, Ogawa R, Hyakusoku H. Anatomical and clinical studies of the supraclavicular flap: analysis of 103 flaps used to reconstruct neck scar contractures. Plast Reconstr Surg. 2009;123(5):1471–80.

Superficial Cervical Artery Perforator (SCAP) Flap

49

Rei Ogawa, Shimpei Ono, and Hiko Hyakusoku

Keywords

Superficial cervical artery · SCAP flap · Fasciocutaneous flap · Skin flap · Vascular pedicle · Musculocutaneous flap · Super-charging · Neck contracture · Donor site · Burn injury · Skin graft

The superficial cervical artery (SCA) fasciocutaneous flap was first reported by Nakajima et al. in 1984 [1]. In 1990, Hyakusoku developed it for use as a skin flap [2], and in 1993, we succeeded in harvesting it as a free flap [3]. Since the SCA is now considered to be a "transverse cervical perforator" or "trapezius perforator" (Fig. 49.1), this flap is widely known as the SCA perforator (SCAP) flap [4]. The cranial part of the trapezius muscle is thought to contain the SCA (i.e., the superficial branch of the transverse cervical artery) and the middle part of the dorsal scapular artery (DSA) (i.e., the deep branch of the transverse cervical artery) [4]. Given its wide arc of rotation, the SCAP flap is large enough to cover large defects after removing neck scar contractures.

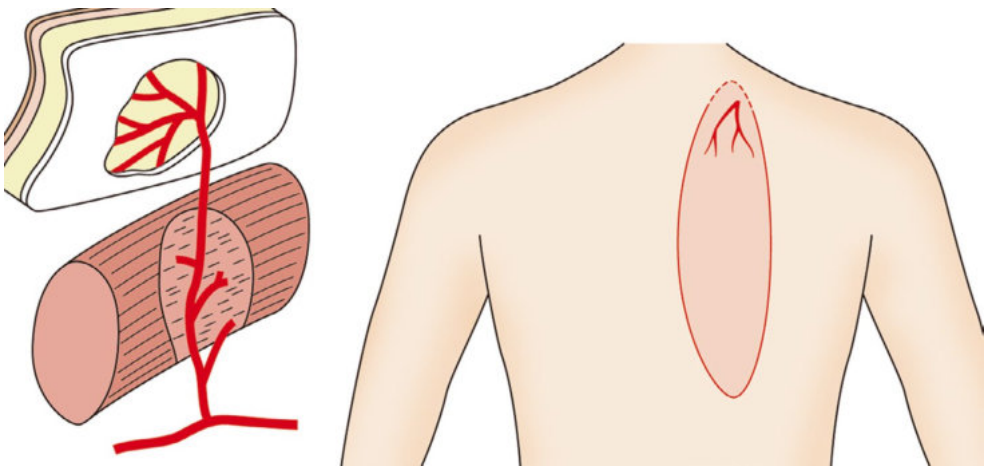


Fig. 49.1 Schematic depiction of the SCAP flap

R. Ogawa (✉) · S. Ono · H. Hyakusoku
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp; s-ono@nms.ac.jp; hyakusok@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_49

49.1 Characteristics of the SCAP Flap

1. SCAP flap shapes can be classified roughly into two types. One is a longitudinal shape that runs vertically from the nape to the medial dorsal region. The other takes an oblique shape and extends from the nape to the scapular area. The maximum flap length is approximately 30 cm. An anatomical study suggests that the minimal survival area for the SCAP flap lies between the first and sixth thoracic vertebrae (Th1 and Th6) [4]. This survival area is likely to be even broader, as we have found that very large flaps between Th1 and Th8 can survive completely on blood flow supplied from the SCAP only.
2. Based on pedicle types, SCAP flaps can be classified into three types, namely, musculocutaneous-pedicled flaps, muscle-pedicled island flaps, and vascular-pedicled island flaps.
3. Since the pedicle diameter exceeds 0.7 mm^4, free SCAP flap transfer is possible in almost all cases.
4. Perforator super-charging is a good option when much larger flaps are needed. In such cases, the dorsal intercostal perforator (DICP, D-ICAP) and the circumflex scapular vessel (CSV) can be employed as super-charging (augmenting) vessels.
5. To obtain "super-thin flaps [5]," the flap can be thinned primarily down to the layer where the subdermal vascular network can be seen through the minimal fat layer. The vascular pedicle area should not be thinned.

49.2 Tips for Harvesting the SCAP Flap

1. The SCA can be identified on the cranial region of the trapezius muscle at the nape. When the pedicle is employed as a vascular pedicle, the SCA should be identified both on and under the muscle. When the pedicle serves as a musculocutaneous or muscle pedicle, it is not necessary to identify the SCA on the muscle.
2. During surgery, care should be taken to avoid injuring the accessory nerve.
3. When a muscle or musculocutaneous pedicle is employed, the flap can be elevated with a small amount of muscle. Musculocutaneous- and muscle-pedicled flaps have the advantage that they are easy to harvest and have reliable venous return. However, pedicled flaps are also limited by the fact that their rotation arc is limited.
4. The donor site should be covered with a split-thickness skin graft or sutured primarily.

49.3 Clinical Cases

49.3.1 Case 1

This 19-year-old male sustained an extensive burn on the upper body and underwent neck contracture release and reconstruction during childhood (Fig. 49.2). However, as the patient grew, the remnant lower neck contracture tightened. Therefore, we planned another reconstruction. A dorsal intercostal perforator (DICP, D-ICAP)-supercharged SCAP propeller flap was designed on his left back. The flap size was 30 × 8 cm. The 7th DICP was attached to the distal portion of the flap, and the flap was harvested with a vascular pedicle of SCAP.

49.3.2 Case 2

A 37-year-old woman sustained a flame burn due to a suicide attempt (Fig. 49.3). Free split-thickness skin sheets had been grafted onto her neck in the Critical Care Medicine Center. However, she subsequently developed a severe neck contracture. We removed the contracture and applied a left SCAP flap that had been super-charged with the contralateral CSVs. The flap measured 28 × 20 cm. It was harvested as a super-thin flap, and the CSVs were anastomosed to the right facial vessels.

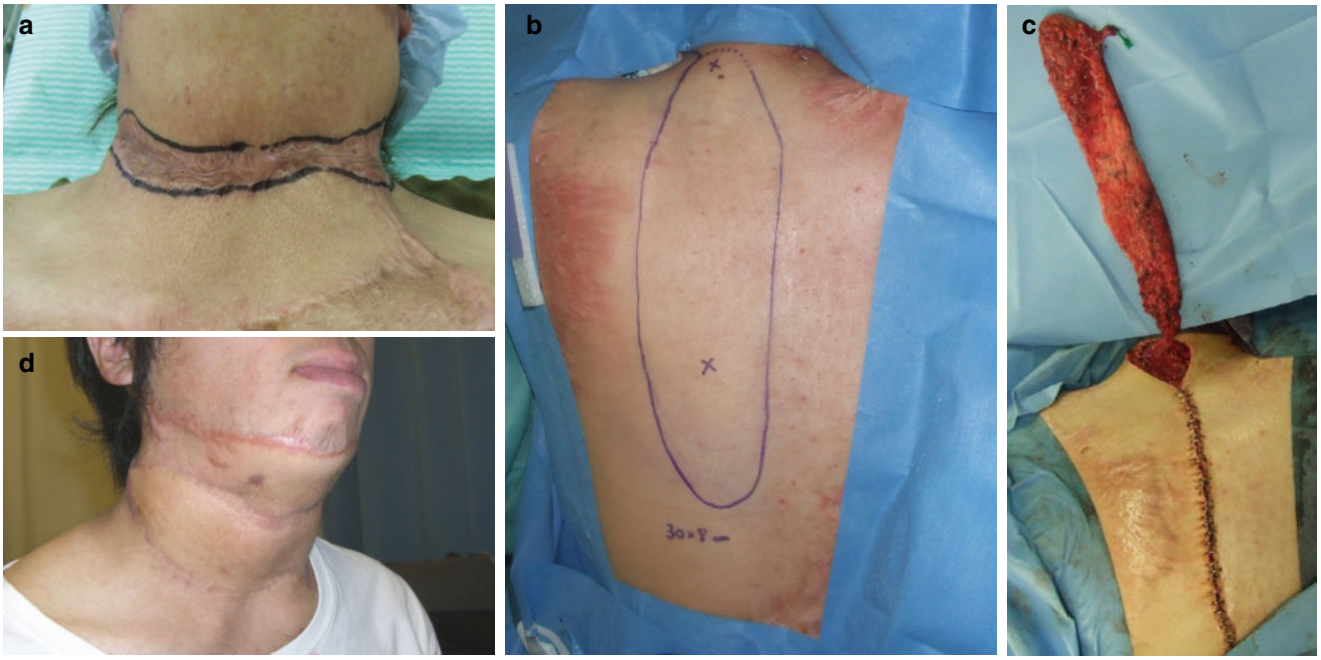


Fig. 49.2 (**a**–**d**) Case 1

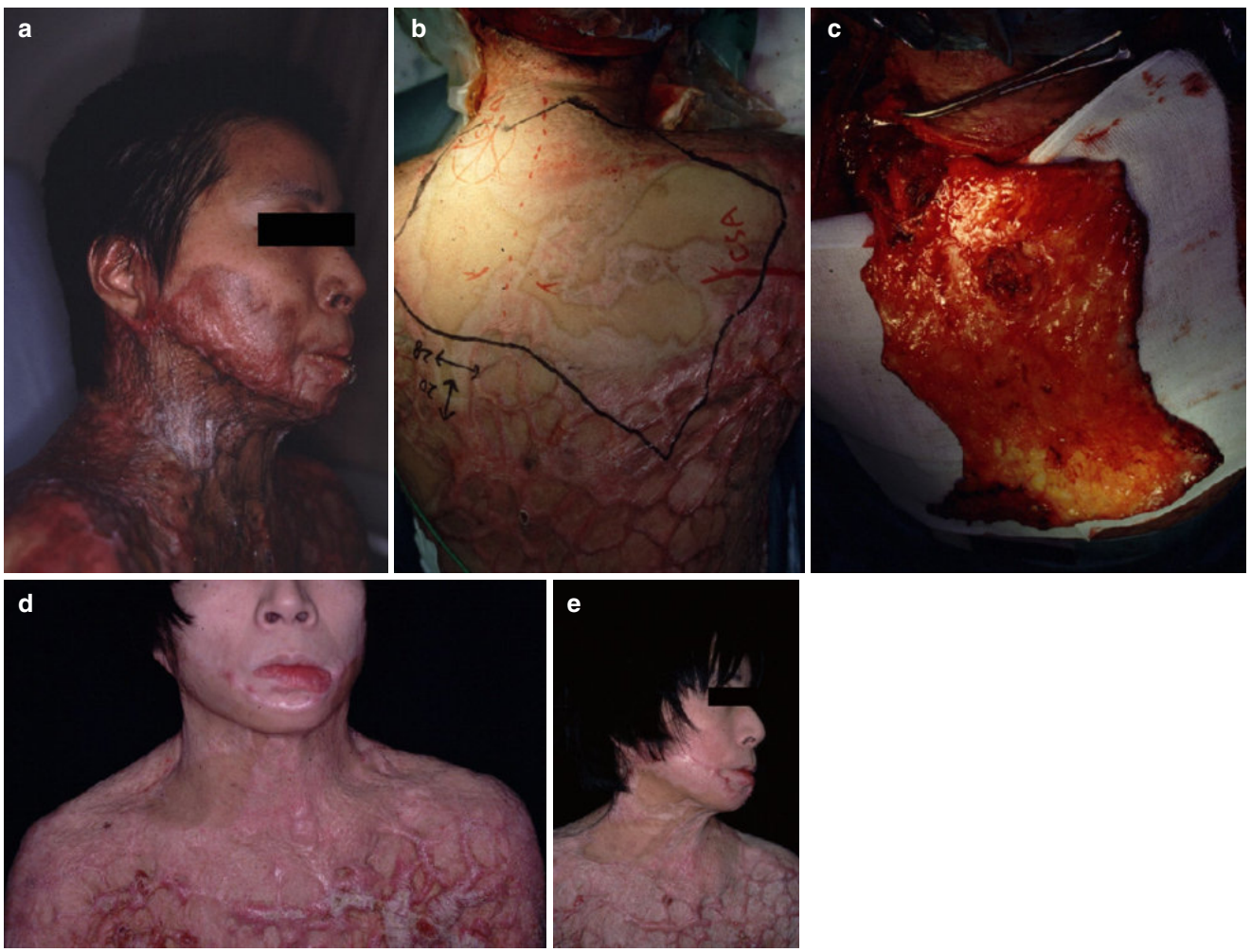


Fig. 49.3 (**a**–**e**) Case 2

49.3.3 Case 3

A 22-year-old man developed a severe postburn neck contracture that was reconstructed with bilateral symmetrical musculocutaneous-pedicled SCAP skin flaps that measured 32 × 12 cm (Fig. 49.4). After flap transposition, the donor sites were closed with meshed skin grafts. The flaps survived completely, the scar contracture was removed, and there have been no subsequent complications.

49.3.4 Case 4

A 40-year-old man who underwent an operation for a brain tumor and was subsequently treated with radiotherapy developed an infection that induced a skin defect in the parietal region, exposing the calvarial bone (Fig. 49.5). The defect was reconstructed with a teardrop-shaped vascular-pedicled SCAP skin flap measuring 30 × 12 cm. Superficial cervical vessels, surrounded by a minimal amount of trapezius muscle, served as the pedicle. The excess skin around the pedicle at the nape was excised 3 months after the primary operation.

49.3.5 Case 5

A 7-year-old girl developed a right axillary contracture after sustaining a burn injury. The contracture was released by cutaneous-pedicled SCAP skin flaps (Fig. 49.6). The range of motion of the shoulder recovered completely after rehabilitation. Several years later, the patient's right breast developed normally without any contractures.

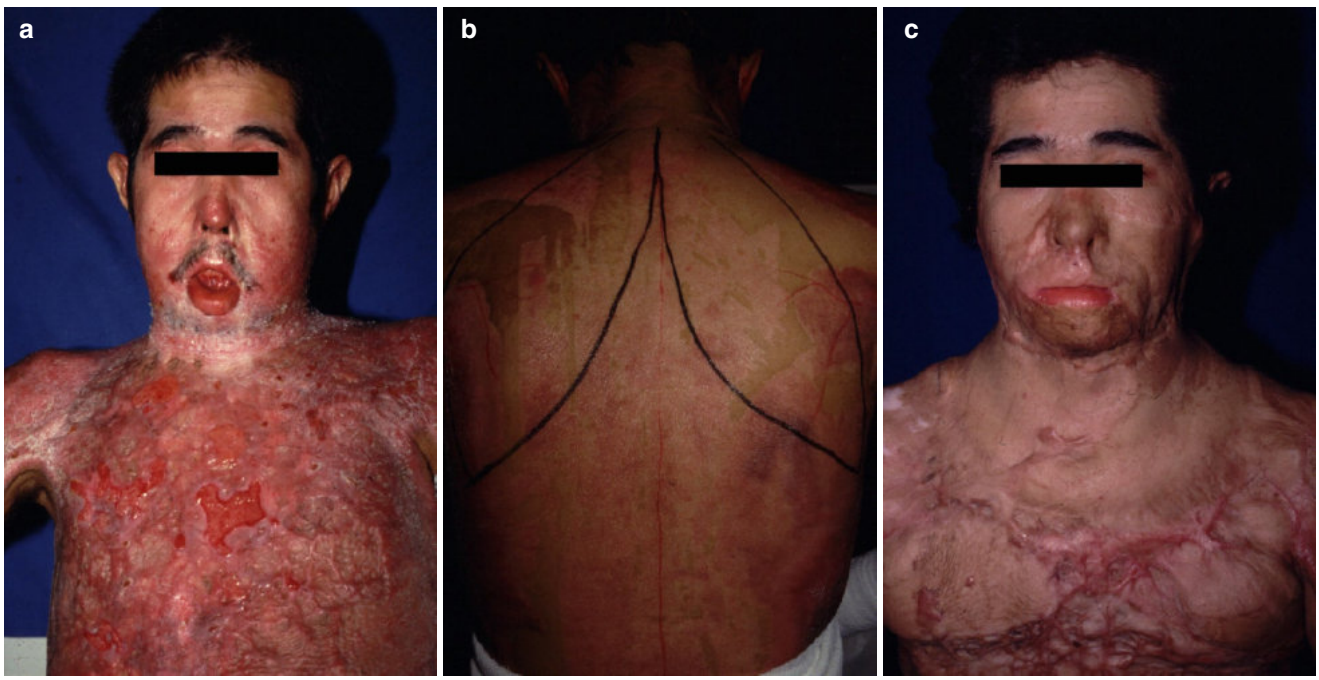


Fig. 49.4 (**a**–**c**) Case 3

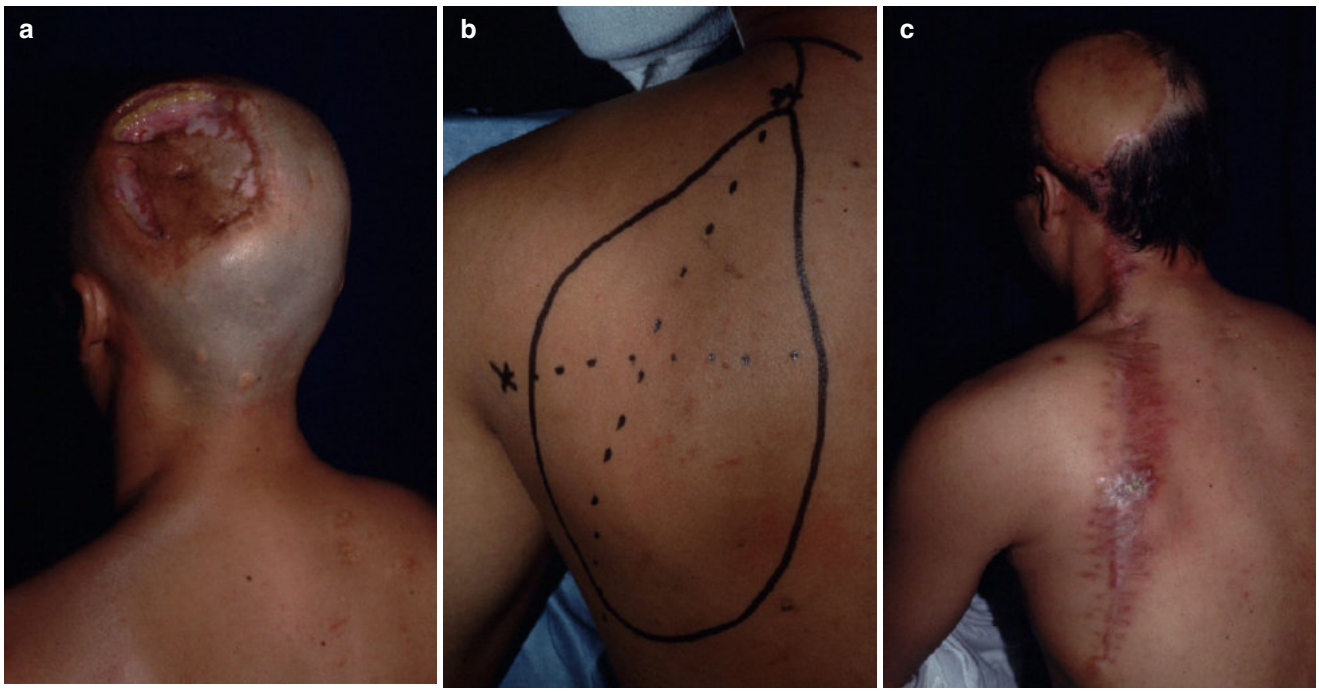


Fig. 49.5 (**a**–**c**) Case 4

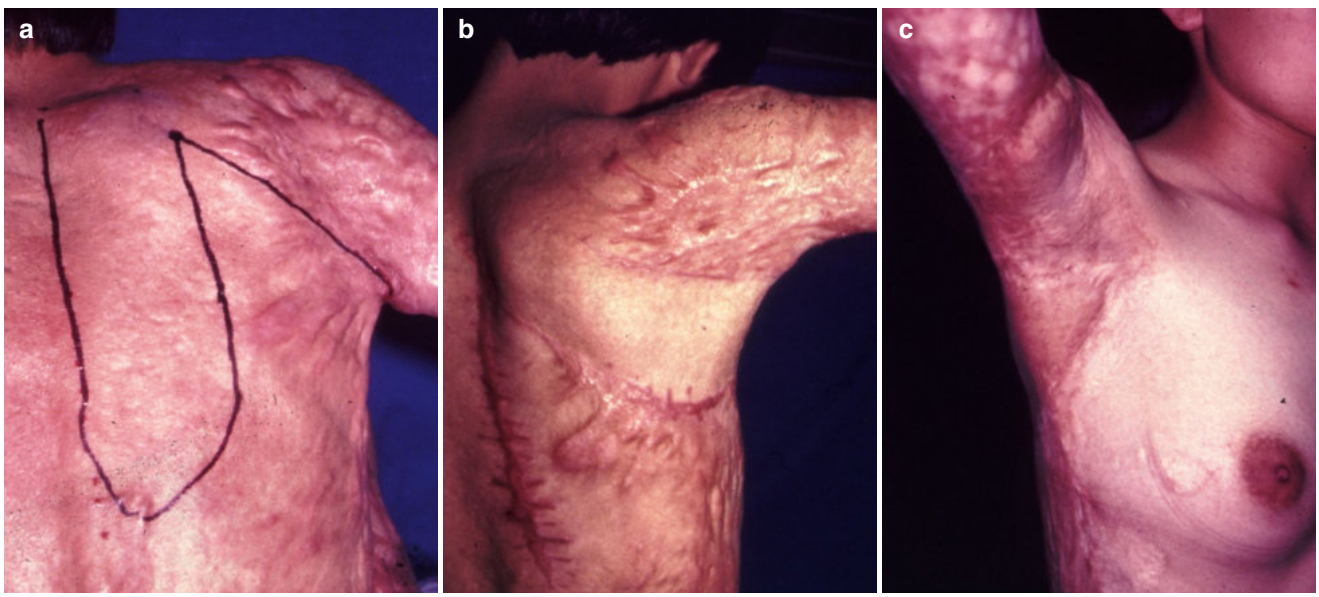


Fig. 49.6 (**a**–**c**) Case 5

References

1. Nakajima H, Fujino T. Island fasciocutaneous flaps of the dorsal trunk and their application to myocutaneous flaps. Keio J Med. 1984;33:59–82.
2. Hyakusoku H, Yoshida H, Okubo M, et al. Superficial artery skin flaps. Plast Reconstr Surg. 1990;86:33–8.
3. Hyakusoku H, Takizawa Y, Murakami M. Versatility of the free or pedicled superficial cervical artery skin flaps in head and neck burns. Burns. 1993;19:168–73.
4. Ogawa R, Murakami M, Vinh VQ, Hyakusoku H. Clinical and anatomical study of superficial cervical artery flaps: retrospective study of reconstructions with 41 flaps and the feasibility of harvesting them as perforator flaps. Plast Reconstr Surg. 2006;118(1):95–101.
5. Hyakusoku H, Gao JH. The "super-thin" flap. Br J Plast Surg. 1994;47(7):457–64.

Super-Thin Flap in Japan

50

Hiko Hyakusoku, Rei Ogawa, and Hiroshi Mizuno

Keywords

Super-thin flap · Perforator flaps · Flap-thinning techniques · Reconstructive surgery · Skin defect Anatomical site · Subdermal-vascular network · Burn injuries · Flap survival · Microvascular augmentation Donor site

50.1 Background of the Super-Thin Flap

Along with the recent development of perforator flaps, thin flaps are now coming into widespread use. Over the past 30 years, our team has developed flap-thinning techniques, allowing us to harvest extremely thin but large flaps. These flaps are mainly used to reconstruct large burn-injured areas.

Thin flaps can be defined as flaps whose thickness is 1 cm or less. They can be categorized as naturally thin flaps and intentionally thinned flaps. Naturally thin flaps are influenced by the anatomical site from which they are harvested (e.g., the chest or the groin) and the body build of the patient (e.g., body mass index). This chapter will focus on intentionally thinned flaps, which can be classified as "thin flaps" (~1 cm thick) and "super-thin flaps" (<1 cm thick).

Thin flaps were first proposed by Colson in 1966 [1] and developed further by Thomas in 1980 [2]. In 1982, an antecedent of our super-thin flap was devised in China, and the Chinese plastic surgeon Situ reported the first super-thin flap in 1986 [3]. His idea seems to have been influenced by the preserved subdermal vascular network (PSVN) full-thickness skin graft that was reported by a Japanese plastic surgeon Tsukada [4]. However, although vascular pedicles were attached to the grafted skin in the Chinese cases, many Chinese plastic surgeons experienced distal epithelial necrosis. In 1990, Jian-Hua Gao from the First Military Medical University in Guangzhou, China, visited Nippon Medical School in Tokyo as a foreign fellow and discussed these and other clinical experiences with one of us, Hyakusoku. A typical case is shown in Fig. 50.1. These discussions led Gao and Hyakusoku to conduct animal experiments in an effort to develop safer procedures. Subsequently, Hyakusoku and the other authors worked to develop super-thin flaps for clinical use. Their super-thin flap was first reported in 1994 [5, 6]. Gao et al. [7, 8] also reported their animal experiments in 1999 and 2000 in Japanese. In 2004, these experiments and new anatomical findings were published in English [9].

H. Hyakusoku · R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: hyakusok@nms.ac.jp; r.ogawa@nms.ac.jp

H. Mizuno
Department of Plastic and Reconstructive Surgery, Juntendo University School of Medicine, Tokyo, Japan
e-mail: hmizuno@juntendo.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_50

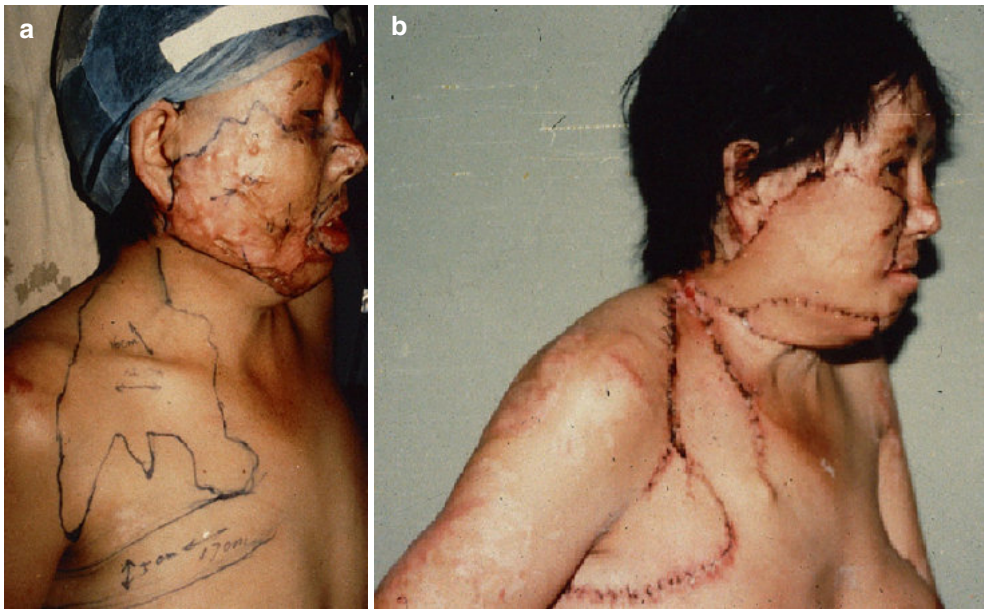


Fig. 50.1 An early super-thin flap case in China. This case was presented by Gao. The surgery was conducted by Zhiyi Yang around 1990 at the 401 PLA hospital in China. Since the flap pedicle seems to have perforators coming from the occipital artery, this flap is considered to be an occipito-cervico-pectoral (OCP) flap [5]. Remarkably, despite the complicated shape of the flap, the flap survived completely. This case propelled the author Hyakusoku to develop the current sophisticated super-thin flap. (**a**) Preoperative design. (**b**) Postoperative view

50.2 Characteristics of Super-Thin Flaps

1. "Super-thin flap" is a generic name; it is more anatomically precise to call this flap the subdermal vascular network (SVN) flap. A key feature of this flap is its extreme thinness: it is primarily thinned down to the layer where the SVN (i.e., the subdermal plexus) can be seen through the minimal fat layer (Fig. 50.2).
2. Theoretically, super-thin flaps can be taken from anywhere in the body. However, most of our reconstructions have been extensive postburn scar contracture cases, where extremely large but thin flaps are needed to reconstruct wide and contour-sensitive areas such as the face, neck, and hands. For this reason, our flaps are mainly harvested from the back and the chest (Fig. 50.3).
3. Primary flap thinning not only generates less bulky flaps; it also prevents blood perfusion steal by adipose tissues. This effectively extends the flap-survival area [10, 11].

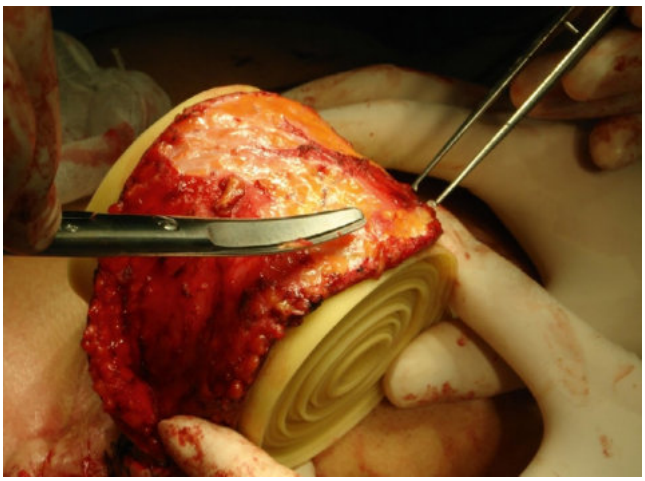


Fig. 50.2 Thinning of the flap. To obtain the super-thin flap, it is thinned primarily with curved scissors until the subdermal vascular network can be seen through the minimal fat layer

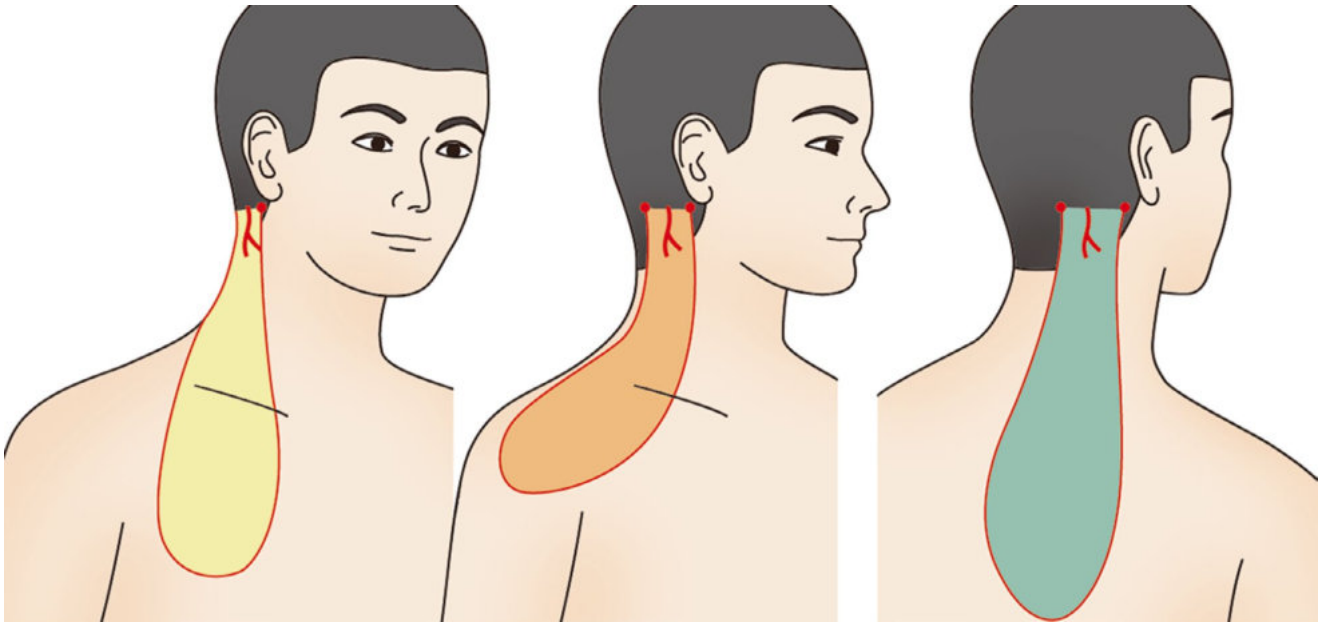


Fig. 50.3 Schematic depiction of common super-thin-flap donor sites

4. When supercharging vessels are attached to the distal area of the flap, extremely large and long flaps can be harvested [12]. These flaps can be termed "perforator-supercharged super-thin flaps." This type of flap is discussed in another chapter of this book.

50.3 Specific Skills Needed to Generate Super-Thin Flaps

Before surgery, the flap is designed to match the shape of the recipient site. The requirement for perforator supercharging is also determined. This judgment should be based on the results of anatomical studies [9, 13] that suggest the most efficient flaps have a pedicle width/flap width/flap length ratio of 1:2:4. This 1:2:4 theory suggests that, in the absence of supercharging, the size of super-thin flaps is limited.

The flap is elevated from the periphery. Since the flap is essentially a transposition flap, it is crucial to stop the dissection as soon as the flap reaches the recipient site. This maximizes the blood flow to the skin flap.

After the flap is completely elevated, it is thinned down with curved scissors until the SVN can be seen through the minimal fat layer (see Fig. 50.2).

After debulking, we also sometimes place a suction drain under the flap and apply slight pressure to prevent subdermal hematoma formation.

After the donor site is covered with a split-thickness skin graft or closed primarily, the thinned flap is rotated and placed onto the recipient site.

50.4 Clinical Cases

50.4.1 Case 1

This 72-year-old woman sustained a third-degree burn on the neck and a second-degree burn on the face and the right hand (Fig. 50.4). The burned areas were reconstructed with a classical cervico-pectoral (CP) super-thin flap with a transverse cervical perforator. The CP flap size was determined on the basis of the skin defect size (20 × 10 cm). The bottom of the flap was on the fourth rib. The donor site on the anterior chest was partially closed with a skin graft. Flap viability was never in question.

50.4.2 Case 2

A 30-year-old man developed postburn scar contractures on his lower lip and chin (Fig. 50.5). After contracture resection, the skin defect was reconstructed with a 31 × 10 cm occipito-cervico-dorsal super-thin flap. The flap donor site was closed with a small flap that was designed next to the main flap. Distal epithelial necrosis was observed, but it epithelialized completely without the need for any salvage skin grafting.

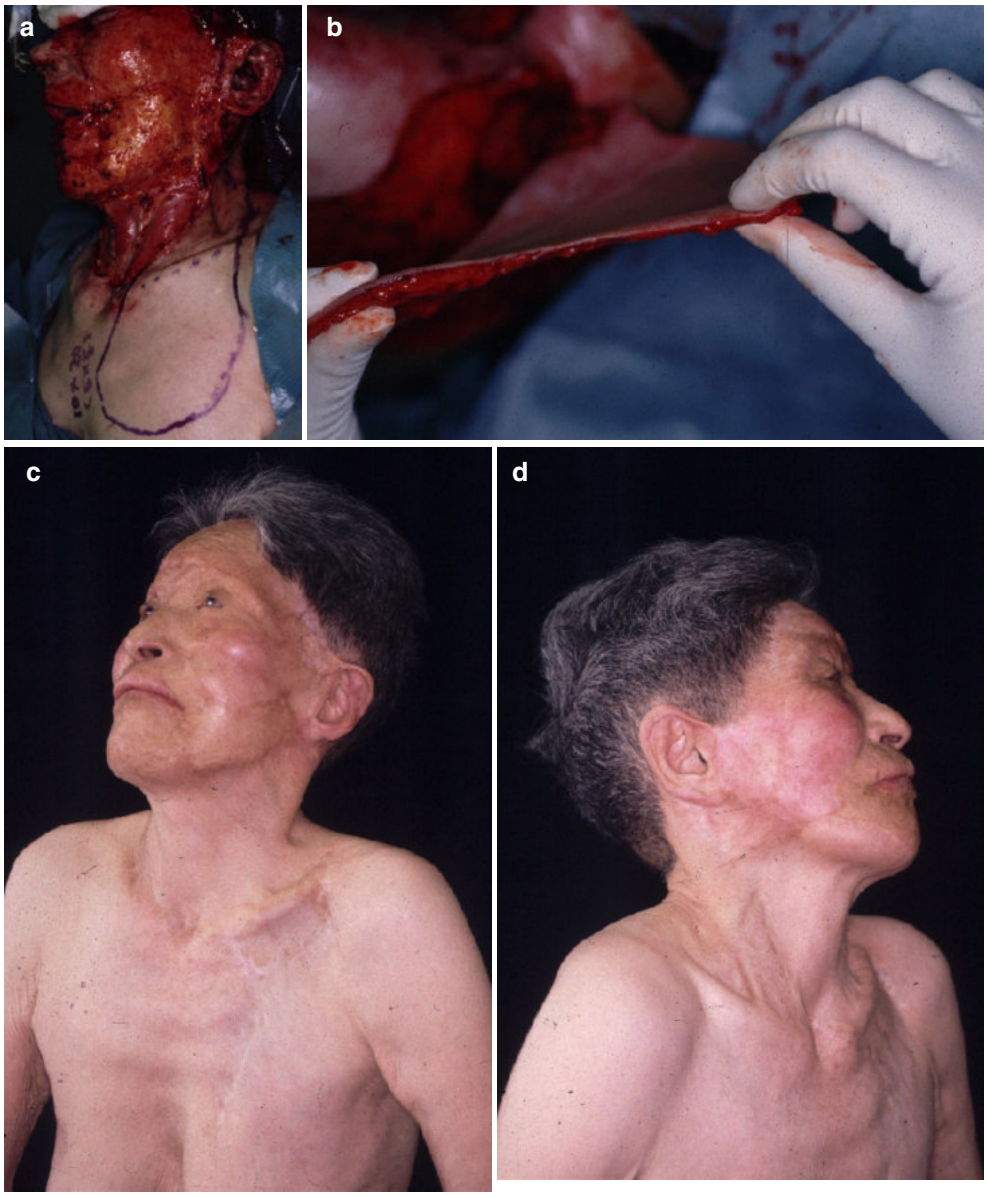


Fig. 50.4 Case 1. (**a**) Preoperative design. (**b**) The thickness of the flap. (**c**, **d**) View at 1 year after surgery

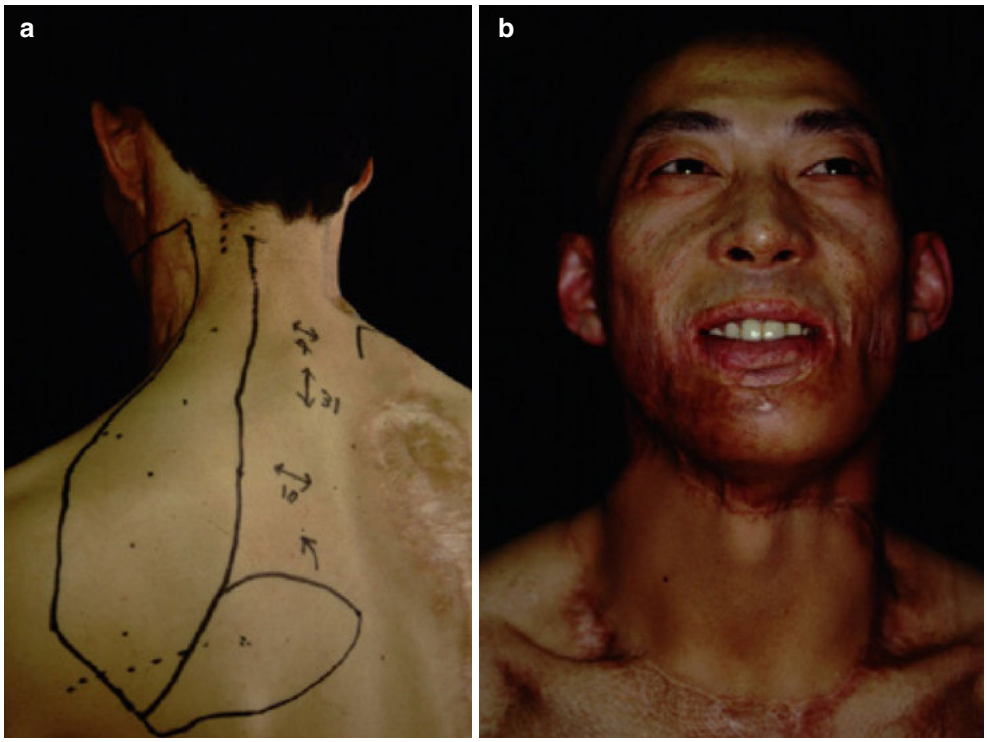


Fig. 50.5 Case 2. (**a**) Preoperative design. (**b**) View at 1 year after surgery

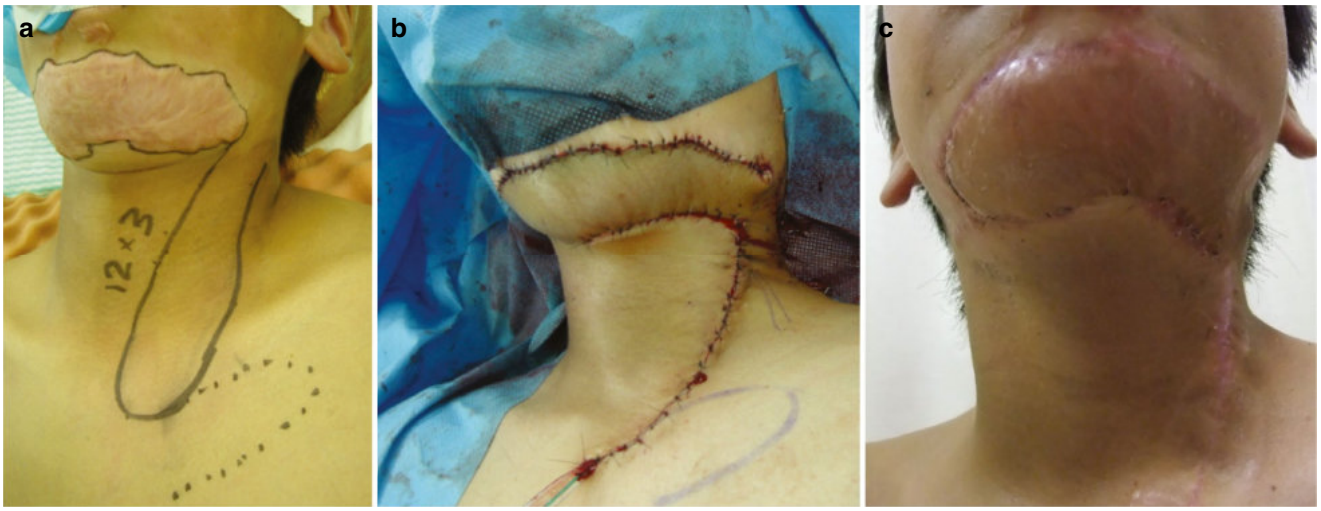


Fig. 50.6 Case 3. (**a**) Preoperative design. (**b**) View immediately after surgery. (**c**) View 3 months after surgery

50.4.3 Case 3

A 14-year-old boy developed hypertrophic scars on his chin after sustaining a facial burn (Fig. 50.6). After resecting the scars, the skin defect was reconstructed with an occipito-cervico-pectoral (OCP) super-thin flap. The flap donor site was closed primarily.

