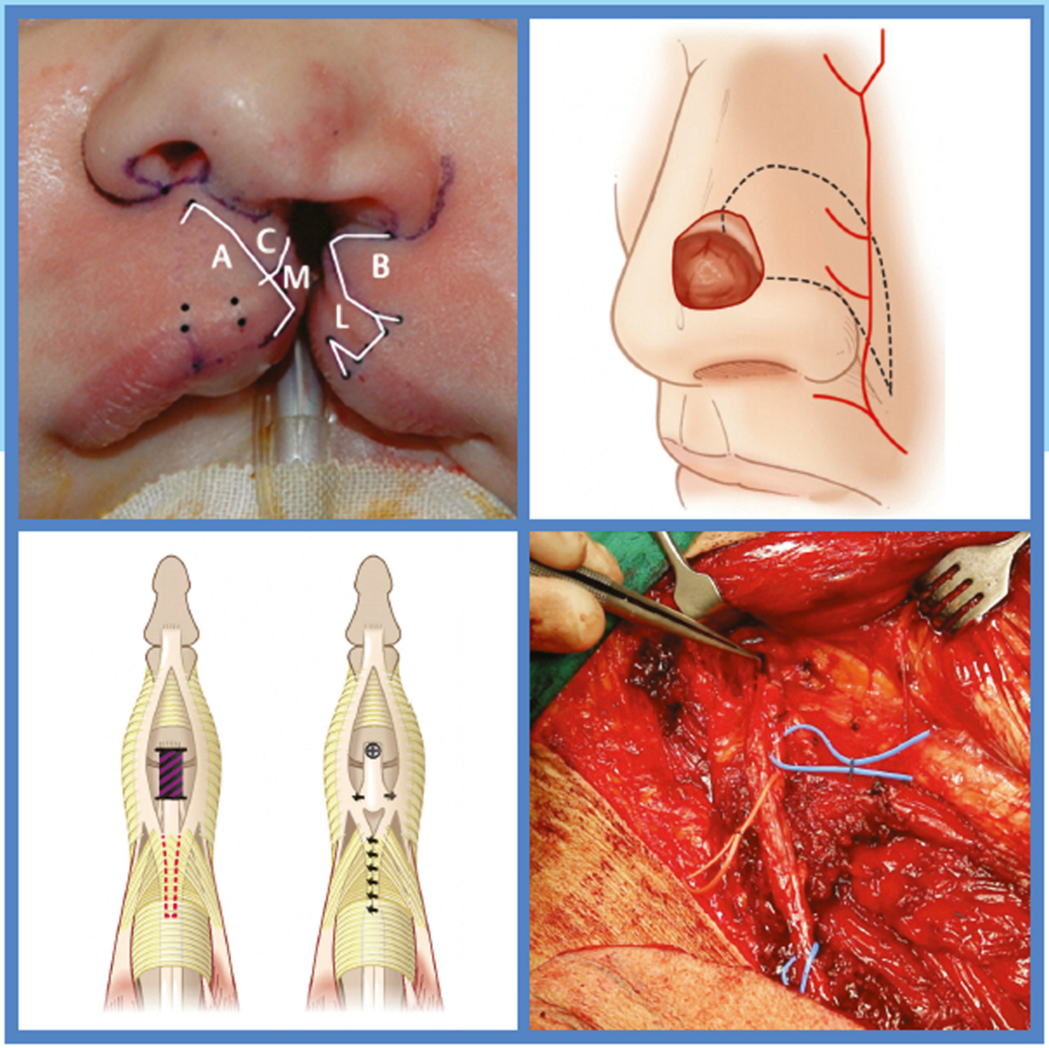
Reconstructive Plastic Surgery

An Atlas of Essential Procedures

Robert X. Murphy Jr.
Charles K. Herman



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Hippocratic Oath

"I swear by Apollo Physician and Asclepius and Hygieia and Panaceia and all the gods and goddesses, making them my witnesses, that I will fulfill according to my ability and judgment this oath and this covenant:

To hold him who has taught me this art as equal to my parents and to live my life in partnership with him… and to regard his offspring as equal to my brothers… and to teach them this art—if they desire to learn it…."

The editors dedicate this book to their professors who shared with them this art—we truly do stand upon the shoulders of giants!—and to the medical students, residents, and faculty whom they have had the privilege of training.

The desire to provide an accessible yet comprehensive procedural guide for students, residents, and early career plastic surgeons was the impetus behind this project. We hope that they derive as much value from utilizing it in their care of patients as we have had in crafting it.

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Foreword

I am delighted to write the foreword for this truly international textbook on reconstructive plastic surgery. Doctors Robert X. Murphy Jr. and Charles K. Herman, both recognized as outstanding educators and surgeons, have reached out to their counterparts worldwide, who are equally well-qualified surgeons, to contribute to this work. I commend them for doing so, as colleagues from all over the world have so much to contribute and so much to teach us. This diverse group of authors, representing five continents, generously share their ideas and clinical expertise within these pages. I find the international authorship of this work not only unique but also one with significant advantages, adding to the contents and clinical value of the book.

As the title suggests, this is a comprehensive text on reconstruction with 67 chapters, the first few of which cover the surgical care of the cleft patients. These early chapters are followed by a "head to toe" inclusive set of chapters covering reconstruction following trauma, tumor resection, burn, congenital deformities, and degenerative conditions.

Each chapter begins with a clear introduction and is followed by a discussion of the pertinent anatomy, surgical indications, operative techniques, concluding with a discussion of complications and long-term results. I found the surgical descriptions easy to follow, especially the clear, high-quality artworks and intraoperative images.

The informative materials from the impressive list of expert contributors from over 15 countries make it a must-read, must-have text. The textbook is a must-have for all who are entrusted with the reconstructive needs of patients worldwide. The work belongs not only in the hands of those in training and those looking for a refresher but also in the hands of seasoned surgeons.

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Preface

The concept for this textbook originated during a dinner a few years ago. The coeditors had been reflecting on how educating multiple generations of plastic surgeons has been one of the most rewarding aspects of their career. During this conversation, they came to the realization that, surprisingly, there were few resources available that could serve as a reference guide to a surgeon looking to walk through an operation, a step-by-step approach, from start-to-finish. Feedback from the medical students and residents over the years confirmed this sentiment.

Each coeditor had returned from an international plastic surgery meeting that reminded them how modern information technology has made knowledge transferable globally and at a speed unfathomable only a decade ago. In particular, plastic surgery has benefited greatly from the contributions of thought leaders from around the world.

As a result, the coeditors became motivated to create this book to address the need for a comprehensive procedural guide and as a means of amalgamating the unique ideas of plastic surgeons from all parts of the world. The coeditors believe that the result is truly greater than the sum of its parts.

This textbook details many of the most essential procedures in the reconstructive plastic surgeons' toolbox. It is organized by anatomic body area, from the head and neck, to the breasts, to the trunk, and the extremities. The authors of each chapter are experts of their domain, many of whom developed procedures that have become the standard of care. Instead of focusing on surgical philosophy, you will find each chapter to be focused on technique and to be very visual, providing clear guidance on the technical progression of each operation as well as its pertinent surgical anatomy.

The editors are indebted to Dr. Foad Nahai, a true innovator and ambassador of plastic surgery not only in the United States but also internationally, for the foreword. As an educator of several generations of plastic surgeons around the world, he embodies the essence of this work. The editors are also highly appreciative of the hard work of the staff at Thieme Publishers, who were able to turn our ideas into reality.

Robert X. Murphy Jr., MD, MS, CPE, FACS
Charles K. Herman, MD, MBA, FACS

Acknowledgments

The editors thank the talented staff at Thieme for bringing this project to fruition. From start to finish, they have shared our vision for the book and made it a reality.

Dr. Murphy would like to thank his family, wife, Meg, and daughters, Margo and Shannon, for their selfless and unwavering love and support. Their love has made every day a blessing. He would also like to recognize his colleagues at the Lehigh Valley Health Network who have supported and nurtured his academic and professional development throughout his entire career.

Dr. Herman appreciates the patience of his family, particularly his wife Olga and son Simon, during the many borrowed hours needed to complete this work.

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Section I

Head and Neck

Subsection IA

Congenital Defects

I

1 Primary/Secondary Cleft Palate Repair

Thomas D. Samson

Abstract
This chapter will focus on the author's preferred technique for surgical correction of both primary and secondary cleft palates. The strategies for addressing common cleft presentations such as complete, incomplete, and submucous as well as the correction of palatal fistulae and velopharyngeal insufficiency will be reviewed. Postoperative care strategies for cleft palate patients will also be discussed.

Keywords: Bardach, cleft palate, fistula, Furlow, intravelar veloplasty, palatoplasty, velopharyngeal insufficiency, vomer flap, von Langenbeck

1.1 Introduction

Repair of the cleft palate defect aims to separate the oral and nasal cavities and anatomically reposition the levator veli palatini muscles for functional speech. Surgical repair of the cleft palate is widely regarded to have begun in the 19th century. The advent of anesthesia brought upon varying techniques of cleft palate repair many of which form the basis of the current popular techniques.

1.2 Indications

Palatal clefts can be described using the Veau classification. Many operative techniques have been used over time with the same guiding principles of two-layer closure and repositioning of the velar musculature as the goal. Review of the many techniques of palate repair is beyond the scope of this chapter. However, the most commonly used repairs today include the Furlow double-opposing palatoplasty, the Bardach two-flap palatoplasty, the von Langenbeck palatoplasty, and the Wardill-Kilner V-Y pushback palatoplasty.[1,2,3,4,5,6,7,8] It should be noted that the Wardill-Kilner V-Y pushback has fallen out of favor due to long-term maxillary growth restriction.

My preferred techniques for Veau types I and II that are less than 10 mm wide is the double-opposing Z-plasty and for clefts wider than 10 mm, or any Veau III–IV, is the Bardach two-flap palatoplasty with intravelar veloplasty (IVV) with or without vomer flaps. Regardless of the technique, repositioning of the levator musculature in its normal anatomic location is the key to success.[9] Surgery is ideally performed at about 12 months of age. Repair prior to 16 months results in better speech outcomes.

In secondary cleft repairs due to fistula, I use the Bardach two-flap palatoplasty with IVV using judicious relaxing incisions. Others have used buccal fat flaps or facial artery myomucosal flaps for larger fistulae. I have used human acellular dermis to augment these repairs in the past but have abandoned the technique after a number of postoperative infections.

In cases of velopharyngeal insufficiency (VPI), I prefer the use of the Furlow double-opposing Z-plasty as my initial repair because if allows radical dissection and retropositioning of the levator muscles without performing a nonanatomic surgery such as the pharyngeal flap or sphincter pharyngoplasty.[10] I have found in my own primarily repaired cleft palate patients that the levator sling has creeped anteriorly even after I have performed what I felt was a radical levator dissection and retropositioning initially. If the repeat Furlow Z-plasty fails, I would perform a pharyngeal flap or sphincter pharyngoplasty. Nasendoscopy can be a very helpful adjunct in determining the correct VPI surgery as it demonstrates the patient's velar closing pattern. Tailoring the surgery to the closing pattern has been well described.

1.3 Operative Technique

All cleft palate repairs begin with appropriate positioning of the patient and insertion of the Dingman mouth gag. The surgeon must confirm the airway function with anesthesia after insertion of the Dingman.

1.3.1 Furlow Double-Opposing Z-Plasty

- Local infiltration: If the cleft width is less than 10 mm, I will mark the palate for double-opposing Z-plasty. I will identify the hamulus and be sure that my back-cut at the hard and soft palate junction does not extend too far laterally near a potential relaxing incision (▶ Fig. 1.1). A 1:1 mix of 0.5% bupivacaine and 0.5% lidocaine with epinephrine 1:200,000 is instilled.
- Incision and dissection:
  - Left-sided oral myomucosal flap is incised and dissection laterally is limited to allow for a relaxing incision as needed:
    - Meticulous dissection of the levator muscle is needed to be sure that the entire muscle is dissected off the

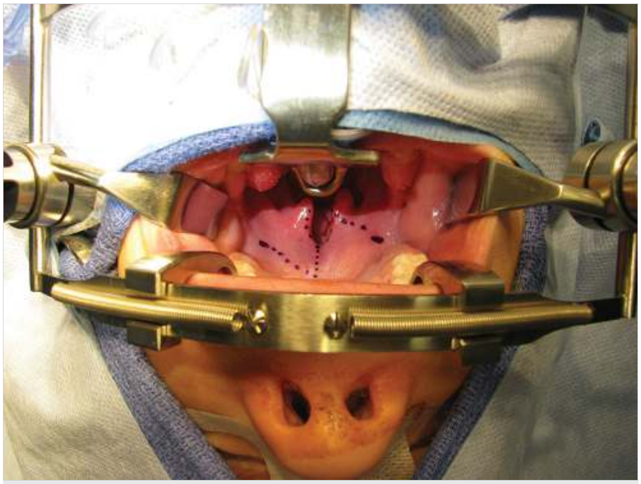

Fig. 1.1 Markings for a Furlow double-opposing palatoplasty.

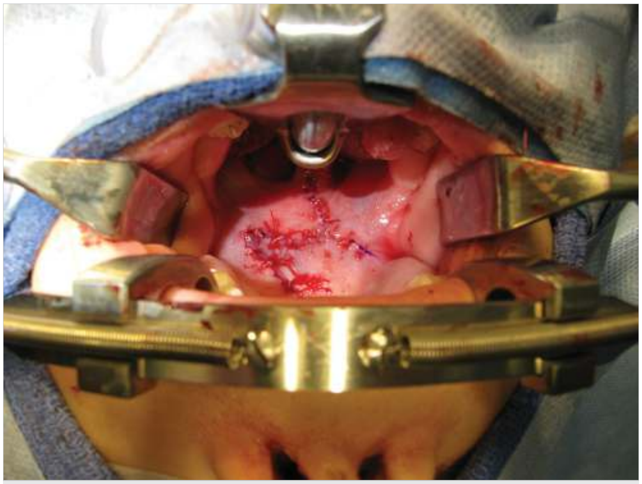

Fig. 1.2 Closure of Furlow double-opposing palatoplasty.

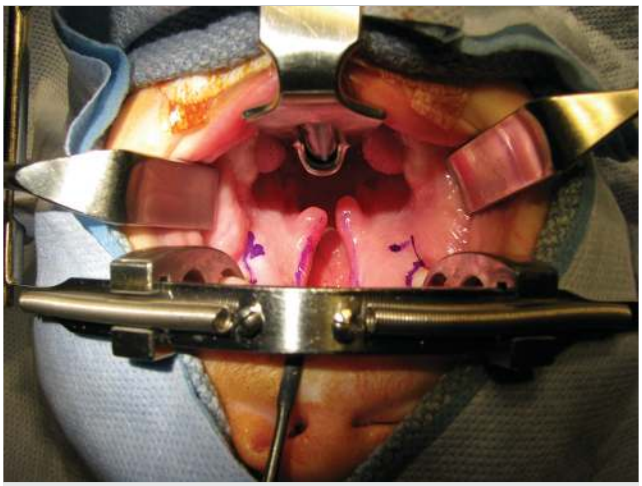

Fig. 1.3 Markings along the posterior soft palate. Lateral marks indicate location of hamulus with lateral relaxing incisions.

posterior edge of the hard palate, freed from the nasal mucosal layer, and radically dissected from the space of Ernst.
    - Tensor aponeurotic fibers are stripped from the hamulus allowing medialization of the entire flap.
  - Right-sided oral mucosa flap is incised and dissected laterally.
  - Left-sided nasal mucosa flap is incised.
  - Right-sided nasal myomucosal flap is incised and elevated, being careful not to extend the mucosal incision too far laterally:
    - Meticulous dissection of the levator muscle is needed to be sure that the entire muscle is dissected off the posterior edge of the hard palate, freed from the nasal mucosal layer, and radically dissected from the space of Ernst.
    - Tensor aponeurotic fibers are stripped from the hamulus allowing medialization of the entire flap.
- Closure: 4–0 and 5–0 absorbable braided suture placed in a horizontal everting fashion. The flap sequence is the right-sided nasal myomucosal flap, the left nasal mucosa-only layer, the

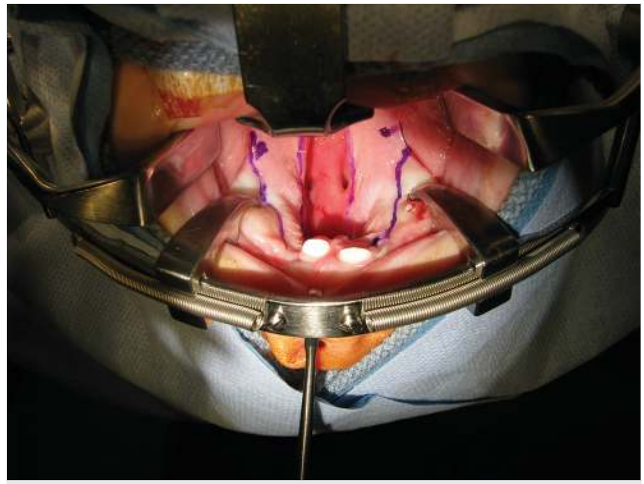

Fig. 1.4 Markings continued on to the hard palate. Note the midline vomer. No markings were made as a vomer flap was not anticipated for this case.

right oral myomucosal flap, and finally the right oral mucosa-only flap (▶ Fig. 1.2).
- Relaxing incisions: I do not routinely use these. If there is any concern for tension along the closure, I will start with a single relaxing incision and not hesitate to make a second incision if needed.
- Nasopharyngeal airway is sized for emergency airway purposes in the postoperative setting. This is placed in a bag on the patient's chart.

1.3.2 Bardach Two-Flap Palatoplasty with Intravelar Veloplasty

- Local infiltration: I mark relaxing incisions lateral to the hamulus, cleft margin incisions, and superiorly based vomer flaps if needed (▶ Fig. 1.3 and ▶ Fig. 1.4). A 1:1 mix of 0.5% bupivacaine and 0.5% lidocaine with epinephrine 1:200,000 is instilled.
- Incision and dissection:
  - Marginal incisions are made with a #12 blade. Relaxing incisions are made bilaterally. The mucoperiosteal flaps on the hard palate are completely incised as unipedicled flaps. This facilitates complete dissection of the greater palatine vessels. If an osseous cuff surrounds the pedicle limiting its medialization, I will carefully osteotimize the bony cuff.
  - Dissection of the levator muscle from the oral and nasal mucosa and freeing the musculature from the posterior edge of the hard palate allow for the retropostitioning of the levator to its normal anatomic positioning.
  - Dissection in the relaxing incision allows for stripping of the tensor aponeurotic fibers from the hamulus and any lateral attachments to the posterior edge of the hard palate. Separation of the superior constrictor from the levator within the space of Ernst completes the levator musculature dissection (▶ Fig. 1.5).
  - Elevation of the nasal mucosa of the hard palate, especially at the junction of the hard and soft palates, completes the dissection.

Fig. 1.5 Note the freer elevator within the space of Ernst. The levator muscle is retropositioned to its normal anatomic placement. The superior constrictor is lateral and there are no tensor fibers distracting the levator anteriorly.

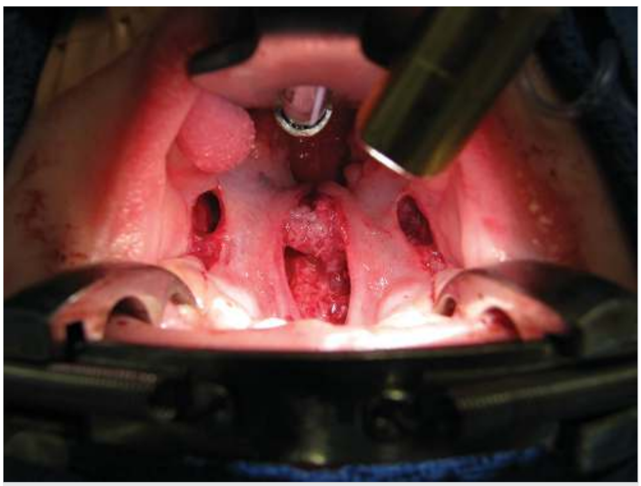

Fig. 1.6 The nasal mucosa has been approximated. The intravelar veloplasty (IVVP) has been completed with the levator sling sitting in the posterior third of the soft palate.

- Vomer flap: If I am concerned with the tension of the nasal closure of the hard palate, superiorly based vomer flaps are elevated.
- Closure: I use 4–0 and 5–0 absorbable braided suture in a horizontal mattress fashion to evert the edges. The nasal lining is closed first, including the uvula. The IVV is completed with 4–0 absorbable braided suture in a figure of eight fashion. Careful attention is paid to place an adequate amount of resting tension on the muscle and to position the muscle at the posterior third of the soft palate (▶ Fig. 1.6). The oral lining is closed (▶ Fig. 1.7) initially by resuspending the anterior edge of the mucoperiosteum to the alveolar gingiva limiting any exposed hard palate bone. No attempt is made to “close” the alveolus. The relaxing incisions are routinely left open.
- Nasopharyngeal airway is sized for emergency airway purposes in the postoperative setting. This is placed in a bag on the patient’s chart.

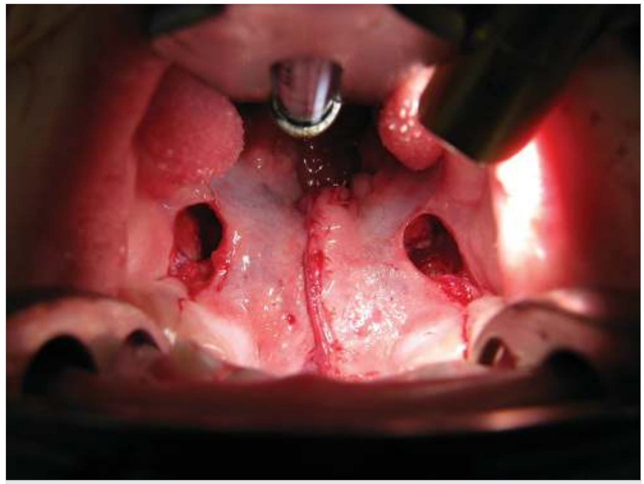

Fig. 1.7 The oral mucosa is approximated with everting horizontal mattress sutures and the relaxing incisions are left open.

1.3.3 Secondary Palatoplasty for Fistula

- Assessment of the fistula is performed using a freer to gently probe the defect. Once the extent of the communication is identified, the intraoral mucoperiosteum is marked at the edge of the fistula and a 1:1 mix of 0.5% bupivacaine and 0.5% lidocaine with epinephrine 1:200,000 is instilled.
- The fistula edge is incised followed by bilateral relaxing incisions. Bilateral unipedicled mucoperiosteal flaps are elevated, being sure to elevate the mucoperiosteum posterior to the fistula for about 5 mm.
- The fistula tract mucosa is carefully excised. Nasal mucosa is elevated. Superiorly based vomer flaps are elevated. Nasal mucosa closure is vital to bilayer closure and success of fistula repair.
- Everting 4–0 and 5–0 absorbable braided suture in a horizontal mattress fashion is placed to evert the edges. Closure of the anterior extent of the mucoperiosteum to the alveolar gingiva is key to avoiding any exposed palatal bone. I do not close the relaxing incisions.
- If the fistula is confined to the hard palate, once the patient meets discharge criteria, he or she is discharged.
- If the repair extends into the soft palate, the patient is kept overnight to monitor airway.

Postoperatively, the patients remain in the hospital overnight to monitor the airway. The patient has an appropriately sized nasopharyngeal airway with the ideal nare to be used on the chart should any airway issues arise. Others place a tongue suture taped to the cheek for emergency airway purposes as well. Patients must demonstrate the ability to take in liquids prior to discharge. Families are encouraged to bring in sippy cups from home. If there are problems taking oral liquids the use of a syringe or red rubber catheter can be used to encourage oral intake.

Once the patients are taking adequate liquids by mouth and their pain is controlled, they are cleared for discharge. Once home, the patient stays on a soft diet for 3 weeks. Encourage sippy cups with no valves and avoid bottles with nipples and pacifiers. I do not use arm restraints as there has been no literature to support their use with a lower flap failure or fistula rate.

Perioperative antibiotics are given for the first day only. I see the patient back in follow-up in 2 weeks.

1.4 Conclusion

Primary or secondary cleft palate repair is challenging and demands a sound operative plan tailored to the patient's defect.

- Two-layer closure along the length of the cleft with minimal tension is vital to avoid fistula formation.
- Complete dissection and approximation of the levator muscles is necessary to establish correct anatomic positioning and leads to improved speech.
- Establishing a normal resting tension on the levator muscles when approximating is necessary to achieve more normal function postoperatively.
- Liberal use of lateral relaxing incisions is utilized to lessen any tension on the midline closure. These incisions are not typically closed.
- When using the Bardach two-flap palatoplasty with IVV you must reapproximate the anterior-most mucoperiosteal flaps to limit exposed bone.
- All patients are kept overnight for airway assessment and continuous pulse oximetry. A nasopharyngeal airway is sized in the operating room and placed in a bag on the chart for use if the patient desaturates.
- Arm restraints are not used postoperatively.[11]
- Soft diet is maintained for 3 weeks or until the first follow-up.

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2 Cleft Lip and Nose Repair

Jonathan Yun Lee and Joseph E. Losee

Abstract

The cleft lip nose deformity has variable presentation, ranging from a unilateral microform cleft lip to bilateral cleft lip with significant nasal deformity. The primary goals of cleft lip repair include: (1) balance Cupid's bow with an upper lip philtral subunit reconstruction and (2) correct the cleft lip nasal deformity. In order to achieve adequate lip length, rotation-advancement with or without triangular flap techniques can be utilized. Multiple modifications of the rotation-advancement have been described; however, they all require rotating the medial element down via a back-cut and filling the resulting defect with either C-flap or advancement flap from the lateral element. Primary cleft rhinoplasty is also strongly recommended at the time of primary lip repair to optimize outcomes. There are several key technical points that should be followed to ensure proper repair:

- The length of the normal philtral column should equal the length of both the noncleft philtral column and the leading edge of the rotation-advancement flap.
- During incision, preserve tattoo marks to facilitate accurate reapproximation of key landmarks.
- The orbicularis muscle requires full release from abnormal attachments to the maxilla, piriform rim, anterior nasal spine, alar base, and caudal septum.
- Cupid's bow and the vertical position of the alar bases should be balanced after muscle repair.

Keywords: bilateral cleft lip, cleft lip nose, incomplete cleft lip, microform cleft lip, minor-form cleft lip, Noordhoff's point, primary rhinoplasty, rotation-advancement, unilateral complete cleft lip

2.1 Introduction

Cleft lip and nose repair combines reconstructive and aesthetic principles to restore form and function. The history and evolution of cleft lip and nose repair is extensive, ranging from 3rd century China to today's modifications of Millard's rotation-advancement technique.[1,2,3] During the 19th century, "straight-line" repairs by Rose and Thompson began to be replaced with "Z-like" repairs using local flaps to reduce lip shortening from scar contracture. The application of the "Z" repair was further popularized in the 20th century with the Tennison-Randall[4] (triangular flap) and Millard[5] (rotation-advancement) techniques. Moreover, these techniques still serve as the backbone for the numerous modifications that are widely used by cleft surgeons today.[6,7,8,9,10,11]

2.2 Indications

Unilateral and bilateral cleft lips can have varying degrees of deformity, and can be classified as either microform, minor, incomplete, or complete (▶ Fig. 2.1). A vermilion notch describes both microform and minor clefts; however, minor clefts have a notch greater than 3 mm in height, vertical depression above the

Fig. 2.1 Types of cleft lips: **(a)** right microform, **(b)** left minor-form, **(c)** left incomplete, **(d)** left complete, and **(e)** bilateral complete.

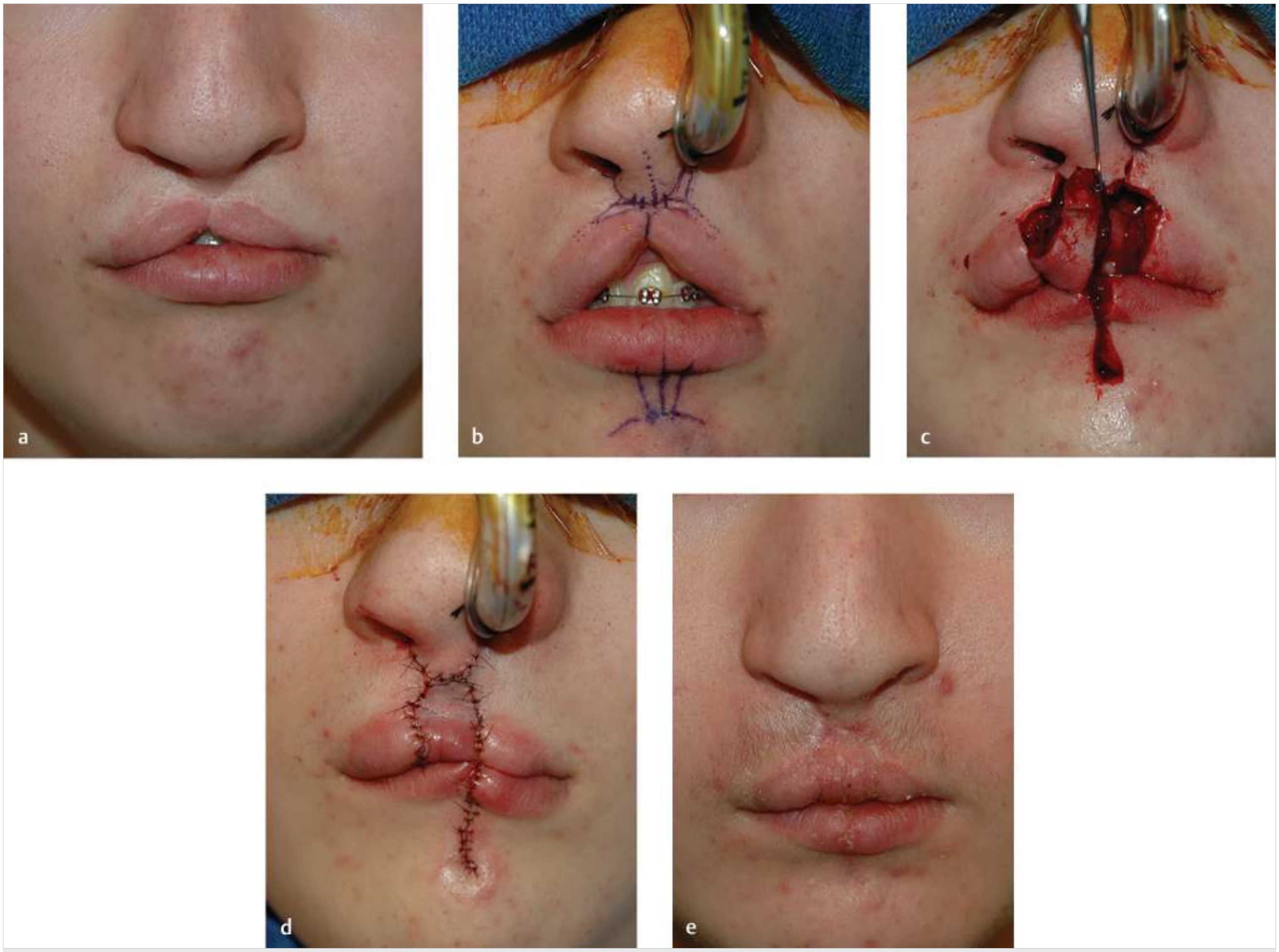

Fig. 2.2 Abbe flap. **(a)** Patient status post bilateral lip repair presenting with a whistle deformity characterized by a deficiency in the central vermilion and lip tubercle. **(b)** Markings. **(c)** Dissection with recreation of the cleft lip defect and transfer of the lower lip flap. **(d)** Inset of the lower lip flap. **(e)** At 6-month follow-up after division and inset of the lower lip flap.

notch extending into the nasal sill, and variable nasal deformity.[12] The distinction between incomplete and complete clefts is debated, specifically when a soft tissue bridge, often called a "Simonart's band,"[3] is located at the nostril base. In order to clarify classification, the senior author proposes that when evaluating cleft lips, the nasal sill should be separated from the lip using a line connecting the alar-facial groove to the columellar-philtral junction. Presence of tissue below this line indicates an incomplete cleft lip, while presence of tissue at or above the line would still be considered a complete cleft lip.[13]

Preoperative assessment of the cleft-affected patient requires a multidisciplinary team consisting of speech pathologist, otolaryngologist, geneticist, pediatrician, feeding specialist, and social worker. Comorbidities and genetic syndromes are identified. The need for presurgical infant orthopedics (PSIO) (passive—nasoalveolar molding; active—Latham device) or lip adhesion prior to formal repair is determined.[14,15]

Regardless of the technique, the goals of cleft lip repair remain constant:

- Philtral subunit lip reconstruction with a balanced and well-shaped Cupid's bow.
- Distinct, continuous, symmetric white roll.
- Normal philtral morphology with full tubercle.
- Symmetric vertical position of nasal ala.
- Functional continuity of orbicularis oris.
- Imperceptible scars.
- Restoration of normal nasal form.

Accomplishing these goals is complicated by cicatricial changes, growth, and type of cleft lip deformity. Secondary repair is indicated when there are deficiencies in the goals after wound maturation. In the revision, the initial repair may need to be taken apart to recreate the defect for significant asymmetries of Cupid's bow, lip height, or animation. A cross-lip flap (Abbe flap) may be indicated after bilateral cleft lip repair if the philtrum is deficient or a significant whistle deformity is present (▶ Fig. 2.2).[16,17,18]

2.3 Operative Technique

2.3.1 Unilateral

A modification of the rotation-advancement is the authors' preferred technique (▶ Fig. 2.3 and ▶ Video 2.1). After the patient

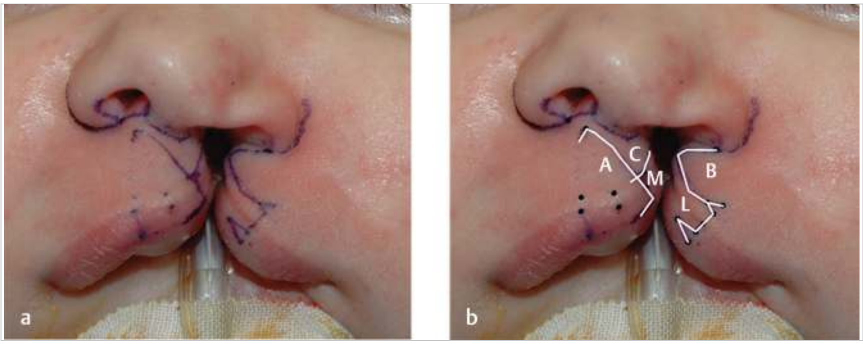

Fig. 2.3 Unilateral markings. **(a)** Markings are first made with a fine marking pen. The cardinal landmarks are then tattooed with methylene blue and a 25-g needle. **(b)** The skin incisions are highlighted in white. A, rotation flap; B, advancement flap; C, columellar flap; L, cleft nasal lining flap; M, medial element mucosal lining flap.

Video 2.1 Left unilateral cleft lip markings

is prepped and draped, the markings are performed with a fine marker and critical points tattooed with methylene blue. The first set of markings includes the nadir, the noncleft peak, and the cleft peak of Cupid's bow on the medial lip element. The distance between the nadir and the noncleft peak is translated medially to determine the location of the cleft peak. The cleft peak of Cupid's bow on the lateral lip element is then marked. This point is also referred to as Noordhoff's point,[19] which corresponds to where the white roll begins to taper and the vermilion is the fullest. The vertical distance between the lateral cleft peak of Cupid's bow and the cleft alar base should be the same as the distance between the noncleft peak and the noncleft alar base on the medial lip element, in order to ensure symmetric lip height. The advancement flap on the lateral element is marked from the cleft peak, extending along the lateral aspect of the white roll, then transitioning along the nasal sill, but not beyond the alar base. The rotation flap on the medial element is marked from the cleft peak, extending to the top of the noncleft philtral column. This rotation flap incision will become the cleft philtral column; it should form an isosceles triangle with the noncleft philtral column; and it should equal the length of the leading edge of the advancement flap on the lateral lip element. A back-cut along the noncleft philtral column is marked, and its length is limited only by the distance needed to rotate the medial element to level Cupid's bow and transpose the top of the new philtrum to the midline of the columella. If additional rotation is necessary to balance Cupid's bow, a small triangular flap (1 mm) from the lateral lip element can be inserted above the white roll of the cleft peak of Cupid's bow. Lastly, the C-flap is marked on the medial element from the cleft peak, extending along the vermilion border to the nasal sill.

The markings are incised and the orbicularis oris muscle is dissected from the skin and mucosa, in addition to elevation of the C-flap. Limited dissection from the skin on the medial element is important to preserve the philtral dimple and the noncleft philtral column; however, the muscle must be dissected free from its abnormal attachments to the nasal septum and anterior nasal spine to allow sufficient rotation. This dissection also allows for repositioning the caudal septum of the nose into the midline. The rotation flap back-cut can now be performed to balance Cupid's bow. Proper dissection of the advancement flap requires a buccal sulcus incision in the lateral element in order to dissect the muscle off the abnormal attachments to the piriform aperture and alar base. Extension of the buccal sulcus incision across the piriform aperture and up on top of the inferior turbinate is often needed to mobilize the alar-lip-cheek complex in the supraperiosteal plane and reposition the alar base.

Repair is started with approximating the mucosal lining with 4–0 and 5–0 Chromic suture. The orbicularis oris muscle is repaired next with eversion of the edges with mattress sutures of 4–0 Vicryl to recreate a philtral column. After muscle repair, the skin edges should be in close approximation with a balanced Cupid's bow and level nasal ala. The skin is reapproximated precisely with buried dermal sutures of 5–0 Monocryl to avoid external sutures. Lip and vermilion height discrepancies can be addressed by insetting the triangular flaps above the white roll and vermilion redline (between the vermilion and mucosa) from the lateral element into the corresponding back-cuts in the medial element. Lastly, the C-flap is tailored and inset to reconstruct the cleft side columella and medial nasal sill (▶ Fig. 2.4).

The senior author also prefers to correct the cleft nose deformity at the time of the primary lip repair (▶ Fig. 2.5). The technique is a semi-open approach, utilizing a Tajima's reverse-U incision[20] on the cleft side and a marginal alar rim incision on the noncleft side. The fibrofatty tissue is dissected off the lower lateral cartilages, including the nasal tip. A double-dome bind with a horizontal mattress suture of 4–0 PDS is performed to approximate the genu of each lower lateral cartilage to narrow the angle of divergence of the nasal tip as well as to reposition the cleft side lower lateral cartilage. Horizontal mattress sutures starting in the lateral nasal vestibule, exiting and re-entering the same puncture site in the alar-cheek junction on the cleft side, and then tied internally, is used to collapse dead space, efface lateral intranasal webbing, and support the repositioned lateral crus of the lower lateral cartilage. All incisions are then closed with 6–0 fast absorbing sutures.

2.3.2 Bilateral

In addition to the goals previously mentioned for unilateral cleft lip repair, bilateral repairs need to create an upper labial sulcus

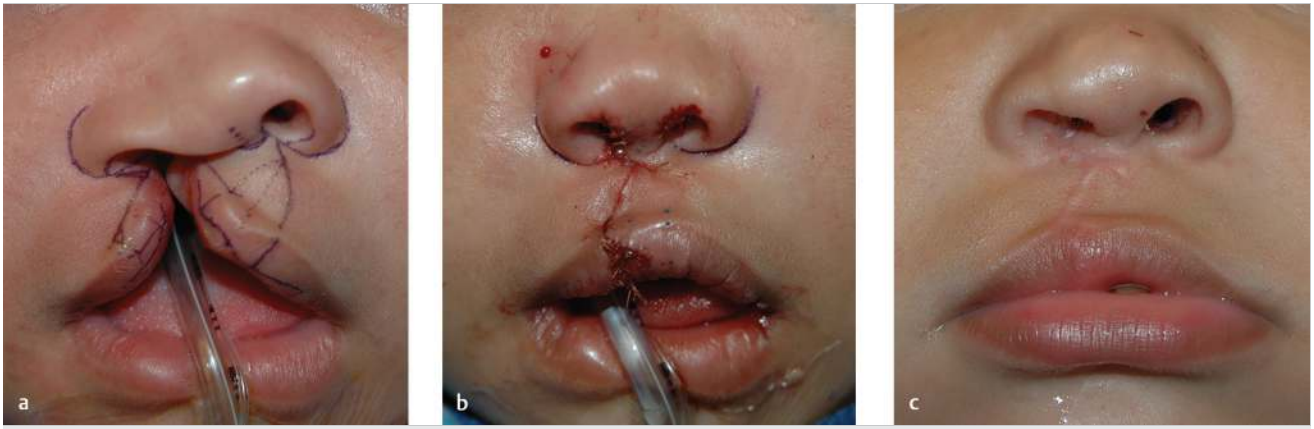

Fig. 2.4 Unilateral lip repair. **(a)** Right unilateral cleft lip with markings. **(b)** Immediately after unilateral cleft lip and nose repair, demonstrating a balanced Cupid's bow and alar symmetry. **(c)** A balanced Cupid's bow maintained at 6 months follow-up; however, mild alar asymmetry despite nasal stenting.

Fig. 2.5 Primary cleft rhinoplasty. **(a)** Markings for bilateral Tajima's reverse-U incisions. **(b)** Immediately after cleft nose repair, demonstrating improved alar shape and contour with inversion of the Tajima's incision into the nostril. **(c)** Silastic nasal stents are fitted (often different sizes between nostrils initially) and the tabs secured to the dorsum of the nose.

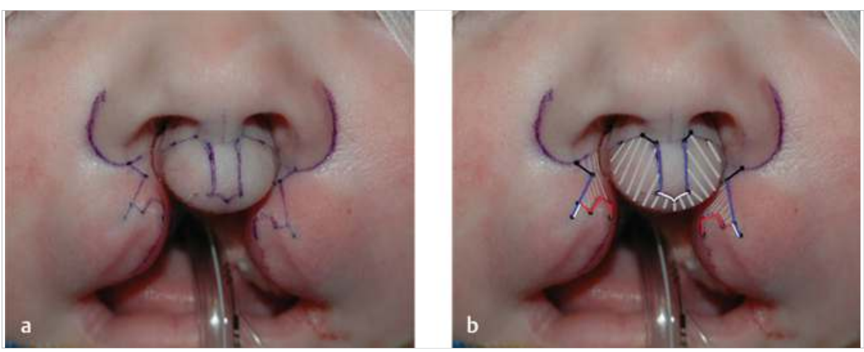

Fig. 2.6 Bilateral markings. **(a)** Markings are first made with a fine marking pen. The cardinal landmarks are then tattooed with methylene blue and a 25-g needle. **(b)** The skin incisions on the prolabium and the lateral elements are highlighted in different colors, corresponding to the incisions that will be approximated during repair. *Black*, columellar-nasal sill junction; *blue*, philtral column; *gray*, discarded skin; *red*, vermilion; *white*, white roll.

and improve columellar length. Furthermore, nasal repair at the time of lip repair is important to reposition the lower lateral cartilages and establish tip projection. The repair described by Mulliken[21] is the authors' preferred technique (▶ Fig. 2.6). Similar to the unilateral repair, the markings on the prolabium and lateral elements are marked with a fine marking pen and the critical landmarks are tattooed with methylene blue. The width of Cupid's bow on the prolabium is marked at 4 mm, and the width of the columellar base is marked at 3 mm. Curved vertical limbs connect the two sets of points, forming the philtrum. The peak of Cupid's bow on the lateral elements are marked where the vermilion is the fullest and where the white roll begins to taper. Points 2 to 3 mm medial to the Cupid's bow peaks are marked, indicating the leading edges of the white roll flaps from the lateral elements that will be used to reconstruct Cupid's bow.

Incision of the markings on the prolabium and lateral elements are made. The philtral skin flap is elevated to the level of the columella, and the remainder of the prolabial skin caudal to the nasal sill is excised. The mucosa of the prolabium is elevated and advanced onto the anterior surface of the prolabium to set the height of the labial sulcus. The nasal sill is then reconstructed by approximating the alar base flaps from the lateral elements to the skin flaps from the prolabium cephalad to the nasal sill. Upper buccal sulcus incisions are made to allow dissection of the alar-cheek-lip complexes off the piriform rim and maxilla. The orbicularis oris muscle from each lateral element is dissected

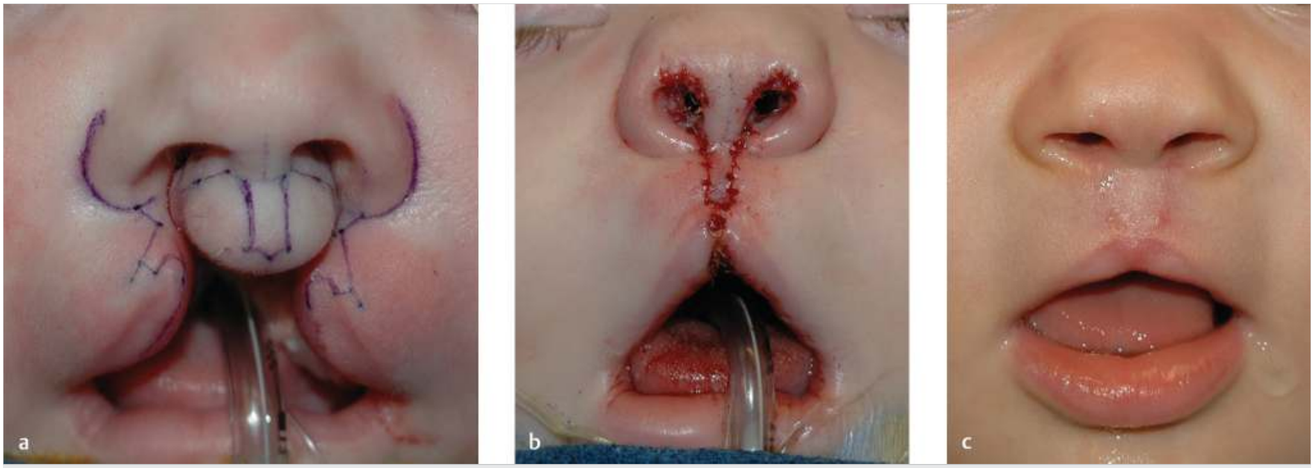

Fig. 2.7 Bilateral lip repair. **(a)** Bilateral complete cleft lip with markings. **(b)** Immediately after bilateral cleft lip and nose repair, demonstrating a balanced Cupid's bow, alar symmetry, narrow philtrum, and tubercle fullness. **(c)** Balanced Cupid's bow, alar symmetry, and tubercle fullness maintained at 6 months follow-up; however, there is mild widening of the philtrum.

from skin and mucosa, ensuring to release any abnormal attachments to the alar base. Both lateral elements should now be fully mobilized toward the midline without significant tension.

The mucosa is repaired first, advancing the upper buccal incisions. The orbicularis oris muscle from each lateral element is approximated to each other across the prolabium. The skin edges of the lateral elements should now be close to the edges of the philtral flap. Cupid's bow is reconstructed with the white roll flaps from the lateral lip elements. The tubercle is reconstructed with the vermilion flaps from the lateral elements, and the final inset of the lateral elements to the philtral flap is performed precisely with buried dermal sutures to avoid external sutures (▶ Fig. 2.7).

The approach and technique to repair the bilateral cleft nose deformity are the same as the unilateral repair described earlier, except bilateral Tajima incisions are utilized. Again, the angle of divergence of the nasal tip needs to be narrowed with a mattress suture, and the lower lateral cartilages need to be fully dissected from the overlying fibrofatty tissue in order for proper repositioning. In both unilateral and bilateral nasal repairs, the use of silastic nasal stents is strongly advocated by the authors. Stents are sized intraoperatively to have a snug fit in the nostril without causing significant blanching of the nasal tip. The stents are secured to the dorsal surface of the nose with an adhesive strip, and the parents are taught how to change and clean the stents daily. Ideally, stenting should be performed for 3 to 6 months.

2.4 Conclusion

The cleft lip repairs described are a modification of the rotation-advancement technique for unilateral clefts and the Mulliken technique for bilateral clefts. The ultimate goals in any cleft lip repair is to (1) balance Cupid's bow, (2) fully detach abnormal insertions of the orbicularis oris muscle, and (3) reestablish continuity of the orbicularis oris muscle. Primary cleft rhinoplasty is also preferred at the time of the lip repair to maximize outcomes. However, the rhinoplasty requires dissection of the fibrofatty tissue from the lower lateral cartilages under direct vision to allow the proper approximation/shaping of the cartilaginous structures and avoid iatrogenic injury.

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3 Velopharyngeal Insufficiency

Mimis Cohen and Ellyn McNamara

Abstract
A number of patients present with residual velopharyngeal insufficiency after repair of cleft palate. Full cooperation of the surgeon and the speech pathologist is needed for accurate diagnosis and successful management. Speech therapy should be implemented first. After unsuccessful completion of a course of speech therapy and extensive evaluation, a determination for surgical management is made. Several surgical options are available, but the chapter will only focus on the superior pharyngeal flap technique, and describe the steps of the procedure in detail, possible outcomes, early complications, and failures.

Keywords: cleft palate speech, pharyngeal flap, velopharyngeal insufficiency, VPI

3.1 Introduction

Despite better understanding of speech production mechanisms, the effects of early palate repair on speech outcome, and improvements in surgical procedures and speech evaluation techniques, a number of patients, up to 20% according to some studies, will present with residual velopharyngeal disturbances after cleft palate repair. This rate does not seem to be influenced significantly by the surgical technique used for the palatoplasty.

3.1.1 Pertinent Anatomy

The anatomy of the velopharynx is complex and well described. Normal speech production depends, among others, on coordination of all involved muscles to achieve complete separation of the oral and nasal cavity during production of oral sounds. The muscles of the soft palate as well as the muscle of the lateral and posterior pharyngeal walls function in cohort to provide a sphincter and prevent air escape from the nose during oral speech sounds.[1] These structures include the paired muscles:

- Levator veli palatini.
- Tensor veli palatini.
- Palatoglossus.
- Palatopharyngeous.
- Muscle uvulae.
- Superior pharyngeal constrictor.

3.2 Indications

Accurate diagnosis is cardinal for a successful outcome. With close cooperation between the surgeon and the speech pathologist, appropriate data is obtained and analyzed, and a treatment plan is formulated based on the individual needs of each patient. A detailed history should be first obtained to gain information on previous interventions, feeding or swallowing problems, nasal regurgitation, presence of fistulas, speech problems, and frequent ear infections among others. Oral and nasal evaluations are also necessary prior to proceeding with specific tests and techniques.

Techniques and measurements used to assess velopharyngeal function generally can be classified into two categories: perceptual and instrumental.

During the perceptual assessment, the speech-language pathologist evaluates the quality and intelligibility of the patient's speech sound articulation and resonance. In particular, they identify and categorize speech articulation errors as developmentally appropriate, obligatory secondary to anatomical differences like malocclusion, or compensatory secondary to velopharyngeal insufficiency (VPI). Additionally, the speech-language pathologist notes intraoral pressure for speech sounds, the presence of nasal air emission, and generalized hyper- or hyponasal resonance.[2]

Although the perceptual assessment is critical to measuring functional speech outcomes, instrumental assessment of velopharyngeal function is crucial for assessment of the anatomy of the area and assist in planning the most appropriate surgical correction. Instrumental assessment may include direct measures of velopharyngeal function primarily with nasopharyngoscopy (▶ Fig. 3.1), videofluoroscopy, and occasionally with dynamic magnetic resonance imaging (MRI). Physiologic measures like pressure flow testing and anatomic evaluation with nasalance scores further augment the preoperative information.[3]

3.3 Operative Technique

3.3.1 Procedures to Correct Velopharyngeal Insufficiency (VPI)

After unsuccessful completion of a course of speech therapy and extensive evaluation, a determination is made for surgical intervention. One of the following options can be considered:

- Redo palatoplasty.[4]
- Furlow double-opposing Z-plasty.[5]
- Superiorly based pharyngeal flap.[6]
- Sphincter pharyngoplasty.[7]
- Retropharyngeal implants/fat grafting.[8,9]
- Prosthetic management (for nonsurgical candidates).[10]

There are specific indications for some of these procedures but overall decision is made based on the individual patient's anatomy and testing results as well as the surgeon's experience and preference. In this chapter, only the superiorly based pharyngeal flap procedure will be discussed.

3.3.2 Pharyngeal Flap

- Nose Q30.2.
- Palate Q35.9:
  - With Cleft Lip (Unilateral) Q37.1:
    - Bilateral Q37.0.
  - Hard Q35.1:
    - With Cleft Lip (Unilateral) Q37.1 or Bilateral Q37.0.
    - With Soft Palate Q35.5.

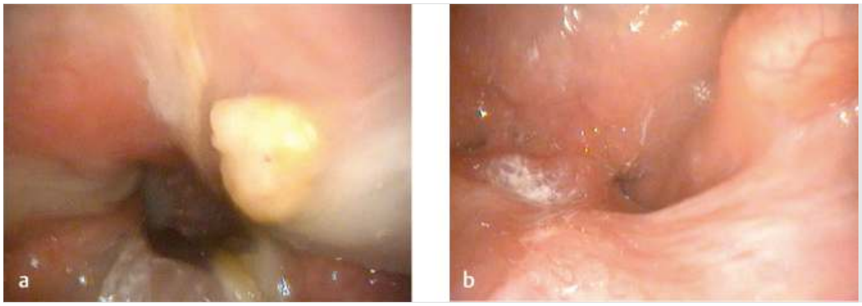

Fig. 3.1 **(a)** Preoperative endoscopic view demonstrating incomplete closure of nasopharyngeal mechanism. **(b)** Postoperative view demonstrating good closure of velopharyngeal speech during production of oral sounds.

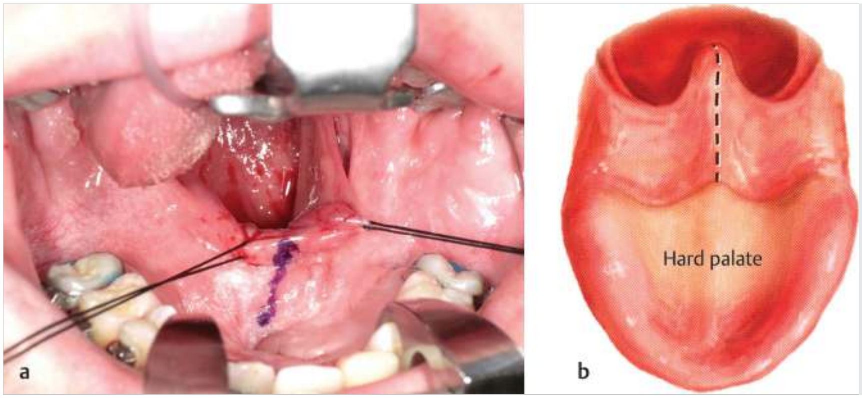

Fig. 3.2 **(a, b)** Superiorly based pharyngeal flap. Soft palate is divided in the scar of the previous palatal repair. From Bentz ML, Bauer BS, Zuker MR. Principles and Practices of Pediatric Plastic Surgery. 2nd ed. New York: Thieme Medical Publishers; 2017.

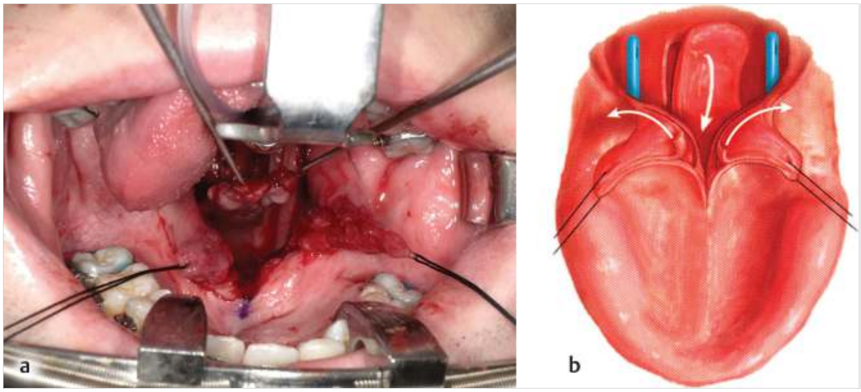

Fig. 3.3 **(a, b)** Superiorly based pharyngeal flap. Bilateral nasal mucosal flap based on the free border of the soft palate is raised to be used for resurfacing the row surface of the pharyngeal flap. From Bentz ML, Bauer BS, Zuker MR. Principles and Practices of Pediatric Plastic Surgery. 2nd ed. New York: Thieme Medical Publishers; 2017.

The superiorly based pharyngeal flap is a widely accepted procedure for management of patients with VPI. This procedure is favored because large gaps are reduced and the flap design allows for more natural movement of the soft palate toward the tubercle of the axis. There are several modifications of the procedure but the basic concept and steps remain the same[11]:

- The soft palate is divided in the midline in a full-thickness fashion from the hard/soft palate junction to the uvula. The two hemipatal segments are retracted cephalad (▶ Fig. 3.2).
- A nasal mucosal flap based on the posterior, free surface of the soft palate is elevated from the muscles of each hemipalate (▶ Fig. 3.3).
- Two parallel incisions on the posterior pharyngeal wall are made from the tubercle of the axis to as far down as possible in the pharynx.
- The dissection is carried through the superior pharyngeal constrictors to the prevertebral fascia.
- A horizontal incision is used to join the lateral incisions and the flap is dissected from distal to proximal till the level of the axis.
- After meticulous hemostasis the donor site is closed with running interlocking absorbable sutures. If undue tension is encountered then the donor site can be left open.
- The flap is then inset on the nasal surface of the soft palate and secured with five interrupted absorbable sutures (▶ Fig. 3.4).
- 14-French red rubber catheters are placed transnasally, passing through each port in order to appropriately tailor the port size around the catheter.
- The previously raised nasal mucosal flaps are sutured together in the midline and secured to the raw surface of the pharyngeal flap. They are also secured to the mucosal edges of the flap, on either side of the constructed ports (▶ Fig. 3.5).
- Attention is needed to tailor the size of ports, avoiding too tight or too large ports.

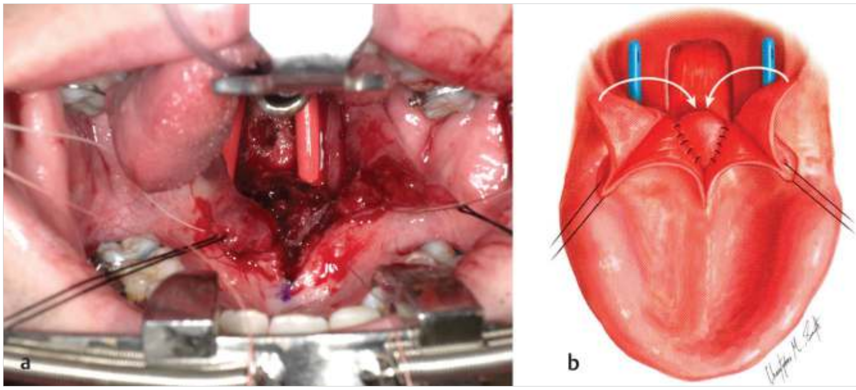

Fig. 3.4 (a, b) Superiorly based pharyngeal flap. The pharyngeal flap is dissected from the posterior pharyngeal wall and inset in the nasal surface of the soft palate. Note the #14 French rubber tubes on either side of the flap to assist in port size. From Bentz ML, Bauer BS, Zuker MR. Principles and Practices of Pediatric Plastic Surgery. 2nd ed. New York: Thieme Medical Publishers; 2017.

Fig. 3.5 (a, b) Superiorly based pharyngeal flap. The soft palate is closed in layers, and the previously raised nasal mucosa flaps are used to cover the raw surface of the flap. From Bentz ML, Bauer BS, Zuker MR. Principles and Practices of Pediatric Plastic Surgery. 2nd ed. New York: Thieme Medical Publishers; 2017.

3.3.3 Early Complications

With advances in pediatric anesthesia, better understanding of the anatomy, and improvement of techniques, the number of perioperative complications decreased significantly. Death due to obstruction is extremely rare, but occasional operative and postoperative bleeding and acute airway obstruction can still be anticipated.

It is currently recognized that, in the vast majority of patients, some degree of transient obstruction will be present immediately after surgery. Such obstruction can be identified clinically and with polysomnographic sleep studies and monitoring of the arterial saturation. Most of the obstructive symptoms resolve shortly after surgery. For these reasons, it is extremely important to carefully monitor the patients in the immediate postoperative period. Nasopharyngeal airway tubes are used, if necessary, to improve breathing and in the extreme cases, reintubation may be necessary to control the airway.[12]

3.3.4 Results after Pharyngeal Flap Surgery

Several long-term studies evaluating the long-term effects of pharyngeal flap surgery on breathing and speech have been reported. Success rates range from 40 to 90%. However, despite its drawbacks, pharyngeal flap surgery remains an important procedure for the management of patients with VPI, as long as the indications for the procedure are well understood and the patients have undergone extensive preoperative evaluation. Attention should be given to all surgical details as well as postoperative follow-up. Postoperative course of speech therapy is also necessary to achieve the best possible speech outcome.[13,14]

3.3.5 Pharyngeal Flap Failures/ Complication

Persistent Hypernasality

Persistent hypernasality is primarily due to technical errors including large port(s), low placement of the flap, partial/complete detachment of the flap, and contracture and narrowing of the flap with residual widening of the ports. Each of these conditions can result in deficient ports on one or both sides of the flap. Established hypernasality requires extensive evaluation before treatment. Once the reason(s) for hypernasality is/are established, revision of the size of the port(s) is recommended using various techniques based on the individual anatomy.[15,16]

Persistent Hyponasality

Partial or complete obstruction is a serious complication of flap surgery with potential detrimental effects on the patient's health. Symptoms may vary including among others snoring, sleep-wake disturbances, loss of olfactory acuity, and intranasal or sinus infections. Obstruction might have significant effects on dentofacial growth and even systemic effect on the cardiopulmonary and other systems. The exact incidence of this complication is not known, because several investigators do not consider hyponasality to be a failure of pharyngeal flap surgery.

Milder hyponasality without other clinical symptoms might be considered an acceptable result but when this condition interferes with speech, or the patient's general health, revision of the ports is recommended. Since there is no appropriate formula for the recommended size of the ports, the surgeon should be very careful to avoid overcorrection, creating ports that are too large and resulting in recurrence of hypernasality.[17]

Procedures range from direct excisions around the ports to complete take down of the flap as a last recourse. Rough surfaces after the intervention should be avoided since they could lead to further scaring and obstruction.[18]

3.4 Conclusion

Residual VPI is a common occurrence after cleft palate repair. After it is determined that maximal outcome has been achieved with speech therapy, surgical options can be considered. Pharyngeal flap reconstructions are mainstay of surgical alternatives. A superiorly based pharyngeal flap is a widely accepted technique. It is important that speech therapy be continued after surgery. Serious complications including bleeding and airway obstruction are rare but possible. More common are varying degrees of persistent hypernasality and hyponasality.

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4 Velopharyngeal Insufficiency: Pharyngoplasty

Husain AlQattan, Leela S. Mundra, Liann Casey, and Seth R. Thaller

Abstract

There are a variety of etiologies causing velopharyngeal insufficiency which is basically characterized by hypernasal speech. Following a comprehensive interdisciplinary team assessment, surgical management can be determined. In cases with poor lateral wall movement, the pharyngoplasty is probably the treatment of choice. Originally described by Hynes in 1950, the sphincter pharyngoplasty has undergone numerous modifications. Basically, the procedure consists of developing myomucosal flaps from the posterior tonsillar pillars including a robust segment of muscle. These are then rotated 90 degrees and inset into the posterior pharyngeal wall in a horizontal plane, thereby creating a physiologic dynamic sphincter, which also enhances the volume of the posterior pharyngeal wall.

Keywords: cleft palate, pharyngoplasty, sphincter pharyngoplasty, velopharyngeal insufficiency, VPI

4.1 Introduction

Velopharyngeal insufficiency (VPI) results from a variety of functional or anatomical derangements that prevent adequate velopharyngeal closure. Patients with VPI often present with speech symptoms such as hypernasality and nasal emissions during speech. Additionally, nonspeech symptoms such as nasal regurgitation results in recurrent ear or sinus infections that can have negative impacts on development and quality of life. Surgical management of VPI aims to close the velopharyngeal port in order to minimize nasal airflow during speech while maintaining the upper airway. This chapter focuses on the sphincter pharyngoplasty technique, describing detailed steps of the procedure, early complications, and postoperative outcomes.

4.2 Indications

Closure pattern of the velopharyngeal sphincter determines the most appropriate surgical procedure for management of VPI. Preoperative evaluation with nasendoscopy and/or video fluoroscopy is crucial. Patients with a coronal or circular closure pattern and a relatively smaller velopharyngeal port are best suited for a sphincter pharyngoplasty. These patients tend to have adequate velar elevation but poor lateral wall motion.[1] Airway morbidity is also significantly reduced in comparison to pharyngeal flaps. Therefore, this procedure is the one of choice in those with a history of obstructive sleep apnea.[2] Sphincter pharyngoplasty should also be considered the procedure of choice if considering future LeFort osteotomy advancement.

Preoperative nasendoscopy can also establish the degree of adenoid hypertrophy. Significant hypertrophy that could limit superior placement of the myomucosal flaps increases the rates of revision surgery. This warrants preoperative or simultaneous adenoidectomy.[3] Enlarged tonsils may obstruct or hinder the raising of the myomucosal flaps, thus requiring preoperative or simultaneous tonsillectomy. This decision is subjective and best made by the operating surgeon. These procedures are best performed 3 months prior to pharyngoplasty, with repeat nasendoscopy and/or video fluoroscopy as closure patterns may have changed. Family must be warned about the possibility of deterioration in speech during this period.

Originally described by Hynes in 1950, sphincter pharyngoplasty has been modified over the years. Goal of this procedure is narrowing the velopharyngeal port to minimize airflow through the nose during speech.[4] Essentially, it involves raising myomucosal flaps from the posterior tonsillar pillars and rotating them 90 degrees medially to inset them into the posterior pharyngeal wall in the horizontal plane.[5] This method is thought to be more physiologic. It creates a dynamic flap while also increasing the volume of tissue at the velopharyngeal port. However, this remains to be completely proven.[2]

4.3 Operative Technique

Adequate exposure is obtained by reflecting the uvula into the nasopharynx (▶ Fig. 4.1). This can be achieved by placing a catheter transnasally, followed by suturing the uvula to the catheter transorally. Catheter is then used to retract the uvula into the nasopharynx to expose the posterior pharyngeal wall. Aberrant internal carotids, especially in those with velocardiofacial syndrome, tend to run in a more medial or submucosal position. Finger palpation of the posterior pharynx prior to making an incision is mandatory. This proximity can place them at risk of injury during the operation. Some authors mandate preoperative magnetic resonance (MR) angiography in all velocardiofacial syndrome patients before pharyngeal surgery.[6] This will delineate the location of the internal carotids in relation to the posterior pharyngeal wall potentially reducing the risk of injury. Its cost-effectiveness remains controversial.[7,8]

Ink is used to mark the planned incision for the myomucosal flaps harvested from the posterior tonsillar pillars, which are retracted medially with forceps. This should outline the anterior and posterior tonsillar pillars, in addition to a horizontal line at their superior aspect that connects them (▶ Fig. 4.2). Length from the superior to inferior aspect of the flap is designed to equal the transverse width of the planned insertion site. Local anesthetic with epinephrine is then infiltrated. Starting with one tonsillar pillar, a unipedicled myomucosal flap, cephalad based, is elevated from the posterior pharyngeal wall. This includes the lateral fibers of palatopharyngeus muscle. Flap is raised superiorly until the insertion site along the horizontal line at the posterior pharyngeal wall is reached. Same maneuver is repeated for the contralateral tonsillar pillar (▶ Fig. 4.3). Preoperative video fluoroscopy aids in planning how high the horizontal incision should be placed. This dictates the flap insertion site and thus the site of planned velopharyngeal closure.

Horizontal line along the posterior pharyngeal wall is then incised. This connects the incisions outlining the myomucosal flap donor sites in an upside-down U. Myomucosal flaps are

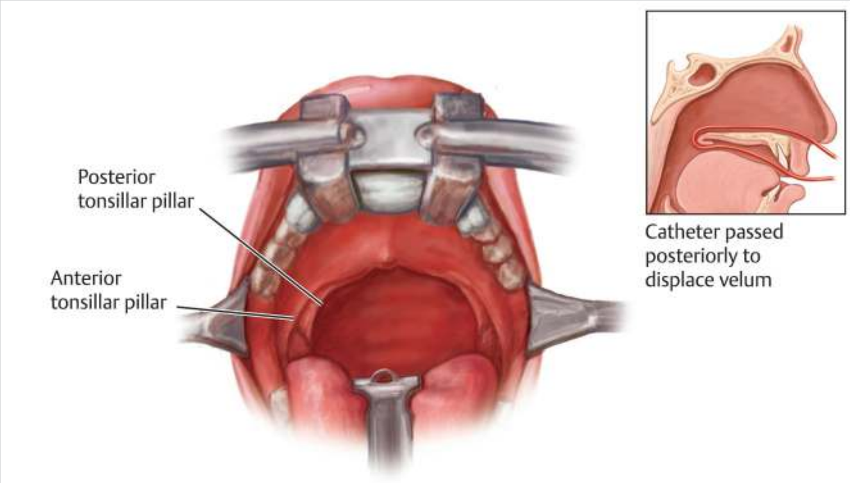

Fig. 4.1 Oropharyngeal exposure. Uvula is reflected superiorly into the nasopharynx by placing a catheter transnasally into the oropharynx and suturing it to the end of the catheter. The catheter is then used to retract the uvula into the nasopharynx to expose the posterior pharyngeal wall.

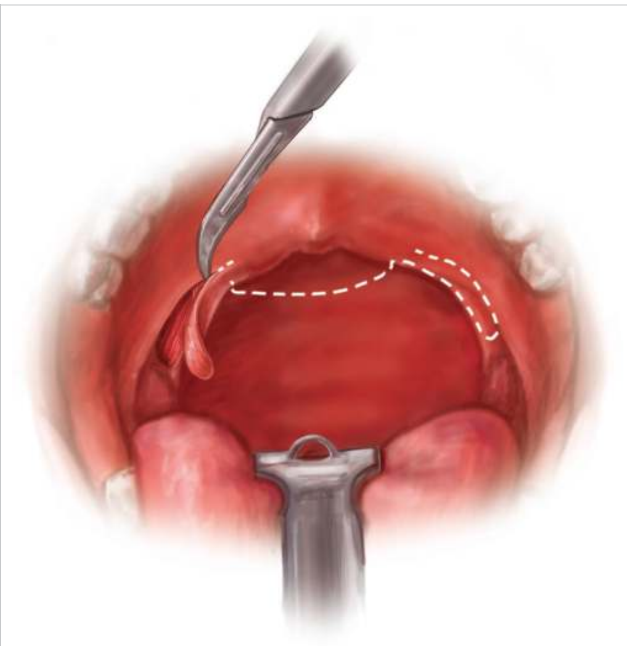

Fig. 4.2 Planning the incisions. Myomucosal flaps are outlined along the posterior tonsillar pillars and a horizontal line along the posterior pharyngeal wall connects the planned flaps. Length from the superior to inferior aspect of the flap is designed to equal the transverse width of the planned insertion site. Preoperative video fluoroscopy aids in planning how high the horizontal incision should be placed.

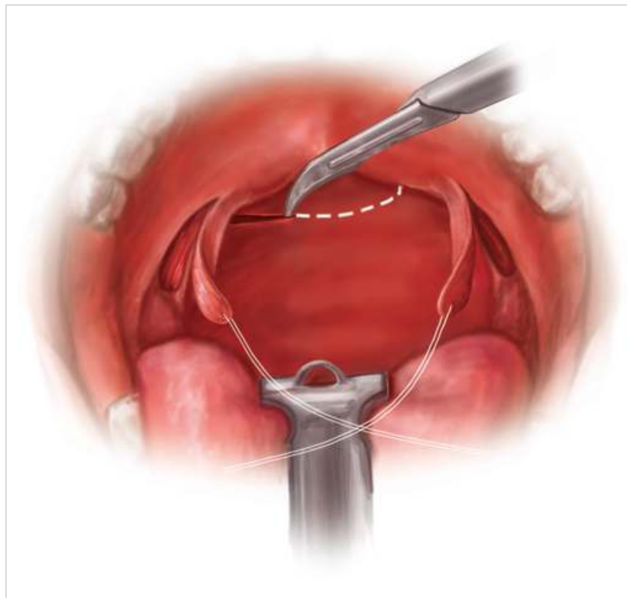

Fig. 4.3 Raising the flaps. After infiltration of local anesthetic, each flap is raised superiorly until the insertion site along the horizontal line at the posterior pharyngeal wall is reached. The horizontal line is then incised, connecting the medial borders of the two flaps.

then rotated 90 degrees medially so that they overlap. Mucosa on the superior side of the right flap is sutured to the mucosa on the superior aspect of the transverse incision along the posterior pharyngeal wall. Mucosa on the inferior side of the right flap is sutured to the mucosa on the superior side of the left flap. Mucosa on the inferior side of the left flap is sutured to the mucosa on the inferior aspect of the transverse incision along the posterior pharyngeal wall. This effectively creates the new sphincter (▶ Fig. 4.4). Additional fixation of the flaps can be achieved by suturing them to the superior constrictor and pharyngobasilar fascia. All sutures should be placed before finally insetting the flaps and securing the knots. Donor sites are then closed with 4–0 absorbable suture (▶ Fig. 4.5).

At the conclusion of the procedure, the opening of the sphincter pharyngoplasty should be no wider than a small fingerbreadth (approximately 1 cm). Openings wider than 1.5 cm and narrower than 0.5 cm are considered loose and tight sphincter pharyngoplasties, respectively.

Postoperatively, patients are typically kept for one night in the hospital to monitor for upper airway obstruction. A nasal trumpet can be used to ensure splinting of the upper airway overnight. The following day, patients are discharged home as long as they can tolerate adequate oral intake and their pain is controlled with oral analgesics. They are seen 1 week postoperatively to examine the wound and resume a regular diet.[9,10,11]

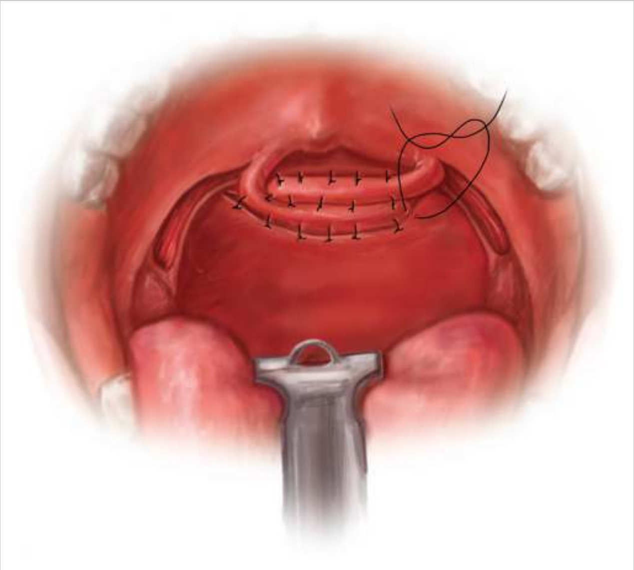

Fig. 4.4 Rotating and suturing. Myomucosal flaps are then rotated 90 degrees medially so that they overlap, effectively creating the new sphincter. Sutures should be placed before finally, insetting the flaps and securing the knots. Additional fixation of the flaps can be achieved by suturing them to the superior constrictor and pharyngobasilar fascia.

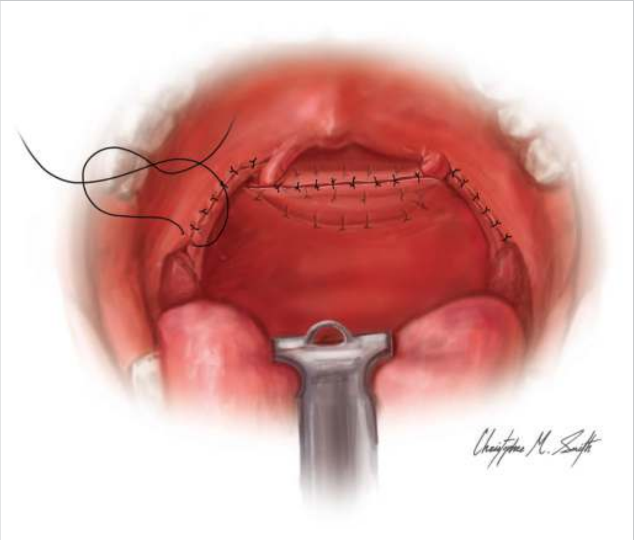

Fig. 4.5 Donor site closure. After securing the flaps to create the new sphincter, donor sites can be closed with 4–0 absorbable suture. The opening of the sphincter pharyngoplasty should be no wider than a small fingerbreadth.

4.4 Conclusion

Although complications are rare, they do occur. Early complications (< 6 weeks) include respiratory difficulties, postoperative bleeding, aspiration, nasal obstruction, injury to anomalous internal carotid arteries, and dehiscence with persistent VPI.[12,13,14] Golinko et al performed a case series of 40 children who underwent a sphincter pharyngoplasty over 10 years by a single surgeon. There were no hematomas, infections, or deaths recorded.[12] Carlisle et al performed a retrospective analysis of 46 children with VPI who underwent treatment at a tertiary care cleft palate and craniofacial clinic. There were no reported early complications.[13] Kilpatrick et al performed a case series with chart review at an academic tertiary medical center. The authors' complications included 13.9% with emesis, 5.8% with fever, 2.8% with small amount of oropharyngeal bleeding that resolved spontaneously, and 2.8% who suffered from a medication allergy. No patients had documented apneic events or desaturations below 95%, although 11.1% patients received supplemental oxygen.[14]

Success rate of pharyngoplasty ranges from 80 to 90%. It depends on factors such as the surgeon and the velopharyngeal port anatomy.[15] Long-term complications (> 6 weeks) include sleep disturbances (postoperative obstructive sleep apnea, snoring), dehiscence, hypernasality, and hyponasality.[11] Golinko et al reported all perceptual speech parameters were statistically significantly improved except for articulation and compensatory articulation. However, 30% of patients required revision surgery due to airway obstruction ($n = 9$), dehiscence ($n = 1$), and hypernasality ($n = 2$).[12] Carlisle et al reported a 13% revision rate in a sample of 46 patients undergoing sphincter pharyngoplasty alone or in combination with Furlow palatoplasty. Persistent hypernasality ($n = 2$), inferior flap position ($n = 2$), flap dehiscence ($n = 1$), and obstructed sleep ($n = 1$) all required surgical revisions.[13]

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5 Cleft Lip Nasal Deformity Repair

John M. Roberts and Donald R. Mackay

Abstract

Cleft lip nasal deformity repair is one of the most challenging surgeries to a successful cleft surgeon. Historically, cleft nasal repair was deferred until facial maturity due to concerns for growth discrepancies and a high likelihood of secondary nasal correction even if early repair was performed. However, the lack of evidence showing altered growth patterns with primary cleft lip nasal repair and the associated social stigma attached to an unrepaired cleft nose have made early intervention the gold standard.

During the unilateral primary cleft lip nasal deformity repair, it is the authors' preference to perform a modification of the McComb type rhinoplasty placing monocryl sutures intranasally to reform and re-establish the appropriate position of the alar subunit. In addition, repositioning the septal cartilage on cleft side of the maxillary crest is imperative. For bilateral cleft repair, alar transfixion and intercartilaginous sutures can be used to reshape the deformed lower lateral cartilage and improve tip shape. Secondary revision surgery can then be performed at the time of subsequent surgeries if there is an associated cleft palate or at the patient's preference.

Keywords: bilateral, cleft lip nasal repair, McComb, secondary revision, septoplasty, unilateral

5.1 Introduction

The cleft lip nasal deformity has been described in the literature for over 85 years,[1] and there have been numerous techniques described to address this issue. McComb first illustrated his repair in 1975 utilizing the typical lip incision to dissect the lower lateral cartilages followed by placement of silk mattress sutures to reposition the alar cartilage.[2] His 10-year follow-up study demonstrated long-lasting results without interfering with nasal growth.[3] We routinely utilize a modification of McComb's repair due to our success with the procedure.

5.2 Indications

Primary repair of cleft lip nasal deformity is indicated for all children with a cleft lip. Many authors use nasoalveolar molding to approximate the alveolar segments and shape the nose prior to the primary lip repair. Revision surgery is often required as the patient approaches skeletal maturity or this may occur sooner if the patient is experiencing social torment.

5.3 Operative Technique

5.3.1 Unilateral Cleft Lip Nasal Deformity Repair

A successful cleft lip nasal repair begins with an understanding of the features of a unilateral cleft nasal deformity which can be seen in ▶ Fig. 5.1. The operation begins with typical incisions for cleft lip repair. At our institution, we typically perform a variant of the Nakajima repair[4] or the Fisher technique.[5] After completing the lip dissection, the dissection of the nose begins using the open wounds at the bases of the columella and ala. Starting laterally, curved scissors are used to dissect the alar base off the piriform aperture. The scissors or Hartmann forceps are then used to widely undermine over the lower lateral cartilage extending above the upper lateral cartilage. Medially, dissection takes place over the medial crus, dome, and along the dorsum (▶ Fig. 5.2). Wide dissection over most of the cleft side of the nose is crucial in order to allow for proper mobility and repositioning of the lower lateral cartilage. Next, both sides of the septum are dissected in a subperichondrial plane using a freer (▶ Fig. 5.3). It is then completely freed from the nasal spine and anterior maxilla and repositioned on the cleft side of the anterior nasal spine. If desired, a tacking suture from the anterior septum to the periosteum of the maxilla can be placed using a 4–0 Monocryl. Following this step, the nasal floor is closed with 4–0 Chromic on a small ophthalmic needle by utilizing the medial septal mucosa and the lateral nasal mucosa near or including the inferior turbinate (▶ Fig. 5.4). The cleft lip is then closed in layers. This must be done prior to further addressing the nose as it will affect the nose aesthetics (▶ Fig. 5.5). Next, the lower lateral cartilage is repositioned to its appropriate position. To do this, two to four 4–0 Monocryl mattress sutures are utilized. With the needle straightened, it is passed intranasally through lower lateral cartilage in the area just lateral to the middle crus. The suture is then advanced in the subcutaneous tissues, superficial to the upper lateral cartilage, and is brought out through the skin on the superior aspect of the dorsum. The needle is then placed through the same puncture site and plane to enter the lower lateral cartilage approximately 2 mm lateral from the prior pass (▶ Fig. 5.6). The stitch is then tied intranasally. The same technique can be used again with the lateral crus and bolstered to the nasal side wall

Fig. 5.1 Major components of the cleft lip nasal deformity includes tip deviation to the noncleft side, attenuation of the lower lateral cartilage, and an alar base that is laterally, inferiorly, and posteriorly positioned.

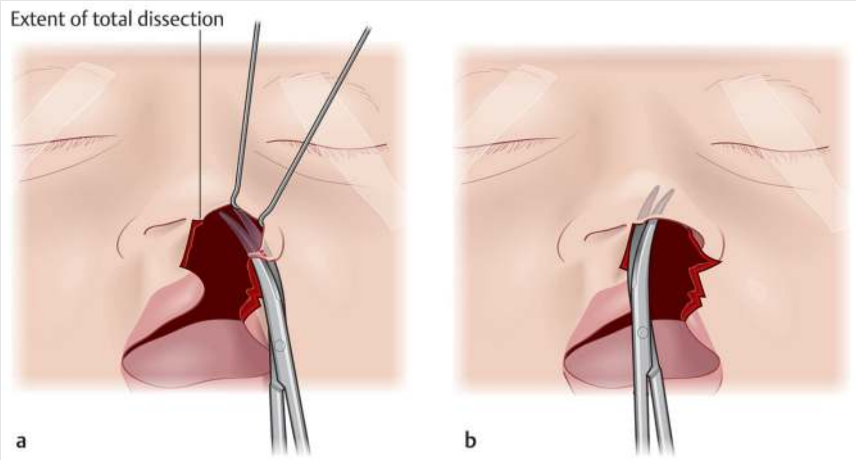

Fig. 5.2 (a, b) Dissection of the nose is performed after resection of the cleft tissue prior to cleft repair. The dissection is in the submuscular plane, superficial to the nasal cartilages. Curved scissors or Hartmann forceps can be used medially and laterally to loosen the soft tissues from the cartilage framework over the nasal side wall. This should be performed up to the cranial aspect of the upper lateral cartilages on the cleft side.

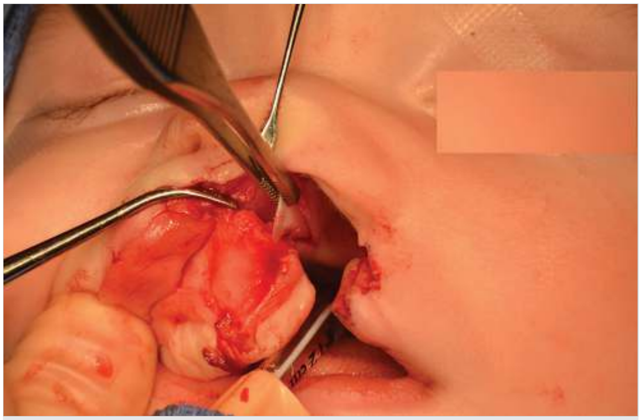

Fig. 5.3 Septoplasty with subperichondrial dissection and movement of the septum to the cleft side of the anterior nasal spine.

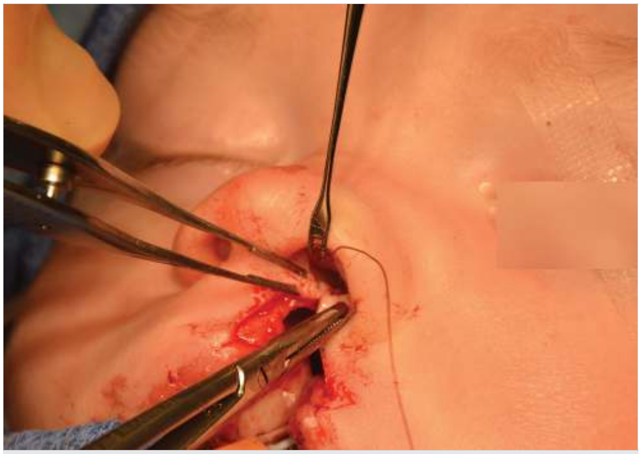

Fig. 5.4 Nasal floor closure is performed using septum mucosa and lateral nasal mucosa.

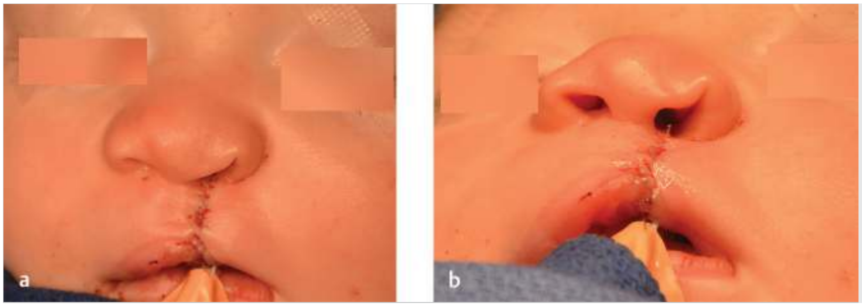

Fig. 5.5 (a, b) Notice that the lower lateral cartilage is positioned in a more "normal" place following lip repair.

in the area of the alar groove in order to elevate and medialize this portion of the cartilage and re-establish this crease (▶ Fig. 5.7). The final result is pictured in ▶ Fig. 5.8.

5.3.2 Bilateral Cleft Lip Nasal Deformity Repair

The dissection for bilateral cleft lip nasal deformity repair is the same as unilateral repair. Once wide undermining has been completed, alar transfixion sutures are placed using the same technique for suture placement as previously described. The straightened needle is passed through the fibrofatty tissue of the lateral ala and brought out through the skin along the alafacial groove to highlight this landmark and reduce vestibular webbing. Next, about two interdomal or medial crural sutures using 4–0 Monocryl are placed to refine the tip and lengthen the columella. Again, alar cinch stitches are imperative to medialize the alar base (▶ Fig. 5.9).

5.3.3 Secondary Revision Rhinoplasty

Secondary revision surgery for residual cleft nasal deformity is frequently required. It is our practice to allow the patients to

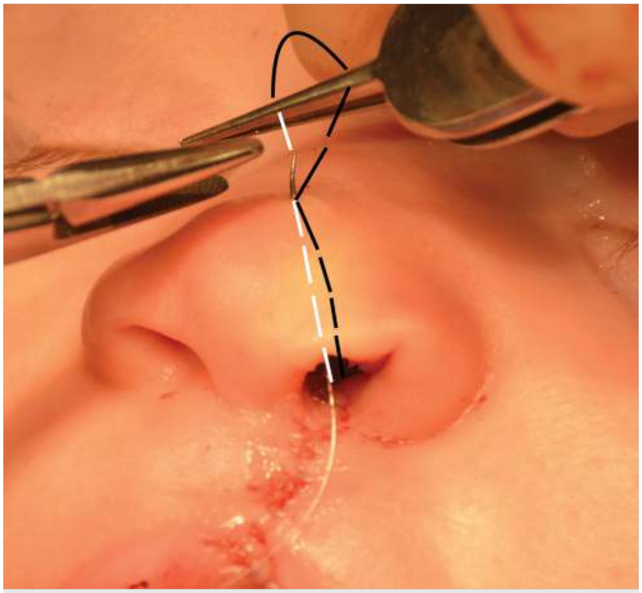

Fig. 5.6 Placement of a medial McComb suture helps to elevate the lower lateral cartilage.

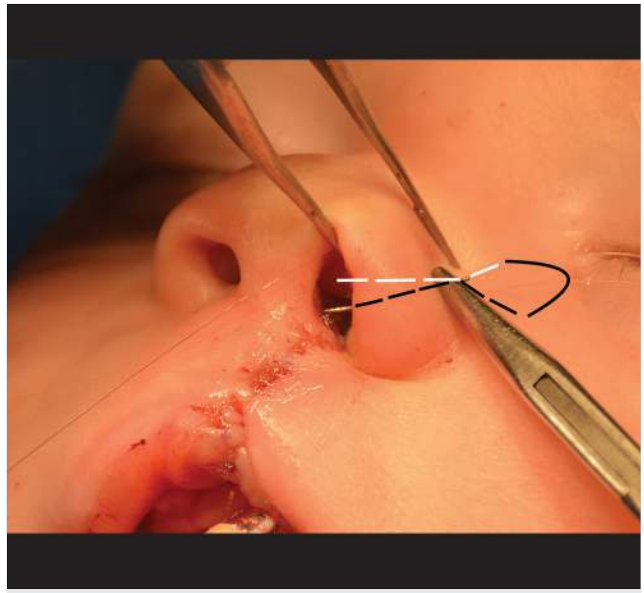

Fig. 5.7 Placement of lateral McComb sutures helps to reposition the lower lateral cartilage superiorly and medially as well as recreate the alar groove.

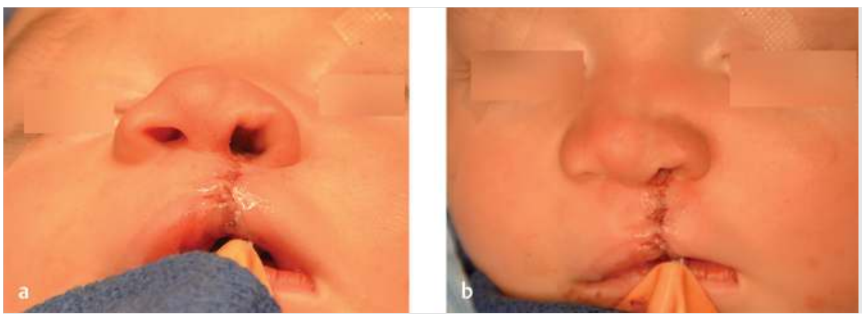

Fig. 5.8 (a, b) Final result using a modified McComb technique.

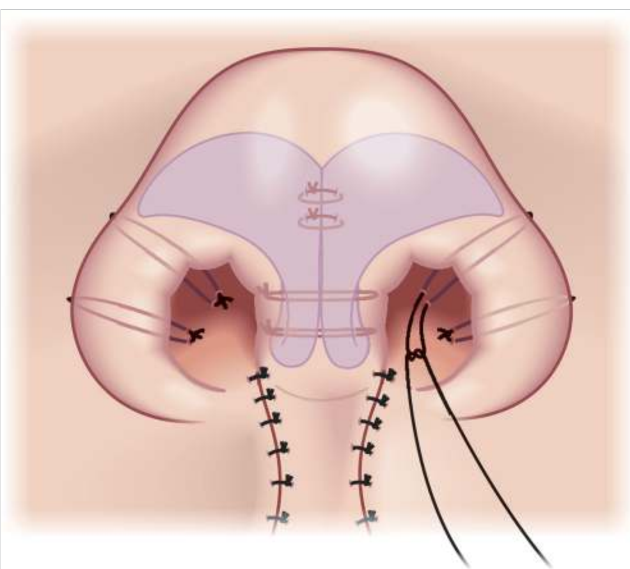

Fig. 5.9 Notice the different suture techniques that may be required for repair of the bilateral cleft lip nasal deformity including alar transfixion, interdomal, medial crural, and alar cinch stitches.

Video 5.1 Cleft nasal deformity repair

determine when this is indicated, which most often occurs around the time of skeletal maturity. The secondary rhinoplasty in cleft patients utilizes similar principles as those in noncleft patients. However, the surgeon must once again be familiar with the abnormalities associated with cleft nasal deformities to best treat these patients. A standard open approach using a stair-step incision at the columellar waist provides the necessary visualization. The septum is dissected out between the medial crura of the lower lateral cartilages and in a subperichondrial plane using a freer. A swivel knife can be used to harvest a portion of the septum, being sure to maintain a 1-cm

L-strut along the dorsal and caudal aspects. Columellar strut and alar batten grafts are frequently required to achieve the best cosmetic result. Osteotomies may be required as the nasal bones are often broad. Also, consider a dorsal augmentation and asymmetric tip grafts based on the preoperative deformity.

5.4 Conclusion

Correcting the cleft lip nasal deformity is a challenging undertaking. Wide undermining over a majority of the cleft side of the nose and a portion of the noncleft side is best performed utilizing the pre-existing incisions for the lip repair. Then, by understanding the abnormal anatomy, the surgeon can place appropriate bolster sutures to reshape the lower lateral cartilages and suspend them to a near-normal position.

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6 Syndromic and Nonsyndromic Craniosynostosis: Surgery of the Vault

Lucie Lessard

Abstract
Syndromic and nonsyndromic craniosynostoses are among the more common pediatric craniofacial conditions with a time-dependent need for treatment required to avoid permanent deformities and neurological well-being. Defined as the premature fusion of one or more cranial sutures, they are easily identifiable due to consistent, recognizable cranial deformities. One must take care to exclude a diagnosis of deformational plagiocephaly, a craniofacial deformity caused by mechanical forces. Appropriate recognition is important, as deformational plagiocephaly can be treated conservatively with physiotherapy and occupational therapy, or orthotic treatment. Appropriate craniosynostosis management begins with a referral to a plastic/craniofacial surgery specialist, who is routinely tasked with leading a multidisciplinary team in order to properly treat and manage these children both in the short and long term. Craniosynostosis also plays an important role in the development of elevated intracranial pressures, which can impact normal neuropsychological development. The field has rapidly evolved from Virchow's early theories on skull growth at fused sutures, to the discovery of mutations in genes implicated in skull growth. With advancements in genetics, imaging techniques, and operative innovation, plastic surgeons are better equipped to provide a patient-based care approach to children with craniosynostosis. After reading this chapter, the physiology of normal pediatric skull growth, the pathogenesis/epidemiology of craniosynostosis, genetic etiologies, classification, associated syndromes, and an appreciation of the general treatment strategies and potential impact on neurocognitive outcomes will be better understood. Comprehensive integrated bone and soft tissue drawings of the most common craniosynostosis are included in the figures for educational purposes.

Keywords: cranial vault surgery, deformational plagiocephaly, distraction osteogenesis, fused sutures, intracranial pressure, multidisciplinary approach, nonsyndromic craniosynostosis, syndromic craniosynostosis

6.1 Introduction

Craniosynostosis is a pediatric craniofacial pathologic condition defined by the premature fusion of one or multiple sutures of the skull.[1,2] The resultant growth restriction of the skull leads to compensatory growth of the skull parallel to the prematurely fused suture(s) and perpendicular to the unaffected sutures, resulting in consistent, recognizable cranial deformities (▶ Fig. 6.1). Craniosynostosis can occur either in isolation or can be associated with other extracranial anomalies. When anomalies outside the skull are present, craniosynostosis is often part of a syndrome and usually involves multiple sutures.[3] The latter syndromic craniosynostoses are less frequent than nonsyndromic craniosynostoses, which have a reported frequency of between 0.4 and 1.0 per 1,000 live births.[3] Craniosynostoses are generally treated in specialized centers using a multidisciplinary team approach. Surgeries are a combined effort between plastic surgeons and neurosurgeons whereas diagnosis and follow-up often involve additional specialists from genetics, ophthalmology, psychology, and respiratory medicine, among others.[4]

The exact etiology of craniosynostosis has not been determined. Premature fusion of the cranial sutures has been associated with genetic mutations, including fibroblast growth factor receptor (*FGFR*) and *TWIST* genes in syndromic craniosynostosis.[5,6,7,8] However, due to the increased prevalence of nonsyndromic craniosynostosis in subsequent pregnancies, more recent research has suggested the role of helper genes or craniosynostosis-causing mutations.[9] Mutations for both isolated sagittal (*BBS9*) and metopic (*FREM1*) craniosynostoses have been identified although their clinical significance is still undetermined.[9,10]

This chapter serves as a primer for students on the topic of craniosynostosis and is by no means exhaustive. Upon completion of this chapter, the reader should have acquired a better understanding of the physiology of normal pediatric skull growth, the pathogenesis and epidemiology of craniosynostosis, the rapid identification of genetic etiologies, its classification and associated syndromes, and an appreciation of the general treatment strategies and potential impact on neurocognitive outcomes.

6.1.1 Anatomy and Growth of the Pediatric Skull

In order to recognize the clinical manifestations of craniosynostosis, one must comprehend the physiology of bone growth at and around the cranial sutures. The growth of the skull occurs through two distinct mechanisms: growth at the sutures (bone growth is perpendicular to the suture line) and appositional growth (bone is reabsorbed on the inner surface of the skull and new bone is deposited on its outer surface).[11,12] The cranial sutures consist of paired (coronal and lambdoid) and nonpaired (metopic and sagittal) sutures (▶ Fig. 6.1). The normal physiology of skull growth is driven by the increasing volume of brain, which triples in size in the first 18 months of life.[11] Suture fusion eventually occurs later in life when brain growth is complete; however, a diagnosis of craniosynostosis is made if any suture fuses prematurely.

A cranial deformity that is commonly misdiagnosed as craniosynostosis is deformational plagiocephaly (DP), which is related to preferential pressure placed on one area of the skull (often associated with congenital torticollis).[4] The resultant head shape is typically a parallelogram and is encountered with growing frequency due to the current recommendation to position babies supine for sleep.[13] DP must be differentiated from synostotic plagiocephaly, which was a formerly used term to

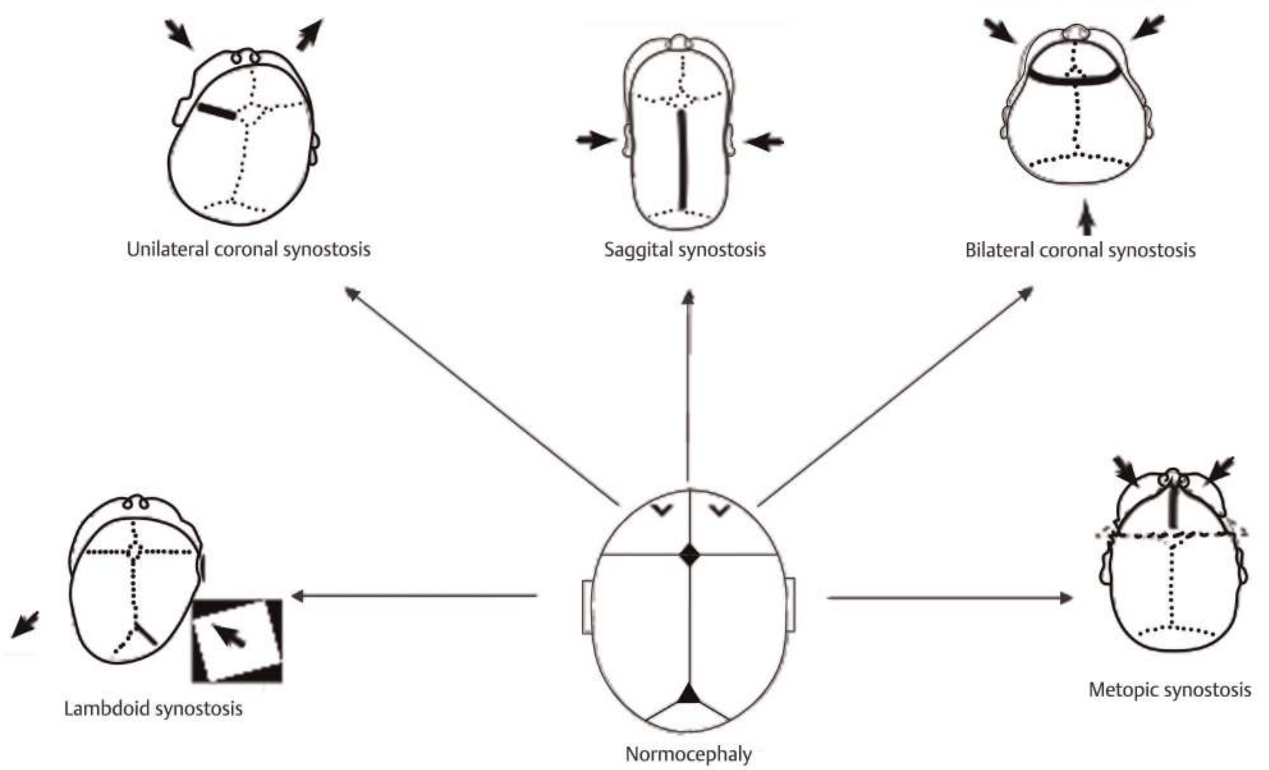


Fig. 6.1 Clinical presentation of various forms of craniosynostosis.

describe unicoronal craniosynostosis (▶ Fig. 6.2). This is a critical diagnosis, as synostotic plagiocephalies often require surgical correction in contrast to DP, which is generally treated conservatively (positioning, physiotherapy, and/or helmeting).[1,2,4,14] When in doubt, children with affected head shapes should be referred to a craniofacial team in a timely manner to ensure that the correct diagnosis is made and the appropriate treatment is initiated. The best outcome and complete correction are achieved only if the treatment is started as soon as possible, between 6 to 10 months, if not, a nonsurgical approach is not possible.

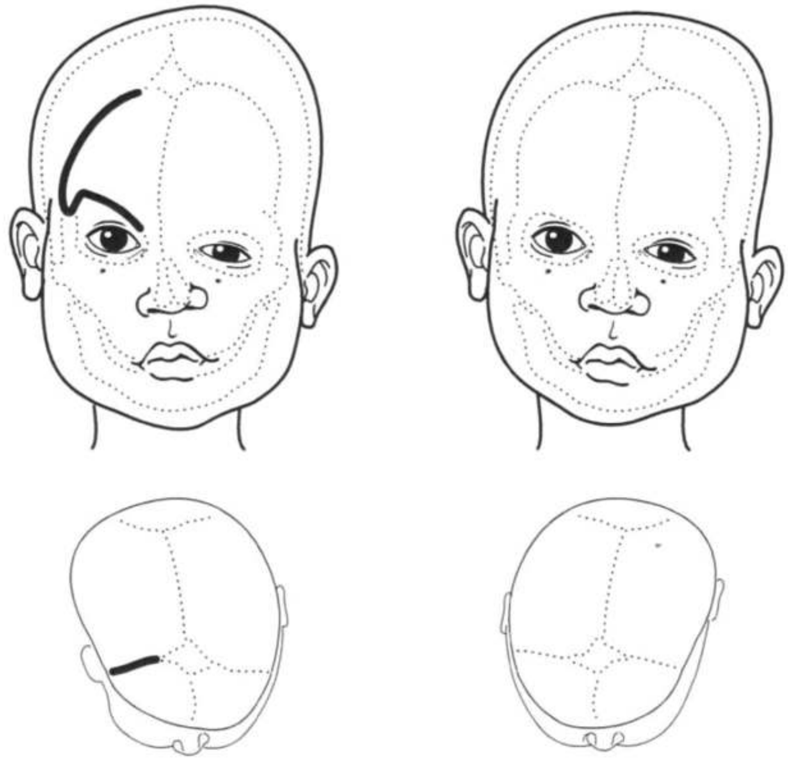
6.1.2 Increased Intracranial Pressure and Hydrocephalus in Craniosynostosis

Infants with craniosynostosis may develop abnormally elevated intracranial pressure (ICP) due to the restricted growth of the skull in association with a normally growing brain.[15] This risk of elevated ICP has been shown to be approximately 13% in cases of isolated craniosynostosis (with a range of 0–33% reported in the literature), rising to above 40% when multiple sutures are involved.[16,17,18] Initially, the skull compensates through accelerated growth at other suture sites, often manifested as “bulging” or “bossing” of the skull.[19] The commons signs of elevated ICP seen in communicative patients, such as headaches, fatigue, and change in vision or loss of vision, are difficult to elicit in a newborn.[19] However, secondary symptoms or signs such as increased irritability, emesis, and plateauing of head circumference growth may be present and should be carefully monitored.[20]

A rare associated feature of both syndromic and nonsyndromic craniosynostosis is the development or presence of hydrocephalus.[16,21,22] More common in syndromic patients (12.1%), hydrocephalus is thought to be secondary to disturbances in the hydrodynamic flow of cerebrospinal fluid (CSF).[23] Appropriate management of hydrocephalus will be addressed by the neurosurgical team and may involve ventricular shunting.

6.1.3 Primary History and Physical Examination

Craniosynostosis can usually be identified at birth or shortly thereafter by the family physician/pediatrician due to the abnormal head shape. Such infants are generally referred to the craniofacial team (craniofacial plastic surgeon and/or neurosurgeon) for assessment. Workup generally includes a physical examination (to rule out possible deformational plagiocephaly and/or to identify other possible syndromic features), skull X-rays, and fundoscopy.[20] The latter is done to rule out evidence of papilledema, which may be a sign of increased ICP.[16,20] Although less common in nonsyndromic synostoses, elevated ICP is considered a relative surgical emergency, prompting rapid expansion of the cranial vault to prevent deleterious effects on brain development. The definitive diagnosis of suture fusion is often made using a three-dimensional computed tomography (CT) scan, which is also



Anatomic features	Right synostotic	Left deformational
Ipsilateral superior orbital rim	• Superior	• Inferior
Ipsilateral ear	• Anterior/superior	• Posterior/inferior
Nasal root	• Ipsilateral deviation	• Midline
Ipsilateral cheek	• Forward	• Posterior
Chin deviation	• Contralateral	• Ipsilateral
Ipsilateral palpebral fissure	• Wide	• Narrow

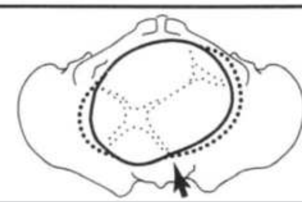


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Fig. 6.2 Differentiation between deformational plagiocephaly and unicoronal craniosynostosis (synostotic plagiocephaly). Plagiocephaly can arise as either due to unicoronal synostosis or deformational plagiocephaly.

useful for surgical planning. Recently, the use of ultrasound and other nonionizing imaging modalities such as magnetic resonance imaging (MRI) for the diagnosis of craniosynostosis have been explored.[24]

Any evidence of syndromic features (midface/orbital involvement, extracranial anomalies) should prompt consultation with genetics and the appropriate specialists (respiratory medicine/ENT for airway concerns, ophthalmology for ocular issues, plastic surgery for congenital hand anomalies, etc.).

6.1.4 Neuropsychological Involvement and IQ Outcomes in Craniosynostosis

A growing interest in the field of craniosynostosis is its effect on neurocognitive development.[25,26,27,28,29,30,31] Although several studies have shown a correlation with a specific craniofacial syndrome or synostosis and neurocognitive delay, it is difficult to decipher whether the syndrome itself or increased ICP is the culprit.[25] Recent studies have shown that early surgical correction (before 6 months of age) may improve neurocognitive outcomes for some types of craniosynostoses.[32]

6.1.5 Classification

As mentioned earlier, craniosynostosis is classified as syndromic (associated with other extracranial anomalies) or, more commonly, as nonsyndromic. Each suture fusion results in a characteristic head shape, which assists in the clinical diagnosis (▶ Fig. 6.3 and ▶ Fig. 6.4). In rare cases, all sutures may fuse, leading to a characteristic head shape named Kleeblattschadel (cloverleaf skull deformity). Please refer to ▶ Fig. 6.3 and ▶ Fig. 6.4 for a description of each class of craniosynostosis.

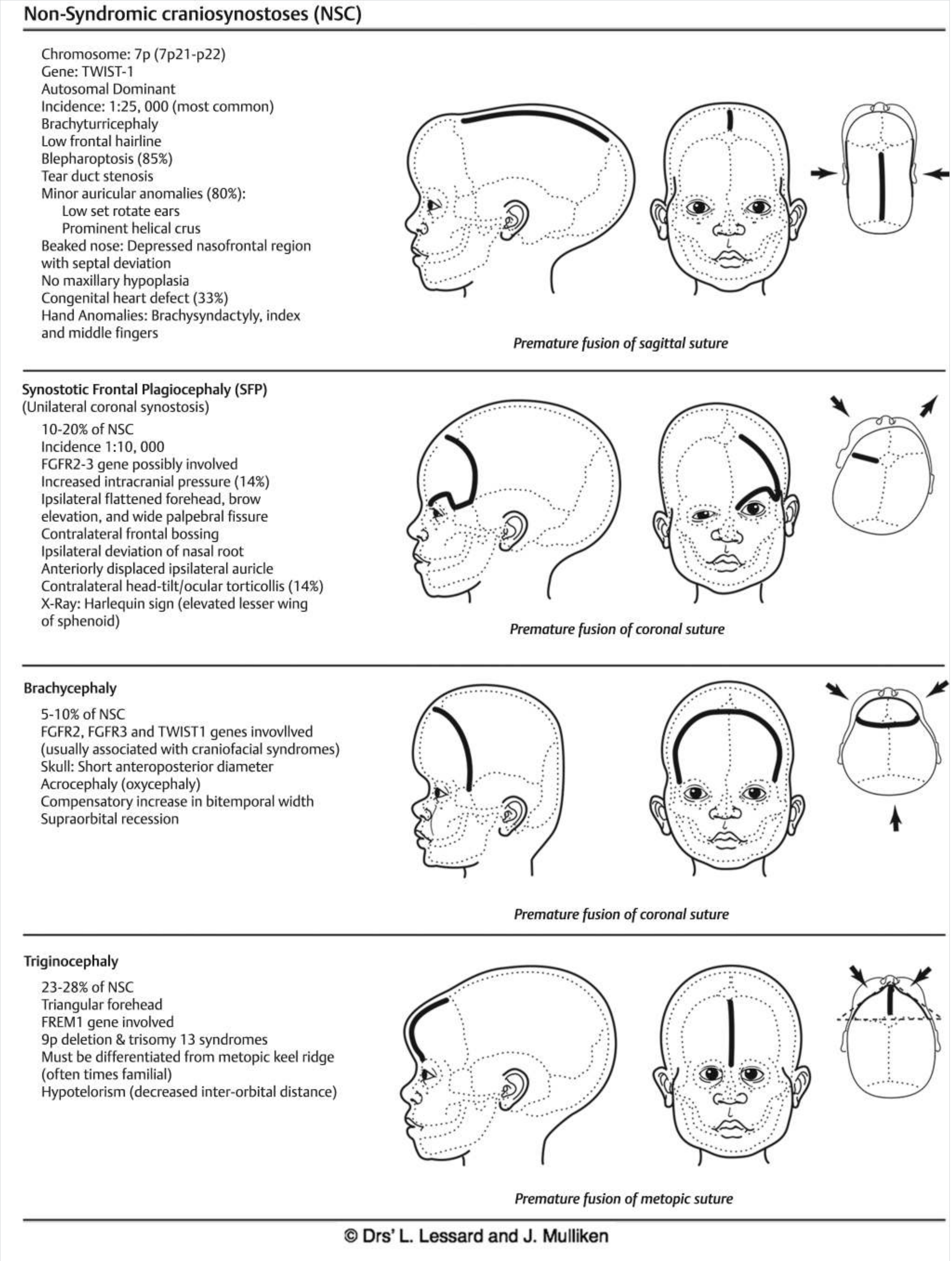


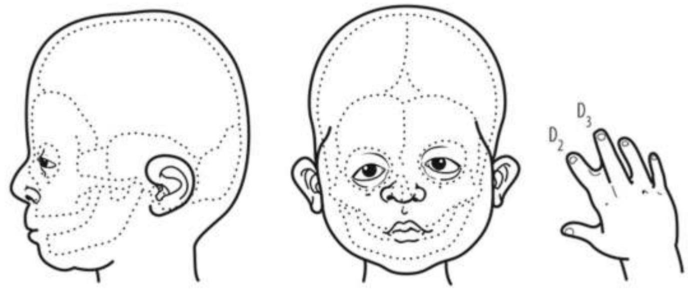
Fig. 6.3 Nonsyndromic craniosynostosis.

Syndromic craniosynostoses

Premature fusion of skull base

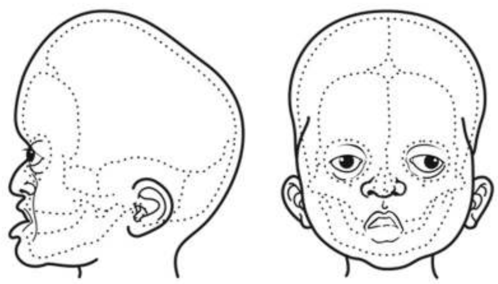
Saethre-Chotzen Syndrome

Chromosome: 7p (7p21-p22)
Gene: TWIST-1
Autosomal Dominant
Incidence: 1:25, 000 (most common)
Brachyturricephaly
Low frontal hairline
Blepharoptosis (85%)
Tear duct stenosis
Minor auricular anomalies (80%):
  Low set rotated ears
  Prominent helical crus
Beaked nose: Depressed nasofrontal region with septal deviation
No maxillary hypoplasia
Congenital heart defect (33%)
Hand Anomalies: Brachysyndactyly, index and middle fingers



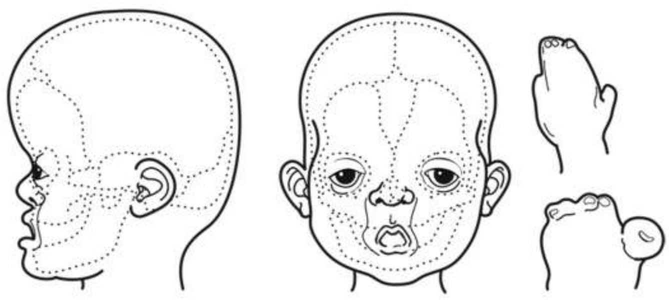
Crouzon Syndrome

- **Chromosome**: 10q (10q25.3-q26)
- **Gene:** FGFR2
- **Autosomal dominant**
- Most cases sporadic, 10% familial
- Incidence: 1:25,000
- Brachycephaly
- Exorbitism (75%)
- Maxillary hypoplasia
- Relative mandibular prognathism
- Conductive hearing loss (50%)
- Cervical spine anomalies
- Chiari | malformation (30%) and cervical syringomyelia (10%)
- **No hand anomalies in most cases**



Apert Syndrome

- **Chromosome:** 10q (10q25.3-q26)
- **Gene:** FGFR2
- **Autosomal dominant**
- Most cases sporadic
- Incidence: 1:72,990
- 4.5% of all craniosynostoses
- Oxycephaly, brachycephaly
- Exorbitism, hypertelorism
- Maxillary hypoplasia +/- V-shaped dental arch
- Relative mandibular prograthism: Class lll malocclusion
- Acne vulgaris (70%)
- Cardiovascular and genito-urinary anomalies (10%)
- Cervical spine anomalies C5-C6
- **Hand anomalies:** complex syndactyly
- **Foot anomalies:** complex syndactyly



Pfeiffer Syndrome

- **Chromosomes:** 8p (8p11.2-/p12) **Gene:** FGFR1
  10q (10q25.3-q26) **Gene:** FGFR2
- **Autosomal dominant**
- Incidence: unknown
- Turribrachycephaly
- Ocular proptosis
- Downslanting palpebral fissures
- Midface hypoplasia variable, Class lll malocclusion
- Cervical spine anomalies
- **Hand anomalies:** broad thumbs variable
- **Foot anomalies:** broad great toes

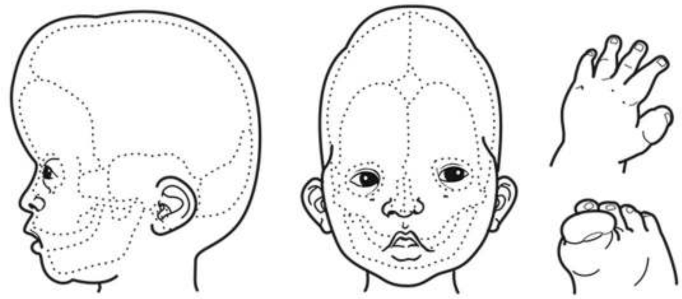


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Fig. 6.4 (a, b) Syndromic craniosynostosis.

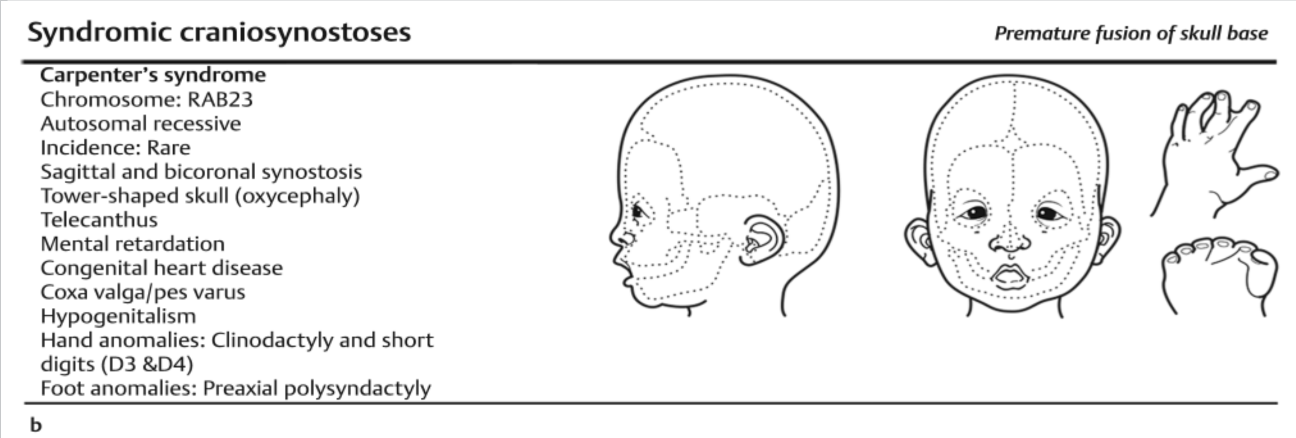

Fig. 6.4 *(Continued)*

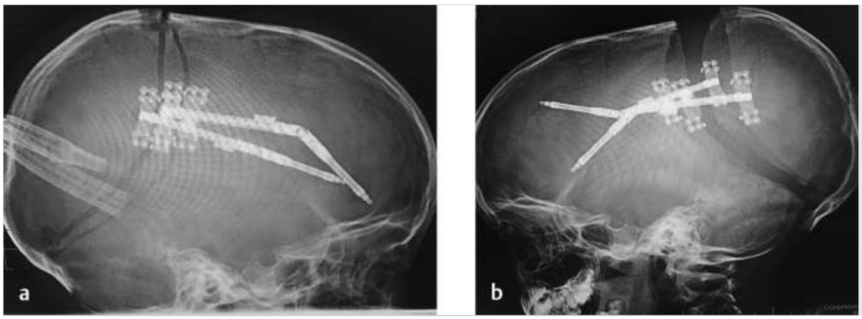

Fig. 6.5 Lateral view X-ray of a sagittal synostosis before and after posterior vault distraction for pansuture synostosis with elevated intracranial pressure. **(a)** Before posterior vault distraction. **(b)** After posterior vault distraction.

6.2 Indications

Once a diagnosis of craniosynostosis has been made, optimal timing is a clinical judgment that balances the risks of development of elevated ICP and the aesthetic outcomes of surgery.[20] Generally, earlier surgery (before 6 months of age) is favored for patients with risks of, or documented increased, ICP, whereas later surgery (9–12 months of age) capitalizes on greater patient safety (blood loss relative to weight) in an older infant and provides a more stable aesthetic result. Blood loss is an important consideration from an anesthetic standpoint, and families must be counselled that patients often require transfusion.[32]

6.3 Operative Technique

Surgical techniques are generally divided into two categories: suturectomies and cranial vault remodeling. The former is reserved for younger patients (less than 4–6 months) and involve surgical resection of the fused bone, often along with other osteotomies to allow compensatory growth or expansion. Such techniques have the advantage of shorter operative times, lower blood loss, and often endoscopic approaches.[26] Disadvantages include the passive nature of the correction that relies on rapid brain growth, possible suture re-fusion, and the potential need for prolonged postoperative helmeting to assist final head shaping.[26]

A newer approach involves the addition of metallic springs implanted at the time of suturectomy to stimulate expansion. Such spring-assisted cranioplasty has been shown to provide effective results but requires an additional surgery to remove the springs.[33,34]

6.3.1 Cranial Vault Remodeling

Cranial vault remodeling is considered the gold standard for craniosynostosis corrections after the age of 6 months, including those that have failed earlier suturectomy techniques.[35] The anterior, posterior, or both cranial vaults can be remodeled via a bicoronal incision.[20] The open approach generally involves a craniotomy performed by the neurosurgical team to allow access to osteotomies of the orbital or skull base region for reshaping. Skull segments are expanded with interpositional bone graft harvested from other parts of the skull and fixated in place with metallic wire, or more commonly, resorbable hardware. This technique involves active reshaping of affected areas and stable expansion of the cranial vault. Disadvantages include the costs associated with longer surgical times and resorbable hardware, increased blood loss, and issues with regression of bony advancement over time.[36,37,38]

6.3.2 Cranial Vault Distraction

A more recent technique, cranial vault distraction, allows for more significant increases in volume due to the gradual expansion of the bony skull and the overlying scalp. The technique involves creating osteotomies in the skull and insertion of internal metallic devices (distractors) that expand the healing osteotomies to form new bone and expand the skull volume (▶ Fig. 6.5). The advantage is the powerful volume increases that are possible along with a lower risk of significant bony defects, while disadvantages include cost of the devices and the need for a second surgery to remove them. This technique is most often applied to the posterior vault in syndromic patients with significant cranial volume constraints due to multisuture synostosis.

6.4 Conclusion

Craniosynostosis assessment, diagnosis, and treatment requires the specialized care of a multidisciplinary craniofacial team. Plastic surgeons are leaders and an integral part of the care of these patients, having pioneered many of the bony and soft-tissue reconstructive techniques required to achieve functional and aesthetic surgical results in this population. Since the days of Dr. Paul Tessier, the father of modern craniofacial surgery, the treatment and outcomes of patients with craniosynostoses continue to improve via a better understanding of the genetics of craniosynostoses, research on neurocognitive outcomes, and the development of innovate surgical techniques.

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7 Ear Reconstruction

David Leshem and Sivan Zissman

Abstract
Tanzer was the first to introduce autologous costal cartilage grafts for auricular reconstruction in 1959. There are several types of microtia, classified according to their appearance by Nagata: (i) lobular type, (ii) concha type, (iii) small concha type, and (iv) anotia (no or minimal remnants of ear) or atypical microtia.

Surgical timing should be influenced by several considerations such as psychological and physical. Generally, we perform the surgery between 8 and 10 years of age.

The surgical approach is divided into two stages:

The first stage is harvesting the costal cartilage and fabricating an ear framework, which is designed according to a template taken from the contralateral ear, and burying under a subcutaneous pocket.

The second stage is the setting out of the reconstructed ear and takes place around 6 months after the first stage. Postoperative complications may include infection, hematoma, skin necrosis, cartilage exposure, and insufficient definition.

Touch-up procedures may be needed for refinement of the reconstructed ear.

Keywords: anotia, extrusion, hematoma, infection, insufficient definition, microtia, noncooperative patient, skin necrosis, traumatic ear defects, unrealistic expectations

7.1 Introduction

Historically, ear reconstruction began at the end of the 19th century and was mainly indicated for traumatic injuries.[1]

Auricular reconstruction with autologous cartilage grafts was first introduced in 1959 by Tanzer[2,3] and since then authors, such as Brent,[4] Nagata,[5,6] Park, and Firmin, have made modifications to improve outcome.

The most important modification was the change from a four-stage reconstruction[4] to a two-stage reconstruction[5,6] with transposition of the lobule and placement of the costal cartilage frame at the same time in the first stage.

Only few surgeons use alloplastic materials due to the increased risk of extrusion.[7,8]

7.1.1 Epidemiology

Microtia is a relatively rare disorder, which occurs once in every 6,000 births based on Grabb's study.[9] Male predominance is seen, with ratios varying from two to three times.

Estimated ratio of right to left to bilateral is 5:3:1 and microtia is much more common in Asians and Hispanics than in whites and blacks.

7.1.2 Relevant Anatomy

Refer to ▶ Fig. 7.1 for external ear anatomy.

7.1.3 Risk Factors

Risk factors may be divided into three main groups:

- Teratogenic: Include the use of Roaccutane® (isotretinoïne) and antiepileptic drugs during pregnancy.[10,11,12]
- Ischemia: Decreased blood supply in utero resulting from obliterated stapedial artery or a hemorrhage into local tissues based on Mckenzie and Craig[13] and Poswillo.[14]
- Hereditary factors: Genetic, anatomic, and morphological relations were shown by Rogers between microtia, constricted, and protruding ears.[15]

7.1.4 Diagnosis and Imaging

There are several types of microtia, classified according to their appearance by Nagata[5,6] (i) lobular type, (ii) concha type, (iii) small concha type, and (iv) anotia (no or minimal remnants of ear) or atypical microtia (▶ Fig. 7.2).

The auricle malformation often appears in association with deformities such as malformations of the jaw and hemifacial microsomia,[16] and increased rate of urogenital tract abnormalities.[17]

- Preoperative assessment should include detailed anamnesis of family history and investigation of optional associated deformities.

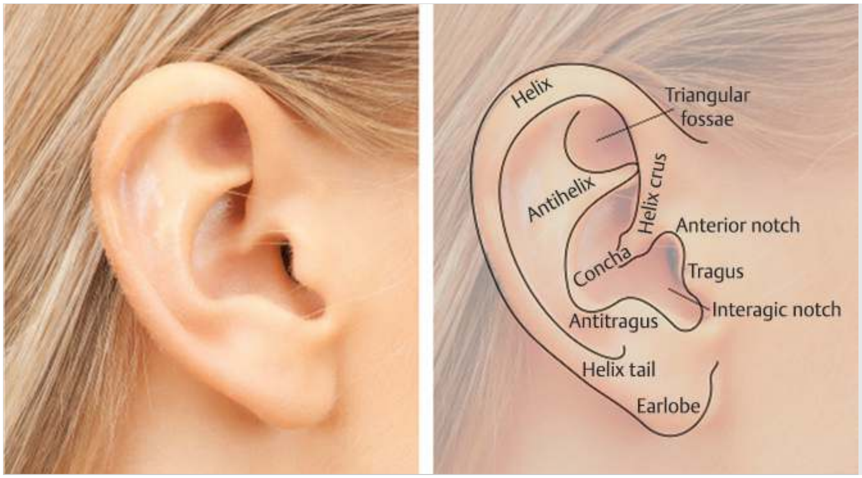

Fig. 7.1 External ear anatomy.

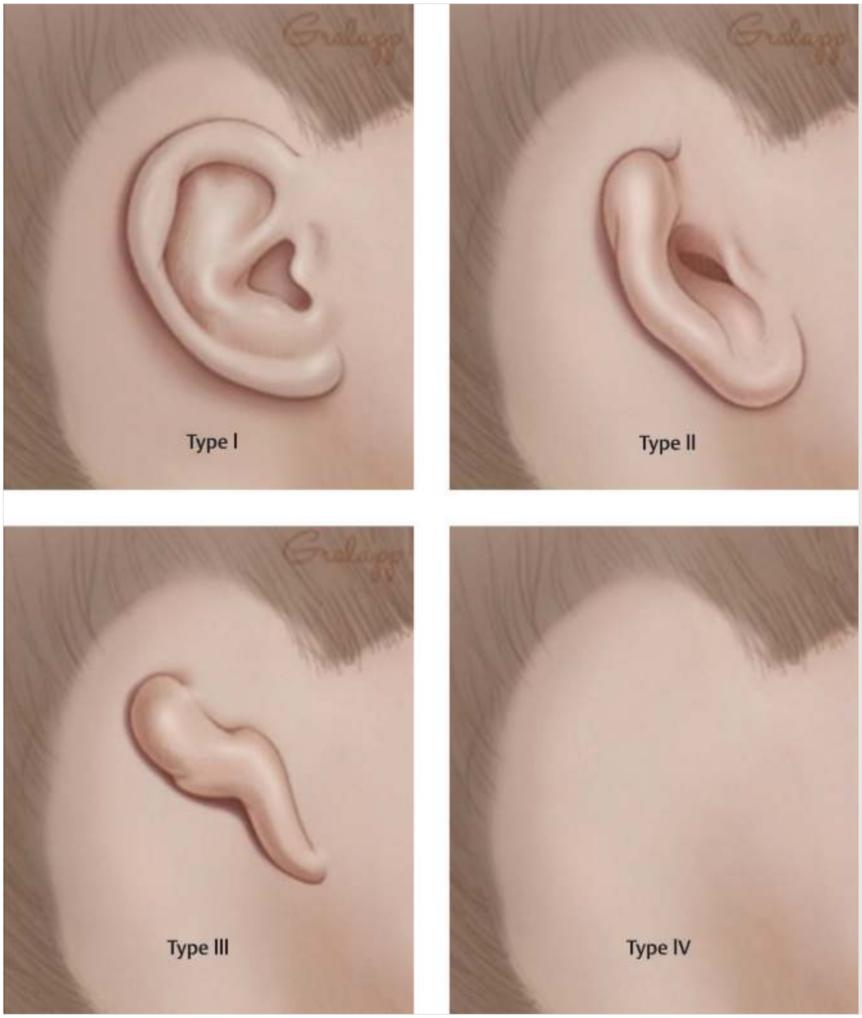

Fig. 7.2 Microtia classification by Nagata in order of severity.[5]

- Physical examination including complete evaluation of both ears and facial symmetry.
- Preoperative conventional diagnostic tests including audiometric testing, computed tomography (CT) scan and rarely magnetic resonance imaging (MRI) to establish the course of facial nerve.