50.4.4 Case 4

A 67-year-old man was exposed to a mixture of caustic soda and 50% sulfuric acid and sustained chemical injuries that were treated conservatively and then developed into scar contractures (Fig. 50.7). A large 19 × 6 cm skin-pedicled flap was elevated from the left pectoral area. We had planned to

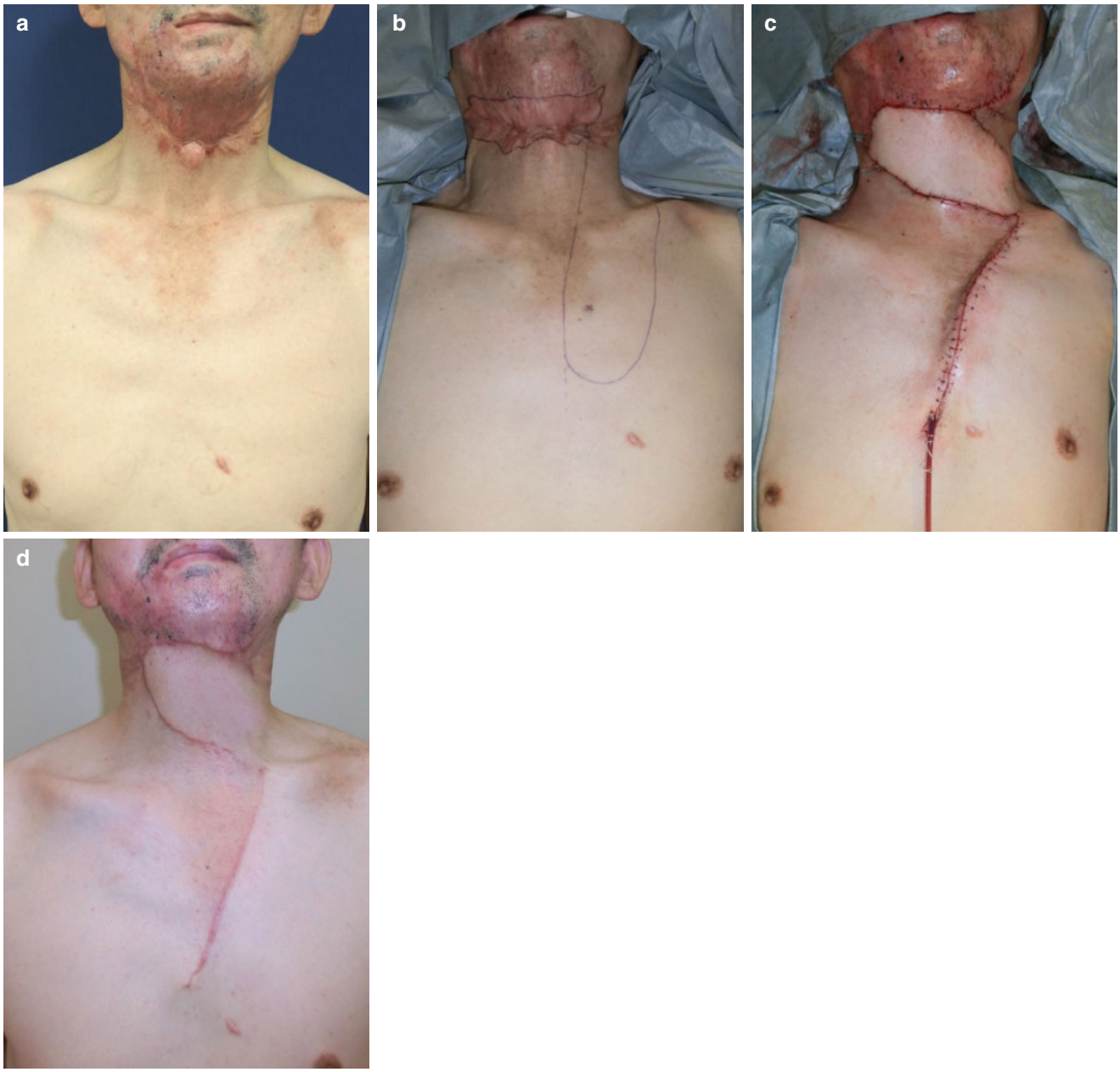


Fig. 50.7 Case 4. (**a**) Preoperative view. (**b**) Flap design. (**c**) View immediately after surgery. (**d**) View 6 months after surgery. (*From* Kondo et al. [14]; *with permission*)

anastomose a second intercostal perforator branch to the peripheral portion of the flap but could not confirm the perforator intraoperatively. We had no choice but to lift the flap without adding the perforator branch. To ensure flap survival, the skin pedicle was dissected as little as possible, and the perforator branch of the platysma muscle was preserved as much as possible. The flap survived completely. The postoperative course was uneventful, and there was little postoperative scarring. Six months after the operation, the neck contracture and the patient's range of neck motion had improved markedly.

50.4.5 Case 5

A 38-year-old man sustained a heat press injury to his left hand that formed a burn ulcer (Fig. 50.8). After debridement, the ulcer was deep, and the tendon was exposed. Thirteen days after the debridement, an ipsilateral intercostal artery perforator (ICAP, ICP)-pedicled super-thin flap measuring 20 × 13 cm was harvested to cover the dorsum of the hand. The eighth posterior intercostal perforator (P-ICAP, PICP) was included in the skin pedicle, and the flap was used as a distant flap. The donor site was closed primarily.

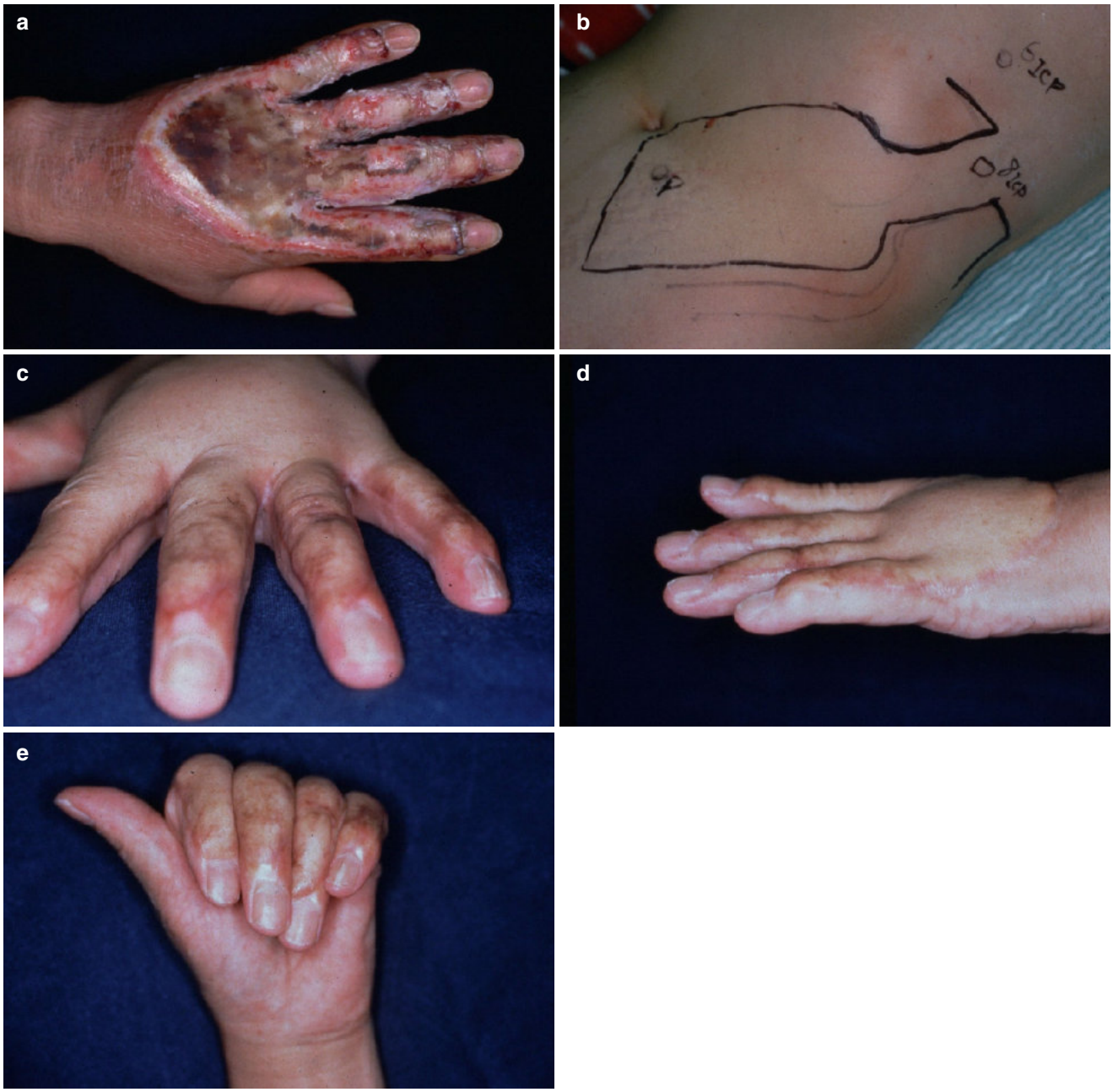


Fig. 50.8 Case 5. (**a**) Preoperative view. (**b**) Flap design. (**c**–**e**) View 1 year after surgery

References

1. Colson P, Janvier H. Le degraissage primaire et total des lambeaux d'autoplastic a distance. Ann Chir Plast. 1966;11:11–20.
2. Thomas CV. Thin flaps. Plast Reconstr Surg. 1980;65:747–52.
3. Situ P. Pedicled flap with subdermal vascular network. Acad J First Milit Med Coll PLA (Chinese). 1986;6:60.
4. Tsukada S. Transfer of free skin grafts with a preserved subcutaneous vascular network. Ann Plast Surg. 1980;4:500–6.
5. Hyakusoku H, Gao JH. The "super-thin" flap. Br J Plast Surg. 1994;47:457–64.
6. Hyakusoku H, Pennington DG, Gao JH. Microvascular augmentation of the super-thin occipito-cervico-dorsal flap. Br J Plast Surg. 1994;47:465–9.
7. Gao JH, Hyakusoku H, Aoki R, et al. An experimental study on the survival of random pattern flaps with a narrow skin pedicle in pigs; comparison of survival and blood supply in thick flaps with various pedicle widths. J Jpn Plast Reconstr Surg. 1999;19:553–9.
8. Gao JH, Hyakusoku H, Aoki R, et al. A study of survival on random pattern flaps with narrow pedicle; comparison in the thinned flaps with various pedicle width and between thinned flap and conventional thick flaps. J Jpn Plast Reconstr Surg. 2000;20:233–8.

9. Ogawa R, Hyakusoku H, Murakami M, Gao JH. Clinical and basic research on occipito-cervico-dorsal flaps: including a study of the anatomical territories of dorsal trunk vessels. Plast Reconstr Surg. 2004;113(7):1923–33.
10. Chetboun A, Masquelet AC. Experimental animal model proving the benefit of primary defatting of full-thickness random-pattern skin flaps by suppressing "perfusion steal". Plast Reconstr Surg. 2007;120(6):1496–502.
11. Ogawa R, Hyakusoku H. Flap thinning technique: the effect of primary flap defatting. Plast Reconstr Surg. 2008;122(3):987–8.
12. Ogawa R, Hyakusoku H, Murakami M. Color Doppler ultrasonography in the planning of microvascular augmented "super-thin" flaps. Plast Reconstr Surg. 2003;112(3):822–8.
13. Vinh VQ, Ogawa R, Iwakiri I, Hyakusoku H, Tanuma K. Clinical and anatomical study of cervicopectoral superthin flaps. Plast Reconstr Surg. 2007;119(5):1464–71.
14. Kondo A, Dohi T, Izumi N, Ochi T, Ogawa R. Anterior neck-scar contracture reconstruction using a long skin-pedicled flap. Plast Reconstr Surg Glob Open. 2021;9(2):e3404.

Super-Thin Flaps

51

Jianhua Gao, Feng Lu, and Yi Yuan

Keywords

Hypertrophic scar · Tissue expander · Internal thoracic artery · Perforator flap · Unify principle.

51.1 Background of the Technique

The concept of thin flaps vascularized by the subdermal vascular network was first described by Situ [1] in 1986. Since then, various types of super-thin flaps have been applied successfully in China and Japan. Basic research were also performed to better explain the excessive survival mechanism [2–5]. The authors have developed these thin flaps, called "super-thin flaps," which were first reported in 1994 [6]. Based on these successful clinical uses, supercharged super-thin flaps [7] and preexpanded super-thin flaps [8] were also reported and are now widely used. Our ultimate goal—development of "thin and reliable flaps"—is a unifying principle between "super-thin flaps" and perforator flaps.

51.2 Classification

In general, super-thin flaps can be classified into three types based on their blood supply (Fig. 51.1):

1. Random pattern super-thin flap: The length:width ratio should be restricted to approximately 1:1.5; no excessive survival can be achieved.
2. Axial pattern super-thin flap: For example, free super-thin anterolateral thigh flap and free DIEP super-thin deep inferior epigastric perforator flap are classified into this type.
3. Super-thin perforator flap: Introduced in 1994 by the authors, various types of "super-thin perforator flaps" have since been applied successfully. Preoperative Doppler or multidetector low-dose CT (3c) examinations are very helpful for identifying perforators. This type includes supercharged and preexpanded super-thin perforator flaps. Theoretically, all distant parts of perforator flaps can be super-thinned and harvested from anywhere in the body.

J. Gao · Y. Yuan (✉)
Department of Plastic and Reconstructive Surgery, Nanfang Hospital, Southern Medical University, Guangzhou, China

F. Lu
Department of Plastic and Reconstructive Surgery, Southern Medical University, Guangzhou, China

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_51

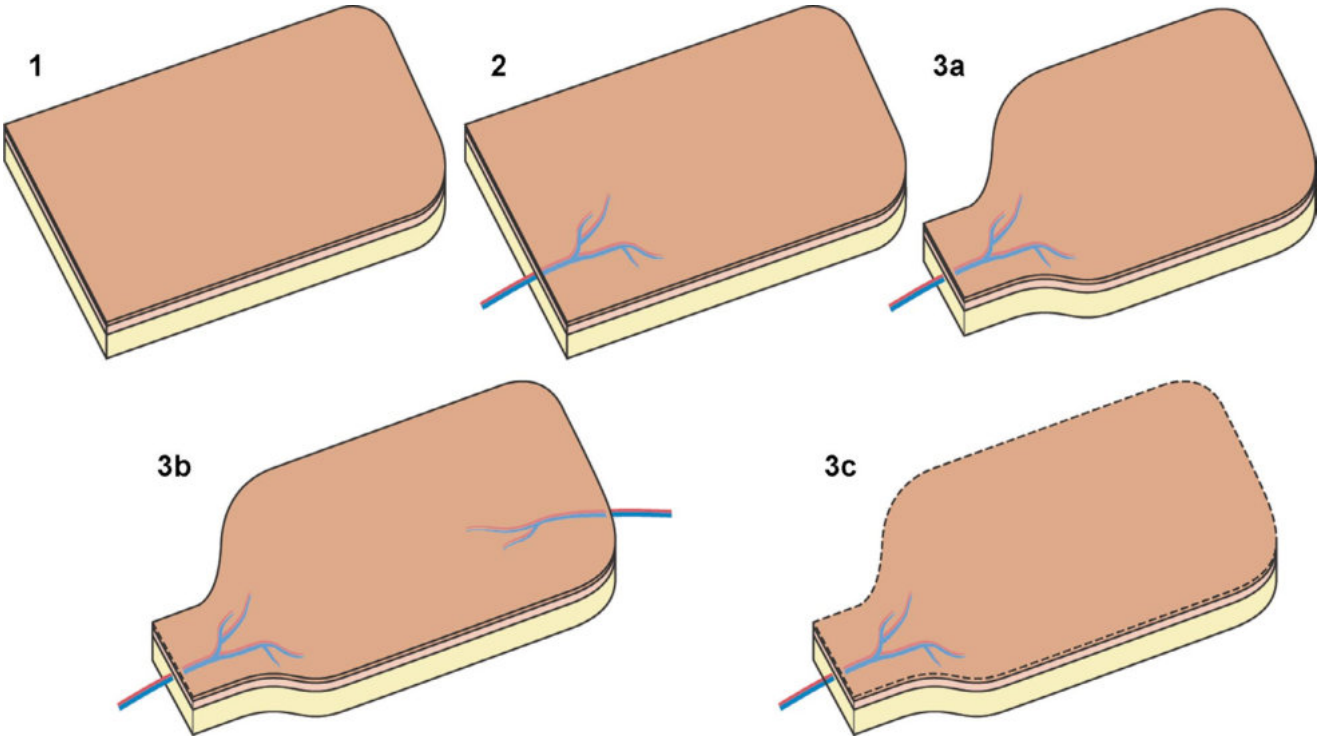


Fig. 51.1 Various super-thin flaps. (1) Random pattern super-thin flap (2). Axial pattern super-thin flap. (3a) Regular super-thin perforator flap. (3b) Supercharged super-thin perforator flap (3c) Preexpanded super-thin perforator flap

51.3 Special Skills of the Method

1. Super-thinning is a microdissection technique for flaps in which fatty tissue is removed and thinned to a level where the subdermal vascular network is visible in the distant two-thirds of the flap. Only a minimal (3c) fat layer is retained. It is better to thin the flap gradually from the distant area toward the pedicle (Fig. 51.2).
2. Soft tissue around the pedicle (2–3 cm) should be kept intact to avoid any damage to the perforator.
3. In the case of preexpanded super-thin flap, it can be prefabricated to the thinnest perforator flap. Tissue expanders should be carefully inserted under the perforator flaps in advance. After expansion for 2 months, any adherent capsule should be completely excised. Further thinning of the flaps is then performed until the subdermal vascular network is clearly visible.

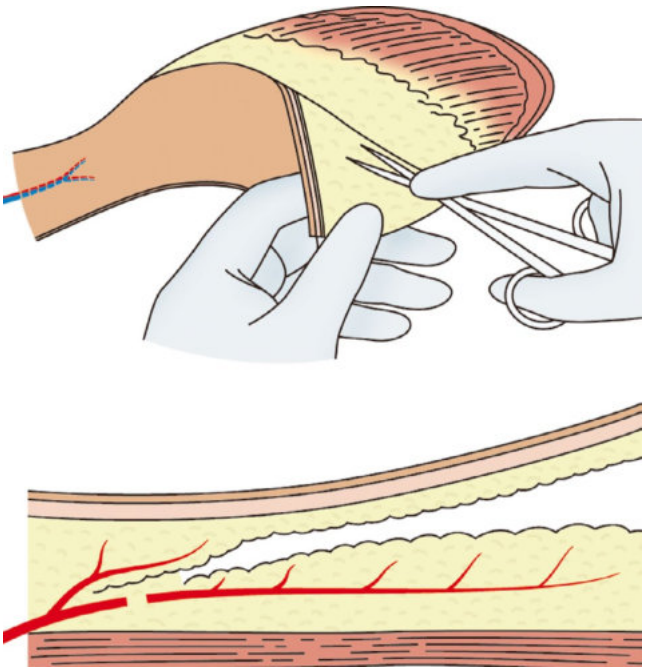


Fig. 51.2 Flap trimming technique

51.4 Clinical Cases

51.4.1 Case 1

A 34-year-old male patient suffered from flame burns 2 years ago, which caused second- and third-degree burns of the back of the right hand. He was admitted for replacement of disfiguring scars (Fig. 51.3a). We designed a pectoral intercostal artery perforator (2–3 cm) flap, with a pedicle that includes the seventh intercostal perforator. This flap was 19 cm long, 13 cm wide, with a narrow 3.5 cm-wide pedicle (Fig. 51.3b). In the first stage, we elevated the distant part of the flap, fatty tissue was removed, and the flap was thinned until the subdermal vascular network was visible (Fig. 51.3c). Scars on the right hand were surgically removed, and the distant part of the posterior intercostal artery perforator (P-ICAP) flap was transferred (Fig. 51.3d). The pedicle was sutured to a tube, and the right hand was kept in a specific posture until division of the pedicle (Fig. 51.3e, f). Ten days later, the pedicle was cut down, and the pedicle flap (3.5 × 5 cm) was transferred to the wrist (Fig. 51.3h). The flap survived well, and satisfactory aesthetic improvement was achieved (Fig. 51.3g). The donor site was closed primarily with a linear scar.

51.4.2 Case 2

A 29-year-old male patient presented with severe neck contractures and hypertrophic scars 8 months after a neck vitriol injury. The patient complained of an ugly appearance of the hypertrophic scars and restricted neck mobility (Fig. 51.4a,

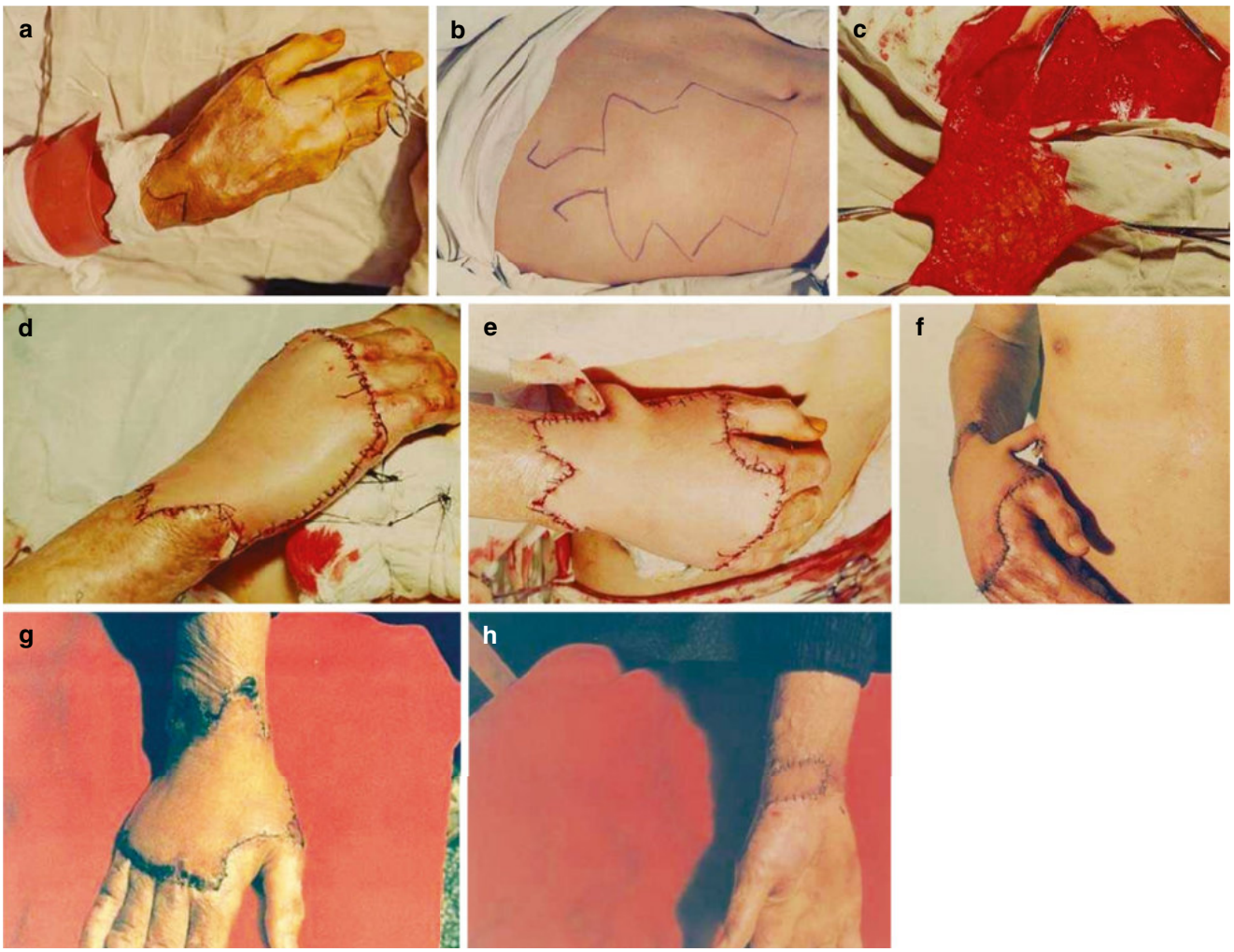


Fig. 51.3 Super-thin perforator flap (**a**) Disfiguring scars on the right hand (**b**) Designed pectoral intercostal artery perforator (2–3 cm) flap. (**c**) The flap was thinned to the level where the subdermal vascular network could be seen. (**d**) P-ICAP flap was transferred. (**e**, **f**) The pedicle was sutured to a tube, and the right hand was kept at a specific posture until division of the pedicle. (**g**) Satisfactory aesthetic improvement was achieved, and the pedicle was cut down. (**h**) The pedicle flap (3.5 × 5 cm) was transferred to the wrist

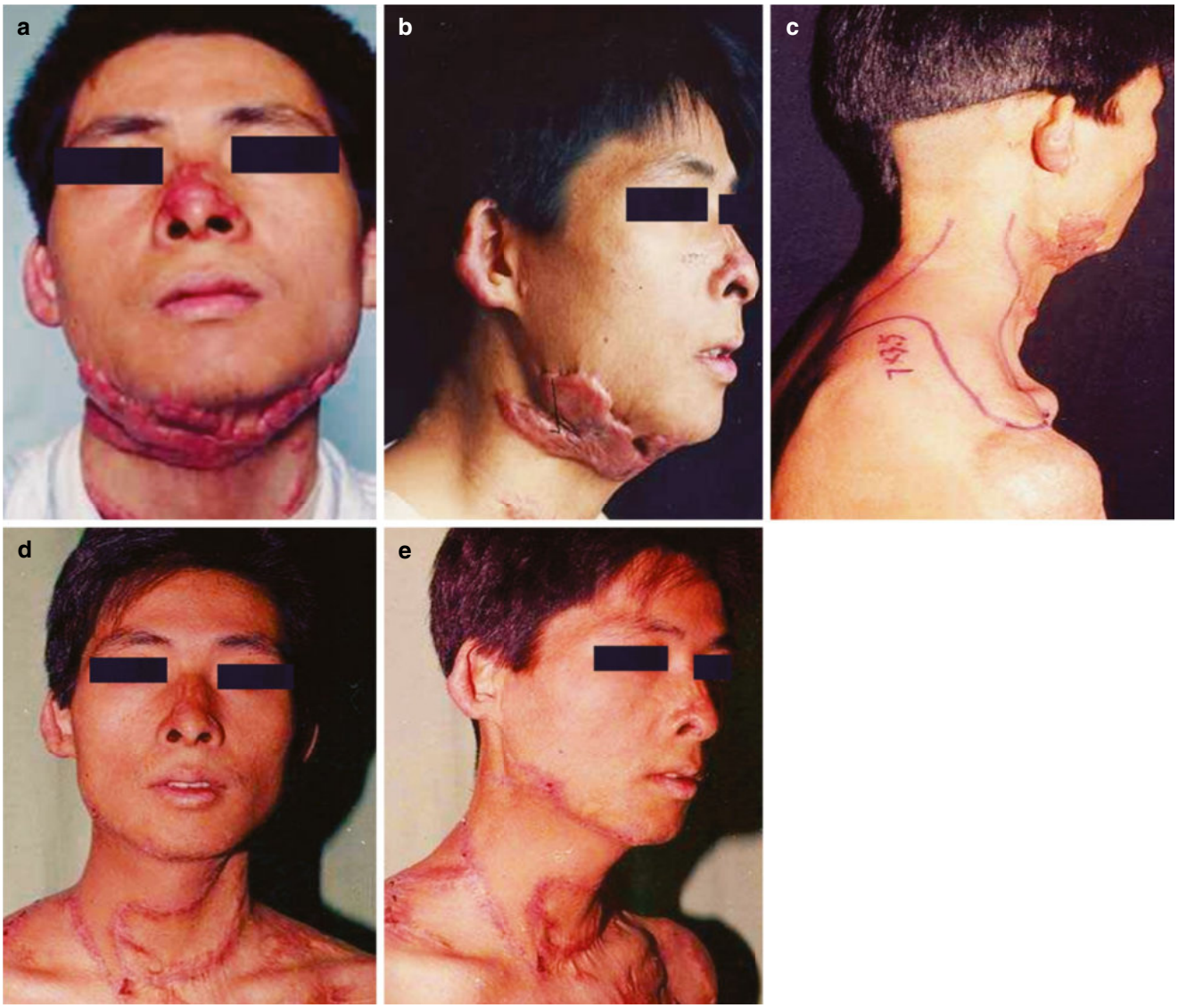


Fig. 51.4 (**a**, **b**) Hypertrophic scars and restricted neck mobility. (**c**) Designed an occipito-cervico-shoulder (OCS) super-thin perforator flap. (**d**, **e**) Satisfactory appearance (symmetry, contour, color, and texture match) and function (mobility and sensation) were achieved after 8 months of follow-up

b). We designed a 21 × 3.5–7 cm occipito-cervico-shoulder (2–3 cm) super-thin perforator flap on the right side of the patient (Fig. 51.4c). A descending perforator of the occipital artery was included in the pedicle. The flap was elevated and transferred to replace the hypertrophic scars and release neck contractures. After 8 months of follow-up, a satisfactory appearance (2–3 cm) and function (2–3 cm) were achieved (Fig. 51.4d, e).

51.4.3 Case 3

A 22-year-old male presented with severe neck contractures 2 years after extensive head and neck vitriol injuries. He was admitted for reconstruction of disfiguring hypertrophic scars in the anterior neck and to improve the mobility (Fig. 51.5a). A typical design of the acromial-pectoral flap with a transverse cervical perforator was made on the axis that connects

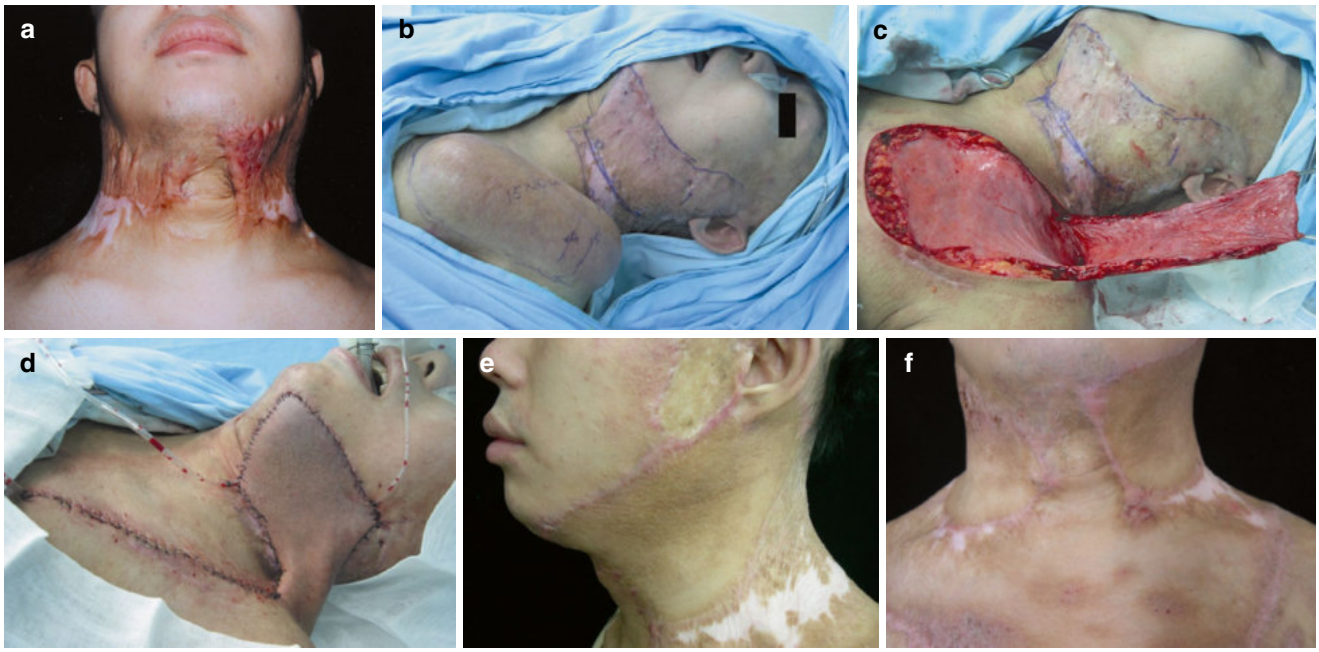


Fig. 51.5 (**a**) Disfiguring hypertrophic scars in the anterior neck. (**b**) Two tissue expanders were used under the acromial-pectoral flap with the transverse cervical perforators. (**c**) The flap was elevated and then thinned. (**e**) Satisfactory appearance and function were achieved. (**f**) Linear scar at the donor site

the root of the perforator of the superficial branch of the transverse cervical artery and the root of the perforator of the second internal thoracic artery. We created two pockets to insert two kidney-shaped tissue expanders just under the acromial-pectoral flap. During the elevation of the flaps, the occipital triangle was kept intact to avoid damaging the perforators that come from the transverse cervical artery. Over 2 months of serial saline injections in the clinic, a maximum expansion volume of 1200 mL was reached on the left side and 600 mL on the right side (Fig. 51.5b). In a second operation, hypertrophic scars on the left recipient site were surgically removed, and the expander was explanted from the donor site. A 15 × 10 cm flap was elevated and thinned. During the elevation of the flaps, the occipital triangle was kept intact to avoid damaging the perforators coming from the transverse cervical artery (Fig. 51.5c). The flap was then thinned and transferred to the neck (Fig. 51.5d). Two weeks later, the pedicle of the left flap was cut down. At the same time, the same super-thin perforator flap (13 × 10 cm on the right side) was formed and transferred to the right side of the neck. Also, the pedicle of the right flap was divided ten days later. After 8 months of follow-up, a satisfactory appearance (13 × 10 cm on the right side) and function were achieved (Fig. 51.5e). The donor sites were closed primarily with linear scars (Fig. 51.5f).

References

1. Situ P. Pedicled flap with subdermal vascular network. Acad J First Med Coll PLA. 1986;6:60–1.
2. Yang ZY, Chen BB, Huong YM, et al. The use of the pedicled overthin flap of the acromiopectoral region in repair of face and neck. J Rep Reconstr Surg. 1991;5:141–2.
3. Yuan XB, Chen WP, Yang Y, et al. (1993) experimental study of Island super thin flap. Chin J Microsurg. 1993;16:188–90.
4. Gao JH, Hyakusoku H, Sato M, et al. A analysis of transcutaneous gas and blood flow in narrow pedicled flap with subdermal vascular network. Chin J Microsurg. 1994;17:248–50.
5. Gao JH, Hyakusoku H, Akimoto M, et al. Experiences in using the super-thin flap. Jpn J Plast Reconstr Surg. 1992;35:1097–103.
6. Hyakusoku H, Gao J-H. The super thin flap. Br J Plast Surg. 1994;47:457–64.
7. Hyakusoku H, Pennington DG, Gao JH. Micro-vascular augmentation of the super-thin occipito-cervico-dorsal flap. Br J Plast Surg. 1994;47:465.
8. Lu F, Gao JH, Ogawa R, Hykusoku H. Preexpanded distant super-thin intercostals perforator flaps for facial reconstruction without the need for microsurgery. J Plast Reconstr Surg. 2006;59:1203–120.

Part VII

Free Flap and Perforator Flap

Anterolateral Thigh Flap for Soft-Tissue Defect Reconstruction

52

Jui-Yung Yang and Fu-Chan Wei

Keywords

Anterolateral thigh flap · Perforators · Musculocutaneous Septocutaneous artery flap · Reconstruction · Vascular Ultrasound

52.1 Background of the Technique

The anterolateral thigh (ALT) flap was originally described as a septocutaneous artery flap by Song et al. [1]. Almost at the same time, the detailed anatomy of this flap and its clinical application were reported by two other Chinese doctors in a Chinese journal [2, 3]. The locations of the perforators on the skin were first reported by the author [4]. After that, the anatomy of this flap was further presented from cadaver dissections or clinical experiences [4–6]. It was found that the blood supply of the anterolateral thigh flap was based on the septocutaneous or musculocutaneous perforators, or both, the vascular variations of which were also reported by Koshima et al. [7].

The large skin territory, reliability, and versatility of the ALT flap have made it one of the best choices for soft-tissue defect reconstruction. Therefore, this flap has been widely used for head and neck, extremity, and trunk defect reconstruction.

J.-Y. Yang (✉)
Division of General Plastic Surgery and Burn Care, Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Linkou Branch, College of Medicine, Chang Gung University, Tao-Yuan City, Taiwan

F.-C. Wei
Linkou Burn Center, Chang Gung Memorial Hospital and University, Taipei, Taiwan
e-mail: isc@cgmh.org.tw

52.2 Anatomy and Location of Perforators

The ALT flap is based on either the septocutaneous or the musculocutaneous perforators, with a diameter of around 0.6–1.0 mm, from the descending branches of the lateral circumflex femoral artery (LCFA). An average of 8–12 cm vascular pedicle can be obtained, and the arterial diameter of the vascular pedicle is approximately 2.0–2.5 mm at the harvest point, which is always accompanied by two veins with a diameter of around 1.8–3.0 mm. The LCFA sends perforators through the septum between the vastus lateralis and the rectus femoris or through the vastus lateralis muscle, and supplies a large skin flap on the anterolateral aspect of the thigh. If a visible septocutaneous perforator is found, the flap can be harvested as a septocutaneous flap. However, if septocutaneous perforators are absent, the flap can then be harvested as a musculocutaneous flap, with a small vastus lateralis muscle cuff for added bulk, or as a perforator flap with intramuscular dissection of the musculocutaneous perforators. In anatomic studies, most authors found the blood supply of the ALT flap to be from the musculocutaneous perforators rather than septocutaneous perforators. In the current series, we found the major blood supply of the ALT flap to be from the musculocutaneous perforators (59.8%), followed by the septocutaneous perforators (40.2%) (see Fig. 52.1).