7.2 Indications

- Acoustic function improvement.
- Social acceptance.
- Speech improvement.
- Increased self-esteem.

7.2.1 Contraindications

- Unrealistic expectations of patients and parents.
- Noncooperative patient.

Prosthetic solutions should always be considered—as in the elderly patients with an ear amputation for cancer or when the area is scarred, the temporoparietal fascia is not available, and the temporal vessels are damaged.

7.3 Operative Technique

Surgical timing should be influenced by psychological and physical considerations, child awareness and willingness, and sufficient costal cartilage for framework reconstruction.

Generally, we perform the surgery between 8 and 10 years of age; at this age we see better patient cooperation, motivation, and acceptance.

7.3.1 First Stage

Preoperative

The reconstructed ear location is predetermined by the anatomical lines of the contralateral normal ear. The landmarks used are the lateral canthus and lobule position of the contralateral side. A template of the contralateral healthy ear is copied on a transparent film, including landmarks for positioning in the right anatomical site (▶ Fig. 7.3).

The ear's slant is positioned to match the opposites side, roughly parallel to the profile of the nose; the distance is matched from the corner of the eye; and the microtic lobe's position is noted (usually displaced upward) when tracing the reverse film pattern, so that the lobe will eventually be

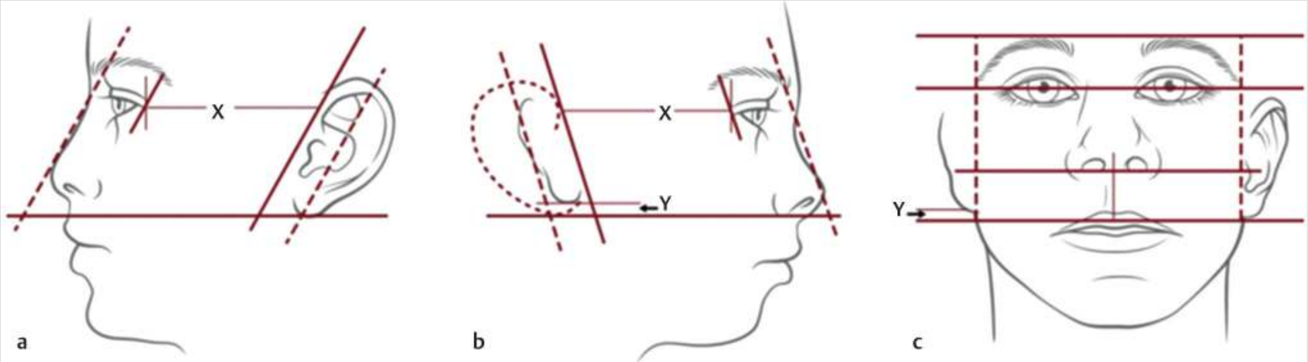

Fig. 7.3 (a–c) Preoperative determination of auricular location.[4] Brent B. Total auricular construction with sculpted costal cartilage. Source: Brent B. Microtia repair with rib cartilage grafts: a review of personal experience with 1000 cases. Clin Plast Surg. 2002; 29(2):257–271.

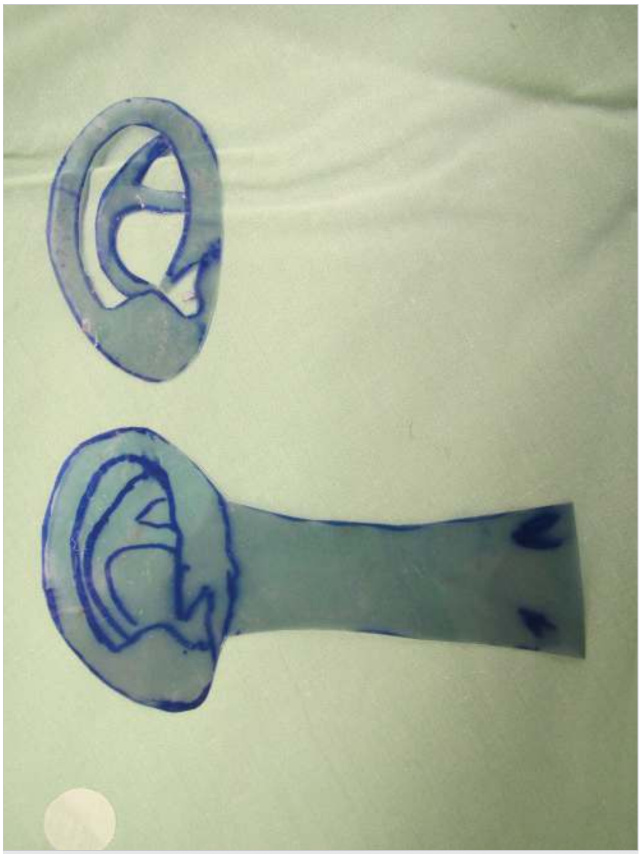

Fig. 7.4 Ear template of contralateral normal ear for reconstruction planning and positioning.

positioned correctly when it is transposed into position and "spliced" onto the new ear during the second stage of the surgical repair.

Costal cartilage is harvested through a horizontal incision on the superior costal border.

It is obtained from the sixth to eighth rib, from the ipsilateral side,[5,6] although it can be harvested from the contralateral side as well.[4]

The perichondrium is preserved and after harvest, it is approximated to allow reshaping of the rib by neocartilage formation.

On a side table, the cartilage is carved using carving instruments. The cartilages from the sixth rib and the seventh rib are used for the base of the framework and antihelix, while the eighth rib is usually used for carving the helix. The framework is designed according to the template taken from the contralateral ear (▶ Fig. 7.4, ▶ Fig. 7.5, and ▶ Fig. 7.6).

The different cartilage parts are sutured together with stainless steel sutures (double armed needles) and the ends are buried into the cartilage to avoid extrusion.

Using the transparent film template, the recipient site is marked and the skin is incised. A subcutaneous pocket is created at the auricular region and the ear cartilage remnants are removed. Sometimes a subcutaneous pedicle is left intact for better circulation of the skin.[18] The lobule, if present, is transposed into the correct position.

After inserting the framework into the pocket, one or two small vacuum drains are positioned in such a way that they achieve good skin draping and definition of the framework.

Skin closure is performed with 5–0 resorbable sutures and meticulous dressing is applied using Vaseline gauze and soft padding.

A piece of the harvested cartilage is banked under the chest donor site incision for the second stage out setting.

Postoperative Treatment

The dressing is left in place for 4 to 5 days, during which the vacuum drain is maintained in order to achieve adequate skin draping. After the dressing is removed, instructions for good hygiene are given.

7.3.2 Second Stage

The second stage is the out setting of the reconstructed ear and takes place around 6 months after the first stage. The banked rib cartilage is harvested from the chest wall and cut into a crescent-shaped block.

An incision is performed along the helical rim. In cases where the postauricular tissue is of substantial quality, a tunnel is made under the cartilage framework and the fascia. The cartilage is inserted and fixed tightly with nonabsorbable sutures.

The remaining postauricular skin defect is closed by a full-thickness skin graft, harvested from the groin or a thick-splint thickness graft harvested from the scalp, and applied to the

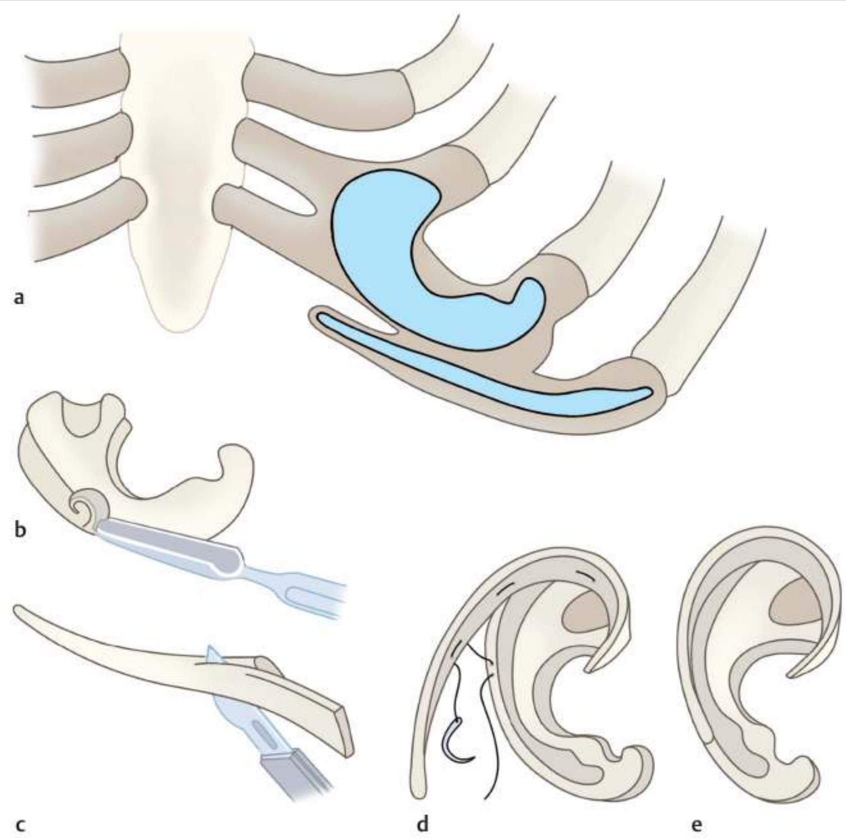

Fig. 7.5 Ear framework fabrication. **(a)** Donor site: The helical rim is obtained from a "floating" rib cartilage, and the main pattern from a fused block of two cartilages. **(b)** Sculpting the main block with chisel. **(c)** Thinning the "floating" rib cartilage to produce the helical rim. **(d)** Affixing the rim to the main framework with nylon sutures. **(e)** Completed framework. From Woo A, Shahzad F, Snyder-Warwick A. *Plastic Surgery Case Review: Oral Board Study Guide*. 1st ed. New York: Thieme; 2014.

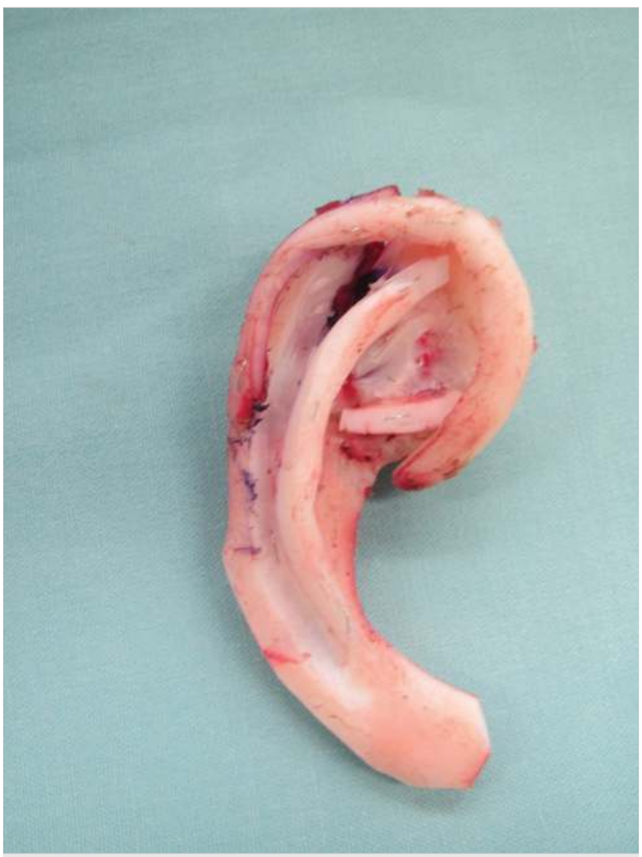

Fig. 7.6 Completed auricular reconstruction sculpted from rib cartilage.

postauricular area and sutured using absorbable sutures. A tie over dressing is applied.

In cases that do not have sufficient soft tissue coverage over the cartilage block after mobilization, a temporoparietal fascia (TPF) flap is turned down for coverage of the posterior side of the ear and cartilage block. A split-thickness skin graft is draped over the TPF and a loose tie over dressing is applied.

Postoperative Treatment

Postoperatively, protective head dressing is applied. The dressing is left in place for about 5 days; no specific care is needed.

After the removal of the bandages, hygiene instructions are given and the patient should avoid contact sports till the healing process is completed.

7.3.3 Partial Ear Reconstruction

In partial defects, the same surgical technique can be used as for total ear reconstruction. In small defects, conchal cartilage from the ipsilateral or the contralateral side can be sufficient. In larger defects, costal cartilage has to be used. The posterior auricular skin or the TPF is used to cover the cartilage framework and a second operation is often needed for mobilization of the ear.

When the lobule is amputated, it can be reconstructed with a bilobed flap using costal or conchal cartilage for support. In case the patient wants to wear earrings, during reconstruction holes can be made in the cartilage frame before insertion to prevent piercing of the cartilage at a later stage.

7.3.4 Complications

Infections rate is low after ear reconstruction.

Cleaning instruction, perioperative antibiotic treatment, and gentle handling of the tissues during surgery decrease the chances significantly.

It is necessary to instruct the patient about alarm signs such as erythema, pain, fever, and skin damage due to pressure or related problems.

- Hematoma is a rare condition, which may be avoided by early recognition and drainage.
- Skin necrosis and cartilage exposure need immediate surgical interventions and varies from local transposition flaps to the use of the TPF depending on the defect size.
- Insufficient definition caused by fibrosis or scar tissue can be treated by local steroid injections and local revision surgery.
- Chest wall donor site related complications such as atelectasis and pneumothorax.

7.3.5 Outcomes

Secondary reconstruction may be needed in ear reconstruction in order to achieve an aesthetic result:

- Groove definition: Injection of steroids can be administered into these areas.
- Lobule refinement or deepening of the tragus-concha area: Minor surgeries can be done.
- A low hairline: Requires laser epilation prior or post reconstructive surgery. Another option for this problem is the use of TPF for the framework coverage and a skin graft.

7.4 Conclusion

Ear reconstruction is a two-stage operative procedure: The first stage is reconstruction of a costal cartilage framework and the second stage is out setting of the reconstructed ear.

A crucial point in the surgery is preparing a suitable thin pocket for achieving good external ear anatomy contour. The pocket must be vascular to avoid skin breakdown and necrosis.

The cartilage should be carved meticulously and with refined definition for best contour result. Complications may include hematoma, skin necrosis, cartilage exposure, insufficient definition, and chest wall donor site related complications such as atelectasis and pneumothorax.

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8 Otoplasty

Guillermo Echeverria

Abstract
The most frequent congenital deformity of the auricular pavilion is the prominent ear, which is manifested by excess cartilage in the auricular shell and absence of antihelix, accompanied sometimes by other deformities. This can cause psychological problems due to derisive commentaries. The ideal age for surgery is during childhood, but the problem can be resolved at any age. There are multiple surgical techniques to correct the deformity helix, antihelix, concha, and lobule that give excellent results.

Keywords: auricle, cartilage, Converse-Wood-Smith, Furnas, Mustardé, otoplasty, prominent ear

8.1 Introduction

The purpose of otoplasty surgery is to correct a common congenital deformity of the external ear that consists of prominent or crown ears in children or adults who have not had surgery to reconstruct the anatomical parts affected.[1] The auricle is the outside ear. The size of the auricle varies according to gender, being on average larger in men than in women, with dimensions that vary in height from 5.74 to 6.04 cm, and 2.88 to 3.02 cm in width.[2,3] No one person has similar ears (▶ Fig. 8.1).

In 1845,[4] Dieffenbach made the first correction of prominent ears, and after him there have been multiple surgical techniques described.

8.2 Indications

The main indication for surgery is the need of the patient to correct the deformity of the ear, which can cause psychological problems, low self-esteem, and difficulty in adapting to the environment in which the person develops. Congenital deformities of the ear occur in 5% of the population. It is considered that by 3 to 5 years of age, the ear has reached 85% of its development and has completed its growth at 7 or 8 years of age, while otoplasty can be carried out at any time. Correction of anatomical structures is personalized for each patient according to the existing deformity after carefully analyzed by the surgeon. An expert knowledge of each part of the ear is indispensable.

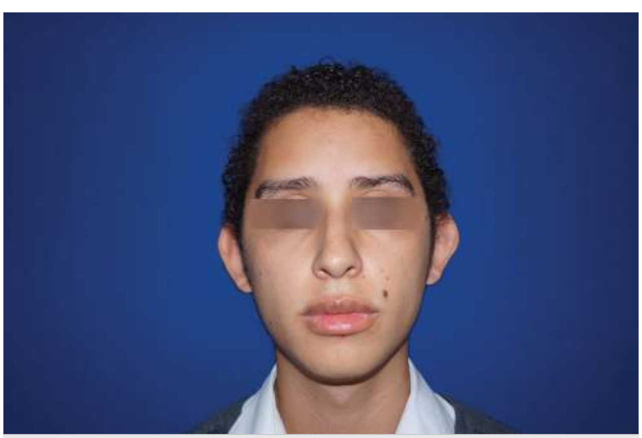

Fig. 8.1 Different shape and size of ears in the same person.

8.2.1 Parts of The Ear

See ▶ Fig. 8.2.

- Concha.
- Helix.
- Antihelix.
- Tragus.
- Antitragus.
- Lobule.

Following a careful clinical examination, the appropriate surgical technique will be applied by the surgeon.

8.3 Operative Technique

After birth, special molds can be used to correct the shape of the ear.[5] These molds must be used during the first 3 days, since later use does not produce the desired results.[6,7]

8.3.1 Anesthesia

Once the case has been analyzed and the decision has been made to do surgery, the procedure is performed in the operating room.

The surgery can be carried out under local anesthesia in patients over 6 years of age who cooperate, and is achieved by blocking the periauricular nerve branches. The use of infiltration of local anesthesia in the postauricular region allows an adequate vasoconstriction and hydraulic dissection of the skin. However, general anesthesia should be used for those who do not cooperate or are too anxious, such as children.[8]

8.3.2 Surgical Techniques

The decision regarding which surgical technique should be used will depend on the existing anatomical deformity and the stiffness of the cartilage.

Mustardé Technique

When the ear deformity is not severe and the cartilage is thin, the buried suture method can be used with the nonabsorbable material described by Mustardé.[9] Exerting pressure with the fingers on the helix forms a new fold of the antihelix, and the central line of the antihelix and the crura of the same are marked with ink (▶ Fig. 8.3). The position of the sutures is marked on the anterior part of the ear, going through the skin and cartilage with number 24 hypodermic needles to mark

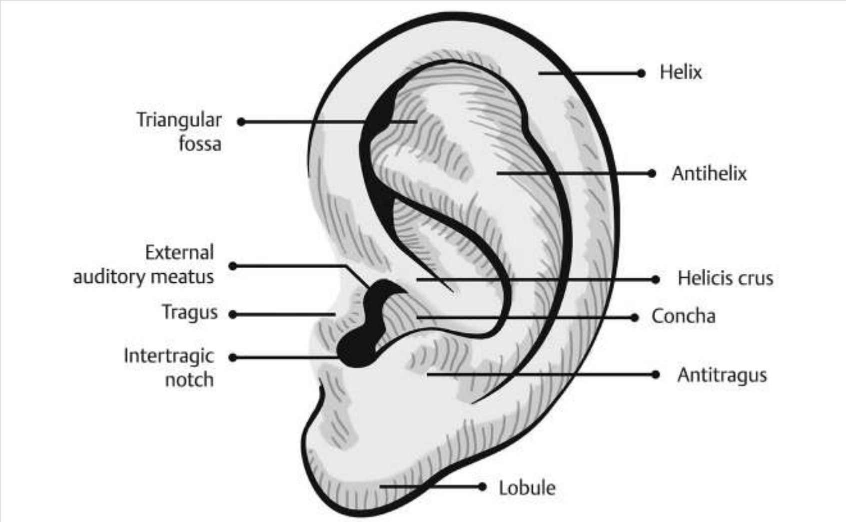

Fig. 8.2 Parts of the ear.

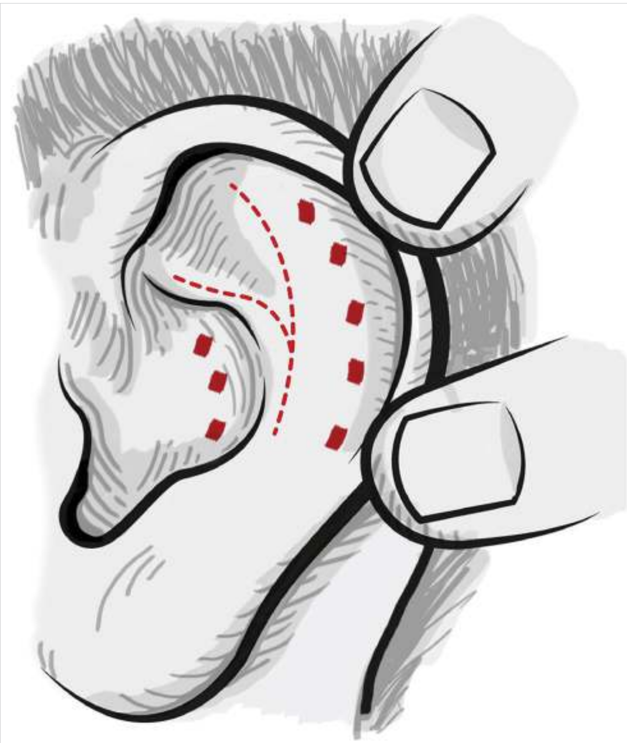

Fig. 8.3 New antihelix fold is formed and outlined with ink.

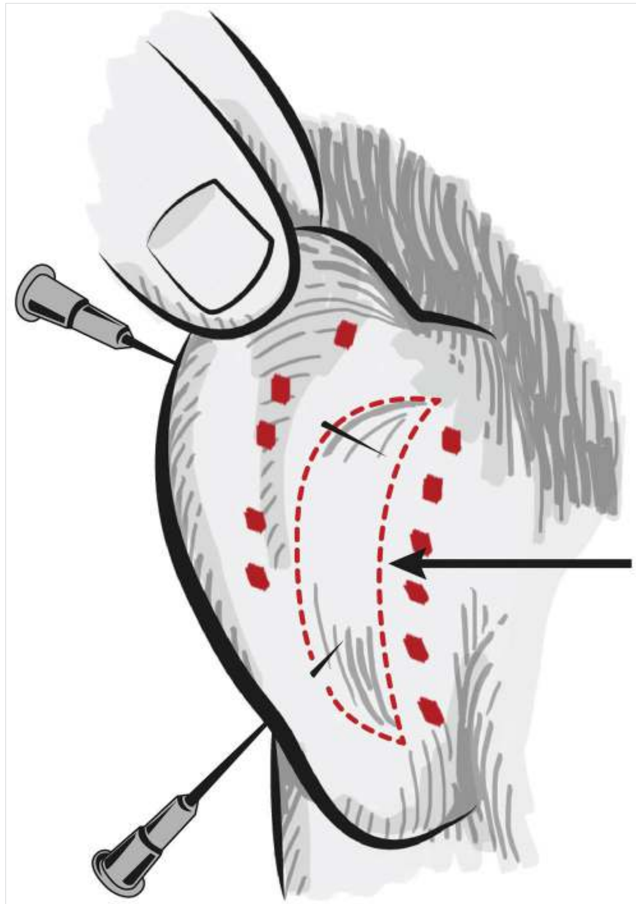

Fig. 8.4 The points of sutures are marked in the anterior ear aspect of the ear with hypodermic needle and ink passing underlying cartilage.

with ink the depth of the tissues (▶ Fig. 8.4). Then an ellipse of skin is resected in the posterior part of the ear, including the perichondrium, which must be made from the edge of the helix to the union with the mastoid region. This is a very important step to achieve a smooth contour. Hemostasis is performed and then sutures are made, preferably with colorless 5–0 or 6–0 nylon. If the ear is small, only three sutures may be needed, but larger ears may require four or five sutures to achieve a smooth contour (▶ Fig. 8.5). The skin is sutured with 5–0 nylon, subdermal suture (▶ Fig. 8.6).

Converse-Wood-Smith Technique

This technique[10] is used when there is a strong cartilage and an antihelix is absent. An ellipse of skin is resected from the back of

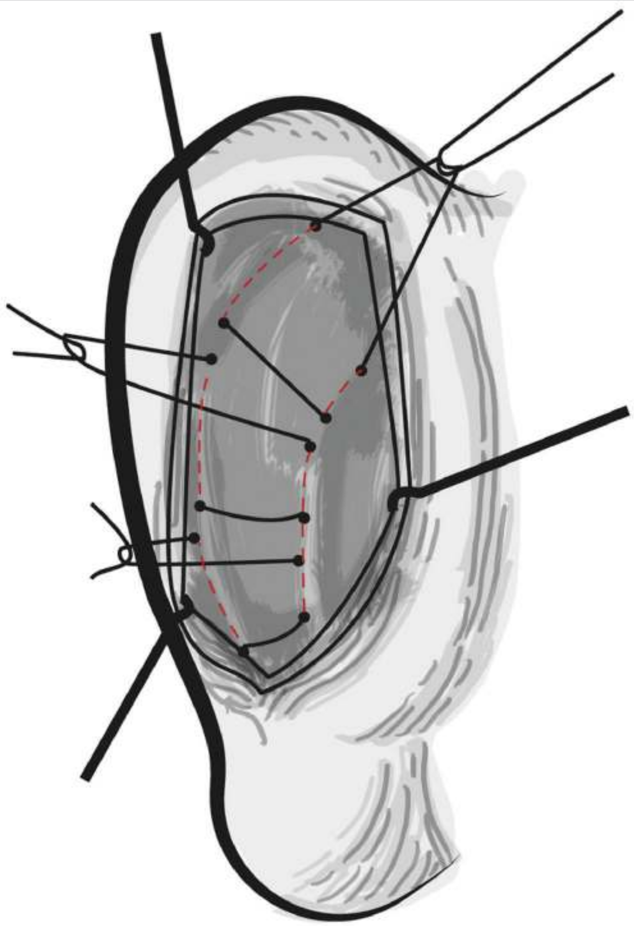

Fig. 8.5 Ellipse of skin is excised, and the buried mattress sutures inserted.

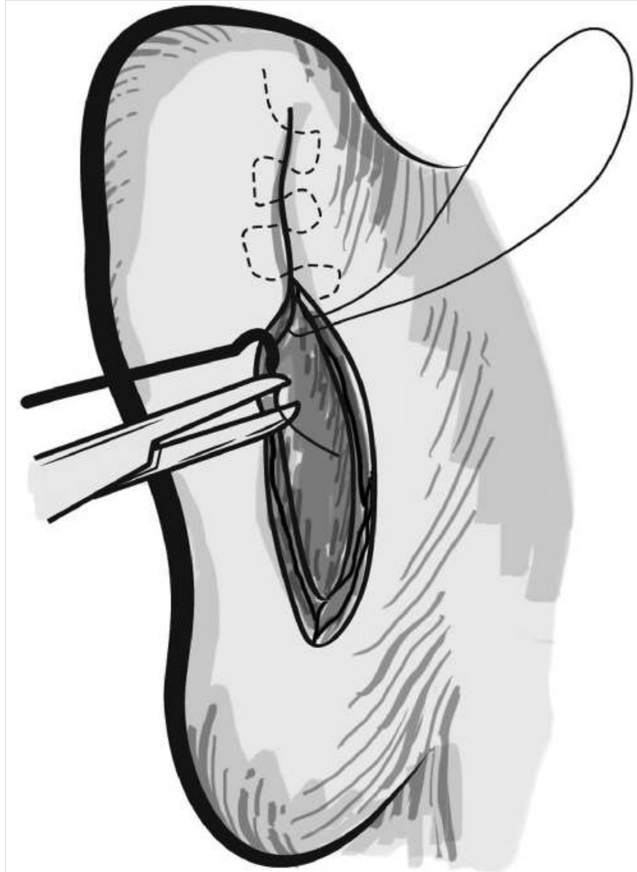

Fig. 8.6 The skin is sutured.

the ear, hemostasis is performed, and the skin and subcutaneous tissue are lifted to the rim of the helix to expose the posterior aspect of the concha (▶ Fig. 8.7). Then the new antihelix to be formed is folded and its edges gone through with number 24 hypodermic needles that will serve as markers as they are impregnated with ink, similar to the procedure on the concha. The needles are removed and the cartilage is cut (incised) without touching the anterior perichondrium. The incisions should not be joined to each other. The cartilage can be thinned to fold, although this is not always necessary. Then the cartilage is folded using 5–0 or 6–0 nylon sutures, forming the new antihelix (▶ Fig. 8.8). An ellipse of cartilage of the concha is resected and sutured in the same way to the residual edge (▶ Fig. 8.9). These sutures must be adjusted with the necessary tension to achieve the desired result (▶ Fig. 8.10). The anterior skin is liberated using a dissector to avoid undesirable folds. The ellipse of posterior skin is sutured with 5–0 nylon subdermal sutures. If necessary, the earlobe should be corrected when it is prominent, as seen in (▶ Fig. 8.11). The correction of the ear with this technique is very good (▶ Fig. 8.12 and Fig. 8.13).

Furnas Technique

The main indication for the use of this technique[11] is the presence of a cup-shaped deep auricular concha with normal presence of the antihelix. The degree of separation of the concha from the mastoid region is first calculated; the amount of cartilage to be resected is identified by pushing with a cotton applicator on the back part of the concha and then marked. A skin ellipse of the back of the ear is then resected and a small area of the mastoid region is dissected to release the posterior auricular muscle. The excess of cartilage previously calculated is resected (▶ Fig. 8.14) and sutured with two or three 4–0 nylon sutures, attaching the auricular cartilage to the mastoid fascia (▶ Fig. 8.15). The skin is then sutured with 5–0 nylon subdermal sutures.

8.3.3 Modifications of Otoplasty

A number of surgical techniques have been described, which are variants of those mentioned above. They differ in the way the atrial cartilage is slimmed down or how the cuts are modified, using different incisions, needles, diamond drills, shavings, Adson's pliers, and different sutures.[12,13,14,15,16,17,18,19]

Minimal Invasive Otoplasty

A number of otoplasty techniques have been described that try to avoid complications, such as hematomas or scars.[20,21,22]

Graham and Gault have described a minimally invasive technique with endoscopic assistance.[23]

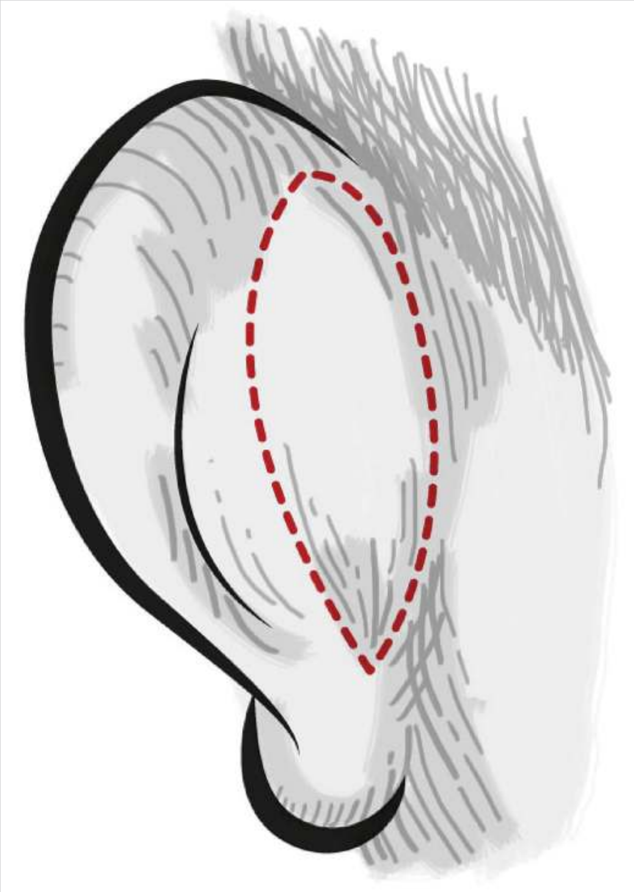

Fig. 8.7 An ellipse of skin is resected.

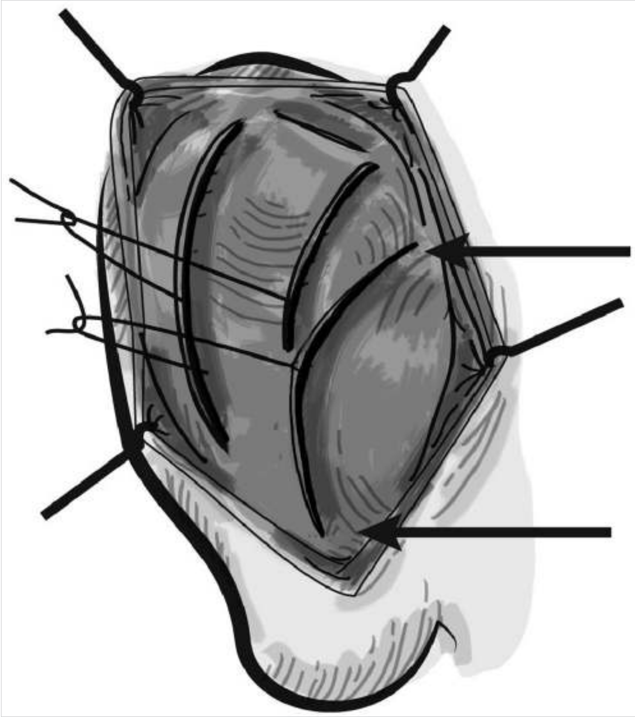

Fig. 8.8 Forming the new antihelix.

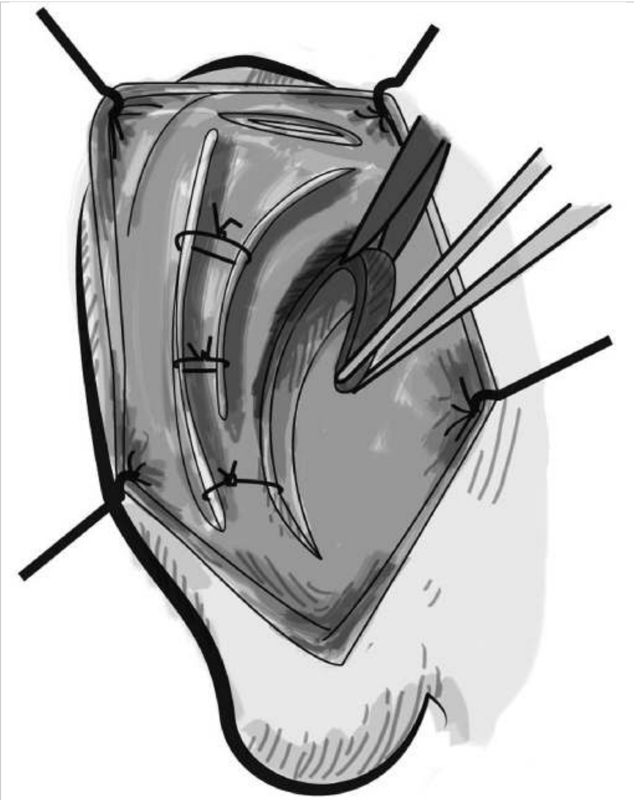

Fig. 8.9 An ellipse of cartilage of concha is resected.

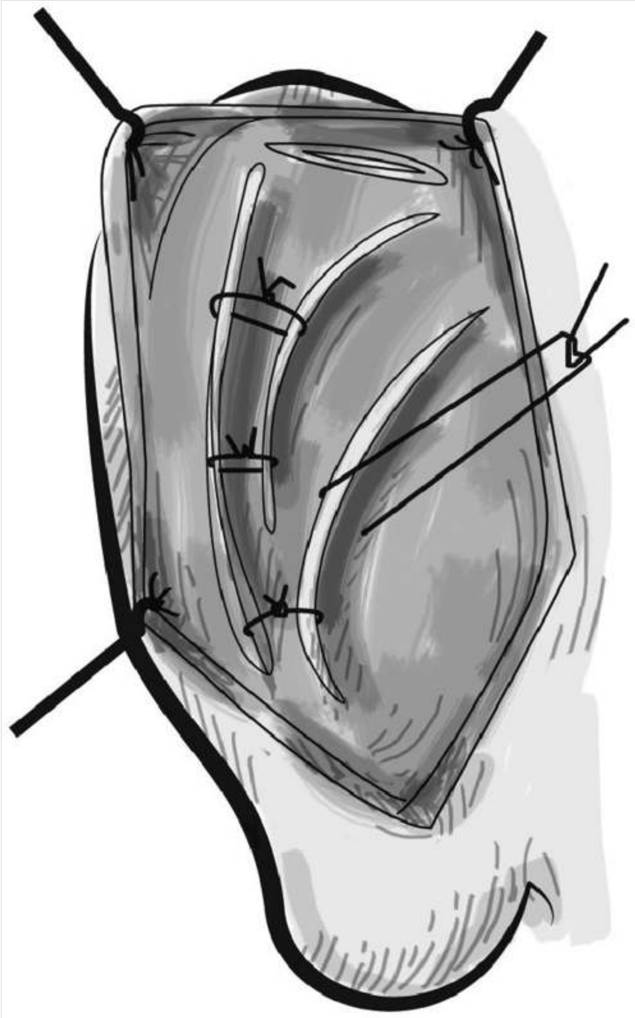

Fig. 8.10 The sutures must be adjusted with the necessary tension.

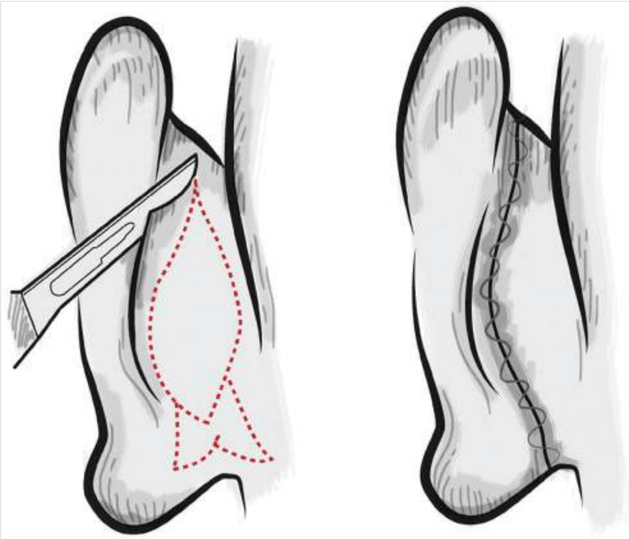

Fig. 8.11 Correction of the lobule.

Fig. 8.12 Patient before surgery.

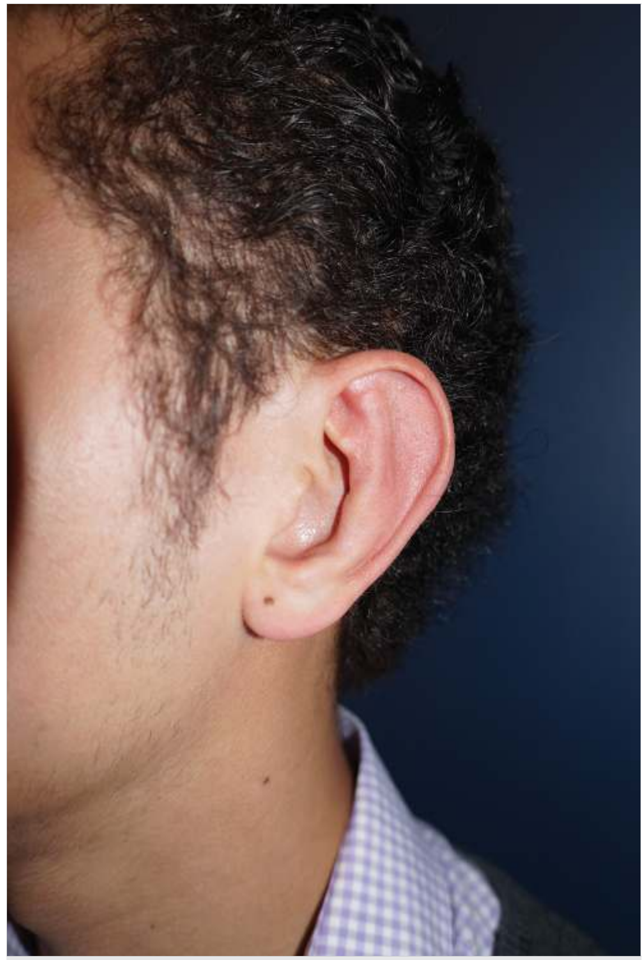

Fig. 8.13 Patient after surgery.

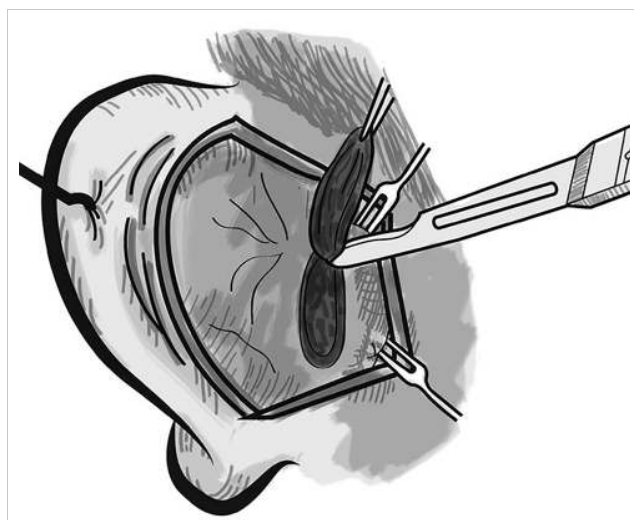

Fig. 8.14 The excess of cartilage previously calculated is resected.

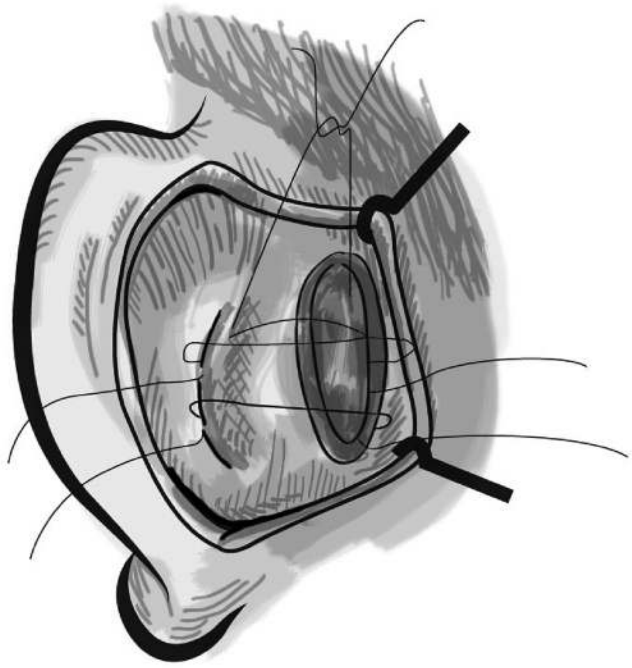

Fig. 8.15 Attaching the auricular cartilage to the mastoid fascia with sutures.

8.3.4 Postoperative Care

Usually, a compression bandage is used with elastic bandages, leaving a damp cotton mold on the corrected surfaces of the ear, so that the shape is not lost. This bandage should be left on for 2 days, after which the patient can cleanse the area daily and continue to use the bandage for 5 more days. Later, it only needs to be used at night for 2 more weeks. Skin sutures are removed within 10 days. Antibiotics are used as prophylactic for no more than 3 days. Analgesics are very important in the postoperative period because the pain can be quite annoying.

8.3.5 Complications

- Hematomas are the most frequent early complication and require an immediate and rigorous resolution, as they can lead to other complications such as perichondritis or atrial deformity. This is usually due to an inadequate compression bandage. The drainage should be done immediately upon discovery of the complication, and appropriate antibiotics should be administered to the patient.
- Inadequate correction is the second most frequent complication, and is due to a superficial preoperative assessment on the part of the surgeon, who chose a surgical technique which will require a second intervention to correct the deformity. Overcorrection may also lead to a second surgical intervention.
- Hypertrophic scars are a common complication that occurs mostly in adults with pigmented skins, which will require conservative treatment and occasionally the injection of intralesional steroids.

8.4 Conclusion

Otoplasty is a very important surgical procedure to correct congenital deformities of the ear and thus avoid problems of self-esteem of the patients. The ideal age for surgery is during childhood, but the problem can be resolved at any age. Many surgical techniques have been described for their correction; however, we describe the techniques aimed at correcting the existing anatomic deformities of the ear, namely, the deformity of helix, antihelix, concha, and lobule, because if these deformities are not corrected with the appropriate technique, the results are poor. All other existing techniques are variations of those mentioned in this chapter.

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Subsection IB

Functional Rhinoplasty

I

9 Open Rhinoplasty

Stefania de Fazio

Abstract
Open rhinoplasty is a technique which utilizes a transcolumellar incision to allow manipulation of the osseocartilaginous structures of the nose under direct vision. It can be used to correct multiple deformities, either congenital or traumatic, and is particularly valuable in treating deformities of the nasal tip.

Keywords: crooked nose, extracorporeal septoplasty, open approach to rhinoplasty, open rhinoplasty, septal deformities, septoplasty via open access, severe septal deviation

9.1 Introduction

Open rhinoplasty refers to the reconstructive aspects of rhinoseptoplasty using an incision through the columella that allows complete visualization of the osseocartilaginous framework of the nose.

Modern open rhinoplasty is a “structural” procedure, which may employ elements of reduction, support, restructuring, and grafting.

The nose is a three-laminar structure, which includes skin, bone and cartilage, and mucosa. Each component can be surgically modified to obtain the desired shape.

One must be sensitive to the fact, however, that the final outcome is also dependent upon the quality of the skin, e.g., subtle structural definition points may be obscured if the skin is too redundant or thick.

There are four basic structures which can be modified in open rhinoplasty, namely, nasal dorsum, nasal tip, nasal septum, and nasal valve/sidewall.

The nasal dorsum is a combination of nasal bone and nasal septal cartilage. Most often, this area requires resection or shaving using either an osteotome or rasp. In some instances, however, augmentation with cartilage for a depressed dorsum or to add definition for patients with thick skin may be required.

The nasal tip is formed by the lower lateral cartilages. Redefining or re-establishing tip support can be addressed by cartilage manipulation via resection, suture modification, or augmentation.

The nasal septum is a combination of bone and cartilage. Reconstruction of this unit is both structural and functional in that the nasal airway is always impacted. In septoplasty, one may straighten the septum, either in situ, by taking it out completely (full extracorporeal), or removing a portion (partial extracorporeal).

The nasal valve/sidewall is an area which depends on cartilaginous support and is both structural and functional. Reconstruction of the external nasal valve is dependent upon straightening the lateral crura and the upper lateral cartilages. Reconstruction of the internal nasal valve requires insertion of cartilage spreader grafts between the upper lateral cartilage and the nasal septum.

In secondary rhinoplasty, reconstruction is challenging and may require multiple techniques to achieve a satisfactory result.

9.2 Indications

Some common scenarios are:

- Nasal dorsal deformities exaggerating dorsal hump (congenital versus post traumatic): Requires reduction of saddle deformity due to trauma or overzealous hump reduction. Proper dorsal height will have to be re-established by reconstructing the plateau first and then adding contour.[1,2,3]
- Tip deformities: Asymmetries, hyper projection, drooping tip, collapse of the lateral wall, all of them must be managed structurally—re-establish proper support of the tip complex, both in its height and in its two sides.[4,5,10]
- Septal deformities (congenital versus post traumatic): Requires full versus partial extracorporeal reconstruction.[6,7,8,9]
- Inverted V deformity: It is due to the loss of the internal valve and the natural spring effect of the upper lateral cartilages. Spreader grafts (a graft which is sutured between the dorsal septum and the medial margin of the upper lateral cartilage) will usually be needed to re-establish proper aesthetic dorsal lines and open up the internal valve.
- Cleft lip nasal deformity: Abnormal lower lateral cartilage with:
  - Hypoplastic alar cartilage with depressed dome.
  - Loss of normal overlap of upper and lower lateral cartilages.
  - Laterally displaced ala.
  - Hypoplasia and retrusion of the bony platform at the pyriform aperture.
  - Deviation of the nasal spine and caudal septum to the non-cleft side.
  - Flattening and displacement of the nasal bones and upper lateral cartilage.
  - Buckling of the lateral crus of the lower cartilage creating a web in the vestibule.

9.3 Operative Technique

The first step of local anesthesia is spreading topical anesthetic cream or 4% topical cocaine solution on the mucosa. This is followed by injecting an anesthetic solution with epinephrine (1:100,000) both locally and to perform regional nerve blocks. One should be cautious not to inject too much local anesthetic to the columellar area so as not to distort the nasal tip structures.

9.3.1 Columellar Incisions

Although the shape of the incision may vary, geometric-type incisions, with multiple corners, are preferred to prevent long scar segments and facilitate flap alignment. Mid-columellar incisions include: “Z,” “V,” modified “V,” inverse “V,” modified inverse “V,” “W,” and transverse incisions.

Better cosmetic outcome is obtained with inverse “V” pattern: the two horizontal components of the incision are placed posteriorly in the columella, while the two components of the inverse “V” are oblique, along the longitudinal axis and so less visible.

Fig. 9.1 Submucous resection preserving "L" strut. Courtesy of Paolo Persichetti, MD, PhD, FEBORPRAS.

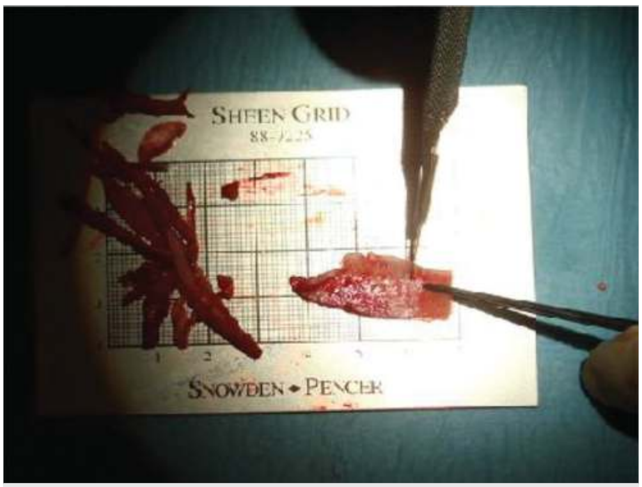

Fig. 9.2 Carving of septal cartilage in extracorporeal septoplasty. Courtesy of Paolo Persichetti, MD, PhD, FEBORPRAS.

9.3.2 Subcutaneous and Submucosal Dissections

The subcutaneous tissue is then dissected from the columnar incision toward the nasal tip with curved iris scissors. The incision is extended intranasally at the rim of the lower lateral cartilage bilaterally with a scalpel. Delicate scissor dissection is continued until such time as the soft tissue envelop is elevated from the columella, nasal tip, and dorsum. An incision can be made on the mucoperichondrial of the nasal septum with a scalpel, followed by submuco-perichondral dissection with a blunt periosteal elevator (▶ Video 9.1).

9.3.3 Septum Dissection

Via the above approach, a severe septal deviation can be rectified with a submucous resection of nasal septum (SMR) or an extracorporeal septoplasty (▶ Fig. 9.1). This entails removal of part of the deviated cartilaginous septum preserving an "L" strut, which is at least 0.5 cm wide. If the simple removal of pathologic cartilage, SMR, rectifies the problem, the operation is complete. However, in more complex situations, an extracorporeal septoplasty is performed (▶ Video 9.2).

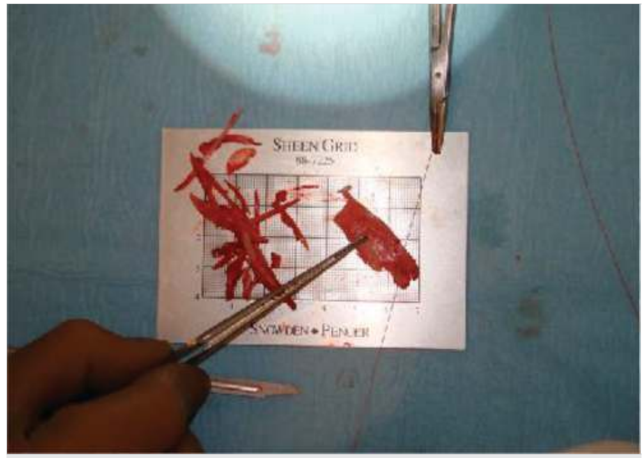

Fig. 9.3 Suture technique of septal cartilage in extracorporeal septoplasty. Courtesy of Paolo Persichetti, MD, PhD, FEBORPRAS.

Video 9.1 Robotti—Access and initial septal dissection (columella vessels, complete dissection with Colorado tip and seasers)

Video 9.2 Robotti: Severe deviation distal septum—partial extracorp

9.3.4 Septoplasty Technique

In severe cases, it is necessary to remove most of the septal cartilage and create a neo septum utilizing straight parts of it or donor grafts, by an extracorporeal septoplasty (▶ Video 9.3).

The removed segment of septal cartilage can be manipulated in multiple ways. It can be carved (▶ Fig. 9.2), reconfigured with mattress sutures (▶ Fig. 9.3), or otherwise manipulated in order

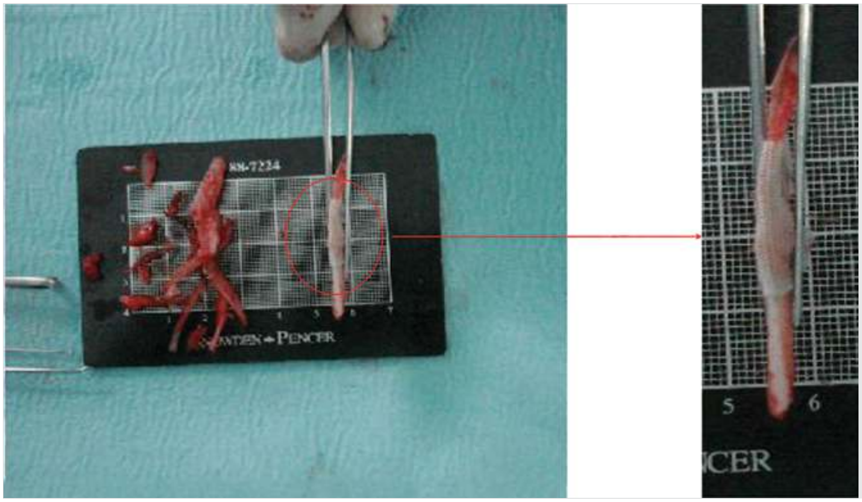

Fig. 9.4 Complex septal reconstruction using Vicryl mesh in extracorporeal septoplasty. Courtesy of Paolo Persichetti, MD, PhD, FEBORPRAS.

Video 9.3 Robotti: Spreader to stabilize septum

Video 9.4 Robotti: Suturing perf ethmoid plate to septum for straightening-stabilization

Video 9.5 Robotti: Septoplasty for deviated septum and splinting L strut with perf ethmoid plate buttress

to provide a straight septum (▶ Fig. 9.4, ▶ Video 9.4, ▶ Video 9.5, ▶ Video 9.6, and ▶ Video 9.7).

Video 9.6 Robotti: Suturing septum to spine in midline

Video 9.7 Robotti: Rib reconstructed septum (secondary)

9.3.5 Graft Harvest

On some occasions, structures require augmentation or reinforcement and require grafts. Common sources of cartilaginous material are nasal septum, ear cartilage, or rib. Rib cartilage (preferred to ear cartilage because of its thickness) can be used to reconstruct or support the "L" of the remaining septum, if cartilage available is poor and inappropriate for the purpose (▶ Video 9.8).

9.3.6 Post Reconstruction

Intranasal incisions are closed with either 5–0 or 4–0 Chromic gut sutures. The columellar incision is closed with 6–0 nylon sutures. An external nasal cast will be worn for approximately 1 week (▶ Fig. 9.5).

Fig. 9.5 Protective nasal cast.

Video 9.8 Robotti: Severe deviation distal septum—partial extracorporeal

9.4 Conclusion

Trying to correct severe pyramidal or septal deformities by a closed approach to rhinoseptoplasty is very challenging.

An open approach, which allows a direct visualization of the underlying structures, may lead to better results.

9.4.1 Advantages

- Complete anatomic exposure.
- Evaluation of complete deformity without distortion.
- Precise diagnosis and correction of deformities.
- Binocular visualization.
- Use of both hands.
- Grafts can be accurately modeled, positioned, and sutured.
- Easier to teach and learn.

9.4.2 Disadvantages

- External nasal incision (transcolumellar scar, sometimes notching of the columella on profile).
- Possibility of skin loss of the columellar flap.
- Prolonged operative time.
- Protractive nasal tip edema.
- More scar tissue contraction and prolonged edema, due to the more extensive dissection of the skin off the osteocartilaginous framework.
- More operating time than the endonasal approach.

Contraindications

- Patients who absolutely refuse to have any external scar.
- A previously scarred columella.

Acknowledgments

My gratitude to Dr. Paolo Persichetti and Dr. Enrico Robotti, Italian pioneers of the Open Rhinoplasty for images, short movies, and support. Thanks to Dr. Vito Toto for his kind cooperation. And last but not the least to the editor and my greatest friend, Dr. Robert X. Murphy Jr.

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10 Closed Rhinoplasty Techniques

Julio Daniel Kirschbaum Fridman

Abstract
Our basic technique of closed rhinoplasty is described.

Following anesthesia, an intercartilaginous incision is made. We separate the soft tissue from the skeleton, removing the bony hump with rasp and the cartilaginous hump with a scalpel. We prefer the low to high osteotomy. The excision of the cephalic portion of the lower lateral cartilage is done through a delivery approach. If we need tip support, protection, or camouflage of the inverted V infracture, we harvest septal cartilage to create columellar strut tip or spreader grafts.

If needed, an alar resection is done. We cover the nose with micropore and a small plaster for 7 days.

Keywords: alar resection, close rhinoplasty, columellar strut, spreaders graft, tip grafts

10.1 Introduction

The first aesthetic rhinoplasty was performed by Dieffenbach in 1845,[1] but it was Jacques Joseph who made it popular in 1931[2] by describing the bases of today's actual methods of closed rhinoplasty.

In the past, the aesthetic surgery of the nose was reduction surgery of a big nose with a convex hump converted into a smaller nose with a concave or straight profile (▶ Fig. 10.1).

In modern times, the idea is not only to create a nice nose, but also, more than anything, to make a natural nose in harmony with the rest of the facial structures.

10.2 Indications

The closed rhinoplasty is indicated in any type of nose surgery.

There are masters of plastic surgery like Ortiz-Monasterio[3] from Mexico who never used the open approach in an aesthetic nose.

10.3 Operative Technique

10.3.1 Anesthesia

The entire nose must be well anesthetized. In general, 15 mL 2% xylocaine with 1/80,000 epinephrine should be enough.

10.3.2 Incision

The nostril is retracted with a double hook with the index finger of the nondominant hand checking the position of the blade.

The incision is made between the upper and lower lateral cartilage (intercartilaginous incision) (▶ Fig. 10.2).

Separation of Soft Tissues from the Skeleton

Soft tissues are separated starting with scissors over the cartilage (▶ Fig. 10.3) and a periosteal elevator over the bone (▶ Fig. 10.4) as close as possible to the structures to allow thicker tissues to redrape the framework (▶ Fig. 10.5).

The dissection is not to extensive, but only what's needed to work comfortably.

Removal of Bony–Cartilaginous Hump

We prefer the fomon rasp for the bone because it is easily controlled and an 11 blade for the cartilaginous dorsum (▶ Fig. 10.6).

Osteotomy

Following reduction of the dorsum, the nasal bones are fractured to restore the nasal pyramid shape.

We prefer an endonasal approach for the lateral osteotomy using a 4-mL guarded curved osteotome. We go low to high to avoid the need for medial osteotomy (▶ Fig. 10.7).

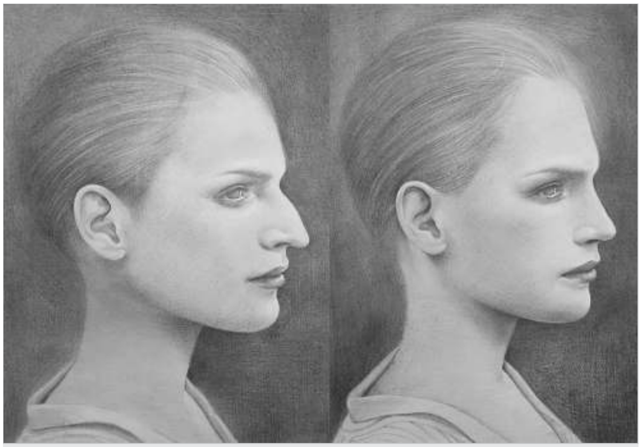

Fig. 10.1 Ideal rhinoplasty result before and after.

Fig. 10.2 Intercartilaginous incision.

Fig. 10.3 Dissection over the cartilage hump.

Fig. 10.4 Introduction of periosteal elevator.

Fig. 10.5 Complete dissection of the tissue over the dorsum.

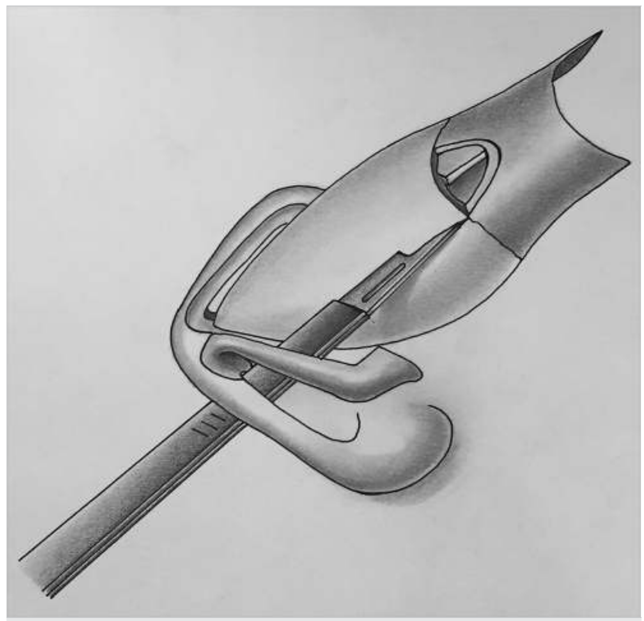

Fig. 10.6 Resection of the cartilaginous hump with a blade scalpel.

Fig. 10.7 Osteotome position as low as possible.

The osteotomies to restore the shape of the pyramid nose usually start low and finish high close to the frontal bone; also it can start low and finish low.

Treatment of Lower Lateral Cartilages

To expose the lower alar cartilages, a marginal incision is made by using a double hook. We evert the caudal margin of the nostril in which an intercartilaginous incision was made, by applying pressure with the middle finger of the nondominant hand. The caudal margin of the lower lateral cartilage is defined, and the incision follows the edge. We dissect the soft tissues from the surface of the lower lateral cartilage with converse scissors. A bipedicle flap is created that can be everted, exposing the lower lateral cartilage (▶ Fig. 10.8).

A variable amount of cephalic alar cartilage crura is removed to reduce the lobular volume.

Another way to narrow the tip is with transdomal sutures that changes the shape of the alar cartilages from a convexity to a concavity (▶ Fig. 10.9).

Fig. 10.8 Delivery of the right lower lateral cartilage.

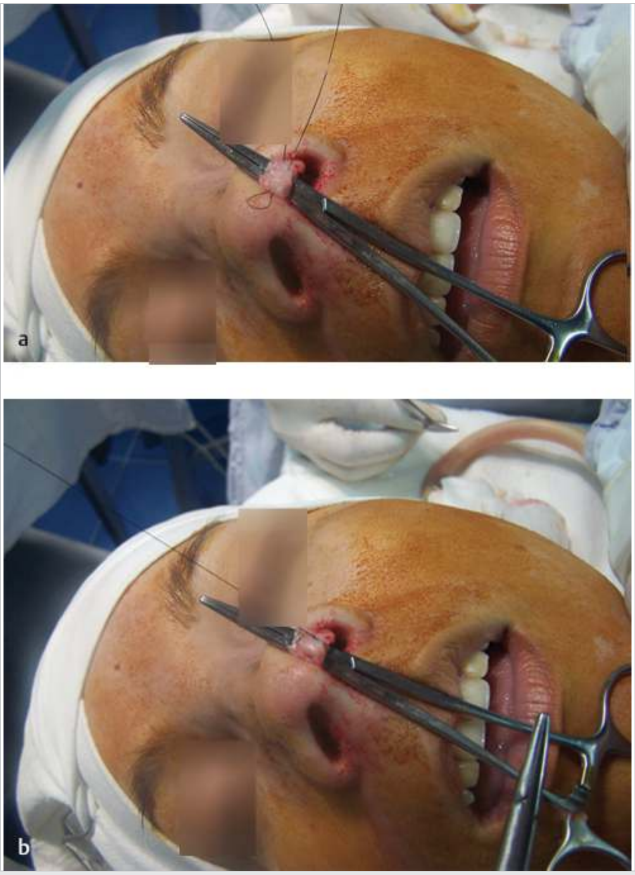

Fig. 10.9 **(a)** Direction of the suture. **(b)** Concavity created by the stitch.

It is important to understand that it is more important that the cartilage remains which will give the shape and support to the tip rather than excise it.

Harvest of Septal Cartilage

The incision is made parallel to the caudal border of the septum and 1 cm from it is 25 mm long on the mucosa on one side. The subperichondrial plane is identified. The dissection continues blunt with a freer elevator for 20 mm. Through the same incision, a blunt dissection is made in the contralateral side; it is very important not to break the mucosa because that can create a septal perforation. With a Ballenger knife, a piece of septal cartilage is obtain.

Placement of a Columellar Strut

A small incision of 3 mm is made through the vestibular skin. With converse scissors, a dissection of a precise pocket is made between both media cruras.

A columellar strut of 10 to 15 mm long by 3 mm wide, on average, of septal cartilage is inserted to give support to the tip (▶ Fig. 10.10).

Placement of a Tip Graft

To avoid visualization and increase tip projection, one or more pieces of septal cartilage of 4 × 3 mm can be put over the columellar strut by marginal incision.[4] It is important to morselize the upper piece of cartilage.

Spreader Grafts

Through small 3 to 5 mm incision near the caudal end of the septum, a precise subperichondrial pocket along the length of the cartilaginous dorsum is made, close to the junction between the septum and the upper and lower lateral cartilages. The graft measures on average 30 mm long by 3 to 4 mm wide.[5]

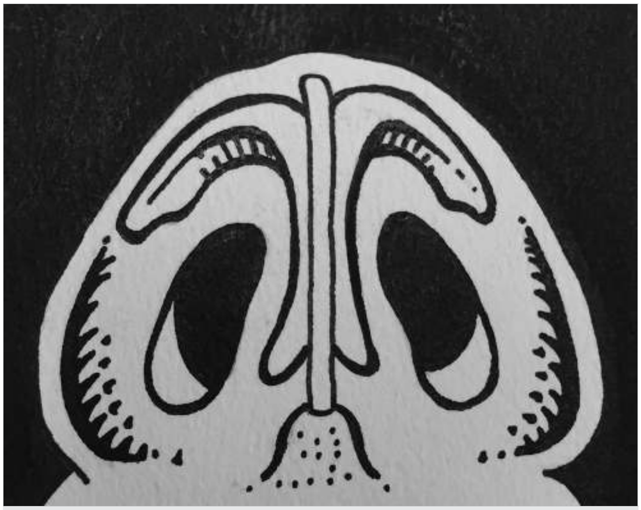

Fig. 10.10 Columellar strut in position between both medial cruras.

Fig. 10.11 Resection of excessive rostral and alar lobule.

Alar Resection

Alar resection should always be conservative as it is very difficult to correct an overresection.

Patients can have appropriate size nostrils and excessive alar lobules. In that case, only the lobules should be resected. In case it is the opposite, only the nostril skin is resected; in case nostril and alar lobules are redundant, we resect both (▶ Fig. 10.11).

Finally, all the incisions are closed with plain Catgut 5/0. Only when we take septal cartilage, we use nasal packing for a maximum of 48 hours.

Dressing

Tincture of benzoin is wiped over the nose and we put strips of micropore followed by a small plaster that we keep for 7 days.

10.4 Conclusion

Closed rhinoplasty is a safe, reproducible technique that can be used in the vast majority of patients. However, it requires a learning curve and can be performed with local anesthesia or general anesthesia. It can be done on an outpatient basis and needs the placement of a splint for approximately 7 days. There are different types of noses and so are the requirements of each patient and this will have to adapt to each case.

It is important to have bloodless field to be able to see all the tissues. To achieve that, we infiltrate 2% xylocaine with 1/50,000 adrenaline and 500 mg of tranexamic acid and wait for 30 minutes before starting the surgery.

The skin over the cartilage hump has enough subcutaneous tissue to camouflage small irregularities or even a tiny overresection.

The skin over the osseous hump is thin. The end result has to be an absolute smooth surface.

In a bulbous tip, it is possible to excise some fat to get better definition. It is important to be conservative, leaving a uniform surface.

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Subsection IC

Neoplasms

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11 Treatment of Skin Cancer of the Head and Neck

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Abstract

Skin malignancies are the most common cancer in the United States, responsible for more than half of all new cancer cases. These can be broken down into melanoma and nonmelanoma skin cancers (NMSC), which includes squamous cell and basal cell carcinomas. The surgical management of cutaneous malignancies should be part of a multidisciplinary approach that includes dermatologists, surgeons, medical and radiation oncologists, and genetic counselors. Determining optimal treatment includes careful consideration of tumor biology, anatomy, tissue function, quality of coverage, and possible adjuvant therapy, discussing with patients their options for diagnostic workup, treatment, and follow-up.

Keywords: basal cell carcinoma, malignant, melanoma, sentinel node biopsy, skin cancer, squamous cell carcinoma

11.1 Introduction

An estimated 5.0 million cases of nonmelanoma skin cancers (NMSC) are diagnosed annually exceeding the incidence of all other cancers combined.[1,2] These skin malignancies are mainly caused by ultraviolet radiation from exposure to the sun and tanning beds, and immunosuppressive medications like those taken by transplant patients with prior radiation to the head and neck area.

Basal cell carcinoma (BCC) is the most common form of skin cancer. It is rarely fatal, but it can become locally aggressive with a potential for perineural invasion. Squamous cell carcinoma (SCC) is the second most common skin cancer. It is more aggressive and may require extensive surgery depending on location and nerve involvement. Melanoma is much less common skin cancer, but it is responsible for more deaths per year than squamous cell and basal cell skin cancers combined. Melanoma is also more likely to spread and may be harder to control.

Location has been known to be a risk factor for NMSC recurrence and metastasis. In general, both BCC and SCC that develop in the head and neck area are more likely to recur than those developing on the trunk and extremities. As with nearly all malignancies, the outcome of melanoma depends on the stage at presentation. In the USA, it is estimated that 84% of patients with melanoma initially present with localized disease, 9% with regional disease, and 4% with distant metastatic disease.[3] In general, the prognosis is excellent for patients who present with localized disease and primary tumors of 1.0 mm or less in thickness, with 5-year survival achieved in more than 90% of patients. For patients with localized melanomas of more than 1.0 mm in thickness, survival rates range from 50 to 90%, depending on tumor thickness, ulceration, and mitotic rate.[4] The likelihood of regional nodal involvement increases with increasing tumor thickness, as well as presence of ulceration and increased mitotic rate.

11.2 Indications

11.2.1 Indications for BCC and SCC

Localized BCC and SCC are most commonly treated with surgery. Traditional techniques such as curettage and electrodessication are mostly supported by older studies, and data from prospective trials with long-term follow-up are scant. In an evidence-based review of the literature, the best results were obtained with surgery.[5]

A therapeutic option for both BCC and SCC is excision with postoperative margin assessment (POMA), consisting of standard surgical excision followed by postoperative pathologic evaluation of margins. This technique has been reported to achieve 5-year disease-free rates of over 98% for BCC and 92% for SCC.[6]

The National Comprehensive Cancer Network (NCCN) recommends 4 mm margins for low-risk BCC and 6 mm for low-risk SCC. Their analysis indicated that if 4 mm clinical margins are taken in an excision of BCC of less than 2 cm in diameter and clinically well circumscribed, that should result in complete removal of the tumor (with a 95% confidence interval). Similarly, if 6 mm clinical margins are taken in an excision of SCC of less than 2 cm in diameter and clinically well circumscribed, that should result in complete removal of the tumor (with a 95% confidence interval). Any peripheral rim of erythema around an SCC must be included in what is assumed to be the tumor.

If lesions can be excised with the recommended margins and closed with a linear closure, excision with POMA is appropriate. However, if tissue rearrangement or skin graft placement is necessary to close the defect, intraoperative surgical margin

Table 11.1 NCCN criteria for BCC lesions

	Low risk	High risk
Location/size	Area L < 20 mm	Area L > 20 mm
	Area M < 10 mm	Area M > 10 mm
	Area H < 6 mm	Area H > 6 mm
Borders	Well defined	Poorly defined
Primary vs. recurrent	Primary	Recurrent
Immunosuppression	(−)	(+)
Site of prior RT	(+)	(−)
Pathology subtype	Nodular, superficial	Aggressive growth pattern
		Perineural involvement
Perineural involvement	(−)	(+)

Abbreviations: BCC, basal cell carcinoma; NCCN, National Comprehensive Cancer Network; RT, radiotherapy.
Notes: Area H = "mask areas" of face (▶ Fig. 11.1) (central face, eyelids, eyebrows, periorbital, nose, lips [cutaneous and vermilion], chin, mandible, preauricular and postauricular, temple, ear), genitalia, hands, and feet.
Area M = cheeks, forehead, scalp, neck, and pretibia.
Area L = trunk and extremities (excluding pretibia, hands, feet, nail units, and ankles).

Table 11.2 NCCN criteria for SCC lesions

	Low risk	High risk
Location/size	Area L < 20 mm	Area L > 20 mm
	Area M < 10 mm	Area M > 10 mm
	Area H < 6 mm	Area H > 6 mm
Borders	Well defined	Poorly defined
Primary vs. recurrent	Primary	Recurrent
Immunosuppression	(−)	(+)
Site of prior RT or chronic inflammation	(−)	(+)
Rapidly growing tumor	(−)	(+)
Neurologic symptoms	(−)	(+)
Degree of differentiation	Well or moderately differentiated	Poorly differentiated
Pathology subtype of adenoid, adenosquamous, desmoplastic	(−)	(+)
Thickness of depth	< 2 mm	> 2 mm
Perineural involvement	(−)	(+)

Abbreviations: NCCN, National Comprehensive Cancer Network; RT, radiotherapy; SCC, squamous cell carcinoma.
Notes: Area H = "mask areas" of face (▶ Fig. 11.1) (central face, eyelids, eyebrows, periorbital, nose, lips [cutaneous and vermilion], chin, mandible, preauricular and postauricular, temple, ear), genitalia, hands, and feet.
Area M = cheeks, forehead, scalp, neck, and pretibia.
Area L = trunk and extremities (excluding pretibia, hands, feet, nail units, and ankles).

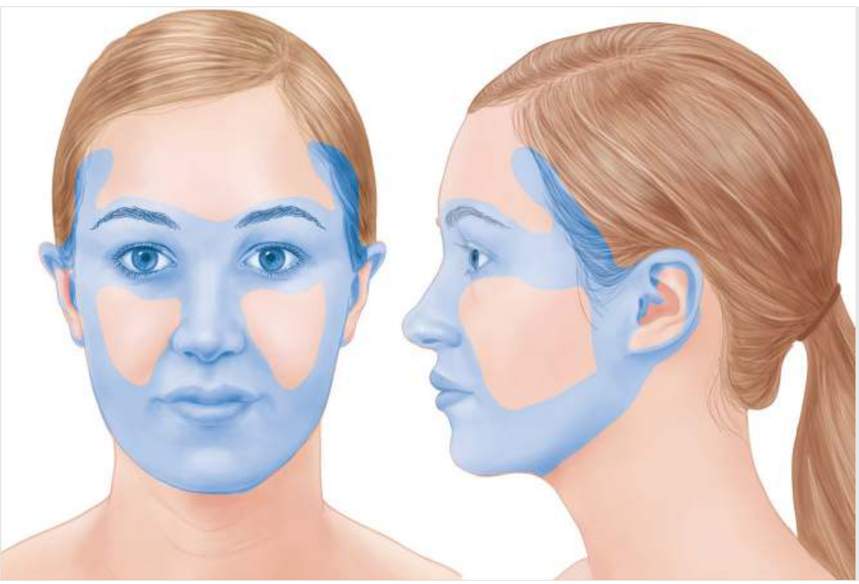

Fig. 11.1 Mask areas of the face include lips (cutaneous and vermilion), chin, mandible, preauricular, postauricular, temple, and ear.

assessment is necessary before closure (▶ Table 11.1, and ▶ Table 11.2, ▶ Fig. 11.1).

Excision with comprehensive intraoperative margin control is the preferred surgical technique for high-risk BCC and SCC. However, if standard excision with POMA is used for treatment of a high-risk tumor due to patient-related clinical circumstances or other variables, wider surgical margins than those recommended for low-risk lesions must be taken and increased recurrence rates should be expected. Generally accepted high-risk features include: tumor diameter > 2 cm, poorly differentiated histology, perineural invasion, invasion beyond subcutaneous tissue/fat, occurrence on the ear, temple, or anogenital regions, desmoplastic growth pattern, and immunosuppressed host status.[7,8]

Excision with complete circumferential peripheral and deep-margin assessment (CCPDMA) using intraoperative frozen section (IOFS) assessment is the preferred surgical technique for high-risk BCC and SCC in the Penn State Melanoma and Skin Cancer Center because it allows the same intraoperative analysis of 100% of the excision margin as Mohs micrographic provides. In order to select the most appropriate surgical alternative for the patient it is extremely important that the surgeon understands the multiple histologic grossing techniques and their implications.

The utility of sentinel lymph node biopsy (SLNB) is not clearly defined in the setting of SCC. For certain high-risk cutaneous SCC, with biopsy proven lymphovascular invasion, SLNB may be considered. A systematic review of 692 patients with cutaneous SCC reported positive sentinel lymph nodes (SLNs) in 24 and 21% of anogenital and nonanogenital patients, respectively.[9] However, the survival benefits of the SLNB remain unclear.

11.2.2 Indications for Melanoma

Patients presenting with a suspicious pigmented lesion should undergo an excisional biopsy, preferably with 1 to 3 mm margins. The orientation of the excisional biopsy should always be planned with definitive treatment in mind. With the increasing use of lymphatic mapping and sentinel node biopsy, biopsies should also be planned to not interfere with this procedure. For the same reason, wider margins for the initial diagnostic procedure should be avoided.

The proposed surgical margins for excision of primary melanoma as recommended by NCCN are outlined in ▶ Table 11.3.

11.2.3 Indications for Sentinel Node Biopsy

SLNB is a common staging procedure for cutaneous melanoma and almost always performed at the time of initial wide local excision. Proximity of cranial nerves and ambiguous lymphatic drainage pose unique challenges to performing the SLNB procedure in the head and neck region.

Preoperative lymphoscintigraphy is required to define the regional lymph basin(s) that drain the primary site; to localize the predominant drainage channels leading to the basin(s); and to localize the number of SLNs within the basin(s) draining through separate lymphatic channels. The radiocolloid commonly used at our center is the sulfur-colloid injected intradermally on four sides of the primary or previous site of the primary tumor. The SLNs are marked externally on the skin of the subject. Dynamic lymphoscintigraphy is performed within 24 hours preceding wide excision and selective lymph node dissection, with initial images at 30 to 45 minutes and delayed images at 1 to 2 hours.

If two or more regional lymph node basins are identified by lymphoscintigraphy, intraoperative lymphatic mapping and selective lymph node dissection should be performed on both lymph node groups.[10]

The current indication for lymphatic mapping and SLNB at the Penn State Melanoma and Skin Cancer Center are as follows:

- Recommended for primary melanomas with Breslow's thickness ≥ 1 mm; offered for primary melanomas with Breslow between 0.76 and 1 mm.
- Clark Level ≥ IV without clinically detected lymph node metastasis.
- Mitotic rate ≥ 1.
- Presence of ulceration.
- We discuss and may offer the procedure for select patients with primary melanomas with Breslow < 0.76 mm if young (≤ 45 years), with ulceration or mitotic rate > 1; or in those patients with lymphovascular invasion.

Table 11.3 NCCN recommended clinical margins

Tumor thickness	Recommended clinical margins
In situ	0.5–1.0 cm
≤ 1.0 mm	1.0 cm
1.01–2 mm	1.0–2.0 cm
2.01–4 mm	2.0 cm
> 4 mm	2.0 cm

Abbreviation: NCCN, National Comprehensive Cancer Network.

In general, SLNB is not recommended for primary melanomas of ≤ 0.75 mm thickness, unless there is significant uncertainty about the adequacy of microstaging. For melanomas of 0.76 to 1.0 mm thickness, SLNB may be considered in the appropriate clinical context. In patients with thin melanomas (≤ 1.0 mm), apart from primary tumor thickness, there is little consensus as to what should be considered “high-risk features” for a positive SLN. Conventional risk factors for a positive SLN, such as ulceration, high mitotic rate, and lymphovascular invasion (LVI), are very uncommon in melanomas of ≤ 0.75 mm thickness. When present, SLNB may be considered on an individual basis.[11]

11.3 Operative Technique

11.3.1 Lymphoscintigraphy and Sentinel Lymph Node Biopsy (SLNB)

Patients undergo preoperative lymphoscintigraphy to identify the regional lymph basin at risk for metastases, and the radioactive individual lymph nodes should have the site of the SLN identified by markings on the skin. At the time of the surgical procedure, the patient should be positioned for easy access to the regional lymph node basin. They are usually positioned supine for melanomas on the head and neck.

Lymphatic mapping with the blue dye is performed before wide local excision. In the head and neck region, 0.5 to 1.0 mL of isosulfan blue is injected intradermally with a 30-gauge needle around the site of the primary lesion or incision biopsy (▶ Fig. 11.2). After massage of the area for approximately 3 to 5 minutes, incision should be performed. In case a delay occurs beyond 30 to 45 minutes for any reason, reinjection should be performed due to dye “washout.”[12]

Fig. 11.2 With a 30-gauge needle, 0.5 to 1.0 mL of isosulfan blue is injected intradermally around the site of the primary lesion or incision biopsy.

Fig. 11.3 Location of the sentinel lymph node (SLN) as approximated by the gamma probe "hot spot."

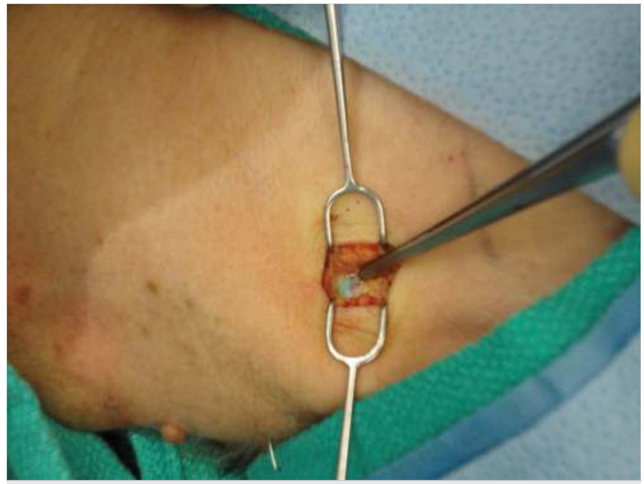

Fig. 11.5 Afferent blue lymphatic channel is found, which leads to the blue-stained node.

Fig. 11.4 Incision of approximately 3 cm may be adequate in some cases—larger incisions should be used without reservation if improved exposure will diminish the risk of complication such as nerve injury.

Fig. 11.6 Ex-vivo gamma count of the excised sentinel lymph node (SLN).

An incision is made in the regional lymph basin of the expected lymphatic drainage, over the site of the SLN marked by preoperative lymphoscintigraphy and the operating gamma probe "hot spot" (▶ Fig. 11.3), and the incision is oriented for inclusion within a complete lymphadenectomy incision (▶ Fig. 11.4).

Once the incision over the SLN has been made, usually an afferent blue lymphatic channel is found, which leads to the blue-stained node(s) as shown in ▶ Fig. 11.5. Careful exploration of the surrounding tissue is necessary to identify any additional nodes and to distinguish them from the SLN(s). Special care needs to be taken in the selective dissection of SLNs in the parotid or spinal accessory nerve area. A nerve stimulator is helpful to guide the dissection to avoid nerve injury. Dissect the lymph node from the surrounding tissue bed. Dissection is facilitated by grasping the tissue adjacent to the node (not the node itself), to not crush or tear the lymph node.

The probe is used to help identify the SLN. Radioactive counts of the lymph node basin are taken once the nodes are removed to determine if any additional radioactive nodes are present. If so, these are excised even if not blue and are labeled as SLNs that are "hot, not blue," if not colored by the dye mixture. The hot node to background ratio will vary depending on the particular radiocolloid used by the institution, as well as the number of hot nodes. Other radioactive nodes do not need to be removed if early lymphoscintigraphic images indicate these are not sentinel nodes but second echelon nodes because they are not directly connected to the primary site by a lymphatic channel. In this case, they are likely to be second echelon nodes or those even further down the drainage pathway. The single-photon emission computed tomography (SPECT-CT) is helpful and should be used when available.

After removal of the lymph node, an ex-vivo count of the node is performed (▶ Fig. 11.6) as well as a total count of the wound bed to assess for additional SLNs. Once the wound bed reading drops below 10% of ex-vivo reading, the true SLNs have been adequately removed.

Intraoperative frozen sections for SLNs are not recommended and the specimen should be sent immediately to pathology for permanent evaluation. Once it has been determined that the basin contains no additional "hot" or "blue" nodes, the deep and superficial fasciae are approximated in separate layers as per surgeon's preference, and the subcutaneous tissue and skin are closed with absorbable suture.

After changing gloves and instruments, the primary site is then widely excised. However, in head and neck melanomas, it is common to have the primary site close to the SLN, creating a strong "radioactive background," not allowing for an accurate SLN identification. In those cases, we perform the wide local excision first.

The success of SLNB depends on appropriate patient selection. Patients with palpable regional disease or distant metastasis are not candidates because additional prognostic information will not be gained. Additionally, patients who have had previous neck dissections or resection of the primary site with wide margins are not deemed candidates owing to lack of accuracy.

Pathologic examination of the SLN must be performed by assessment of permanent sections prepared from formalin-fixed and paraffin-embedded tissues. SNLs should not undergo frozen section examinations. When the node specimen is sent to pathology, the requisition form should state the number of nodes, the anatomic locations, the color as observed in the operating room, and the radioactivity for each node recorded.

11.3.2 Full-Thickness and Split-Thickness Skin Grafts

Skin grafts are generally avoided and are used only when primary or flap closure cannot be designed. However, in some older, thin-skinned, pale-white patients with large tumors, a skin graft may produce an acceptable cosmetic result. A full-thickness skin graft (FTSG) harvested from either preauricular or postauricular skin, neck, supraclavicular, or trapezius skin tends to produce a better texture and color match.

Eyelid defects are best replaced with FTSG usually harvested from postauricular, upper eyelid or supraclavicular skin. These grafts require meticulous trimming and thinning, because the graft must be flexible yet firm enough to support the shape of the defect after healing.

A template of the recipient area can be made with paper, foil, or surgical gauze pressed into the wound to provide a blood-tinged imprint and then cut to the approximate size and shape of the recipient area. The template is then placed on the donor area and the edges outlined with a marking pen. Be aware that on average, an FTSG may contract by about 15% when removed from the donor site.

Once the donor area is marked, the skin is prepared and anesthetized with local anesthetic. An incision is made around the graft marked on the donor site, with care taken to cut through the full thickness of the skin down to the subcutaneous fat. The graft is removed with a thin layer of subcutaneous fat. Hemostasis is obtained through point coagulation and pressure.

The graft must be defatted by trimming subcutaneous fat away from the underside by placing the graft epidermis down on the index finger of the nondominant hand. Using small serrated scissors, all fat is gently teased away from the dermal surface of the graft. When completely cleaned, the graft should have no obvious yellow globules of fat clinging its undersurface. Once the graft is prepared, it is placed, dermis down, onto the wound surface. Approximation of an FTSG to the wound edges can be done with simple interrupted or running sutures. The graft should fit comfortably down onto the wound surface avoiding any tenting, bunching, or puckering. For the skin graft to survive, the graft must be immobilized and must adhere well to the recipient bed. A bolster suture is applied over the skin graft to enhance contact between the graft and the recipient base, decreasing dead space beneath the graft and preventing formation of seroma and hematoma. Once the graft is secured on the recipient site, the donor site is closed primarily after any necessary undermining.

Significant advantages of the FTSG over the split-thickness skin graft (STSG) include:

- Provide replacement for deeper defects.
- Better texture and color match to recipient skin.
- No special equipment is required for harvesting the graft.
- Technically easier to perform.
- Less patient care is needed for the donor site.

Significant disadvantages of the FTSG compared with the STSG include:

- Lower rate of successful takes because of thickness.
- Limitation on size because of the availability of and repair of the donor area (▶ Fig. 11.7).

11.3.3 Simple Rectangular Advancement Flap

The flap is designed by extending an incision along two parallel sides of the defect and lifting a tongue of tissue that is then pulled directly over the defect. To close a circular defect, the flap is designed by cutting tangents on both sides of any given diameter of the defect. Full undermining of the flap and all of the area around the pedicle is carried out. The skin on the opposite side of the defect may be also undermined if desired, to move the wound edge toward the flap. Once the flap has been elevated and is demonstrated to cover the defect completely, the flap tips may be squared off, if necessary. Usually, dog-ears form at the base of the flap and can be removed as a Burow's triangle.

The advancement flap is drawn so that the length is approximately two and a half to three times longer than the defect with care taken to stay in the subcutaneous plane during the excision of the lesion. Counter traction is helpful during incision and excision. Tenotomy or Metzenbaum scissors can be used to undermine as well as to cut the deep layers of the soft tissues. The skin incisions themselves should be made with a sharp #15 or #10 blade and care is taken to incise perpendicular to the skin edges.

The entire flap is undermined in a layer between the skin and the deeper subcutaneous tissues. The undermining is continued beyond the extent of the dissection as much as necessary, or an average of 1 to 2 cm in all directions for smaller defects. This allows for easier flap mobility.

Fig. 11.7 (a–c) Morpheaform basal cell carcinoma (BCC) pre and post complete circumferential deep and peripheral margin assessment (CCDPMA) with frozen sections with full-thickness skin graft reconstruction.

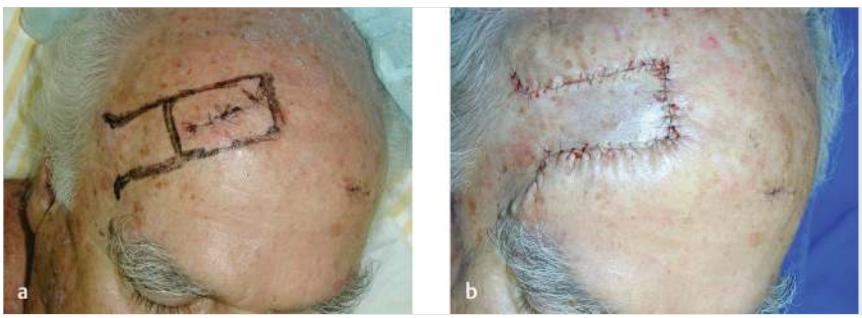

Fig. 11.8 (a) Proposed skin markings for rectangular advancement flap with inclusion of Burow's triangles. **(b)** Final incision and closure after completion of the excision and advancement flap.

The first suture is placed in the center of the flap edge and through the midpoint of the defect margin. Care is taken to prevent slipping of the knot by keeping constant tension on the sutures, and sutures are cut with a small tail that prevents unwinding of the suture material over time. The corner sutures are placed next, since they are the other primary sites of tension in this flat design. The flap edge is then closed with the principle of halving with the first central sutures placed in the middle of the edge of the flap and in the middle of the corresponding skin flap. Subsequent sutures are then placed to split the difference between the previous sutures until enough sutures are placed for adequate closure. In this way, the redundant skin is spread evenly across the entire closure and results in a smooth wound edge (▶ Fig. 11.8).

11.3.4 Bilateral Rectangular Advancement Flap

A flap may be advanced from both sides of the defect using the same steps and technique design of the simple one. The flaps may or may not join at the center of the defect, because the elasticity of the skin is variable. The flaps from the two sides do not necessarily have to be of the same length. At times, the anatomical location dictates that one side be longer than the other.

The bilateral advancement flap is an extensive procedure requiring long suture lines, wide areas of undermining, and large cut surfaces. It is commonly used in the forehead (▶ Fig. 11.9).

11.3.5 A to T Flap

The A to T (A-T) flap, another type of bilateral advancement flap, represents the shape of a triangular defect closed by advancing flaps from opposite sides of the triangle. A dog-ear almost always forms at the apex of the defect and is repaired by making an incision that bisects the angle, taking tissue necessary to remove the dog-ear. If the surgical defect is round or oval, the surgeon superimposes a triangle in his mind with the base up or down. Burow's triangles may also form at the edges of the flaps and can be resected, allowing the flaps to move more easily.

The real advantage of this flap lies in its possible variations, which allow the limbs of the T to be hidden in hairlines, around alar creases, or along the vermilion junction (▶ Fig. 11.10).

11.3.6 V-Y Flap

The V-Y Flap is a versatile flap for reconstruction of head and neck defects. The linear donor sight scar camouflages well in

Fig. 11.9 **(a)** Preoperative and **(b)** final defect after excision of the lesion and with the limbs of the bilateral rectangular advancement flap marked. **(c)** Note the final closure with permanent sutures in the typical "H" pattern. **(d)** The final scar camouflages well with the transverse forehead rhytids.

Fig. 11.10 **(a)** Final defect after excision of a lesion at the anterior hairline with design of the lateral limbs of the "T" oriented to lay along the natural transverse rhytids and congruent with the hairline. Wide undermining in **(b)** all directions allows adequate mobilization of the surrounding tissues to aid in a final tension-free closure and a barely perceptible final scar **(c)**.

the aging face and may be preferentially designed for placement along natural rhytids. A particular advantage may be gained by using the V-Y flap in reconstruction of nasal ala or sidewall defects as the donor site can be hidden well within the nasolabial fold.

After resection and confirmation of clear margins, the flap may be designed. The flap is first designed by marking the limbs of the "V" with care taken to ensure adequate coverage of the defect. This is often based on the facial or angular artery. The surrounding tissues are then widely undermined in the usual fashion. However, the area under the proposed flap is not violated to avoid disruption of the flap's vascularity.

The limbs are then incised with a #15 blade scalpel through the skin and dermis. As the flap is advanced into the defect, gentle blunt dissection of any fascial attachments may be performed as necessary to ensure a tension-free closure while

Fig. 11.11 V-Y advancement flap: **(a)** Preoperative lesion and **(b)** post excision are shown with involvement of multiple facial subunits including the cheek, nasolabial fold, superolateral lip, and lateral alar base. The limbs of the advancement flap are designed in parallel to relax skin tension lines with tissue recruited from the inferolateral/cervicofacial areas. **(c)** After final closure, the flap lies along the nasolabial fold with the inferior single limb extending inferiorly. **(d, e)** Final scar blends well with the surrounding tissues and anatomic subunits.

avoiding any perforating vessels to the flap. This advancement is then inset with a combination of deep absorbable sutures followed by permanent skin sutures. The inferior aspect of the donor site (or the apex of the “V”) is then closed linearly with a final scar in the typical “Y” pattern (▶ Fig. 11.11).

11.3.7 Dorsal Nasal Advancement Flap

The nasal advancement flap is typically indicated for cutaneous nasal defects involving the nasal dorsum, medial sidewall, or extending to the nasal tip. Due to the relatively large axial inflow, the flap and surrounding tissues may be widely undermined with confidence, and allows coverage of relatively large defects, which would otherwise be too large for primary closure or a bilobed flap. The operation is started by first undermining widely in all directions surrounding the defect. Once this is accomplished, the dorsal advancement flap is then designed with the flap pedicle/inflow based on the ipsilateral nasal sidewall and angular artery. The contralateral limb is carried along the sidewall-dorsum junction superiorly to the glabella with a back-cut proceeding inferiorly as necessary.

An incision along the proposed markings is then accomplished with a #15 blade scalpel and the entire flap is then undermined in a supraperichondrial/supraperiosteal plane with either blunt dissection or use of electrocautery. The flap may then be transposed inferiorly and inset into the defect with resorbable sutures in the deep dermis and final closure accomplished with interrupted permanent sutures. The flap donor site from the glabella and back-cut are closed in a V-Y fashion (▶ Fig. 11.12).

11.3.8 O-Z Closure

The popularity of O-Z closure is based on the fact that its design can be described simply as a variation of the standard ellipse. The design resembles a giant ellipse having a defect in the center. The uninvolved skin is not sacrificed on either side of the defect. Rather, it is made into flaps and rotated or advanced over the central defect. Undermining is carefully done in all directions, and the leading edges of the flaps are brought together tentatively. Key sutures join the leading edges of the flaps. The O-Z flap is an excellent flap to close large defects on the hair-bearing skin of the scalp (▶ Fig. 11.13).

11.3.9 Note Flap

Once the lesion is removed, the other limbs of the note flap are drawn. The first limb is approximately one and a half times the diameter of the lesion and the second limb that is equal to the diameter of the lesion is now cut at approximately 60 degrees angle. The dissection begins at the apex of the 60 degrees angle, with wide undermining as previously described.

The triangular flap is then transposed into the circular defect. The apex will have some excess tissue, which will need to be

Fig. 11.12 **(a)** Note the cutaneous defect involving the nasal tip, soft triangles, and extending partially to bilateral nasal ala. **(b)** A dorsal nasal advancement is designed and incised with a #15 blade scalpel. **(c)** After wide undermining, the flap may be transposed inferiorly without tension on the **(d)** nasal tip. **(e)** The final scar is hidden well within the glabellar rhytids.

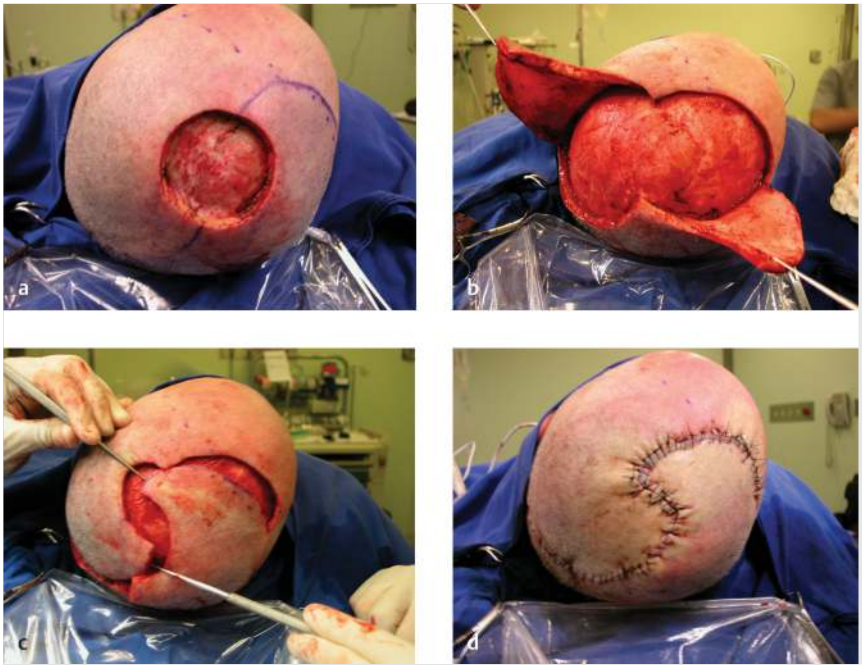

Fig. 11.13 Note the large scalp defect extending to the underlying pericranium. The opposing rotational advancement flaps are marked **(a)** after excision. These flaps are then incised and **(b)** widely undermined to allow **(c)** adequate advancement into the defect. **(d)** This is then closed in the usual layered fashion.

Fig. 11.14 **(a)** The note flap incision is designed with care taken to keep the final scar within or parallel to relaxed skin tension lines. **(b)** Adjacent inferolateral skin is advanced into the defect **(c)** without distortion of aesthetic subunits.

Fig. 11.15 **(a)** Bilobed flap design adjacent to a nasal defect involving multiple nasal subunits **(b, c)** followed by final closure and final aesthetic result.

trimmed. Any remaining dog-ear is marked with a hook placed at the apex of the dog-ear. Care is taken to always cut away from the flap so as to not interfere with blood supply (▶ Fig. 11.14).

11.3.10 Bilobed Flap

The bilobed flap is particularly useful to reconstruct facial defects and specifically lesions near or involving the nasal subunits. The first flap which is approximately three quarters to full diameter of the lesion is marked to be removed and a second flap is designed, which is approximately a half to three-fourths of the diameter of the lesion. The subsequent angles are approximately 45 to 50 degrees along the long axis flap.

The first flap is more circular to match the area of the defect. The two flaps are rotated into position after wide undermining either with dissection with scissors or #15 blade. The excess at the tip of these flaps may be trimmed as needed to allow adequate insetting of the flaps. The donor site from the second flap is then closed linearly (▶ Fig. 11.15).

11.3.11 Rhomboid Flap

The rhomboid flap is composed of limbs of equal length and the angles are 60 and 120 degrees. First, the lesion is excised by utilizing a #15 blade. Notice the other limbs of the flap are of the same length as the parallelogram of the rhomboid flap with angles of 120 and 60 degrees. Again, a #15 blade or the dissection scissors are used to widely undermine tissue to minimize any unnecessary tension. Once the flap and adjacent tissues are widely undermined, the flap is rotated into the defect. The first sutures are placed at all apices of the flap as these tend to be the points of maximal tension (▶ Fig. 11.16).

11.3.12 Paramedian Forehead Flap

The paramedian forehead flap, based on the supratrochlear artery, is particularly useful for reconstruction of large (greater than 1.5 cm) defects of the nose, or defects that involve reconstruction of multiple nasal subunits. Prior to reconstruction, it is essential to ensure all surgical margins are clear of microscopic disease. They may then be scheduled for staged reconstruction.

Upon evaluation in the operative suite, the flap is designed with the assistance of a Doppler probe to center the flap on the supratrochlear artery. The vertical axis of the supratrochlear artery is most frequently located approximately 2.0 cm lateral to the midline at the location of the medial border of the eyebrow. A minimum of 1.5 cm wide pedicle is designed to ensure venous outflow.

A template for flap harvest is outlined based on the three-dimensional defect using sterile paper or suture packaging/foil trimmed to the appropriate size. If more than 50% of a given nasal subunit is lost, the remaining aspect of the subunit should be resected and reconstructed to optimize aesthetic outcomes. If the defect involves loss of cartilage, then it is first reconstructed

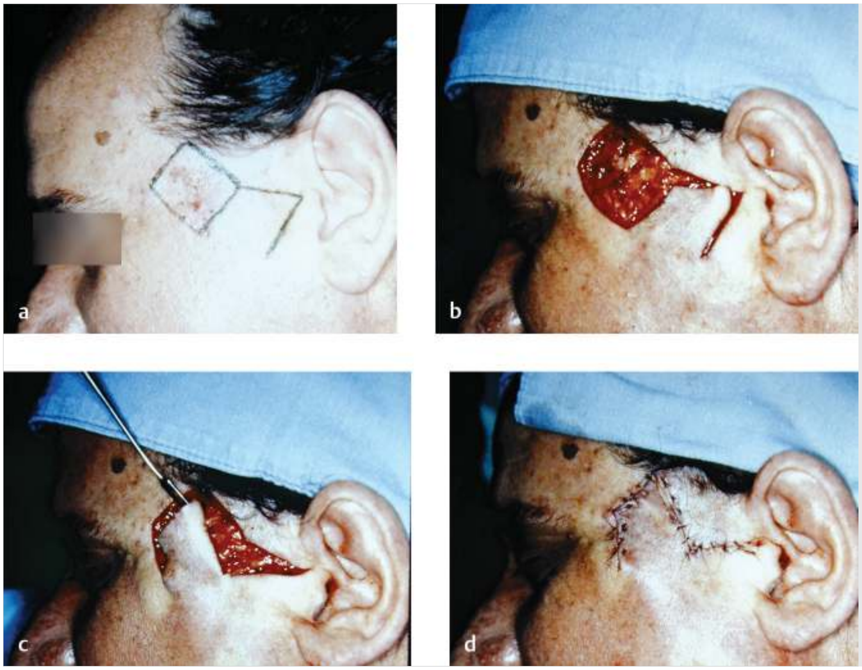

Fig. 11.16 **(a)** The rhomboid flap is drawn to match the size of the proposed surgical excision. **(b)** After excision of the lesion and wide undermining of the surrounding tissues, **(c)** the flap may be transposed into the defect. **(d)** This is then closed in layered fashion.

prior to creation of the template. The template is then superposed to the most superior aspect of the flap based on the desired pedicle length.

The flap is then elevated from superior to inferior in the subfascial plane and above the periosteum until the corrugators are reached. The muscle is then dissected away from the underlying periosteum bluntly and the pedicle is mobilized away from the bony orbit. During elevation, the pedicle is evaluated by Doppler multiple times within the flap noting persistent Doppler pulse. The flap is then tacked into the nasal defect to ensure proper folding of the flap. The donor site is then closed with wide local undermining in the submuscular aponeurotic plane. The tissue is then closed using deep interrupted 2–0 absorbable sutures and a running 5–0 nylon.

Next, the insetting of the flap is begun. This proceeds with the previously dissected nasal mucosa lining on the dorsal septal region with flap inset using a running 4–0 Chromic from the start of the nasal bone to the nasal tip. Next, the nasal dorsum region is sutured with interrupted 5–0 nylon in a horizontal mattress fashion followed by the lateral nasal sidewall in a similar fashion. The flap is then thinned distally to allow better folding and proper inset of the reconstructed nasal tip. The folded flap is then inset into the surrounding tissue to create the nasal mucosal lining of the nasal sill and external nasal valve. Nasal packing may be placed with Xeroform gauze in addition to Xeroform placed beneath the forehead flap in the area of exposed tissue.

After assessing for adequate revascularization in subsequent postoperative visits (temporarily occluding the pedicle with a vascular clamp), the next stage of the operation may be scheduled to complete the pedicle division and inset of the flap in approximately 2 to 3 weeks.

Upon return to the operating room, the flap pedicle is incised along the scar of its base, and the most proximal third is generally resected and discarded. The flap is then inset with the potential for minor revisions to be addressed at this stage (▶ Fig. 11.17).

11.3.13 Nasolabial (Melolabial) Flap

Tissue adjacent to the nasolabial fold may also be utilized to reconstruct small to medium size defects. Both V-Y advancement and superiorly based rotational flaps from this region may be used routinely for nasal reconstruction with minimal scarring, which is often well hidden and in line with the nasolabial fold.

The rotational nasolabial flap is designed to be rotated across the sidewall, ala, or dorsum based on the angular artery. After infiltration of the surgical sites with a local anesthetic, the edges of the nasal defect are excised to ensure healthy tissue. The flap is then incised along the proposed markings with a #15 blade scalpel and then elevated using Bovie cautery from inferior to superior, leaving an adequate base of soft tissue and dermis superiorly to support the flap.

The superiorly based flap is then transposed over onto the nasal ala and sidewall, and if needed, the very tip can be turned down to recreate the nasal mucosa. At the mucosal edge, the flap is tacked into place with 4–0 Chromic or other resorbable horizontal mattress sutures. Then using 4–0 Vicryl in an interrupted fashion, the flap is inset. The remaining flap is then inset typically with a nonreactive permanent suture such as 6–0 nylon or prolene in a vertical or horizontal mattress pattern to ensure wound edge eversion. The donor site at the nasolabial fold is then closed as per surgeon's preference but usually by layers (▶ Fig. 11.18).

11.4 Conclusion

- Cutaneous malignancies comprise more than 50% of all new cancer diagnoses in the United States and are strongly linked

Fig. 11.17 (a, b) Nasolabial flap for reconstruction of a large nasal defect involving multiple anatomic subunits. **(c–g)** The staged reconstruction and results in a well-camouflaged flap, which matches the surrounding skin quality and texture.

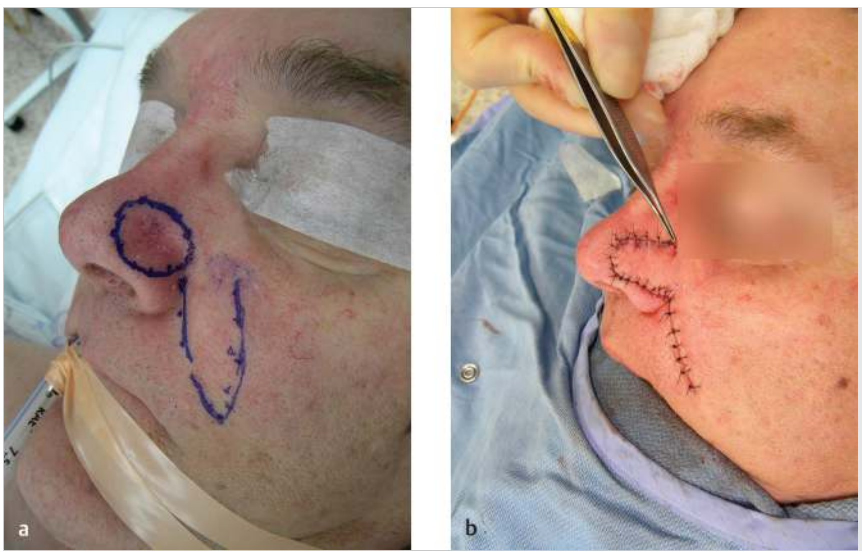

Fig. 11.18 (a, b) Example of a nasolabial flap for closure of a nasal defect. This is designed to ensure the final scar is hidden within the nasolabial fold.

to UV light exposure and, increasingly, artificial tanning beds.

- Proper management is first dependent on acute diagnosis through sound surgical and biopsy principles.
- Curative resection is most commonly achieved through adherence to well-established surgical margins based on specific tumor biology and growth patterns.
- Reconstruction of the resulting defect begins with proper surgical planning, supplemented by the reconstructive ladder and an armamentarium of local flaps.

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12 Reconstruction after Neoplasm Resection with Regional Flaps

Rachel Georgopoulos, Christopher Edward Fundakowski, and Sameer A. Patel

Abstract
Repair of defects created following an extirpative surgery can be a challenging endeavor. This is particularly true when repairing defects of the head and neck where anatomy is complicated and maintenance of not only cosmetic, but also functional integrity is essential. Regional flaps serve as an important option to have in the armamentarium when designing a treatment plan for these patients. This chapter will outline three of the workhorse regional flaps used in head and neck reconstruction, namely, the submental flap, pectoralis flap, and supraclavicular artery island flap.

Keywords: flaps, pectoralis, regional, submental, supraclavicular

12.1 Introduction

12.1.1 Submental Flap

Originally described by Martin and colleagues in 1993.[1]

Flap Composition

- Fasciocutaneous.
- Myocutaneous.
- Osteomyocutaneous.

Anatomy

Artery: Submental Artery

- Branches off the facial artery anterior and superficial to the submandibular gland.
- A third of the time the artery may run between the submandibular gland and inferior boarder of the mandible.[2]
- 5 to 6 cm in length, 1 to 1.7 mm diameter.
- It is deep to the anterior digastric muscle 70 to 80% of the time.[2,3]
- The submental artery anastomoses with the contralateral submental artery 90% of the time.[2]

Skin Paddle

- Submental artery supplies up to 10 × 16 cm of the skin in the midline neck.[3]

Skin Perforators

- Skin perforators may be variable:
  - Two major:
    - Proximal to digastric muscle.
    - Distal to digastric muscle.
  - Minor:
    - Come through the anterior belly of the digastric muscle.[3]

It is therefore common to harvest the ipsilateral anterior belly of the digastric in continuity with the flap to maximize perforators.

Vein: Submental Vein

- Tributary of the facial vein that has 2.2 to 3.2 mm diameter.[3]

Marginal Mandibular Nerve

Courses within the superficial layer of the deep cervical fascia over the submandibular gland.

12.1.2 Pectoralis Flap

- Originally described by Ariyan in 1979.[4,5]
- Most commonly used myofascial or myocutaneous flap in the head and neck surgery.
- Does not cause significant functional disability or donor site morbidity.
- Often used in salvage reconstruction of the head and neck after failed microvascular free tissue transfer, in patients medically unsuitable for free tissue transfer, or in vessel depleted necks.

Flap Composition

- Muscle.
- Myocutaneous.
- Osteocutaneous free flap (harvest fifth rib).

Anatomy

- Muscle: Pectoralis major muscle.

Attachments

- Cephalad (clavicular)—attaches to the medial one-third of the clavicle.
- Central (sternal)—arises from the sternum and the first six ribs.
- Caudal (abdominal)—arises from the aponeurosis of the external oblique muscle.
- Lateral—attaches to the greater tubercle of the humerus and forms an axillary fold.

Artery

- Pectoral branches of the thoracoacromial artery, which enters the undersurface of the pectoralis major muscle at about the midpoint of the clavicle.[6]
- Lateral thoracic artery enters the pectoralis major muscle laterally and is often sacrificed during harvest to maximize arc of rotation of the flap.
- Superior thoracic artery.
- Intercostal artery.

Skin Paddle

- Skin perforators:
  - Thoracoacromial system.
  - Medial skin:
    - From the internal mammary artery especially those arising from rib interspaces two, three, and four with perforators from three and four playing a particularly prominent role.

Nerve

- Lateral (C5–C7) and medial (C8–T1) pectoral nerves.

12.1.3 Supraclavicular Flap

Flap Composition

Fasciocutaneous Flap

- Artery.
  - The supraclavicular artery is superficial to the deltoid muscle and it consistently branches from the transverse cervical artery. It courses parallel to the clavicle and then gives off an anterior perforator, which crosses the clavicle and travels toward the clavipectoral groove, and an additional perforator toward the acromion tip.[7]
  - It is 1 to 1.5 mm in diameter and allows creation of a 3 to 4 cm pedicle.[8,9]
  - The artery is located in a triangle created by sternocleidomastoid muscle medially, the external jugular vein posteriorly, and the clavicle anteriorly.
  - The artery is 3 cm above the clavicle, 2 cm from the sternocleidomastoid muscle, and 7 to 8 cm from the sternoclavicular junction.
- Vein: Two Venae Comitantes:
  - Drains into the transverse cervical vein.
  - Drains into the external jugular or subclavian.[8]
- Supraclavicular Sensory Nerve:
  - Three to five branches supplying skin of the shoulder.
  - Superficial cutaneous branches of the cervical plexus derived from C3–C4.

Skin Paddle

Supraclavicular region to the rotator cuff, approximately 4 to 10 cm wide by 20 to 40 cm long.[7,9,10,11]

12.2 Indications

12.2.1 Submental Flap

Indications for the submental flap include several anatomic and soft tissue defects after ablative procedures[12]:

- Soft tissue defects of the face.
- Oral cavity defects:
  - Tongue.
  - Floor of mouth.
  - Palate.
  - Lip.
  - Buccal mucosa.
  - Mandible.
- Repair of cervical esophagus.
- Repair of laryngectomy defects.
- Repair of pharyngocutaneous fistulas.
- Coverage of hardware used in spine surgery.

Contraindications

- Metastatic cervical lymphadenopathy at level Ia.
- Medical comorbidities that preclude surgical intervention.
- Trauma/burns that would preclude closure of the donor site.

12.2.2 Pectoralis Flap

- Oral cavity/oropharynx:
  - Tongue, floor of mouth, retromolar trigone, palate.
- Face:
  - Cheek and orbit, mastoid, chin, central face, auriculectomy defect.
- Pharynx/esophagus/trachea.

Contraindications

- Poland's syndrome—congenital absence of the pectoralis muscle.
- Significant chest wall trauma/surgery/burns.
- Morbidly obese—relative contraindication.

12.2.3 Supraclavicular Flap

- Chest wall defect.
- Temporal/auricular defects.
- Oral cavity defects.
- Pharyngeal defects.
- Posterior lateral skull base defects.
- Parotidectomy defects.
- Anterior/lateral neck skin defects.

Contraindications

- Medical comorbidity that precludes surgery.
- Previous modified radial neck dissection.

12.3 Operative Technique

12.3.1 Submental Flap

The patient is placed in the supine position with the head in a donut head pad turned to the contralateral side with the neck extended. After the conclusion of the extirpative surgery, the defect is measured so as to plan the size and thickness of the skin paddle necessary to repair the defect. In the event that a neck dissection is planned for management of the patient's neoplastic process, the incision is designed to allow for adequate visualization during the neck dissection and elevation of a crescent-shaped submental skin flap (▶ Fig. 12.1). It is important to remember that the anterior/posterior dimensions of the flap are limited by the available skin laxity that can be used to close the donor site primarily. The desired anteroposterior dimensions of the flap are determined by employing a skin

Fig. 12.1 Preoperative design of a submental flap.

pinch test. The skin is pinched to ensure that there is enough laxity to close the donor defect.

Next, a Doppler ultrasound is used to identify the perforator. This is important to ensure that the perforator is not excluded when elevating the skin flap. It is usually identified inferior to the lower border of the mandible, near the anterior aspect of the submandibular gland.[12]

The dissection of the lateral neck portion is made first, through the platysma, and subplatysmal flaps are raised until reaching the inferior border of the mandible and the submandibular gland is identified. The facial vein is often encountered superficial to the posterior belly of the digastric muscle and should be preserved. At this point the submandibular gland is often easily visualized. The superficial layer of the deep cervical fascia is elevated off the gland with an inferiorly based incision and blunt dissection is used in order to protect the marginal mandibular branch of the facial nerve, which lies within this fascia. Removal of the submandibular gland greatly facilitates ease of pedicle dissection and exposure. The facial artery will be located approximately 2.5 cm from the mandibular angle in close proximity to the submandibular gland.[2] The submental pedicle will be identified at this point in time at the superior aspect of the gland, approximately 5 mm from the mandibular border.[2] Of note, the submental artery supplies branches to the lower lip, the mylohyoid muscle, the digastric and mandibular periosteum, platysma, and submental skin. Any perifacial adenopathy can be dissected at this point and marginal nerve preserved.

Next, the contralateral incisions are made, carried through platysma, and the flap is elevated to the midline in a subplatysmal plane. At this point the superior ipsilateral incisions can be made, again through the platysma. As the dissection is carried out ipsilaterally, be mindful of the facial vessels as they cross the inferior border of the mandible. Next, the ipsilateral dissection can take place by transecting the superior attachment of the ipsilateral anterior belly off the mandible, and the inferior attachment off the hyoid. Remember that in the majority of cases the submental artery will be found deep to the anterior digastric, and perforators can be identified both medial and lateral to this muscle. Level Ia is then split in the midline or just medial to the ipsilateral anterior belly of the digastric until the mylohyoid is identified. The mylohyoid can also be included in the flap to increase thickness and/or provide an extra layer of protection for the submental vascular pedicle. In these instances, the mylohyoid is split in the midline and the flap is elevated off the ipsilateral geniohyoid muscle in an areolar plane. If the mylohyoid is not harvested, an areolar plane also exists between the digastric and mylohyoid. Once this plane is elevated, the flap will be free and only attached by the pedicle.

If pedicle elongation is required to reach the desired defect, the facial vessels can be divided distal to the origin of the submental artery. This provides an additional 1 to 2 cm of pedicle length.[13] Furthermore, Multinu et al described a V-Y procedure where the communicating branch between the facial and external jugular veins was isolated and the trunk of the facial vein was divided just proximal to the communicating branch.[14] This allows for an additional 5 cm of pedicle length. For lateral face/parotid defects, additional length can be obtained by hybridizing the flap and anastomosing the posterior facial vein to the external jugular vein, as the vein is commonly the limiting factor in reaching and rotating posteriorly.

In cases where this flap is used to repair intraoral defects, a tunnel is made through the floor of the mouth. The flap is tunneled through the floor of the mouth, being mindful not to twist the pedicle (▶ Fig. 12.2). The flap is inset and a Doppler is again used to confirm a strong vascular signal. The donor site platysma is closed primarily with 3–0 Vicryl and subcutaneous and cutaneous layers as per surgeon's preference.

12.3.2 Pectoralis Flap

The patient is placed in the supine position with the head in a donut head pad. After the conclusion of the extirpative surgery, the defect is measured so as to know the size of the flap necessary to repair the defect (and required components—myocutaneous vs. myofascial) (▶ Fig. 12.3 and ▶ Fig. 12.4). In addition, measure the distance from the distal-most defect to the lower edge of the clavicle with an unrolled gauze sponge in order to approximate the landmarks for the inferior flap incisions, and to ensure that the pedicle will rotate into the defect with minimal tension. A line is drawn from the xiphoid process to the acromion, followed by a perpendicular line, which crosses at the mid-clavicle (this line will serve as a landmark for the thoracoacromial artery, which runs deep to the pectoralis major muscle in the pectoral fascia). Various flap designs can be undertaken depending on the size of the defect, reach required, chest wall thickness, and extent of breast tissue, while keeping in mind the perforators for a deltopectoral flap, should this be needed.[6]

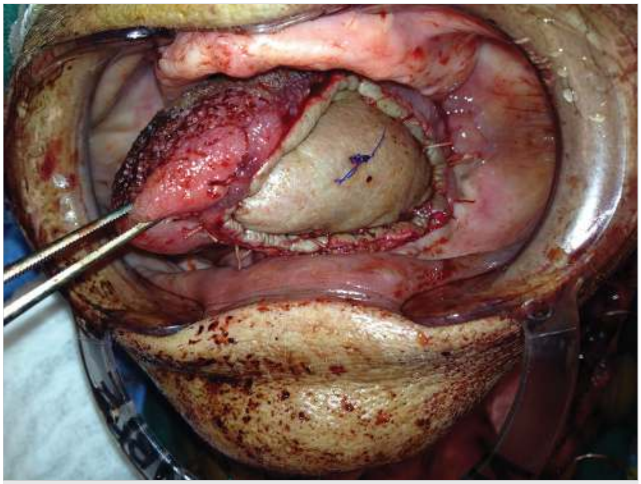

Fig. 12.2 Inset of the submental flap.

Fig. 12.3 Preoperative photo of a patient with a squamous cell carcinoma of the skin with cervical metastasis.

Skin incision is made with a scalp through the skin and subcutaneous tissue down to the pectoralis fascia (▶ Fig. 12.5). When elevating the skin paddle care must be taken so as to not

Fig. 12.4 Preoperative design for a pectoralis major flap.

undercut or shear the skin island from the muscle in order to preserve skin perforators from the underlying muscle.

The superior skin is then elevated in a suprafascial plane over the clavicle until the operative field of the neck is reached. The lateral skin is then also elevated in a suprafacial plane until the lateral border of the pectoralis major is identified and the plane between the pectoralis major and minor is identified.

Next, the inferior cuts are made through the muscle (or rectus fascia if needed) and a submuscular plane of dissection is maintained. The pectoralis minor will be identified during the course of dissection. This can be taken further using blunt dissection to the level of the clavicle.[6] Intercostal perforators are encountered and should be clipped to prevent intrathoracic bleeding.[6] The pectoral branch of the thoracoacromial artery will be seen on the undersurface of the pectoralis muscle. The muscle is then released from its medial sternal attachments superiorly until the clavicle is encountered. Internal mammary perforators will be identified medially, and they should be preserved for possible future deltopectoral flap use. The humeral head of the muscle should then be divided. At this point the lateral vascular pedicle along with the lateral and medial pectoral nerves are sacrificed to allow for a greater arc of rotation for the flap. The lateral pedicle is not required for flap viability. In addition, sacrifice of the pectoral nerves leads to muscle atrophy, which is advantageous when filling in defects of the head and neck where low profile flaps are preferable. It is of additional importance to

Fig. 12.5 Elevation of the skin paddle over the pectoralis major muscle.

identify and divide the nerve traveling immediately adjacent to the vascular pedicle as it can cause compression (piano-wire effect) of the vessels as the flap is rotated and inset.

After the flap is elevated a tunnel in the subcutaneous plane is created to allow the flap to be passed through the neck. The tunnel under the clavicular skin needs to be large enough to accommodate the flap and it is therefore recommended that at least 3 to 4 finger breaths of space be created to ensure that the vascular pedicle is not compressed.[6] The flap is passed through the subcutaneous tunnel keeping in mind to minimize kinking and torqueing of the vascular pedicle. Once the flap is sutured in place, drains are placed at the donor site. The donor site is then closed primarily with interrupted 3–0 Vicryl and skin is closed with staples or nylon (▶ Fig. 12.6). Occasionally, a skin graft is required to repair the skin paddle of the donor site.

Complications

In a recent retrospective study, You et al evaluated outcomes of 120 cases of patients who underwent pectoralis major flap reconstruction for head and neck defects in male sex with albumin levels < 3.8; defects of the hypopharynx correlated with increased occurrence of postoperative complications:[15]

- Low total failure rates (1.5–4.1%).[16]
- Necrosis uncommon.
- Local wound infection.
- Hematoma.
- Fistula formation.

Fig. 12.6 Closure of pectoralis major flap after inset.

Fig. 12.7 Preoperative design of the supraclavicular artery island flap.

12.3.3 Supraclavicular Flap

A Doppler ultrasound is used to identify the supraclavicular artery. The patient is in the supine position with the neck extended and the head turned opposite to the side of the flap (▶ Fig. 12.7). The supraclavicular artery is identified within the

Fig. 12.8 Elevation of the skin paddle over the deltoid.

Fig. 12.9 Elevation of the supraclavicular artery island flap.

triangle created by the sternocleidomastoid, clavicle, and external jugular vein. The defect is measured to plan the size of the flap. The flap is defined by the trapezius muscle posteriorly and a parallel line along the deltoid muscle anteriorly.[8] The skin, subcutaneous tissue, and fascia are incised over the deltoid (▶ Fig. 12.8). When the flap is harvested in island fashion, the medial incision and flaps are elevated in a subdermal plane as this will increase the amount of soft tissue surrounding the pedicle and eliminate the need for later de-epithelization of the flap. Dissection continues to the subfascial plane over the deltoid and the flap is harvested from distal to proximal up to the supraclavicular fossa. Over the medial clavicle the flap is dissected from the bone in a subperiosteal plane and the periosteum is again excised on the posterior edge of the clavicle to further free the pedicle. Exercise caution when dissecting the periosteum medially as this is where the supraclavicular artery branches off the transverse cervical artery. The trapezius muscle fibers are carefully dissected from the flap. Establishing a plane between the flap and the trapezius muscle defines the previously mentioned triangle around the origin of the supraclavicular artery. Medially, the flap is elevated in a subplatsymal plane (▶ Fig. 12.9). It is important to keep in mind that the supraclavicular artery runs in a more superficial plane more proximally and in some instances can be just below the platysma. At this point in the case it is advisable to have no or minimal anesthetic paralysis as the spinal accessory nerve is at risk. Cutaneous sensory nerves from the cervical plexus innervate the skin of the flap and when possible should be preserved. The nerves are identified posteriorly, running deep to the platysma.[7] In some instances, these need to be sacrificed in order to improve the arc of rotation of the flap. To improve arc of rotation, the transverse cervical artery can be transected after its division into a supraclavicular cutaneous branch. This releases the pedicle and increases the arc of rotation. The flap is tunneled under the skin of the neck to reach the defect to be repaired. Care should be taken to ensure that there is minimal torsion on the pedicle. The flap is inset and sutured in place. The donor site is closed over a suction drain with a combination of 2–0 and 3–0 deep Vicryl sutures and the skin is closed with staples. If a large flap is harvested it may be necessary to get a skin graft to assist with repair of the donor site (▶ Fig. 12.10).

12.4 Conclusion

12.4.1 Submental Flap

The submental flap is a versatile flap with many potential applications in head and neck surgery. The flap requires careful attention to anatomic detail. Many of the pearls described above can help facilitate reconstruction of these various defects while reducing the morbidity of more extensive surgeries such as free tissue transfers.

Fig. 12.10 Inset and closure of the supraclavicular artery island flap.

12.4.2 Pectoralis Flap

The pectoralis flap is a versatile flap with several indications in head and neck reconstruction. The flap can be elevated with muscle only or with a skin paddle. The anatomy of the flap is relatively straightforward and consistent and complications rates are low.

12.4.3 Supraclavicular Flap

The supraclavicular flap can be harvested as a pedicled flap or a free flap. It provides soft, pliable soft tissue for various defects around the head and neck region to help facilitate functional as well as aesthetic reconstructions. Careful dissections are required to avoid risk of spinal accessory nerve injury and chyle leak.

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13 Reconstruction after Head and Neck Neoplasm Resection with Free Flaps

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Abstract
Reconstruction after head and neck neoplasm resection with free flaps has become the standard of care following the advent of microvascular surgery. Though technically more challenging, free tissue transfer has eliminated many of the problems associated with the use of pedicled flaps and is now the reconstructive method of choice for large composite defects of the head and neck. In this chapter, we review the general approach and principles of free flap reconstruction of such defects. We also summarize the three most useful free flaps for head and neck reconstruction—the anterolateral thigh, radial forearm, and fibula flaps—highlighting safety issues and technical pearls.

Keywords: anterolateral thigh flap, fibula flap, free flap, head and neck, radial forearm flap, reconstruction

13.1 Introduction

Reconstruction of head and neck defects resulting from tumor resection poses unique challenges. Defects are often complex with multicomponent tissue loss and possible exposure of vital structures. Loss of the intraoral seal and subsequent salivary leakage may result in life-threatening complications such as blowout of the great vessels of the neck. Immediate reconstruction is critical to minimize complications and achieve the following primary goals:

- Restore integrity of the intraoral seal and alimentary tract.
- Restore anatomy of the face and neck.
- Preserve function, in particular swallowing, speech, mastication, and facial expression.
- Restore appearance and optimize aesthetic outcomes.

In the head and neck region, free tissue transfer has become the gold standard for reconstruction of large composite defects involving skin, soft tissue, and bone. Large volumes of new robust tissue can be transferred and contoured to match defect requirements in a single-stage procedure. These tissues have improved vascularity and thus have better wound healing and increased resistance to radiation therapy compared to nonvascularized grafts or implants. A two-team approach is also permissible as flaps can often be harvested from a remote donor site. Regional flaps, although technically simpler and safer to perform in the critically ill or less surgically fit patient, are less versatile in terms of providing volume and variety of tissue for like-for-like reconstruction.

In this chapter, we will first summarize our approach to free tissue transfer for reconstruction of head and neck defects following tumor extirpation. We will then describe the three workhorse free flaps most commonly used in our practice that have enabled us to reconstruct virtually any type of defect in the head and neck region—the anterolateral thigh (ALT), radial forearm, and fibula flaps.

13.1.1 Approach to Free Tissue Transfer in the Head and Neck Region

The reconstructive approach begins with evaluation of the defect and tumor specimen once tumor resection is complete. Areas of the wound that may be primarily closed are repaired to allow accurate assessment of the critical defect. Defect size and missing soft tissue components are noted.

Defects may be classified into six anatomical regions for reconstructive considerations: scalp, cutaneous, midfacial, mandibular, intraoral, and cranial.