Either the septocutaneous or musculocutaneous perforators are always present at the anterolateral aspect of the thigh and will allow this flap to be elevated safely. Computed tomographic angiography (CTA) can detect perforating vessels with a diameter of approximately 0.3 mm and can visually display the type, location, shape, and variation of perforating vessels [8]. Contrast-enhanced ultrasound combined with three-dimensional reconstruction can accurately examine the position, shape, and blood flow quality of perforating vessels, facilitating the selection of appropriate perforating vessels and donor areas before surgery [9]. Photoacoustic tomography (PAT) technology can use near-infrared pulsed laser beams and ultrasound to visualize blood

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_52

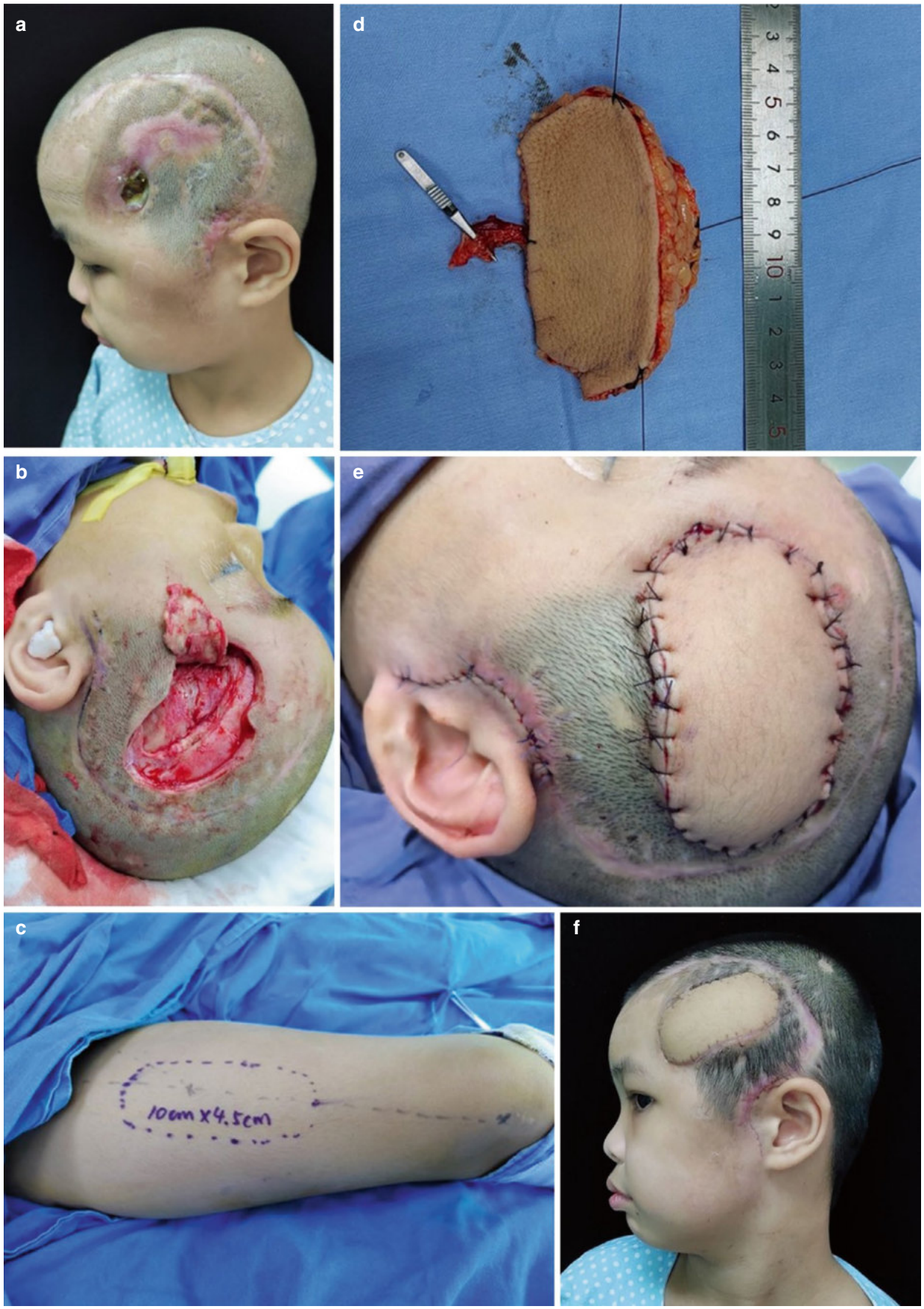


Fig. 52.1 Case 1

vessels. The detected data are formed into a three-dimensional image through a software system for surgical design and operation. The evaluation of visualized blood vessels can reach a depth of 13.0 mm on the anterolateral thigh [10]. The application of new technologies facilitates preoperative evaluation and flap design, but in our clinical experience, the ultrasonic Doppler flowmeter is the most useful in determining the locations of the perforators preoperatively. Almost all perforators are located within an approximate 5-cm radius (92% perforator within a 3-cm radius, 80% perforator points concentrated in the inferior lateral quadrant region) from the midpoint of the line between the anterior superior iliac spine and the lateral border of the patella on the donor thigh (see Fig. 52.2).

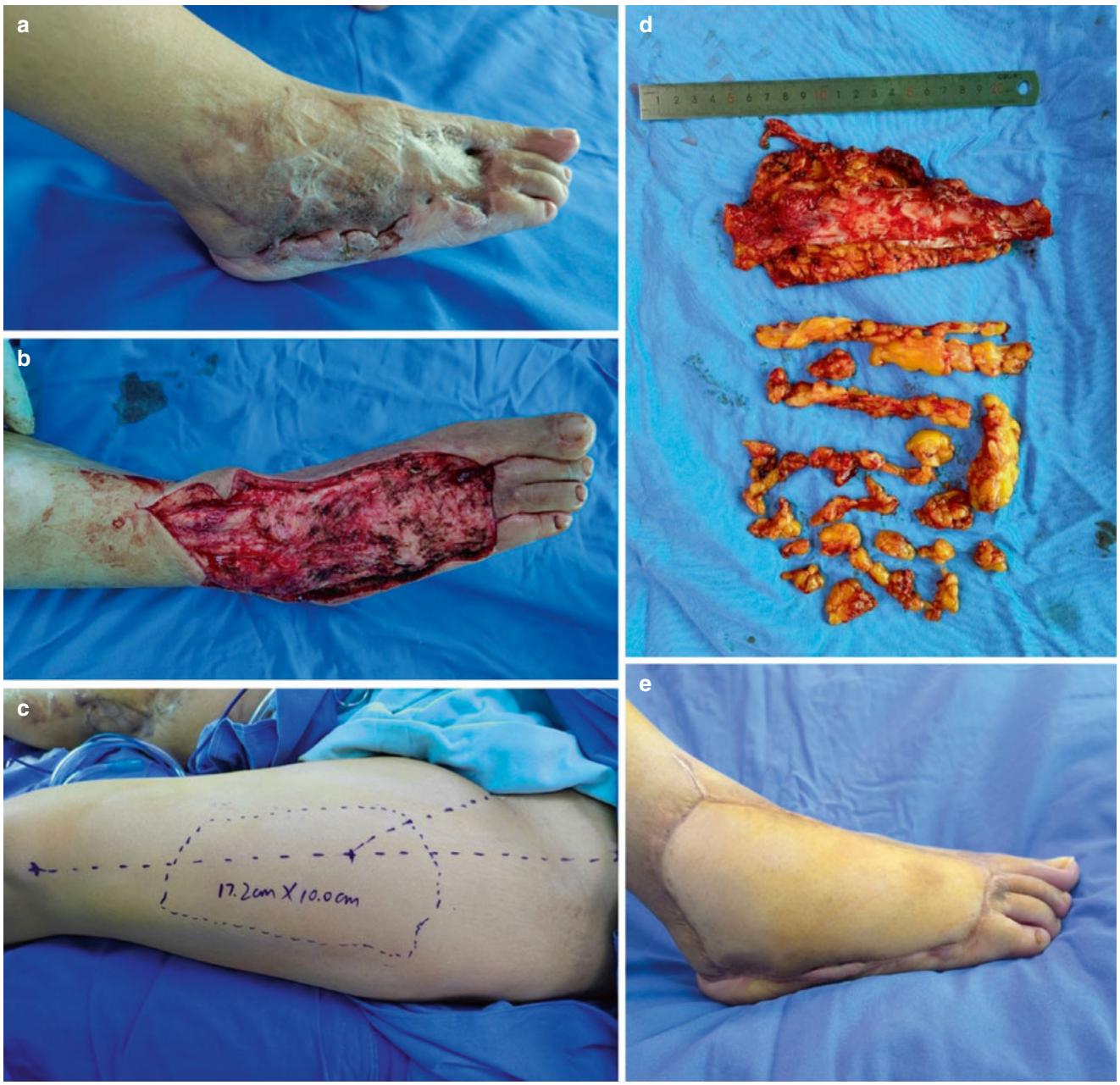


Fig. 52.2 Case 2

52.3 Surgical Techniques

1. A preoperative ultrasonic Doppler flowmeter is used to determine the locations of the perforators, and the flap can be designed around these perforators. In general, the flap size should be controlled within 15 × 28 cm. An "S"-pattern skin incision is made directly above the rectus femoris muscle. The descending branch of the LCFA can be easily seen within the intermuscular septum of the rectus femoris and vastus lateralis muscles.
2. The thigh skin is then raised and retracted laterally by a subfascial plane dissection, which will expose the septocutaneous or musculocutaneous perforators. If the septocutaneous perforator exists, it always lies superficially on the vastus lateralis muscle and traverses in the intermuscular septum of the rectus femoris and vastus lateralis muscles proximally. The dissection becomes easier if it is from the distal to the proximal.
3. If no septocutaneous perforator exists, we can always identify two to three musculocutaneous perforators emerging from the vastus lateralis muscle. The most proximal one is the preferred choice because of the relatively larger diameter of the perforator. The intermuscular septum of the rectus femoris and vastus lateralis muscle is dissected to explore the descending branch of the LCFA. The intramuscular dissection of the musculocutaneous perforator is then begun, also from distal to proximal. The musculocutaneous perforator is then elevated with a 0.5-cm cuff of vastus lateralis muscle attached after careful division and ligation of several muscular branches.
4. The descending branch of the LCFA is isolated after division and ligation of several muscular branches to the rectus femoris and vastus lateralis muscles.

52.4 Advantages and Disadvantages

Compared with other free flaps, the ALT flap has numerous advantages, including (1) a large skin paddle can be harvested even when only a single major cutaneous perforator is available (the largest one is 20 × 30 cm in Koshima's comment), (2) the flap may be thinned and is suitable for reconstruction of extremity or intraoral defects, (3) a long vascular pedicle can be obtained, (4) sensory flaps using the lateral femoral cutaneous nerve can also be obtained, (5) there is minimal morbidity at the donor site, (6) part of the vastus lateralis muscle can be used to fill dead space in the neck and floor of the mouth floor or bony defects of the extremity to avoid infection after surgery, and (7) blood supply can be restored to the distal end of the wound through blood flow bridging while repairing the wound.

There are some disadvantages to this flap. The donor site scars associated with the use of skin grafts in a large defect may preclude their use, particularly in female patients. Another disadvantage is that the anatomy of the perforator supplying the ALT flap is variable.

In sum, the ALT flap, harvested as a septocutaneous flap, a perforator flap with intramuscular dissection, or as a musculocutaneous flap, is versatile and useful for a variety of reconstructive problems. It can be harvested easily and safely to reconstruct large, complicated soft-tissue defects with minimal donor site morbidity.

52.5 Clinical Cases

52.5.1 Case 1

A 9-year-old boy who underwent brain cerebral glioma resection 6 months ago showed scalp necrosis and deep dural exposure because of the local compression of hematoma after the operation (Fig. 52.1a). After removing necrotic tissue, the skull defect and the endocranium were exposed (Fig. 52.1b). An anterolateral thigh flap (ALT flap, 10.0 × 4.5 cm) was designed for the defect (Fig. 52.1c). During the incision, the vascular perforator was separated from the intermuscular space, and part of the subcutaneous adipose tissue was removed (Fig. 52.1d). The vessels of the ALT flap were anastomosed with the superficial temporal vessels of the recipient area, and the donor area was sutured directly (Fig. 52.1e). The patient was treated successfully with a satisfactory appearance after a 6-month follow-up (Fig. 52.1f).

52.5.2 Case 2

A 31-year-old female patient suffered from skin avulsion of the right lower limb after a car accident. The wound was repaired with skin graft but soon underwent scar contracture, repeated ulceration, and fluid leakage, accompanied by local pain and restricted movements of the toes (Fig. 52.2a). The contracted scar tissue was removed to release the restricted joint (Fig. 52.2b). An ALT flap (17.2 × 10.0 cm) was designed for reconstruction (Fig. 52.2c). Carrying the fascia lata, the vascular perforator was separated from the intramuscular space, and part of the subcutaneous adipose tissue was removed. The fascia lata was sutured with the distal and proximal ends of the extensor toe tendon. The vessels of the flap were anastomosed with the anterior tibial vessels (Fig. 52.2d). The patient was treated successfully with a satisfactory appearance after a 6-month follow-up (Fig. 52.2e).

References

1. Song YG, Chen GZ, Song YL. The free thigh flap: a new free flap concept based on septocutaneous artery. Br J Plast Surg. 1984;37:149.
2. Luo LS, Gao JH, Chen LF, et al. Clinical application of free anterolateral thigh flap. Di Yi Jun Yi Da Xue Bao. 1984;4(1):1–4. (Chinese).
3. Xu DC, Zhong SZ, Liu MZ, et al. Anatomy of the anterolateral thigh flap. Lin Chuang Jie Pou Xue Za Zhi. 1984;2(3):158–60. (Chinese).
4. Gao JH, Luo LS, Chen LF, et al. The skin locations of the perforators of anterolateral thigh flap. Lin Chuang Jie Pou Xue Za Zhi. 1984;2(3):161–3. (Chinese).
5. Xu DC, Zhong SZ, Kong JM, et al. Applied anatomy of the anterolateral thigh flap. Plast Reconstr Surg. 1988;82:305.
6. Zhou G, Qiao Q, Chen GY, Ling YC, Swift R. Clinical experience and surgical anatomy of 32 free anterolateral thigh flap transplantations. Br J Plast Surg. 1991;44:91.
7. Shimizu T, Fisher DR, Carmichael SW, Bite U. An anatomic comparison of septocutaneous free flaps from the thigh region. Ann Plast Surg. 1997;38:604.
8. Zhang Y, Pan XY, Yang H, et al. Computed tomography angiography for the chimeric anterolateral thigh flap in the reconstruction of the upper extremity. J Reconstr Microsurg. 2017;33(3):211–7.
9. Su WJ, Lu LG, Lazzeri D, et al. Contrast-enhanced ultrasound combined with three-dimensional reconstruction in preoperative perforator flap planning. Plast Reconstr Surg. 2013;131(1):80–93.
10. Tsuge I, Saito S, Yamamoto G, et al. Preoperative vascular mapping for anterolateral thigh flap surgeries: a clinical trial of photoacoustic tomography imaging. Microsurgery. 2020;40(3):324–30.

Deep Inferior Epigastric Perforator "Thin" Flap

53

Vu Quang Vinh

Keywords

Deep inferior epigastric artery · Perforator flap · Breast reconstruction · Flap thinning · Zone IV necrosis Liposuction technique · Flap perfusion · Flap design Microcirculation structure · Cosmetic outcomes · Donor site closure · Burn scar contracture

53.1 Background of the Technique

The deep inferior epigastric perforator (DIEP) flap was first described in 1989 by Koshima et al. The DIEP flap is a fasciocutaneous flap from the lower abdominal wall that is supplied by the perforator branch from the deep inferior epigastric artery (DIEA), which is one of the two superior vessels of the rectus muscle. The perforating branches pierce the rectus fascia to supply the abdominal fat and skin. The DIEA and the accompanying veins are pictured in the illustration entering the muscle below the junction of the middle and lower third of the muscle. There often is symmetry with the contralateral vessels, however, this is not consistent. The difference in blood supply areas—zones I, II, and III—are safe blood supply areas. In contrast, zone IV is most susceptible to reduced arterial pressure due to increased distance from the pedicle and carries the highest risk of necrosis.

The deep inferior epigastric perforator (DIEP) flap is widely used in reconstructing many regions, with the advantage of being autologous tissue, highly cosmetic, soft, and concurrently has little effect on the function and improvement of the body shape. The DIEP flap is the best material for breast reconstruction after mastectomy for breast cancer; according to Hartrampf's study, zone IV of the flap is often resected due to being outside the blood supply range of the flap. Thus, making a thin DIEP flap to be obtained the thin and to expand territories of zone 4 for covering large defect at high aesthetic requirements such as the chin and neck area will be reported in this paper.

53.2 Flap Design

The abdominal skin island is designed with the lower aspect of the incision transversely placed above the pubic bone, in line with the typical transverse Cesarean section incision. It extends laterally with a gentle curve superior to the inguinal ligament, finishing adjacent to the anterior superior iliac spines. The upper incision is placed above the umbilicus and gently curves laterally to meet the lower transverse incision marking, with the patient in the supine position and the knees slightly flexed (Figs. 53.1, 53.2, and 53.3).

V. Q. Vinh (✉)
Department of Plastic and Reconstructive Surgery, Vietnam
National Institute of Burn, Thanh-Tri, Hanoi, Vietnam

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_53

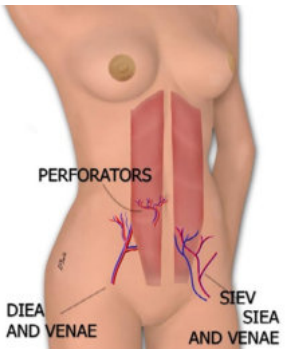


Fig. 53.1 Anatomy of the abdominal skin harvested with the DIEP flap. On the right side of the abdomen, a large DIEP perforator through the rectus muscle is illustrated. On the contralateral side, the superficial inferior epigastric artery (SIEA) and the superficial inferior epigastric vein (SIEV) are demonstrated. (*From* Scheflan and Dinner; with permission)

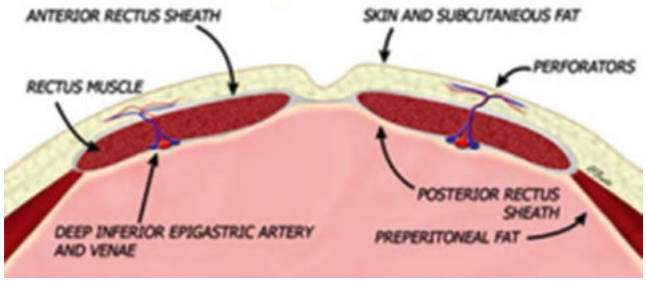


Fig. 53.2 Cross-section of the abdominal wall demonstrating DIEA perforators. In this case, a central DIEA system is shown with a perforating system piercing the rectus muscles and supplying the overlying skin and fat. (*From* Scheflan and Dinner; with permission)

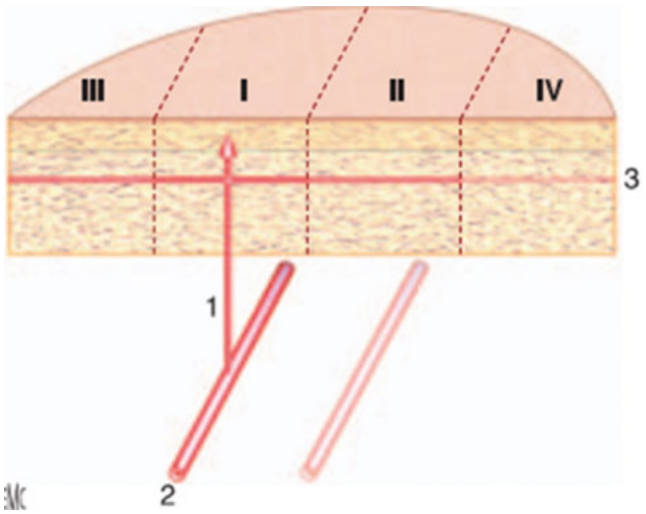


Fig. 53.3 Four physiological zones of blood supply in the DIEP flap (Hartrampf's zones), namely zones I, II, III, and IV. (*From* Scheflan and Dinner; with permission)

53.3 Thinning of DIEP Flap

After designing the DIEP flap, the thinned skin flap is remarked by liposuction. This zone is administered subcutaneously with saline solution containing lidocaine at 35 mg/kg body weight at a ratio of 1 mL per square centimeter.

The liposuction zone is defined as a flap area within a radius of 3 cm outside the circle. The center is the location of the perforator. Liposuction is performed with a 3 mm cannula, parallel to the skin surface, 1.2–1.7 cm from the skin surface. Liposuction that is too shallow can damage the subdermal plexus, affecting the blood supply to the skin. The flap is then lifted, and the main artery is dissected and separated.

To evaluate the flap perfusion, check for IV bleeding by removing a small subcutaneous portion and observing the bleeding. We can assess the flap perfusion using fluorescein angiography (Fig. 53.4).

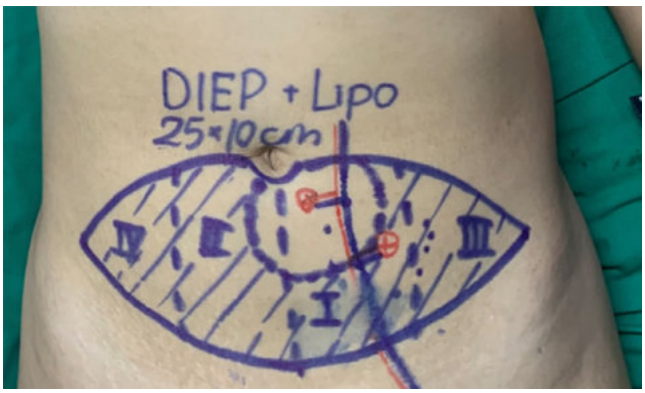


Fig. 53.4 Designing the flap of skin in a trapezoid shape on the lower abdomen with appropriate dimensions for the reconstruction requirement. The liposuction zone is remarked

53.4 Advantages and Disadvantages of DIEP "Thin" Flap

Thinning the flap: Liposuction helps reduce the volume of the flap while maintaining the microcirculation structure that supplies blood to the layers of the flap. Reducing the volume of fat tissue at the distal portion of the flap minimizes the burden on the microcirculation system, thereby contributing to the perfusion of the remaining tissue and preventing congestion.

Expansion of flap size: DIEP thin flaps have excellent perfusion and no venous stasis in the IV region according to the classification of Hartrampf. Thus, we harvested a large flap without removing part of it with just a bunch of blood vessels, preserving the size of the flap for reconstruction in cases of broad defects after removing the scar from the burn in the chin and neck area.

Softness and matched color of the skin flap: The thin DIEP flap maintains the stable structure of the flap after liposuction, ensuring flexibility in reconstruction and color matching with the surrounding flap, especially in areas requiring high aesthetic, such as the chin and neck.

Donor site: The skin flap area is the abdominal area under the umbilicus. After the flap harvest, the donor area underwent full abdominoplasty and primary closure, thereby not affecting function and allowing the scar at the donor site to be more easily concealed, while improving the form and aesthetics of the abdomen..

53.5 Clinical Cases

53.5.1 Case 1

A 25-year-old woman had a severe burn scar contracture of the chin and neck after flame burns (Fig. 53.5). Thus, we planned to reconstruct the cervicomental using the DIEP flap with liposuction during flap dissection. Flap thickness was 40 mm and decreased to 13 mm after surgery. The "thin" DIEP flap was elevated with dimensions of 32 cm length and 18 cm width. The flap was transferred to cover the defect after removing the scar contractures. The flap survived completely. Good functional and cosmetic outcomes were observed 1 year post-surgery. The donor site was the primary closure.

53.5.2 Case 2

A 34-year-old woman suffered alcohol burns to the neck and chest (Fig. 53.6). An entire neck scar contracture developed. A thin deep inferior epigastric perforator flap was used for reconstruction. The thickness of the flap before surgery was 38 mm. The flap was 30 × 14 cm and elevated with a 13-mm thickness. The flap was transferred to cover the defect. The deep inferior epigastric perforator vessel was anastomosed to the right facial artery. The donor site was closed primarily. Twenty months have elapsed, and the results are functionally and cosmetically satisfactchory.

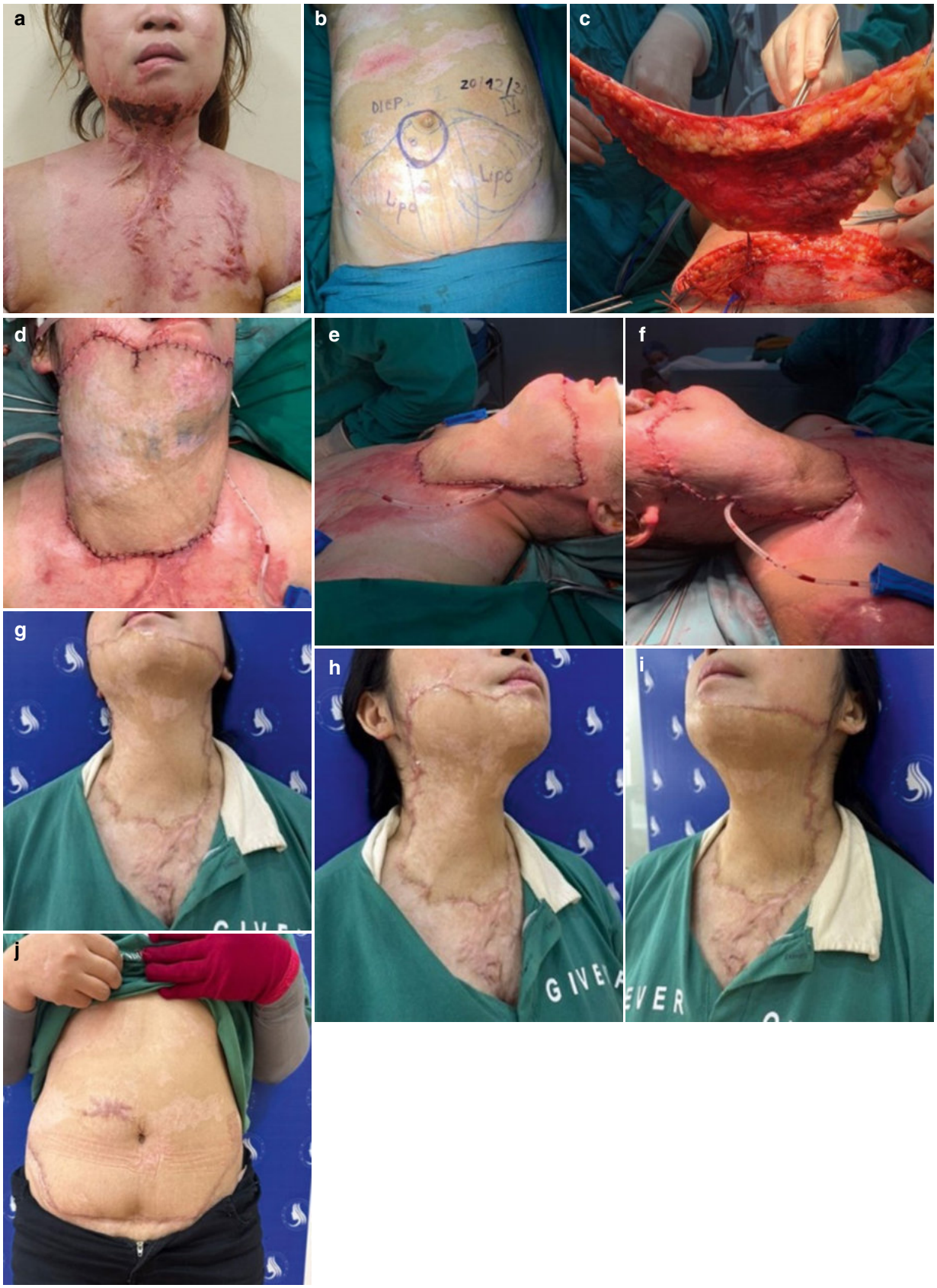


Fig. 53.5 A "thin" deep inferior epigastric perforator flap measuring 32 × 18 cm was used. The flap thickness was 40 mm and decreased to 13 mm after liposuction. The flap survived completely. The functional and cosmetic outcomes were observed 12 months post-surgery. (**a**) Preoperative view (frontal view). (**b**) Flap design. (**c**) Elevated flap. (**d**) Immediately after the operation (frontal view). (**e**, **f**) Immediately after the operation (lateral view). (**g**) One year post-surgery (frontal view). (**h**, **i**) One year post-surgery (lateral view). (**j**) The donor site after surgery

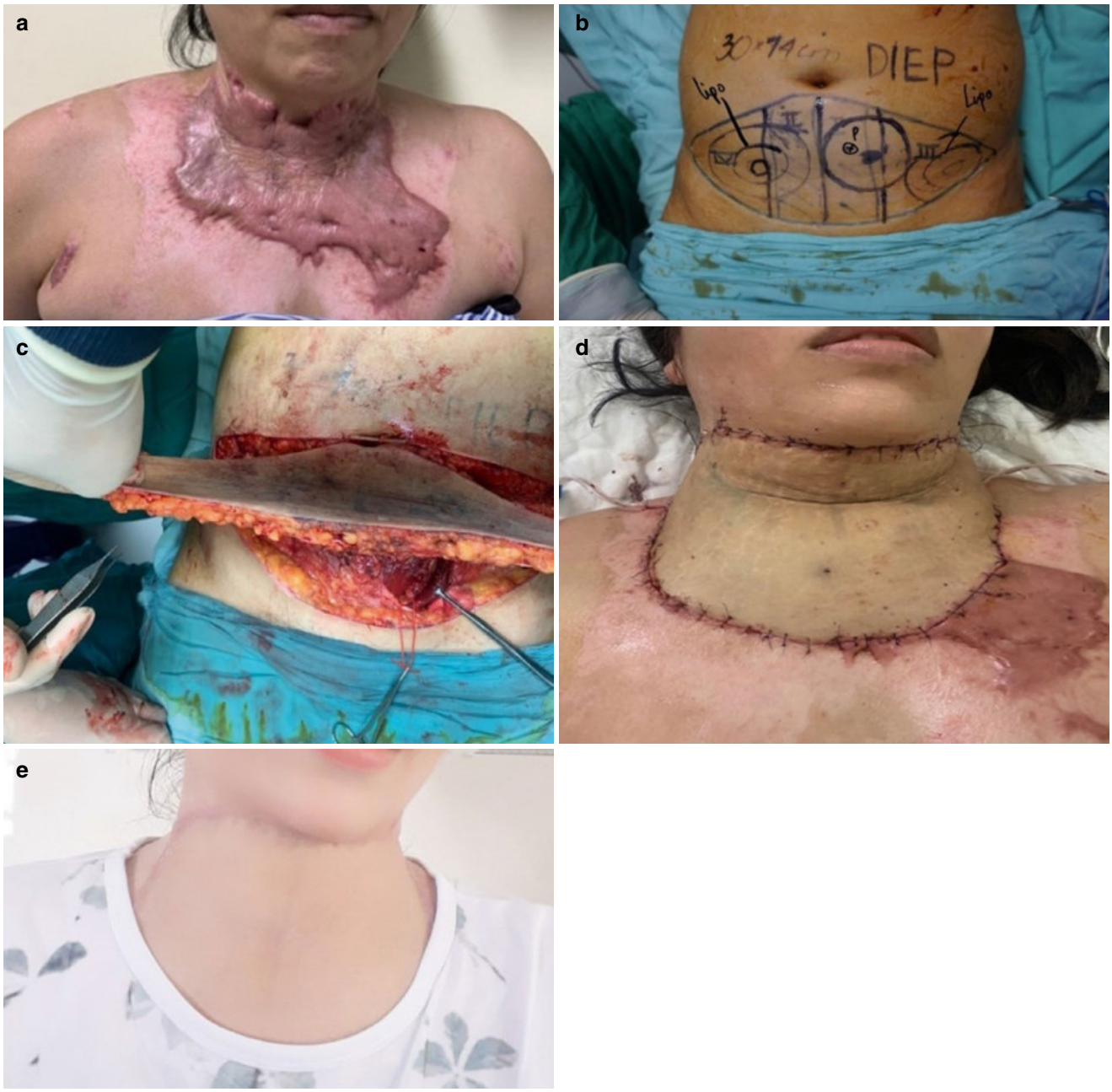


Fig. 53.6 A "thin" deep inferior epigastric perforator flap measuring 30 x 14 cm was used. The flap survived completely. The functional and cosmetic outcomes were determined 20 months post-surgery. (**a**) Preoperative view (frontal view). (**b**) Flap design. (**c**) Flap thickness after liposuction. (**d**) Immediately after the operation. (**e**) Twenty months post-surgery (frontal view)

Suggested Readings

1. Blondeel P. One hundred free DIEP flap breast reconstructions: a personal experience. British journal of plastic surgery. 1999;52(2):104–11. Situ P. Pedicled flap with subdermal vascular network. Acad J First Med Coll PLA (Chinese). 1986;6:60.
2. Chetboun A, Masquelet AC. Experimental animal model proving the benefit of primary defatting of full-thickness random-pattern skin flaps by suppressing "perfusion steal". Plast Reconstr Surg. 2007;120(6):1496–502.
3. Chirappapha P, Chansoon T, Bureewong S, et al. Is it reasonable to use indocyanine green fluorescence imaging to determine the border of pedicled TRAM flap zone IV? Plast Reconstr Surg Glob Open. 2020;8(9)
4. Hartrampf CR, Scheflan M, Black PW. Breast reconstruction with a transverse abdominal Island flap. Plast Reconstr Surg. 1982;69:216.
5. Hyakusoku H, Gao JH. The "super-thin" flap. Br J Plast Surg. 1994;47(7):457–64.

6. Ince B, Yarar S, Dadaci M. Simultaneous flap thinning with ultrasound-assisted liposuction during free flap surgery: preliminary results. Microsurgery. 2019;39(2):144–9.
7. Mathes SJ, Nahai F. Classification of the vascular anatomy of muscles: experimental and clinical correlation. Plast Reconstr Surg. 1981;67(2):177–87.
8. Ohjimi H, Taniguchi Y, Kawano K, Kinoshita K, Manabe T. A comparison of thinning and conventional free-flap transfers to the lower extremity. Plast Reconstr Surg. 2000;105(2):558–66.
9. Scheflan M, Dinner MI. The transverse abdominal Island flap: part I. Indications, contraindications, results, and complications. Ann Plast Surg. 1983;10(1):24–35.
10. Scheflan M, Dinner MI. The transverse abdominal Island flap: part II. Surgical technique. Ann Plast Surg. 1983;10(2):120–9.
11. Thomas CV. Thin flaps. Plast Reconstr Surg. 1980;65(6):747–52.

Free Flap for Burned Hand

54

Shimpei Ono and Rei Ogawa

Keywords

EYWORDSHand burns · Functional reconstruction Aesthetic restoration · Systemic management · Second-degree burns · Tangential excision · Split-thickness skin grafting · Intrinsic plus position · Pedicled flaps Anterolateral thigh flaps · Microvascular anastomosis Tendon reconstruction

Hand burns occur due to various causes and are relatively common. Treatment must address both functional reconstruction and aesthetic restoration. For localized hand burns, it is feasible to develop a treatment plan that actively resolves these issues from the early stages. However, in cases of extensive burns involving the hands, systemic management and burn treatment as life-saving measures are prioritized. To ensure optimal functional outcomes for hand burns, attention to hand-specific care is essential even during the initial treatment phase.

54.1 Basic Treatment Principles for Hand Burns

Second-degree burns, including superficial dermal burns (SDB) and deep dermal burns (DDB), typically have the potential for epithelialization; therefore, the primary goal is to avoid interfering with early wound healing. Conservative treatments, including the application of ointments based on petroleum jelly or wound dressings, are commonly employed. Superficial SDB and DDB localized to the palmar aspect of the hand generally pose fewer challenges related to scarring or contractures post-healing. However, extensive DDB affecting the dorsal hand may lead to delayed wound healing and severe scar contractures, necessitating tangential excision and split-thickness skin grafting (STSG) within a few days post-injury, followed by appropriate rehabilitation [1].

For third-degree burns (DB), particularly those centered on the dorsal hand, early debridement, STSG, and immobilization in an intrinsic plus position are generally indicated [1]. When surgery is delayed, interim active and passive rehabilitation should be initiated. For burns primarily affecting the palmar hand, conservative management is initially employed, with the reconstruction plan determined after assessing burn depth. Deep injuries involving tendons, bones, or joints often require reconstruction with free flaps or pedicled flaps (commonly pedicled abdominal or groin flaps), as STSG alone is insufficient [2].

Flap selection for hand burn reconstruction should prioritize thin, pliable flaps capable of restoring the hand's contour. Reconstruction is most often performed for dorsal hand burns, where free flaps from the thigh, such as anterolateral thigh (ALT) flaps, are particularly useful due to their structural similarity to the upper limb [2, 3]. While pedicled abdominal flaps

S. Ono (✉) · R. Ogawa
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: s-ono@nms.ac.jp; r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_54

are a safe and reliable option, they necessitate staged procedures and pose limitations on rehabilitation [3].

54.2 Case Presentations

54.2.1 Case 1: Reconstruction of an Electrical Burn Defect in the Index Finger Using a Free Anterolateral Thigh Flap

A 36-year-old man sustained an electric burn on the right index finger from a 200 V direct current during electrical work. He presented to the emergency department with pain and swelling in the right index finger and forearm. Vital signs and an electrocardiogram were normal. A necrotic wound was anticipated on the radial-palmar side of the right index finger (Fig. 54.1a). Debridement and reconstruction were planned in two stages. Given the anticipated extent of the defect, a free flap was selected over local flap reconstruction [2].

On Day 11 post-injury, necrotic tissue was debrided, preserving the radial neurovascular bundle, and an Integra dermal regeneration template was applied. On Day 16, further debridement revealed necrosis extending to the subcutaneous layer of the dorsal hand (Fig. 54.1b). Reconstruction using a free ALT flap from the right thigh was planned (Fig. 54.1c) [3]. The flap was elevated at the deep fascia level without debulking (Fig. 54.1d). The radial artery and vein at the snuffbox were chosen as recipient vessels for microvascular anastomosis (Fig. 54.1e). The donor site was closed primarily (Fig. 54.1f, g).

Postoperatively, the flap experienced temporary congestion but epithelialized without requiring revision surgery. At 3 years and 10 months postoperatively, the patient exhibited mild hyperpigmentation of the flap and limited extension of the metacarpophalangeal joint (−15°) of the index finger but reported no functional limitations in daily or occupational activities (Fig. 54.1h–j).

54.2.2 Case 2: Comprehensive Reconstruction of Heat Press Injury in the Dorsal Hand: Tendon Reconstruction and Free Anterolateral Thigh Flap Coverage

A 67-year-old woman suffered a heat press injury at work. Initially treated conservatively, her burn progressively deepened, and she was referred to our hospital. Debridement revealed extensive defects involving the extensor tendonsExtensor pollicis longus (EPL) and extensor digitorum communis (EDC) for the index, long, and ring fingers and dorsal wrist capsule, necessitating tendon excision (Fig. 54.2a). Vacuum-assisted closure therapy was used for temporary management (Fig. 54.2b), followed by tendon reconstruction and free flap coverage [2, 3].

Tendon defects were reconstructed using tendon grafts (Fig. 54.2c). Soft tissue defects were covered with a free ALT flap harvested from the right thigh (Fig. 54.2d). The radial artery and vein at the snuffbox served as recipient vessels for microvascular anastomosis (Fig. 54.2e). The flap was inset, and a drain was placed beneath the flap (Fig. 54.2f). The donor site was closed primarily (Fig. 54.2g, h).