Scalp and cutaneous defects are generally resurfaced with thin fasciocutaneous flaps for optimal contour. Midfacial defects may involve the orbit, nose, maxilla, and hard or soft palate. Reconstructive efforts must restore support of the orbit to prevent dystopia, recreate separation of the oral cavity from the nasal cavity, and obliterate dead space to maintain midface projection. Mandibular defects involving bone gaps of more than 6 cm are best reconstructed with vascularized bone flaps, which tolerate radiation and permit insertion of osseointegrated implants to allow mastication.[1] Intraoral defects comprise of defects of the tongue, floor of mouth, buccal mucosa, oropharynx, hypopharynx, and cervical esophagus. These defects require thin and pliable flaps due to space constraints and the need to maintain tongue mobility. Watertight closure is essential to avoid leakage of saliva and for preservation of speech and swallowing. For cranial defects involving the base of skull, the brain must be sealed off from the alimentary tract and dead space obliterated to prevent herniation of intracranial contents and leakage of cerebrospinal fluid. Other dural defects also require watertight fascial repair to prevent cerebrospinal fluid leakage and brain exposure.

The selection of recipient vessels is key to ensuring success of microsurgical free tissue transfer. It is preferable to utilize large healthy vessels away from a previously irradiated field. At least one artery and one vein are prepared by atraumatic dissection under loupe magnification. Sufficient vessel length must be mobilized to facilitate easy vessel positioning for microvascular anastomosis and to avoid tension on the pedicle throughout full range of neck motion. Vessel quality is confirmed by observing good pulsation of the artery and pulsatile flow from the artery or unobstructed flow from the vein upon division. The options for recipient vessels are numerous in the head and neck region. For the recipient artery, branches of the external carotid, such as the superior thyroid or facial arteries, are commonly used. In cases of prior neck irradiation, the superficial temporal and transverse cervical arteries are usually remote from the previous operative or irradiated field and provide ideal vessels for anastomosis. As a last resort, end-to-side anastomosis can be performed directly to the external carotid artery. For the recipient vein, the external jugular vein, branches of the internal jugular vein, or venae comitantes of the selected artery may be used. In cases where ipsilateral vessels are depleted, interpositional vein grafts allow utilization of contralateral neck vessels.

The flap is harvested under loupe magnification once the defect requirements are known. The radial forearm flap is used if the defect is small to medium in size, while the ALT flap is used for medium to large defects or defects with bulky three-dimensional tissue loss. The fibula flap is the flap of choice in cases where bone replacement is required. After the preparation of recipient vessels is complete, the flap is detached and transferred to the defect. Partial inset is performed, starting at the most inaccessible areas until only the superficial and easy-to-reach areas are left. This holds the flap in place preventing dislodgement during microvascular anastomosis and avoids inadvertent dehiscence of the anastomoses by excessive flap manipulation afterwards.

Before microvascular anastomosis, the vessel lie is checked to confirm the absence of tension or redundancy. The latter may lead to twisting, folding, or kinking of the pedicle with patient movement. Performing the arterial anastomosis first minimizes ischemia time and allows immediate evaluation of venous return for selection of the best flowing vein for venous anastomosis. One venous anastomosis is usually sufficient. However, in cases where the vein is small in relation to the artery or the flap appears congested after completion of the venous anastomosis, a second vein is anastomosed to improve outflow. It is important to remember that although skin and bone can tolerate up to 3 hours of ischemia, skeletal muscle is much less tolerant of prolonged ischemic periods.[2] Once flap color and bleeding are satisfactory, the lie of the pedicle may be "set" in position with fibrin glue or tagging sutures. Final flap shaping and inset is then performed. Drains are placed as necessary in dependent areas and wound closure completed.

Postoperatively, patients are nursed with the head in neutral position. Excessive turning of the head away from or toward the side of microvascular anastomosis in the neck may cause tension or kinking of the pedicle, respectively. Encircling ties or tapes around the neck are strictly avoided. Tracheostomy tubes are secured with sutures. Gentle head elevation to 30 degrees by inclining the bed assists with venous drainage and helps to reduce swelling. Flap monitoring is performed hourly for at least the first 24 hours and progressively deescalated over several days in the absence of worrying signs. Clinical evaluation of flap color, temperature, turgor, capillary refill time, cutaneous bleeding following pin-prick, and percutaneous Doppler assessment is sufficient. In our practice, anticoagulants such as unfractionated heparin are used only when anastomotic patency is at risk, such as when intraoperative thrombosis occurs or in flap salvage cases.

13.1.2 Anterolateral Thigh Flap

Since its introduction by Song et al in 1984,[3] the ALT flap has become one of the workhorse flaps in reconstructive surgery. It is most commonly supplied by perforators from the descending branch of the lateral circumflex femoral artery (LCFA), and also other sources such as the oblique branch of the LCFA.[4] Despite variability in anatomy, it has a dependable blood supply and can be reliably harvested in most patients. Other advantages include pedicle length, good vessel caliber, and the feasibility of a two-team approach with most defects in the body. Donor site morbidity is minimal compared to other common free flap options for head and neck reconstruction.

13.1.3 Radial Forearm Flap

Use of the radial forearm flap was first reported in China in the 1970s and subsequently described as a free flap by Yang et al in 1981.[5] Thus known as the "Chinese flap," it is one of the choice flaps for providing thin and pliable soft tissue coverage. The other advantages of the radial forearm flap include a long sizeable vascular pedicle, constant anatomy, reliable vascularity, and ease of flap harvest. The major drawbacks include sacrifice of one of the two principal forearm arteries and a conspicuous donor defect that requires skin grafting or local flaps for closure.

13.1.4 Fibula Flap

Initially used as a pedicled flap for tibial reconstruction, the fibula flap was first described as a free vascularized bone flap by Taylor et al in 1975.[6] Earlier difficulties with skin paddle survival were circumvented with improved understanding of perforator anatomy. It has since become one of the workhorse flaps for bony reconstruction of the head and neck. With a reliable blood supply, it can be modified to include skin, muscle, and fascia for reconstruction of composite three-dimensional defects. It provides an unrivalled length of solid vascularized bone with relatively low donor site morbidity.[7]

13.2 Indications

13.2.1 Anterolateral Thigh Flap

The ALT flap is extremely versatile, allowing incorporation of skin, fat, fascia, muscle, or nerve in various combinations depending on defect requirements. The flap may be raised as a subcutaneous, fasciocutaneous, adipofascial, or myocutaneous flap. Thin and pliable flaps are created by suprafascial harvest or by judicious thinning of deeper fat layers.[8] Extensive composite three-dimensional defects may be reconstructed with chimeric ALT flaps, with different soft tissue components raised based on separate perforators. Fascia lata can be included for reconstruction of oral commissure and dural defects. Myocutaneous flaps incorporating the vastus lateralis (VL) or rectus femoris (RF) muscles provide tissue bulk to obliterate dead space. Incorporation of the lateral femoral cutaneous nerve (LFCN) allows for a sensate flap while inclusion of the motor nerve to VL provides motor function to the myocutaneous flap.[9]

Common indications in head and neck reconstruction include:

- Scalp reconstruction.
- Cutaneous defects in the head and neck region (▶ Fig. 13.1).
- Full-thickness defects, e.g., through-and-through cheek defects:
  - Folded-over flap or chimeric flap.
- Intraoral reconstruction, e.g., tongue, floor of mouth, buccal mucosa.
- Large composite defects, e.g., maxillectomy, mandibulectomy:
  - Myocutaneous or chimeric flaps.
  - Combined with other flaps, e.g., free fibular flap.
- Pharyngoesophageal reconstruction:
  - Tubed flap.
- Skull base defects.

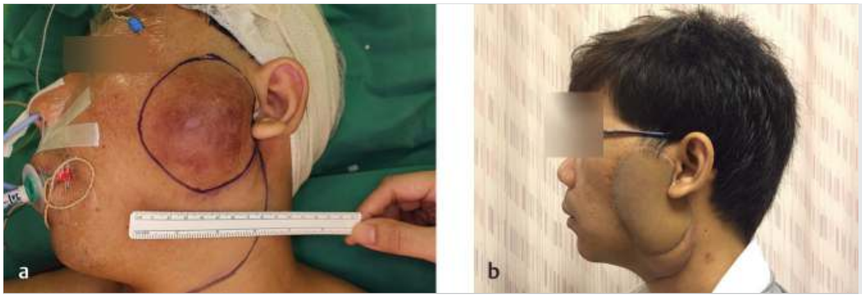


Fig. 13.1 Anterolateral thigh (ALT) flap reconstruction of a cheek defect following total parotidectomy with overlying soft tissue resection and preservation of facial nerve branches. (a) A 26-year-old man with a vascular malformation invading into the parotid gland. (b) Postoperative appearance 6 months after reconstruction with a fasciocutaneous ALT flap.

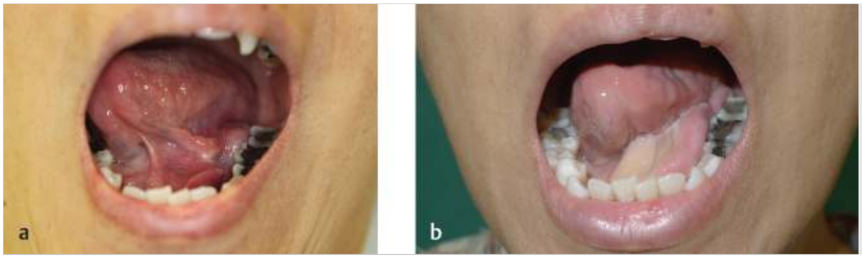


Fig. 13.2 A 42-year-old woman who presented with a left-sided floor of mouth squamous cell carcinoma. The resultant defect following tumor resection was reconstructed with a fasciocutaneous radial forearm flap. (a) Preoperative picture showing the floor of mouth tumor. (b) Postoperative appearance 6 months later showing a well-healed reconstruction.

13.2.2 Vascular Pedicle

The ALT flap is most commonly supplied by perforators arising from the descending branch of the LCFA. Usually, two venae comitantes accompany the artery within the pedicle.

- Mean arterial caliber: 2.0 to 2.5 mm.
- Mean venous caliber: 2.0 to 3.0 mm.
- Pedicle length: up to 15 cm.

13.2.3 Radial Forearm Flap

As a fasciocutaneous flap, the radial forearm flap provides thin pliable tissue with sufficient volume for resurfacing of small to medium size defects. A broad skin paddle can be harvested to allow flap tubularization. Inclusion of the medial or lateral antebrachial cutaneous nerves allows the flap to be sensate. Composite flaps incorporating palmaris longus tendon or a segment of distal radius are also possible. The extensive fascial vascular plexus allows harvest of thin adipofascial flaps without a skin component and also prelamination with mucosal grafts[10] or allotransplants[11] for heterotopic revascularization. The flap can also be used as a conduit flow-through flap to “piggy-back” a second free flap in complex facial reconstruction.[12]

Indications in head and neck reconstruction include:

- Cutaneous defects in the head and neck region.
- Mucosal reconstruction, e.g., intraoral and oropharyngeal defects (▶ Fig. 13.2).
- Mandibular reconstruction:
  - Osteofasciocutaneous composite flap with a segment of radius.
- Complex defects:
  - Prelaminated flap, e.g., nasal reconstruction, laryngotracheal reconstruction.
  - Combined with other free flaps.
- Pharyngoesophageal reconstruction:
  - Tubed flap.
- Facial augmentation:
  - Adipofascial flap.

13.2.4 Vascular Pedicle

The radial forearm flap is supplied by the radial artery. Venous drainage occurs by both superficial and deep systems. Superficial venous drainage occurs via the cephalic vein and other adjacent cutaneous veins. The deep system is based on the venae comitantes (usually two veins) of the radial artery.

- Mean arterial caliber: 1.5 to 2.0 mm.
- Mean venous caliber:
  - Venae comitantes: 1.0 to 1.5 mm.
  - Cephalic vein: 1.5 to 2.0 mm.
- Pedicle length: up to 20 cm.

13.2.5 Fibula Flap

The free fibula flap is primarily used for reconstruction of bony defects resulting from trauma, osteomyelitis, radiation-induced osteoradionecrosis, or tumor extirpation. Intraosseous and segmental blood supply of the fibula permits multiple osteotomies for contouring of this straight bone. The fibula has good bone stock, allowing insertion of osseointegrated implants for functional dental rehabilitation. However, only limited volumes of soft tissue can be transferred with this flap; thus other flaps may need to be used in combination with it for reconstruction of large composite defects.[12]

The main indications for use of this flap in head and neck reconstruction are:

- Mandibular reconstruction (▶ Fig. 13.3).
- Maxillary defects involving the alveolus or palate.

13.2.6 Vascular Pedicle

The fibula flap is supplied by the peroneal vessels. The peroneal artery is typically accompanied by two venae comitantes. If necessary, adjacent cutaneous veins may be used to augment venous drainage of the skin paddle.

- Mean arterial caliber: 1.5 to 2.5 mm.
- Mean venous caliber: 2.0 to 3.0 mm.

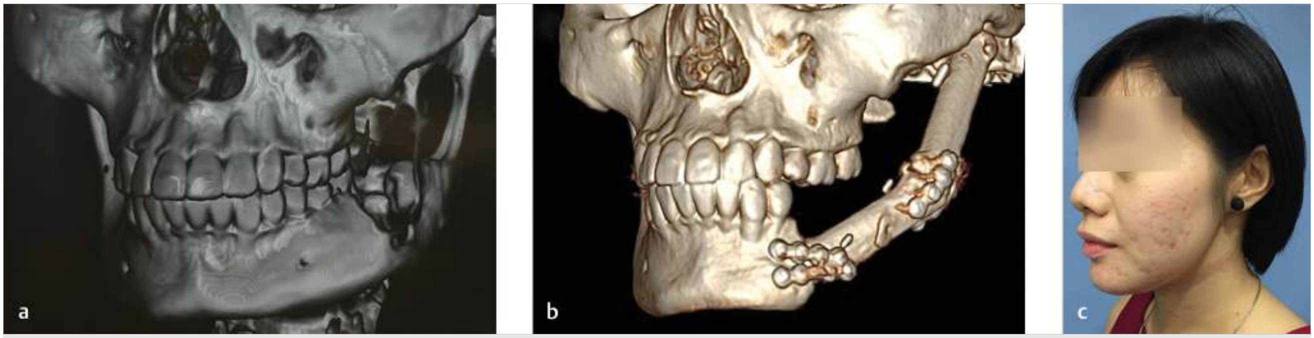


Fig. 13.3 Reconstruction of a segmental mandibular defect with a free fibula osteoseptocutaneous flap. **(a)** Preoperative computed tomography (CT) three-dimensional reconstructed image of a mandibular ameloblastoma in a 33-year-old woman. **(b)** Postoperative CT three-dimensional reconstructed image showing reconstruction of the mandibular body and angle defect with a vascularized fibula flap. **(c)** Postoperative appearance 6 months later showing good jaw contour and a well-healed scar in the neck.

- Pedicle length: Variable, depending on the length of vessels dissected beyond the bony segment harvested. This can be further increased by shortening unnecessary bone proximally.

13.3 Operative Technique

13.3.1 Anterolateral Thigh Flap

Preoperative Considerations

There are few contraindications to ALT flap harvest. Even in patients with multiple comorbidities including significant peripheral vascular disease (PVD), reconstruction with this flap has been shown to be safe without need for additional preoperative investigations.[13] In cases with previous trauma or surgery to the upper thigh, preoperative computed tomography (CT) angiography is advised to ensure that the circulation to the flap has not been disrupted. In obese patients, the resultant flap may be too bulky, although this can be reliably reduced with the suprafascial approach.

Patient Positioning

With the patient in supine position, the thigh is cleaned and draped circumferentially from the groin to the knee.

Flap Design and Markings

A straight line is drawn between the anterior superior iliac spine (ASIS) and the superolateral border of the patella (▶ Fig. 13.4). This approximates the location of the lateral intermuscular septum between the RF and VL muscles. It is within this septum that the descending branch of the LCFA lies together with its venae comitantes and nerve to the VL. The artery gives off multiple perforators that traverse the septum or the VL muscle to the skin. Majority of perforators are musculocutaneous (85%) rather than septocutaneous (15%).[4]

With a handheld Doppler, skin perforators are identified along this line. The most consistent perforator can be found within a 3 cm radius around the midpoint between the ASIS and the patella (the "B" perforator). Proximal and distal to this perforator, one or two more perforators may be identified, typically 5 cm proximal (the "A" perforator) or 5 cm distal (the "C" perforator) to the "B" perforator.[14] The "A" perforator tends to have a straight septocutaneous course, while the "B" and "C" perforators tend to run a tortuous musculocutaneous course.

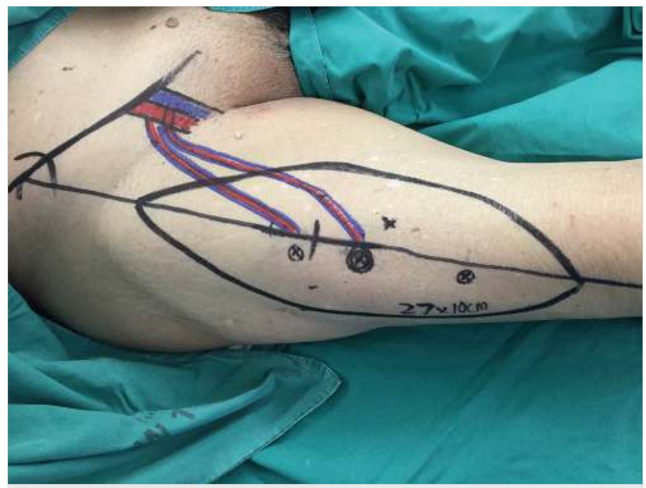


Fig. 13.4 Skin markings of the right anterolateral thigh flap. The line from the anterior superior iliac spine to the superolateral border of the patella marks the lateral intermuscular septum that separates the rectus femoris and vastus lateralis muscles. A circle with a 3-cm radius around the midpoint of this line marks the area with the highest density of skin perforators (the "B" perforator). Perforators found around 5 cm proximal and distal to this midpoint are known as the "A" and "C" perforators, respectively.

The skin paddle is then designed to incorporate the marked skin perforators. Flap dimensions are marked based on the size of the recipient defect. Although up to 35 cm by 25 cm of skin can be harvested based on a single dominant perforator, it is advisable to incorporate more than one perforator with larger flap designs to minimize ischemic complications.[15] The ability to close the donor defect is highly dependent on the patient's skin tone, quality, and body habitus. The pinch test is used to determine the width of the flap that permits primary closure. This is generally between 6 and 9 cm.[16] When larger flaps are required, single-stage options for donor site closure include skin grafting and local flaps.

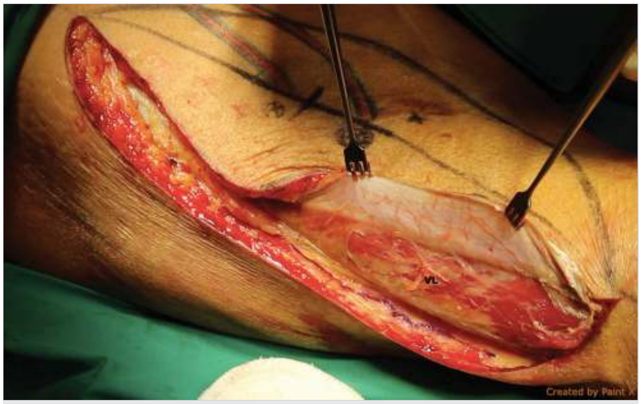


Fig. 13.5 Lateral approach to harvesting the anterolateral thigh flap. Subfascial dissection proceeds medially across the fascia lata and subsequently the vastus lateralis (VL) before the rectus femoris muscle is reached. The perforators first encountered will be the musculocutaneous vessels traversing the vastus lateralis.

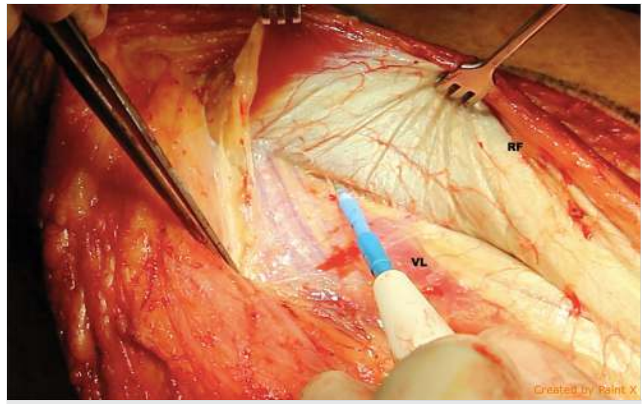


Fig. 13.7 Dissection through the intermuscular septum to identify the main vascular pedicle. The rectus femoris (RF) is retracted medially and the vastus lateralis (VL) dissected away to reveal the descending branch of the lateral circumflex femoral vessels (*blue arrow*). Proximal dissection of the pedicle to the source vessel will provide an additional 3 to 5 cm of pedicle length.

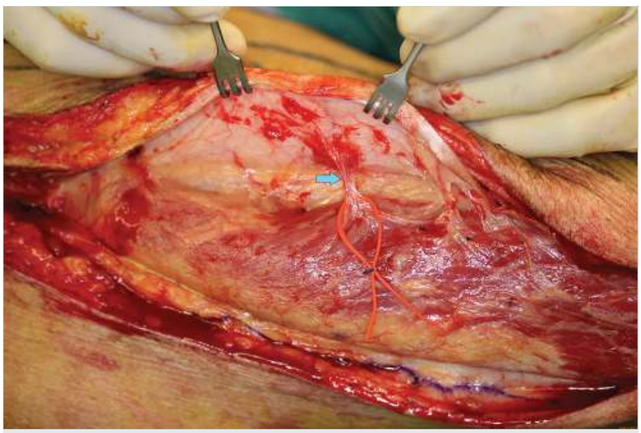


Fig. 13.6 Subfascial dissection with identification of musculocutaneous vessels perforating the vastus lateralis (VL) to supply the overlying skin paddle. A red vessel loop encircles the largest perforator (*blue arrow*), which corresponds to one of the Doppler-identified points on the skin paddle.

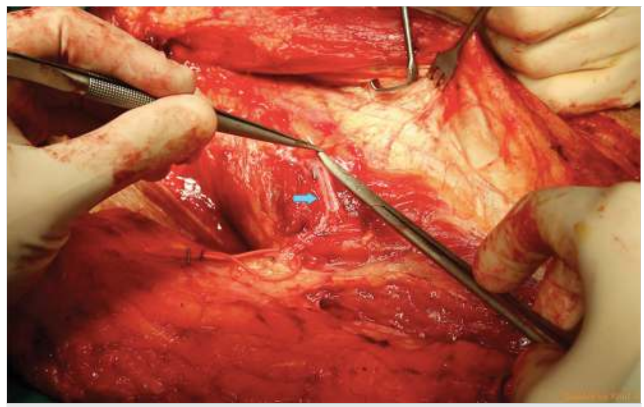


Fig. 13.8 Intramuscular perforator dissection. Meticulous intramuscular dissection of the intermuscular perforator (*blue arrow*) is key for safe harvest of the anterolateral thigh flap.

Video 13.1 ALT flap harvest

Flap Harvest

Flap elevation may first be approached medially or laterally. The objective of either approach is to isolate the perforators that supply the skin paddle. In ▶ Video 13.1, we describe the lateral approach, which allows early identification of perforators coursing through the VL muscle. These are perforators originate directly from the descending or oblique branch of the LCFA. With the medial approach, the first perforators encountered are those travelling through the RF muscle. These perforators typically arise from RF branches of the descending branch of the LCFA.

First, the lateral incision is made through the deep fascia. Subfascial dissection proceeds medially across the fascia lata toward the VL (▶ Fig. 13.5). Subfascial dissection proceeds medially until the Doppler-identified perforators are reached (▶ Fig. 13.6). The flap is then elevated from the medial margin until the flap is islanded on the chosen perforator.

Once the perforators are identified, they are traced to their source vessel. Identification of the lateral intermuscular septum helps to identify the RF muscle, which is then retracted medially to expose the descending or oblique branch of the LCFA (▶ Fig. 13.7). Septocutaneous perforators are relatively easily dissected away from their surrounding attachments as they traverse the septum. Musculocutaneous perforators traveling through VL require meticulous intramuscular dissection for mobilization (▶ Fig. 13.8). A suprafascial approach can be similarly performed by elevating the flap in the plane above the deep fascia.[17]

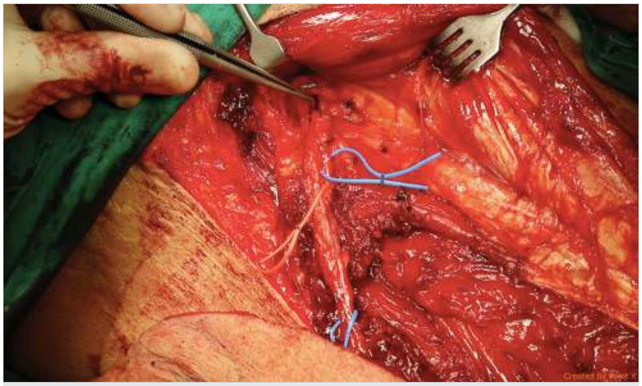


Fig. 13.9 Vascular pedicle of the anterolateral thigh flap. Completion of pedicle dissection here illustrates the added vessel length that can be obtained. The red vessel loop and forceps indicate the descending branch of the lateral circumflex femoral artery, which has been marked on its anterior surface. The blue vessel loops indicate the two venae comitantes.

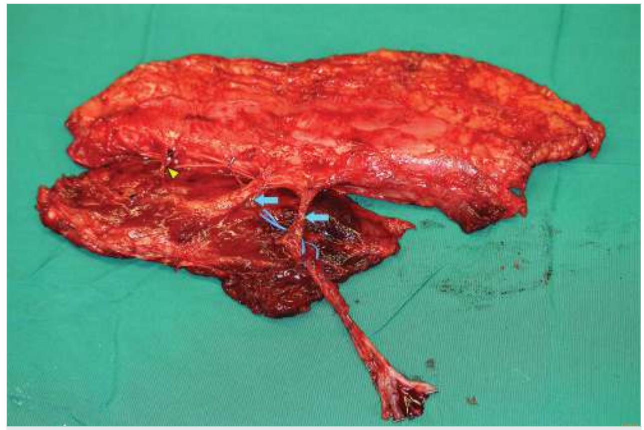


Fig. 13.10 The myocutaneous anterolateral thigh (ALT) flap. The ALT flap harvested here is supplied by two separate skin perforators (*blue arrows*). A separate perforator (*yellow triangle*) supplies part of the vastus lateralis (VL) muscle, which has been harvested to replace volume loss of the defect.

Following perforator mobilization, the descending branch of the LCFA is ligated distal to the perforator. The pedicle can then be dissected proximally to increase pedicle length by approximately 3 to 5 cm (▶ Fig. 13.9). As one approaches the inguinal ligament, branches to the RF muscle are seen arising from the descending branch of the LCFA. These provide the dominant blood supply to the RF muscle and should be preserved to avoid its necrosis and resultant weakness of knee flexion. This thus forms the upper limit of pedicle dissection.

A portion of VL muscle can be harvested to increase volume of the flap (▶ Fig. 13.10). The motor nerve to VL muscle is easily identified running alongside the main vascular pedicle and can be harvested with the VL to provide motor function for this myocutaneous flap.[9] Branches of the LFCN may be found over the anterior and lateral parts of the thigh and can be included when a sensate flap is required, e.g., for tongue reconstruction.

When the flap is ready to be transferred to the recipient defect, the vessels are mobilized circumferentially distal to the branch to RF. Before division, the anterior wall of the artery is marked with a skin marker for orientation to prevent twisting of the pedicle during inset (▶ Fig. 13.9).

Additional Tips

Strict attention is paid to avoid traction on the pedicle at all times. During harvest, the flap may be placed on a stack of towels to avoid the weight of the flap pulling on the pedicle. Excessive manipulation of the vessel during perforator dissection may lead to vasospasm and should thus be minimized. Vasospasm can be relieved with topical application of papaverine or lidocaine.

Although the deeper fat layers of the flap may be thinned to reduce bulk, this is risky as excessive defatting may compromise flap perfusion, particularly to the peripheral areas. It is our preference to perform flap debulking as a secondary procedure several months later.

Donor Site Closure

Closed suction drainage is not routinely required but may be placed in the septum between the VL and RF muscles if muscle was harvested. Cut muscle edges are repaired and the VL and RF muscles tagged together to recreate the intermuscular septum. The wound edges are undermined and layered closure performed if they can be approximated without excessive tension. Defects that cannot be closed primarily are skin grafted or covered with local flaps.

Postoperative Care

Patients are discouraged from weight-bearing on the donor limb for at least 5 postoperative days. Drains at the donor site are removed once output drops below 30 mL per day. If the donor site was skin grafted, bed rest is reinforced until the graft has been taken.

13.3.2 Radial Forearm Flap

Preoperative Considerations

The nondominant upper limb is typically chosen as the donor site. The Allen's test must be performed preoperatively to ensure adequate collateral supply to the hand via the ulnar artery following sacrifice of the radial artery. Previous trauma to the forearm and hand warrant CT angiography to confirm integrity of the forearm vessels to avoid risk of flap failure or donor site ischemia. X-rays are required if an osteofasciocutaneous flap is to be harvested to evaluate dimensions of the radius and to exclude pathology such as old fractures.

Patient Positioning

The patient is placed supine with the shoulder abducted at 90 degrees and supinated on a hand table. A sterile tourniquet is placed around the upper arm.

Flap Design and Markings

The following surface markings are made over the distal aspect of the forearm (▶ Fig. 13.11):

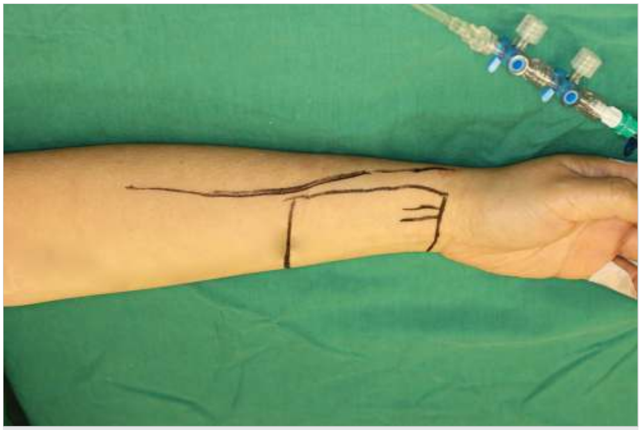


Fig. 13.11 Skin markings of the radial forearm flap. The radial artery (RA) is easily palpable at the wrist while the cephalic vein (CV) can be mapped out after occlusion of the upper arm with a tourniquet.

Video 13.2 Free radial forearm flap

- The radial artery, which is palpable just lateral to the flexor carpi radialis (FCR) tendon.
- The cephalic and/or other large superficial veins; inclusion of these veins is recommended with larger flap designs to augment venous drainage.
- The distal extent of the flap, at the most proximal wrist crease.
- The skin paddle, according to defect size requirements; centering the skin paddle over the radial aspect of the forearm allows inclusion of the cephalic vein for additional venous drainage but increases visibility of the donor wound.

Flaps up to 30 cm long and 15 cm wide may be safely raised.[15] A bridge of skin at least 3 cm wide should be left intact along the ulnar aspect of the forearm to preserve lymphatic drainage of the hand. This area of skin is also the most poorly supplied by the radial vessels.

Flap Harvest

For easier identification of structures, the flap is raised under tourniquet control. The cuff is inflated to approximately 150 mm Hg above systolic blood pressure. In practice, 250 mm Hg usually suffices. Partial exsanguination is first achieved by elevating the arm for 1 minute and wrapping it gently with a crepe bandage.

Dissection begins from the ulnar border of the flap ▶ Video 13.2. The skin incision is deepened through the subcutaneous fat. The flap is raised in the suprafascial plane toward the FCR tendon. The palmaris longus tendon is found lateral to the FCR tendon above the fascia, although it can be absent in a proportion of people (▶ Fig. 13.12). This may be included with the flap for reconstruction of eyelid and lip defects.

Fig. 13.12 Elevation of the radial forearm flap off the volar aspect of the distal forearm. The flap is dissected from the ulnar and radial borders in the suprafascial plane until the radial border of the flexor carpi radialis (FCR) tendon and ulnar border of the brachioradialis (BR) tendon is reached. The radial artery and its venae comitantes (RA) lie immediately beneath the deep fascia between the FCR and BR tendons. The vascular pedicle is elevated with the skin paddle in a distal-to-proximal direction. Here, the cephalic vein (CV) has been harvested to improve venous drainage of the flap. Branches of the superficial radial nerve (SRN) lie laterally in the subcutaneous plane above the fascia and are preserved where possible. The palmaris longus (PL) tendon that lies medial to the FCR tendon may be harvested for reconstruction of eyelid and lip defects.

The incision is completed around the flap until the deep fascia layer is reached. On the radial border of the flap, care must be taken not to injure the cephalic vein and superficial branches of the radial nerve, which are found in the subcutaneous plane (▶ Fig. 13.12). The flap is raised off the deep fascia until the brachioradialis (BR) muscle is reached. The cephalic vein may be harvested with the flap for additional venous drainage. The superficial radial nerve branches are preserved where possible to prevent sensory loss and painful neuromas. The lateral cutaneous nerve of the forearm also lies in the same plane and may be harvested for a sensate flap.

At the distal flap edge, the radial artery runs with its venae comitantes between the tendons of FCR and BR (▶ Fig. 13.12). The vascular pedicle is found just beneath the fascial layer and is enveloped in deep fascia. Once identified, the vessels are circumferentially mobilized and ligated. A traction suture may be placed to facilitate dissection of the pedicle off the deep layer of the deep fascia in a distal to proximal direction, also known as the "bottom-up" approach.[18] If only a fasciocutaneous flap is required, perforating branches to deeper structures such as the radius are ligated with hemoclips. The deep fascia is progressively incised along the radial border of the FCR and ulnar border of the BR as the pedicle is lifted off. Preservation of the deep fascia over these tendons prevents bow-stringing and facilitates donor site closure by skin grafting.

For an osteofasciocutaneous flap, a segment of radius can be harvested by preserving perforating branches to the bone.

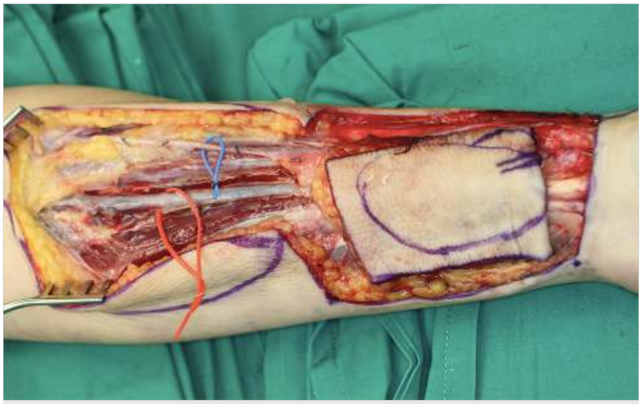


Fig. 13.13 Extension of the skin incision to allow proximal dissection for increased pedicle length. During dissection, the vascular pedicle (*red vessel loop*) lies within the intermuscular septum between the flexor carpi radialis and brachioradialis muscles. The cephalic vein (*blue vessel loop*) is found in the subcutaneous plane on the lateral aspect of the forearm.

Fig. 13.14 The radial forearm flap harvested with the cephalic vein (*asterisk*).

Wedge osteotomies are performed at the free edge of the radius between the insertion of pronator teres muscle to the radial styloid process. This removes a boat-shaped wedge of cortical bone with a wide periosteal attachment. Since the popularization of the free fibula flap, the radial forearm flap is rarely used to reconstruct bony defects as it provides a limited amount of bone with a risk of donor site fracture and functional impairment.

Proximally, the skin incision is extended to allow dissection of the pedicle as far as its bifurcation from the brachial artery (▶ Fig. 13.13). In the upper forearm, the pedicle travels within the lateral intermuscular septum between the FCR and BR muscles. Dissection is facilitated by retracting these muscles apart.

The tourniquet is released and hemostasis secured before the flap is divided and transferred to the recipient site (▶ Fig. 13.14).

Additional Tips

Complete exsanguination of the limb before tourniquet use is avoided as this makes smaller vessels more difficult to identify. Tourniquet time should not exceed 2 hours to minimize flap

Fig. 13.15 Coverage of the wrist donor defect with a full-thickness skin graft.

and forearm ischemia. Removal of more than 40% of the circumference of the radius should be avoided as this increases the risk of subsequent fracture.[19] In cases where excessive bone has been harvested, the remnant radius should be prophylactically plated before closure.

Donor Site Closure

A drain may be left in the forearm to minimize seroma or hematoma formation if dissection has been extensive. Depending on skin laxity, smaller defects of 2 to 3 cm may be closed directly. For larger defects, coverage is most easily achieved with a full-thickness skin graft from the groin area (▶ Fig. 13.15), which affords a better cosmetic and functional result than split-thickness grafts. Prior to grafting, the deep fascia is sutured to ensure complete coverage of the FCR and BR tendons. The use of artificial dermis further improves the cosmetic outcome while minimizing skin graft contracture and tethering of tendons but requires a two-stage approach with delayed skin grafting.[20] Alternatively, the defect may be closed with local flaps such as V-Y advancement flaps based on the ulnar artery perforators.[21] However, this is associated with increased rates of flap necrosis, chronic lymphedema, and further denervation of the remnant forearm skin.

Postoperative Care

In oropharyngoesophageal reconstruction cases, oral swallowing is withheld for at least 7 days to permit healing of the suture lines. Drains are removed once output drops below 30 mL per day. If skin grafting was performed, a below-elbow plaster cast is placed with the hand and wrist in intrinsic plus position until the graft is adherent. With primary closure, the wrist is casted in flexion for several days to avoid tension on the distal suture line. If bone was harvested, an above-elbow cast is required for at least 3 weeks. This can be reduced to a below-elbow cast or splint if radiography confirms the absence of a fracture.

13.3.3 Fibula Flap

Preoperative Considerations

Routine imaging to confirm patency of the peroneal vessels is not required. Clinical examination to confirm good pulsation of the dorsalis pedis and posterior tibial arteries is sufficient. However, donor limb vascularity may be questionable if distal pulses are impalpable or if there is a history of PVD or previous trauma to the lower limb. In these instances, preoperative evaluation with duplex ultrasonography or CT angiography is advised to confirm viability of the pedicle.

Patient Positioning

The patient is positioned supine with the knee flexed to 90 degrees. Placement of a wedge of sterile towels beneath the foot against the heel helps to maintain this position during flap elevation.

Flap Design and Markings

The outline of the fibula is marked on the calf (▶ Fig. 13.16). The marking of the posterior border of the fibula overlies the posterior crural intermuscular septum between the soleus and peroneus longus (PL) muscles. The septocutaneous perforators travel within this septum from the peroneal vessels to supply the overlying skin.

The proximal and distal 7 cm of the fibula are marked and excluded from harvest. Preservation of the proximal 7 cm preserves knee stability and prevents injury to the deep peroneal nerve that winds around the fibular neck. Preservation of the distal 7 cm maintains ankle joint stability.

The length of the fibula is divided equally into thirds. A handheld Doppler is used to locate arterial signals immediately posterior to the fibula margin over the distal and middle third segments, excluding the area overlying the distal 7 cm of bone. Centering the skin paddle over these distal perforators alone is sufficient for a reliable skin paddle of up to 8 by 25 cm.[22]

Flap Harvest

The flap is harvested with the tourniquet inflated to approximately 250 mm Hg above systolic blood pressure. In practice, 350 mm Hg usually suffices. Before this, the limb is partially exsanguinated by elevating the limb and gently wrapping it with a crepe bandage.

The anatomy of the mid-leg is shown in ▶ Fig. 13.17. Harvest of the fibula osteoseptocutaneous flap begins from the anterior border of the marked skin paddle ▶ Video 13.3. The skin

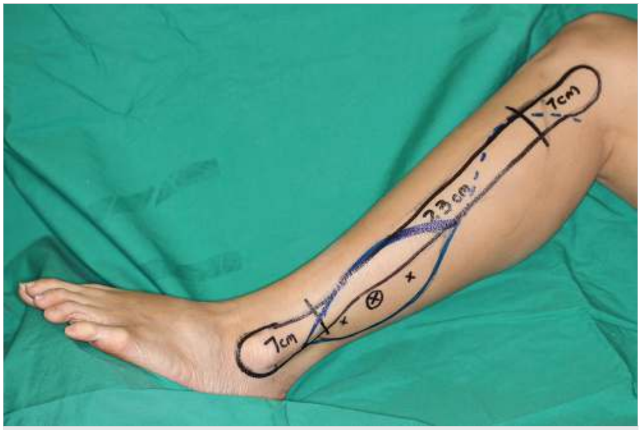


Fig. 13.16 Skin markings of the fibula flap. The line of posterior border of the fibula corresponds to the intermuscular septum within which septocutaneous perforators from the peroneal vessels travel to supply the overlying skin. The proximal and distal 7 cm of bone are excluded from flap harvest to avoid disruption of joint stability and damage to the common peroneal nerve proximally.

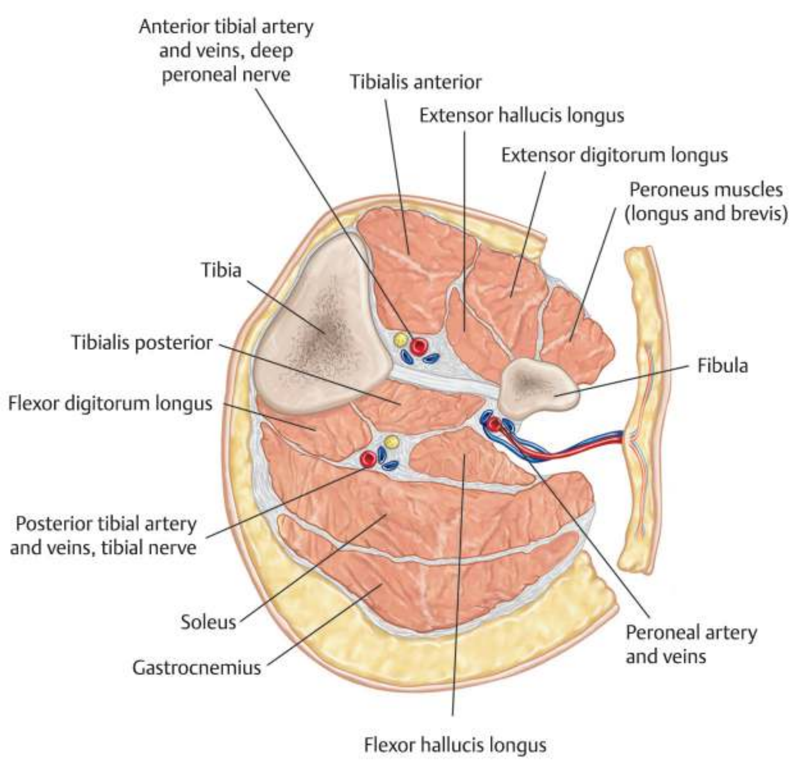
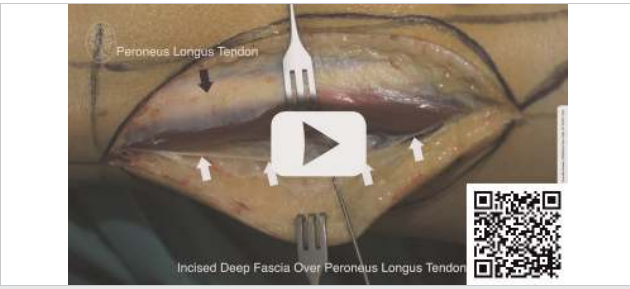


Fig. 13.17 Cross-section of the left mid-leg. The main vascular pedicle, the peroneal artery and its venae comitantes, lies against the inferomedial aspect of the fibula. EDL, extensor digitorum longus; EHL, extensor hallucis longus; FDL, flexor digitorum longus; FHL, flexor hallucis longus; G, gastrocnemius; P, peroneus muscles (longus and brevis); S, soleus; TA, tibialis anterior; TP, tibialis posterior.



Video 13.3 Free fibular osteoseptocutaneous flap

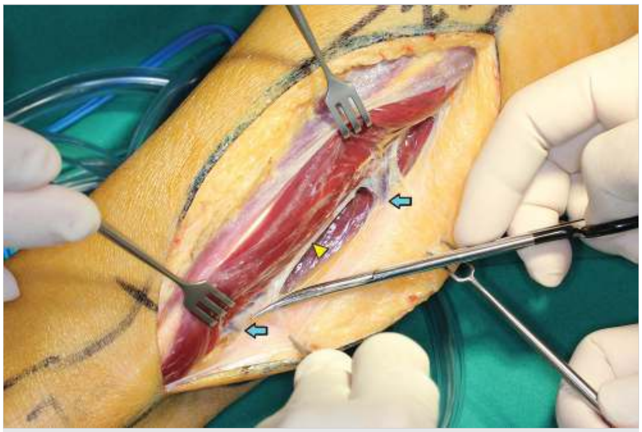


Fig. 13.18 Elevation of the skin paddle from the anterior border. Initial dissection proceeds in the suprafascial plane to maintain the deep fascial covering of the peroneus longus (PL) tendon to facilitate skin graft take. Beyond the posterior border of this tendon, dissection continues in the subfascial plane toward the posterior intermuscular septum (*yellow triangle*). Within the septum, two septocutaneous vessels (*blue arrows*) are visualized, corresponding to the Doppler-identified points on the skin paddle.

incision is deepened through the subcutaneous layer and the flap is raised suprafascially until the tendon of the PL muscle is reached. At the posterior margin of this tendon, the deep fascia is incised to allow subfascial dissection posteriorly until the posterior crural septum is reached (▶ Fig. 13.18). Preserving fascial coverage of the PL tendon is important to ensure skin graft take and also the integrity of superficial peroneal nerve, which travels anterior to the tendon just beneath the fascia.

The posterior edge of PL is progressively released, exposing the posterior crural septum. Septocutaneous vessels are usually seen coming into view, corresponding to Doppler-identified points on the skin paddle. If none are visualized, the Doppler markings likely represent musculocutaneous perforators traveling through the soleus instead.

The peroneus muscles (lateral compartment) are dissected off the fibula bone. Dissection progresses medially over the anterior border of the fibula, releasing the attachments of extensor hallucis longus and extensor digitorum longus (anterior compartment). Care is taken not to damage the periosteum and its circulation, leaving behind a thin sliver of muscle if necessary.

To access the medial border of the fibula safely, osteotomies are required to allow external rotation of the freed segment. The distal osteotomy is performed first at least 7 cm away from the ankle joint (▶ Fig. 13.19). The periosteum is elevated

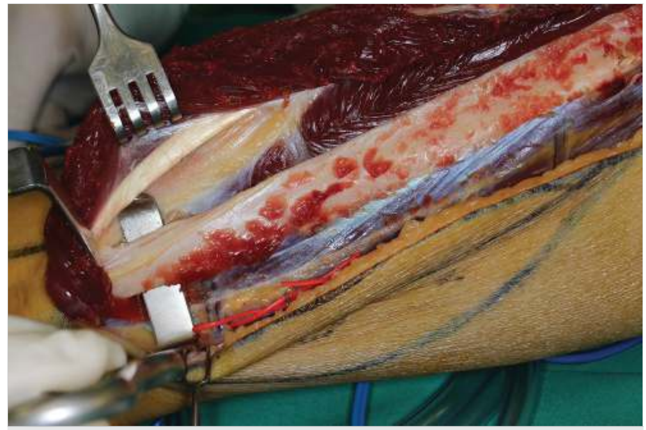


Fig. 13.19 Performing the distal osteotomy. Once the fibula has been freed of its muscular attachments, its periosteum is elevated circumferentially over a 1 cm distance at the osteotomy site to allow a Langenbeck retractor to be passed behind it. This protects the vascular pedicle during the osteotomy. At least 7 cm of bone is preserved distally to maintain stability of the ankle joint.

circumferentially off the fibula at the planned osteotomy site over a 1 cm distance. This allows a retractor to be passed around the posterior aspect of the fibula to protect the peroneal vessels that lie against its inferomedial aspect during the osteotomy. The proximal osteotomy is then similarly completed anywhere below the first 7 cm of bone from the knee joint, depending on the length of bone required.

The freed fibular segment can now be rotated outwards to present its medial aspect and the vascular pedicle. Beyond the extensor muscle attachments, the thick interosseous membrane is encountered, on which the anterior tibial neurovascular bundle lies more medially. This membrane is cut as close to the fibula as possible, revealing the peroneal vessels beneath sandwiched between tibialis posterior (TP) and flexor hallucis longus (FHL) (▶ Fig. 13.20). The posterior tibial neurovascular bundle can be found more medially between the same muscles. The vessels are circumferentially mobilized near the distal osteotomy site and ligated.

The posterior border of the skin paddle is now incised through to the deep fascia with care to avoid injury to the sural nerve and short saphenous vein that run together in the subcutaneous plane (▶ Fig. 13.21). The skin paddle is raised in the subfascial plane off the soleus anteriorly toward the posterior crural septum. Musculocutaneous vessels may be safely ligated if a sizeable septocutaneous perforator was identified anteriorly. Once the septocutaneous perforator is isolated, it can be traced to its origin from the peroneal vessels. If none are found, intramuscular dissection of the musculocutaneous perforators through the soleus is required. The posterior attachments of the peroneal pedicle to the FHL muscle are then freed.

Remnant attachments of the pedicle and fibula are now freed in a distal to proximal direction. The pedicle may be dissected up to its bifurcation from the tibioperoneal trunk for increased length. The tourniquet is released to confirm flap viability and hemostasis secured. The flap is allowed to perfuse for at least 20 minutes before dividing the pedicle proximally.

Once the flap is freed, the fibula is shaped by performing osteotomies along its length and using plate and screw fixation

Fig. 13.20 Exposure of the peroneal vessels that lie on the inferomedial aspect of the fibula. After distal ligation of the vascular pedicle (*blue arrow*), the osteotomized fibular segment is rotated outwards to allow release of the anterior compartment muscles and interosseus membrane from the bone.

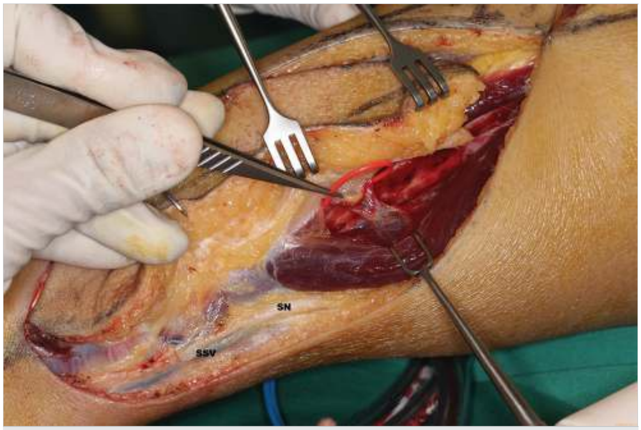


Fig. 13.21 Elevating the skin paddle from its posterior border. The flap is raised off the soleus muscle in the subfascial plane until the intermuscular septum is reached. The septocutanous perforator is thus isolated and can be traced to its origin from the peroneal vessels. Inferiorly, the short saphenous vein (SSV) is seen coursing through the subcutaneous layer together with the sural nerve (SN).

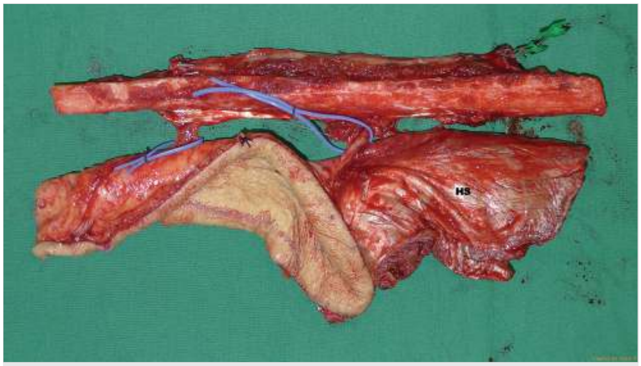


Fig. 13.22 The fibula flap harvested with the lateral hemisoleus muscle (HS) prior to bone contouring.

to secure the segments. Care must be taken to avoid injuring the nutrient vessel that enters the middle third of the bone. Unicortical screws on the anti-peroneal vessel aspect of the fibula are sufficient for fixation and avoiding inadvertent pedicle injury. To maximize vascularity of the bony segments, the number of osteotomies and screws placed should be limited and excessive periosteal stripping avoided.

If additional soft tissue bulk is needed for the flap, the lateral hemisoleus muscle can be harvested with the flap based on constant muscle branches that arise from the peroneal artery proximally (▶ Fig. 13.22).[23]

Additional Tips

During mobilization of the vascular pedicle, dissection must be maintained medial to the vessels and the pedicle kept with the fibula throughout. To increase pedicle length, unnecessary bone may be shortened proximally. Routine inclusion of a skin paddle with the flap is advised even when it is not required for reconstruction as it permits postoperative flap monitoring. The skin paddle is later resected once the flap is stable.

Donor Site Closure

After securing hemostasis, the FHL and TP muscles are reattached to the interosseous membrane. A drain is placed within the posterior intermuscular septum and the soleus and PL muscles tagged together to repair the septum. If a skin paddle width of 4 cm or less was taken, the donor site can generally be closed primarily with acceptable tension.[15] Wider skin paddles usually require skin grafting (▶ Fig. 13.23). Excessive wound tension must be avoided as this risks wound dehiscence and compartment syndrome. Any exposed segments of PL tendon are buried beneath adjacent fascia with sutures to improve skin graft take.

Postoperative Care

If the donor site was skin grafted, the leg is kept immobilized in a plaster cast until the graft is adherent. Drains are removed once output falls below 30 mL per day. Weight-bearing on the donor limb is avoided for the first 2 weeks after surgery.

13.4 Conclusion

13.4.1 Anterolateral Thigh Flap

The ALT flap is a perforator flap that is particularly versatile for head and neck reconstruction due to its long pedicle length, large source vessel diameter, and versatility in flap volume and soft tissue composition. It can be reliably harvested by the surgeon familiar with perforator dissection and results in relatively minimal donor site morbidity.

13.4.2 Radial Forearm Flap

The radial forearm flap is a versatile flap for head and neck reconstruction and is most commonly used as a fasciocutaneous flap for resurfacing intraoral defects. Its constant vascular anatomy, long pedicle, and large vessel size greatly simplify technical

Fig. 13.23 Coverage of the lateral leg donor site with a split-thickness skin graft.

aspects of microvascular surgery. Main drawbacks relate to the donor site with an aesthetic deformity that is difficult to conceal and occasional functional deficits that may be permanent.

13.4.3 Fibula Flap

The free fibula flap is a mainstay option for reconstruction of bony defects of the head and neck region, due to its reliable vascularity, long and sizeable pedicle, and its ability to provide a long segment of bone with good bone stock. With progressive refinements in surgical technique, high success rates with this flap are attainable with reduced complications and donor site morbidity. The commonest early and late donor site problems are delayed wound healing (17.4%) and limited range of motion of ankle (11.5%), respectively.[7]

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14 Lip Reconstruction

William Y. Hoffman

Abstract
Lip reconstruction is best done with like tissue, using adjacent lip tissue or cross-lip flaps for smaller defects, and rotation of one lip to the other for larger defects. Distant flaps can be utilized especially for the lower lip but these do not have orbicularis muscle so it can be difficult in terms of re-establishing lip competence.

Keywords: Abbe flap, Karapandzic flap, lip, philtrum, vermilion

14.1 Introduction

The lips form a unique structure that can be difficult to replicate. Smaller defects can be reconstructed through a variety of techniques, ranging from direct closure to local flaps. Larger defects present unique difficulties, and one could argue that total upper and lower lip reconstruction was one of the motivating factors in the development of face transplants.

14.1.1 Anatomy

- Landmarks.
- Blood supply.
- Innervation—sensory and motor.
- Orbicularis muscle.
- Wet and dry mucosa.

Normal anatomy is always the benchmark for any reconstruction. The upper lip has three anatomic units, with the philtrum in the center and two lateral segments. Maintaining a normal appearance of the philtrum and its position in the midline should be a basic consideration in any surgery on the upper lip. The lower lip is really one unit and is more amenable to some pull to either side. The modiolus is the coalescence of the orbicularis muscle with the elevators and depressors of the lip at the oral commissure.

In general, the normal lip relationship is one in which the upper lip projects farther than the lower. This is affected by occlusion. Normal tooth show of the upper teeth is about 2 to 3 mm of the tooth showing at rest, and up to the gingiva with smile.

The white roll (also called the mucocutaneous junction or vermilion border) is a key landmark in lip repair or reconstruction. There are two types of mucosa in the lips, wet and dry, and exposure of the wet mucosa will give rise to chronic dryness and cracking. Care should be taken to preserve dry mucosa whenever possible as this is specialized tissue that cannot be replaced by other mucosal grafts or flaps.

The blood supply to the lips is from the paired labial arteries, which arise from the facial artery on either side, with collateral flow from the angular artery. (Tip: The labial artery can be located under the mucosa and submucosal glands on a horizontal line through the white roll.)

Motor innervation is the buccal branch of the facial nerve. Sensory innervation is from the infraorbital nerve (V.2) in the upper lip, with a contribution from the columella to the philtrum. The lower lip is innervated by the mental nerve (V.3), emerging from the mental foramen below the second bicuspid.

14.2 Indications

Normal function as well as appearance is a primary aim of reconstruction. Here the ability of the lips to contact each other is critical, both for oral competence (lack of drooling, maintenance of fluids when drinking) and for speech (bilabial sounds such as “b,” “p,” and “m”). The orbicularis oris muscle is critical to this function as it provides a sphincter function. Maintaining continuity of the orbicularis oris muscle is a critical aspect of lip reconstruction. Defects are typically the result of cancer or trauma.

14.3 Operative Technique

14.3.1 Goals of Surgery

- Normal appearance.
- Normal function—oral competence.
- Sensation.
- Preservation of dry mucosa.

14.3.2 Smaller Defects

Small lesions of the lip can be directly excised and closed but attention must be paid to potential distortion—horizontal closure may pull the mucosa toward the cutaneous portion, while vertical closure may elongate the area and distort the vermilion border. Oblique orientation may be preferable if the lesion is more than 1 cm from the vermilion border. Closer to the vermilion border a vertical excision is preferable; don’t be afraid of crossing the white roll. Full-thickness wedge excision including muscle may be required for lesions over about 1.5 cm in width.

Wound closure of full-thickness defects should always begin with alignment of the white roll and repair of the orbicularis muscle if necessary. It is useful to tattoo the vermilion border with methylene blue and a fine needle prior to using any local anesthesia with epinephrine as the blanching may obscure the white roll. The skin and mucosa can then be repaired appropriately. Consider a Z-plasty in the wet mucosa to prevent notching.

Mucosal resection is often done in the lower lip, where the majority of malignancies are found due to greater solar exposure. This can be reconstructed with a mucosal advancement flap of wet mucosa, although chapping will be a problem requiring lip moisturizers.[1,2,3,4]

14.3.3 Larger Defects

Larger defects require more extensive procedures. Traditionally, full-thickness wedge resections of the lip can be performed for one-fourth of the upper lip and one-third of the lower lip. If an expansile lesion (tumor, vascular malformation) is being removed, more of the lip can be removed without distortion.

14.3.4 Cross-Lip Flap

These are workhorse flaps in lip reconstruction. The classic cross-lip flap dates to the 18th century, although Abbe did not describe it until 1898. The traditional use of the Abbe flap is for reconstruction of the philtrum, with scars replacing the philtral columns. The Abbe-Estlander flap is a modification of this technique for lateral defects involving the area around the commissure. In either case, the labial artery is preserved in the flap with a narrow bridge of mucosa to protect it; this is divided under local anesthesia after 2 weeks (possibly longer in older patients).

14.3.5 Entire Lip

When an entire upper or lower lip is resected, local flaps can be used if possible, as they have the most similar match of texture and color. The upper lip can be reconstructed with two nasolabial flaps, which may be elevated with mucosa if needed, and an Abbe flap for the philtrum.

The Gillies fan flap borrows tissue from the cheeks to reconstruct the lower lip; the Bernard-Burow's flap utilizes a similar principle but from the lower vestibule, with cutaneous incisions following the labiomental crease. In all of these flaps, mucosa is brought in from the cheeks along with skin, and attention must be paid to leaving adequate mucosa for opening the mouth.

Karapandzic flaps, most commonly used for lower lip reconstruction, can be reversed for the upper lip. This flap requires an incision in the nasolabial folds with preservation of nerves and vessels while mobilizing skin and muscle, bringing the former region of the commissure together in the midline. This creates significant microstomia with a need for commissuroplasty.

An alternative to local flaps is remote or microvascular reconstruction. In a male patient, a scalp flap pedicled on the superficial temporal artery may be used for the upper lip, with buccal mucosal flaps for lining. This provides hair-bearing skin and a moustache can conceal the lack of contour. Lower lip reconstruction can be done with a free flap. The radial forearm is probably the best option because of the thin flap, and the palmaris tendon can be used for suspension of the flap. The upper lip can also be reconstructed in this manner but is more difficult to achieve a natural appearance due to the more complex contour of the upper lip.

14.4 Conclusion

Lip reconstruction is both cosmetic and functional. The goal of surgery is a functional reconstruction that restores oral competence and facilitates speech. Restoring or preserving continuity of the orbicularis oris muscle is critical to achieving a successful outcome. Smaller defects may be managed through primary closure or local advancement flaps of skin, muscle, and/or mucosa. Wedge excision is typically limited to defects involving up to one-fourth of the upper lip or one-third of the lower lip. Larger defects require more complicated reconstructions. Options include cross-lip flaps, the Gillies fan flap, and Karapandzic flaps, or via microvascular reconstruction with free flaps.

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15 Eyelid Reconstruction

Karen Kaplan, Wrood Kassira, Seth R. Thaller, and Chrisfouad R. Alabiad

Abstract

The surgeon has three objectives when reconstructing the eyelid: protect the globe, restore function of the eyelid, and restore cosmesis. A thorough understanding of the eyelid anatomy is required to attain these objectives. Special attention should be paid to the depth of the defect (full thickness versus partial thickness, e.g., skin/muscle), involvement of the tear drainage system, the medial and lateral canthal angles, and whether the levator palpebrae superioris has been disinserted from its attachment to the tarsal plate (in the rare case of complete upper eyelid resection). The surgeon must also create an operative plan that maintains the integrity of the facial nerve while avoiding the use of vertical vectors that promote eyelid malposition such as lagophthalmos and ectropion.

There are numerous methods to reconstruct the upper and lower eyelids. However, this chapter will focus on the techniques that reconstruct most upper and lower eyelid defects.

Included below are descriptions of the pentagonal wedge resection, Tenzel flap, and Hughes flap.

Keywords: eyelid reconstruction, Hughes flap, oculoplastic surgery, pentagonal wedge resection, primary closure, semicircular flap, tarsoconjunctival flap, Tenzel flap

15.1 Introduction

15.1.1 Pentagonal Wedge Resection and Primary Closure

If there is enough horizontal laxity of the eyelid, eyelid defects of up to approximately 33% can be reconstructed primarily.[1] This allows for preservation of the native eyelid margin and reconstruction in a single stage. A full-thickness defect can be modified to take form of a pentagon. The configuration eliminates dog-ears and promotes closure using a horizontal vector. Wound tension can be alleviated by further augmentation using a lateral canthotomy with inferior cantholysis.

15.1.2 Tenzel Semicircular Flap

The Tenzel semicircular flap was first described by Dr. Richard Tenzel in 1975.[2] The semicircular flap is useful for reconstruction of central lower eyelid defects. The reverse Tenzel semicircular flap is performed for central upper eyelid defects. This procedure is an extension of the pentagonal wedge resection and affords closure of upper and lower eyelid defects spanning 50 to 66% the horizontal length of the eyelid. This reconstruction requires that tarsal plate be present on both the medial and lateral aspects of the wound defect. The procedure also requires reconstruction of the lateral canthus to restore the canthal angle and the blink dynamic. This is accomplished through fixation of the flap to the periosteum of the lateral orbital rim.

15.1.3 Hughes Tarsoconjunctival Flap

The Hughes tarsoconjunctival flap was initially described in 1937 as a means of reconstructing posterior lamellar defects of the lower eyelid.[3] This procedure allows reconstruction of lower eyelid margin defects encompassing as much as 90to 100% of the lower eyelid. The tarsoconjunctival flap entails advancing a flap of upper eyelid conjunctiva and tarsus down to the lower eyelid. A portion of the upper eyelid tarsal plate and conjunctiva is left intact to maintain upper eyelid stability. The anterior lamellar defect is reconstructed during the same operation with a local myocutaneous flap or full-thickness skin graft. The tarsoconjunctival flap requires a second-stage procedure 6 to 8 weeks later to divide the flap. In the interim, the eyelid is partially closed, so it is important to make sure that the patient has functional vision in the contralateral eye.

15.2 Indications

15.2.1 Pentagonal Wedge Resection and Primary Closure

- Defects of the upper or lower eyelid (< 33% of the horizontal length).

15.2.2 Tenzel Semicircular Flap

- 33 to 66% lower (Tenzel flap) or upper (reverse Tenzel) eyelid defect.
- Tarsal plate present on both sides of the surgical defect.

15.2.3 Hughes Tarsoconjunctival Flap

- Full-thickness lower eyelid margin defect.
- Defect > 50% of horizontal dimension of eyelid.

15.3 Operative Technique

15.3.1 Pentagonal Wedge Resection and Primary Closure

- 2% lidocaine with 1:100,000 epinephrine is injected in subcutaneous fashion in the area of the skin markings and in a subconjunctival fashion in the lower eyelid fornix (▶ Fig. 15.1).
- A chalazion clamp is then placed along the area of the skin markings.
- #15 blade is used to excise the full-thickness piece of eyelid.
- Hemostasis is obtained with bipolar cautery.
- The chalazion clamp is removed.
- Pretarsal orbicularis is bluntly dissected off the tarsal plate along the medial and lateral aspects of the wound defect using Westcott scissors (▶ Fig. 15.2).
- The eyelid margin is reapproximated using a 4–0 silk suture in a vertical mattress fashion (do not tie this suture until the completion of the next step; ▶ Fig. 15.3).

Fig. 15.1 Pentagonal wedge resection markings.

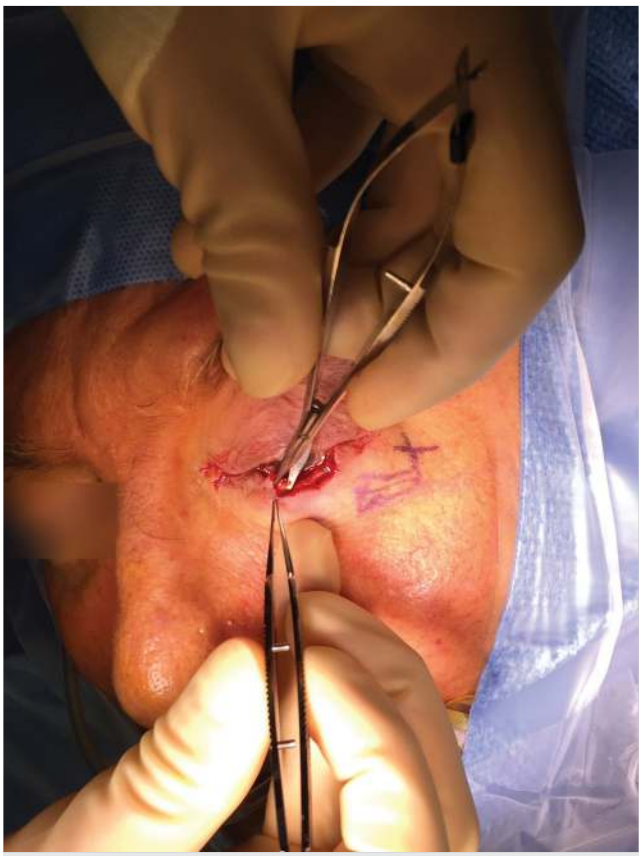

Fig. 15.2 Pretarsal orbicularis is bluntly dissected off the tarsal plate along the medial and lateral aspects of the wound defect using Westcott scissors.

- The posterior lamella is reapproximated in a horizontal lamellar fashion with 5–0 Vicryl on a spatulated needle (▶ Fig. 15.4). All sutures are tied at this point.
- The lash line is then further reinforced with 5–0 Vicryl suture (▶ Fig. 15.5).
- The overlying skin is then closed using 7–0 Vicryl suture (▶ Fig. 15.6).
- The eye is dressed with antibiotic ophthalmic ointment.

Fig. 15.3 The eyelid margin is reapproximated using a 4–0 silk suture in a vertical mattress fashion.

Fig. 15.4 The posterior lamella is reapproximated in a horizontal lamellar fashion with 5–0 Vicryl on a spatulated needle.

Complications

- Eyelid retraction (too tight).
- Cicatricial ectropion (unintentional vertical vector).
- Eyelid margin notching (poor apposition of margin suture).

15.3.2 Tenzel Semicircular Flap

Preoperative Markings

- Semicircular flap of approximately 2 cm in diameter is designed.
- Upside down “U” shaped for lower eyelid; “U” shaped for upper eyelid.

Intraoperative Details

- Semicircular flap incised with dissection of myocutaneous flap to lateral orbital rim.
- Lateral canthotomy is performed.
- Inferior cantholysis (lower eyelid); superior cantholysis (upper eyelid).

Fig. 15.5 The lash line is further reinforced with 5–0 Vicryl suture.

- Pretarsal orbicularis is bluntly dissected off the tarsal plate along the medial and lateral aspects of the wound defect using Westcott scissors.
- The eyelid margin is reapproximated using a 4–0 silk suture in a vertical mattress fashion (do not tie this suture until the completion of the next step).
- The posterior lamella is reapproximated in a horizontal lamellar fashion with 5–0 Vicryl on a spatulated needle. All sutures are tied at this point.
- The lash line is then further reinforced with 5–0 Vicryl suture.
- Semicircular flap mobilized and advanced horizontally to close initial defect (▶ Fig. 15.7).
- Lateral canthus reconstructed by suturing deep portion of semicircular flap to periosteum.
- Semicircular flap is trimmed and sutured in place.

Postoperative Care

- Pressure dressing to remain in place for 5 to 7 days.
- Silk suture on eyelid margin removed after 14 days.

Possible Complications

- Ectropion.
- Eyelid notching.
- Facial nerve damage.
- Lower eyelid retraction.

15.3.3 Hughes Tarsoconjunctival Flap

Two-Stage Operation

- First stage:
  - 2% lidocaine with 1:100,000 epinephrine is injected into the wound and the upper eyelid.
  - Frost suture is placed on upper eyelid.
  - Upper eyelid is everted over a Desmarres retractor.
  - With lower eyelid wound edges gently drawn pulled together, the width of the flap along upper eyelid is marked.
  - Horizontal incision through conjunctiva and tarsus is made 4 mm above upper eyelid margin.
  - Pretarsal orbicularis is dissected off the flap.

Fig. 15.6 Closed incision after pentagonal wedge resection.

Fig. 15.7 Mobilization of semicircular flap.

  - Vertical cuts are made on both sides of the flap extending to superior fornix.
  - Muller's muscle is dissected from conjunctiva using Westcott scissor.

Fig. 15.8 Hughes tarsoconjunctival flap mobilized inferiorly.

  - The flap is advanced inferiorly into the defect and secured to the lower eyelid retractors (▶ Fig. 15.8).
  - The flap is secured to the tarsal plate medially and laterally.
  - A local myocutaneous flap is created (with a horizontal vector) to cover the defect.
  - Pressure patch is left in place for 5 to 7 days.
  - Divide the flap after 4 to 8 weeks.
- Second stage:
  - Local anesthesia is achieved with 2% lidocaine with 100,000 epinephrine.
  - Grooved director is placed under the eyelids.
  - Incision is made with Westcott scissor to recreate the lower eyelid margin.
  - Upper eyelid is everted and remaining excess flap tissue is excised at its base.
  - Postoperatively, ophthalmic antibiotic ointment is applied three times a day for 3 days.

Possible Complications

- Upper eyelid retraction.
- Lower eyelid retraction.
- Lower eyelid ectropion.

15.4 Conclusion

15.4.1 Pentagonal Wedge Resection and Primary Closure

- If more laxity is needed along the eyelid, a lateral canthotomy with an inferior cantholysis can be performed.
- It is useful for defects of up to 33% of the horizontal length of the eyelid.
- The pentagon shape allows for a linear scar and avoids closure with a vertical vector.

15.4.2 Tenzel Semicircular Flap

- The Tenzel semicircular flap is useful for reconstruction of central lower eyelid defects.
- The reverse Tenzel semicircular flap is performed for central upper eyelid defects.

15.4.3 Hughes Tarsoconjunctival Flap

- The Hughes tarsoconjunctival flap is a two-stage procedure that allows reconstruction of lower eyelid margin defects encompassing as much as 90 to 100% of the eyelid.
- The rectangular flap is sized according to the size of the defect.
- The tarsus of the tarsoconjunctival flap may be sutured to a periosteal bone flap at the lateral canthus if there is no residual tarsus lateral to the defect or if the length of the tarsoconjunctival flap falls short.
- Multiple options are available for reconstruction of the anterior lamella, including semicircle flap, Mustarde flap, and skin and muscle transposition flap from the upper eyelid or full-thickness skin graft harvested from the upper eyelid, supraclavicular, or postauricular region.
- If a full-thickness skin graft is used, then it is better to create the tarsoconjunctival flap to include Muller's muscle so as to improve blood supply to the skin graft.

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16 Nasal Reconstruction

Bharat Ranganath, M. Shuja Shafqat, Randolph Wojcik Jr., and Chetan Satish Nayak

Abstract
Reconstruction of nasal defects is perhaps the earliest and most widely described of all plastic surgery procedures. The first techniques of flaps for nasal defects were described by *Sushrutha* in the 9th century BC India, and the rediscovery and advancement of these techniques by European surgeons in the Middle Ages and Renaissance form the cornerstone of our current treatment principles. Today, the large majority of nasal reconstruction occurs after cancer extirpation and relies on the evolution of age-old principles based on the underlying anatomy, as size, location, and depth of the defect inform and dictate optimal reconstructive options.

Keywords: bilobed flap, forehead flap, nasal reconstruction, nasal defect, nasolabial flap, subunits

16.1 Introduction

16.1.1 Anatomy and General Principles

- Nine anatomic subunits: The nose is classically described as having nine distinct subunits (▶ Fig. 16.1):
  - Dorsum.
  - Two nasal sidewalls.
  - Nasal tip.
  - Two soft triangles.
  - Two ala.
  - Columella.
- Anatomic subunit principle: Although not universally accepted, this principle states that when greater than 50% of a given subunit is resected, the entire subunit should be removed and reconstructed as a whole in order to yield the best aesthetic outcome.[1,2,3,4]
- Three layers:
  - Outer coverage: Skin.
  - Middle support: Cartilage and bone:
    - Lower lateral cartilages (paired).
    - Upper lateral cartilages (paired).
    - Nasal bones (paired).
    - Midline cartilaginous and bony septum.
  - Inner lining: Skin and mucosa.
- General surgical principles:
  - All three layers should be present in any reconstruction:
    - Flaps and grafts can be combined; however, combining two grafts (i.e., cartilage graft under a skin graft) is contraindicated.
  - Small defects in areas of concavity (i.e., near canthus) can be allowed to heal by secondary intent, while convex areas should be reconstructed with flaps/grafts.
  - For small defects and best restoration, restoration of normal **contour** is more important than scarring.
    - "Contour before scar" as scar is well tolerated but contour abnormalities are not.[1]

16.1.2 Algorithm for Local Flaps for Small Skin Defects

- Vertically oriented defects: Use flaps that move horizontal like V-Y or nasolabial:
  - V-Y flaps: Based on angular artery perforators:
    - Tissue lateral to defect and extends onto the cheek.
    - Keep above the alar groove.
    - After transfer, flap should be completely on the nose.
- Horizontally oriented defects: Use flaps that move vertical like glabella, frontonasal/miter, bilobed.
- Nasal thirds algorithm (▶ Fig. 16.2 and ▶ Fig. 16.3)[5]:
  - Proximal one-third—central subunit:
    - Glabella flap: More superior defects.
    - Frontonasal/Miter flap: More inferior defects.
  - Proximal one-third—lateral subunit:
    - Glabella flap: More horizontally oriented defects.
    - V-Y advancement: More vertically oriented defects.
  - Combined defects:
    - Forehead flap.
  - Middle one-third—central subunit:
    - Frontonasal/Miter flap.
    - Direct closure: If extremely vertically oriented.
  - Middle one-third—lateral subunit:
    - Frontonasal/Miter flap: More horizontally oriented defects.

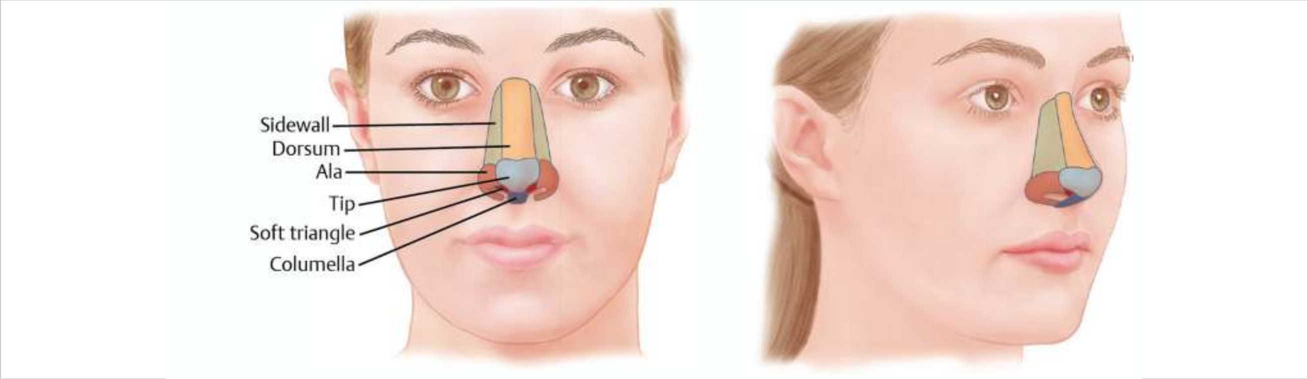

Fig. 16.1 Anatomic subunits of the nose. This figure shows the nine anatomic subunits of the nose—the dorsum, two sidewalls, the tip, two soft triangles, two ala, and the columella.

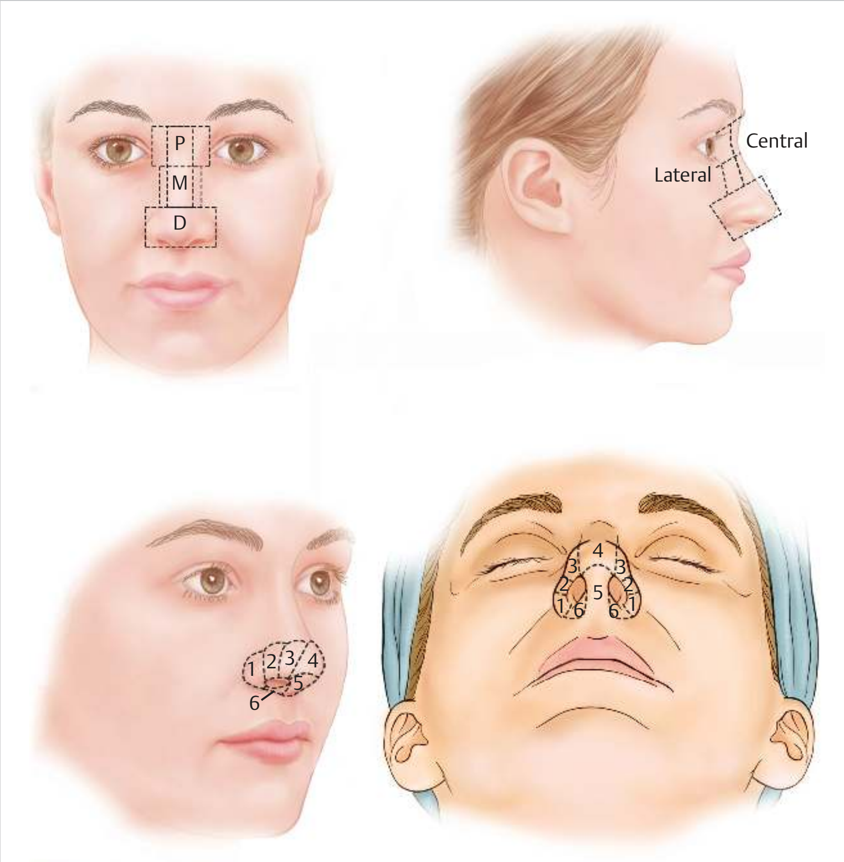

Fig. 16.2 Thirds of the nose. This figure divides the nose into proximal, middle, and distal thirds in order to better delineate reconstructive options based on location of a given defect.

   - V-Y advancement or nasolabial: More vertically oriented defects.
  - Combined defects:
    - Forehead flap.
  - Distal one-third—alar and domal-alar groove subunits:
    - Nasolabial flap.
    - V-Y advancement: Design flap above the alar groove and extend into nasolabial area.
  - Distal one-third—dome and central subunits:
    - Bilobed flap.
    - Extended V-Y: If more lateral in these subunits and vertically oriented.
    - Frontonasal/Miter flap: More horizontally oriented defects.
    - Columella: Skin grafting.
    - Nasal sill: Nasolabial island flap.
- See ▶ Fig. 16.4 for commonly used local flap options.
- Complex defects:
  - Forehead flap.

16.1.3 Preoperative

- Ensure all margins are free of cancer; this may require temporizing defects and staged procedures with initial placement of a skin graft or dermal substitute.
- Small superficial defects can often be treated utilizing only local anesthesia, while larger more complex defects and patient factors may necessitate general anesthesia.
- Be sure to consider possible skin and cartilage graft sites in advance and prep out these locations (i.e., posterior auricular, supraclavicular, etc.).

16.1.4 Intraoperative

- Establish size, extent, and depth of defect and which subunits and layers are involved and need to be reconstructed.
- Local anesthetic with epinephrine can aid in providing a dry, clear surgical field.

16.1.5 Postoperative

- Generally, patients can be allowed to wash/shower gently over incisions after 24 to 48 hours.
- Apply antibiotic ointment to incision lines.
- Bolster skin grafts with removal of bolster in approximately 5 to 7 days.
- Interpolated flaps are generally divided and inset in approximately 21 days; however, some authors report doing so in as little as 7 to 10 days.[6]

16.2 Indications

16.2.1 Dorsal Nasal Flap (Frontonasal Flap)

- Good for elderly patients needing single-stage reconstruction.

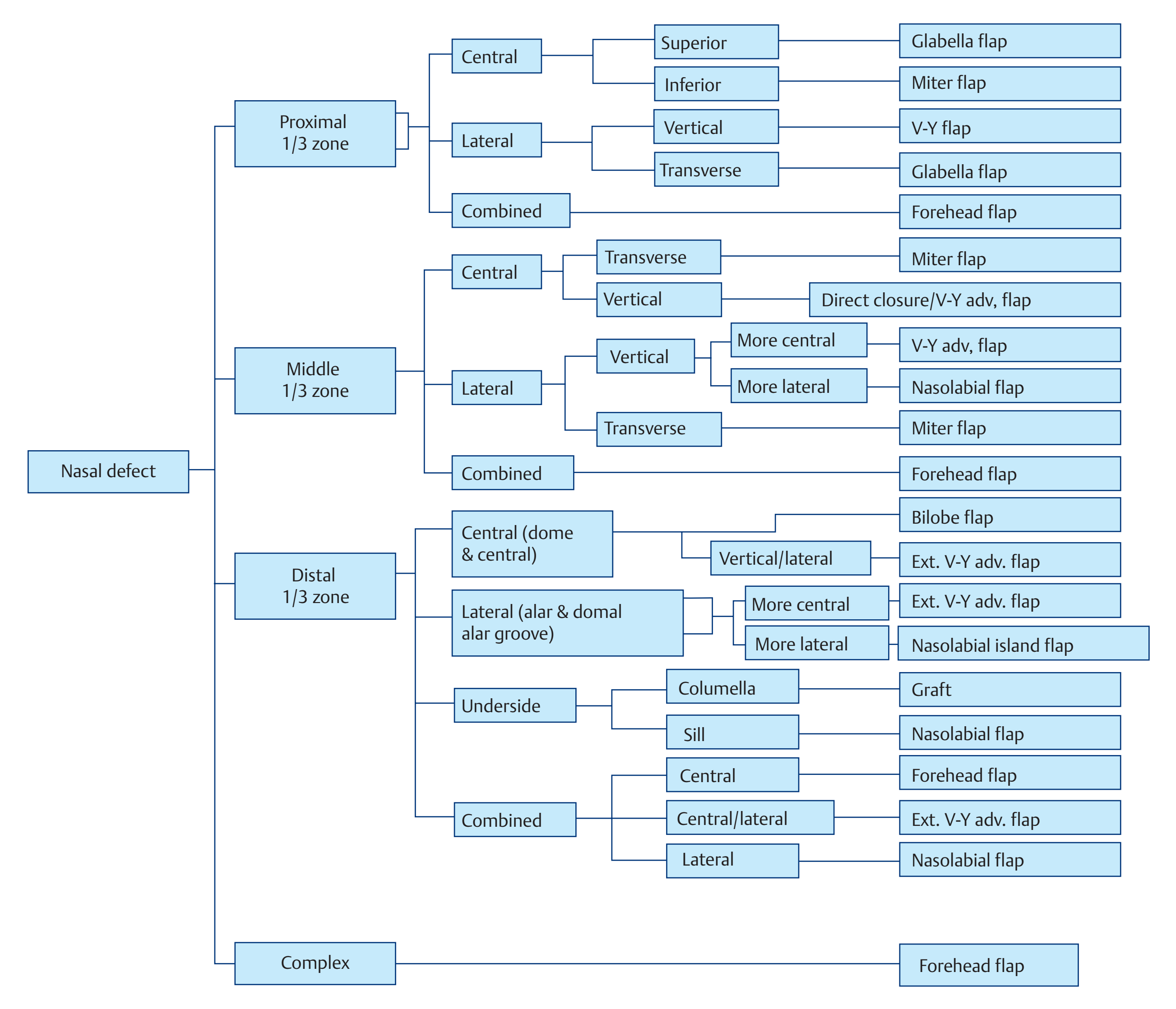

Fig. 16.3 Algorithm from Guo et al describing flap choice based on location of nasal defect.

- Good for:
  - Defects within the inferior dorsum, supratip, and superior tip.
  - Large nose and droopy tip.

Limitations

- Cannot reconstruct full tip subunit, infratip, or columella.
- Not for defects extending below tip defining points.
- Not good for young or middle age patients.

16.2.2 Bilobed Flap

- The bilobed flap is a double transposition random skin flap best used for defects of the nasal tip and dorsum by recruiting more lax cheek and sidewall skin (▶ Fig. 16.5).[1,2,4,7]
- Bilobed flap can be used to reconstruct defects of up to 1.5 cm^2.

Limitations

- Defects ≥ 1.5 cm^2.
- Can leave dog-ears and pin cushion/trap door scarring that need to be revised.

16.2.3 Nasolabial Flap

- Ideal for alar and lower sidewall defects.
- Takes advantage of lax skin and excess subcutaneous fat just lateral to the nasolabial (melolabial) fold.
- Allows linear scar to be camouflaged in area of nasolabial fold
- Can be superiorly or inferiorly based.
- Can be primarily inset or interpolated and require two stages.
- Can be designed large enough to fold around to create inner lining as well.

Limitations

- May require two stages.
- Limited to lateral/inferior nasal defects.
- May need cartilage graft for alar support.

16.2.4 Paramedian Forehead Flap

- Excellent option for nasal tip defects, large nasal defects, and complex defects.
- Can be folded distally to reconstruct nasal lining in addition to outer coverage.
- Axial pattern flap based on supratrochlear artery with rich intercommunications in forehead between supratrochlear, supraorbital, and dorsal nasal arteries which allows for a variety of patterns for flap with thin pedicle based in medial canthus.
- Flap can be thinned distally to reduce bulk and allow contouring of reconstructed nasal tip/ala.

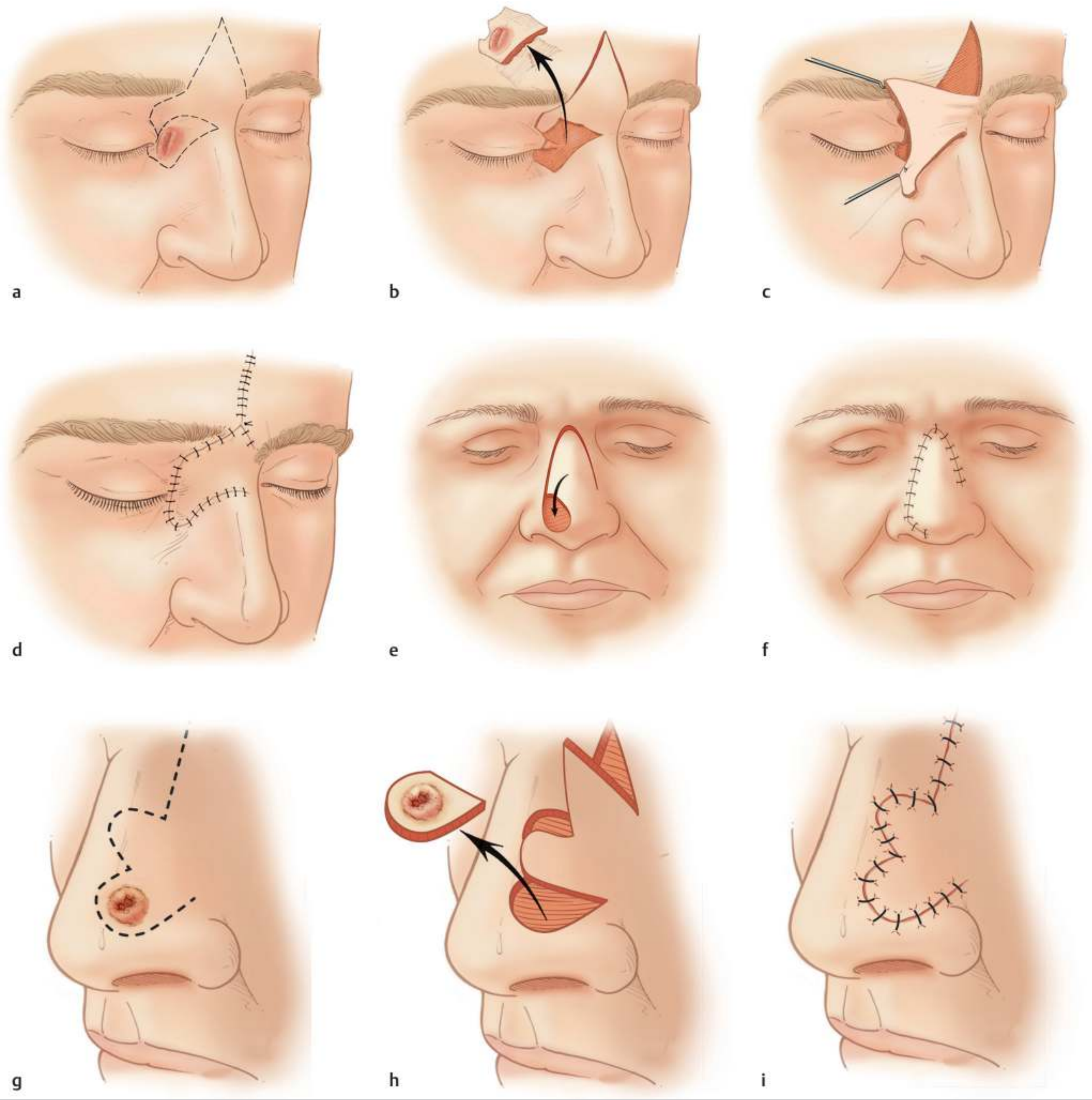

Fig. 16.4 Local flaps for nasal reconstruction. Shows design and rotation of several commonly used local flaps for nasal reconstruction. **(a–d)** Design of glabellar flap, excision of defect, raising of flap, and rotation and inset. **(d–f)** Design of dorsal nasal/miter flap and rotation into defect. **(g–i)** Bilobed flap.

(*Continued*)

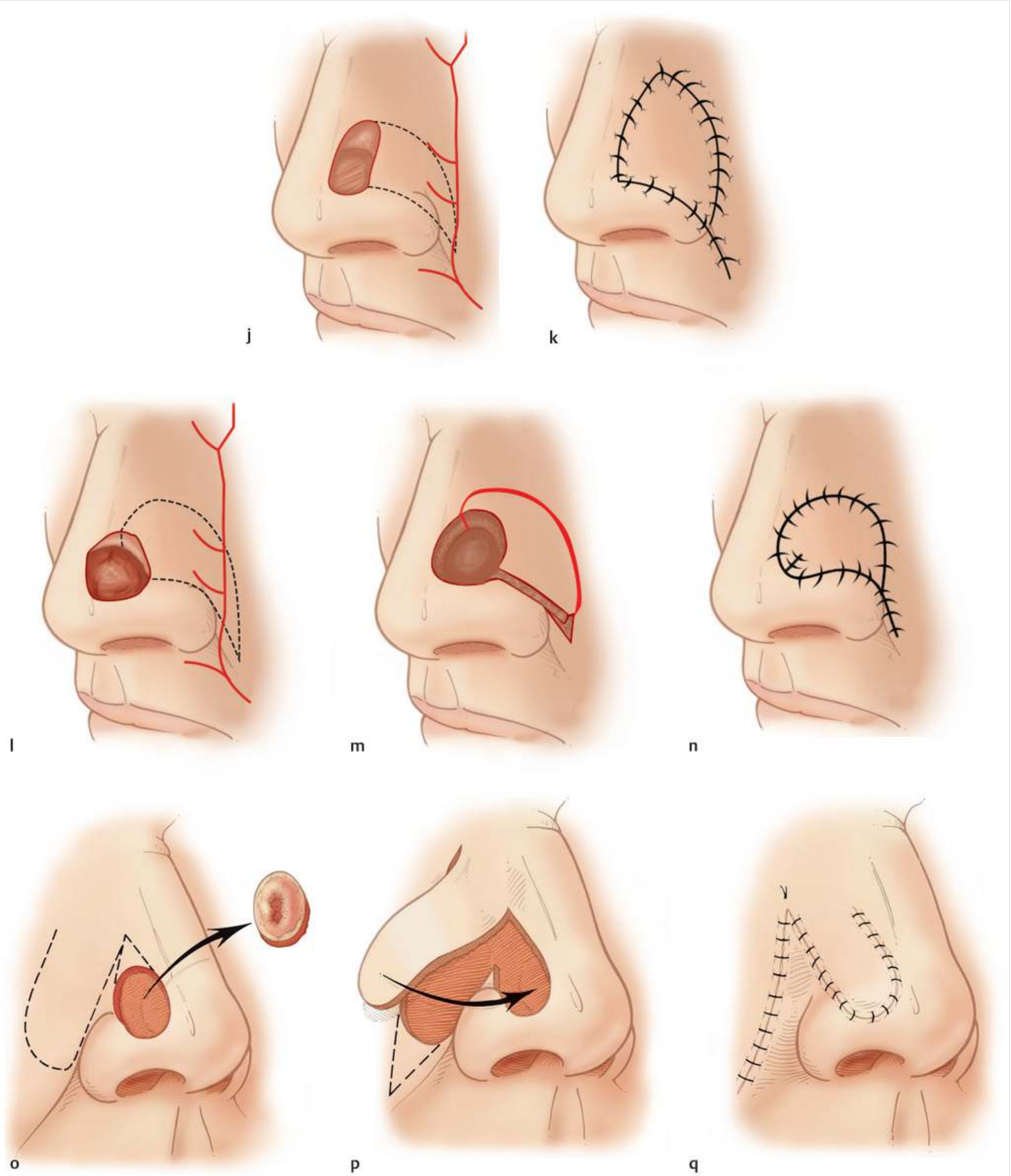

Fig. 16.4 (j–k) *(Continued)* Inferiorly based nasolabial flap designed as V-Y advancement. **(l–n)** Inferiorly based nasolabial flap designed as rotation flap. **(o–q)** Superiorly based nasolabial flap.

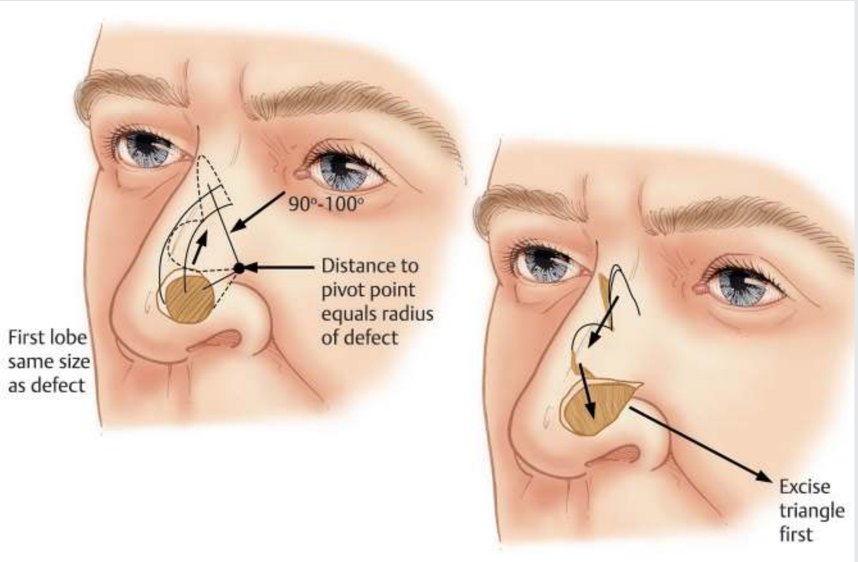

Fig. 16.5 Bilobed flap. Shows design and rotation of a bilobed flap for reconstruction of a nasal dorsum/tip defect. Two quarter circles are designed. One from the medial end of the defect superolaterally, which determines the distal extent of the first lobe, and other from the middle of the defect superolaterally, which determines the proximal extents of the first and second lobes. Note that the first lobe is equal in size to the primary defect and is at about a 45 degrees angle from the pivot point, while the second lobe is at approximately 90 to 100 degrees angle from the pivot point and about half the size of the first lobe. The second lobe is designed in an area of thin loose skin and in a geometry that allows primary closure. A triangle must be excised adjacent to the defect to make a "teardrop" shape to allow for flap rotation.

- Interpolated flap can be divided usually at 3 weeks but can be as early as 10 to 14 days.[8]
- Multiple forehead flaps can be used (▶ Fig. 16.6).[1,3,4,8]

Limitations

- Requires multiple stages of reconstruction, including division of inset of pedicle and likely flap debulking and contouring.
- Requires appropriate patient selection and buy-in as interpolated flap can be quite unsightly until division and inset.

16.2.5 Complex Nasal Reconstruction

- Complex nasal defects are multilayered, and one must diagnose and understand the defect first.
- Multiple procedures are needed and it may be necessary to stage the procedures with prelamination.

16.3 Operative Technique

16.3.1 Dorsal Nasal Flap (Frontonasal Flap)

- Advantage: Transfer of tissue from an area of excess (glabella) to area of deficiency (tip and ala).
- Disadvantage: Can shift thick glabellar skin to thin medial canthal skin or thin dorsal skin to thick tip skin:
  - Can also create dog-ears at the base:
    - Usually at the alar crease or nasal sidewall.
    - Alar back-cut = improved flap transposition.
    - Nasal sidewall back-cut = improved flap rotation.
- Flap design (▶ Fig. 16.7):
  - Redesign defect to a geometrically favorable shape and put scars at borders of subunits.
  - Flap is cutaneous in the radix and glabella and myocutaneous in the nasal dorsum.
  - *Type I flap*: Standard design with skin of the dorsum and sidewall.
  - *Type II flap:* Extended design going onto the contralateral sidewall.
  - Raise flap in a submuscular plane and rotate into defect.
  - Inset flap with absorbable buried sutures and close with nylon or prolene sutures ensuring good eversion of skin edges and minimizing tension.
  - Excise dog-ear in a wedge shape or crescent shape.
  - Can modify cartilage after flap is harvested.
  - Proximal flap design:
    - Determined by glabellar frown lines (vertical or horizontal) and inter-brow distance.
  - Distal flap design:
    - Straight (bilateral tip coverage) or stairstep (unilateral tip coverage ± soft triangle defects).
  - May need cheek flap to close secondary defect on the contralateral nasal sidewall.
- Considerations[9]:
  - Nose size can be variable:
    - Larger nose = larger flap.
    - Standard design flap in a large nose may have the same surface area as an extended design flap in a small nose.
    - In the tip, usually use extended flaps.
    - In the supratip, usually use standard flaps.
  - Tip scars:
    - In thin skin tips, unilateral reconstruction with stairstep scars can heal well.
    - In thick sebaceous skin tips, scars across the nasal tip should be avoided.
  - Alar retraction:
    - Occurs in reconstructions at the nasal rim or soft triangle.
    - Can be combatted by using alar batten grafts or rim grafts.
  - Drooping tips:
    - Use suturing techniques and cephalic trim to rotate tip upward and overcome a short flap.
  - Large dorsal hump:
    - Flap harvest allows direct reduction of the nasal framework and closure.

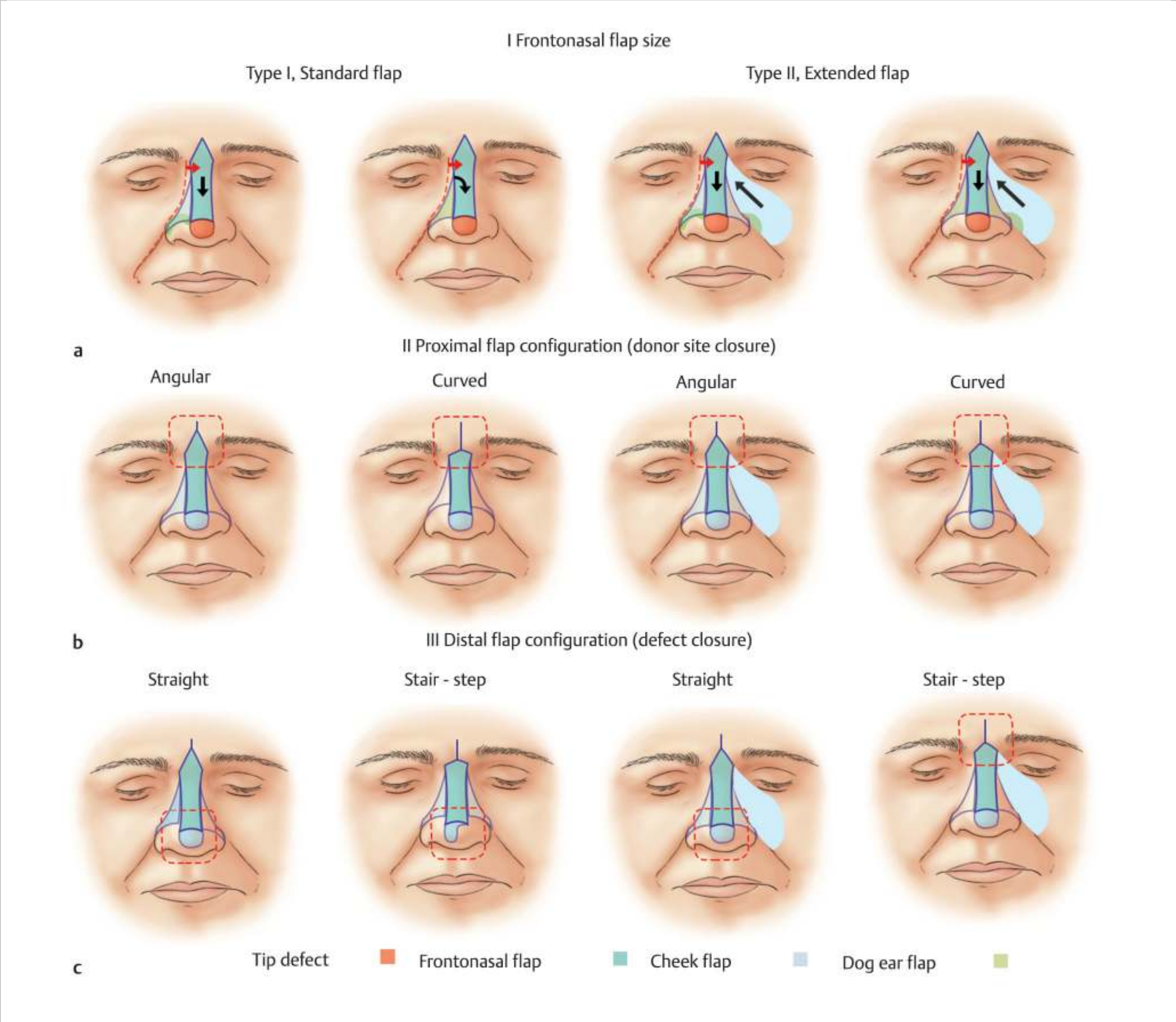

Fig. 16.6 Paramedian forehead flap. This figure shows a standard paramedian forehead flap. This flap is very versatile for distal tip defects, and large subtotal or total nasal reconstruction. It can be done in multiple stages to add cartilage grafting, lining, and contouring/thinning the flap. It can be based on either supratrochlear artery or supraorbital artery. The main disadvantage of this flap is the donor site and the need for at least two stages, if not more. **(a)** Design of flap of appropriate length to be easily transposed and reach nasal defect. **(b)** Stage 1: Flap raised and tubed and inset into nasal defect with donor site mostly closed. **(c)** Stage 2: Division of pedicle with final closure and inset.

16.3.2 Bilobed Flap

- Flap design (▶ Fig. 16.5):
  - You should start first by making two quarter circle marks that rotate superiorly and around the pivot point. One from the end of the defect extending superiorly and toward the area you plan to take the flap from. The second extends in a similar arc but from the midpoint of the defect.
  - The first lobe of the flap is designed adjacent to the primary defect and to be at a 45 degrees angle from the pivot point of the flap in relation to the primary defect. This lobe is of about equal size to the primary defect.
    - The length of this lobe is the same as the length of the defect or the outer edge of this lobe touches the outer arc.
    - The inner arc determines the proximal extent of the flap.
- The second lobe of the flap is designed to be approximately 90 to 100 degrees from the pivot point of the flap and is more elliptical and about half the width of the first lobe. This should be in an area and in such an orientation that you can close it primarily.
- You should also design triangle to be excised that has its base at the defect and its apex at the pivot point.
- After marking and infiltrating adequate local anesthesia, the skin is incised with a scalpel.
- Both lobes can be incised and raised at once, or they can be incised and raised in sequence with “cut to fit.”
- Care must be taken not to back-cut across the base of the flaps.
- Flaps are raised preferably in a submuscular plane to optimize vascularity.

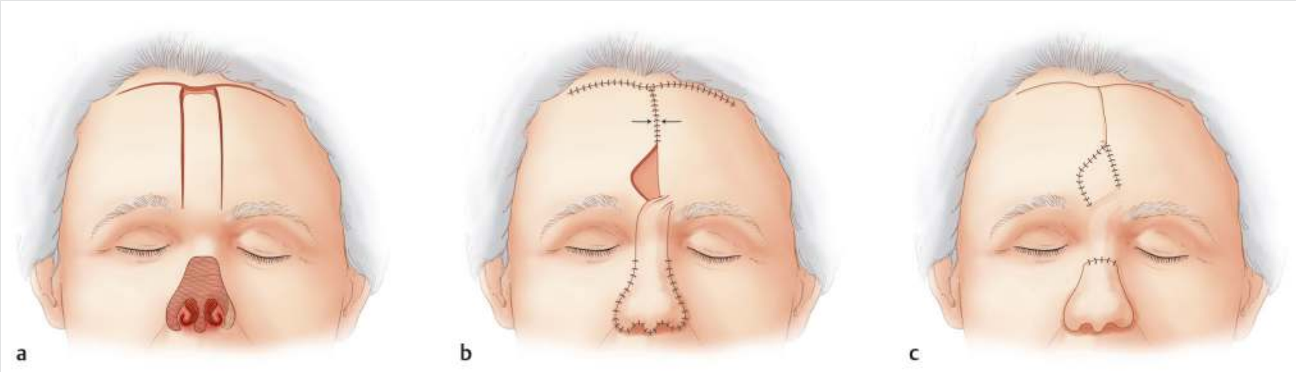

Fig. 16.7 (a–c) Frontonasal (dorsal nasal) flap. Shows the design and modifications of the frontonasal flap described by Scheufler et al.

- Flap lobes and donor defect are widely undermined to reduce tension.
- The first lobe is rotated and inset into the original defect and secured with buried deep-dermal absorbable sutures.
- The second lobe is then rotated and inset into the secondary defect.
- The defect from the second lobe is closed primarily.
- Dog-ears and areas of pin cushioning can be addressed at this time with direct excision or Burow's triangles.
- Skin is closed with 5–0 an 6–0 nylon or prolene sutures.

16.3.3 Nasolabial Flap

- Inferiorly based nasolabial flap (▶ Fig. 16.8)[1,2,4,6]:
  - Design flap inferior to or adjacent to alar/sidewall defect based inferiorly along the course of angular artery.
  - Can be designed as a V-Y flap.
  - Incise and raise flap in deep subcutaneous plane and advance/rotate into defect.
  - May need to pedicle/interpolate the flap and divide and inset at a later time.
  - Donor site can be closed in a straight line within nasolabial fold.
- Superiorly based nasolabial flap:
  - Design flap lateral and adjacent to alar/sidewall defect based superiorly in area of upper nasal sidewall.
  - Inferior aspect of flap should be elliptical and lie within area of existing nasolabial fold.
  - Incise and raise the flap in deep subcutaneous or submuscular plane.
  - Rotate and inset the flap into defect—this may require excision of intervening skin bridges or interpolating flap and dividing at a second stage.
  - Donor site can be closed in a straight line to lie within and extend upon the nasolabial fold.

16.3.4 Paramedian Forehead Flap

- Axial flap based on the supratrochlear artery:
  - Supratrochlear artery is found 1.7 to 2.2 cm from midline[8] and exits orbital septum and travels briefly superficial to corrugator and deep to orbicularis oculi muscle.
  - It pierces orbicularis in an area approximately 1 cm superior to the brow and then travels in subcutaneous/subdermal plane:
    - This allows the flap to be thinned distally beyond this point to include just the skin.
  - It allows pedicle to be narrow at its base and in the area of medial canthus in order to maximize length and ease transposition.
- Doppler the course of supratrochlear artery from medial canthus to distal reach of the flap.
- Define the size, geometry, and depth of the defect to determine the outline of the flap and need for intraoral lining.
- Base the flap in medial canthal region over Dopplered artery and determine the length needed.
- Design the flap on superior forehead to match the defect. Various flap designs are described:
  - Using a foil template of the defect can be very useful in this step; the opposite side subunit can be used to design the template.
  - Template should fit the defect exactly in three dimensions and it should not be designed markedly larger than the defect.
  - The flap can be curved to avoid going into hairline or within hair-bearing scalp if necessary.
  - "Gullwing" flap can be designed to reconstruct nasal tip and alae.[1,2,8]
  - The length of the flap is determined by a suture based at the mid brow and rotated between the distal extent of the defect and then up on to the forehead.
- Keep the pedicle/skin bridge on forehead at least 1.5 to 2 cm in width and along the course of the Dopplered supratrochlear artery; this can be narrowed somewhat at the base of flap/pivot point.
- Incise superior flap down through the skin, subcutaneous tissue, muscle, and fascia to a plane above the frontal bone (distal flap can be thinned later).
- Continue to raise the flap from superior to inferior in this plane until a point approximately 2 cm above the brow in the area of the corrugator muscle.
- Corrugator muscle is then dissected away from the underlying periosteum bluntly with scissors or a periosteal elevator.
- Sometimes, supratrochlear artery can be identified here, underneath the frontalis and above the corrugator; corrugator

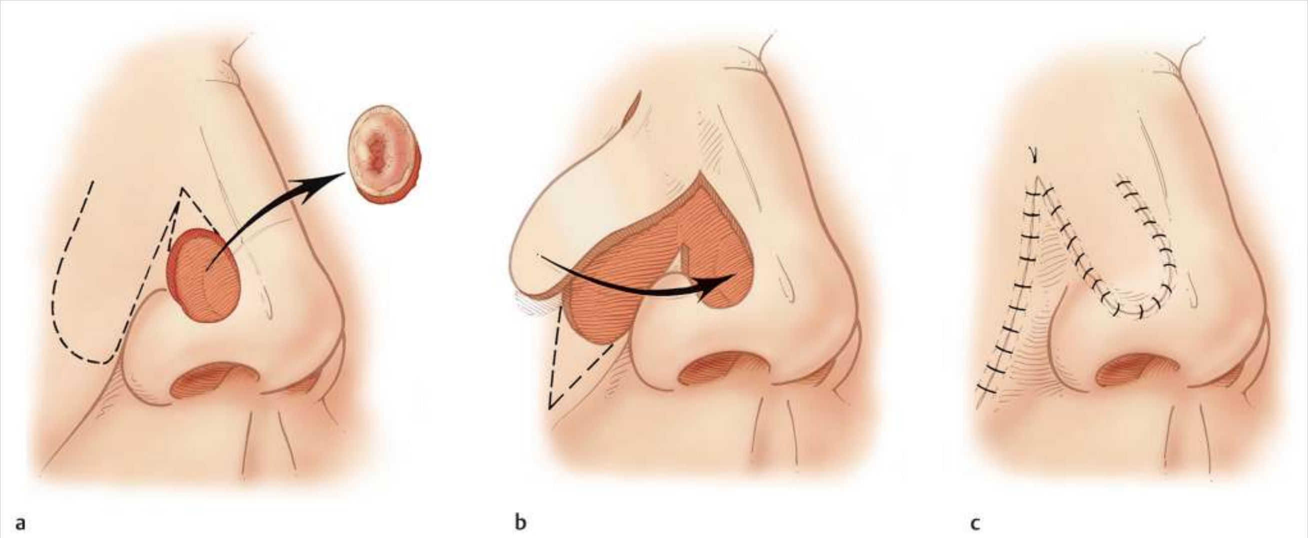

Fig. 16.8 Nasolabial flap. Shows a superiorly based nasolabial flap for alar reconstruction. This flap can be based superiorly or inferiorly depending on the requirements. The donor site is hidden within the nasolabial fold. This flap may require two stages if not interpolated. **(a)** Design of flap and excision of lesion. **(b)** Raising of superiorly based flap. **(c)** Inset of flap and primary closure of donor defect.

generally must be divided on either side of pedicle to allow adequate elevation and rotation of flap.

- Pedicle in this area is bluntly dissected away from surrounding tissues and freed. Dissection is downward into medial canthal region and root of nose until sufficient pedicle length and flap mobility are achieved to allow tension-free closure.
- Distal flap is thinned directly to remove muscle/fascia and most subcutaneous tissue:
  - Some advocate to keep the flap full thickness in the first stage to preserve vascularity with plans to thin the flap and obtain improved contour in a second stage. This is for a three-stage forehead flap as opposed to a two-stage forehead flap.
- Flap is inset with nonabsorbable sutures in the skin.
- Donor site closure requires wide undermining in the submuscular/subfasial plane; scoring of galea may be necessary.
- Donor site is closed in layers, except in the area of base of pedicle that is left loosely open.
- If superior portion of the flap is not able to be closed (generally for defects greater than 4–5 cm), this area can be left to heal by secondary intent.
- Raw surface of pedicle is covered with petroleum gauze dressing and changed daily. Antibiotic ointment is applied several times per day.
  - Alternatively, you can consider covering the raw surface of the pedicle with a temporary full-thickness skin graft from the groin.
- Flap can be divided and inset generally in 3 weeks.
- Generally, another step for debulking and final contouring is necessary.

16.3.5 Complex Nasal Reconstruction

Reconstructive Options Based on Layer

Inner Lining

- Thin but dry and cannot supply primary cartilage grafts.
- Can support delayed primary grafts.
- Place split-thickness or full-thickness skin graft on healthy bed (underside of flap) and place cartilage at the second stage:
  - Intranasal mucosal flaps:[1,2,3]
    - Thin, can be fragile.
    - Ipsilateral septal mucoperichondrial flap[1,3,10] (▶ Fig. 16.9).
    - The septal branch of the superior labial artery supplies the septum lateral to the nasal spine.
    - Base a septal flap with or without cartilage with a small mucosal pedicle.
    - Contralateral septal mucoperichondrial(DeQuervain's) flap (▶ Fig. 16.9).
    - Based on anterior septal blood supply and hinged laterally.
    - Lateral reach inhibited by dorsal septal strut left in place.
    - Bipedicled flap.
    - Mucosa at alar level will crust and bleed.
    - Create bipedicled vestibular flap based on septum and nasal floor.
    - Close donor defect with ipsilateral septal mucoperichondrial flap or skin graft.
  - Intraoral mucosal flaps:
    - Facial artery musculomucosal (FAMM) flap.
    - Unilateral or bilateral superiorly based, tunneled through incisions in gingivobuccal sulcus.
    - Good blood supply—can be long and folded
    - Humidify air.
    - Preferred to skin grafts and random mucosal flaps.
    - Thick and cause temporary nasal obstruction—can be debulked.
  - Folded extranasal flaps:
    - Forehead and nasolabial flaps can be designed large and folded around and into defect to utilize distal flap skin to recreate inner nasal lining.
  - Free flaps:
    - For necrosis of nasal lining during reconstruction or primary loss of lining.

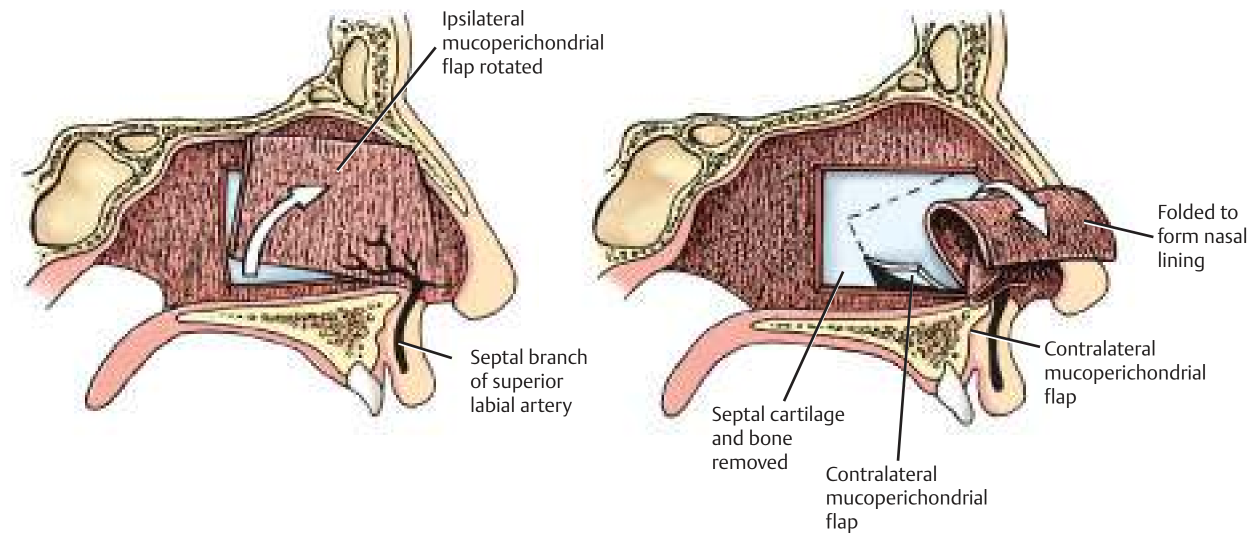

Fig. 16.9 Ipsilateral and contralateral septal mucoperichondrial flaps. The ipsilateral septal mucoperichondrial flap is rotated based on an anterior pedicle from the septal branch of the superior labial artery.

- Radial forearm free flap.
- One or two chambers, upper lip defects.
- Use in areas that have been scarred.

Support

- Donor sites[1,2,3,11]:
  - Costal cartilage and bone:
    - Strong, good for central support.
  - Septal cartilage:
    - Strong, limited quantity.
  - Auricular cartilage:
    - Weak, but has intrinsic curve.
    - Easy to mold.
    - Warping can be an issue over time.
  - Cranial bone:
    - From parietal skull.
    - Secure to remaining bony pyramid with plates and screws.
    - Good for central support, can also be used for lateral side-walls.
- Midline support:
  - Bone or cartilage strut (Gillies technique):
    - Can be sutured or anchored to nasal bones or radix.
    - Can create an L strut with costal cartilage; warping can be an issue.
  - Create a septal composite pivot flap (Menick) of cartilage and septal mucosal lining with a separate dorsal strut or septal hinge flap (Millard) bringing L strut of septal cartilage forward.
  - May need tip grafts or columellar strut grafts for distal tip support.
- Lateral support:
  - Needed to recreate and support alar contour.
  - Often placed underneath flap reconstructions of outer skin.
  - Anatomic alar grafts:
    - Shaped cartilage grafts to model normal lateral crus of lower lateral cartilages and recreate alar rim/contour to resemble normal anatomy.
  - Nonanatomic alar grafts:
    - Alar batten grafts: Fixed cephalad to alar rim from lateral crus of lower lateral cartilage and extending down toward piriform rim. These are used to build up alar collapse.
    - Alar contour grafts: Placed in pocket at inferior-most portion of ala to recreate contour of alar rim. This helps combat external nasal valve collapse.

Outer Cover

- Any of the appropriately chosen and designed flaps described above can be used for coverage.
- Forehead flap:
  - Best in color and texture for the nose.
  - Can be based solely on the rich periglabellar vascular network.

Multilayered Flaps

- Laminated flaps:
  - Ascending auricular helical free flap:
    - Similar in structure to the nasal ala.
    - Has cartilage sandwiched between thin skin on either side.
    - Close donor site with helical advancement flap or postauricular flap.
- Prelaminated flaps:
  - Prelamination at a distant side allows for recruitment of additional tissue for adjacent defects, and allows for scar contracture and settling to occur without altering local/regional flaps.
  - Allows forehead flap to be used after contractive forces have settled.

16.4 Conclusion

Nasal reconstruction is perhaps the oldest and most described procedure in plastic surgery, with origins dating back to the ancient ages. In modern times, a large majority of nasal reconstruction occurs after cancer excision but still relies on the tenets of age-old principles based on the underlying anatomy in order to determine the optimal reconstructive method and technique.

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17 Cheek Reconstruction

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Abstract

Cheek reconstruction is a key but often overlooked concept in plastic surgery. It is a common problem after resection of cutaneous malignancies, and the same principles can be used to reconstruct large complex defects as after head and neck tumor resection or trauma. This chapter aims to outline the concepts, the variety of options, and procedural specifics of various reconstructions of the cheek. Zones of the cheek, key considerations, specifics of primary closure of cheek, and local/regional flaps will be reviewed including details on performing cervicofacial and cervicopectoral flaps, a workhorse in large cheek defect reconstruction. In addition, facial artery perforator flaps and parotid duct repair will be reviewed.

Keywords: cervicofacial flap, cheek advancement, cheek reconstruction, facial artery perforator, parotid duct

17.1 Introduction

17.1.1 Borders and Anatomic Subunits

The cheek is a key aesthetic unit of the face. Being a large noticeable surface, untoward scarring can be quite obvious especially in younger patients with fuller faces and elastic skin. The cheek is bound superiorly by the eyelid-cheek junction medially and the zygomatic arch laterally; inferiorly by the inferior border of the mandible; medially by the lips, nasofacial junction, and the nasolabial fold; and laterally by the preauricular crease.[1]

The cheek is also divided into individual aesthetic subunits or zones as described by Zide and Longaker.[1,2,3,4] As the cheek is a cosmetically sensitive area, we prefer to reconstruct defects by aesthetic subunits whenever possible as opposed to simply closing a wound. Three zones of the cheek have been described (▶ Fig. 17.1).

- Zone 1 (suborbital) comprises the upper medial cheek, malar cheek, and eyelid-cheek junction going inferiorly to the mid cheek. There is less laxity in this area than in other areas due to tethering by the orbitomalar ligament and the zygomatic ligaments. In this zone, scars can be hidden in the eyelid-cheek junction and the nasolabial fold.
- Zone 2 (preauricular) comprises the full height of the cheek laterally and posteriorly. Primary closure is relatively easier in this zone.
- Zone 3 (buccomandibular) is the inferomedial cheek below Zone 1. In this zone, skin can be “borrowed” or advanced from the neck.[1,2,3,4]
- ▶ Fig. 17.1.

17.1.2 Key Considerations

The cheek has a distinct pattern of creases and relaxed skin tension lines (RSTLs) that should be always be taken into account when designing primary closures or local flaps.[5] You should always attempt to place incisions at the cheek margins, subunit borders, within the already present creases, or within the RSTL (▶ Fig. 17.2).[3]

Since the cheek comprises a large part of the face and many of these defects can be closed primarily or with local flaps, distortion of neighboring functional or aesthetic structures must be taken into consideration. As stated earlier, reconstructing aesthetic subunits in adjacent defects individually is preferred. For example, if the lip, nose, or eyelid is involved, you should try to reconstruct those areas separately if able.

- Zone 1: Pay careful attention to tension on the lower eyelid, especially in patients with preoperative eyelid laxity.[1,3] You should examine eyelid laxity and look for scleral slow or frank ectropion prior to reconstruction. When reconstructing zone 1, always try to direct tension medially and laterally rather than superiorly and inferiorly.[4,5]
- Zone 2: Be careful not to distort borders of the hairline and bring hair-bearing skin into non-hair-bearing areas and vice versa. Avoid distorting the temporal hairline and the side burn as well as the beard at the inferior mandibular border in men.[1,3]
- Zone 3: Ensure not to distort the upper or lower lip.[1,3] In general, attempt to close adjacent lip defects using more traditional lip reconstruction techniques if able.

If the defect is complex and involves the facial nerve, this should be reconstructed at a later time. You should use a nerve stimulator, identify the cut ends, and tag them for later reconstruction.[3]

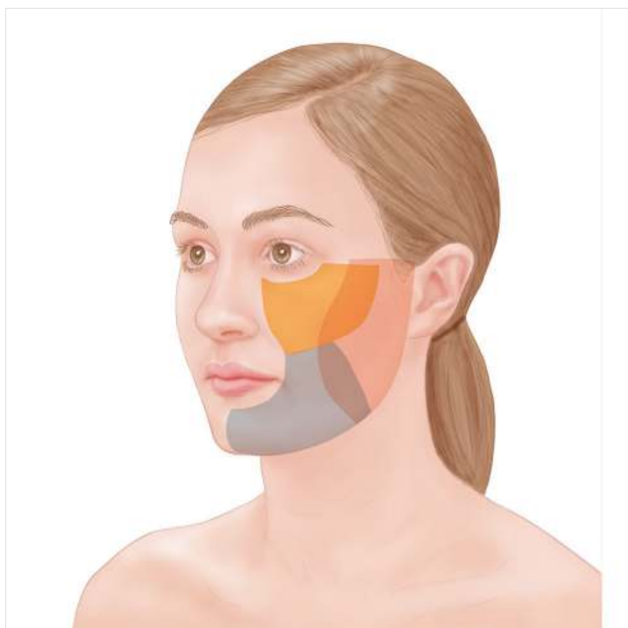

Fig. 17.1 Zones of the cheek as described by Zide and Longaker. Zone 1: suborbital. Zone 2: preauricular. Zone 3: buccomandibular.

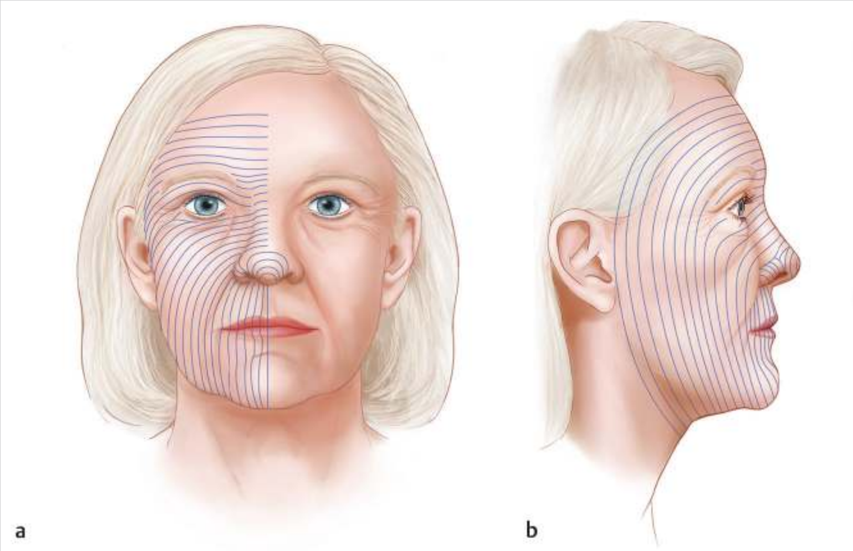

Fig. 17.2 (a, b) Relaxed skin tension lines (RSTLs) of the face. These will always be oriented 90 degrees to the pull of the underlying muscle. A circular incision will become an oval after excision where the long axis will be along the RSTL.

17.2 Indications

17.2.1 Preoperative

- Obtain a thorough history and physical of the patient. Take particular note of:
  - Medical comorbidities: May relatively contraindicate a prolonged procedure.
  - Previous facial or neck procedures: May preclude certain reconstructions.
  - Anticoagulants: Large vascular flaps with wide dissections may have a higher risk of hematoma and potential flap loss.
  - Smoking: Can negatively impact wound healing and large random pattern flaps.
- Defect should be *thoroughly analyzed* after resection, whether done by the plastic or head and neck surgeon, after Mohs resection, or traumatic injury.
  - First note the size of the defect and your preliminary understanding of its simplicity or complexity.
  - You should always note *what is present and what is missing* in any defect:
    - Is there adequate well-vascularized surrounding tissue or changes such as radiation, trauma, or infection?
    - Are there intact deeper layers such as mucosa/muscle or is the defect full thickness?
    - Is there injury to the facial nerve, parotid duct, or vascular structures?
    - These are just some of the questions that should be considered and not a complete list of all considerations.
  - You should analyze which subunits the defect comprises and pay attention to the key considerations as above.
  - You should note if the defect involves other units of the face such as the nose, lips, lower eyelid, ear, scalp, or neck.
- Examine any other specific areas that are needed:
  - Check for lower eyelid distraction and perform snap-back test for suborbital reconstruction.
  - Check for facial nerve function.
  - Cannulate and irrigate the parotid duct.

17.2.2 Intraoperative

- If you are the one performing the excision, we recommend:
  - Use of local anesthetics with epinephrine and allowing adequate time for it to take effect prior to incision. The face is highly vascular and inadvertent damage to critical structures can occur in a bloody field.
  - Excising defects in as much of a circular shape as possible. After excision, a circular wound will take an ovoid shape. This will show the surgeon the direction in which the wound "wants to close" or how the RSTLs are oriented.
- Anchor flaps to prevent distortion of other structures:
  - Anchor flaps to the infraorbital rim or place a lateral support suture tacking flap above zygomatic arch to prevent lower eyelid traction.[1,3,5]
- Excise redundant dog-ears, especially in the nasolabial fold.[3,5,6]
- Consider using drains for large flaps.[1]
- Consider lower eyelid canthopexy or canthoplasty to avoid ectropion.[3]
- Specifics and various flap options are discussed in the following sections.