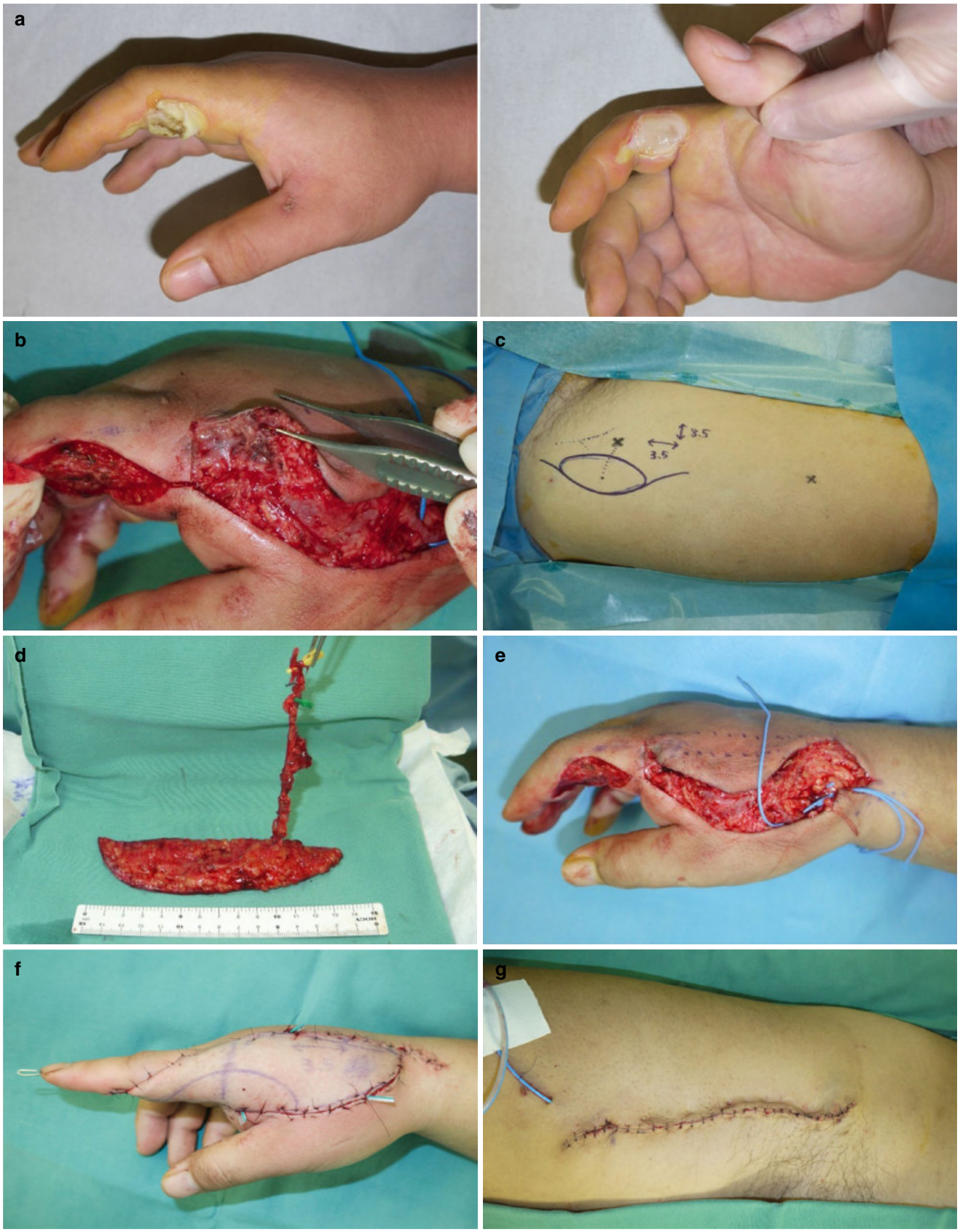


Fig. 54.1 (**a**–**j**) Case 1: Reconstruction of an electrical burn defect in the index finger using a free anterolateral thigh flap

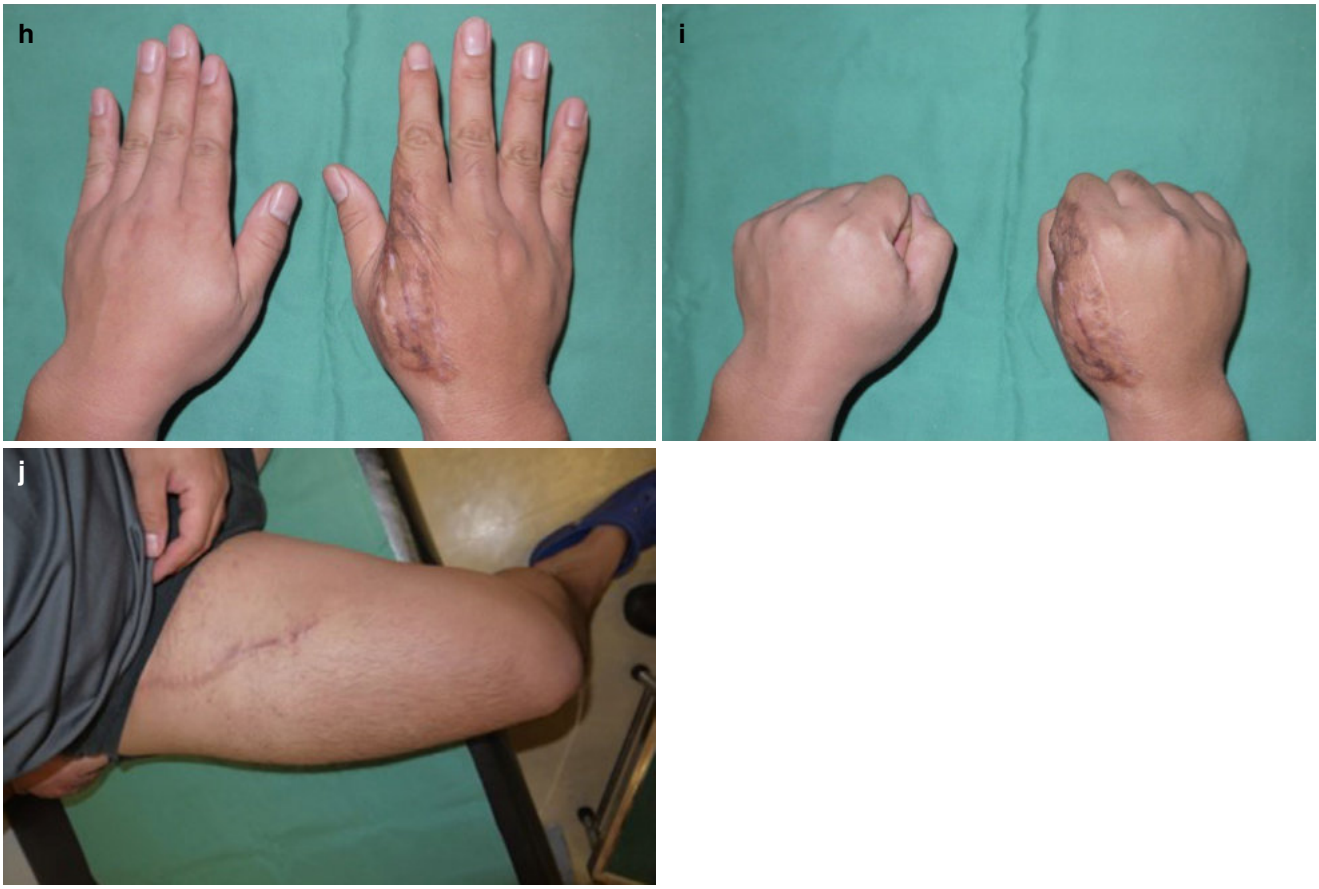


Fig. 54.1 (continued)

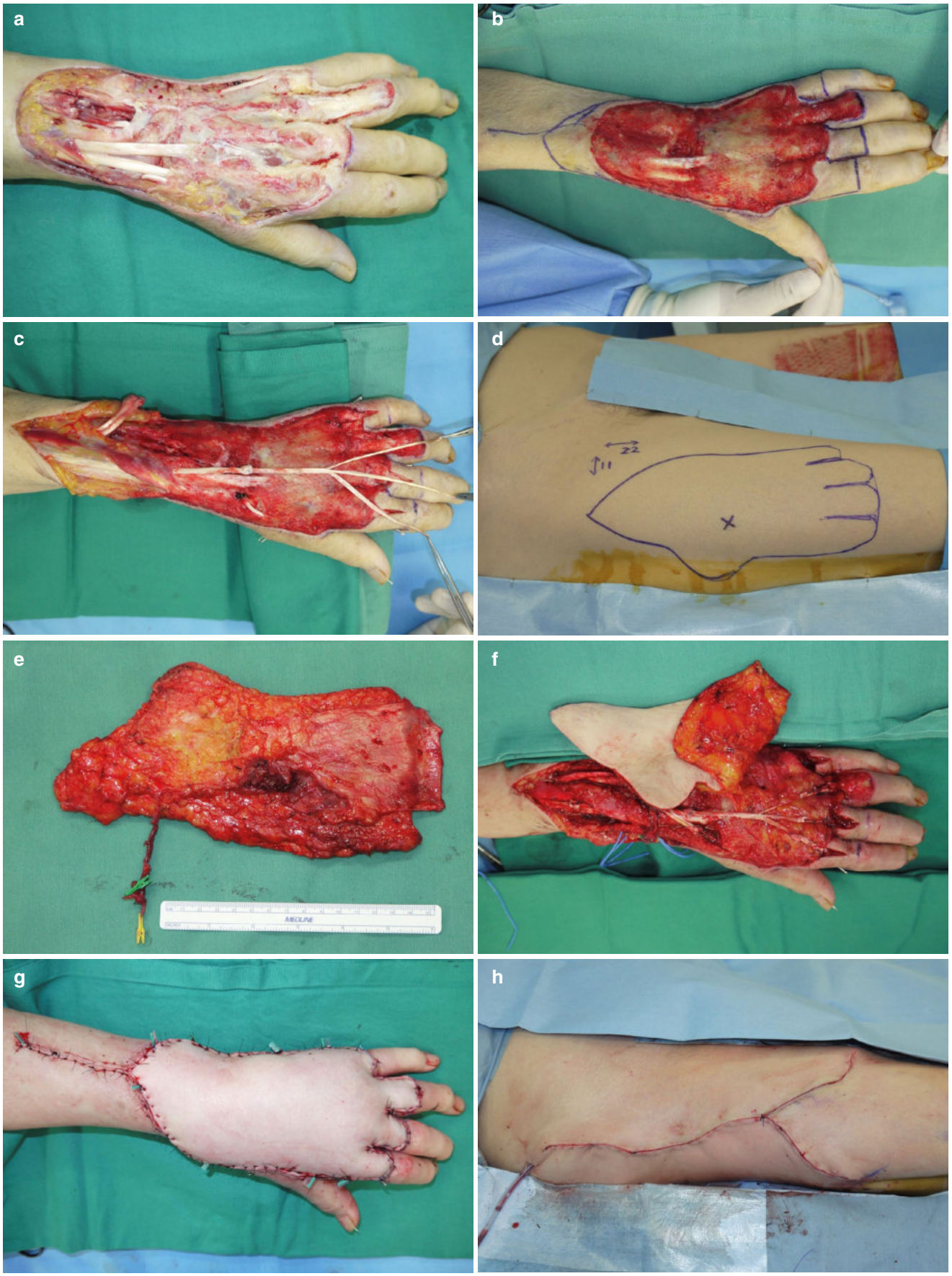


Fig. 54.2 (**a**–**i**) Case 2: Comprehensive reconstruction of heat press injury in the dorsal hand: tendon reconstruction and free anterolateral thigh flap coverage

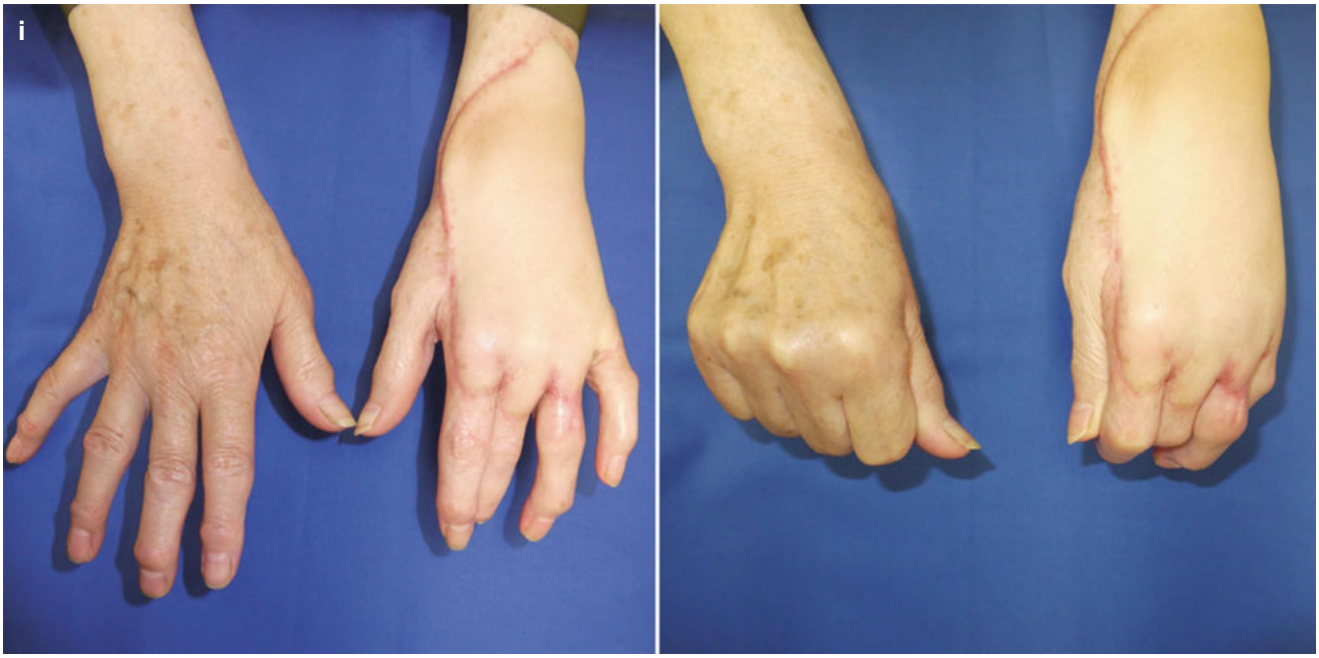


Fig. 54.2 (continued)

At 1 year and 9 months postoperatively, the flap demonstrated excellent contour restoration with minimal scarring (Fig. 54.2i). Although some joint contractures limited the range of motion and grip strength, the patient reported no pain and was able to perform daily activities without difficulty.

References

1. Janzekovic Z. A new concept in the early excision and immediate grafting of burns. J Trauma. 1970;10:1103–8.
2. Harii K, et al. Anterolateral thigh flap for reconstruction of hand and forearm defects. Plast Reconstr Surg. 1984;74:141–9.
3. Yildirim S, et al. Reconstruction of hand defects using free anterolateral thigh flaps. J Plast Reconstr Aesthet Surg. 2008;61(10):1231–6.

Free Muscle Flaps for Lower Extremity Burn Reconstruction

55

Cagri A. Uysal and Burak Ozkan

In recent decades, perforator flaps have transformed the field of reconstructive surgery [1]. Muscle-preserving techniques, such as super-thin flaps, have gained popularity in many centers to minimize donor site morbidity [2, 3]. Despite this, the use of free muscle flaps has declined compared to the 1990s and early 2000s [4]. However, there remains a significant need for muscle flaps, particularly for severe burn patients with limited donor sites [5]. Free muscle flap transfers to the extremities are more common compared to head and neck defects [6].

55.1 Extremity Challenges

Lower extremity burns pose significant challenges for reconstructive surgeons. Tendons and bones are superficial and prone to exposure in deep burns [7]. High-voltage electric burns and chemical burns can be especially threatening due to their impact on deep structures and the risk of progressive necrosis. Performing extremity-free muscle flap transfers require specific considerations.

55.2 Deciding the Timing

Patients eligible for free muscle transfers have usually been exposed to burn injuries for an extended period or have experienced high-voltage electric burns. Before free flap surgery, it is vital to maintain hemodynamic stability and the patient's general health. Higher rates of flap failure have been reported during the acute phase (first 21 days) of burn injuries, often due to inadequate debridement and progressive necrosis [8]. Therefore, comprehensive and adequate debridement is necessary before reconstruction. However, in case of extremity-threatening injuries, early free flap transfers may be required. Closing neurovascular structures reduces the risk of infection and necrosis, increasing the survival of the extremity, while early closure of bone defects decreases the likelihood of osteomyelitis [9]. The preferred approach in lower extremity trauma centers involves bone fixation using external fixation combined with free muscle transfers [10].

55.3 Selecting the Recipient Vessel

When choosing the recipient vessel, it is essential to prioritize anastomosis outside the injury zone to minimize the risk of thrombosis and infection [11]. The assessment of the trauma zone can be conducted through clinical observation, although innovative methods like indocyanine green angiography can be beneficial for detecting areas of necrosis. In the mid-tibial region, both the anterior tibial artery and posterior tibial artery run deep and become more superficial in the distal tibia. While these vessels are relatively protected in the proximal two-thirds of the tibia in burn cases, it is essential to perform preoperative vascularity assessment using preoperative angiography or Doppler ultrasound [12]. End-to-side anastomosis is the preferred choice to avoid disrupting the distal flow of the extremity. Elevating the deeply situated recipient vessels can be accomplished with a microsurgical hammock created using an Esmarch bandage at the mid-tibial level [13].

55.4 Deciding the Flap

Muscles with longer pedicles, such as the latissimus dorsi muscle, rectus abdominis muscle, and vastus lateralis muscle, may be needed, particularly in electric burn patients, to reach beyond the trauma zone. These muscles can provide pedicles up to 15 cm in length. The extent of the defect is another crucial factor in flap selection. For extensive defects like circumferential defects, the latissimus dorsi muscle flap can cover the extremity [14]. The thoracodorsal system

C. A. Uysal (✉) · C. Ozkan
Department of Plastic, Reconstructive and Aesthetic Surgery, Baskent University Faculty of Medicine, Ankara, Turkey

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_55

offers various flap options when dealing with multi-location defects or the need to reconstruct multiple structures (Figs. 55.1, 55.2, 55.3, 55.4, and 55.5) [15]. Bulky tissues are generally not required in lower extremity burns due to the lower incidence of cavities. However, defects associated with the calcaneal, patellar, and mid-tibial bones may necessitate free muscle transfers to fill the spaces. The gracilis muscle flap can be considered in such cases, and the muscle

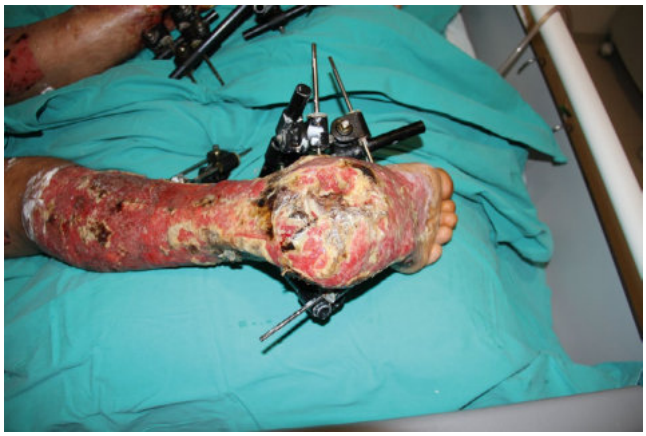


Fig. 55.1 A worker fell into an acid tank after contact with high-voltage electric current, leading to a cavitary calcaneal defect encountered after serial debridements

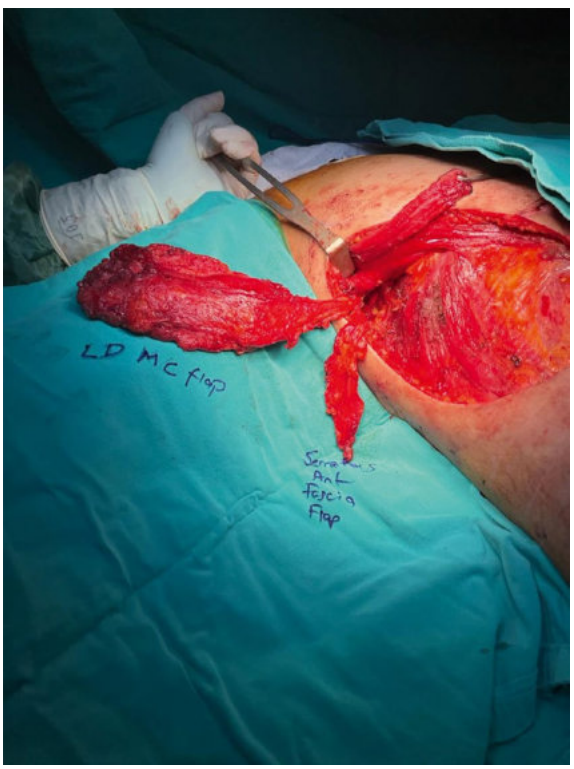


Fig. 55.2 A chimeric latissimus dorsi musculocutaneous-serratus anterior fascia flap was elevated to fill the cavitary calcaneal defect and cover the bimalleolar and Achilles region

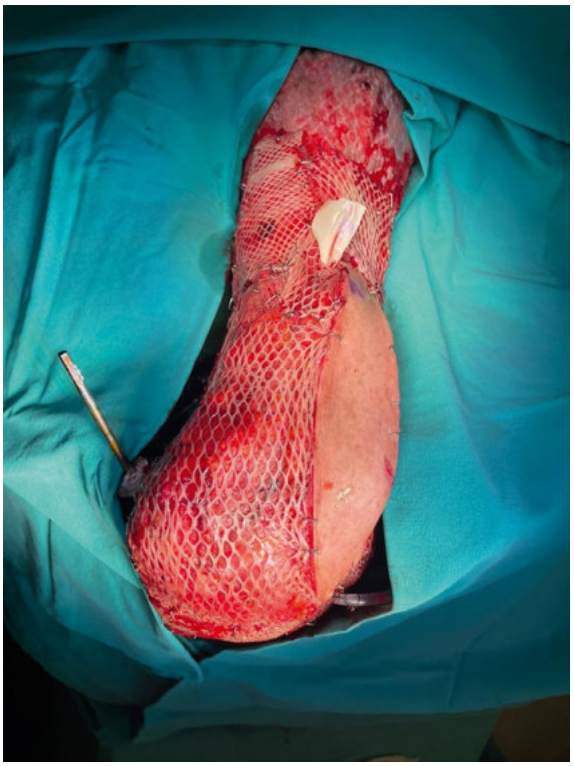


Fig. 55.3 Anastomoses were performed to the posterior tibial artery and vein in an end-to-side fashion. A meshed split-thickness skin graft was applied over the latissimus dorsi muscle

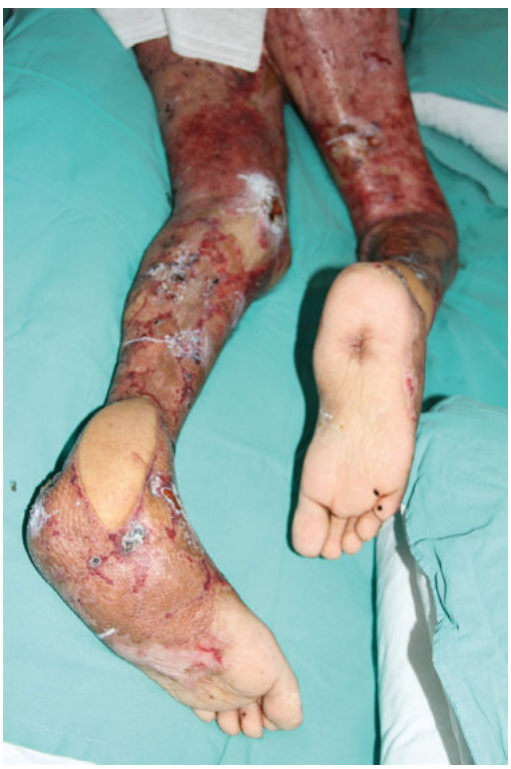


Fig. 55.4 Postoperative image at 1 year after the procedure

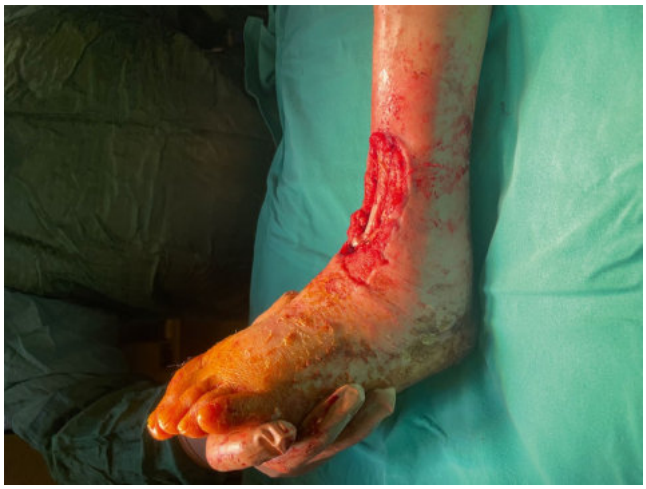


Fig. 55.5 A 67-year-old male patient sustained a chemical burn resulting in an exposed anterior tibialis tendon and tibial bone

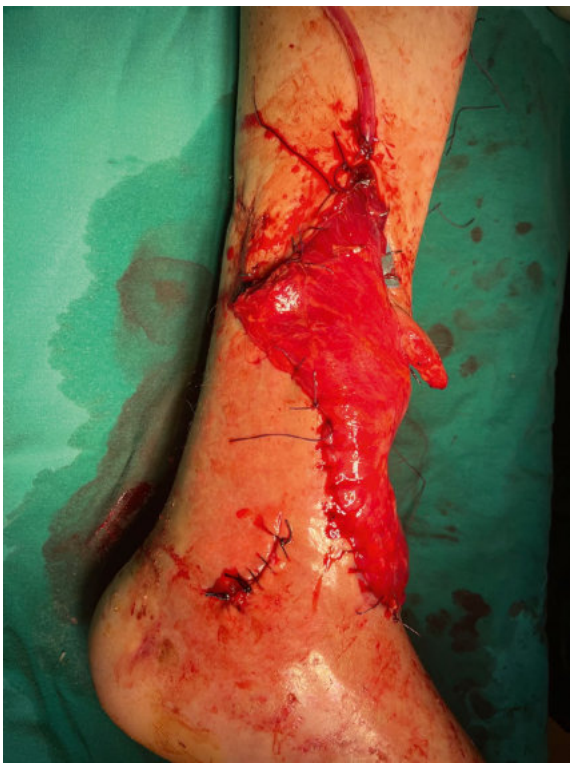


Fig. 55.6 The defect was covered with a free gracilis muscle flap. Anastomoses were performed to the anterior tibial artery and concomitant veins in an end-to-side fashion. Immediate meshed split-thickness skin graft was applied over the muscle flap

surface can be increased with epimysial scoring if necessary (Figs. 55.6 and 55.7).

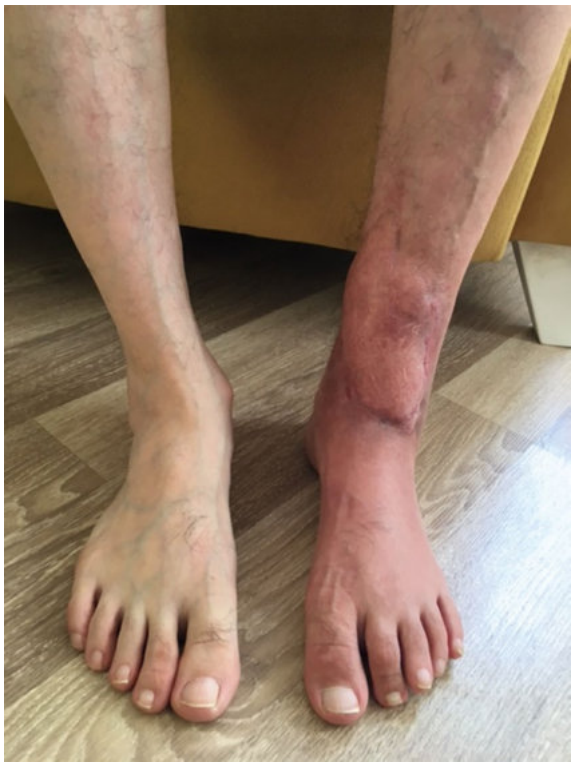


Fig. 55.7 Postoperative image at 8 months shows a recognizable reduction in muscle bulk in the patient

Acknowledgments The authors gratefully acknowledge the contribution of Huseyin Borman to this chapter as it appeared in the first edition of the book.

References

1. Pignatti M, Ogawa R, Mateev M, et al. Our definition of propeller flaps and their classification. Semin Plast Surg. 2020;34(03):139–44. https://doi.org/10.1055/s-0040-1715158.
2. Ozkan B, Aydogan C, Uysal CA, Albayati A, Ertas NM, Haberal M. The role of pedicled perforator flaps in burn reconstruction. Burn Care Prevent. 2021;1:26–31.
3. Orgill DP, Ogawa R. Current methods of burn reconstruction. Plast Reconstr Surg. 2013;131(5):827e–36e. https://doi.org/10.1097/PRS.0b013e31828e2138.
4. Hallock GG. A history of the development of muscle perforator flaps and their specific use in burn reconstruction. J Burn Care Rehabil. 2004;25(4):366–71. https://doi.org/10.1097/01.BCR.0000132174.02252.9A.
5. Baumeister S, Köller M, Dragu A, Germann G, Sauerbier M. Principles of microvascular reconstruction in burn and electrical burn injuries. Burns. 2005;31(1):92–8. https://doi.org/10.1016/j.burns.2004.07.014.
6. Sauerbier M, Ofer N, Germann G, Baumeister S. Microvascular reconstruction in burn and electrical burn injuries of the severely traumatized upper extremity. Plast Reconstr Surg. 2007;119(2):605–15. https://doi.org/10.1097/01.prs.0000246512.47204.da.

7. Ozkan B, Tatar BE, Albayati A, Uysal CA. Utilization of perifascial loose areolar tissue grafting as an autologous dermal substitute in extremity burns. J Investig Surg. 2023;36(1):2192786. https://doi.org/10.1080/08941939.2023.2192786.
8. Oni G, Saint-Cyr M, Mojallal A. Free tissue transfer in acute burns. J Reconstr Microsurg. 2012;28(02):077–84. https://doi.org/10.1055/s-0031-1284239.
9. Saint-Cyr M, Daigle JP. Early free tissue transfer for extremity reconstruction following high-voltage electrical burn injuries. J Reconstr Microsurg. 2008;24(04):259–66. https://doi.org/10.1055/s-2008-1078697.
10. Gopal S, Majumder S, Batchelor AGB, Knight SL, Boer PD, Smith RM. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. J Bone Jt Surg. 2000;82(7)
11. Koul AR, Patil RK, Philip VK. Early use of microvascular free tissue transfer in the management of electrical injuries. Burns. 2008;34(5):681–7. https://doi.org/10.1016/j.burns.2007.08.025.
12. Jabir S, Frew Q, Magdum A, El-Muttardi N, Philp B, Dziewulski P. Microvascular free tissue transfer in acute and secondary burn reconstruction. Injury. 2015;46(9):1821–7. https://doi.org/10.1016/j.injury.2015.04.029.
13. Ozkan B, Savran S, Albayati A, Uysal CA. The use of hammock method for an end-to-side arterial anastomosis in lower extremity flap transfers. Microsurgery. 2023;43(7):750–1. https://doi.org/10.1002/micr.31098.
14. Ziegler B, Hundeshagen G, Will PA, Bickert B, Kneser U, Hirche C. Role, management, and outcome of free flap reconstruction for acute full-thickness burns in hands. Ann Plast Surg. 2020;85(2):115–21. https://doi.org/10.1097/SAP.0000000000002412.
15. Seth AK, Friedstat JS, Orgill DP, Pribaz JJ, Halvorson EG. Microsurgical burn reconstruction. Clin Plast Surg. 2017;44(4):823–32. https://doi.org/10.1016/j.cps.2017.05.014.

Bipedicled Thin Groin Flap for Anterior Neck Reconstruction

56

Hajime Matsumine and Hiroyuki Sakurai

Abstract

The skin on the anterior neck is thin and flexible as a result of its functional characteristics, and extensive scarring and contracture are likely to occur after severe burns to this area. In cases of severe burn-related cervical contracture, the deformity may involve not only the neck but also the lower lip, torso, and anterior chest. Treatment of cervical scar contracture aims to improve both function and cosmetics. When there is scar contracture after extensive neck burns, it is important to replace the skin with the widest and thinnest possible skin flap to reconstruct a cosmetically acceptable submentocervical angle. By including the vascular pedicles of the groin flap on both right and left sides and placing the center of the flap in the midline of the inferior abdominal region, we have developed an extensive flap of sufficient range to allow primary closure of the donor site. This chapter provides a detailed explanation of our so-called "bipedicled thin groin flap" technique for anterior neck reconstruction.

Keywords

Groin flap · Neck reconstruction · Bipedicled flap · Scar contracture · Thin flap

56.1 Background of the Technique

Severe burns to the anterior neck are likely to result in extensive scarring and contracture because the skin in this area is thin and flexible as a result of its functional characteristics. In cases of severe cervical contracture in burn injury, the deformity covers a wide area and may involve not only the neck but also other areas, including the lower lip, torso, and anterior chest. Treatment of cervical scar contracture aims to improve both function and cosmetic appearance.

Revision surgery using simple local flaps, such as Z-plasty, is appropriate for small linear scar contractures and minor localized scars. However, when the scar contracture occupies more than 50% of the entire neck area, suturing the flap can increase skin tensile strength and gravity, causing an unattractive irregular contour of the neck. Therefore, in cases of scar contracture after extensive neck burns, it is important to replace the skin with as wide and thin a skin flap as possible to reconstruct a cosmetically acceptable submentocervical angle.

The free groin flap was first reported by Daniel et al. in 1972 and since then has been used for reconstruction in various anatomical areas [1]. Given that it can be elevated as a thin flap on the distal edge, there have been some reports of this flap being used for reconstruction in cases of cervical scar contracture [2]. However, if the width of the skin flap exceeds 10 cm, primary closure of the donor site becomes difficult, so there are limits to its suitability for reconstruction that requires a wide skin island. Therefore, by including the vascular pedicles of the groin flap on both the right and left sides and placing the center of the flap in the midline of the inferior abdominal region, we have developed an extensive flap within the range where primary closure of the donor site can be performed [3]. This chapter provides a detailed explanation of our "bipedicled thin groin flap" technique for anterior neck reconstruction.

H. Matsumine (✉) · H. Sakurai
Department of Plastic and Reconstructive Surgery, Tokyo Women's Medical University, Tokyo, Japan
e-mail: matsumine.hajime@twmu.ac.jp; sakurai.hiroyuki@twmu.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_56

56.2 Characteristics and Indications of the Method

Our technique is indicated for cases in which the lower abdominal skin can be used as a donor site for a free skin flap. The traditional definition of a groin flap is an area of skin 10 cm superior and inferior to the inguinal ligament with a border on the sides that is 10 cm lateral to each anterior superior iliac spine. In Fig. 56.1, the right border of the groin flap is labeled A, the left border is labeled B (both shown in green), and C is the region located between A and B (shown in yellow) in the hypogastric midline region. The bipedicled thin groin flap is designed within the region comprised of A, B, and C (Fig. 56.1), meaning that this flap adds to the angiosome of both inguinal areas supplied by the superficial circumflex iliac artery (SCIA) on the right and left sides and the adjacent central abdominal region is supported by blood flow from the SCIA on both sides. Consequently, an extensive flap measuring over 30 cm in length and 10 cm in width can be elevated.

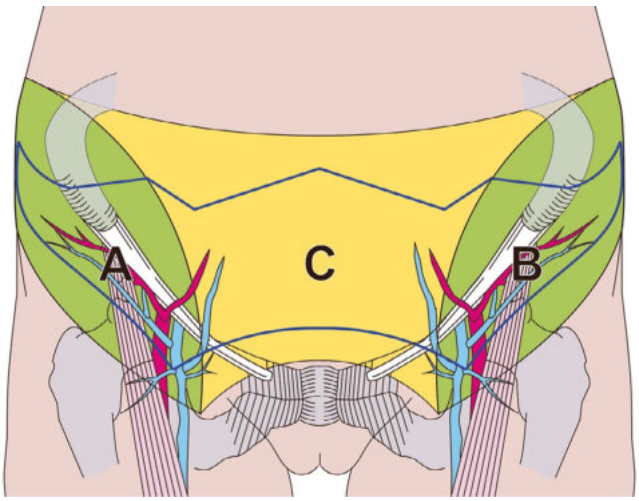


Fig. 56.1 Design of the bipedicled thin groin flap. The traditional definition of a groin flap is an area of skin 10 cm superior and inferior to the inguinal ligament with a border on the sides 10 cm lateral to each anterior superior iliac spine. A indicates the right border of the groin flap and B indicates the left border of the groin flap (both shown in green). C is the region located between A and B (shown in yellow) in the hypogastric midline region. The bipedicled thin groin flap is designed within the region comprised of A, B, and C. When harvesting the skin flap, it is possible to remove adipose tissue safely in region C down to the level of the subdermal plexus. However, in areas A and B, thinning of the adipose tissue should be performed as minimally as possible to avoid damaging the SCIA in the vascular pedicles

56.3 Specifics of the Technique

First, under general anesthesia, the patient is placed in a supine position with the neck overextended, and the neck scar contracture is sufficiently released. In the neck, there are many cases where not only the skin and subcutaneous tissue but also the platysma muscle is contracted, and this is also adequately released if necessary. After releasing the contracture and confirming that the neck can fully extend, the recipient arteries and veins are dissected and exposed in pairs on the left and right sides of the lateral neck. Next, within the area shown in Fig. 56.1, a bipedicled thin groin flap is designed and elevated in the lower abdomen to fit the size of the skin defect in the neck. After exposing the SCIA and the superficial circumflex iliac vein (SCIV) as vascular pedicles on both sides of the inguinal region, the flaps are elevated from the deep fascia. The skin flap is thinned immediately before transecting the vascular pedicle. Fat tissue is removed from the central part of the flap, which is sandwiched between the left and right SCIA, to a level where the subdermal vascular network can be seen. Fat removal is kept to a minimum around the vascular pedicles at both lateral edges of the flap to avoid damaging the feeding vessels. After sufficient hemostasis of the skin flap, the vascular pedicles from the SCIA and SCIV are transected at the bifurcation with the femoral artery and the saphenous bulb, respectively. The flap is then transferred into the skin defect wound after the cervical scar contracture is released. When suturing the flap, the center of the flap is sutured by tacking to the soft tissue near the hyoid bone to form the submentocervical angle. Before the flap is completely sutured, microvascular anastomoses are performed between the flap pedicles and recipient's vessels in the neck. Primary closure is performed at the lower abdominal donor site.

56.4 Tips

The advantages of the bipedicled thin groin flap are as follows: (1) there is no need to change the patient's position during surgery; (2) the primary suture at the donor site can be performed up to a flap width of about 12 cm; (3) vascular pedicles are located at both ends of the flap, making it easier to perform vascular anastomoses with recipient's vessels on both sides of the neck: and (4) the central part of the flap is furthest from the vascular pedicle, making it possible to perform thinning safely at this site. As described above, we believe that our bipedicled thin groin flap is one of the most effective surgical methods for reconstruction of scar contracture after burn injury to the anterior neck, provided that the lower abdominal skin can be used as a donor site.

56.5 Clinical Cases

56.5.1 Case 1

The patient was a 51-year-old woman with no notable family history or medical history whose clothing caught alight from a gas stove. She sustained 2% second-degree burns and 16% third-degree burns to the cervical region, precordial region, and both upper arms. On the same day, she was admitted to the Burns Unit at Tokyo Women's Medical University Hospital, where her burns were debrided four times, and a split-thickness skin graft was performed. Subsequently, widespread scar contracture was observed from the inframandibular rim to the anterior cervical and precordial regions, and extension of the cervical region became difficult (Fig. 56.2a, b). There was no scarring in the hypogastric area. A relatively large thin flap was considered necessary, so 8 months after the injury we performed reconstructive surgery using a bipedicled thin groin flap. In a position of hyperextension, after release of the contracture, the area of the cervical skin defect was calculated to be 30 cm × 11 cm (Fig. 56.2c). The hypogastric area was used to produce a bipedicled thin groin flap for transfer to the cervical region (Fig. 56.2d–f). Microvascular anastomoses were performed between the right SCIV and the right common facial vein, the right superior thyroid artery and the right SCIA, the left superthyroid artery and the left SCIA, and the left SCIV and the left internal cervical vein. The flap took favorably, and its thinness and size were maintained at 1 year after surgery. Extension of the cervical region became possible, and the shape of the submentocervical angle was very favorable (Fig. 56.2g, h). There were no functional complications at the donor site, and favorable cosmetic progress was observed (Fig. 56.2i).