17.2.3 Postoperative

- If you are worried about vascular issues in your flaps, we have found nitroglycerin ointment extremely helpful. Rapstine et al also advocate for 2% nitroglycerin ointment postoperatively if there are any issues with vascular compromise or congestion.[1]
- Head elevation to decrease swelling:
  - Avoid ice to prevent vasoconstriction to your flap!
- Our preferred dressing is a thin layer of antibiotic ointment (bacitracin) three times daily and allowing a shower 48 hours after wound closure.
- After healing has been achieved, Rapstine et al advocate for 3 months of silicone sheeting and Bio-Oil® for scar softening. We have also found Bio-Oil® to be extremely helpful. Triamcinolone intralesional injections can be performed for hypertrophic scarring.[1]

   - Caution should be taken with steroid injections in the face as subcutaneous atrophy, scar widening, and discolorations can lead to worsening of the scars.
   - Laser therapy is an alternative consideration.

17.3 Operative Technique

17.3.1 Options for Cheek Reconstruction

As is dogma in plastic surgery, you should always consider replacing tissue with "like" tissue. Therefore, primary closure and local tissue are the first choice in cheek reconstruction.[5] Rapstine et al in a series of 422 patients closed 53% of cheek defects primarily and 19% with cervicofacial flaps.[1]

17.3.2 Primary Closure

Small wounds can be converted to an ellipse and closed relatively easily.[5] One must attempt to close in the direction of the RSTLs and not create any undue tension on adjacent structures. Up to 4 cm of undermining can be done in either direction to allow for tension-free closure but undermining should only be done as much as necessary.[4] In addition, excising redundancies or "dog-ears" at either end will prevent postoperative cosmetic deformity.[3]

In the Rapstine et al series, they advocate for the following[1]:

- First, sit the patient upright to examine for any pre-existing scleral show or ectropion.
- Use sutures to close the wound temporarily in different orientations to determine the best direction in which to close it.
- Only undermine as much as necessary!
   - You may burn the bridge for a future reconstruction with unnecessarily aggressive and wide undermining.
- Precisely excise any dog-ears as they may not completely settle in areas of loose skin.

Additional Tips

- After excising defects, circular wounds will take on an ovoid shape showing the surgeon the direction of the RSTLs.
- Undermining should be done in a subcutaneous plane as in a facelift and can be done with electrocautery or scissors.
- Have your assistant place two single or double hooks on the edge of the wound.
- When they provide traction, it should be directed straight toward the ceiling at 90 degrees to the floor to prevent uneven undermining or "button holing" the skin.
- Use your nondominant thumb to provide traction toward yourself on the side of the retractors closest to you. Use your nondominant index finger to provide counter traction on the flap on the opposite side of the retractors farther from you. Again, this is similar to a facelift type of dissection.
- When dissecting, align the skin surface with your eye. This allows you to keep an even depth of undermining and a consistent flap thickness.
- We prefer closure with 5–0 PDS (4–0 if the wound is larger with higher tension) and 6–0 nylon or prolene in an interrupted or running fashion.

17.3.3 Skin Grafts

Skin grafts can be a useful adjunct in certain scenarios. Patients who are elderly or have certain comorbidities who cannot undergo a prolonged procedure are good candidates.[1,3] Patients with small defects around the eyelid-cheek junction or the medial canthus may also be amenable.[1] The best scenario in which to place a skin graft is in *patients with large tumors, ill-defined borders, or any other scenario where you are waiting for definitive margins or patient is at high risk for local recurrence.*[3,4]

We prefer full-thickness skin grafts (FTSGs) whenever possible as wound contraction can complicate split-thickness skin grafts.[1,4] In addition, poor color match can be an issue.[1] It is preferable to take a full-thickness graft from the preauricular, postauricular, supraclavicular, or upper back regions to better match the color.[3,4]

Our preferred technique:

- Harvest the skin graft in an elliptical fashion in a subdermal plane to make defatting the graft quicker.
- Place four mosquito clamps on the corners of the ellipse and drape the graft over your nondominant index finger with the dermis side up.
- Using a curved iris scissor with the point of the scissors facing up, press the midportion of the blades into the graft to defat and thin it.
- Place the graft into the wound and secure with multiple 4–0 silk sutures around the periphery leaving one tail long to tie over a bolster.
- Inset graft in between the silk sutures with 4–0 or 5–0 Chromic in an interrupted or running fashion.
- Place xeroform and wet sterile cotton over the graft and tie the silk sutures over the bolster dressing.
- Leave this bolster on for 5 to 7 days.

17.3.4 Local Flaps

If the defect is too large to close primarily, small local flaps can be useful. Two main categories of local flaps for cheek reconstruction are advancement and transposition flaps.[3]

- Advancement flaps:
   - Unipedicle advancement flap.
   - V-Y advancement flap:
      - Flap should be designed in RSTLs.[1]
      - This is a good option for medial defects close to the alar base as the flap can be designed in the nasolabial fold.[1,3]
      - Consider excising the lesion as a square or rectangle to match the leading edge of the flap.[3]
   - Consider anchoring these flaps to the periosteum of the zygoma or maxilla to prevent traction on adjacent structures.[3]
- Transposition flaps:
   - Bipedicled transposition flaps.[4]
   - Geometric flaps: Banner flaps, bilobed flaps, rhomboid flaps:[3]
      - Bilobed flaps: Consider creating the donor site at the jaw line or in the neck for hiding the scar better and using lax neck skin.[4] These are good for *chin defects*.[1]
      - Rhomboid flaps: Extension from the 120-degree angle of the defect should lie in the RSTL (▶ Fig. 17.3).[4]

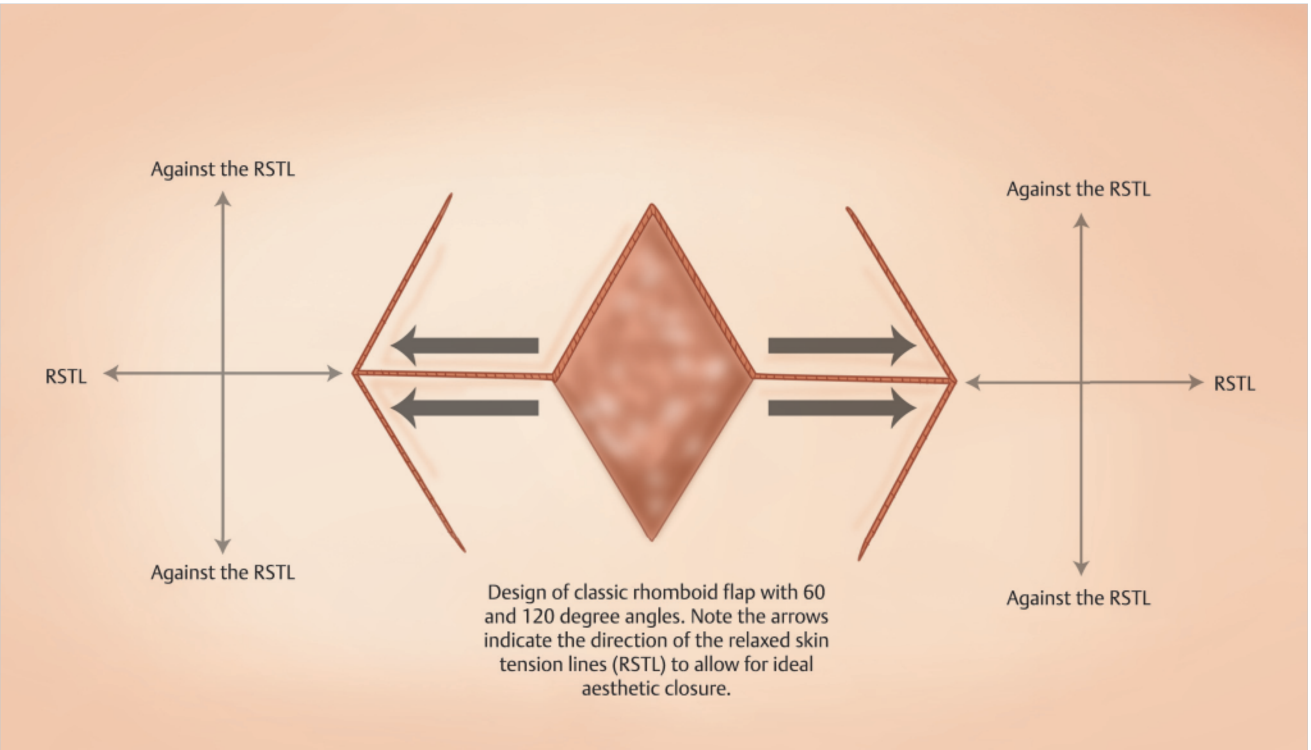

Fig. 17.3 Rhomboid flap design. Design of a classic rhomboid flap with 60- and 120-degree angles. Note the *arrows* indicate the direction of the relaxed skin tension lines (RSTLs) to allow for ideal aesthetic closure.

 - Take time to plan the donor sites within the RSTLs, existing creases, or the nasolabial fold.[3]
 - There are some inherent disadvantages to these flaps like pin cushion or trap door scars.[3] In addition, due to their geometric configuration, inevitably some of the incisions will be against the RSTLs and cause more noticeable scarring.[1]

17.3.5 Cervicofacial and Cervicopectoral Flaps

These flaps are the workhorse local flaps for larger cheek defects. In the Rapstine et al series, almost 20% of defects were closed with a cervicofacial flap.[1] These flaps are made in a "cut as you go" fashion as they can be designed from small to very large, extending onto the chest. You should keep dissecting until you can obtain a tension-free closure.[6] One tip is to design and raise these flaps prior to sentinel lymph node biopsies/neck dissections or parotid resections as they may interfere with your flap (▶ Fig. 17.4).[4]

- When planning for these flaps, look for the areas of skin excess. If there is excess skin on the neck and chest, then an *anteriorly or medially based* flap would be more beneficial. However, if there is excess skin on the jowl, this would be most useful for a *posteriorly or laterally based* flap.[3,5,6]
- Anteriorly/Medially based flaps (▶ Fig. 17.5): *These flaps rotate forward*[1,3,5,6]
  - Design should start at the superior aspect of the defect and travel superolaterally in the eyelid-cheek junction.
    - Avoid subciliary incisions and violating the eyelid if possible. This may bring thick cheek skin onto the lower eyelid.
  - At the lateral canthus, the incision turns horizontal to travel in the lateral canthal lines and extends across the temporal region or at the superior aspect of the zygomatic arch.
  - At the sideburn you can design the flap around the sideburn or into the hairline.
    - Designing around the sideburns prevents bringing hair-bearing skin onto the non-hair-bearing skin especially in women.
  - At the root of the helix, incision turns inferiorly and designed into the preauricular crease.
    - Posterior pressure on the facial skin toward the ear can show this crease if it is not already well defined.
  - Incision is then designed similar to a facelift: Around the lobule, superiorly in the retroauricular crease, and transitioning inferiorly into or at the occipital hairline at the level of the tragus.
  - Subcutaneous undermining taken down to the level of the clavicle.
  - If additional length is needed (for > 6-cm defects), a cervicopectoral flap is created:
    - Incision can be designed down into the neck and travel 2 to 3 cm behind the anterior border of the trapezius, lateral to the acromioclavicular joint, into the deltopectoral groove and along the lateral border of the pectoralis major.
    - 2 to 3 cm above the nipple, at the level of the third or fourth intercostal space, the incision is designed across the chest.

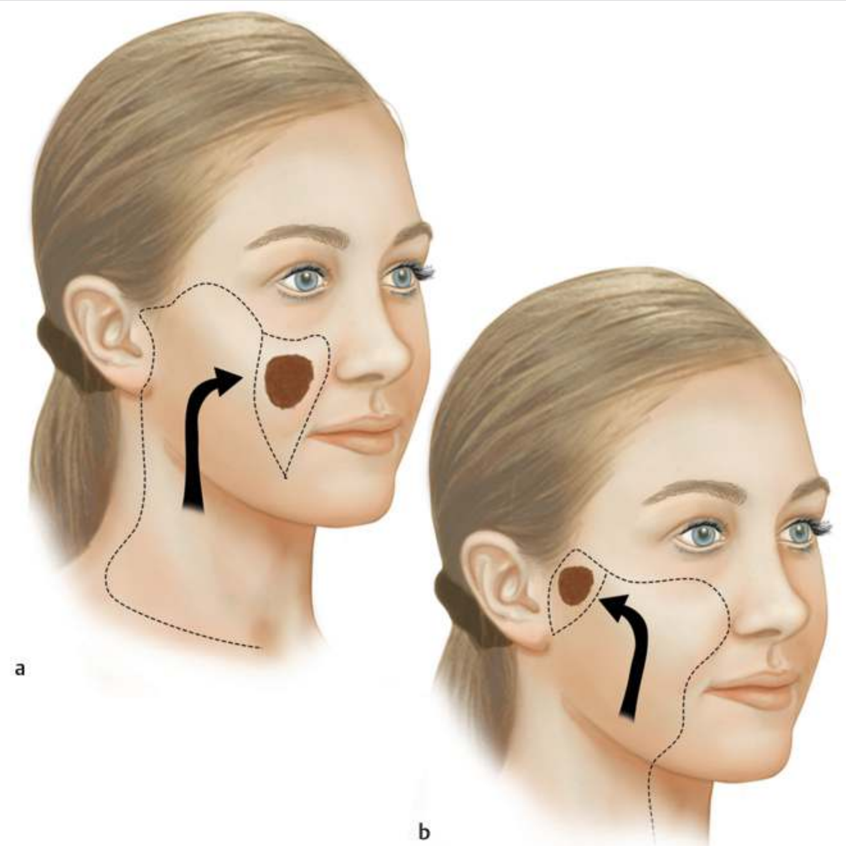

Fig. 17.4 **(a)** Anteriorly and **(b)** posteriorly based cervicofacial flaps.

- A small back-cut can be made along the parasternal border.
- The flap is then undermined and *transitioned from subcutaneous to subplatysmal 2 to 4 cm below the mandibular border. The platysma is then elevated with the flap*.
- The flap is based on the internal mammary artery perforators from the second and third intercostal spaces.

◦ Flap is then rotated anteriorly and any dog-ear is excised within the nasolabial fold or an RSTL.
◦ A lateral support stitch should be placed and be directed superiorly at the lateral canthus above the zygomatic arch to prevent ectropion.
◦ Periosteal anchoring of the flap can prevent traction on the lower eyelid.
  – Care must be taken to prevent distal flap necrosis with this technique.
◦ Consider lower eyelid canthopexy or canthoplasty.
◦ Consider drain placement.
◦ Donor site can be closed primarily, with FTSG or V-Y closure.
◦ Disadvantages/complications: Flap necrosis, hairline displacement, ectropion, lower eyelid edema:
  – Posteriorly/Laterally based flaps: *These flaps rotate up* (▶ Fig. 17.6).[3,6]
◦ Design should begin at the superior aspect of the defect travelling medially.
◦ The incision should then travel inferiorly in the nasolabial fold.
◦ For moderate-sized defects, the incision can then continue across the mandibular border into the middle or lower one-third of the neck.
  – One can then design a back-cut across the neck toward the sternocleidomastoid, parallel to the mandibular border and turn superiorly toward the mastoid process or the earlobe.
◦ For larger defects, the vertical neck incision can continue into the parasternal region.
  – Design can then turn laterally across the chest 2 to 3 cm above the nipple.
  – A back-cut can be designed along the lateral border of the pectoralis major.
◦ For larger flaps, the platysma can be included by dividing it 2 to 4 cm below the mandibular border and dissecting below the platysma.
◦ Periosteal anchoring of the flap can prevent traction on the lower eyelid.
  – Care must be taken to prevent distal flap loss with this technique.
◦ Consider lower eyelid canthopexy or canthoplasty.
◦ Consider drain placement.
◦ Donor site can be closed primarily, with FTSG or V-Y closure.
◦ Disadvantages/complications: Scar in the central face, lower eyelid edema, medial ectropion, nasolabial fold asymmetry, flap necrosis:
  – For the posteriorly/laterally based flaps, flap necrosis is less common.

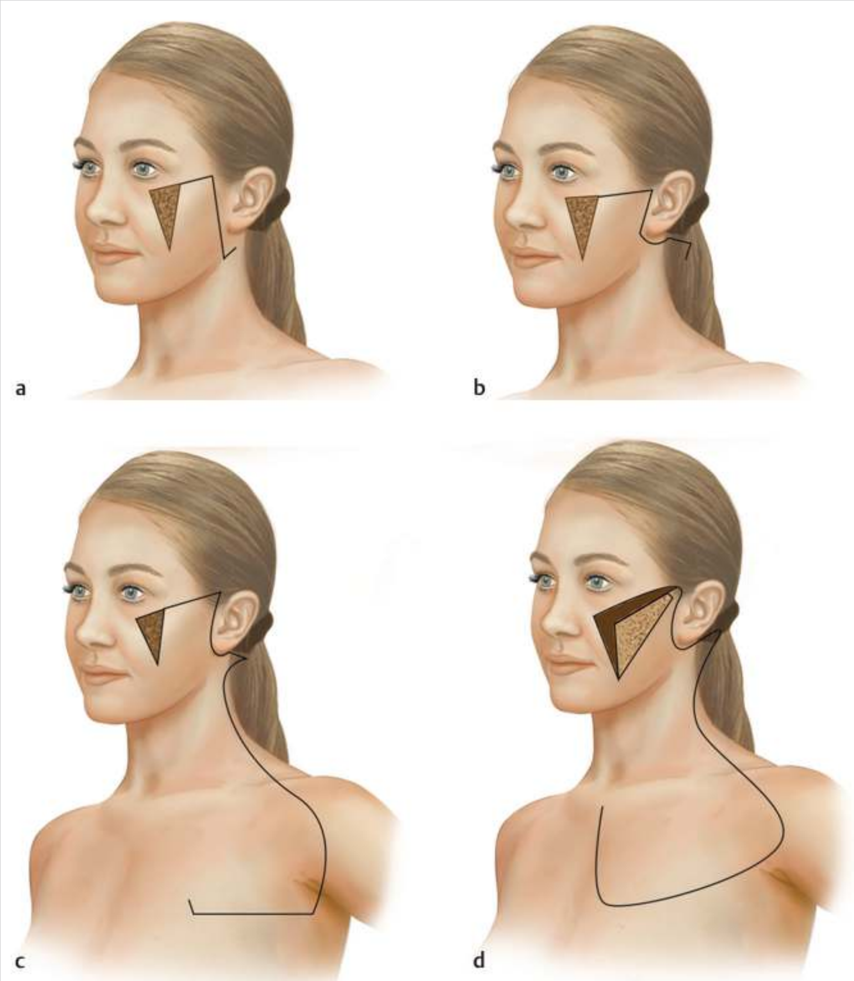

Fig. 17.5 (a–d) Anteriorly based rotation flaps. The various designs of anteriorly based cervicofacial and cervicopectoral flaps.

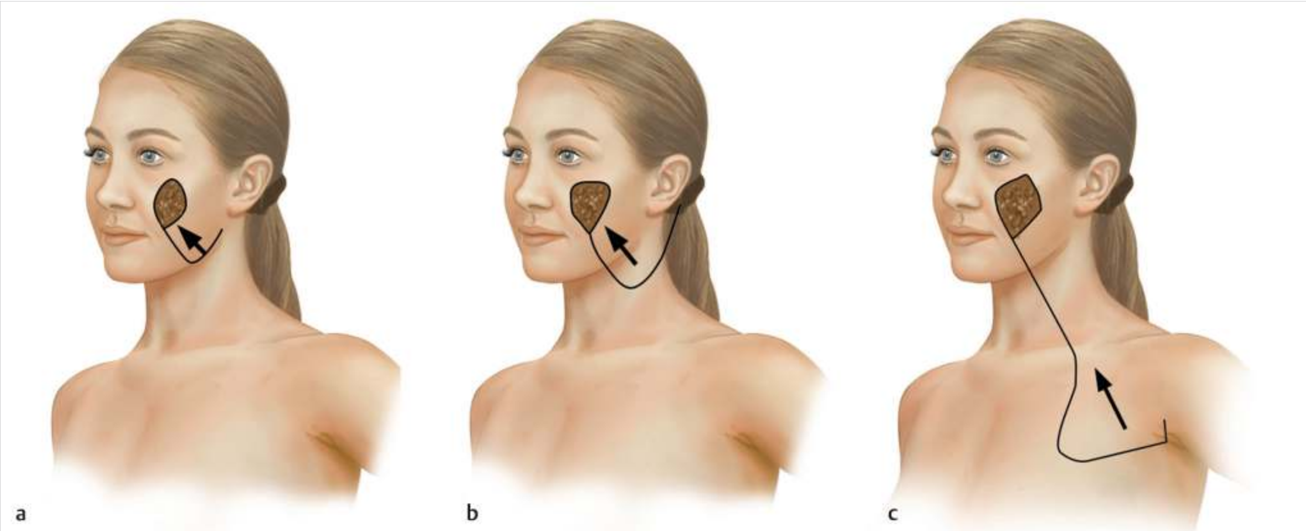

Fig. 17.6 (a–c) Posteriorly based rotation flaps. The various designs of posteriorly based cervicofacial and cervicopectoral flaps.

17.3.6 Regional Flaps

Regional flaps can also be an option for very large defects or if they may provide a more aesthetic result.

- Submental artery flap.[5]
- Trapezius flap.[3]
- Pectoralis major flap:[3,4]
  - Can be used as a myocutaneous flap for lower lateral defects that are complex and require lining:
    - Use a 6 to 7 cm vertically oriented skin paddle medial to the nipple.
  - Can be very bulky.
  - Best for patients with complex defects and unable to undergo more extensive procedures.
  - Use caution to avoid extensive subcutaneous undermining deep to the breast especially in patients with macromastia: Significant skin/fat/nipple necrosis can occur.

17.3.7 Free Flaps

In certain circumstances a free flap may be required. Scenarios in which free tissue transfer may be necessary are a patient who has a large complex defect, requires intra- and extraoral coverage, or has exposed critical structures and is able to undergo a prolonged procedure. Skin from the upper chest or back may have a better color match than other areas. One can also consider de-epithelialization and split-thickness skin graft from the scalp for improved color match.[5] Options for free flaps are[4,5]:

- Scapular and parascapular: Best color match option, large surface area, can include bone.
- Radial forearm: Thin, can include bone, can be sensate.
- Anterolateral thigh (ALT): Large surface area, thicker in obese patients, poor color match, can be sensate.

17.3.8 Special Topic: Facial Artery Perforator Flaps

Perforator flaps have become a standard treatment for reconstruction of defects around the body whether pedicled or free. The development of the perforasome concept has brought these flaps into popularity.

Facial artery perforator flaps have been described in the literature and are a good adjunct to treat defects of the cheek and adjacent defects of the upper and lower lips. Hofer et al showed a minimum of 3 and an average of 5.7 perforators along the course of the facial artery with an average diameter of 1.2 mm. The length of the perforators was between 1.3 and 5.1 cm and most of them were found *6 to 8 cm from the facial artery origin*.[7] Qassemyar et al, in a study of 101 facial artery perforators, found an average of 5 perforators that were greater than 0.5 mm in diameter and an average diameter of 1 mm. Most were found *4 to 6 cm from the facial artery origin*. In addition, they performed selective injections to determine the average perforasome supplied by each perforator, which was around 8 cm^2.[8] Hofer et al proposed the following technical steps[7]:

- Follow the course of the facial artery with a handheld Doppler.
- Create a template of the defect and design it over the facial artery.
- Make an incision on one side of the proposed flap.
- Dissect and identify any perforators going into the flap.
- Once a perforator is identified, the rest of the flap can be incised, dissected, and rotated.

We have found that perforators can be localized using a handheld Doppler without interference from the main source vessel. Therefore, we identify the perforator with the Doppler, design the flap over it, and incise/dissect the flap without excessively skeletonizing the pedicle. *As with other small perforator flaps where the arterial and venous systems do not run together (i.e., dorsal metacarpal artery perforator flap), a cuff of subcutaneous fat must be kept around the pedicle to preserve small veins and allow for appropriate drainage of the flap.*

17.3.9 Special Topic: Parotid Injury

Although parotid duct injury may not occur routinely with cheek tumor resections, it is crucial to be aware of the parotid gland and duct and how to deal with any injury if necessary.[9]

Diagnosis

Parotid duct injuries are usually suspected in any injury or resection along a line from the tragus to the oral commissure or mid upper lip. The best diagnosis is to cannulate the duct intraorally. A small pediatric angiocatheter attached to a syringe can be used to cannulate the papilla on the buccal mucosal surface opposite the second maxillary molar. Injection of saline will produce extravasation if there is a ductal injury. We do not recommend irrigation with methylene blue as the tissues can be stained making finding facial nerve or other structures much more difficult. Alternatively, the gland can be massaged to see if saliva extravasates into the wound.

Concomitant Injury

The buccal branches of the facial nerve have a high rate of concomitant injury with the parotid duct. Facial nerve injury can occur in 20% of patients with injury to the parotid gland and 50% of patients with injury to the parotid duct. A line from the lateral canthus to the antegonial notch is a good landmark to keep in mind. Any nerve laceration lateral to this line should be repaired.

Vascular injury, injury to the external auditory canal, and trauma to the temporomandibular joint are all possible as well.

Gland and Duct Repair

Any injury to the parotid gland should have a capsular repair alone.

Injury to the duct should be repaired if possible. The distal stump is usually easy to find with the retrograde passing of a silicone stent or pediatric feeding tube. The proximal end can be difficult to find. Massaging the gland to produce salivary extravasation can help locate it. Partially approximating the wound can bring the distal stump into the area where the proximal end may be found. If it cannot be found, ligation is recommended.

Once both ends are identified, a silicone stent or pediatric feeding tube is placed in both ends and the duct is repaired with 8–0 or 9–0 nylon suture using a microsurgical technique. If there is too much tension, a vein graft is an option. The end of the tube or stent is sutured to the buccal mucosa.

Postoperative Care

Antisialogogues (i.e., atropine) and antibiotics are given. External compression is usually applied for at least 48 hours. The stent can be removed in 2 weeks.

17.4 Conclusion

Cheek reconstruction is often overlooked in its "simplicity" but there are key maneuvers that can improve its success from a functional and aesthetic standpoint. Local flaps are the workhorse in cheek reconstruction. Understanding how to appropriately design and execute the variety of flap options is paramount to success. The surgeon should not shy from anchoring flaps and performing lower eyelid support procedures as it is easier to avoid the cicatricial ectropion rather than correct it. Drains should be highly considered for larger flaps with extensive undermining to avoid hematoma and flap compromise. Regional flaps are a good option if microsurgery is not available. However, free tissue transfer may offer an improved outcome if possible.

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Subsection ID
Trauma

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18 Mandible Reconstruction

Jason Yoo

Abstract

Mandible reconstruction after trauma can be approached through various methods depending on the stability, location, and type of fracture, and clinical characteristics of the patient. Mandible fractures are common facial fractures. Computed tomography (CT) scan is the gold standard for radiological evaluation. Teeth in line of the fracture should be extracted when infected or mobile. The atrophic mandible has a tenuous blood supply and periosteal stripping should be minimized. Closed reduction with arch bars or fixation screws is often sufficient for minimally displaced fractures. Open reduction internal fixation (ORIF) can be performed using intraoral or extraoral approaches depending on the site of the fracture and may be used in conjunction with maxillomandibular fixation.

Keywords: fracture, mandible, maxillomandibular fixation, ORIF, trauma

18.1 Introduction

Mandible fractures are one of the most common fractures of the face, second to nasal bone fractures.[1] In the United States, mandible fractures occur most frequently in men and between the age of 18 and 54 years of age. Mechanism of injury is more commonly from assault followed by motor vehicle accidents and falls. In women, etiology is more commonly from motor vehicle accidents. In elderly patients, mandible fractures result mostly from falls.[2] Given the high incidence of the mandible involvement in facial fractures, the plastic surgeon must be equipped with the skills for their management. In this chapter, the evaluation and operative management of mandible fractures are discussed.

18.2 Indications

18.2.1 History and Physical Examination

- Mechanism of fracture.
- Other injuries.
- Associated comorbidities.
- Surgical history.
- Dental history.
- Palpation: Assess for step-offs, tenderness, and crepitus.
- Neurological examination: Assess sensation in the V3 region and facial nerve function.
- Intraoral examination: Assess gingiva, soft tissue, dentition, and dental hygiene.
- Assess occlusion.
- Preinjury photos, if possible.

18.2.2 Imaging

Plain Films

- At least two views must be obtained such as orthopantomogram (panoramic view) and posteroanterior view at 10 to 15 degrees.
- Alternatively, mandible film series: Posteroanterior, lateral, reverse Towne, and oblique lateral views.
- Decreased sensitivity for identifying coronoid fractures.

Computed Tomography

- Gold standard for identifying mandible fractures.
- Increased sensitivity.
- Option of three-dimensional reconstruction imaging available for preoperative planning.

18.2.3 Closed Reduction with Maxillomandibular Fixation

- Minimal displacement.
- Minimal bone defect.
- Favorable reduction.
- In conjunction with open reduction internal fixation (ORIF).

Contraindications to Closed Reduction

- Poor patient adherence.
- High risk of airway compromise.
- Severe pulmonary dysfunction.
- Psychosis.
- Seizure disorders.[3]

Placement of Screws

- At least two mandibular and two maxillary sites of fixation spanning across each side of the fracture (▶ Fig. 18.1).
- Regions of high bony stock:
  - Anterior vestibular region: Anterior maxilla to symphyseal/parasymphyseal mandible.
  - Anterolateral transition zones (canine/premolar): Zygomaticomaxillary crest to the region of the oblique line of the mandible.
- Avoid regions at high risk of dental root injury or minimal bony stock: Maxillary and mandibular molar regions.
- Minimize placement of screws through areas of excessive soft tissue:
  - Mentalis and lower lip depressor muscles of the mandible between the mandibular canines reduce the height of the inferior labial sulcus requiring the inferiorly angulated placement of the screws to allow for screw head exposure.[4]

Fig. 18.1 Placement of maxillary and mandibular screws for screw fixation in a patient with a right mandible angle fracture.

Fig. 18.2 External fixation of a severely comminuted mandible.

18.2.4 Tooth Involvement within the Fracture Line

- Tooth extraction indicated when:
  - Active infection of the tooth is present including dental caries.
  - Mobile tooth: Compromised periodontium.
  - Fractured roots, exposed roots.
  - Prevents proper reduction of fracture.[5]
- Every attempt should be made to retain teeth.
- Administer systemic antibiotic therapy.

18.2.5 Edentulous, Atrophic Mandible

- Atrophic mandible defined as < 20 mm of mandibular height.
- Usually involve the elderly population whose medical comorbidities and decreased vascular supply to the mandible are concerning for poor fracture healing.
- When using an open approach, avoid stripping the periosteum to prevent damage to the periosteal blood supply.
- Closed management typically difficult as elderly patients tend to tolerate maxillomandibular fixation (MMF) less.
- Other closed approaches available such as external fixation.
- Gunning splints and circummandibular wiring which avoid periosteal stripping (▶ Fig. 18.2).[6,7]

18.2.6 Comminuted Fractures

- Management via open rigid fixation or closed reduction depends on the nature of the fracture.
- Indications for closed management:
  - Fractures are minimally displaced.
  - Bridge to definitive therapy in the setting of soft tissue defect.
  - Tenuous blood supply to the mandible.
- Indications for open management:
  - Fractures are significantly displaced requiring adequate reduction.
  - Bony avulsion injuries.
  - Other procedures are performed requiring an open approach (i.e., bone graft).[8]

18.2.7 Condylar Fractures

- Indications for open management:
  - Displacement into middle cranial fossa.
  - Lateral extracapsular displacement.
  - Presence of foreign body.
  - Fragment angulation > 30 degrees.
  - Bone gap greater than 4 to 5 mm.
  - Inability to perform closed reduction.[9]
  - Failure of conservative management.

18.3 Operative Techniques

18.3.1 Closed Reduction: Maxillomandibular Fixation

Arch Bar Fixation

Erich Arch Bars

See the example of Erich arch bars in ▶ Fig. 18.3a.

- Attempt manual reduction of the dental arch and mandible as close to occlusion as possible.
- Cut the arch bar to the length of each dental arch without extending past the most distal tooth.
- With the lugs oriented toward the arch bars concave apically; secure the arch bars just apical to the crown of each tooth with 24- or 26-gauge wires that pass circumdentally with the free ends of the wires oriented buccally.
- With the lugs of the arch bars oriented concave apically to the body of the arch bar and the other end of the wire oriented occlusal to the body of the arch bar, intertwine the ends of the wires together by twisting in a clockwise fashion until the arch bar is secured in place. Ex vivo data suggests grasping the wires 5 to 10 mm from the arch bar and twisting at a 45 degrees angle relative to the tooth axis to reduce wire fatigue and failure.[10]

Fig. 18.3 (a) Panoramic view of a patient with a right parasymphyseal fracture status post open reduction internal fixation (ORIF) and maxillomandibular fixation (MMF) with Erich bars. **(b)** Postoperative photo demonstrating ORIF and the use of orthodontic rubber bands instead of wires for MMF.

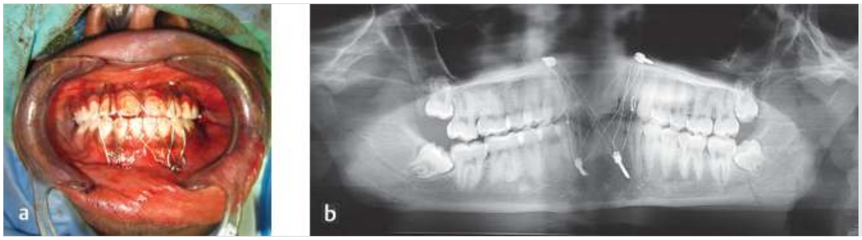

Fig. 18.4 (a) Four-point fixation with fixation screws and cerclage wiring. **(b)** Panoramic view of four-point fixation.

- Tighten the wires on the greater segment (segment with more teeth) of the mandible first.[11] With the fracture reduced, tighten the wires on the lesser segment. Ensure that the wires are apical to the widest portion of the crown prior to tightening to prevent wire loosening using a wire pusher.[11]
- Trim the ends of the wires with a wire cutter and bend the ends so that they are oriented toward the gingiva.
- Bone wax may be applied to the wires to prevent gingival and mucosal irritation.
- Alternatively, orthodontic rubber bands may be used instead of wires (▶ Fig. 18.3b).
- Place the maxilla and mandible in occlusion and secure the lugs of each respective arch bar together using wires or rubber bands.
- Remember to keep wire cutters at the bedside in case of emergency removal of wires.

Fixation Screws

- Locate and palpate the areas for screw fixation at the level of the mucogingival junction within the interradicular space to assess the bone quality.
- Expose the underlying bone by incising the gingival mucosa with needle electrocautery or a #15 blade.
- If using self-drilling screws, use constant and moderate pressure to pierce the outer cortex of the bone until the screw engages. Once past the outer cortex within the spongy bone, there will be a decrease in resistance until contact is made with the inner cortex. If there is no drop in resistance, it is possible that the screw is in contact with a tooth root and repositioning of the screw is required.
- When attempting bicortical placement, continue to drill the screw through the inner cortex to the lingual mucoperiosteum with constant irrigation of the drill. Palpate the lingual mucosa to ensure that the screw was not overadvanced to prevent irritation to the tongue.
- If self-tapping screws or if the outer cortex is greater than 2.5 to 3 mm in thickness, use a drill to create a burr hole through the outer cortex making sure to irrigate the drill during use.
- Advance the screw at least two-thirds of its length and assess for stability. Avoid overcompression of the mucosa with the screw head to prevent soft tissue necrosis.
- Orient the screw heads so that the ligature holes for cerclage wire placement are facing their respective screws opposite themselves.
- Pass the cerclage wires through the ligature holes and secure by twisting the wire ends. While reducing the fracture, tighten the cerclage wires and trim the wires. Avoid direct contact of the cerclage wires with the tooth to prevent enamel injury (▶ Fig. 18.4).[4]

18.3.2 Closed Reduction: Percutaneous Circummandibular Wiring with a Mandibular Splint

- Using an awl, pass a wire percutaneously in the submental space from the inferior edge of the mandible to the lingual side of the mandible making sure the awl passes just behind the mandible, but taking care not to enter subperiosteally.
- Secure the free end of the wire with a needle driver.
- Withdraw the awl slowly to the inferior edge of the mandible wrapping around it, and advance superiorly along the labial side of the mandible.
- When the awl exits the soft tissue, release the wire from the awl.
- Wrap the ends of the wire over the mandibular splint and twist to tighten.
- Place the circummandibular wires on opposite sides of the fracture, wiring the greater segment first, and the lesser segment last, while holding the fracture in reduction.
- Alternatively, an intravenous cannula stillete can be used instead of an awl.[7]

18.3.3 Lag Screw Fixation

- To identify an area for screw insertion, locate an entry point that will allow for the lag screw to penetrate both fragment segments so that the ends of the screw will eventually lie equidistant from the fracture line.
- Intraoperative MMF may be required for proper reduction of the fracture prior to application of the lag screw.
- Make a 1-cm incision on the entry site either extraorally or intraorally to expose the outer cortex.

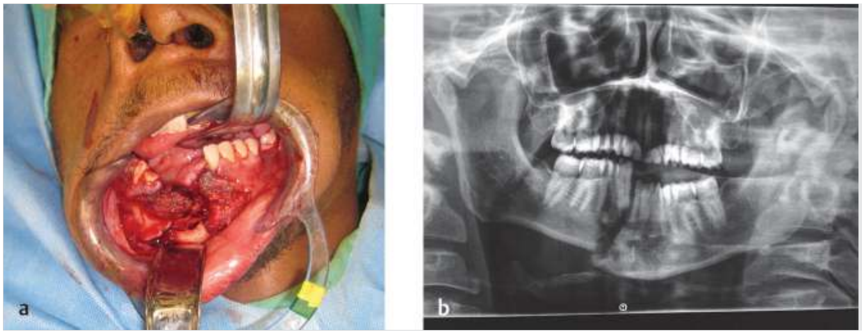

Fig. 18.5 (a) Open right parasymphyseal fracture. (b) Panoramic view of an open right parasymphyseal fracture.

- Use a drill to make a gliding hole through the first segment taking care to not enter the lingual cortex.
- Insert the lag screw and slide the screw through the gliding hole until its end makes contact with the opposite segment.
- Drill the lag screw into the opposite segment while applying a counterforce to the screw.[12]

18.3.4 Open Reduction Internal Fixation

Symphysis/Body

See an example of an open right parasymphyseal fracture in ▶ Fig. 18.5.

- Using a transoral approach, make an incision in the vestibule 5 to 7 mm from the mucogingival junction to allow for sufficient soft tissue for closure.
- Dissect inferiorly to expose the bone surrounding the fracture, while being careful to identify the mental nerve in the premolar region. Once the mental nerve is identified, skeletonize the nerve for increased mobility.[3]
- Identify the fracture and free any soft tissue that may be entrapped in the line of the fracture.
- Use manual reduction or bone forceps to reduce the fracture and apply the selected mode of internal fixation.

Champy's Technique

- Body/Parasymphyseal: Apply a single miniplate across the fracture line in the zone of tension located at the superior border of the mandible proximal to the first premolar tooth inferior to the apices of the teeth. Bend the plates to conform to the contour of the bony surfaces. Use monocortical screws to secure the plate. Additional rigid plating of the inferior border of the mandible may also be performed if there is significant bone loss or comminution.[3]
- Symphysis: Apply two miniplates spaced 4 to 5 mm apart across the symphyseal fracture.

Angle

Champy's Superior Border Technique

- Through a transoral approach, make an incision just medial to the external oblique ridge, extending from the first molar to the ascending ramus leaving 5 to 7 mm of soft tissue in the mucogingival junction available for closure.
- Perform a subperiosteal dissection to the fracture line in order to prevent injury to the lingual nerve.
- After proper reduction in achieved, use a 2.0 mm noncompression miniplate that crosses the fracture line along the external oblique ridge and secure with monocortical screws.[13]

Superior Border Technique

- Alternatively, a noncompression miniplate along the superior border of the angle of the mandible traversing the line of the fracture can be used for internal fixation.

Inferior Border Technique

- Using an extraoral approach, make a submandibular incision 2 cm below the inferior border of the mandible in order to avoid potential injury to the marginal mandibular branch of the facial nerve.[14]
- Dissect down to the bone and expose the fracture.
- Use 2.3-mm plates positioned along the inferior border of the mandible traversing the fracture line and secure with monocortical screws.

Risdon Approach

- Make an incision at 2 to 3 cm below the inferior mandibular border between the angle of the mandible and the facial notch of the mandible, and dissect to the level of the platysma muscle.
- Incise through the cervical fascia taking care not to injure branches of the facial nerve.
- Dissect down to the angle of the mandible to expose the fracture site (▶ Fig. 18.6).

Condyle

Risdon (Submandibular) Approach

- Make an incision at 2 to 3 cm below the inferior mandibular border between the angle of the mandible and the facial notch of the mandible, and dissect to the level of the platysma muscle.
- Incise through the cervical fascia taking care not to injure branches of the facial nerve.
- Dissect through the masseter muscle at the inferior mandibular border superiorly to the periosteum to expose the fracture.[15]

Modified Submandibular Approach

- Through an extraoral approach, make a 4 to 5 cm incision at the first skinfold posterior to the angle of the mandible.

Fig. 18.6 **(a)** Risdon approach to exposing a right mandibular angle fracture. **(b)** Post–open reduction internal fixation (ORIF) photo of a right mandibular angle fracture using the Risdon approach.

- Dissect superficially to the platysma cranially until 1 cm inferior to the inferior mandibular border.
- Carefully dissect through the fibers of the platysma muscle and continue the dissection superiorly superficial to the masseter muscle. Identify the branches of the facial nerve overlying the masseter.
- Identify a region in between the branches of the facial nerves and dissect through the masseter at the level of the mandibular ramus or subcondylar region. Retract the superior portion of the masseter cranially to protect the buccal branches of the facial nerve. Likewise, retract the inferior portion of the masseter caudally to protect the marginal mandibular branches of the facial nerve.[16]

Retromandibular Approach

- Make an incision along the posterior border of the mandible and dissect superficial to the parotid gland anteriorly.
- Incise through the parotid capsule and bluntly dissect through the parotid glands to the masseter, retracting the branches of the facial nerve as they are identified.
- Divide the masseter muscle along the fibers of its muscle to expose the mandible and the fracture.[17]

Modified Retromandibular Approach

- Through a retromandibular incision, dissect superficial to the parotid capsule to its posterior border.
- Dissect around the posterior border of the parotid gland and retract the parotid gland with its facial nerve branches anteriorly and superiorly off the surface of the masseter.
- Divide the masseter muscle along the fibers of its muscle to expose the mandible and the fracture.[18]

Internal Fixation

- In general, the fracture should be fixed with a two-plate system in a parallel, nonparallel arrangement. Other frame patterns exist including trapezoid and square orientations.[19]
- If a single plating system is used, apply at least two screws on each side of the fracture.[19]

18.4 Conclusion

Mandible reconstruction after trauma can be approached through various methods depending on the stability, location, and type of fracture, and clinical characteristics of the patient. Mandible fractures are common facial fractures. CT scan is the gold standard for radiological evaluation. Teeth in line of the fracture should be extracted when infected or mobile. The atrophic mandible has a tenuous blood supply and periosteal stripping should be minimized. Closed reduction with arch bars or fixation screws are often sufficient for minimally displaced fractures. ORIF can be performed using intraoral or extraoral approaches depending on the site of the fracture and may be used in conjunction with MMF.

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19 Upper Midface Trauma

Kant Y.K. Lin, Anthony J. Archual, and Sarah A. Cazorla

Abstract
Frontal sinus fractures are a significant subset of craniofacial traumatic injuries whose management is focused around avoidance of contour irregularity and long-term sequelae of nasofrontal outflow tract (NFOT) obstruction. If the anterior wall is displaced resulting in visible contour deformity without NFOT obstruction, open or endoscopic open reduction internal fixation (ORIF) is appropriate. Unilateral NFOT obstruction can be managed with intersinus septum destruction while bilateral obstruction requires an obliterative procedure. After complete, careful removal of the mucosa, vascularized autologous tissue is the preferred option for filling of the resultant dead space. If the posterior wall is heavily damaged, seek neurosurgical assistance for a cranialization procedure.

Keywords: cranialization, frontal sinus fracture, nasofrontal outflow tract, pericranial flap, upper midface trauma

19.1 Introduction

Fractures of the facial skeleton can be subdivided into the upper, middle, and lower regions. This chapter will address upper facial fractures, which include the region above the orbits. The upper face houses paired frontal sinuses lined by respiratory epithelium and mucus glands. These sinuses become radiographically visible between the age of 5 and 7 years and pneumatically expand until the age of 18 to 20 years.[1] Since Riedel described exoneration of the sinuses in 1898, surgeons have sought to improve outcomes and cosmesis for patients with injuries to these structures.[2] Techniques for management include open reduction and internal fixation of fragments, sinus obliteration, and cranialization.

19.2 Indications

Frontal sinus fractures account for 5 to 15% of craniofacial injuries and are typically associated with high-energy mechanisms of injury. Although physical examination for forehead depression, associated lacerations, bony crepitus, and cerebrospinal fluid (CSF) rhinorrhea are important, thin slice computed tomography (CT) scanning is essential in evaluation of frontal sinus fractures[3,4] (▶ Fig. 19.1). The integrity of the anterior and posterior tables should be assessed as well as the patency of the nasofrontal outflow tract (NFOT). In Rohrich's algorithm published in 1992, displacement (> 1 table thickness) was used to determine whether anterior table fractures in the absence of NFOT obstruction required surgical management. Untreated obstruction of the NFOT risks mucocele, meningitis, or abscess formation.[3] In obstructing injuries without posterior table involvement, we favor sinus obliteration with pericranial flap (▶ Fig. 19.2), autologous fat, or bone grafting. If the posterior table is comminuted or persistent CSF leak is a problem, we favor cranialization.

19.3 Operative Technique

Open operative techniques for management of frontal sinus fractures are typically approached via a coronal incision, although use of any traumatic lacerations is possible if location is suited for exposure. Because of the high-energy mechanism required to fracture the sinus (800–2,200 lb of load to the anterior wall), other maxillofacial fractures are often also present and repaired concurrently. Presence of nasoorbitoethmoid (NOE), orbital roof, and frontal sinus floor or medial wall suggest involvement of the NFOT.[5] Assessment and diagnosis of NFOT obstruction can be difficult. Evaluation should be carried out with review of CT scans, with sagittal views being of particular use. Definitive diagnosis of NFOT obstruction is made with nasal endoscopy, but early edema can lead to pseudo-obstruction making equivocal results possible. If diagnosis of NFOT obstruction is unclear, observation with repeat CT scan in 2 months can be warranted to re-evaluate aeration of sinuses. If opacification of sinus is noted on repeat imaging, then NFOT obstruction is diagnosed. Alternatively, if NFOT obstruction is considered likely, intraoperative assessment may be carried out

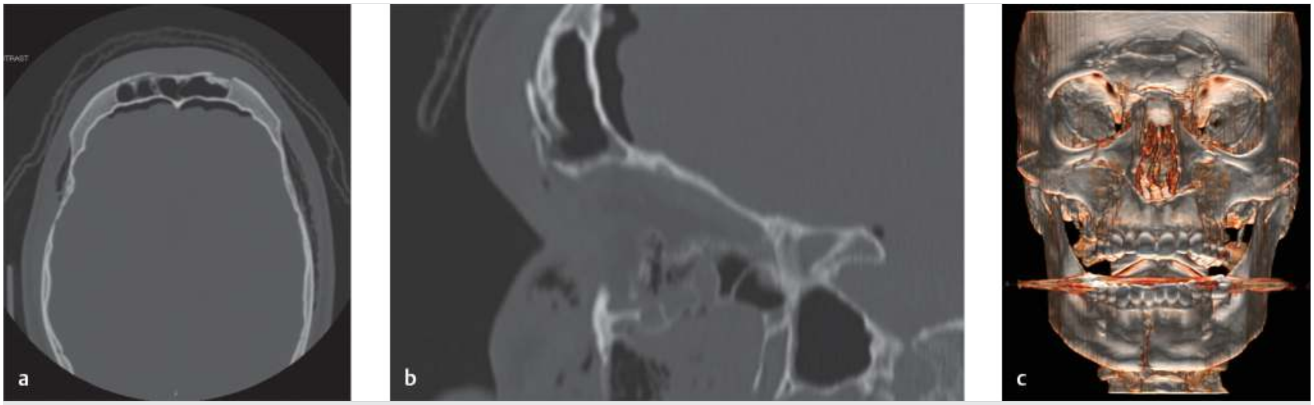

Fig. 19.1 (a–c) Computed tomography (CT) scan of a patient with comminuted anterior frontal sinus fractures. Posterior table component was minor and no nasofrontal outflow tract (NFOT) obstruction was noted intraoperatively, so the patient was treated with open reduction internal fixation (ORIF) of anterior table with several low-profile plates.

by placing pledgets into retropharyngeal space via nostrils and placing a small amount of methylene blue into the frontal sinus through the exposure fractures. If after 20 minutes of instillation the pledgets are removed and found to be unstained by the dye, NFOT obstruction is diagnosed.

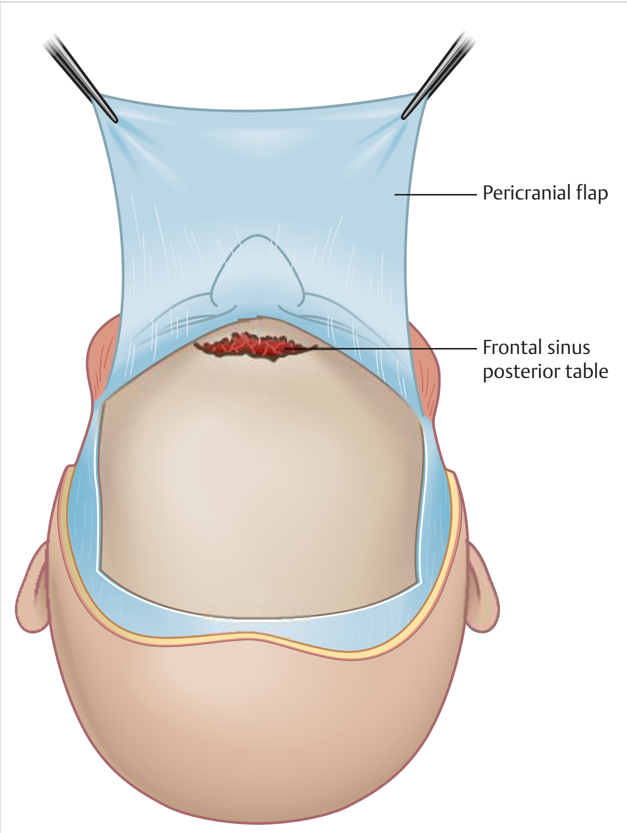

Fig. 19.2 Artist's rendition of elevated pericranial flap. Artist's rendition of anterior table with open nasofrontal outflow tract (NFOT). Artist's rendition of anterior table with blocked NFOT. Artist's rendition of posterior table fracture with a second image of the surgical treatment.

Isolated anterior table fractures without NFOT obstruction are primarily a cosmetic concern. Often the degree of contour irregularity cannot be assessed in the acute setting and in equivocal cases, 3 to 4 weeks can be allowed to elapse before deciding on the need for surgical intervention, which is guided by patient's preference. Care must be taken to assess patient's hairline and aesthetic concerns; specifically the potential poor aesthetic outcome of a coronal incision in a receding hairline should be discussed with the patient prior to surgery as the scar in some cases can be more noticeable than an uncorrected contour irregularity.

In the setting of displaced fractures isolated to the anterior table without NFOT disruption, we favor open reduction and internal fixation with low-profile titanium or resorbable plates and screws with the goal of re-establishing baseline forehead contour as this is not a load-bearing segment of the facial skeleton.[6] Via a coronal incision, the frontal sinus is approached in a subperiosteal plane. A combination of skin hooks and Kirschner wires is used to establish and maintain reduction of fragments while plates and screws are applied. Though comminuted fractures may require an open approach, simple fractures may be amenable to endoscopic approach. As in an endoscopic brow lift, the frontal sinus is approached with a 30-degree endoscope in the subperiosteal plane via two lateral hairline incisions. Reduction instruments and screws are placed via stab incisions over the forehead.[7]

If the NFOT is interrupted and outflow cannot be restored, measures must be taken to prevent complications such as meningitis or mucocele.[3] If there is unilateral NFOT obstruction, the intersinus septum can be directly taken down with a rongeur or rotating burr allowing flow of sinus secretions through the unaffected NFOT. If bilateral NFOT obstruction is present, the sinus must be obliterated. One common technique involves use of a pericranial flap (▶ Fig. 19.2). First, the frontal sinus mucosa and a layer of underlying bony cortex are removed using a rotating burr taking care to obliterate the deepest channels of Brechet, which may house mucosa. Prior to filling the resulting cavity, the NFOT must be plugged; we favor creation of a plug from bone chips or autologous fat. The sinus cavity can be obliterated with spontaneous osteogenesis, pericranial flap, or bone or fat grafting.[1] We favor pericranial flap for its ease of dissection and reliable pedicles (▶ Fig. 19.3). The flap is elevated by

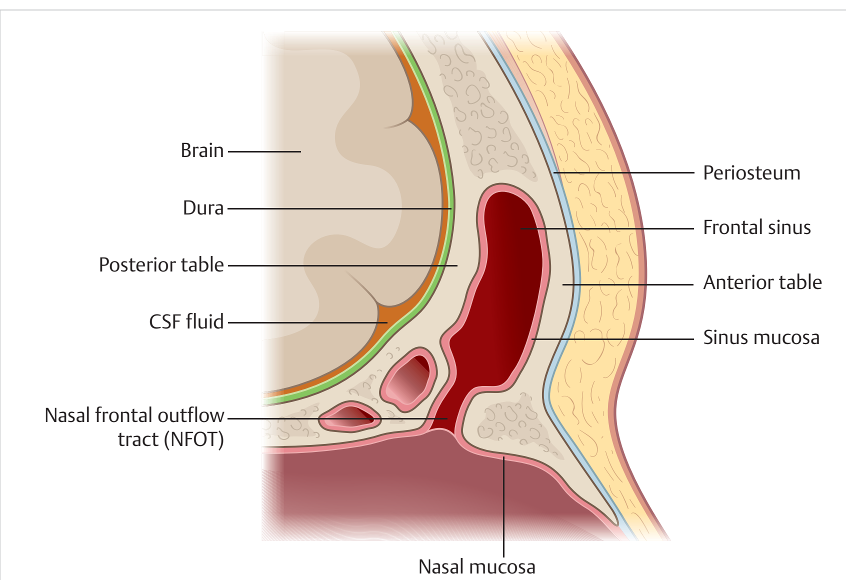

Fig. 19.3 This is an artist's rendition of normal frontal sinus anatomy including the anterior and posterior tables, the mucosal lining of the sinus, and the nasofrontal outflow tract (NFOT). In frontal sinus obliteration, the mucosa is fully and completely removed with a rotating burr. The space is then obliterated using a pericranial flap (our preferred method), autologous fat, or bone chips. The NFOT* is plugged using bone chips. *NFOT= nasal frontal outflow tract.

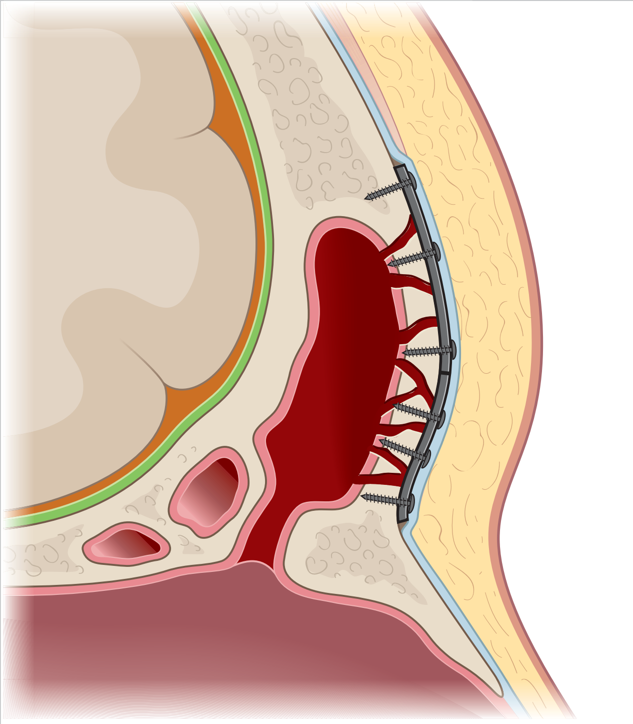

Fig. 19.4 Extensive anterior table fracture with patent nasofrontal outflow tract (NFOT) requiring plating of the anterior table only.

dissecting in the loose areolar plane deep in the galea from the edge of the coronal incision skin flap to the level of the supraorbital rim taking care to preserve the supraorbital and supratrochlear arteries, which serve as the pedicles of this flap (▶ Fig. 19.2a). The lateral extents of the flap are incised, and it is rotated posteriorly and inferiorly into the frontal sinus (▶ Fig. 19.2b). The anterior sinus wall is then reconstructed as above (▶ Fig. 19.2c).

Other options for autologous tissue to fill the obliterated sinus include autologous fat and bone. Because of the ease of harvest, we favor fat.

The use of alloplastic materials for frontal sinus obliteration is controversial and is an area of active investigation. Hydroxyapatite bone cement (Bone Source, Stryker, Dallas, TX) and bioactive glass ionomer cement (Abmin Technologies, Turku, Finland) have both been supported by authors for use in this manner.[8,9]

19.4 Conclusion

In patients with extensive posterior table fractures and persistent CSF leak, cranialization is the preferred operative option (▶ Fig. 19.4). Technically, this is performed in a manner similar to anterior obliteration, with removal of the posterior wall and the mucosa and superficial cortical bone with a burr, allowing the brain to expand into the resulting space (▶ Fig. 19.5). Due to the risk of dural tear or brain injury, any cranialization procedure should be performed in conjunction with neurosurgical colleagues.

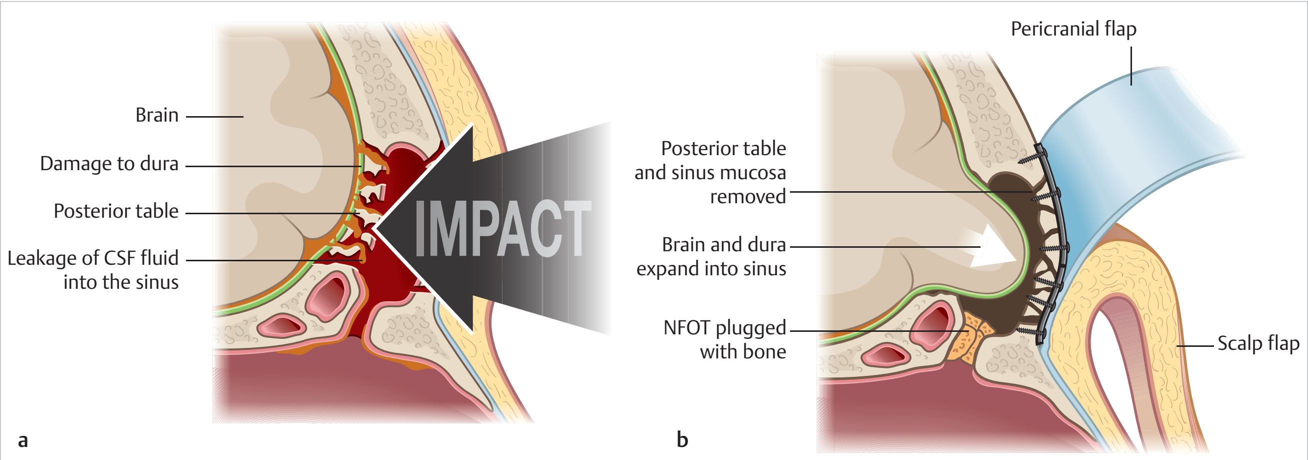

Fig. 19.5 **(a)** The arrow that says impact needs to be moved anterior to the anterior table. The image should say: Extensive posterior table fractures with disruption of dura necessitating cranialization. **(b)** The mucosa has been thoroughly removed, the anterior table plated, the nasofrontal outflow tract (NFOT) plugged, and the posterior table removed allowing the brain to expand into the sinus cavity.

In the case of cranialization, the anterior wall should be reconstructed as described above to ensure proper forehead contour.

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20 Nasal Fracture

Amr Reda Mabrouk

Abstract
Nose fracture is one of the commonest fractures that happen in the facial skeleton as its central position and anterior projection on the face makes it susceptible to traumatic injuries with an incidence of up to 40% of the facial fractures and is the third commonest fracture that happens in humans.[1] It is mainly due to accidents, sport injuries, and physical confrontations. A lot of times, this fracture is neglected as simple. They are sometimes accompanied by other trauma and that is why a lot of nasal deformities that we see in daily practice wouldn't have occurred if the underlying trauma had been addressed correctly in the acute phase.[2] Hippocrates has written in his treatise On Joint "that treatment of nasal fractures doesn't require any particular skill of the doctor," but he was mistaken for proper management of nasal fractures require proper diagnosis, experience, and adequate skill.[3] Nasal anatomy, fractures epidemiology, diagnosis, and modes of management will be outlined. Complications are highlighted and discussed aiming to give proper introduction to treatment options of such fractures.

Keywords: closed reduction, maxillofacial trauma, nasal bone fracture, nasal deformity, nasoseptal fractures, open reduction

20.1 Introduction

The nose is a central structure in the face. It has a dual function fulfilling the cosmetic function of the face acting as an attractive midline structure and forming the main pathway for air to achieve nasal breathing. Due to its central position and anterior projection on the face, nose fracture is one of the commonest fractures that happen in the facial skeleton as these factors make it more susceptible to traumatic injuries. It is the third commonest fracture that happens in humans.[1] It is mainly due to accidents, sport injuries, and physical confrontations.[4] This fracture is usually accompanied by soft tissue and cartilaginous injuries. A lot of times this fracture is neglected as simple. As they are sometimes associated with other trauma, a lot of nasal deformities that we see in daily practice wouldn't have occurred if the underlying trauma had been addressed correctly in the acute phase. These deformities and cosmetic problems may necessitate surgical procedures, including rhinoplasty, to restore the anatomy. The fact that these patients come first to causality departments where the receiving physicians are less experienced, the diagnosis could be easily missed especially if the patient is a victim of multiple traumas.

20.2 Indications and Epidemiology

The annual incidence of nasal fractures in the United States is 53,2/100,000 and the incidence of posttraumatic nasal deformity if left untreated varies from 14 to 50%. Nasal fractures in men is double that in women. Athletic injuries and interpersonal confrontations are more common causes than falls and road traffic accidents.[1] In countries like Brazil, a study about the incidence of facial fractures in children aged 5 to 17 years found out that nasal fractures were most common (51.3%) of facial fractures, and fractures in men were three times more than in women.[5]

Nasal fractures are seen in polytraumatized patients and in these patients sometimes the diagnosis is missed.

Since 1993, the incidence of nasal fractures has reduced dramatically with the advent of laws that force passengers to use seat belts in addition to airbags. Airbags alone don't prevent fractures, and restraint with seat belts is more important. The prevalence of use of seat belts has reached 85% in the US.[6] About 47% of nasal fractures are associated with septal fractures due to the close relation between the nasal bone and the septum.[7] One report states that septal fractures can occur without nasal fractures.[8]

Nasal fractures can occur at any age with different etiology. It can occur due to trauma during vaginal delivery and its incidence varies from 1 to 23%. Probably this variation is due to different variables used in different studies such as time of examination, ethnic variation, and definition of whether it is trauma of soft tissues of the nose or fracture. In a lot of incidents, this is self-corrected and does not need intervention. Nasal trauma during childhood is almost a normal occurrence; all children suffer from nasal trauma during their early years. The sequel of trauma varies from minor abrasions and self-healed pumps to fracture in the nose and septum and deformities that increase by years. If they are not managed properly, even minor trauma could lead to drastic effects.[3]

Nasal surgery in childhood can definitely affect the nasal growth and it is proved that any surgery to the septum or triangular cartilage will affect the growth of the nose and so will surgery to the bony pyramid as well but to a lesser extent. Therefore, management of the fracture of the nose in childhood should be with minimal interference and close reduction should be the method[9] as much as possible while open reduction is saved for the severely comminuted and mutilated nose to avoid affecting the growth.

20.2.1 Relevant Anatomy and Biomechanics of the Fracture

The nose as a semi-pyramidal structure that has a bony and a cartilaginous framework that includes two bones that join each other in the midline. The lower part of the bone is thin and fragile with more liability to fracture while the upper part is thick and attached strongly to the frontal bone and the maxillary frontal process; hence it is difficult to get fractured. The cartilaginous element forms the septum; the upper and the lower lateral cartilages have a very sophisticated attachments together that help to support the lower half of the nose. However, the cartilaginous elements include the alar and the sesamoid cartilages. These osseocartilaginous elements give support to the muscles, the mucosa nerves, the vascular structures, and the skin, which is thin and mobile over the dorsum and sides of the nose and adherent to nasal tip and surrounding cartilages (▶ Fig. 20.1 and ▶ Fig. 20.2).[10]

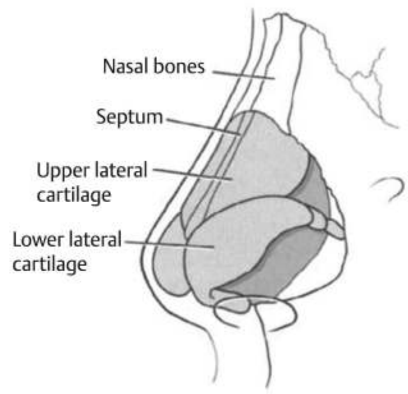

Fig. 20.1 Bony and cartilaginous volt anatomy. From Bullocks JM, Patrick WH, Izaddoost SA, Hollier LH, Stal S. Plastic Surgery Emergencies. New York: Thieme Medical Publishers; 2008.