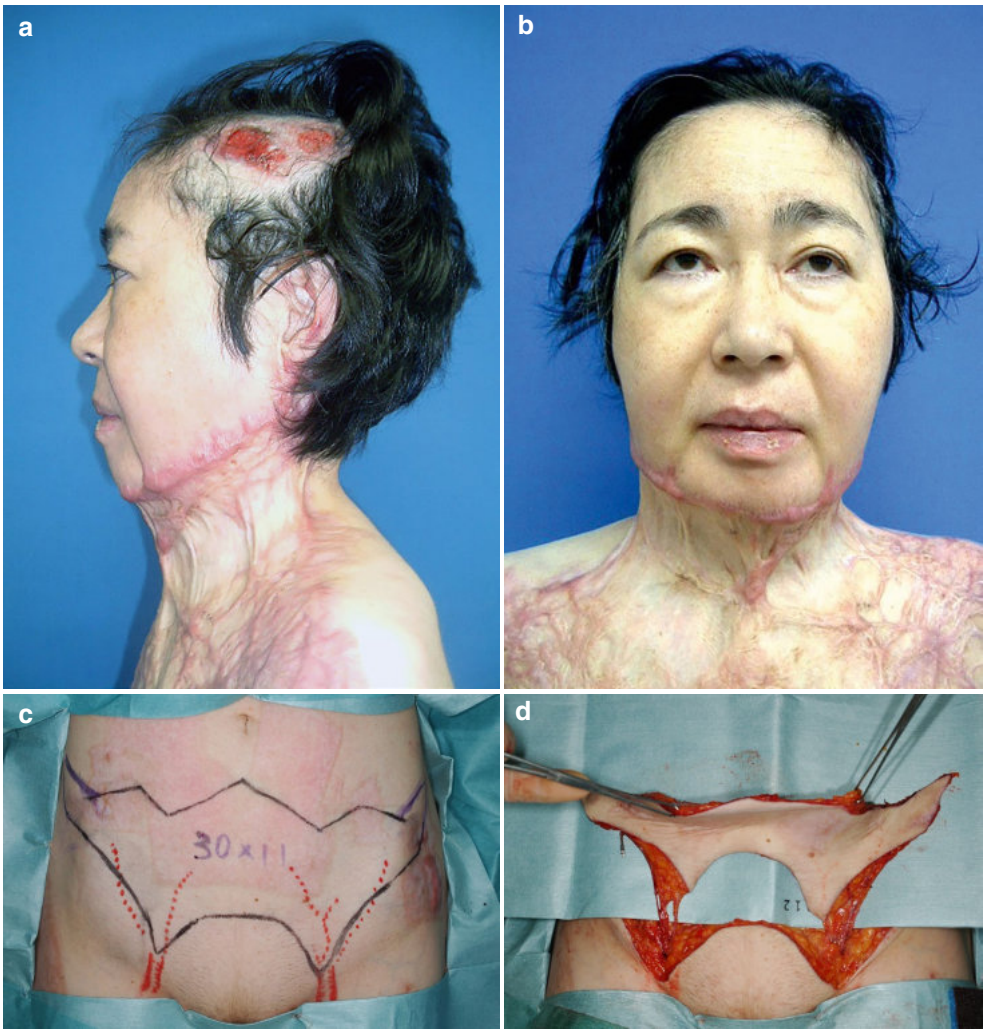


Fig. 56.2 Case 1. Preoperative lateral (**a**) and frontal (**b**) views. Intraoperative views (**c**), (**d**), and (**e**). (**c**) The bipedicled thin groin flap planned, measuring 30 cm × 11 cm. (**d**) Harvesting of the flap that was thinned by removing as much adipose tissue from the central region of the flap as possible. (**e**) Transfer of the flap to the defect. (**f**) Primary suture of the donor site. Postoperative lateral (**g**) and frontal (**h**) views in the cervical region and a view of the donor site (**i**) at 1 year after neck reconstruction. (*From* Matsumine et al. [3]; *with permission*)

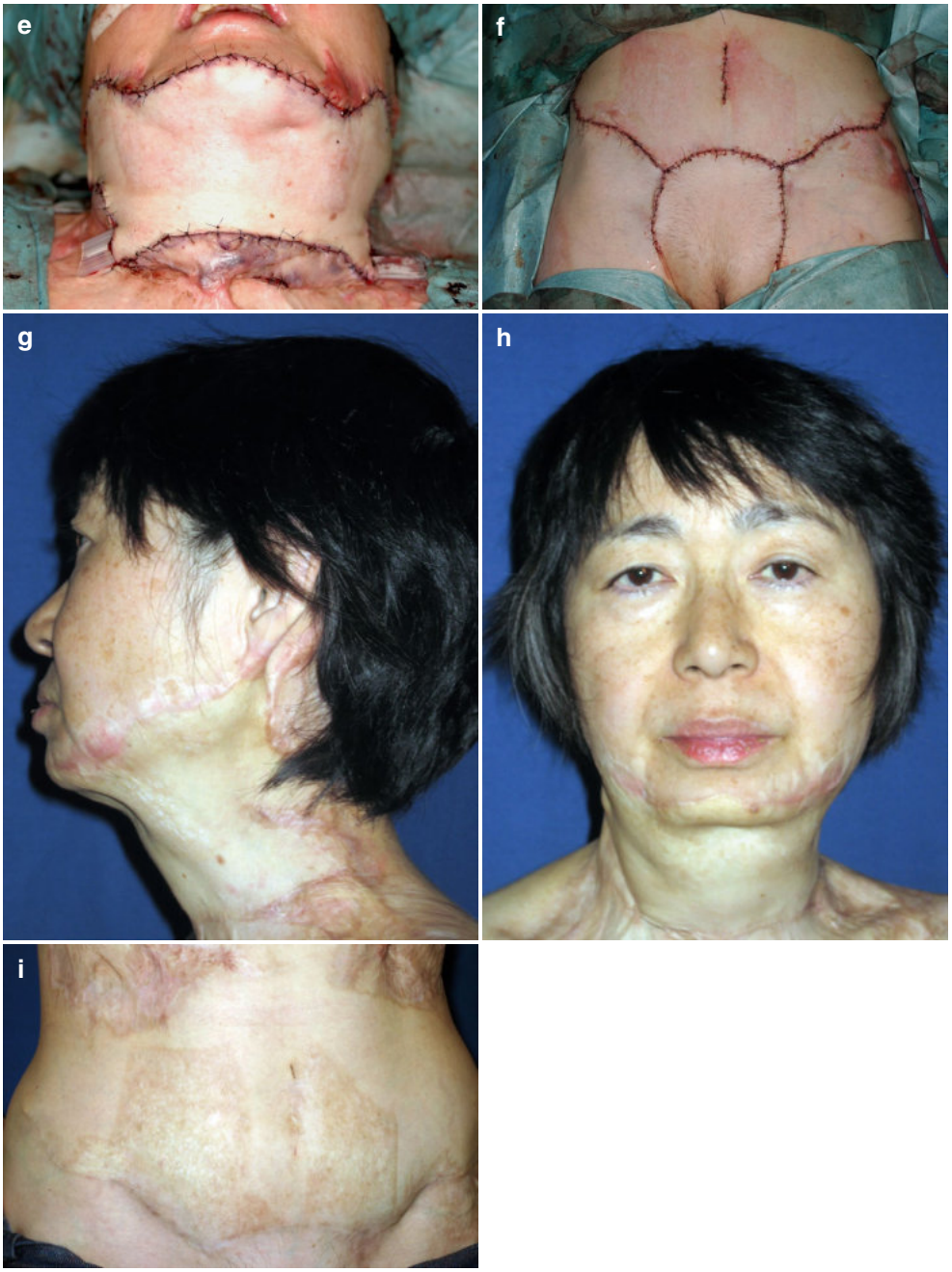


Fig. 56.2 (continued)

56.5.2 Case 2

The patient was a 50-year-old woman with no notable family history and a medical history of depression and epilepsy. She attempted suicide at her mother's house using a lighter to set her clothes alight, which resulted in 5% second-degree burns and 20% third-degree burns to her face, cervical and precordial regions, left upper arm, and back. On the same day, she was emergently admitted to Tokyo Metropolitan Government Hospital, where her burns were debrided four times, and a split-thickness skin graft was performed. Scar contracture was subsequently observed to extend from the mandible to the cervical region, restricting cervical movement (Fig. 56.3a). Surgery using a unilateral groin flap was planned, but because there was a strong desire to both release the scar contracture and mitigate the fear caused by an exten-

sive mesh graft, 5 months later the patient underwent reconstructive surgery using a 25 cm × 11 cm bipedicled thin groin flap (Fig. 56.3b, c). Microvascular anastomoses were performed between the right SCIV and the right common facial vein, the right superthyroid artery and the right SCIA, the left superthyroid artery and the left SCIA, and the left SCIV and the left facial vein (Fig. 56.3d). One year after reconstructive surgery, an adequate cervical extension was possible and scarring of the mesh graft was replaced for the most part by normal skin. No defatting was necessary to form the submentocervical angle, and remarkably favorable reconstruction was achieved (Fig. 56.3e). There were no functional complications at the donor site, and cosmetic progress was favorable.

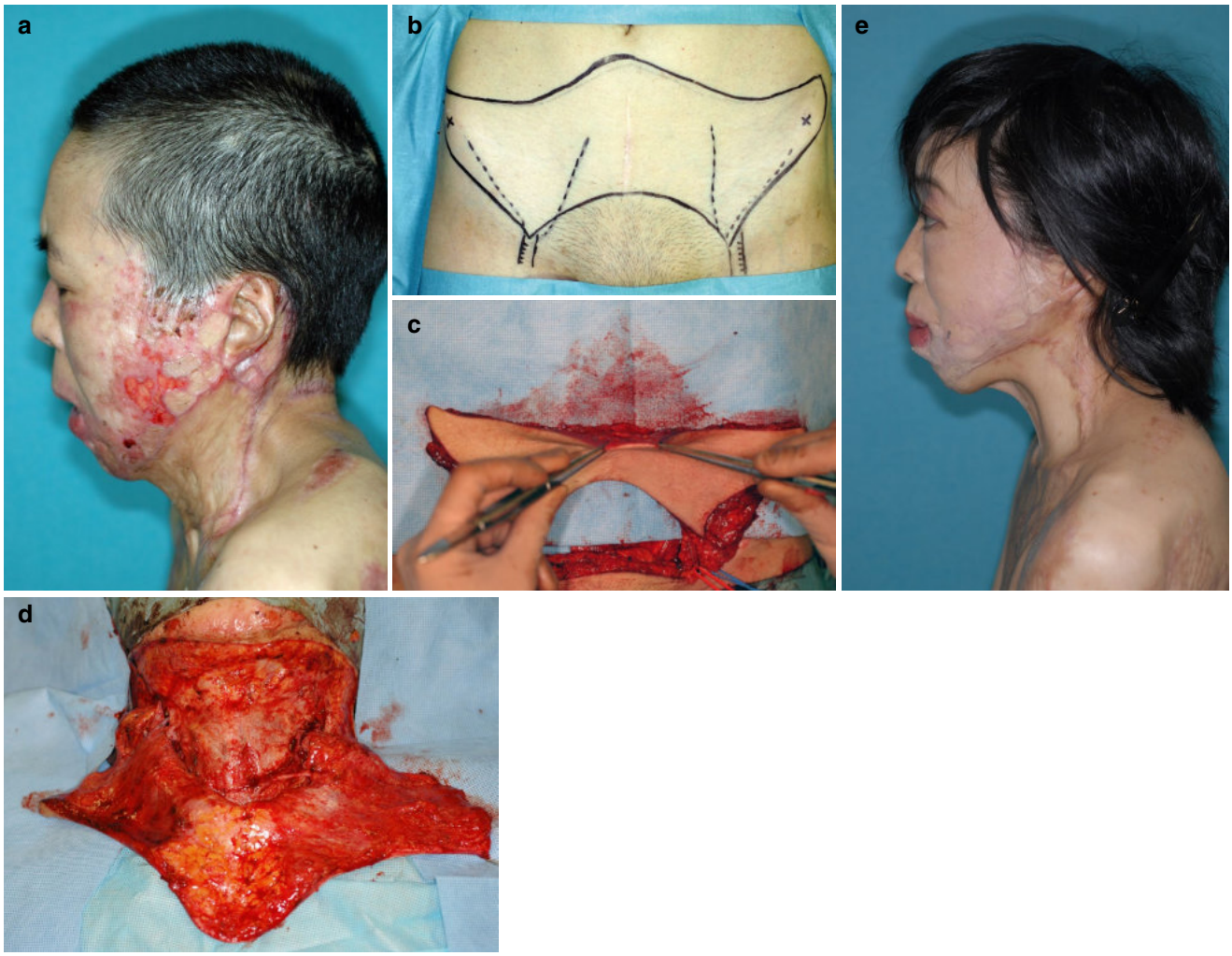


Fig. 56.3 Case 2. (**a**) Preoperative lateral view. Intraoperative views (**b**–**d**). (**b**) The bipedicled thin groin flap planned, measuring 25 cm × 11 cm. (**c**) Harvesting of the flap that was thinned by removing as much adipose tissue from the central region of the flap as possible. (**d**) Transfer of the flap to the defect. (**e**) Postoperative lateral view at 1 year after neck reconstruction. (*From* Matsumine et al. [3]; *with permission*)

References

1. Daniel RK, Taylor GI. Distant transfer of an Island flap by microvascular anastomoses. A clinical technique. Plast Reconstr Surg. 1973;52(2):111–7. https://doi.org/10.1097/00006534-197308000-00001.
2. Ohkubo E, Kobayashi S, Sekiguchi J, Ohmori K. Restoration of the anterior neck surface in the burned patient by free groin flap. Plast Reconstr Surg. 1991;87(2):276–84. https://doi.org/10.1097/00006534-199102000-00009.
3. Matsumine H, Sakurai H, Nakajima Y, et al. Use of a bipedicled thin groin flap in reconstruction of postburn anterior neck contracture. Plast Reconstr Surg. 2008;122(3):782–5. https://doi.org/10.1097/PRS.0b013e318180ed43.

Shape-Modified Radial Artery Perforator (SM-RAP) Flap for Burned Hand Reconstruction

57

Musa A. Mateev and Rei Ogawa

Keywords

Shape-modified flap · Radial artery · Perforator flap
Hand reconstruction · Donor-site morbidity · Scar contractures · Flap design · Recipient site · Flap elevation
Flap survival

57.1 Background of the Methods

The radial forearm flap was first reported by Yang et al. [1] in 1978. It is one of the most reliable conventional flaps for hand reconstruction. However, it is associated with donor-site morbidity, which includes problems due to major artery sacrifice, numbness of the dorsal hand, and the development of unfavorable scars. Consequently, many modifications of the radial forearm flap have been reported. These modifications have resulted in the expanded flap [2], the distally based flap [3], and the perforator-based flap/perforator flap [4–6] methods. In a further modification, we developed the "shape-modified radial artery perforator flap (SM-RAP flap) method" [7–9].

This chapter focuses on this SM-RAP flap. This is a thin radial forearm flap that is divided into 2–3 sections that are each fed by a separate perforator. The separate sections can be rotated individually, meaning that the flap can take a variety of shapes that match the shape of the recipient site. This and the thinness of the flap facilitate the inset of the flap and give it a huge advantage over other flap types. Moreover, the fact that the flap is constitutively long and narrow means that the donor site can be closed primarily with low skin tension, which avoids donor-site complications (Fig. 57.1).

We believe that radial artery sacrifice will not result in any serious deleterious short- or long-term outcomes**.** Nonetheless, it is important to carefully observe patients over a long term follow-up period.

M. A. Mateev
Department of Plastic, Reconstructive and Microsurgery and Hand Surgery, National Hospital of Kyrgyz Republic, Bishkek, Kyrgyzstan

R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_57

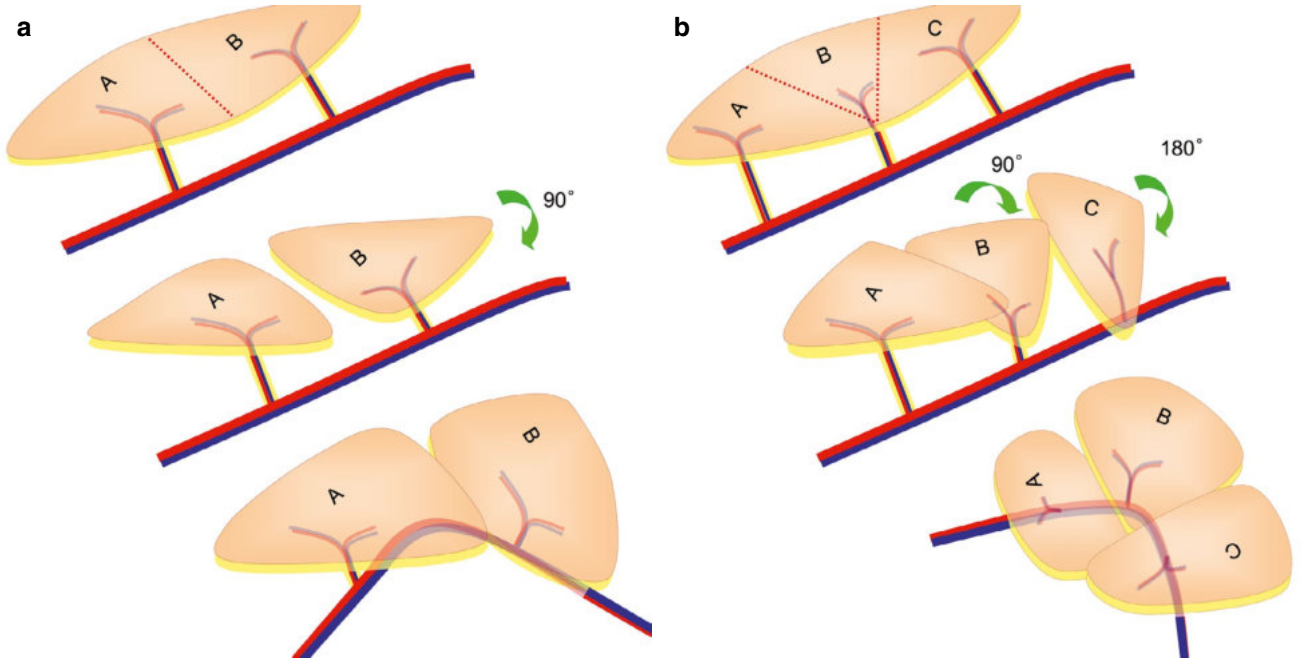


Fig. 57.1 (**a** and **b**), Depiction of the shape-modified radial forearm perforator flap (SM-RAP flap). This figure shows three separate perforator flaps. The top left and right ellipsoid flaps, which are fed by two and three perforators, respectively, can be transposed into ellipsoid recipient sites without any further dissection. However, these flaps can also be further divided into two and three sections, respectively. Rotation of these sections can then achieve different shapes. For example, the second section of the two-perforator flap can be rotated by 90° to achieve a triangular shape (bottom left). Similarly, the second and third sections of the three-perforator flap can be rotated 90° and 180°, respectively to achieve a square/round shape (bottom right). Thus, this narrow flap can be subdivided and reorganized to fit a wide range of differently shaped recipient sites

57.2 Specific Skills Needed

1. The flaps should be designed after debridement or complete release of scar contractures.
2. Depending on the size and shape of the recipient site, an elliptically shaped flap is designed on the radial forearm. This allows primary closure of the donor site (Fig. 57.1). The maximum width of the flap is defined by simply pinching the skin on the forearm. In our case series [9], the maximum width ranged from 3 to 7 cm (average 5.12 cm).
3. The average number of perforators that run from the radial artery is approximately 12 [10]. This not only permits the division of the flap into 2–3 sections, but it also means that each section can be designed in a comparatively free manner.
4. Flap dissection should be performed on a tourniquet.
5. Flap elevation is initiated from the lateral margin to identify perforators in the septocutaneous components. The medial border of the flap is then incised and the flap is islanded completely.
6. The perforator vessels are carefully dissected along their course to the radial artery in the lateral intermuscular septum. The flexor carpi radialis muscle is then retracted medially and the brachioradialis muscle is retracted laterally. The perforator vessels are then isolated from each other.
7. After elevating the flap, the donor site should be closed primarily while a tourniquet is applied.
8. The flap is then divided into two or three sections according to the course of the perforators to fit the shape of the recipient site (Fig. 57.1).
9. The proximal portions of the radial vessels are ligated and cut for distally based pedicled-flap transfer for ipsilateral-hand reconstruction.

57.3 Clinical Cases

57.3.1 Case 1

A 23-year-old man was involved in a car accident and developed scar contractures on his left hand over the following year (Fig. 57.2). After removing the scars, the tendons of the hand were exposed. The SM-RAP flap was used to cover the exposed structures. The flap was divided into two parts

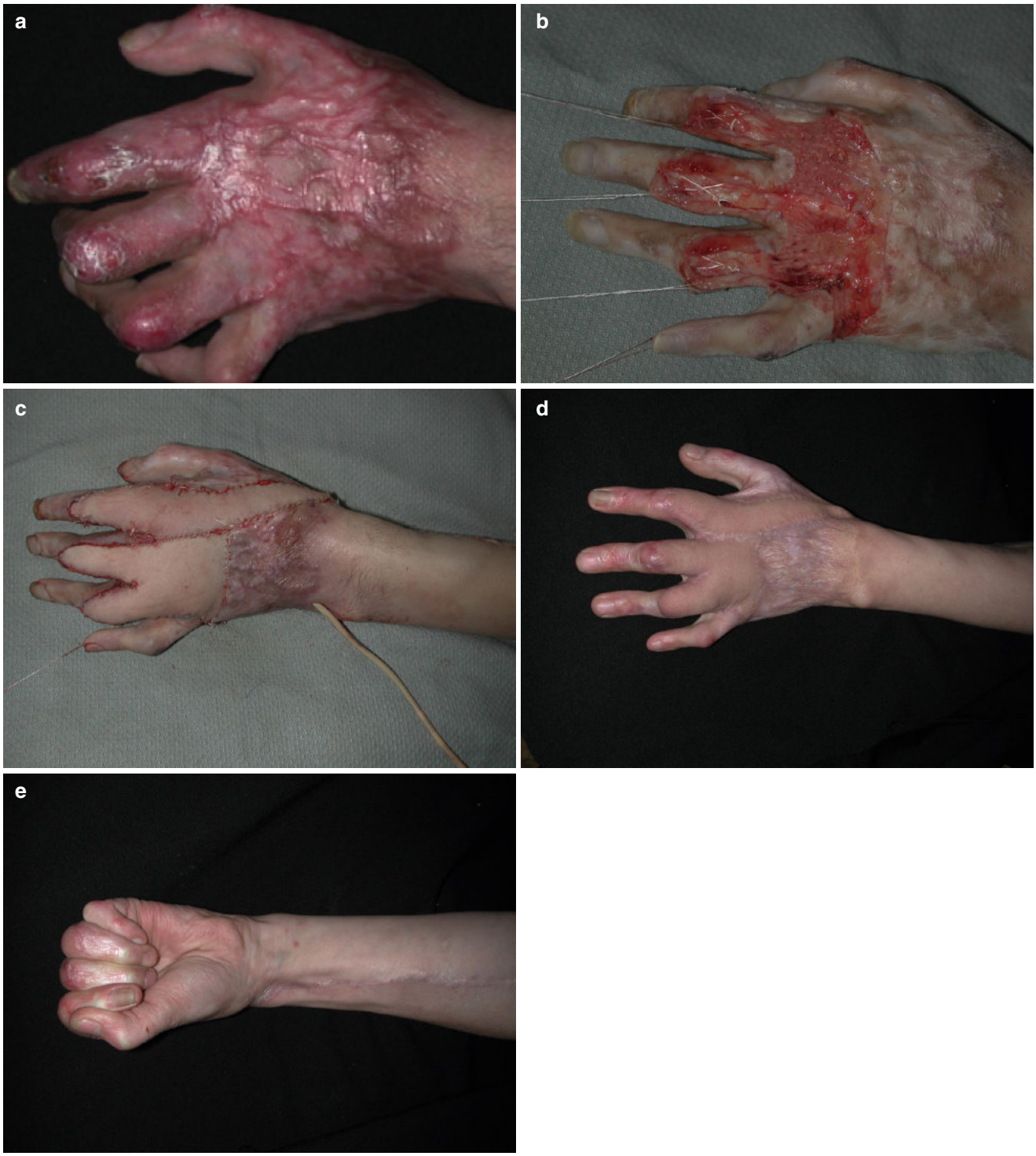


Fig. 57.2 (**a**–**e**), Case 1

according to its perforators. The first part was used to cover the index finger while the second part was rotated 180° to cover the middle and ring fingers. The flap survived completely and the functions of the affected fingers were recovered.

57.3.2 Case 2

A 23-year-old man sustained a left dorsal hand burn that resulted in scar contractures (Fig. 57.3). The tendons were exposed after completely releasing the contractures and the

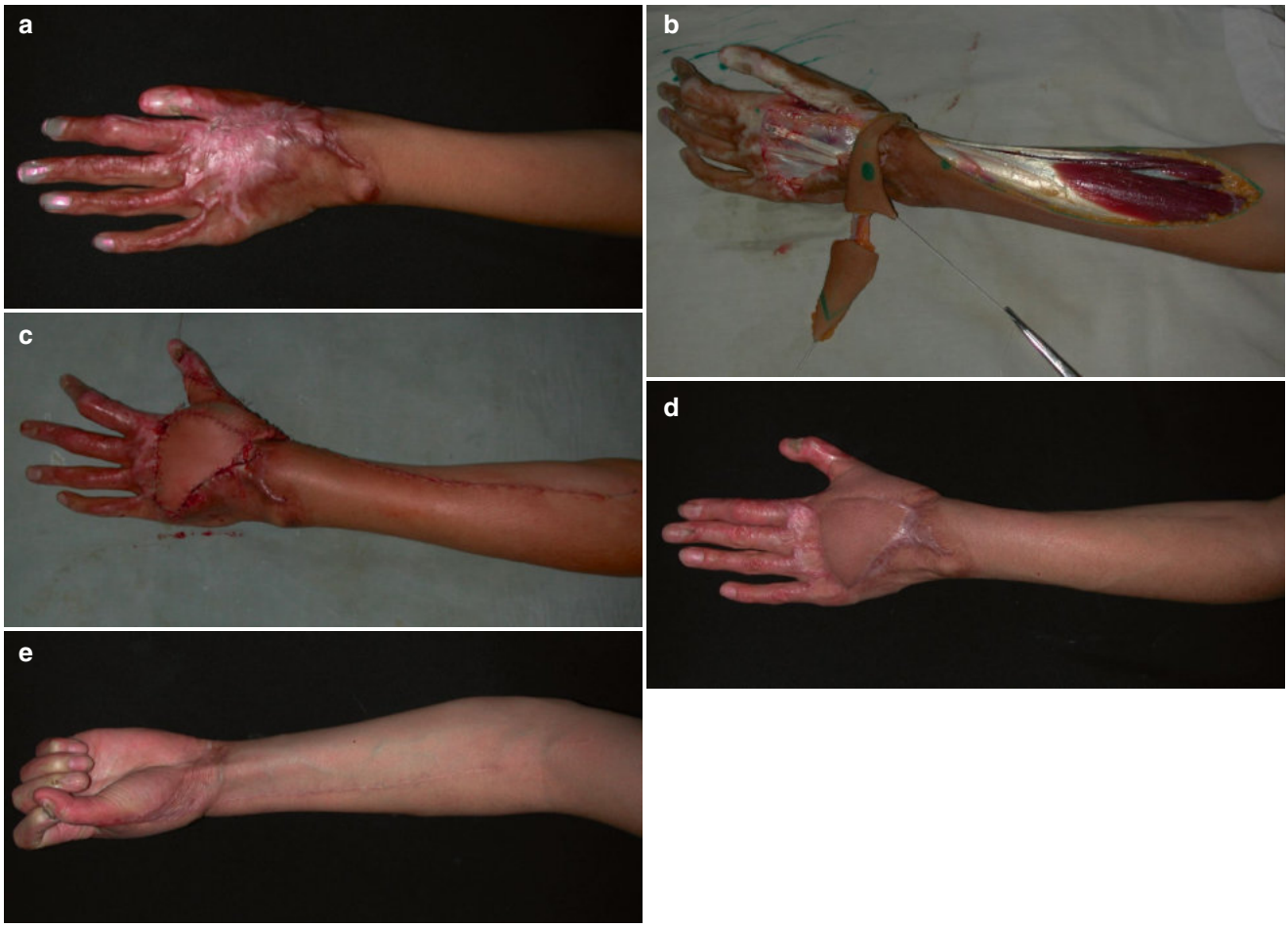


Fig. 57.3 (**a**–**e**), Case 2

wounds were covered with a 19 × 6 cm SM-RAP flap. The flap was rotated 180° as a propeller flap and then divided into two components according to the locations of the radial artery perforators. The proximal component was rotated 90° and used to cover the ulnar side of the dorsal hand. As a result, the metacarpophalangeal joints recovered their full range of motion. There were no complications, including numbness of the dorsal hand.

57.3.3 Case 3

A 5-year-old girl sustained a scald burn on the right palm from hot water (Fig. 57.4). The scar contractures that developed were released and reconstructed with an SM-RAP flap. Thus, the flap was divided into two parts. The first part was slightly incised to fit the recipient-site shape on the finger. The second part was advanced and placed next to the first part. The flap survived completely. Dysfunction of the hand has not been observed for 4 years now.

57.3.4 Case 4

A 21-year-old woman sustained a burn on the left-hand dorsum and developed scar contractures (Fig. 57.5). The contractures were released and reconstructed with an SM-RAP flap. Thus, the flap was divided into two parts and folded at the center of the flap so that the flap covered the recipient site. Aesthetic and functional improvements were observed.

57.3.5 Case 5

A 1.5-year-old woman sustained a severe burn on the right palm (Fig. 57.6). The contractures were released and reconstructed with an SM-RAP flap. The flap was divided into two parts and folded at the center of the flap so that the flap covered the recipient site. Aesthetic and functional improvements were observed. We did not observe any blood circulation or functional problems over 5 years after the operation.

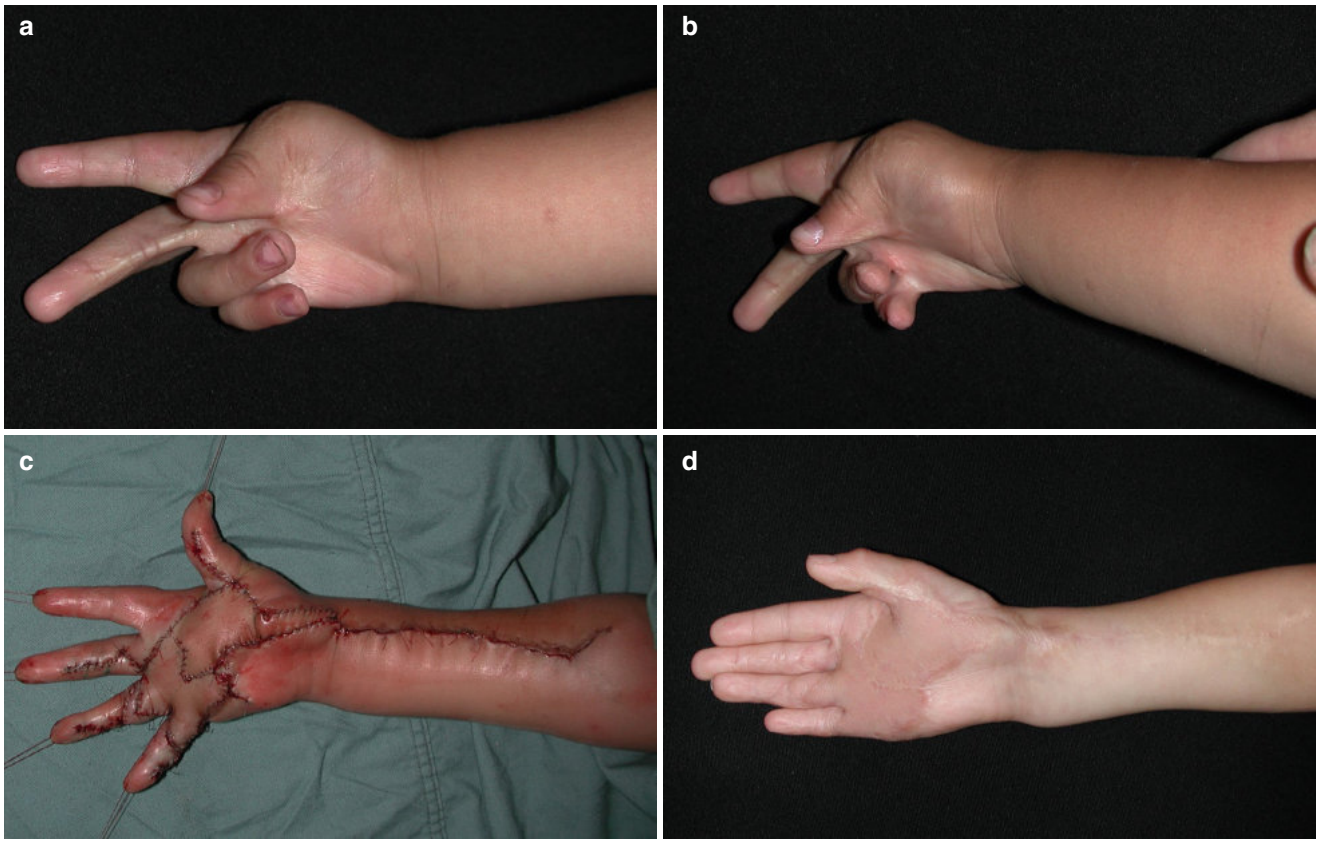


Fig. 57.4 (**a**–**d**), Case 3

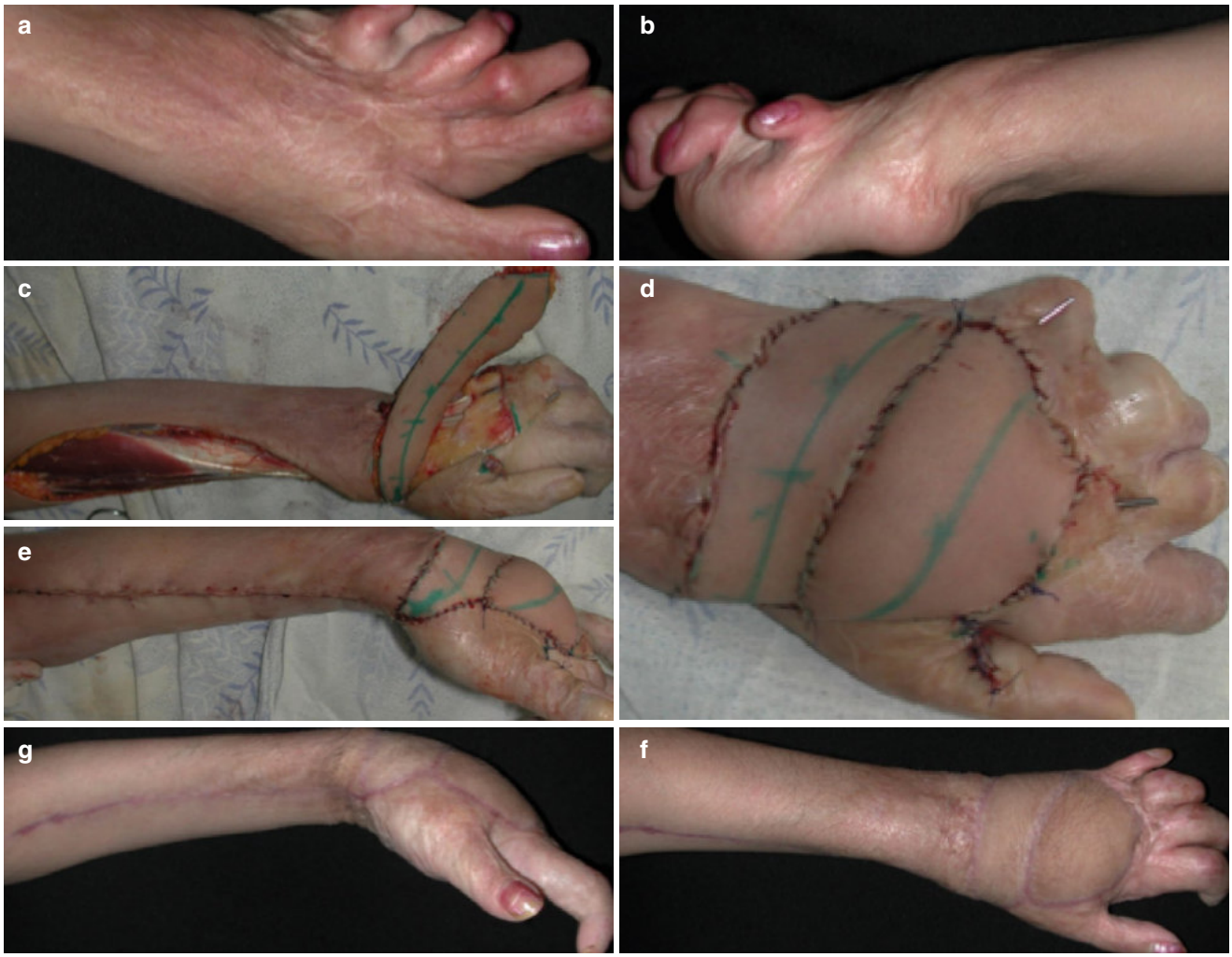


Fig. 57.5 (**a**–**g**), Case 4

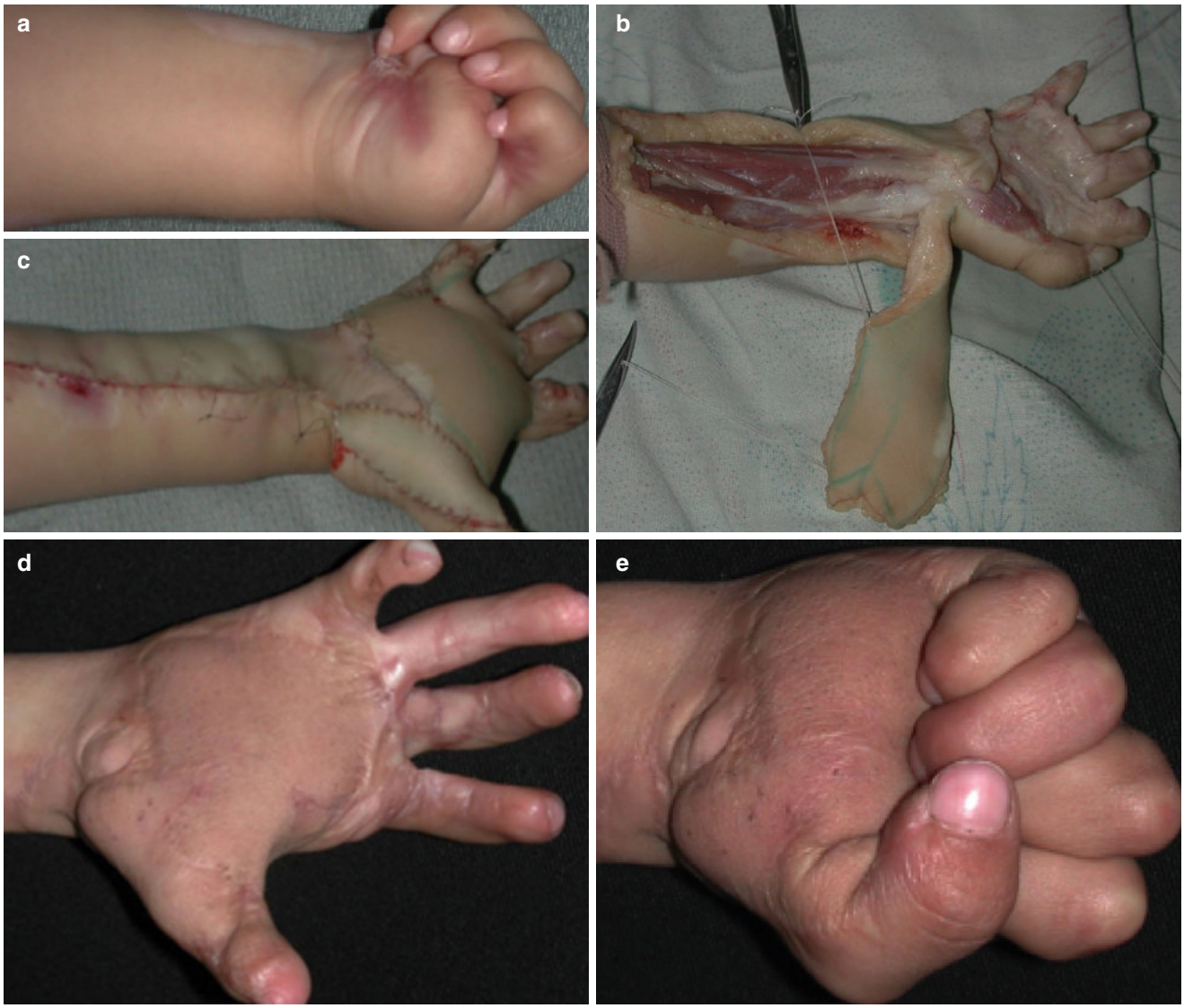


Fig. 57.6 (**a**–**e**), Case 5

References

1. Yang G, Chen B, Gao Y. The forearm free skin flap transplantation. Natl Med J China. 1981;61:139.
2. Kenney JG, DiMercurio S, Angel M. Tissue-expanded radial forearm free flap in neck burn contracture. J Burn Care Rehabil. 1990;11:443.
3. Weinzweig N, Chen L, Chen ZW. The distally based radial forearm fasciosubcutaneous flap with preservation of the radial artery: an anatomic and clinical approach. Plast Reconstr Surg. 1994;94:675.
4. Koshima I, Moriguchi T, Etoh H, Tsuda K, Tanaka H. The radial artery perforator-based adipofascial flap for dorsal hand coverage. Ann Plast Surg. 1995;35:474.
5. Safak T, Akyürek M. Free transfer of the radial forearm flap with preservation of the radial artery. Ann Plast Surg. 2000;45:97.
6. Koshima I, Tsutsui T, Nanba Y, Takahashi Y, Akisada K. Free radial forearm osteocutaneous perforator flap for reconstruction of total nasal defects. J Reconstr Microsurg. 2002;18:585.
7. Mateev M, Beermanov K, Subanova L, Novikova T. Reconstruction of soft tissue defects of the hand using the shape-modified radial forearm flap. Scand J Plast Reconstr Surg Hand Surg. 2004;38:228.
8. Mateev MA, Beermanov KA, Subanova LK, Novikova TV, Shaltakova G. Shape-modified method using the radial forearm perforator flap for reconstruction of soft-tissue defects of the scalp. J Reconstr Microsurg. 2005;21:21.
9. Mateev MA, Ogawa R, Trunov L, Moldobaeva N, Hyakusoku H. Shape-modified radial artery perforator flap method: analysis of 112 cases. Plast Reconstr Surg. 2009 May;123(5):1533–43.
10. Yang D, Morris SF. Radial artery perforator flap. In: Blondeel, Hallock, Morris, Neligan, editors. Perforator Flaps. St Louis, Missouri: Quality Medical Publishing, Inc; 2006. p. 301–17.

The Radial Artery Perforator-Based Adipofascial Flap for Coverage of the Dorsal Hand

58

Isao Koshima, Mitsunaga Narushima, and Makoto Mihara

Keywords

Adipofascial flap · Dorsal hand · Reverse flow flaps
Radial vessels · Anterior interosseous artery

Although the coverage of deep burn defects on the dorsal hand is quite complex and time-consuming, it can be accomplished by several techniques. Introduction of reverse flow island flaps obtained from the ipsilateral forearm or hand [1–4] has made the reconstruction easier, but even with the use of those flaps, the following serious problems often arise: (1) the sacrifice of major vessels of the arm and hand [5], (2) an unacceptable donor scar on the forearm or dorsal hand, and (3) the need for careful and complex dissection of vascular pedicles of small caliber. I believe these are the disadvantages of the reverse flow flaps. To overcome these disadvantages of the reverse flow skin flaps, adipofascial flap, which is fascial flap with overlying fatty tissue, is preferable to simple fascial flap because adipose tissue acts as an effective gliding surface of extensor tendons of the hand. We developed a radial artery perforator-based adipofascial flap for the repair of defects on the hand dorsum with minimal surgery [6]. In this chapter, we describe two cases in which radial artery perforator-based adipofascial flaps were successfully used.

58.1 Anatomical Considerations

58.1.1 Anterior Aspect of the Forearm

Most of the fasciocutaneous perforators emerge from the gaps between the muscles and tendons of the forearm. Several upper and lower branches of the radial artery supply the forearm skin. The upper branches supply the brachioradialis and the flexor carpi radialis muscles (3), while the lower branches penetrate through the fascia between the brachioradialis and the extensor carpi radialis longus muscles to supply the skin over the flexor aspect of the lower third of the forearm, taking a gently ascending direction.

At the distal one-third of the lateral border of the forearm, the radial artery gives off a few dorsal branches. After giving off the feeding capillary of the superficial radial nerve, one of the dorsal branches (3) runs posteriorly under or over the brachioradialis tendon and penetrates through the intertendinous space between the brachioradialis and the abductor pollicis longus tendons to supply the fascia on the lateral and the posterior aspects of the forearm (Fig. 58.1).

The suprafascial capillaries of the radial artery perforators run transversely in the lower two-thirds of the anterior aspect of the forearm. Only those radial perforators that follow the cutaneous nerves run in a direction parallel to the long axis of the forearm. On the lateral aspect of the forearm, the capillary network is tightly packed.

58.1.2 Posterior Aspect of the Forearm

The most important fasciocutaneous arteries arise from the posterior and anterior interosseous arteries. The descending branch of the posterior interosseous artery runs downward toward the wrist through the intermuscular septum between the extensor carpi ulnaris and the extensor digiti minimi muscles. After perforating the fascia at the distal one-third of the forearm, the descending branch divides into medial and lateral branches that ramify in the skin covering the flexor carpi ulnaris and the superficial extensor muscles.

The anterior interosseous artery has two main perforating arteries of the forearm (3). The superior branch passes through the space between the abductor pollicis longus and the radius and perforates the fascia at four fingerbreadths from the radial styloid process. It vascularizes the skin over

I. Koshima (✉) · M. Narushima · M. Mihara
Departments of Plastic and Reconstructive Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan
e-mail: koushim@hiroshima-u.ac.jp

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_58

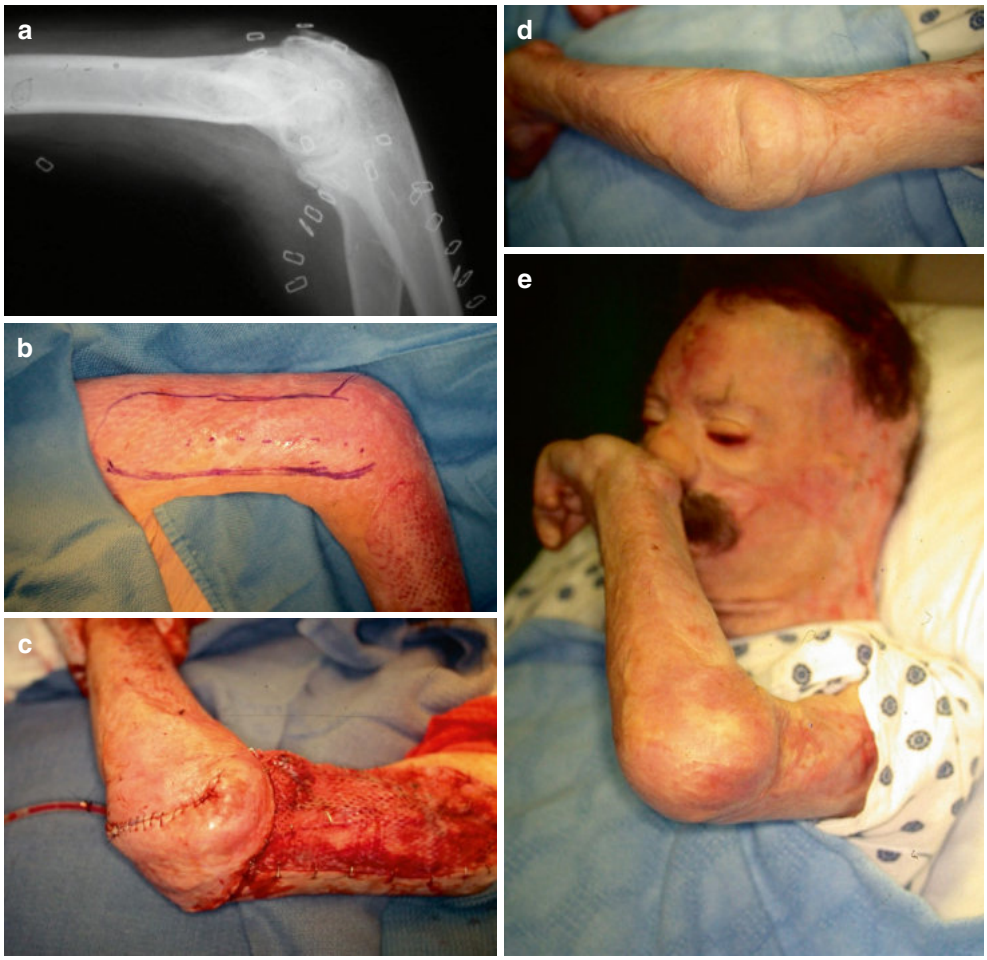


Fig. 58.1 Schematic drawing of the location of perforators on the posterior aspect of the forearm. *v* radial artery; *R* perforator of the radial artery; *A* perforator of the anterior interosseous artery; *P* perforator of the posterior interosseous artery; *n* superficial radial nerve; *a* abductor pollicis longus; *e* extensor pollitis longus; *b* extensor carpi radialis brevis; *L* extensor carpi radialis longus; *r* brachioradialis; *d* extensor digitorum; *m* extensor digiti minimi; *u* extensor carpi ulnaris

the lower third of the posterior surface and the lateral border of the forearm. The inferior perforating artery supplies most of the deep muscles of the posterior compartment.

58.2 Operating Technique

Prior to the flap transfer, Doppler audiometry and/or stereoscopic arteriograms of the affected arm are examined and a few fasciocutaneous perforators, arising from the radial vessels within 10 cm proximal to the radial styloid process, are detected in the lateral aspect of the distal forearm (Figs. 58.1 and 58.3a).

As for the flap transfer, after resection of the scar around the defect, an S-shaped incision through the posterolateral aspect of the forearm is made. Through this incision, a few fasciocutaneous perforators, including the dorsal superficial branch of the radial vessels can be found in the distal one-third of the lateral aspect of the forearm. They arise through the intertendinous septum between the brachioradialis, the abductor pollicis longus, and the flexor carpi radialis tendons, and enter the forearm adipofascia. After the proximal end of the adipofascial flap is transected, a distally based adipofascial flap with the dorsal superficial branch is elevated from the posterior aspect of the forearm. The proximal base of the flap is preserved widely, involving fascia and adipose tissue, around the fasciocutaneous perforator because skeletonization of the perforator often damages the blood circulation of the flap. The lateral forearm cutaneous veins and nerves (3) can be dissected and freed from the flap. They should be left on the forearm muscles. The flap is then turned distally to cover the defect on the dorsal hand, and a small amount of bleeding from the capillary vessels in the flap can be seen. Finally, after the donor forearm defect is closed directly, the transferred flap is covered with a split thickness or full thickness skin graft. Postoperatively, a bandage with slight pressure and without a tie-over is employed.

58.3 Clinical Cases

58.3.1 Case 1

A 38-year-old man suffered from a deep dermal burn on the left distal forearm and dorsal hand caused by a traffic accident. Two months after the burn, the resulting defect was

covered with a split thickness skin graft. However, the extensor tendons had been exposed to the skin defect of the dorsal aspect of the hand (Fig. 58.2a).

Prior to secondary repair, stereoscopic arteriograms of the affected arm were examined and a few fasciocutaneous perforators arising from the radial vessels were detected in the lateral aspect of the distal forearm, 6–9 cm proximal to the styloid process.

Half a year after the burn, a secondary operation was performed. After debridement around the defect, the dorsal superficial branch of the radial vessels was found in the distal one-third of the forearm. A distally based adipofascial flap was then elevated from the distal two-thirds of the posterior aspect of the forearm. Only the distal fasciocutaneous perforator was left as a vascular pedicle, and the flap was turned to cover the defect. Finally, the flap was covered with a split thickness skin graft.

The postoperative course was uneventful, and there was no necrosis of the skin graft, or forearm herniation. Active motion of the hand was allowed 3 weeks after surgery and the patient complained of forearm muscle dysfunction due to adhesion. One year after the flap transfer, the patient could use the affected hand without difficulty (Fig. 58.2b).

58.3.2 Case 2

A 26-year-old woman suffered from an avulsion injury of the dorsal hand and transection of the extensor tendon caused by a press machine. Although initial repair with the tendon suture and wound closure was performed, the avulsed skin became necrotized, resulting in a deep defect with exposure of the tendons (Fig. 58.3a). Preoperative stereoscopic arteriograms showed a fasciocutaneous perforator arising from the radial vessels in the lateral aspect of the distal forearm, 4 cm proximal to the styloid process.

Two months after the injury, following debridement of the necrotized skin, the perforator was found through an S-shaped longitudinal incision on the forearm. Then, a distally based adipofascial flap was raised from the entire posterior aspect of the forearm. The elevated flap with a perforator was passed through a subcutaneous tunnel in the lateral aspect of the wrist and turned to cover the defect on the hand (Fig. 58.3b). Finally, a full thickness skin graft with very thin fatty tissue from the groin region was placed over the transferred flap.

Postoperatively, the active motion of the hand was started 3 weeks after surgery. One year after the flap transfer, the reconstructed hand had no problems with minimal scarring and no sensory disturbance due to damage of the superficial radial nerve (Fig. 58.3c & d).

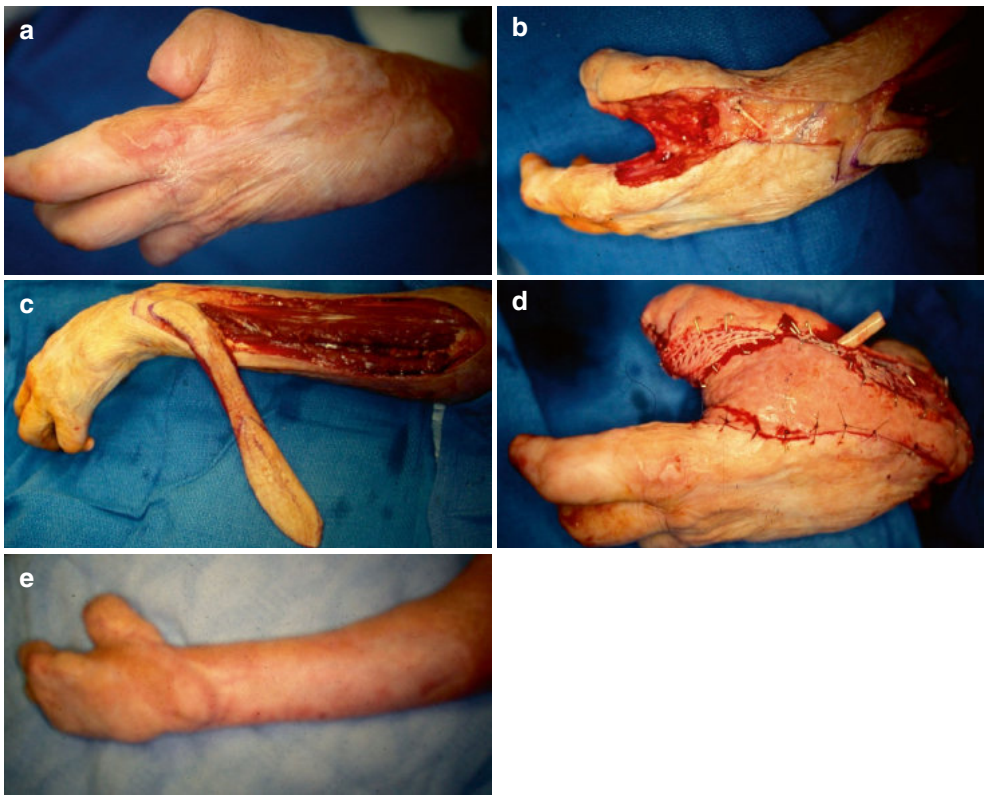


Fig. 58.2 A 38-year-old man with a deep dermal burn on the dorsal hand. (**a**) Even with a split thickness skin graft, tendon-exposing defects still remain. (**b**) Radial artery perforator adipofascial flap was elevated. (**c**) The flap turned over tendon, and split graft covered the flap. (**d**) Half a year after the surgery

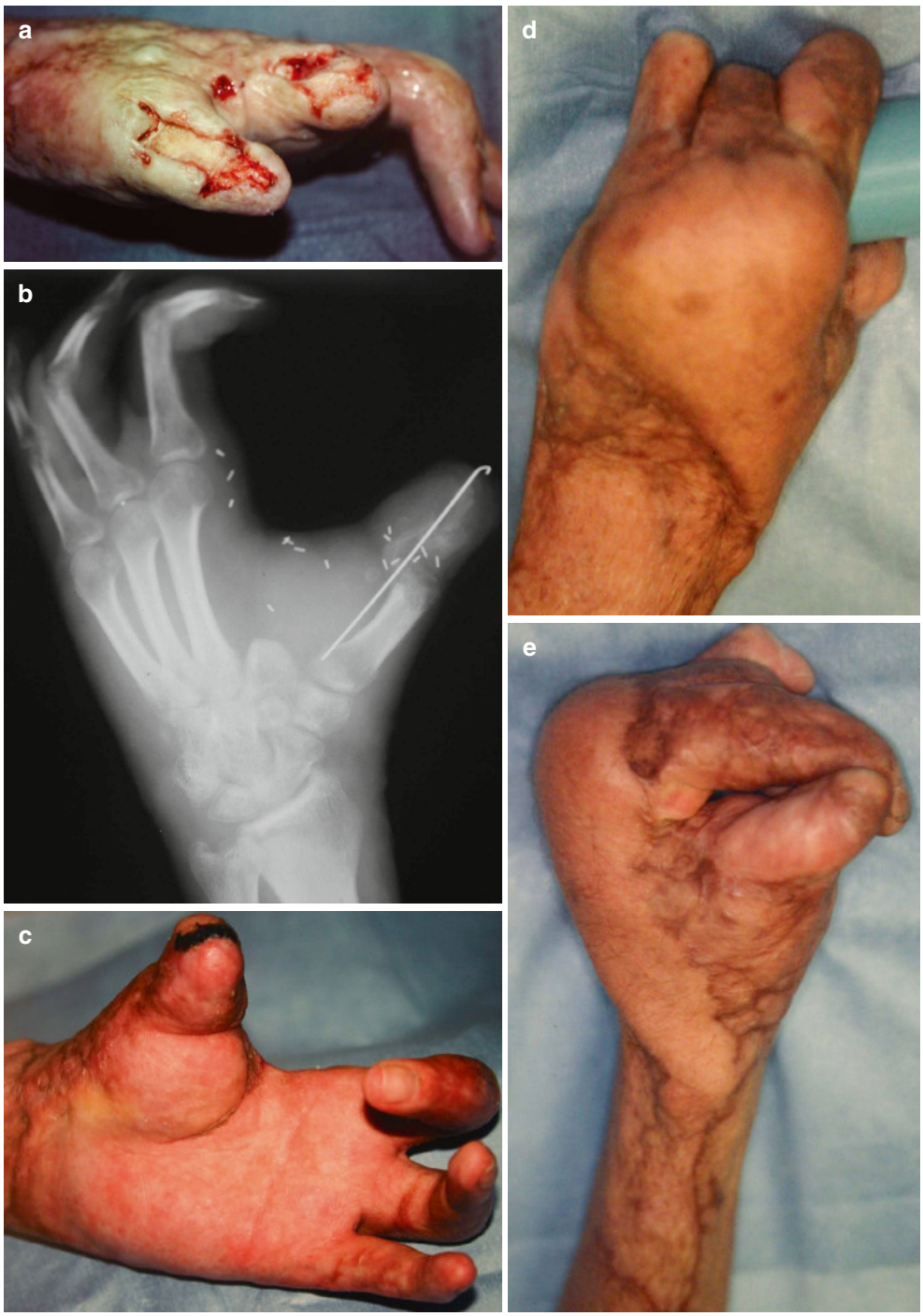


Fig. 58.3 (**a**) A 26-year-old woman with dorsal skin necrosis. (**b**) A distally based adipofascial flap with a perforator (*arrowhead*) is elevated and turned to cover the defect. (**c**) Full thickness skin graft from the groin region covered the fascia. (**d**) One year after the surgery

References

1. Song R, Song Y, Yu Y, Song Y. The upper arm free flap. Clin Plast Surg. 1982;9:27–35.
2. Soutar DS, Tanner NSB. The radial forearm flap in the management of soft tissue injuries of the hand. Br J Plast Surg. 1984;37:18–26.
3. Foucher G, Genechten F, Merle N, Michon J. A compound radial artery forearm flap in hand surgery: an original modification of the Chinese forearm flap. Br J Plast Surg. 1984;37:139–48.
4. Penteado CV, Masquelet AC, Chevrel JP. The anatomic basis of the fasciocutaneous flap of the posterior interosseous artery. Surg Radiol Anat. 1986;8:209–15.
5. Jones BM, O'Brien CJ. Acute ischaemia of the hand resulting from elevation of a radial forearm flap. Br J Plast Surg. 1985;38:396–7.
6. Koshima I, Moriguchi T, Etoh H, Tsuda K, Tanaka H. The radial artery perforator-based adipofascial flap for dorsal hand coverage. Ann Plast Surg. 1995;35:474–9.

Perforator Pedicled Propeller Flaps

59

Hiko Hyakusoku, Shimpei Ono, Musa Mateev, T. C. Teo, and Rei Ogawa

Keywords

Propeller flap · Axial rotation · Pedicle perforator · Soft tissue coverage · Local flap · Subcutaneous pedicled Muscle pedicled · Scar contracture · Flap classification Eccentric rotation · Preoperative evaluation · Island flap

59.1 Background of the Technique

Hyakusoku et al. [1] introduced a propeller flap for reconstructing the axilla and cubitus in 1991. Initially, the original propeller flap was used for intact fossa and was designed as a subcutaneous pedicled island flap. Since then, this flap has undergone significant refinement, leading to the development of various types of propeller flaps [2–11]. The most notable evolution is the perforator pedicled propeller (PPP) flap [5], which has become an essential option in the use of perforator flaps. The use of an eccentric perforator pedicle (Fig. 59.1a) enables a 180° rotation [6, 7], allowing it to cover defects over longer distances (Fig. 59.1b).

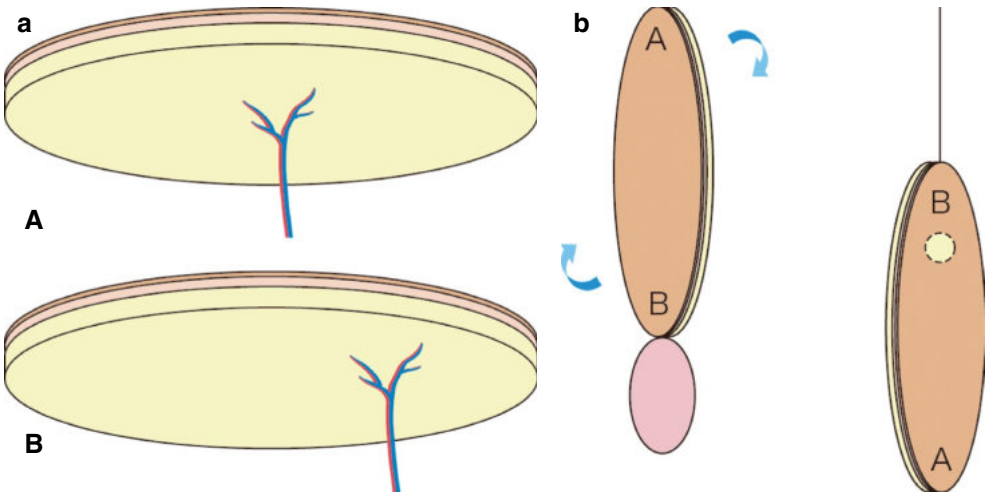


Fig. 59.1 (**a**) Location of the pedicle. (**b**) Rotation of the propeller flap

H. Hyakusoku
Nippon Medical School, Tokyo, Japan

S. Ono · R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

M. Mateev
Department of Plastic, Reconstructive and Microsurgery and Hand Surgery, National Hospital of Kyrgyz Republic, Bishkek, Kyrgyzstan

T. C. Teo
Department of Plastic and Reconstructive Surgery, Queen Victoria Hospital, East Grinstead, UK

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_59

59.2 Definition and Classification of the Propeller Flap

59.2.1 Definition

A propeller flap is defined as an "island flap with axial rotation." It is distinct from other flaps, such as advancement flaps, transposition flaps, and non-island rotation flaps. A propeller flap is essentially a local island flap based on a single dissected perforator, where the perforator acts as the pivot point for rotation.

59.2.2 Classification

Propeller flaps can be classified by type of pedicles (Fig. 59.2):

1. Subcutaneous-pedicled propeller (SPP) flap
   When a subcutaneous pedicle has multiple perforators, refinement of perforators is not required, but achieving a full 180° rotation is more challenging due to pedicle kinking compared to the perforator pedicle.
2. Perforator pedicled propeller (PPP) flap
   Refined perforators facilitate a 180° rotation, allowing for wider coverage than the SPP flap. This is the most widely adopted type of propeller flap.
3. Muscle-pedicled propeller (MPP) flap
   If musculocutaneous perforators are present, refinement is not necessary. A small portion of muscle can be attached to the skin island, forming an MPP flap.
4. Perforator-supercharged (PS) propeller flap
   When a longer propeller flap is needed, supercharging the perforators is beneficial.

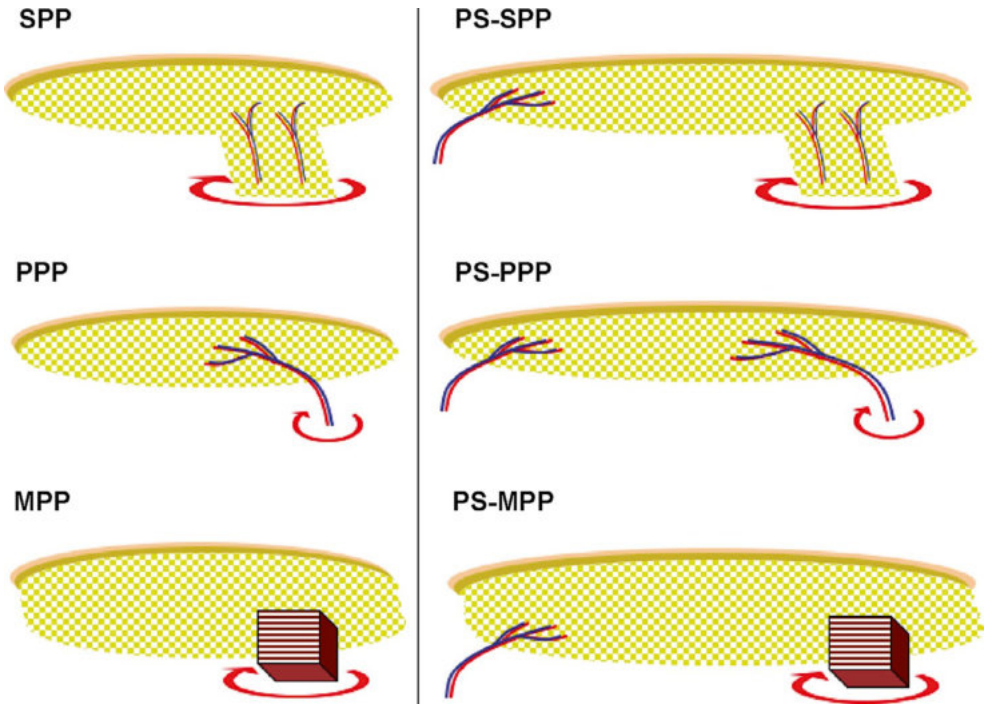


Fig. 59.2 Classification of the propeller flap

59.3 Specific Steps of the Method

The theoretical survival area of pedicled propeller flaps is similar to that of free perforator flaps. The course and distribution of perforators vary by region, necessitating a thorough preoperative evaluation using Doppler ultrasound, color Doppler ultrasonography, or multi-detector computed tomography (MD-CT) [12]. According to random pattern flap theory, a 1:2 (width-to-length) ratio ensures survival anywhere in the body, while 1:4 flaps are considered safe if a central vascular axis exists.

59.4 Clinical Cases

59.4.1 Case 1: Posterior Tibial PPP Flap

A 62-year-old man presented with an unstable burn scar on the medial aspect of his left ankle. He had sustained contact burns from hot ashes 50 years earlier, and although the original wound was treated with a skin graft, it failed to integrate over the medial malleolus and Achilles tendon regions. The wound eventually healed by secondary intention, resulting in an area of unstable scarring that intermittently broke down (Fig. 59.3a). Preoperative evaluation using a handheld Doppler ultrasound detected a strong signal from a perforator artery located 12 cm from the distal edge of the unstable scar. An island fasciocutaneous flap, based on this single perforator from the posterior tibial artery, was planned. The flap measured 21 cm in length and 5 cm in width (Fig. 59.3a). During surgery, the unstable scar was excised, resulting in a 4 × 7 cm defect. A generous posterior incision and subfascial approach (Fig. 59.3b) were used to locate the perforator (Fig. 59.3c). Other perforator vessels (Fig. 59.3d) were identified and ligated, except for the selected one (Fig. 59.3e). The flap was then rotated 180° around the perforator to cover the defect. The secondary defect on the proximal calf was closed directly (Fig. 59.3f). Healing was uneventful, and at the final review 8 months later (Fig. 59.3g), the flap had successfully replaced the unstable area with no further breakdown.

59.4.2 Case 2: Facial Artery PPP Flap

A 31-year-old woman with epilepsy sustained a deep dermal burn from hot water during a seizure 2 years prior (Fig. 59.4a, b). Following scar debridement, a 12 × 7 cm defect was noted, prompting the design of a facial artery PPP flap on her left neck (Fig. 59.4c). The flap was elevated and transferred to the recipient site. An additional flap was created using cheek skin, and the defect was covered by rotation (Fig. 59.4d, e). Both flaps survived completely, leading to an improvement in the disfigurement of her left face (Fig. 59.4f).

59.4.3 Case 3: Radial Artery PPP Flap

A 23-year-old man sustained a deep burn 2 months prior to the operation (Fig. 59.5a). An 8 × 4 cm defect on his right forearm was reconstructed using a radial artery PPP flap (Fig. 59.5b). Dissection began from the medial side of the marked line (Fig. 59.5c), proceeding above the deep fascia. The perforator, originating from the radial artery, was identified 2 cm from the distal part of the flap, with a length of 2 cm and a diameter of 1.5 mm. The flap was then dissected from the proximal to the distal side along the lateral aspect. The final flap size was 11 × 5 cm. It was elevated and rotated 135° (Fig. 59.5d). The flap survived completely, resulting in full functional recovery (Fig. 59.5e, f).

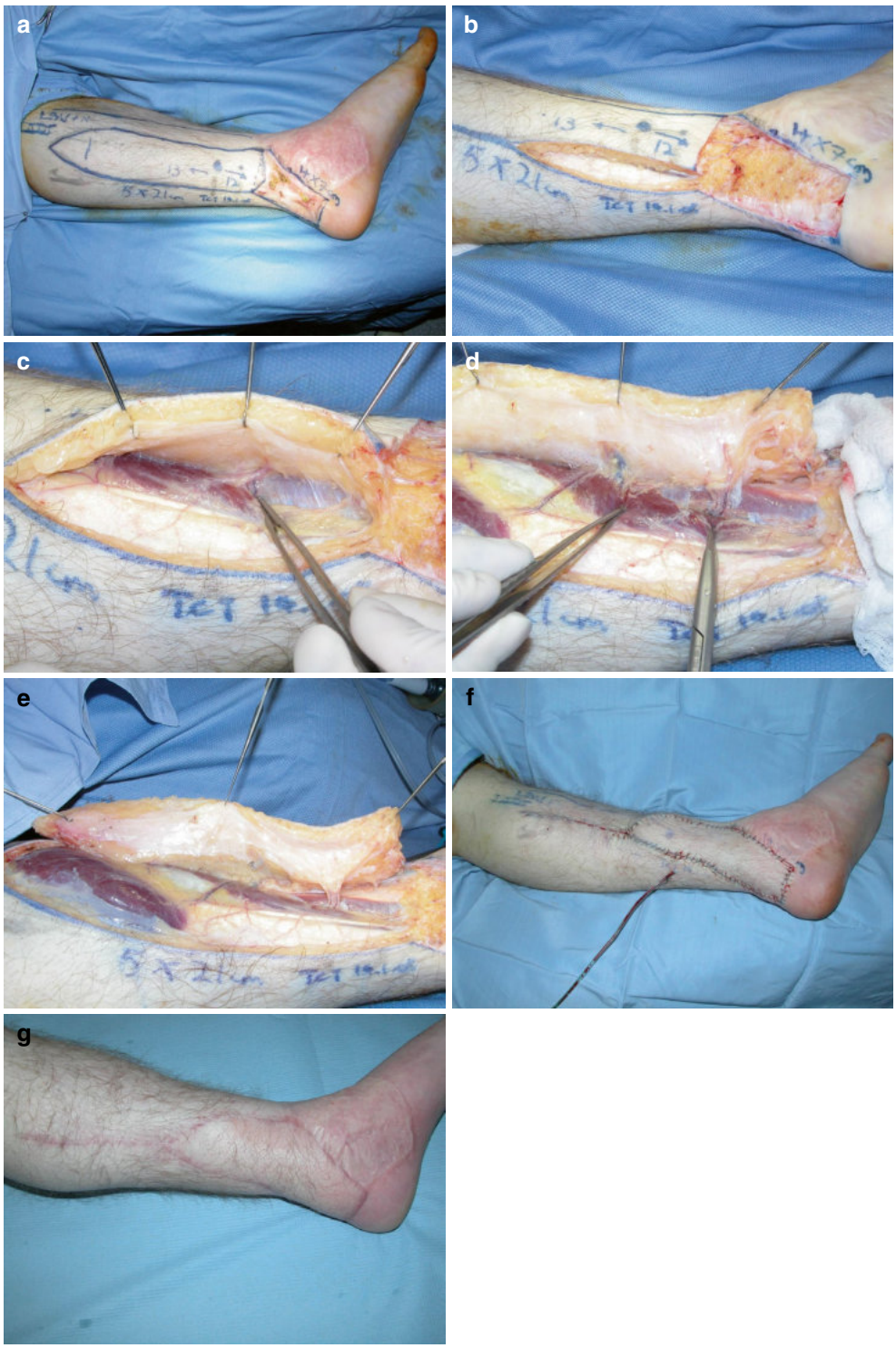


Fig. 59.3 (**a**) Flap design (**b**) Posterior incision of the flap (**c**) Main perforator (**d**) Additional perforator (**e**) Flap fully elevated (**f**) Immediate postoperative view (**g**) Eight-month postoperative view. Case 1: Posterior tibial PPP flap

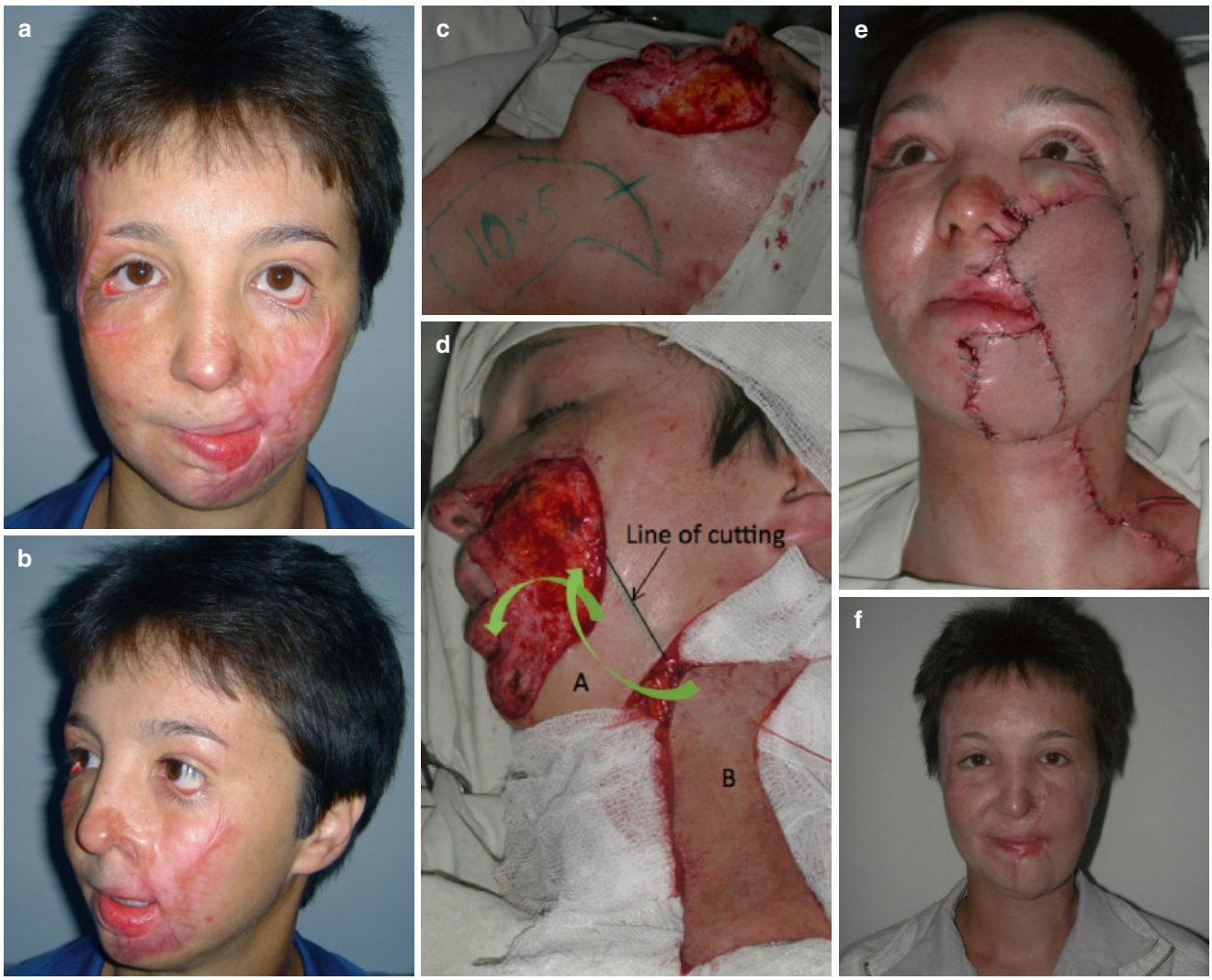


Fig. 59.4 (**a**) Preoperative frontal view (**b**) Preoperative lateral view (**c**) Flap design (**d**) Flap rotation (**e**) Immediate postoperative view (**f**) Six-month postoperative view. Case 2: Facial artery PPP flap

59.4.4 Case 4: Dorsal Pedis Artery PPP Flap

A 14-year-old boy sustained an extensive scald burn on his left foot 5 years ago, which led to contracture and deformity of the first toe (Fig. 59.6a). After releasing the scar contracture, a 6 × 3 cm defect was noted on the plantar surface (Fig. 59.6b). An interphalangeal longitudinal Kirschner wire was inserted to stabilize the joints. Elevation of the dorsal pedis artery PPP flap began at the medial border of the flap, under the fascia, and extended to the distal part of the dorsal pedis artery (Fig. 59.6c, d). The perforator was located 3 cm distally from the proximal part of the flap (Fig. 59.6e), measuring 2 cm in length and 1 mm in diameter. The flap was then rotated 110°, and the donor site was closed primarily (Fig. 59.6f, g). The Kirschner wire was removed 2 weeks later. The flap survived completely (Fig. 59.6h).

59.4.5 Case 5: Circumflex Scapular Artery PPP Flap

A 30-year-old man presented with severe scar contracture of the left axilla following a full-thickness burn injury sustained in Vietnam (Fig. 59.7a, b). The contracted area was initially incised, and the upper arm wound was sutured. Due to the extensive raw surface extending from the anterior axillary line to the back, a propeller pedicled propeller flap (PPP flap) was designed in the scapular region (Fig. 59.7c), with the circumflex scapular artery serving as the pedicle. A small flap was created in the upper scapular region to facilitate easier closure of the donor site, forming a bilobed flap. The flap was then rotated 180° and sutured to the recipient site (Fig. 59.7d, e). It survived completely, and rehabilitation began 2 weeks postoperatively (Fig. 59.7f).

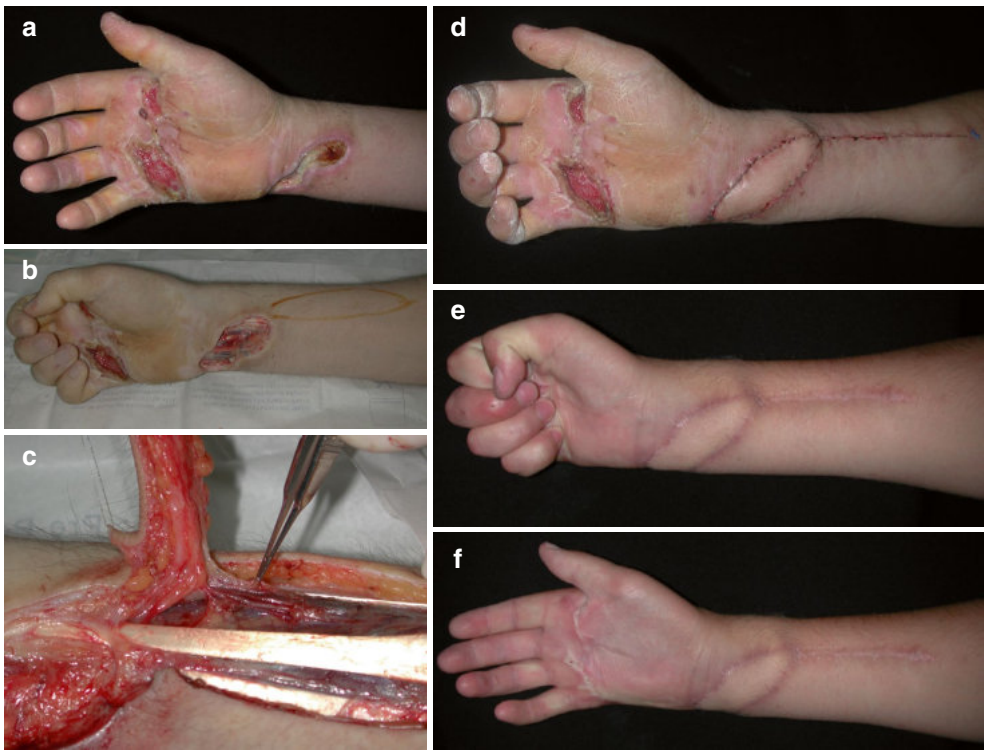


Fig. 59.5 (**a**–**f**), Case 3: Radial artery PPP flap

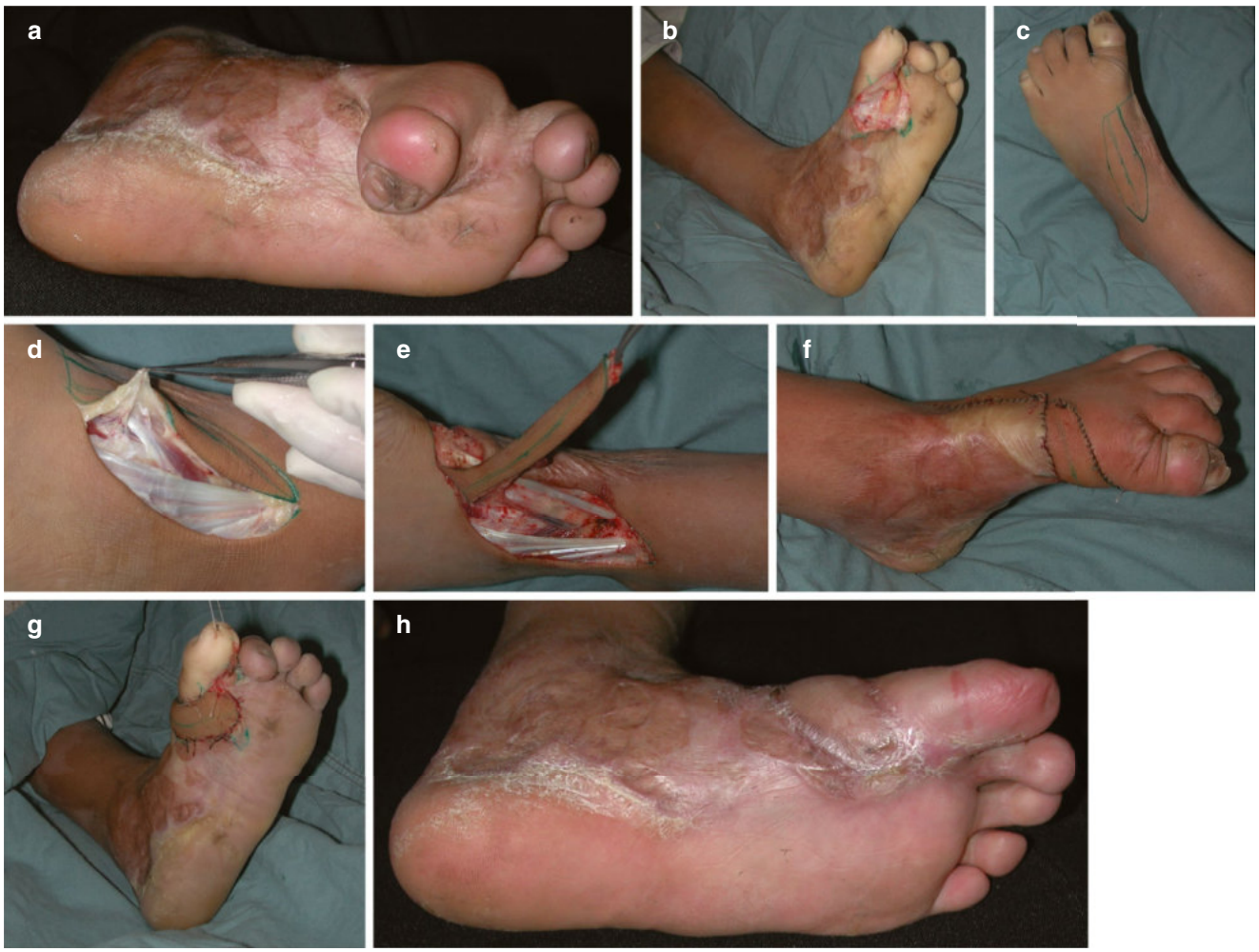


Fig. 59.6 (**a**–**h**), Case 4: Dorsal pedis artery PPP flap

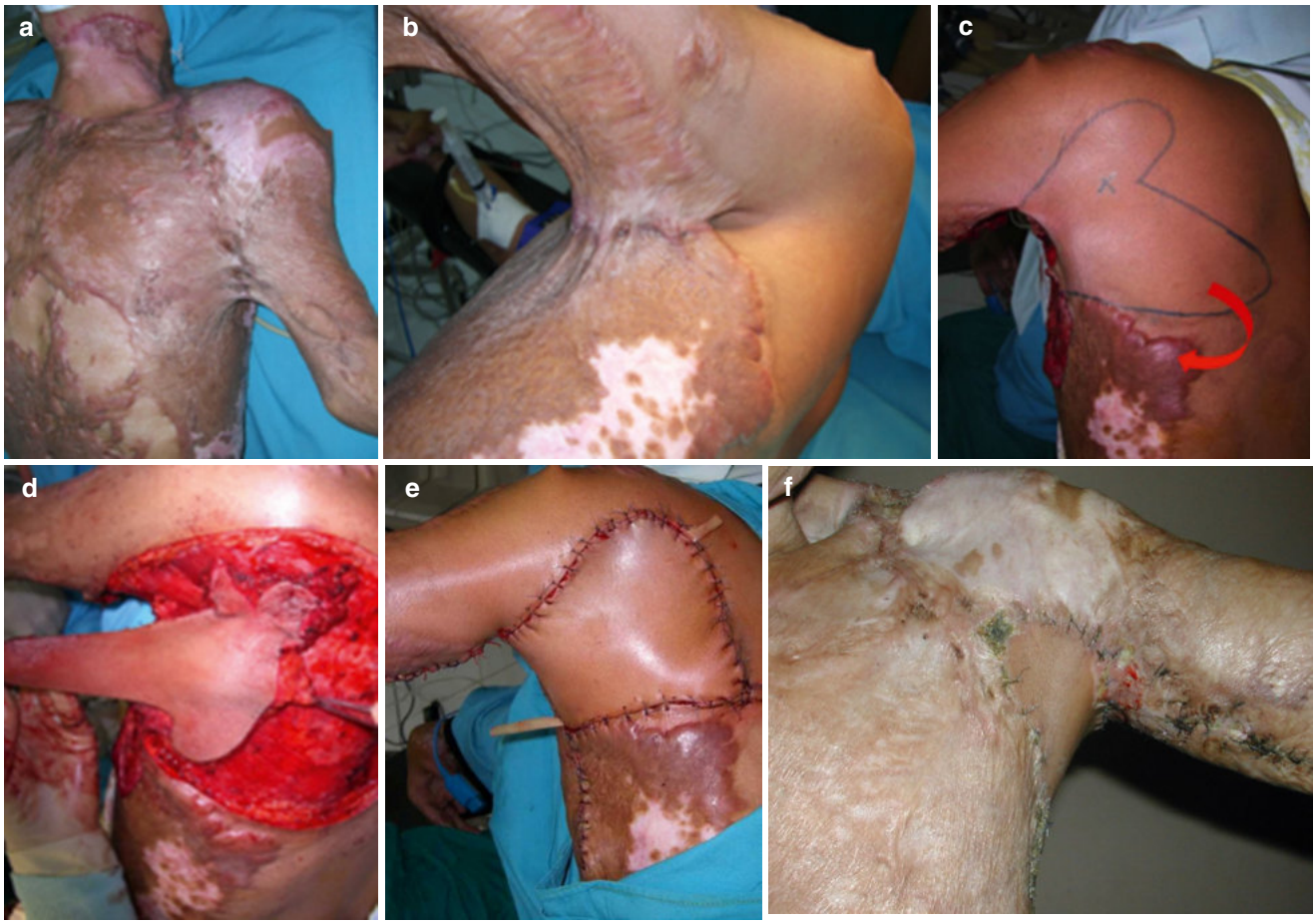


Fig. 59.7 (**a**–**f**), Case 5: Circumflex scapular artery PPP flap

59.4.6 Case 6: Perforator Supercharged PPP Flap

A 40-year-old woman with scar contracture from the anterior aspect of the left shoulder joint to the axilla (Fig. 59.8a) underwent scar contracture release and flap reconstruction. Preoperatively, shoulder abduction was 70° and extension was 20°. After releasing the scar contracture, an 18 × 6 cm defect from the anterior shoulder to the axilla was created (Fig. 59.8b). As the scapular circumflex artery perforator-based propeller flap alone was insufficient in size, the distal portion of the skin island was extended toward the posterior neck, incorporating a transverse cervical artery perforator, creating a perforator-supercharged propeller flap (Fig. 59.8c). The flap was elevated, identifying and including the scapular circumflex artery perforator (blue arrow) and the transverse cervical artery perforator (yellow arrow) within the flap (Fig. 59.8d). The skin island was rotated 180° (e), and the additional perforator and accompanying vein at the distal end of the skin island were anastomosed to the thoracoacromial artery and vein on the defect side (Fig. 59.8f). The flap fully survived, and shoulder abduction improved to 150° and extension to 45° (Fig. 59.8g).

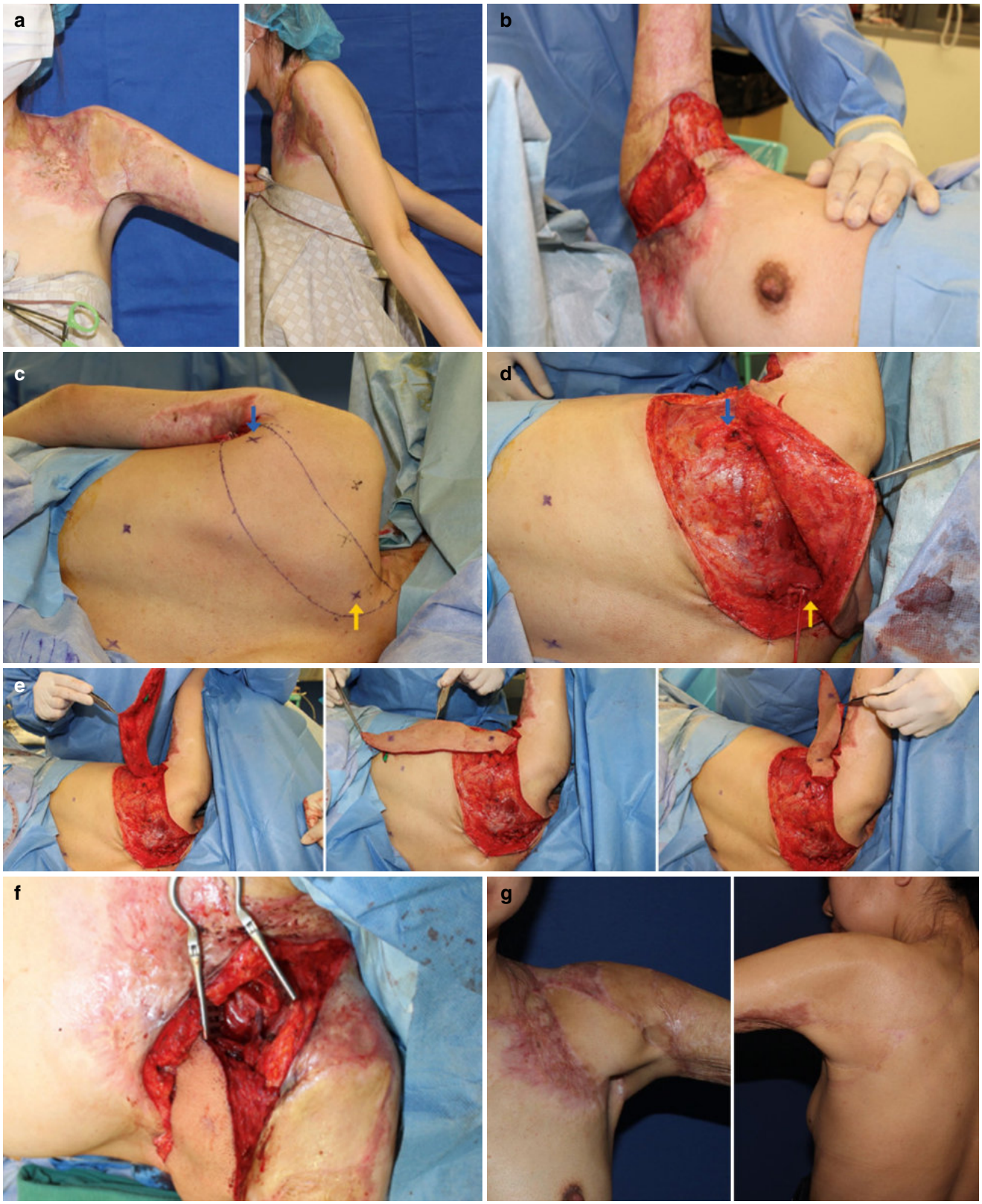


Fig. 59.8 (**a**–**g**), Case 6: Perforator supercharged PPP flap

References

1. Hyakusoku H, Yamamoto T, Fumiiri M. The propeller flap method. Br J Plast Surg. 1991;44:53–4.
2. Hyakusoku H, Iwakiri I, Murakami M, Ogawa R: Central axis flap methods.Burns 32: 891–896, 2006.
3. Hallock GG. The propeller flap version of the adductor muscle perforator flap for coverage of ischial or trochanteric pressure sores. Ann Plast Surg. 2006;56(5):540–2.
4. Moscatiello F, Masià J, Carrera A, Clavero JA, Larrañaga JR, Pons G. The 'propeller' distal anteromedial thigh perforator flap. Anatomic study and clinical applications. J Plast Reconstr Aesthet Surg. 2007;60(12):1323–30.
5. Hyakusoku H, Ogawa R, Oki K, Ishii N. The perforator pedicled propeller (PPP) flap method: a report of two cases. J Nippon Med Sch. 2007;74:367–71.
6. Jakubietz RG, Jakubietz MG, Gruenert JG, Kloss DF. The 180-degree perforator-based propeller flap for soft tissue coverage of the distal, lower extremity: a new method to achieve reliable coverage of the distal lower extremity with a local, fasciocutaneous perforator flap. Ann Plast Surg. 2007;59(6):667–71.
7. Wong CH, Cui F, Tan BK, Liu Z, Lee HP, Lu C, Foo CL, Song C. Nonlinear finite element simulations to elucidate the determinants of perforator patency in propeller flaps. Ann Plast Surg. 2007;59(6):672–8.
8. Pignatti M, Pasqualini M, Governa M, Bruti M, Rigotti G. Propeller flaps for leg reconstruction. J Plast Reconstr Aesthet Surg. 2008;61(7):777–83.
9. Rubino C, Figus A, Mazzocchi M, Dessy LA, Martano A. The propeller flap for chronic osteomyelitis of the lower extremities: a case report. J Plast Reconstr Aesthet Surg. 2008;62:e401.
10. Schonauer F, La Rusca I, Di Monta G, Molea G. Choosing the correct sense of rotation in 180 degrees propeller flaps. J Plast Reconstr Aesthet Surg. 2008;61(12):1492.
11. Rad AN, Singh NK, Rosson GD. Peritoneal artery perforator-based propeller flap reconstruction of the lateral distal lower extremity after tumor extirpation: case report and literature review. Microsurgery. 2008;28(8):663–70.
12. Ono S, Chung KC, Hayashi H, Ogawa R, Takami Y, Hyakusoku H. Application of multidetector-row computed tomography in propeller flap planning. Plast Reconstr Surg. 2011;127:703–11.

Perforator Supercharged Super-Thin Flap

60

Rei Ogawa and Hiko Hyakusoku

Keywords

Perforator-supercharged flap · Super-thin flap · Scar contracture · Reconstructive surgery · Vascular-pedicled flaps · Skin pedicle · Anatomical studies · Flap elevation · Anastomosis · Donor site · Microvascular techniques

60.1 Background of the Perforator Supercharged Super-Thin Flap

Most of our reconstructions have been extensive post-burn scar contracture cases, where extremely large but thin flaps are needed to reconstruct wide and contour-sensitive areas such as the face and neck [1–9]. For this reason, the flaps that we use are generally harvested from the back and chest as super-thin flaps whose blood flow is augmented by perforator supercharging (Fig. 60.1).

A key feature of the super-thin flap is its extremely thin and large form. This reflects the fact that it has been primarily thinned to the point that the subdermal-vascular network (subdermal plexus) can be seen through the minimal fat layer. However, the length and size of the super-thin flap can also be greatly increased by attaching perforators to the flap. Thus, these flaps can be considered to be "made-to-order flaps."

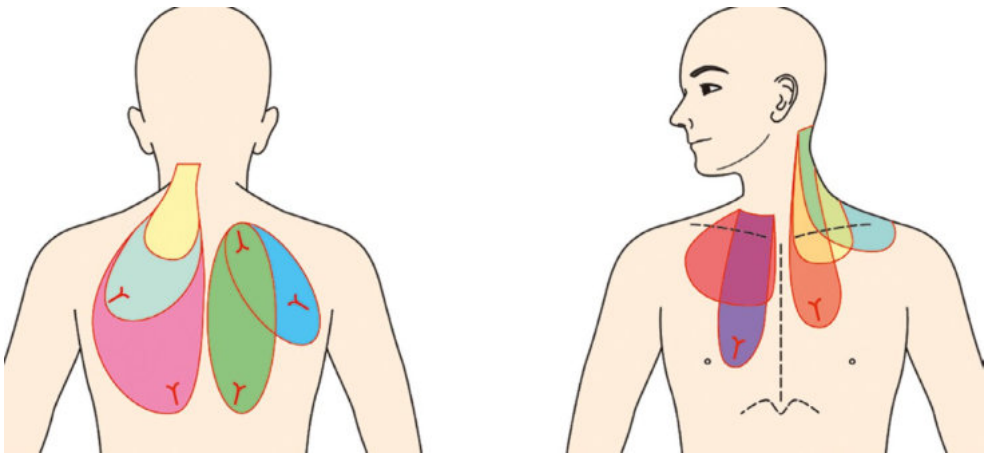


Fig. 60.1 Attaching a perforator to the flap means that free-style long and large flaps can be harvested

R. Ogawa (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan
e-mail: r.ogawa@nms.ac.jp

H. Hyakusoku
Nippon Medical School, Tokyo, Japan

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_60

60.2 Characteristics and Indications of Perforator-Supercharged Super-Thin Flaps

1. Attaching a perforator to the flap means that free-style long and large flaps can be harvested (Fig. 60.1).
2. Various flap types can be harvested, including free flaps, vascular-pedicled flaps, and skin-pedicled flaps. However, the skin-pedicled type is most reliable. Since venous drainage is a common problem of extremely thin flaps, flap reliability will increase if we can retain just one skin pedicle.

60.3 Specific Skills Needed to Generate Perforator-Supercharged Super-Thin Flaps

1. Before surgery, the flap is designed to match the shape of the recipient site. The requirement for perforator supercharging is also determined. This judgment should be based on the results of anatomical studies [6–8]. The existence of perforators that are proposed to supercharge the flap and recipient vessels should be confirmed by Doppler flowmetry [3]. Multi-detector CT (MD-CT) is also useful for detecting these vessels [10].
2. The flap is elevated from the periphery, after which the proposed perforators are confirmed macroscopically and attached to the flap.
3. After the flap is completely elevated, it is thinned down with curved scissors until the subdermal-vascular network can be seen through the minimal fat layer.
4. After debulking, we sometimes place a suction drain under the flap and apply slight pressure to prevent subdermal hematoma formation.
5. After the donor site is covered with a split-thickness skin graft or closed primarily, the thinned flap is rotated and placed onto the recipient site. The vessels are then anastomosed under a microscope and the flap is sutured to the wound bed.

60.4 Clinical Cases

60.4.1 Case 1

A 35-year-old woman sustained flame burns to 25% of her total body surface area (Fig. 60.2a). After emergent skin grafting, she developed severe scar contracture of the anterior neck. A super-thin flap that was based on a skin pedicle and supercharged with the dorsal intercostal perforator (D-ICAP, DICP) and the circumflex scapular vessels (CSVs) was transferred to reconstruct the area from the chest to chin, including the anterior neck (Fig. 60.2b–d). The flap area was very large (approximately 35 × 19 cm). The CSV was anastomosed to the facial vessels, and the D-ICAP was anastomosed to the transverse cervical vessels. The cervico-mental angle was clear. Three years after the operation, no recurrence of scar contracture or shrinking of the flap was observed (Fig. 60.2e, f).

60.4.2 Case 2

A 33-year-old woman developed a cervical scar contracture after a split-thickness skin graft was used in another hospital to treat an extensive burn (Fig. 60.3a). We planned to reconstruct it with a CSV-supercharged super-thin flap from the left back (Fig. 60.3b). The flap measured 30 × 15 cm and had a narrow 4 × 4-cm skin pedicle (Fig. 60.3c). The CSVs were anastomosed to the right facial vessels at the recipient site (Fig. 60.3e, f). The donor site was closed with a meshed skin graft. No shrinking of the flap was observed after 6 months (Fig. 60.3g, h).

60.4.3 Case 3

A 43-year-old woman sustained severe flame burns to 30% of her total body surface area during an accident. After emergent skin grafting, the patient developed severe scar contractures of the anterior neck and chest (Fig. 60.4a). To reconstruct the anterior neck and chest, we planned to transfer a perforator-supercharged super-thin flap (Fig. 60.4b). The flap was thus elevated with the CSV and D-ICAP/DICP (Fig. 60.4c). These vessels were then anastomosed to the facial vessels and transverse cervical vessels under a microscope, respectively. The patency of the D-ICAP artery could not be maintained due to technical problems during the case. The flap was sutured with nylon and the operation was concluded (Fig. 60.4d). However, in retrospect, supercharging of the D-ICAP artery was not needed in this case. The D-ICAP vein might help drain the blood in the distal area of the flap. The donor site was closed with a meshed skin graft. No shrinking of the flap was observed after 8 months (Fig. 60.4e, f).

60.4.4 Case 4

A 20-year-old man sustained burns and then developed an anterior neck contracture. The scar contracture was reconstructed with a large 22 × 7-cm super-thin skin-pedicled flap (Fig. 60.5a). Since the flap was too long to survive on the

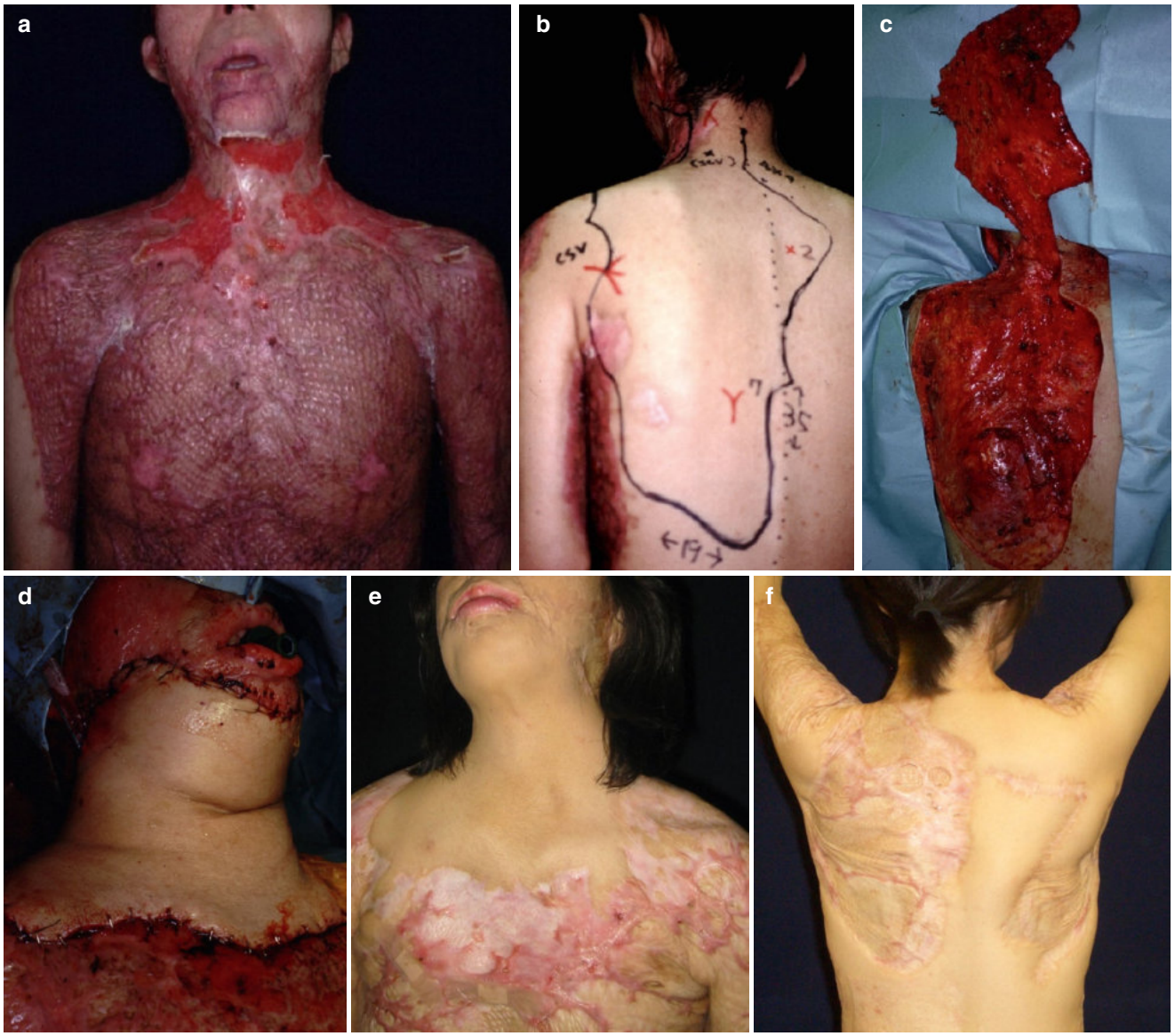


Fig. 60.2 (**a**–**f**), Case 1

basis of its skin pedicle alone, the second internal mammary artery perforator (IMAP) was attached to the distal end of the flap (Fig. 60.5b). The perforators were anastomosed to the facial artery and veins at the recipient site under a microscope (Fig. 60.5c). The flap survived completely and the contracture was effectively released 3 months after surgery (Fig. 60.5d). The scars matured 18 months after surgery (Fig. 60.5e).

60.4.5 Case 5

A 71-year-old man sustained burns and developed an anterior neck contracture. The contracture was reconstructed with a large 28 × 6 cm skin-pedicled super-thin flap (Fig. 60.6a). Since the flap was too long to survive on the basis of its skin pedicle alone, the second internal mammary artery perforator (IMAP) was attached to the distal end of the flap (Fig. 60.6b). Intraoperatively, both the second and seventh IMAPs were found, and both were attached to the flap (Fig. 60.6c). However, since only the position of the second IMAP matched with the recipient vessels, the second IMAP was anastomosed to the facial artery and veins (Fig. 60.6d). The flap survived fully and the contracture was largely released. Two years after surgery, the skin pedicle widened further and released the remaining tension. Three years after surgery, the scars had matured (Fig. 60.6e).

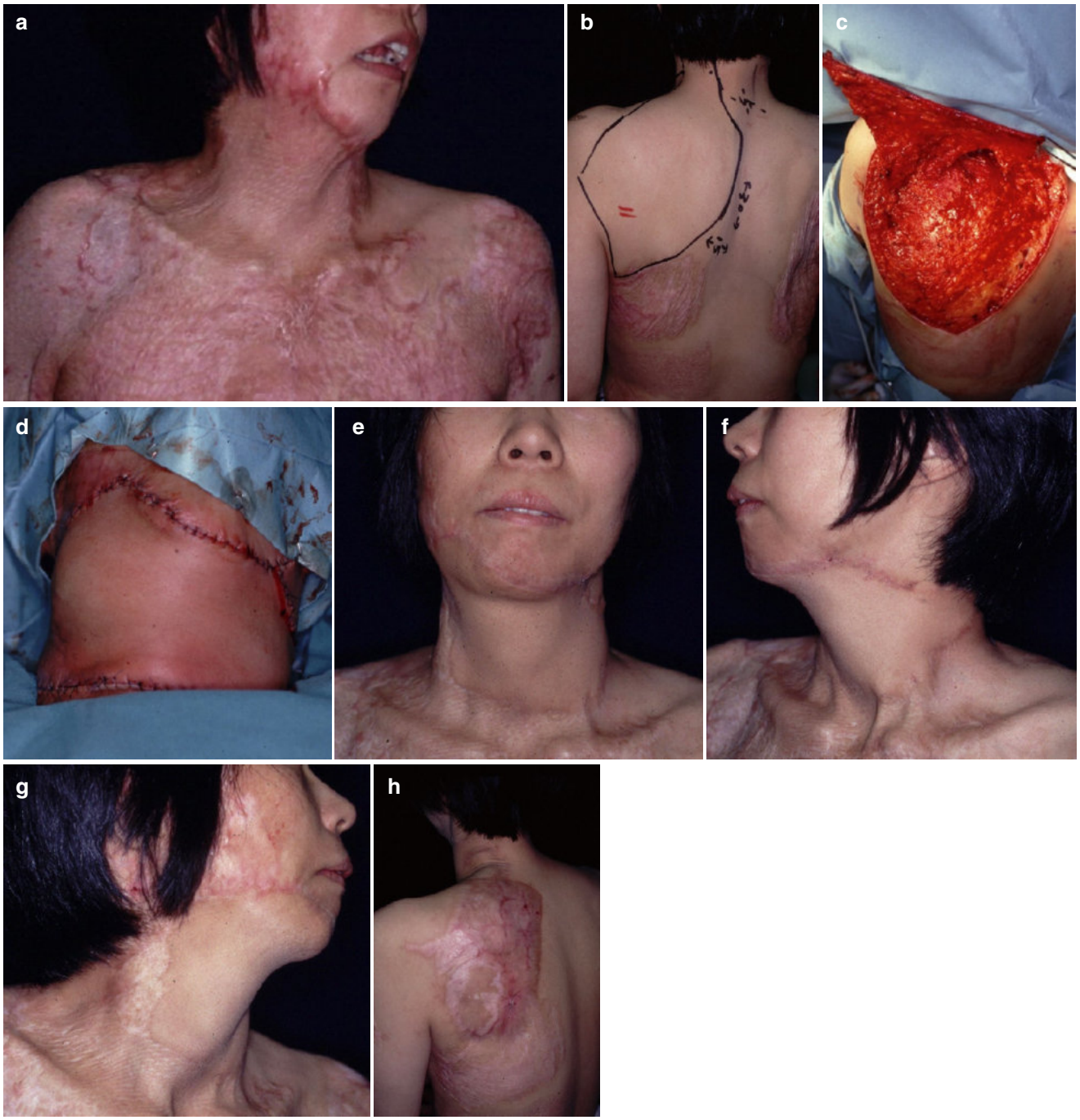


Fig. 60.3 (**a**–**h**), Case 2

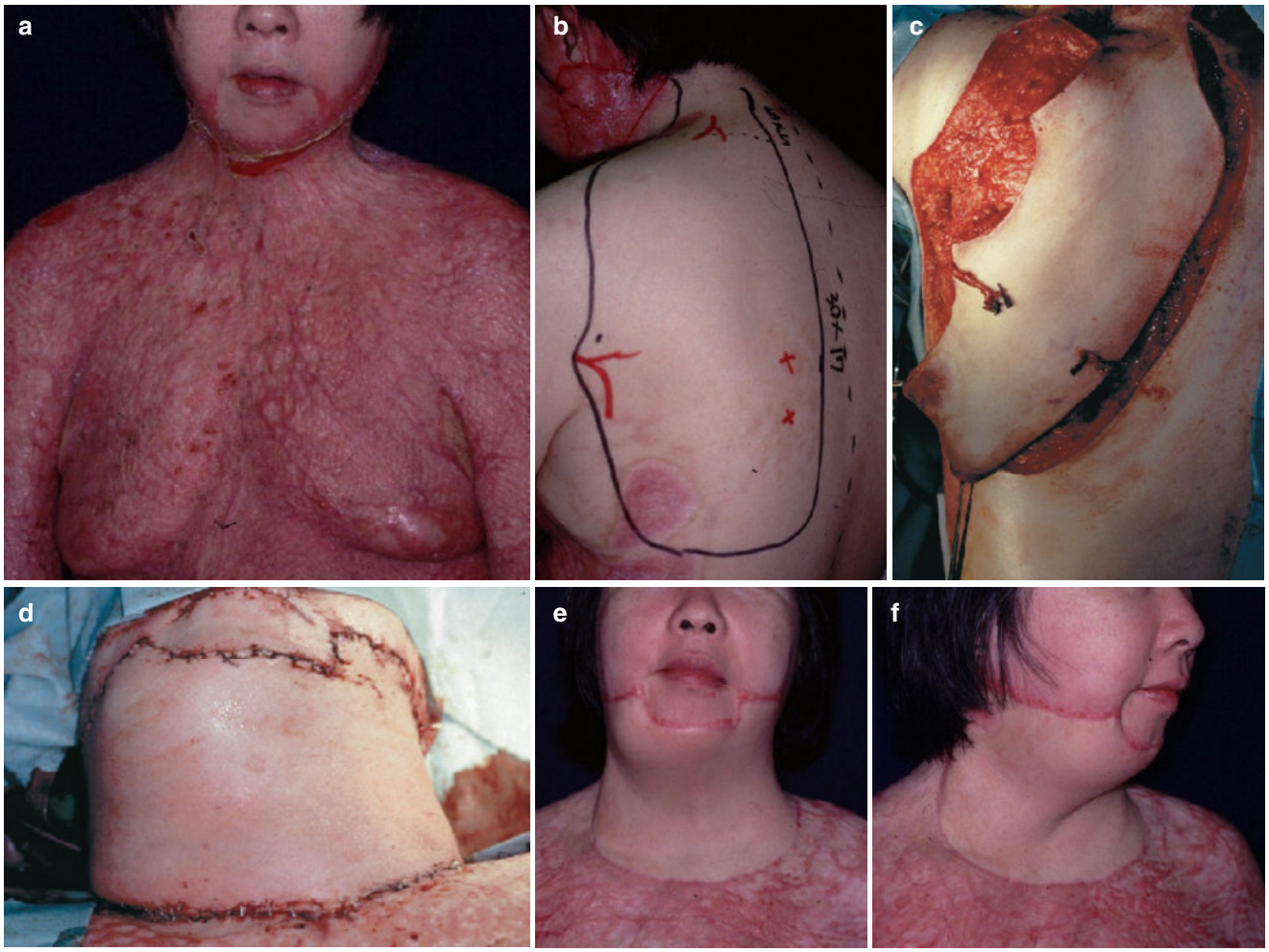


Fig. 60.4 (**a**–**f**), Case 3

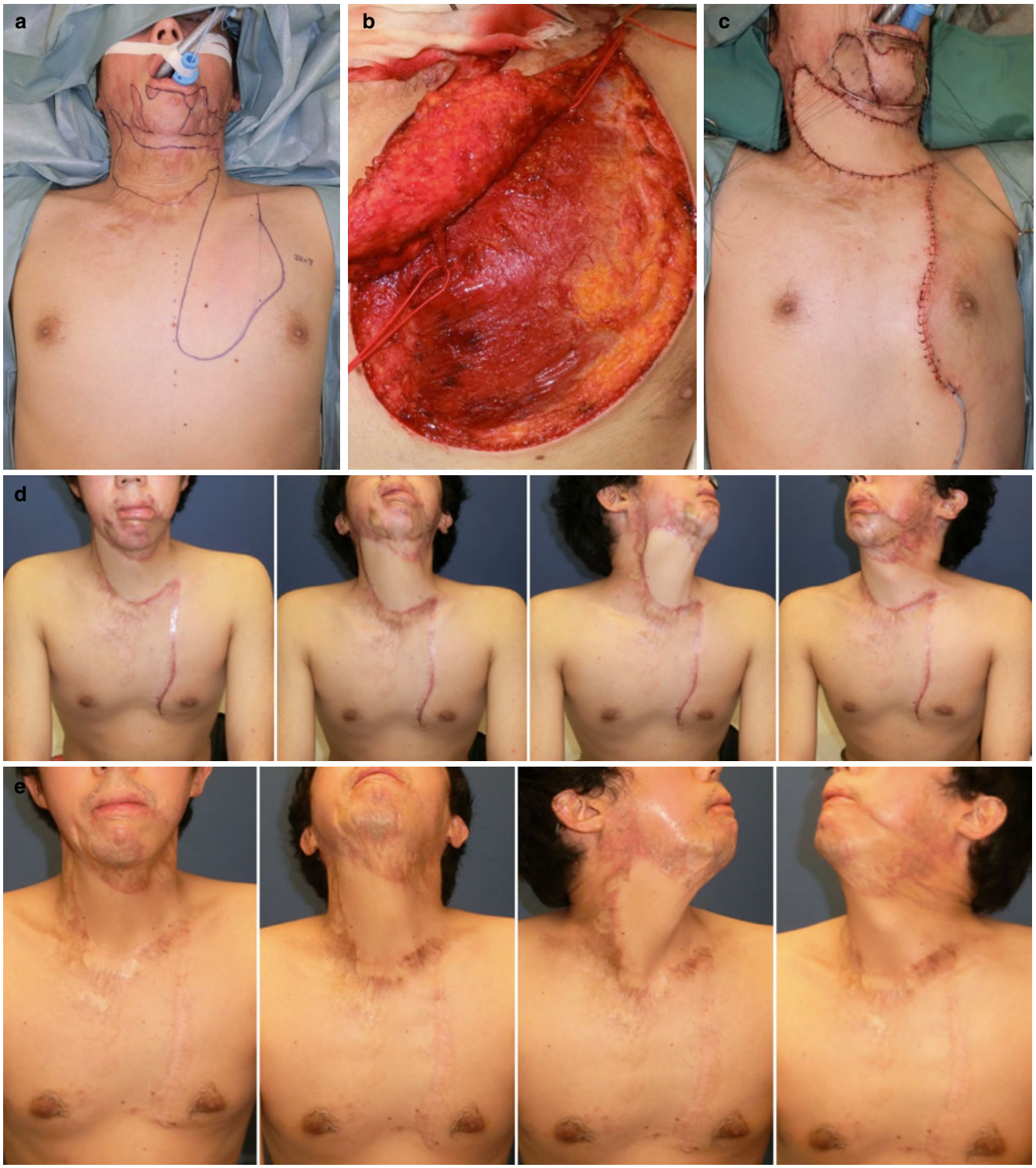


Fig. 60.5 (**a**–**e**), Case 4. (*From* Pribaz and Ogawa [11]; *with permission*)

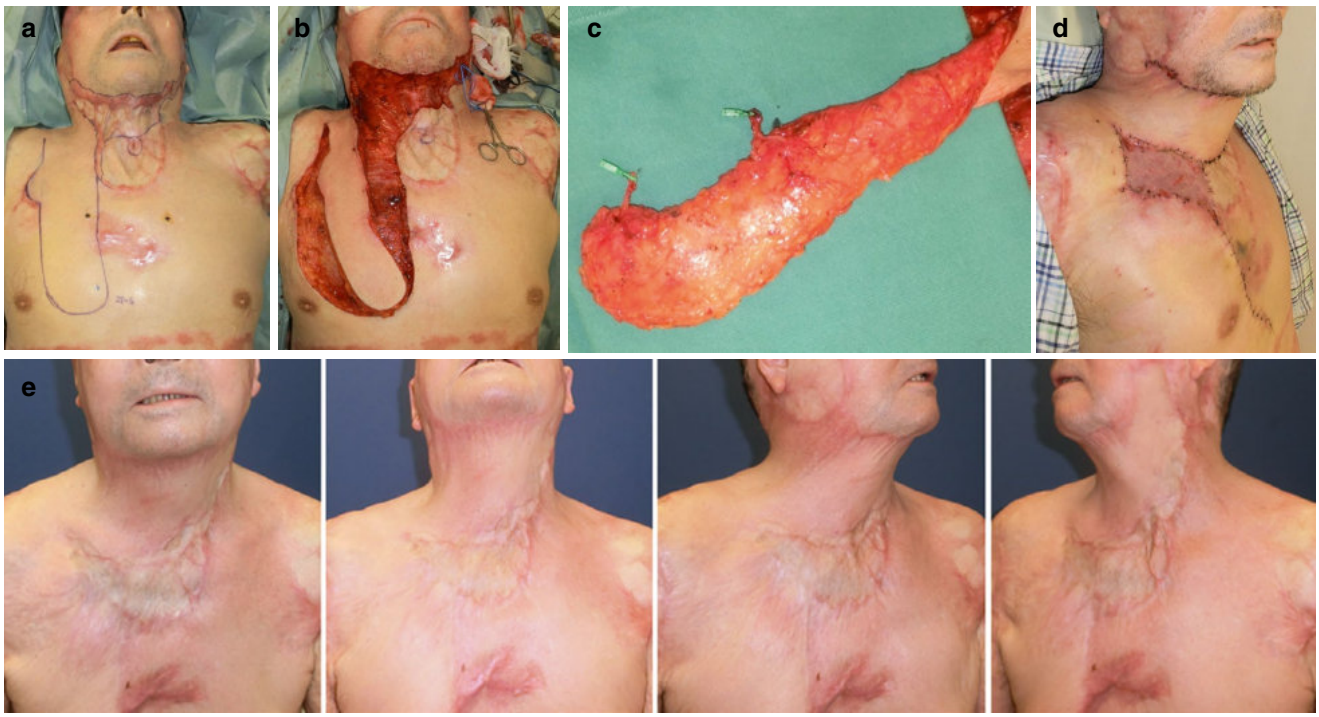


Fig. 60.6 (**a**–**e**), Case 5. (*From* Noda et al. [12]; *with permission*)

References

1. Ogawa R, Hyakusoku H, Murakami M, Aoki R, Tanuma K, Pennington DG. An anatomical and clinical study of the dorsal intercostal cutaneous perforators, and application to free microvascular augmented subdermal vascular network (ma-SVN) flaps. Br J Plast Surg. 2002;55(5):396–401.
2. Hyakusoku H, Gao JH, Pennington DG, Aoki R, Murakami M, Ogawa R. The microvascular augmented subdermal vascular network (ma-SVN) flap: its variations and recent development in using intercostal perforators. Br J Plast Surg. 2002;55(5):402–11.
3. Ogawa R, Hyakusoku H, Murakami M. Color Doppler ultrasonography in the planning of microvascular augmented "super-thin" flaps. Plast Reconstr Surg. 2003;112(3):822–8.
4. Ogawa R, Hyakusoku H, Iwakiri I, Akaishi S. Severe neck scar contracture reconstructed with a ninth dorsal intercostal perforator augmented "Super-Thin Flap". Ann Plast Surg. 2004;52(2):216–9.
5. Ogawa R, Hyakusoku H. Bipedicled free super-thin flap harvesting from the anterior chest. Plast Reconstr Surg. 2004;113(4):1299–300.
6. Ogawa R, Hyakusoku H, Murakami M, Gao JH. Clinical and basic research on occipito-cervico-dorsal flaps: including a study of the anatomical territories of dorsal trunk vessels. Plast Reconstr Surg. 2004;113(7):1923–33.
7. Chin T, Ogawa R, Murakami M, Hyakusoku H. An anatomical study and clinical cases of 'super-thin flaps' with transverse cervical perforator. Br J Plast Surg. 2005;58(4):550–5.
8. Vinh VQ, Ogawa R, Iwakiri I, Hyakusoku H, Tanuma K. Clinical and anatomical study of cervicopectoral superthin flaps. Plast Reconstr Surg. 2007;119(5):1464–71.
9. Gao JH, Ogawa R, Hyakusoku H, Lu F, Hu ZQ, Jiang P, Yang L, Feng C. Reconstruction of the face and neck scar contractures using staged transfer of expanded "Super-thin flaps". Burns. 2007;33(6):760–3.
10. Ono S, Hyakusoku H, Ogawa R, Oki K, Hayashi H, Kumita S. Usefulness of multidetector-row computed tomography in the planning and postoperative assessment of perforator flaps. J Nippon Med Scheme. 2008;75(1):50–2.
11. Pribaz J, Ogawa R. Flap reconstruction using microsurgery. Herndon: Total Burn Care, 6/e In Press.
12. Noda Y, Kuwahara H, Morimoto M, Ogawa R. Reconstruction of anterior neck scar contracture using a perforator-supercharged transposition flap. Plast Reconstr Surg Glob Open. 2018;6(2):e1485.

Perforator Supercharged Super-Thin Flap

61

Vu Quang Vinh

Keywords

Super-thin flap · Subdermal vascular network · Perforator vessels · Scar contracture reconstruction · Circumflex scapular vessels · Dorsal intercostal perforators Split-thickness skin graft · Bipedicled free flap · Doppler flowmetry · Microsurgical anastomosis · Flap elevation Burn scar

61.1 Background

Introduced in 1994 by Hyakusoku and Gao et al., the "super-thin flap" is a distinctively thin flap primarily thinned to the layer where the subdermal vascular network (subdermal plexus) can be seen through minimal fat layer (primary defatting). The properties of "super-thin flaps" have been defined as (1) being thicker than skin grafts, (2) thinner than conventional free flaps, and (3) composed of vascularized skin with a minimal thickness of adipose tissue that preserves the subdermal vascular plexus. Moreover, Hyakusoku et al. developed various types of long and large super-thin flaps. These flaps can be harvested mainly on the back and chest by selecting flaps with attached perforators (perforator supercharging).

Reconstruction of severely disfigured neck and face can be performed using the occipito-cervico-dorsal super-thin flap that is harvested from the dorsal region and supercharged by the circumflex scapular vessels. We used bipedicled super-thin free perforator flaps to reconstruct scar contractures on half of the face, the whole face, or the whole chin-neck area. Bipedicled super-thin free perforator flaps may be an excellent choice for reconstruction of severe neck scar contracture.

61.2 Bipedicled "Super-Thin" Free Perforator Flaps

The flap was designed on the dorsal area to match the shape of the recipient site. For this, candidate perforator vessels were identified by handheld Doppler flowmetry. Five types of perforators are available on the dorsal area (this enhances the versatility of the super-thin flap). During surgery, the recipient site was debrided, and the recipient vessels (the facial vessels and veins and/or superficial temporal vessels) were identified in the supine position. The position was then changed from supine to prone, and the flap was elevated from the periphery. The perforators that were found by handheld Doppler flowmetry to be anastomosis candidates were confirmed macroscopically. After complete elevation of the flap, the flap was thinned by scissors to the point that the subdermal vascular network could be seen through a minimal fat layer. The donor site was covered with a split-thickness skin graft. The vessels were anastomosed under a microscope, after which the flap was sutured to the recipient.

Type 1 consists of the circumflex scapular vessels and the contralateral dorsal intercostal perforators (Fig. 61.1a).

Type 2 consists of the circumflex scapular vessels and the ipsilateral dorsal perforators (Fig. 61.1b).

Type 3 consists of the bilateral circumflex scapular vessels (Fig. 61.1c).

Type 4 consists of the posterior intercostal perforator vessels and contralateral posterior intercostal perforator vessels (Fig. 61.1d).

Type 5 consists of the posterior intercostal perforator vessels and ipsilateral posterior intercostal perforator vessels (Fig. 61.1e).

V. Q. Vinh (✉)
Department of Plastic and Reconstructive Surgery, Vietnam
National Institute of Burn, Thanh-Tri, Hanoi, Vietnam

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_61

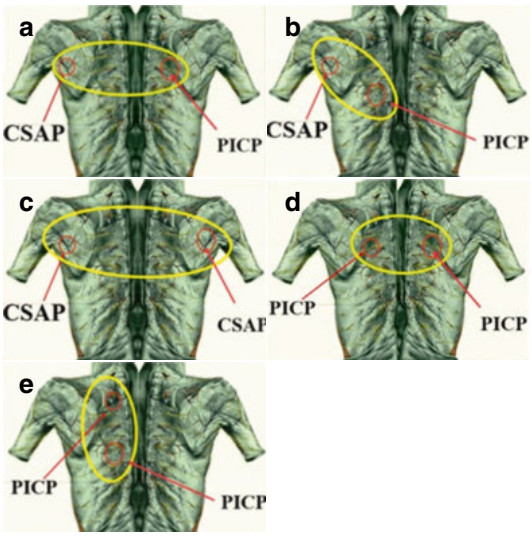


Fig. 61.1 (**a**–**e**), Five types of bipedicled "super-thin" free perforator flaps. In dorsal region, we have lots of the available pedicled vessels to design the bipedicled free flaps. Generally, the circumflex scapular arteries would prefer to select in design of double pedicles flap. However, in case of these abnormal arteries, for example burn scar, trauma, we do not utilize these vessels to design the flap because of the risk of failure. Based on the knowledge of territories of vessel, we have flexible changes in design depending on individual case

61.3 Clinical Cases

61.3.1 Case 1

A 35-year-old woman suffered an extensive acid burn on her whole face (Fig. 61.2). She received split full-thickness skin grafts, but scar contractures developed. After removing the whole scar from her face, the left superficial temporal and right face vessels were chosen as the recipient vessels. A type 1 bipedicled free perforator flap was designed on her dorsal area. The flap measured 27 × 21 cm and bore the right circumflex scapular vessels and contralateral seventh intercostal perforators. These vessels were harvested with lengths longer than 4 cm to fit the sizes of recipient vessels. After harvesting, the flap was completely elevated and thinned between 2 vessels. The flap was thinned down with curved scissors to the layer where the subdermal vascular plexus could be observed. Then, after anastomosis of the right circumflex scapular vessels and left superficial temporal vessels, the middle area of the flap was divided into 2 parts to match the open mouth and nose tip. The left intercostal perforators were then anastomosed with the right facial vessels. The flap survived completely.

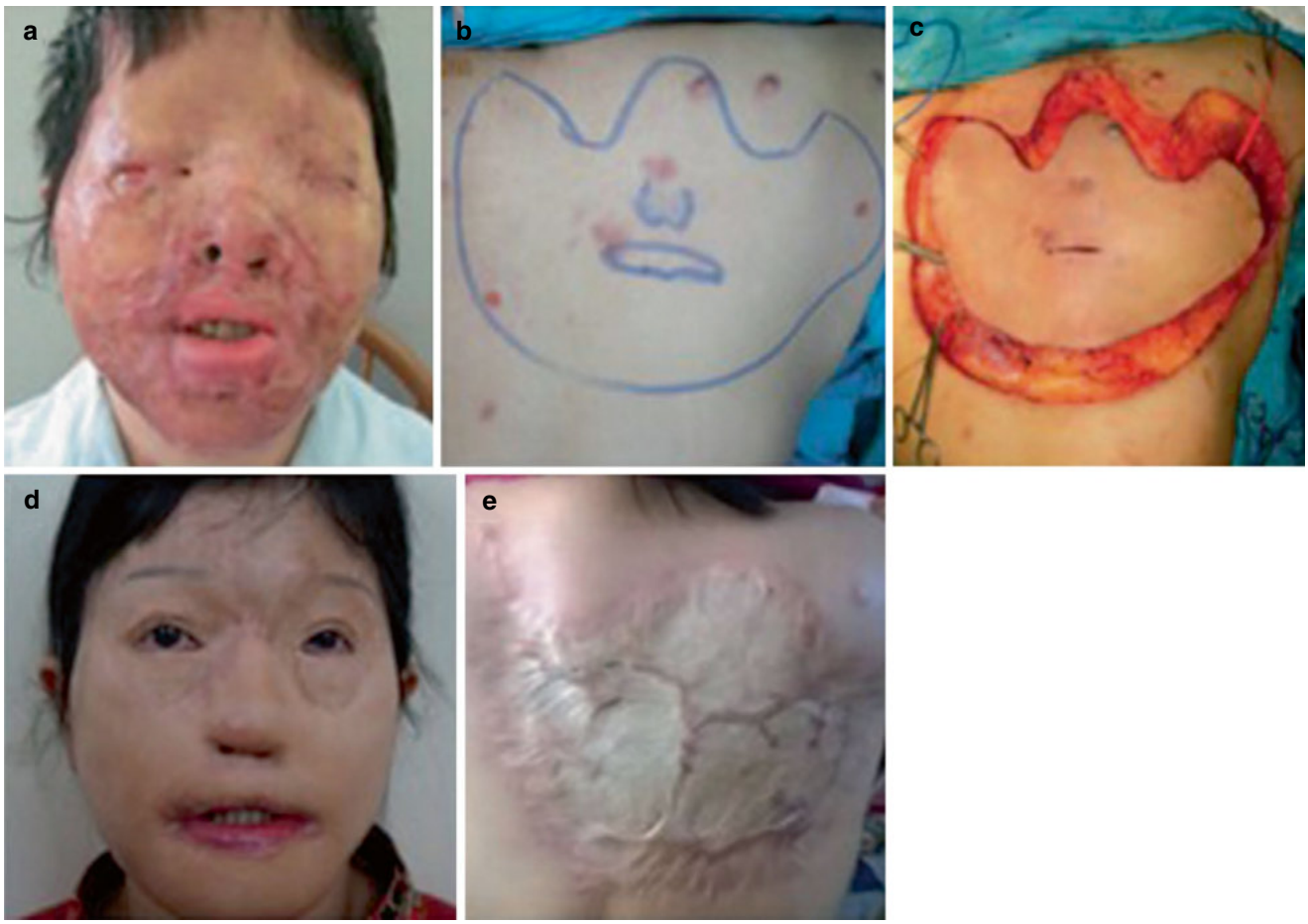


Fig. 61.2 Pre-, peri-, and postoperative views: (**a**) The preoperative view reveals severe disfigurement of the whole face. (**b**) Flap design. The right circumflex scapular artery perforator and the contralateral posterior intercostal perforator VII were chosen. (**c**) After flap elevation. (**d**) Postoperative view after 1 year. (**e**) View of the donor site after 1 year

The eye could be opened, and the functional results 6 months after the operation were good.

61.3.2 Case 2

This 20-year-old man suffered a flame burn and was given a lifesaving skin graft (Fig. 61.3). One year later, scar contractures had developed on the neck and half of the face. After removing the whole scar from his face, both the superficial temporal vessels and the right facial vessels were chosen as the recipient vessels. Muscles were intact, but large flaps were needed to cover the entire surface. A type 2 flap that measured 22 × 17 cm was designed on his dorsal area. The seventh intercostal perforators were identified and used. The left circumflex scapular vessels were attached to the flap. The circumflex scapular vessels and right superficial temporal vessels and the intercostal perforator vessels and right facial vessels were anastomosed one by one. The flap survived completely, and there were no complications. The flap matched well with the surrounding skin in terms of texture and color.

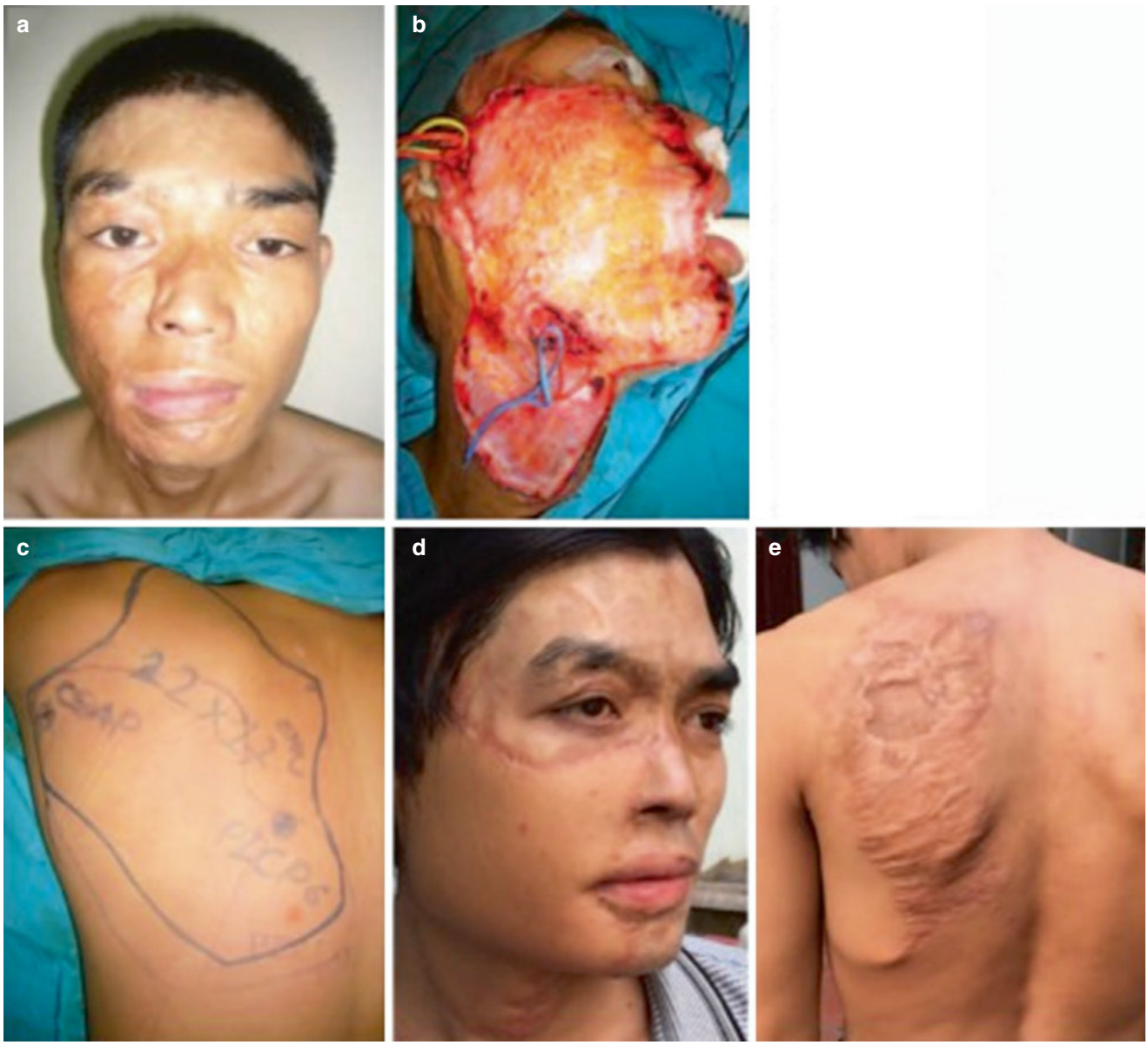


Fig. 61.3 Pre-, peri-, and postoperative views: (**a**) The preoperative view reveals a scar on half of the face. (**b**) After flap elevation. The recipient vessels that were dissected include the right superficial temporal artery and the ipsilateral facial vessels. (**c**) Flap design. The left circumflex scapular artery perforator and the ipsilateral posterior intercostal perforator VI were chosen. (**d**) Postoperative view after 1 year. (**e**) View of the donor site after 1 year

61.3.3 Case 3

A 15-year-old boy suffered an extensive flame burn on the face (Fig. 61.4). The face received split full-thickness skin grafts, but scar contractures developed. After the whole scar was removed from the face, the left and right superficial temporal vessels were chosen as the recipients. A type 3 bipedicled free flap that measured 41 × 13 cm was designed on the dorsal area. The right and left circumflex scapular vessels were attached to the flap. After anastomosis of the vessels, the donor site was covered by a split full-thickness skin graft. The flap survived completely. Hypertrophic scars developed on the flap margin after surgery but improved naturally over time.

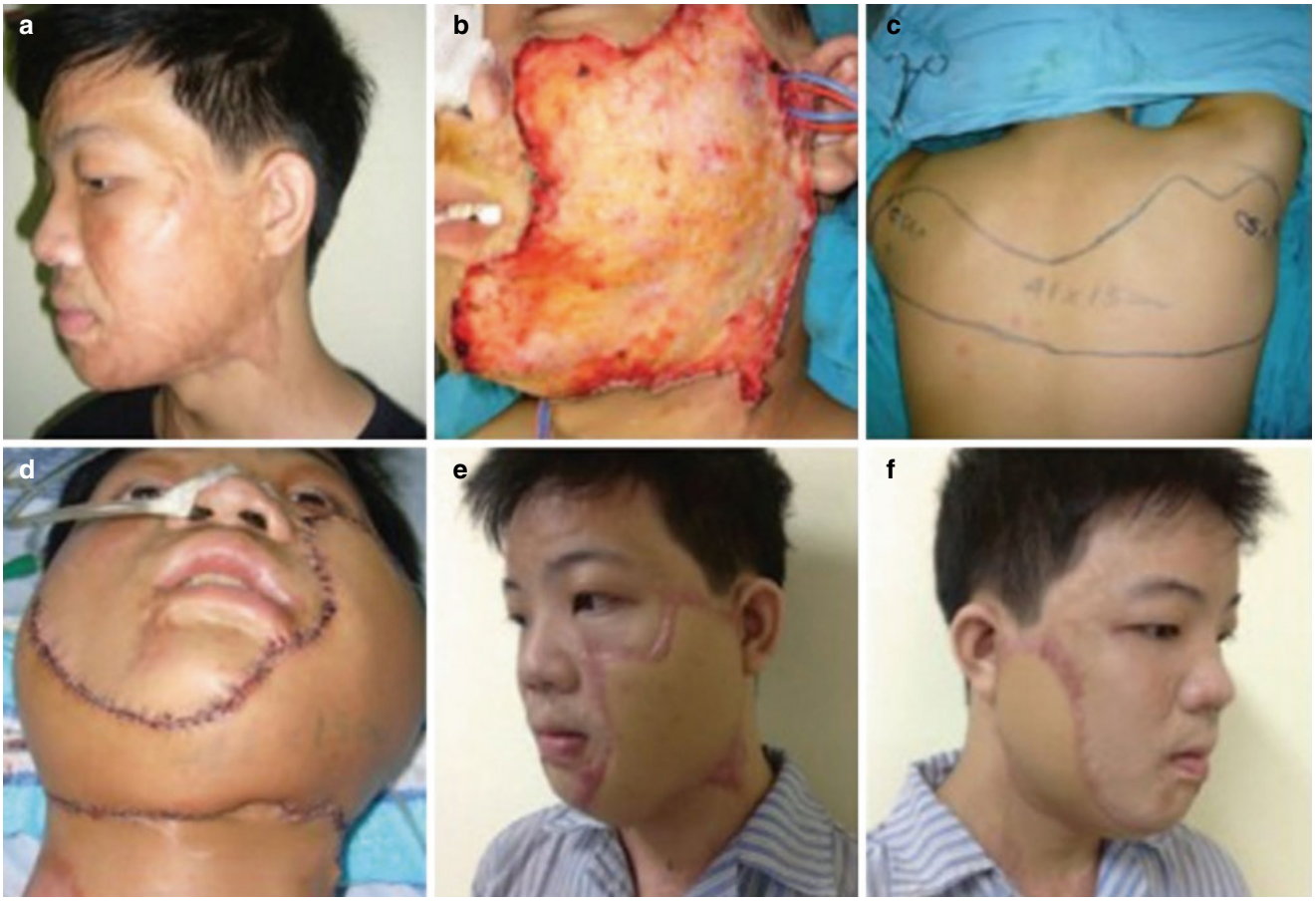


Fig. 61.4 Pre-, peri-, and postoperative views: (**a**) The preoperative view. (**b**) The right facial vessels served as the first recipient. The left superficial temporal artery served as the second recipient. (**c**) Flap design. Flap dimensions were 41 × 13 cm, and the flap included both circumflex scapular artery perforators. (**d**) One day after the operation. (**e**) The left side 1 year after surgery. (**f**) The right side 1 year after surgery

Suggested Reading

1. Angrigiani C, Grilli D. Total face reconstruction with one free flap. Plast Reconstr Surg. 1997;99(6):1566–75.
2. Hyakusoku H, Gao JH. The "super-thin" flap. Br J Plast Surg. 1994;47(7):457–64.
3. Hyakusoku H, Pennington DG, Gao JH. Microvascular augmentation of the super-thin occipito-cervico-dorsal flap. Br J Plast Surg. 1994;47(7):465–9.
4. Hyakusoku H, Aoki R, Murakami M, et al. The microvascular augmented subdermal vascular network (ma-SVN) flap: its variations and recent development in using intercostal perforators. Br J Plast Surg. 2002;55(5):402–11.
5. Ogawa R, Hyakusoku H, Murakama M, et al. An anatomical and clinical study of the dorsal intercostal cutaneous perforators, and application to free microvascular augmented subdermal vascular network (ma-SVN) flaps. J Plast Reconstr Aesthet Surg. 2002;55(5):396–401.
6. Ogawa R, Hyakusoku H, Iwakiri I, et al. Severe neck scar contracture reconstructed with a ninth dorsal intercostal perforator augmented "super-thin flap". Ann Plast Surg. 2004;52(2):216–9.
7. Ogawa R, Hyakusoku H, Murakami M, et al. Clinical and basic research on occipito-cervico-dorsal flaps: including a study of the anatomical territories of dorsal trunk vessels. Plast Reconstr Surg. 2004;113(7):1923–33.
8. Tsai FC. A new method: perforator-based tissue expansion for a pre-expanded free cutaneous perforator flap. Burns. 2003;29(8):845–8.
9. Vinh VQ, Ogawa R, Anh VT, et al. Reconstruction of neck scar contractures using supraclavicular flaps: retrospective study of 30 cases. Plast Reconstr Surg. 2007;119(1):130–5.
10. Vinh VQ, Van Anh T, Nam L, et al. Reconstruction of acid-injured face with occipitocervicodorsal super-thin flaps. Plast Reconstr Surg. 2009;124(1):167e–9e.
11. Vinh VQ, Van Anh T, Ogawa R, et al. Anatomical and clinical studies of the supraclavicular flap: analysis of 103 flaps used to reconstruct neck scar contractures. Plast Reconstr Surg. 2009;123(5):1471–80.

Part VIII

Facial Allotransplantation

Facial Allotransplantation

62

Viola A. Stögner, Sam Boroumand, and Bohdan Pomahac

Keywords

Facial transplantation · Vascularized composite allotransplantation · Reconstructive surgery · Donor selection criteria · Facial allograft · Immunosuppression Post-transplantation outcomes · Functional restoration Face transplant indications · Psychosocial evaluation Extracorporeal perfusion · Immune tolerance

Facial transplantation stands as one of the most advanced reconstructive techniques in plastic surgery, mostly reserved for patients with extensive facial defects unable to be ameliorated by conventional reconstructive approaches. Categorized as vascularized composite allograft (VCA) transplantation, a facial graft comprises a variety of different tissue entities, including skin, mucosa, muscles, fat, bones, nerves, vessels, and cartilage, which enable the restoration of both facial form and function to patients [1]. This concept is rather young in the field of transplantation, with the first facial transplantation being performed in 2005 in Amiens, France [2]. Since then, a total of 50 face transplantations across more than a dozen different international centers have been completed [3], and the great benefit and efficacy of this procedure validated. In contrast to solid organ transplantation (SOT), the transfer of a face is considered a "life-giving" rather than "life-saving" procedure, highlighting the critical functional, expressive, and sensory faculties of the human face interacting with the social world. Facial transplantation, therefore, provides severely disfigured and disabled patients the opportunity for social acceptance and reintegration. Although the revolutionary procedure has immense capacity for changing a patient's quality of life, it is not without its own challenges and risks. This chapter will provide a holistic overview of the current state of transplantation, evaluating its indications, technical and immunological considerations, as well as current outcomes and future directions of the field.

62.1 Indications for Facial Transplantation

Although there are no standardized indications for facial transplantation, indications adopted by various centers are often strict and are established by a multi-disciplinary team, including plastic surgeons, transplant specialists, dentists/oral-maxillofacial surgeons, psychological therapists, and speech therapists among others. The most widely accepted indication for the procedure entails significant facial trauma resulting in considerable loss of facial tissue and disruption of crucial functional anatomical structures, especially those in the central portions of the face. Specifically, impacted structures can include total destruction of the nose, eyelids (i.e., orbicularis oculi), and/or lips (i.e., orbicularis oris), unamenable to standard reconstructive approaches utilizing local flaps or free tissue transfers [4]. The etiology of the trauma in reported cases has been varied but most frequently has fallen into one of five classifications: ballistic injuries, animal attacks, burns, neurofibromatosis-induced facial disfigurement, or post-excision of facial cancers.

Alongside the surgical indication, a detailed evaluation of the patient's medical history should be taken as well. Following facial transplantation, patients are required to maintain a lifelong regimen of immunosuppressive medication. While active malignancies, except of skin cancer, represent an absolute contraindication for face transplantation, a history of malignancy is considered a relative contraindication to the procedure, given that the risk of de novo malignancy is two- to four-fold higher in immunosuppressed patients [5]. In addition, patients with past histories of any significant burns, transfusions, or any notable immunomodulatory pathologies (e.g. human immunodeficiency syndromes) should be approached with caution as the increased developmental risk of immunosensitization can heighten risks for rejection of the donor allograft [6]. Patient candi-

V. A. Stögner · S. Boroumand · B. Pomahac (✉)
Department of Surgery, Division of Plastic and Reconstructive Surgery, Yale School of Medicine, New Haven, CT, USA
e-mail: bohdan.pomahac@yale.edu

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8_62

dates with any active malignancy or end-organ dysfunction would be strongly contraindicated from the procedure.

A candidate's psychosocial condition should also be thoroughly evaluated and accounted for prior to receiving a facial transplantation. The immediate weeks to months post-operatively are often the most challenging for patients both physically and emotionally as they grow accustomed to their new face and rehabilitate its functionality. As a result, patients must have a strong support system in place with regular assessments of their mental well-being and care givers available to assist them, given the difficult nature of this transitional period as well as the strict compliance with immunosuppressive medications that is required [6]. This notion is especially compounded for those patients who had any previous psychiatric diagnosis, history of substance abuse, or are receiving their face transplant as a result of an unsuccessful suicide attempt. Patients should have any previous psychiatric disorder diagnosis resolved and/or well-managed before undergoing the procedure and as a component of their post-operative care longitudinally.

62.2 Technical Considerations

62.2.1 Donor Selection Criteria

The donor selection criteria for VCA in general is much more challenging and intensive than SOT models. In the same vein as SOT, potential face transplant recipients must be matched by blood type and sufficient immunological human leukocyte antigen (HLA) markers. However, many demographic factors must also be evaluated, including skin pigmentation, hair color, and ensuring donor cephalometric proportions would be acceptable for the recipient. Additionally, an evaluation must be completed of the exact extent and quality of the facial allograft required by the recipient patient. Some patients necessitate a full facial transplant in comparison to just a partial in others. Although there is no strictly delineated distinction between full and partial face transplants, the former is often defined by a facial allograft that encompasses the majority of the whole face, including the fronto-temporal portions of the forehead, while the latter is often limited to facial regions below the brow ridge/nasal bone. The specific tissue types included in the donor facial allograft are also variable from patient to patient. Candidate recipients who have suffered significant bony destruction of their mandibular or maxillary regions often require an osteomyocutaneous VCA that includes bony anatomical components to fill the corresponding bony defects in the recipients. However, if the facial trauma is limited to just soft tissue with an anatomically intact facial skeleton, then a myocutaenous VCA that lacks bony tissue is most appropriate for the patient. Given the extensive matching criteria that needs to be met along with limitations to the total cold ischemia time procured donor VCA's can endure, many facial transplant candidates have to wait months to years for a donor allograft. In this regard, novel techniques, such as extracorporeal perfusion, enabling extended tissue preservation outside the body, hold great potential to increase the odds of VCA transplantation [7].

62.2.2 Technical Approach to Face Transplantation

Face transplantations are highly individualized to the facial defects and needs of the recipient. Thus, currently there is no standardized approach for executing the procedure; however, below the critical steps are summarized for both allograft procurement from the donor as well as transplantation onto the recipient.

Donor Allograft Procurement

1. Preoperative allograft mapping is crucial and includes imaging techniques as well as the outlining of both the recipient and donor face, which can be translated into helpful templates or molds (e.g., 3D printing). Primary incisions are performed according to the accurately defined and marked margins and graft elevation is started.
2. Axial Dissection (Fig. 62.1)
   (a) Cranial-to-Caudal: Starting with a coronal incision, a dissection is performed in the subgaleal plane going caudally until 1 cm above the supraorbital rim at which point the dissection then follows down to the level of glabella and root of the nose in the subperiosteal plane. Important that the sensory nerve branches of the upper face, including the supraorbital and supratrochlear nerve, are identified where they exit their respective foramina.
   (b) Lateral-to-Medial: Starting at the preauricular incisions, dissection is performed above the parotid fascia to the anterior border of the masseter muscle in the sub-superficial musculoaponeurotic plane. Following this, dissection across the entire mandible and/or maxilla is completed within the subperiosteal plane. All five facial nerve branches should be individually identified and tagged. For cases that include bony tissue in the donor allograft, the custom cutting guides are utilized to determine the sites of osteotomy as needed for the maxilla and mandible.
3. Dissection of Neck

   The initial periauricular incisions are then extended caudally to the neck and a dissection in the subplatysmal plane is conducted. At this juncture, it is important to identify and tag the facial vessels with vessel loops, prior to dissecting down to the jugular veins and external

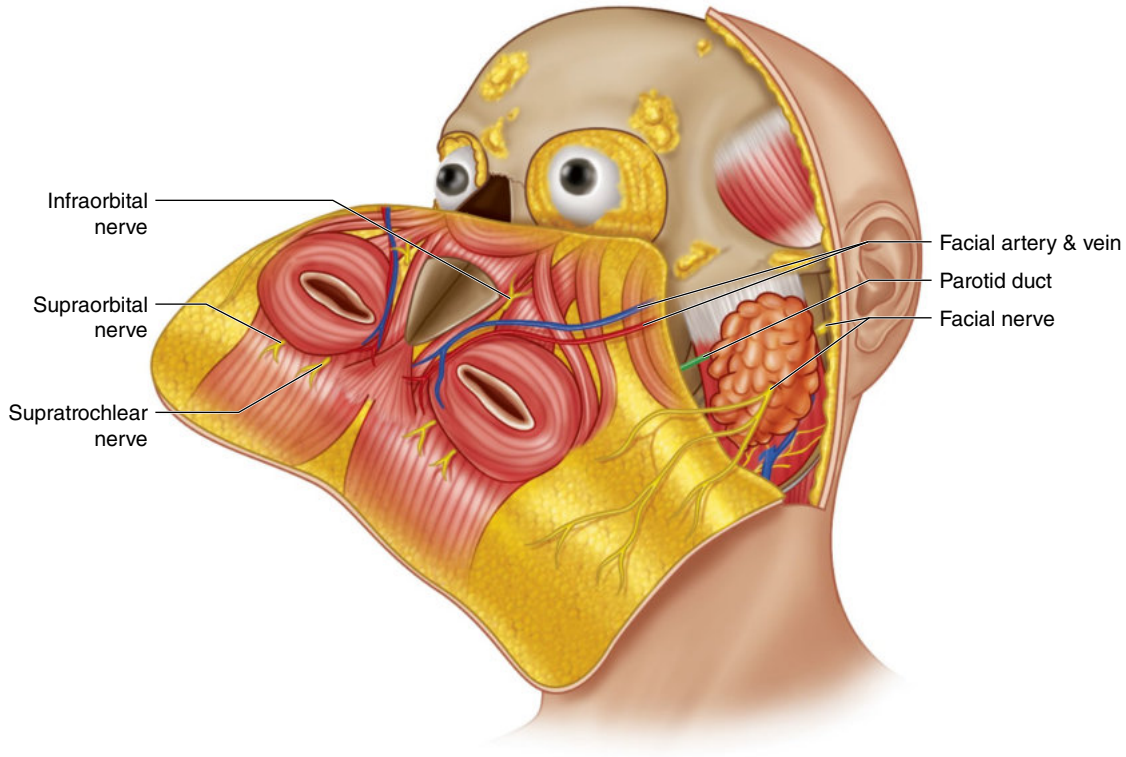


Fig. 62.1 Axial dissection is performed in a cranial-to-caudal and lateral-to-medial direction

carotid arteries. A dissection approach along the subperiosteal plane can be taken in a cranio-to-caudal axial direction, which helps ensure the facial artery remains safely housed within the raised tissue. The hyoid bone is included in the final neck dissection and is utilized as a landmark to be secured to the recipient's hyoid.

4. Dissection of the Periorbital Region

   For allografts that will include the eyelids, the approach is to incise the conjunctival fornix of the eyelids and transect the levator palpebrae muscles. The conjunctival incision is then progressed to the lateral and medial canthal ligaments leading to them both being freed from their respective osseous insertions, and thus releasing the eyelids to the allograft.

5. Skeletal Dissection

   As highlighted previously, bone cutting guides will be utilized to perform the necessary osteotomies of the maxilla and mandible. However, it should be noted that the nasal bone pyramid should be integrated in all facial transplantations in order to provide a central landmark for alignment of the nose in the recipient.

6. Vessel Clamping and Allograft Detachment (Figs. 62.2 and 62.3)

   Once the donor allograft has been dissected across all its fascial attachments, the facial artery/external carotid and their corresponding veins are subsequently clamped, which starts the ischemia countdown. These vessels are

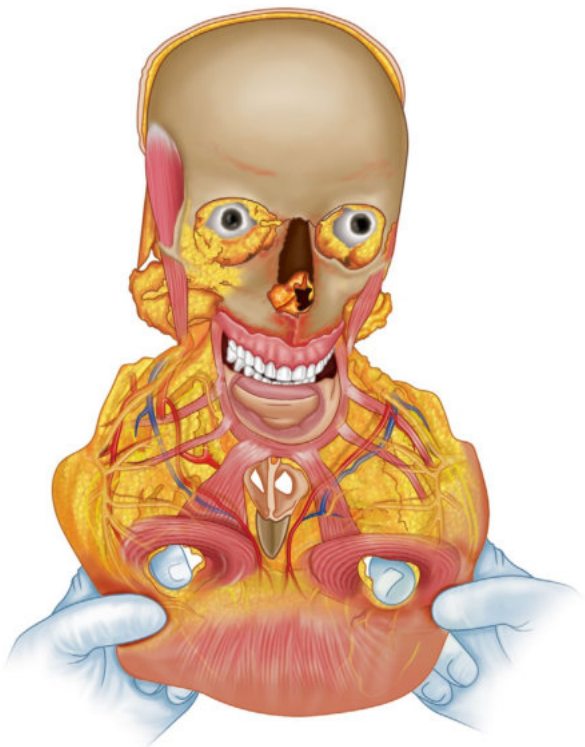


Fig. 62.2 Completely elevated, still attached, facial allograft, including facial skin, muscles, and nerves, the nasal bone pyramid, as well as the facial artery and vein

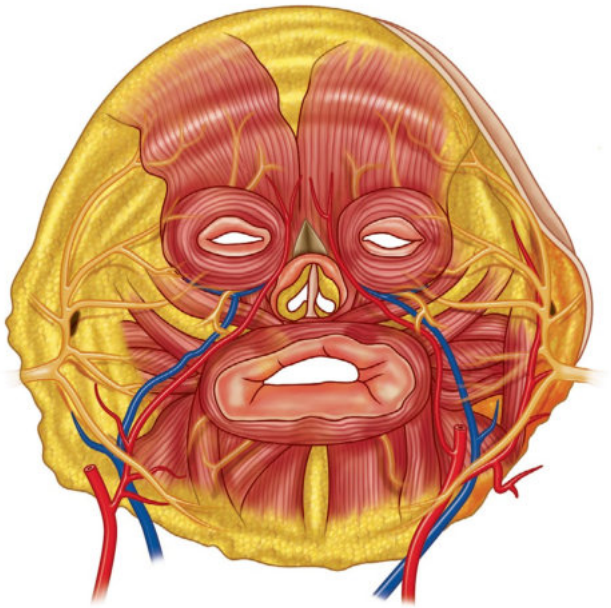


Fig. 62.3 Detached facial allograft, including facial skin, muscles, and nerves, the nasal bone pyramid, as well as the facial artery and vein

then incised, and the donor allograft is transferred over to the recipient for transplantation.

Recipient Transplantation

1. Preparation of the Recipient

   The incision markings are made on the recipient's face to mirror the exact ones performed on the donor's face. Dissection begins with exposure of the external carotid artery and its terminal branches as well as the internal jugular retromandibular veins and branches. The specific vessels and sites to be utilized as anastomosis locations is dependent on the recipient's native vessel anatomy and how compromised it may be from their facial trauma and/or prior reconstructive procedures. All the motor and sensory nerves of the face need to be identified with the facial nerve requiring additional dissection from its main trunk in a retrograde fashion.
2. Allograft Transplantation

   Given the limited ischemia window, the vascular anastomoses are performed first. To facilitate this step, the allograft is placed on the recipient's chest with the exterior skin side facing down to allow for easy visualization and accessibility of the vessels. After completing the vessel anastomosis, facial allograft insetting is continued in a central-to-lateral and inferior-to-superior approach. After appropriate anatomical positioning, osteosynthesis is performed. Multiple, well-distributed Mitek anchors for soft tissue fixation to the facial skeleton are preferred specifically at sites including the zygoma, supraorbital bar, and the mandible. Horizontal mattress sutures are utilized to achieve water-tight intraoral closure.

62.2.3 Post-Transplantation Immunological Considerations

Similar to SOT and other VCA models, all facial transplant patients require immunosuppressive medication in both the peri- and post-operative period. An induction and maintenance paradigm approach is utilized for this. Thymoglobulin is the most frequently utilized induction agent, often given to patients immediately prior or during the transplantation surgery [8]. It is an FDA-approved T-cell depleting agent, utilized to minimize the risk of acute rejection, which is often highest in the immediate hours following transplantation. Following their operation, patients are then started on a maintenance immunosuppressive regimen which usually consists of a multidrug (triple to quadruple) approach, most commonly utilizing a calcineurin inhibitor, a nucleotide antimetabolite agent, and a steroid-based agent. The most common combination of these agents utilized is tacrolimus, mycophenolate mofetil, and a prednisone, respectively. Trialing the T-cell costimulation blocker belatacept as part of quadruple immunosuppressive regimens, our team observed promising first results with great kidney protective potential in face transplant recipients. Patients will continue their immunosuppressive treatment for life, while dosages and drugs can be adjusted as needed. Toxicity effects, such as calcineurin inhibitors-induced acute kidney injury, or steroid-induced metabolic complications, may require reducing doses of culprit drugs, whereas rejection episodes may necessitate temporary increases in immunosuppressive dosages. Beyond that, recipients should undergo continuous and regular surveillance for infectious and malignant complications possibly resulting from long-term immunosuppression [9]. In addition, biopsies of the skin and mucosal components of the facial allograft should be taken from the patient on a regular basis to evaluate for histological signs of rejection, which is graded utilizing the Banff classification. Beyond that, our group recently identified skin elasticity as a promising surrogate marker for facial allograft fibrosis, which holds great potential to enable non-invasive allograft monitoring [10].

62.2.4 Facial Allograft Outcomes

Outcomes for patients having undergone face transplantation have been overall promising to date. Post-transplantation

nearly all patients across the global cohort have improved capacity for basic facial functions, including abilities to smell, eat, breathe, speak, and show facial expressions [11]. Motor recovery for most patients typically occurs between 6 and 18 months post-transplantation [2]. Return of facial sensation, including thermal, light touch, two-point discrimination, pain sensation, and pressure often occurs on a much quicker timeframe of a few weeks to months post-transplantation with majority of patients achieving the greatest return within the first year [12]. From a psychosocial perspective, patients receiving facial allografts have reported improved quality of life, including greater social integration, sense of self, and reduced prevalence of depression [6]. While highly encouraging, it should be noted that these outcomes must be balanced with risks of long-term immunosuppressive medication as outlined previously in the chapter and further contextualized with the need for regular, continuous clinical surveillance for acute and chronic allograft rejection.

62.3 Future Directions in the Field

Major challenges in reconstructive transplantation, such as short graft ischemia time—restricting graft provision, as well as long-term immunosuppression—limiting its indication, are subject of intensive ongoing research efforts. Extracorporeal tissue preservation techniques, such as ex-vivo perfusion, reveal highly promising to allow extended graft ischemia times and thus increase the availability of VCA [7, 14, 15]. The introduction of novel selective or targeted immunotherapeutic approaches, on the other hand, bears great potential to minimize or even bypass the side effects associated with long-term immunosuppression. The successful achievement of long-term immune tolerance seems to play a key role in these undertakings [13] and would significantly broaden the applicability for face transplantations, e.g., in cancer patients, or partial facial defects.

VCA transplant programs in and outside of the United States are growing and so are the numbers of performed procedures. This will likely contribute to further refinements of surgical techniques, yielding in even better functional and esthetic outcomes in the future.

References

1. Giatsidis G, Sinha I, Pomahac B. Reflections on a decade of face transplantation. Ann Surg. 2017;265(4):841–6.
2. Vyas K, et al. Facial transplantation. Facial Plast Surg Clin North Am. 2022;30(2):255–69.
3. Govshievich A, et al. Face transplant: current update and first Canadian experience. Plast Reconstr Surg. 2021;147(5):1177–88.
4. Pomahac B, et al. Face transplantation. Curr Probl Surg. 2011;48(5):293–357.
5. La Padula S, et al. Face transplant: indications, outcomes, and ethical issues-where do we stand? J Clin Med. 2022;11(19):5750.
6. Kantar RS, et al. Facial transplantation: principles and evolving concepts. Plast Reconstr Surg. 2021;147(6):1022e–38e.
7. Krezdorn N, et al. Twenty-four-hour ex vivo perfusion with acellular solution enables successful replantation of porcine forelimbs. Plast Reconstr Surg. 2019;144(4):608e–18e.
8. Rifkin WJ, et al. A comparison of immunosuppression regimens in hand, face, and kidney transplantation. J Surg Res. 2021;258:17–22.
9. Kauke-Navarro M, et al. Cytomegalovirus-related complications and management in facial vascularized composite allotransplantation: an international multicenter retrospective cohort study. Transplantation. 2022;106(10):2031–43.
10. Stögner VA, Boroumand S, Vafa AZ, et al. Skin Elasticity: A Potential Surrogate Marker for Facial Allograft Skin Fibrosis-A Case Series. Clin Transplant. 2025;39(6):e70175.
11. Fischer S, et al. Functional outcomes of face transplantation. Am J Transplant. 2015;15(1):220–33.
12. Tasigiorgos S, et al. Five-year follow-up after face transplantation. N Engl J Med. 2019;380(26):2579–81.
13. Kueckelhaus M, et al. Vascularized composite allotransplantation: current standards and novel approaches to prevent acute rejection and chronic allograft deterioration. Transpl Int. 2016;29(6):655–62.
14. Stögner VA, et al. Forty-eight hour ex vivo perfusion and two-hour simulated reperfusion after a major traumatic upper extremity amputation. J Reconstr Microsurg Open. 2023;08(01):e28–31.
15. Haug V, et al. Hypothermic ex situ perfusion of human limbs with acellular solution for 24 hours. Transplantation. 2020;104(9):e260–70.

Index

R. Ogawa et al. (eds.), *Color Atlas of Burn Reconstructive Surgery*, https://doi.org/10.1007/978-3-031-88353-8