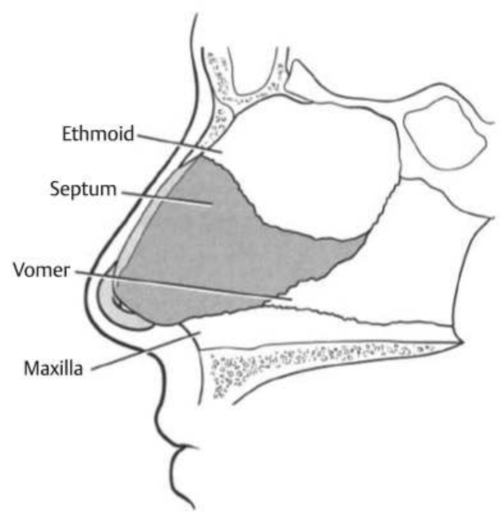

Fig. 20.2 Nasal septal anatomy. From Bullocks JM, Patrick WH, Izaddoost SA, Hollier LH, Stal S. Plastic Surgery Emergencies. New York: Thieme Medical Publishers; 2008.

Due to the prominence of the nose, its position, and the thinness of the bone, it is more prone to fracture with minor force, but at the root the force needed to fracture is higher and if the force is sufficient to fracture the nose, it will be enough to fracture nearby facial bones such as the frontal bone, the ethmoid, and the orbit.[6]

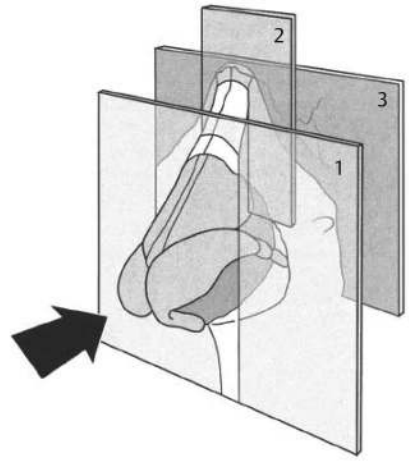

Fig. 20.3 Stranc–Robertson nasal fracture classification. From Bullocks JM, Patrick WH, Izaddoost SA, Hollier LH, Stal S. Plastic Surgery Emergencies. New York: Thieme Medical Publishers; 2008.

Epistaxis is common even with minor trauma to the nose. Epistaxis can occur with minor nasal trauma due to the dense vascular supply with the Kiesselbach's plexus. Bleeding can occur from anterior ethmoidal artery in the anterior part of the nose while posterior nasal bleeding can occur from sphenopalatine artery.[11]

20.2.2 Classifications of Nasal Fractures

The strength and the direction of the force are responsible for the degree of fracture sustained. Stranc–Robertson classification divides nasal fractures into lateral fractures and frontal fractures depending on the direction of force (▶ Fig. 20.3). The lateral oblique fractures vary from unilateral nasal bone fracture, which leads to depression of the nasal sidewall, to unilateral depression and deviation of the opposite nasal bone with fracture of the frontal process of the maxilla.[10]

Frontal type fractures are less common and they are classified according to the plane of injury:

- Type 1: Does not go beyond a line drawn from the lower nasal bone to the maxillary spine.
- Type 2: Leads to flattening of the cartilaginous and bony elements of the nose with fracture in septum and injuries of the nasal mucosa.
- Type 3: Lead to severe collapse of the nose and cartilages with telescoping of the septum and may be associated with other injuries in the orbit and cranium.[11,12]

20.2.3 Diagnosis and Imaging

It is very easy to miss nose fracture if the physician in charge is not alert enough to search for its presence in victims of trauma. That is why the negligence of early management can lead to complications and more complicated procedures are needed to restore the nasal function and aesthetics.

20.2.4 History

Taking proper history is the first step in reaching a proper diagnosis. The patient who gives history of any of the four main causes of nose fracture, namely, interpersonal assault, sport accidents, falls, and road traffic accidents, should ring a bell in the physician's mind to have more detailed questions about the incident and the direction of force. Also, the presence of previous history of facial fractures, nasal obstructions, and nasal deformity should be checked. However, the report of the patients that their nose looked better before is not accurate even if they present photographs to prove the point.[10]

20.2.5 Physical Examination

Accurate and careful physical examination of the nose and the face is vital for reaching a proper diagnosis and to determine the urgency of surgical management, the method of interference, whether closed reduction or open reduction, and the type of anesthesia, whether it is local anesthesia or general anesthesia. The examination includes proper inspection and palpation, searching for bony and cartilaginous deformity. A lateral or depressed bone is a positive sign and so is the internal or external cartilaginous deformity. Proper evaluation of the soft issue involvement is must. Septal examination using a nasal speculum[13] or nasal endoscopy, as adopted by some authors,[2] is crucial to determine the presence of septal fracture and to exclude the presence of septal hematoma, which if present necessitates urgent intervention to evacuate the hematoma; otherwise perforation of the septum could occur.

20.2.6 Imaging

Plain X-ray for identifying nose fracture is a routine investigation and a high percentage of the patients present to the physician with these X-rays. Some authors claim that although it is of a limited value yet for medicolegal reason it is a must. Computed tomography (CT) of facial bones is also an important tool to diagnose nose fracture and other associated fractures. The three-dimensional reconstruction helps to avoid missing any fracture and acts as a common ground to share with the patient and his or her relatives (▶ Fig. 20.4).

The conductor assisted nasal sonography is used routinely to evaluate patients with acute nasal fractures except in open nasal wounds. A surgical glove filled with water is used as a conductor for probe to make adequate contact with the surface of the nose. Any disruption, lateralization, or loss of continuity of the nasal bone or aberrant subcutaneous air is diagnosed as nose fracture. Chou et al claim very accurate diagnosis using this technique.[4]

Fig. 20.4 Computed tomography (CT) scan of facial bones with three-dimensional evaluation shows Type 1 fracture in the nose.

20.3 Operative Technique

The treatment was described originally by the ancient Egyptians and the Greeks. Following in their footsteps, few modifications have been made to these ancient techniques. Although some report reduction of the fracture from 3 to 30 days, it is preferable to intervene as soon as possible before edema occurs in the first few hours. It is suggested that the closed reduction should be performed within the first 14 days in adults and 10 days in children from fear of ossification after these periods.[10] Should malunion occur, rhinoplasty or septorhinoplasty will be the best option in adults.

20.3.1 Local versus General Anesthesia

Local anesthesia is sufficient and safe even in office setup but it needs a cooperative patient and hence pediatric patients are excluded. Inject 1% lidocaine with 1:100,000 epinephrine on the lateral side of nasal bone along the premaxilla and the septum. The infraorbital nerve and nasociliary nerve of the first branch of the trigeminal nerve are also included (▶ Fig. 20.5, ▶ Fig. 20.6, and ▶ Fig. 20.7). Nasal sprays such as oxymetazoline or neo-synephrine

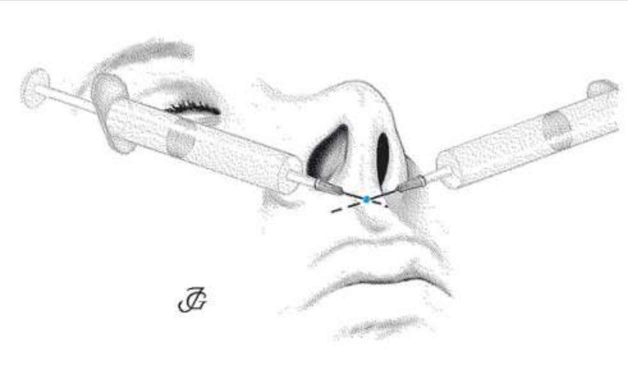

Fig. 20.5 Local infiltration of the lobular base. From Huizing EH, De Groot J. Functional Reconstructive Nasal Surgery. New York: Thieme Medical Publishers; 2015.

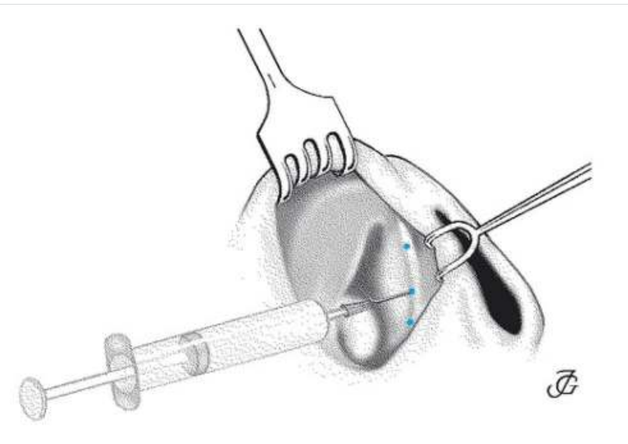

Fig. 20.6 The caudal septal end is subcutaneously infiltrated. From Huizing EH, De Groot J. Functional Reconstructive Nasal Surgery. New York: Thieme Medical Publishers; 2015.

are used for nasal decongestion. Several minutes are allowed to pass before secure anesthesia is achieved.[10]

20.3.2 Approach

Closed and open approaches have been described in literature with advocates of both for acute nasal fractures.

Closed Reduction versus Open Reduction

The closed reduction is easy and safe with the least possible complications, and experience can be gained easily in such technique. The success rate may reach from 60 to 90% with different authors. Some authors report that septorhinoplasties may be needed in up to 50% of patients and they recommend the open reduction as a first choice. However, it is advised that the open approach be saved for patients with failed closed reduction or patients with Stranc frontal type 3, and those associated with fracture of craniofacial bones or patients with skin avulsion septal hematomas that need to be evacuated as early as possible in addition to patients with failed control of epistaxis.[10]

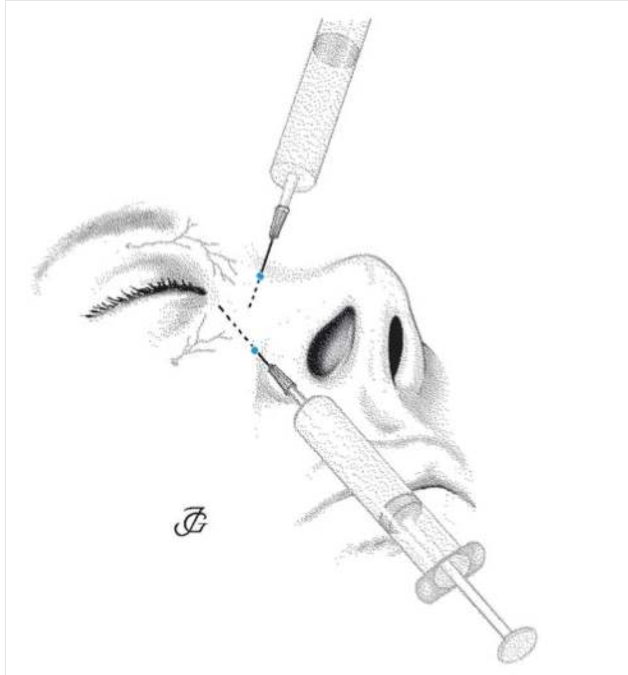

Fig. 20.7 Subcutaneous infiltration of the paranasal area and the nasal root blocks the branches of the infraorbital and supraorbital nerves. From Huizing EH, De Groot J. Functional Reconstructive Nasal Surgery. New York: Thieme Medical Publishers; 2015.

Technique of Closed Reduction

To reduce the depressed nasal bone, you need a Walsham forceps, which is introduced through the external nares intranasally and pushed against the nasal bones. The nasal mucosa should be protected by placing a cotton wool or gauze separating the instrument from these valuable tissues. The depressed bone is pushed out while the nasal pyramid is directed toward the midline. Reduction should be aimed to reposition the nose to the midline. The nasal pyramid should be reshaped and this might need out-fracturing of the nasal sidewalls. Reduction is assessed by visualization and palpation. The fingers of the other hand are used as an external guide. The repositioned pyramid is supported by internal dressings and protected by strips and splint for several days (▶ Fig. 20.8 and ▶ Fig. 20.9).

Septal fractures are reduced with Ash forceps by introducing the forceps intranasally. A dorsal nasal splint is applied for 7 days, which is made of malleable metal or thermoplastic polymer. The maintenance of intranasal splints for 7 to 10 days is advised if there is comminution of the nasal bones or if there is septal dislocation or extensive nasal mucosal lacerations. The use of silastic splints helps in keeping the serum in place and prevents development of synechiae.[1,8,10]

Technique of Open Reduction

Septal hematomas are evacuated and septum is repositioned. The fractured nasal bones should be totally mobilized as usually the fracture is not complete. Lateral osteotomies are made to completely freeze the bone and hence repositioning can be

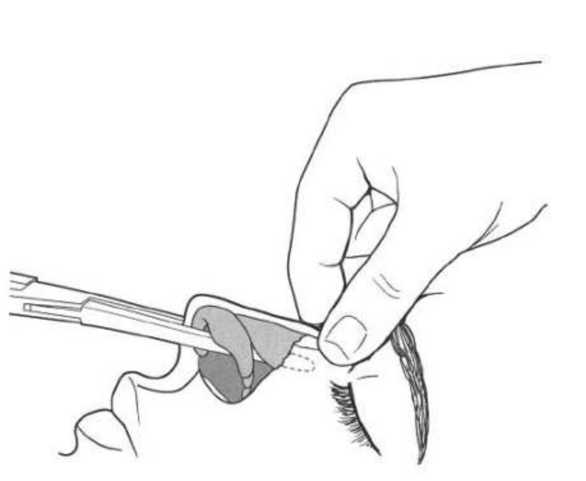

Fig. 20.8 Closed reduction of nasal fracture using Walsham forceps. From Bullocks JM, Patrick WH, Izaddoost SA, Hollier LH, Stal S. Plastic Surgery Emergencies. New York: Thieme Medical Publishers; 2008.

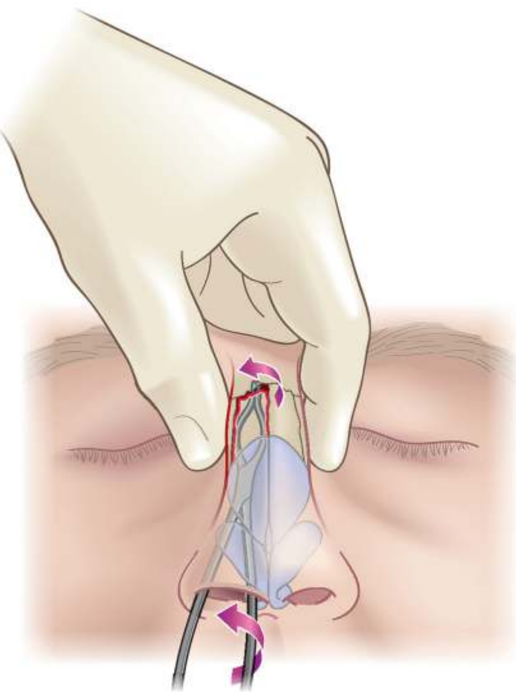

Fig. 20.9 The nasal fracture is reduced with a lateral and superior rotation of the reduction forceps.

achieved. All lacerated wounds in the mucosa and skin are repaired in layers including the cartilage. For lacerated wounds minimal debridement is done as healing of these wounds is expected with minimal scarring and contraction. The use of intranasal splints and external nasal splint is preferred as much as possible. If adjacent bones are fractured, reconstruction using miniplates is advised to acquire stability.[1]

20.3.3 Complications

The most important complication of management of nose fracture is the need for doing a septorhinoplasty due to failure of the proper reduction resulting in malunion. Therefore, the patients should be well informed of this probability. This can be performed as early as 6 to 9 months postoperatively. The occurrence of epistaxis is easily managed by local conservative methods. Should septal hematomas occur, immediate drainage should be done to prevent septal perforation or deformities. Other complications such as nasolacrimal duct injury could be suspected if there is persistent epiphora after few weeks. Late complications include nasal obstruction from neglected septal fracture management and synechiae from unrepaired nasal mucosa.[13]

20.4 Conclusion

Nose fracture is one of the commonest fractures that happen in the facial skeleton as its central position and anterior projection on the face makes it susceptible to traumatic injuries with an incidence of up to 40% of the facial fractures. It is the third commonest fracture that happens in humans.[1] It is mainly due to accidents, sport injuries, and physical confrontations. A lot of times, this fracture is neglected as simple. They are sometimes accompanied by other trauma and that is why a lot of nasal deformities that we see in daily practice wouldn't have occurred if the underlying trauma had been addressed correctly in the acute phase.[2]

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21 Treatment of Orbital Wall Fractures

Jong-Woo Choi and Wooshik Jeong

Abstract
The most common type of orbital wall fracture is the blowout fracture pattern, in which pressure against the globe causes the thin medial and inferior orbital wall to fracture. The most important thing in orbital wall reconstruction would be the anatomic reconstruction similar to the original structures. Various surgical approaches can be used such as transconjunctival and transcaruncular approaches to access the medial and inferior orbital wall. Recent computer-aided design and computer-aided manufacturing-based treatment of orbital wall fractures can be helpful for optimal restoration using custom-made implant.

Keywords: CAD-CAM–based treatment, medial wall fracture, orbital floor fracture, orbital wall fracture, transcaruncular approach, transconjuctival approach

21.1 Introduction

An orbital wall fracture is unlike other facial bone fractures. The most common type is the blowout fracture pattern, in which pressure against the globe causes the thin medial and inferior orbital wall to fracture (▶ Fig. 21.1). If the orbital walls were thick, it would cause the globe to rupture. This anatomic feature may be the result of evolutionary adaptation to the environment. As the fractured orbital walls are very thin, especially medially and inferiorly, a defect should not usually be reconstructed with the fracture fragments, but with materials such as a Medpor or degradable PLA/PLGA implant, titanium, or autogenous bone or cartilage grafting. The most important thing in orbital wall reconstruction would be the anatomic reconstruction similar to the original structures as the shape of the orbit is complex (▶ Fig. 21.2).

21.2 Indications

The indications of the orbital wall fractures are as follows:
- Acute enophthalmos (more than 2 mm).
- Mechanical restriction of gaze.
- The area of the defect exceeds the 2 cm^2 on computed tomography (CT) scan[11,12]
- Persistent diplopia
- Compressed optic canal

21.3 Operative Technique

21.3.1 Orbital Floor Fracture

To access the inferior orbital wall, various surgical approaches can be used. Traditionally, the subciliary approach using the gray line just below the lower eyelid margin has been used (▶ Fig. 21.3). Although this approach can usually provide good aesthetic outcomes with minimal scarring, sometimes, it may result in ectropion or scarring. To overcome these problems, the transconjunctival approach has been used, and is aesthetically desirable as it does not result in a skin scar (▶ Fig. 21.3a). However, an entropion or a limited visual field during surgery is sometimes troublesome, especially with extensive and complicated orbital wall fractures. Although the transconjunctival approach with lateral canthotomy can extend the operative visual field, a lateral canthal deformity often occurs. Recently, an extended transconjunctival approach using a paracanthal incision has been introduced (▶ Fig. 21.4). While extending the operative visual field, this approach leaves a minimally visible scar in the paracanthal area. The procedure is the same as that for the traditional transconjunctival approach, with the only difference being an incision approximately 5 mm medial to the lateral canthus. Based on clinical anatomy, as the technique uses a tarsal strap cut, the operative visual field will be immediately much wider. Meticulous closure is required, especially on the lower eyelid margin.

A preseptal or retroseptal approach can be used for dissection (▶ Fig. 21.3b). The retroseptal approach is more direct. As the preseptal approach can provide an avascular dissection plane and preserve the septal fat compartment, it is used more than the retroseptal approach. To prevent an ectropion and preserve the retaining function of the orbicularis oculi muscle (OOM), the initial dissection should be done above the OOM. After proceeding with the dissection for about 5 to 10 mm, further dissection between the OOM and anterior orbital septum is recommended. Then, the periosteal layer on the inferior orbital rim should be cut and elevated subperiosteally. Dissection between the periosteum and the inferior orbital nerve can be challenging. The dissection

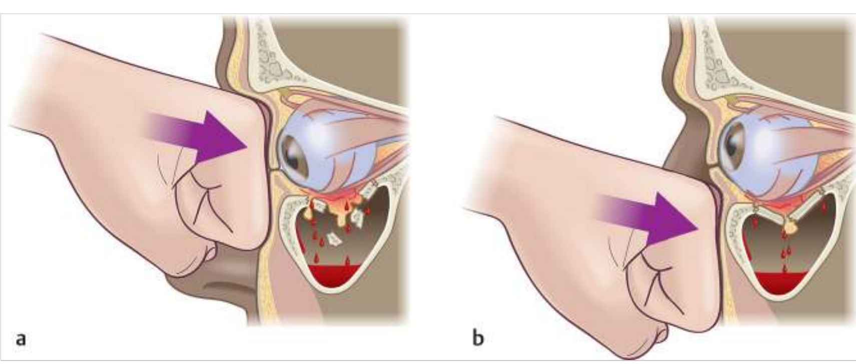

Fig. 21.1 The most common type of orbital wall fracture is the blowout fracture pattern. **(a)** Blowout **(b)** blow-in.

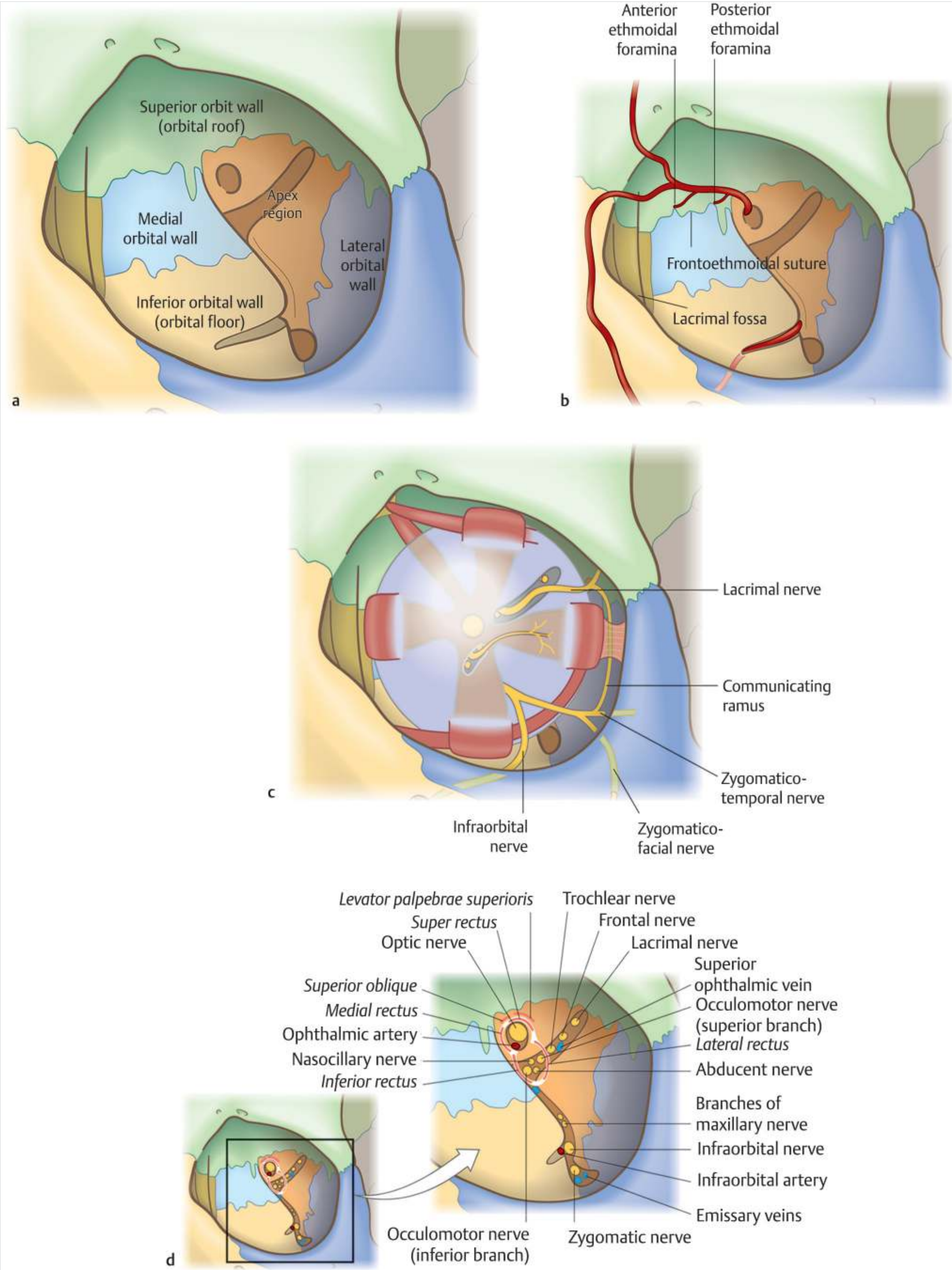

Fig. 21.2 (a–d) Anatomy and structures of orbital wall.

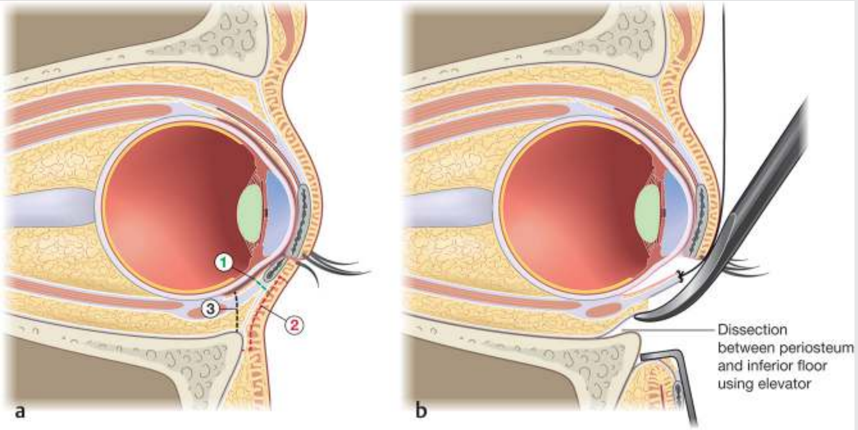

Fig. 21.3 (a) Transconjunctival approach. 1—tarsal plate. 2—orbicularis muscle. 3—orbital septum. **(b)** Dissection is carried deep to the periosteum onto the orbital floor.

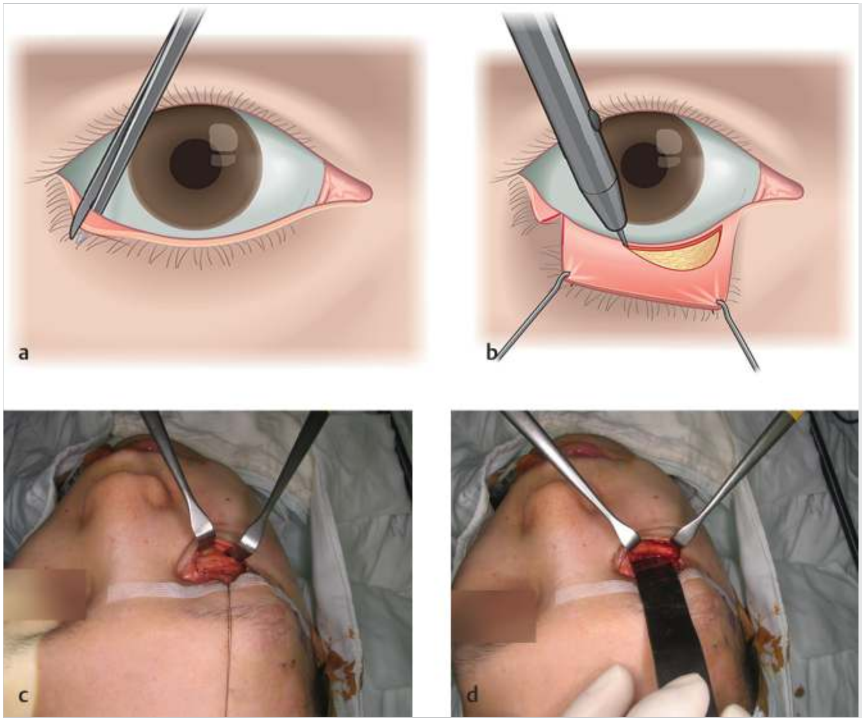

Fig. 21.4 (a–d) Extended transconjunctival approach.

is mostly done by bipolar cutting or with an elevator. Meticulous dissection is necessary to avoid injuring the nerves and vessels. The reduction of the herniated orbital contents can be difficult, especially in late exploration. Gentle and meticulous reduction using forceps and bipolar cutting will be necessary. Finally, reconstruction of the orbital wall is based on the preinjury orbital anatomy. Without this information, unwanted enophthalmos can develop. The orbit has a conical shape, with a 45 degrees medial slant and an undulating 15 to 20 degrees upward inferior slant; the posterior ledge of the orbital wall defect should be explored or a customized prefabricated implant should be used to restore the optimal original orbital anatomy ▶ Video 21.1.

Video 21.1 Transconjunctival approach for orbital floor fracture

21.3.2 Medial Orbital Wall Fracture

To access the medial orbital wall, a medial eyebrow or W approach has been used. However, these surgical approaches leave a definite scar at the medial canthal area. Fortunately, an innovative, transcaruncular approach has been introduced (▶ Fig. 21.5a). This approach provides the surgeon with excellent exposure of the medial orbital wall fracture site with minimal scarring at the caruncle. The introduction of the transcaruncular approach has given surgeons greater reassurance in medial orbital wall fracture surgery. The initial incision

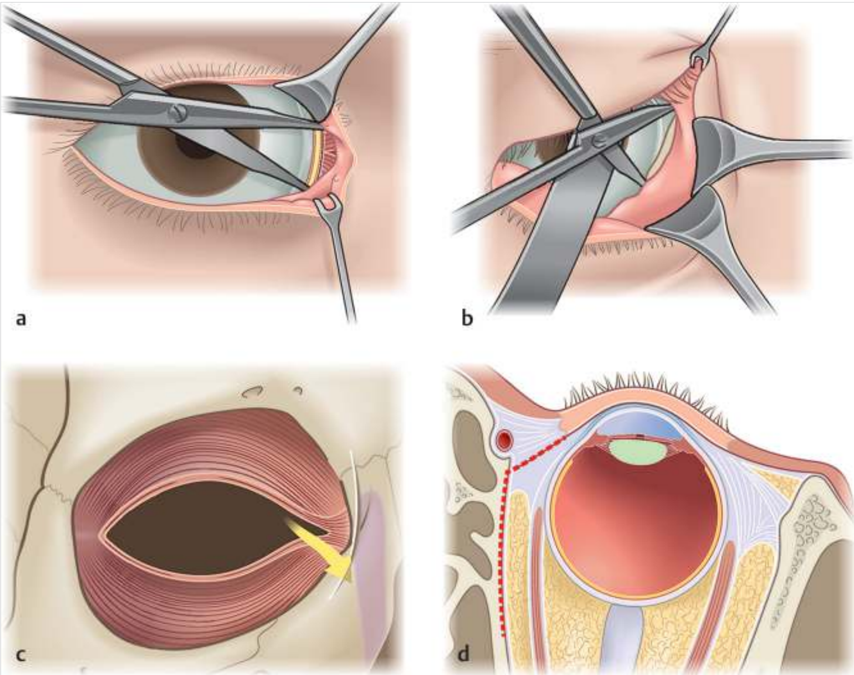

Fig. 21.5 (a–d) Transcaruncular approach to medial orbital wall.

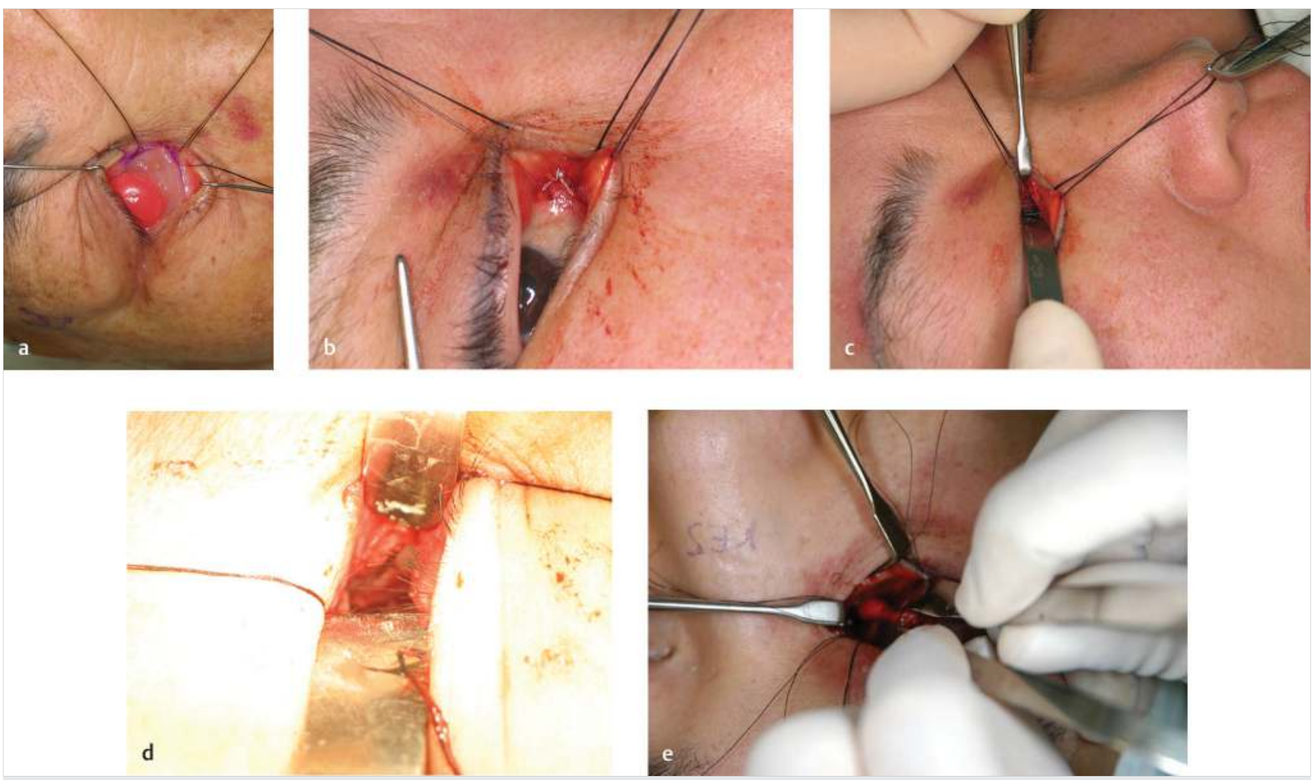

Fig. 21.6 (a–e) Clinical case of transcaruncular approach.

should be made at the midpoint of the caruncle (▶ Fig. 21.6a, b). Then dissection should be performed above the orbital septum and Horner's muscle at first (▶ Fig. 21.6c). Just posterior to the lacrimal groove, the periosteal line should be cut, followed by subperiosteal dissection (▶ Fig. 21.5b and ▶ Fig. 21.6d). Since the subciliary approach for the orbital floor uses the plane between the OOM and orbital septum, the dissection plane is similar. However, the visual field is not adequate for extensive orbital wall defects. Recently, the combination of transcaruncular and transconjunctival approaches has been applied in extensive defects to obtain better exposure (▶ Fig. 21.6e). This combination offers a much better solution for complicated orbital wall fractures accompanied by a bony buttress between the medial and inferior orbital walls.

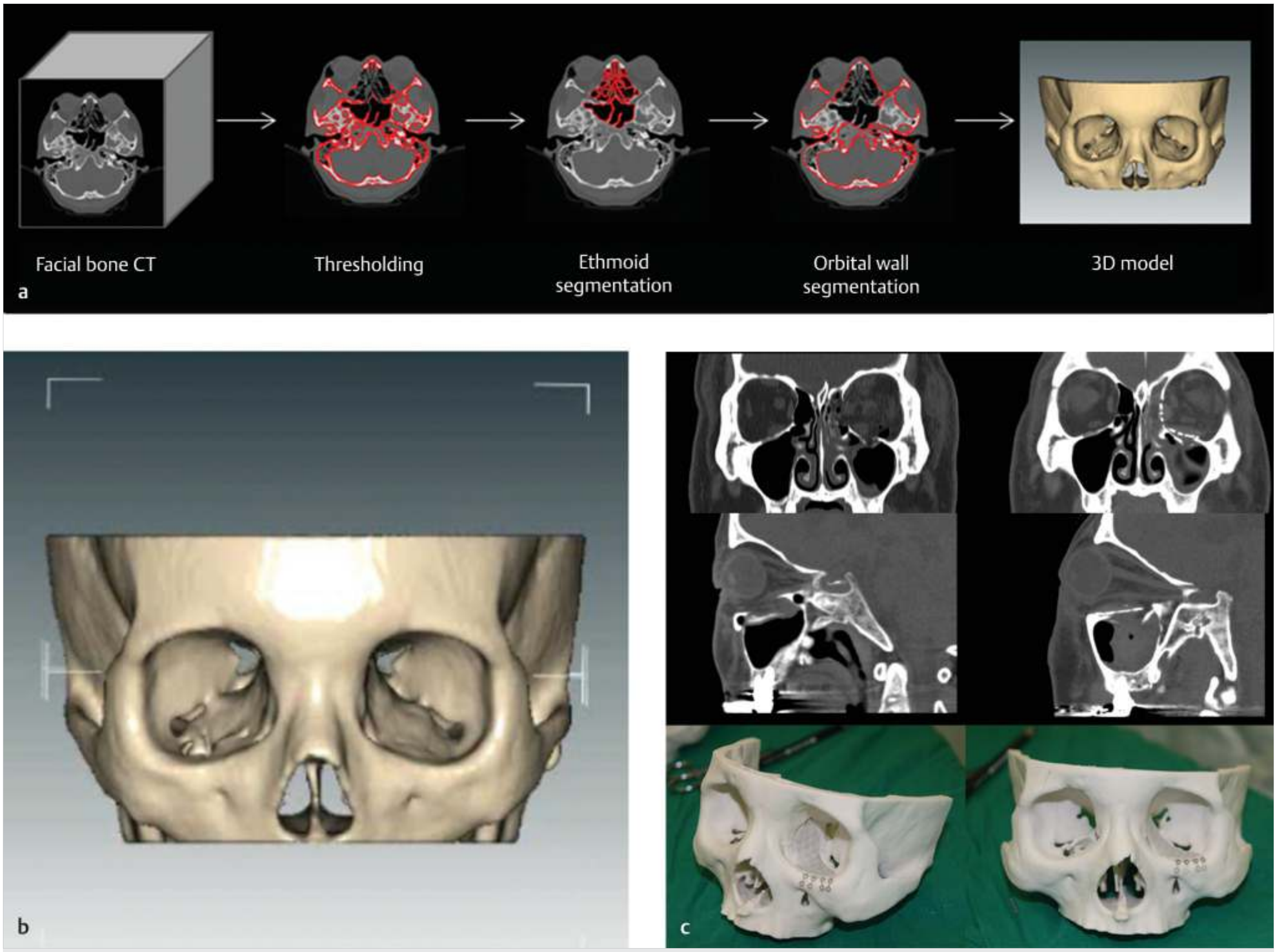

Fig. 21.7 (a–c) Computer-aided design and computer-aided manufacturing (CAD-CAM)–based treatment of orbital wall fractures.

Video 21.2 Transcaruncular approach for medial orbital wall fracture

The obstacles to this combination approach include the possibility of damage to the lacrimal apparatus and inferior oblique muscle ▶ Video 21.2.[14]

21.3.3 General Recommendations

The principles of orbital wall fracture surgery include the following:

- Minimally invasive skin or conjunctival incisions.
- Establishment of as wide a visual field as possible while preserving the orbital contents and lacrimal apparatus.
- Confirmation of the posterior ledge as much as possible.
- Reduction of the herniated contents.
- Orbital wall reconstruction with autogenous or alloplastic materials.
- Maintenance of the original orbital wall contour (about 45 degrees angulation of the medial orbital wall and 30 degrees angulation of the orbital floor).
- Avoiding dissection over the posterior ethmoidal artery on the medial orbital wall and the location close to the annulus of Zinn, so as to prevent damage to the optic nerve.

21.3.4 Computer-Aided Design and Computer-Aided Manufacturing (CAD-CAM)–Based Treatment of Orbital Wall Fractures

In order to reconstruct the damaged orbital wall, the anatomy of the contralateral healthy orbit can be used, based on CAD-CAM technology. With CT Digital Imaging and Communications in Medicine data, the ideal orbit can be three-dimensionally reconstructed using volume-rendering technique (▶ Fig. 21.7a, b). Then a three-dimensional printed model can be used to mold the implant, or a custom-made implant can be used for optimal restoration of the original orbital anatomy (▶ Fig. 21.7c). In addition, three-dimensional navigation can be used for correct implantation, with navigation systems guiding the precise location and technique.[13,15]

21.4 Conclusion

As the early detection of thyroid cancer led to an increase in the number of operations for treating it, ease of detection because of increased use of CT scans has led to an increase in the frequency of detection of orbital wall fractures. Indications for the treatment of orbital wall fractures are somewhat controversial, but surgeons should develop their own criteria. In addition, the restoration of original orbital anatomy may be difficult, but it is essential. Finally, we need to keep in mind the principle that "the first surgery matters most in trauma management in order to prevent complications."

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22 Facial Paralysis

Eyal Gur and Daniel Josef Kedar

Abstract

Paralysis of the facial mimetic muscles is a devastating condition with a profound functional, aesthetic, and psychological consequences. Reanimation of the paralyzed face focuses on restoration of form and function. Goals are to achieve protection of the eye, facial symmetry at rest, voluntary symmetric facial movement, and restoration of involuntary mimetic facial expression. The most significant unit for reconstruction, from a functional and aesthetic perspective, is the buccal-zygomatic muscle complex, which is responsible for smiling and for the tone of the cheeks. Surgical management must be individualized for each patient—patient's age, and the type and duration of denervation all play a role in the choice of the operative approach. In an acute facial nerve damage, primary repair yields the best outcomes. In recent paralysis (in which the mimetic musculature may be reactivated by provision of neural input), a nerve graft is used to relay facial input. A long-standing paralysis necessitates both reinnervation and muscle transfer.

Keywords: cranial nerve, cross-face nerve graft, facial palsy, facial paralysis, facial reanimation, free flap, gracilis muscle transfer, innervated muscle flap, neurorrhaphy, sural nerve graft

22.1 Introduction

Paralysis of the facial mimetic muscles causes loss of voluntary facial movements, loss of involuntary facial expression, and dysfunction in facial tone. It is a devastating condition with a profound functional, aesthetic, and psychological consequences.

Symptoms may include ocular dryness and tearing, speech difficulties, oral incontinence, impairment in mastication, and obstruction of nasal airway. Significant emotional distress results from facial disfigurement, impaired communication, and social dysfunction.

Facial paralysis manifests as a spectrum of conditions, presenting as either unilateral or bilateral, and range from partial to complete weakness.

Etiology is either congenital or acquired, the latter including neoplasms, trauma, infection, iatrogenic, and idiopathic causes.

Reanimation of the paralyzed face focuses on restoration of form and function. Goals are to achieve protection of the eye, facial symmetry at rest, voluntary symmetric facial movement, and restoration of involuntary mimetic facial expression.[1]

The most significant unit for reconstruction, from a functional and aesthetic perspective, is the buccal-zygomatic muscle complex (BZMC), which is responsible for smiling and for the tone of the cheeks. This complex includes the risorius, the zygomaticus major and minor, and the levator anguli oris muscles and is normally innervated by tributaries of the zygomatic and buccal branches of the facial nerve. Significant functional problems are associated with paralysis of the oral musculature, including drooling and speech difficulties. Flaccid lip and cheek can lead to difficulties with chewing food, cheek biting, and pocketing food in the buccal sulcus. However, the main emphasis of surgery is usually centered on reconstruction of a smile.

Three elements are required for the formation of a smile: neural input, a functioning muscle innervated by the nerve, and a proper muscle orientation. All three factors contribute to the decision as to which reconstruction would be individualized.

The timing from which the facial nerve damage is diagnosed to the time of intervention is a key factor for the choice of reconstruction.

In an acute facial nerve damage, primary repair must be considered. In recent paralysis (in which the mimetic musculature may be reactivated by provision of neural input), a nerve graft is used to relay facial input. A long-standing paralysis necessitates both reinnervation and muscle transfer.

22.2 Primary Repair

22.2.1 Indications

Acute facial paralysis should be reconstructed within 72 hours from injury onset, if proximal and distal facial nerve stumps are present on the paralyzed side.

In an acute facial nerve damage such as in trauma or operation, immediate primary repair must be considered within 72 hours. For acute traumatic injuries primary repair of the nerve renders the best outcome.[2]

The advantages of acute repair include the ability to perform intraoperative nerve stimulation (which aids in locating the nerve stumps), to optimize motor nerve recovery, and to adequately gain exposure and mobilize nerve ends without the interference of scar tissue.

Nerve ends have been reported to still contain neurotransmitters for up to 72 hours of injury and from a histopathologic standpoint, nerve ends have symmetrically apposed fascicles immediately after transection but then become increasingly difficult to match, as Schwann cell proliferation, fibrosis, and angiogenesis occur at each end.[3]

In cases of immediate injury due to penetrating trauma, surgical exploration should be undertaken. The wound should be copiously irrigated, and appropriate antibiotics should be administered.

22.2.2 Operative Technique

An operative microscope is usually used for all nerve repair cases as it aids in accurate placement of epineural sutures and minimizes damage to nerve tissue.

The proximal and distal portions of the nerve must be identified. The use of an electric nerve stimulator can be useful in identification of distal branches. The nerve ends must be neurolyzed from the surrounding scar tissue bed. During this step, it is critical to avoid physical damage (i.e., crushing or tearing) to the nerve ends.

Adequate exposure also entails injured nerve end resection in order to visualize healthy nerve tissue and facilitate fascicle apposition. Given the healing process initiated at the nerve ends after traumatic injury, more end resection is required as the time from injury increases. In cases where there is uncertainty of the viability of the nerve, an intraoperative histology is used.

Repair must be achieved with minimal tension. Even in the setting of a fresh nerve laceration, some tension exists because of the elastic nature of nerves. A failure to hold an end-to-end repair with a single 9–0 suture is a sign of undue tension.[4] As tension on the neurorrhaphy seems to diminish perfusion and neural regeneration, if there is insufficient length of nerve for primary repair, an interpositional graft from the great auricular nerve, sural nerve, or other suitable donor nerve should be performed.

A few epineural sutures are placed, the preferred suture material being nylon with caliber typically 9–0 or 10–0. The repair is performed on a blue background made from a small piece cut from the stand cover.

The repair should be on the looser rather than tighter side. The most destructive error is a repair that is too tight, whereby opposing fascicles are forced to pass each other. Repairing the back wall first in a slightly loose fashion is helpful to initially align the nerve ends and to keep the back-wall fascicles contained. Repairing the remainder of the nerve so that the fascicles *barely* touch is the goal. At the end of the repair, there should be no deformity to the nerve. At the repair site, the edges of the nerve should be flush without any kinks. No fascicles should be escaping the repair site. If minimal, this situation can be salvaged by a minimal trimming of escaping fascicles. Otherwise, the repair should be repeated but looser.

Coaptation of the nerve at a site more proximal than the stylomastoid foramen should be avoided, when possible, as the arrangement of nerve fibers in this region is less favorable and can lead to greater synkinesia.

22.3 Nerve Grafting—Ipsilateral and Cross-Facial

22.3.1 Indications

Recent facial paralysis reconstruction should be managed not later than a year after injury onset.

For patients over 60 years, a cross-face nerve graft should not be used and the masseter motor nerve should be connected to the distal, ipsilateral, facial nerve stump.

Recent paralysis is defined as a paralysis in which the mimetic musculature may be reactivated by provision of neural input, and the time limit is generally 18 to 24 months.

Preoperative electromyography (EMG) may help to rule out early irreversible atrophy, which seldom develops earlier than 12 months after the onset of palsy, particularly in cases of recurrent facial palsy, palsy caused by radiotherapy, and Ramsay Hunt syndrome. Patients with recent paralyses have fibrillations of the mimetic musculature, and if these fibrillations cannot be recorded, the paralysis must be considered longstanding.

By reactivation of the mimetic musculature of the face, the muscle tone can be preserved. The patient will gain better facial symmetry by preventing the dogmatic facial sagging of the affected side, better eye closure (with innervation of the orbicularis oculi), and better oral continence (with innervation of the orbicularis oris).

In the past, if a functional facial nerve branch was available only on the contralateral face, a cross-face nerve graft was used to relay facial nerve input across the face to the BZMC.

Axons from the contralateral facial nerve regenerate through the sheath of the graft and innervate the muscle over 4 to 6 months.[5,6,7]

Because muscle atrophy could develop while the facial nerve regenerates, an ipsilateral motor nerve was transposed to serve as a temporary innervator (“babysitter”) to the muscle. Thus, muscle tone was preserved while waiting for the cross-face grafts to grow across and spontaneous smiling would be restored (▶ Fig. 22.1).[1,8] Yet in the authors’ experience, this type of reanimation by itself will usually result in a weak muscle contraction, so even with the preservation of muscle tone and the added compliance of the orbicularis oris and oculi, a poor and unsightly smile will result.

In recent years, since we have noticed that a cross-face nerve graft did not deliver a good smile, it is now the authors’ choice, even in recent paralysis, to use a muscle transfer for production of a pleasing smile.

In this approach, in the first stage the distal stump of the facial nerve at the affected side is reinnervated. This innervation can be either based on an ipsilateral facial nerve, if present (in cases where the nerve was cut or partially dissected), or by a cross-cranial nerve reinnervation (mostly facial to masseter nerve) as a permanent innervation.

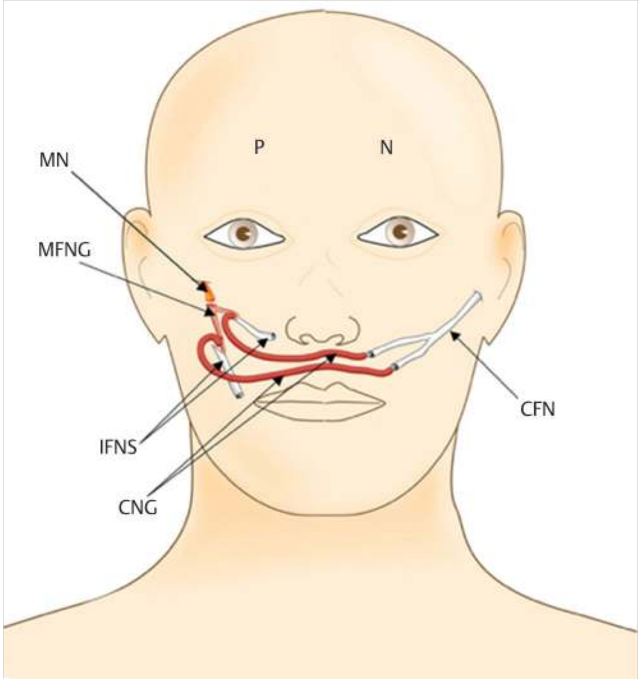

Fig. 22.1 The “babysitter” procedure: two cross-face cable grafts together with cable graft from motor master nerve to facial nerve. CFN, contralateral facial nerve; CNG, cross-face nerve graft; IFNS, ipsilateral facial nerve stumps; MFNG, masseter to facial nerve grafts; N, normal; NM, nerve to masseter; P, paralyzed.

Fig. 22.2 Surface landmarks for sural nerve harvest.

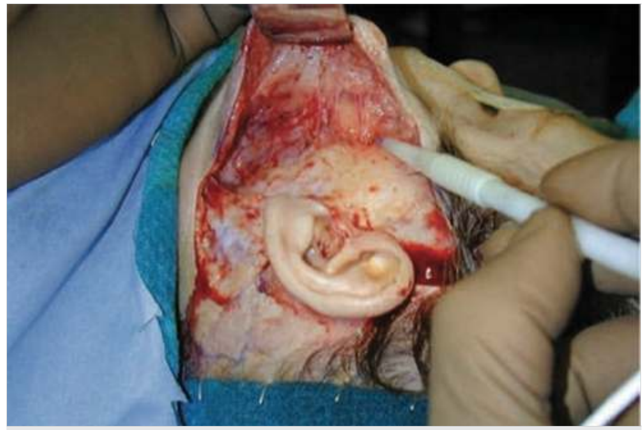

Fig. 22.3 Mapping and identification of the normal contralateral facial nerve branch to be sacrificed.

In the same surgery, a cross-face nerve graft is coapted to the lower trunks of the normal contralateral facial nerve. Then it is tunneled across the face through the upper lip and banked for the second stage.

Within 2 to 3 months, the paralyzed muscle will regain tone and then will begin to function in a mass pattern motion.

In the second stage (9 months later), a free muscle is transferred, and the cross-face nerve graft is used to innervate the free muscle. Within 3 to 6 months, spontaneous facial nerve motion is initiated by the contralateral facial nerve that should take control of the motion of the transferred muscle.

In cases where the masseter nerve was used to innervate the mimetic muscles, if the masseter nerve action is still noticeable at the BZMC and unsightly, the facial nerve branches to the BZMC can be transected at later procedure so that the smile will be solely produced by the transferred muscle.

22.3.2 Operative Technique

Sural Nerve Harvest

The sural nerve comes out from the tibial nerve at the popliteal region. It goes deep in between the two heads of the gastrocnemius muscle, emerges superficially along its course to the heel and is directed subcutaneously to the posterior aspect of the lateral malleolus. Around the malleolus, it splits into several small branches that give sensation to the lateral aspect of the foot up to two-thirds the distance to the toes (▶ Fig. 22.2).

Dissection starts with a 1.5 cm horizontal or longitudinal incision about 3 cm from the popliteal fossa. The nerve is detected usually with the lesser saphenous vein escorting it along its course. The nerve is transected proximally and a dull edge vein stripper is introduced to bluntly dissect the nerve to a branching point where another skin opening is made. The process is repeated until adequate nerve length is achieved (usually 11–14 cm).

Cross-Face Nerve Graft

On the nonaffected side, through a modified face lift incision extending slightly to the neck, superficial dissection of the superficial muscular aponeurotic system (SMAS) is carried out until the anterior border of the parotid gland is reached. At that point, the dissection goes deeper to the thin fascia that covers the masseter muscle. Dissection of facial nerve branches at that level is limited to the space between the lower border of the zygoma to the Stensen duct.

Using a nerve stimulator, two relatively large facial nerve branches responsible for the motion of the BZMC will be identified (▶ Fig. 22.3). The one with less intense stimulus on the BZMC and less effect on the orbicularis oculi will be sacrificed and serve as the donor motor nerve branch for the cross-face graft.

The sural nerve graft is then tunneled in a subcutaneous level across the cheek and upper lip to the contralateral upper buccal sulcus right above the canine tooth (▶ Fig. 22.4). Through a buccal sulcus incision, it is verified that the nerve graft has reached its place. If banked, the nerve is marked with a 3/0 blue nylon suture. Under the operating microscope, the sural nerve is anastomosed to the facial nerve branch in an interfascicular fashion and the incisions are closed over a Penrose drain.

Cross-Cranial Nerve Innervation Procedure

In the area outlined by the anterior border of the parotid gland, posterior border of the masseter muscle, zygomatic arch cranially, and parotid duct inferiorly, the masseteric branch of the trigeminal nerve is exposed with blunt dissection of the masseter. The nerve is then sectioned as distally as possible to facilitate approximation of its stump to the facial nerve branches located more superficially. The facial nerve branches are sectioned more proximally or distally depending on their distance from the masseteric nerve. In a case where there is a gap, a short nerve cable graft is used (either from the sural nerve or the great auricular nerve).[1,6,9] Nerve coaptation is performed with a microscope and interrupted epineural sutures of 10–0 nylon.

In case of a cross-face facial reanimation without the intention to use a free muscle transfer, when the cable graft is coapted at the same procedure (as a one-stage procedure), the coaptation of the cross-facial nerve is done at the same location as the masseter nerve, while in a two-stage procedure (6–9 months later) the cross-face nerve will be coapted distally to the masseter-facial nerve repair, to a nerve branch responsible for the motion of the BZMC.

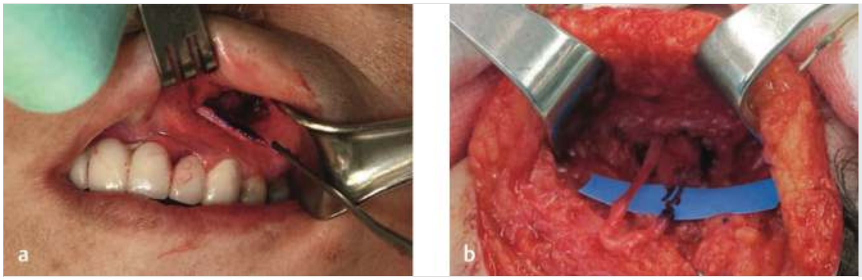

Fig. 22.4 (a, b) Anastomosing and tunneling of the sural nerve graft to the paralyzed side upper buccal sulcus.

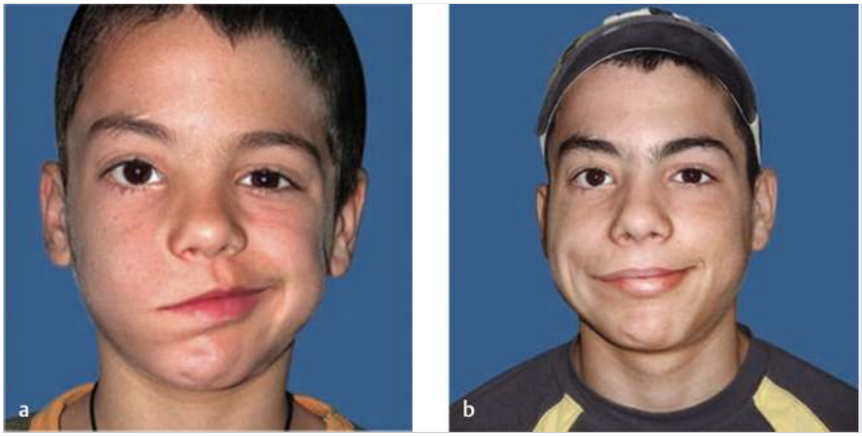

Fig. 22.5 (a) patient with congenital right complete facial paralysis before reconstruction **(b)** after reconstruction.

22.4 Innervated Free Flaps

22.4.1 Indications

- Long-standing facial paralysis can be reconstructed at any time using the staged cross-face nerve graft and free gracilis transfer for patients younger than 60 years (▶ Fig. 22.5a, b).
- ▶ Fig. 22.6 shows a schematic of the procedure (▶ Fig. 22.7a for before and ▶ Fig. 22.7b for after).
- Long-standing facial paralysis can be reconstructed at any time using the free gracilis transfer connected to a viable ipsilateral facial nerve stump (if present) at any age (▶ Fig. 22.8).
- Long-standing facial paralysis can be reconstructed at any time using free gracilis transfer connected to the masseter motor nerve for patients older than 60 years or for bilateral facial paralysis patients (including Möbius syndrome).
- In cases where a distal segment of the facial nerve was sacrificed for oncologic purposes, a free gracilis transfer is needed for the reconstruction.
- For the most optimal results concerning a smile, even in recent facial paralysis, a muscle transfer procedure is indicated.
- Patients with partial facial weakness, where there is good neural input yet weak muscle contraction and smile due to muscle atrophy, can benefit from a free muscle transfer to an ipsilateral facial branch.

Facial nerve-based reanimation for long-lasting paralysis (in which sufficient time has passed since the onset of the facial nerve injury that the facial muscle motor end plates have undergone fibrosis) necessitates both reinnervation and muscle transfer.

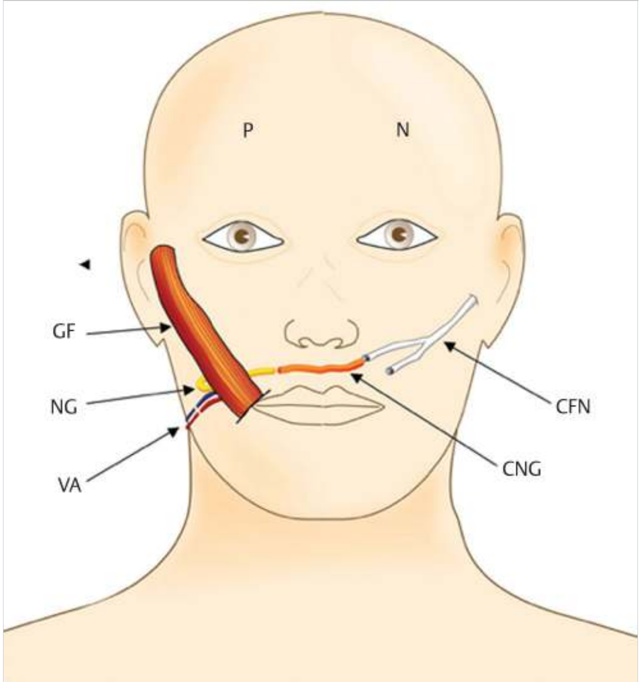

Fig. 22.6 Two-stage cross-face nerve graft and free gracilis muscle transfer shown at the end of the process. CFN, contralateral facial nerve; CNG, cross-face nerve graft; GM, gracilis muscle; N, normal; NG, nerve of gracilis (part of obturator nerve); P, paralyzed; VA, venous and arterial anastomoses.

In the authors' point of view so do recent facial paralysis patients who seek the most optimal result surgically possible.

Various muscles are available for muscle transfer. However, the gracilis muscle is the most preferred of all. Neuromuscular

Fig. 22.7 **(a)** Patient with facial paralysis due to arteriovenous (AV) malformation and intracranial hemorrhage before reconstruction **(b)** after reconstruction.

pedicle is reliable and relatively easy to prepare. A segment of muscle can be cut to any desired size based on the neurovascular pedicle, thereby making the flap customizable to the patient's facial proportions. There is no functional loss in the leg and the scar is reasonably well hidden.[10]

When an ipsilateral nerve is available, a one-stage free gracilis muscle flap transfer is performed. The flap is inset subcutaneously in the paralyzed cheek from the modiolus to the temporal fascia above the auricle. The blood vessels of the flap are anastomosed to facial or superficial temporal vessels and its motor nerve is sutured to the ipsilateral facial nerve zygomatic branch.

When an ipsilateral nerve is unavailable, a two-stage cross-face sural nerve graft and free gracilis muscle transfer procedure is fabricated. In the first stage, the nerve graft is harvested, coaptated to a contralateral facial branch responsible for smiling stimulus, tunneled across the face to the paralyzed side, and banked in the upper buccal sulcus. In the second stage (which is scheduled 9 months later), the free gracilis is transferred and the motor nerve is sutured to the cable graft that was banked. Reanimation of the muscle commences after 4 to 8 months. It reaches full capacity within a year.[5,6]

When facial nerves are absent on both sides or the patient is over 60 years of age and nerve growth is impaired, a nonfacial nerve reanimation is performed and is based on the ipsilateral motor nerve to the masseter that is connected to a free muscle transfer (▶ Fig. 22.3). Thus, the stimulus to create smiling movement depends on voluntary actions such as teeth clenching. These efforts may become more natural over time. In this procedure, there is no donor nerve morbidity.

Patients who are unsuitable or do not wish to undergo a microsurgical procedure may be reconstructed by transfer of a local muscle flap, namely, the temporalis or masseter muscles.[11] The temporalis muscle procedure usually achieves fair static and dynamic results. However, it does not provide spontaneous smile.

22.4.2 Technique—Free Gracilis Transfer

Free Gracilis Transfer

Surface landmarks for gracilis muscle harvest (▶ Fig. 22.9): A line is drawn in the medial side of the thigh, from the pubic tubercle to the medial condyle of the femur. The gracilis muscle lies 2 cm posteriorly to that line. The neurovascular pedicle should be found about 8 cm from the tubercle.

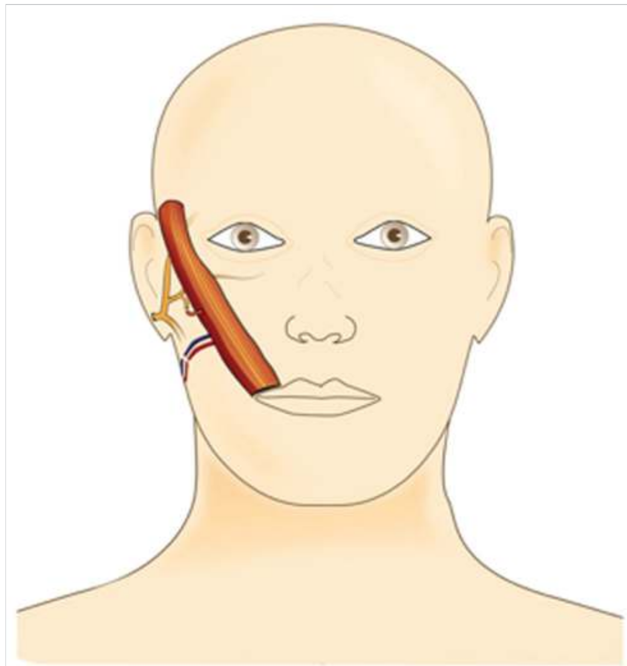

Fig. 22.8 One-stage free gracilis muscle transfer to ipsilateral facial nerve shown at the end of the process.

An 8 to 10 cm incision is performed on the assumed location of the muscle. After the superficial and deep fascias of the thigh are incised longitudinally, the muscle should be present right under, with several perforating vessels coming from its surface to the skin (▶ Fig. 22.10). The muscle is dissected lengthwise and the fascia between the gracilis and the adductor longus is incised.

Right behind that fascia, the neurovascular pedicle is identified and serves to identify and verify the gracilis muscle. At this stage, the nerve is dissected to its origin from the obturator foramen and then transected to give the longest nerve pedicle as possible. The gracilis vascular pedicle is then dissected between the adductor longus and the adductor magnus up to its origin to the profunda femoris vessels (▶ Fig. 22.11). The gracilis muscle is further dissected and freed 360 degrees. The

Fig. 22.9 Surface landmarks for gracilis muscle harvest.

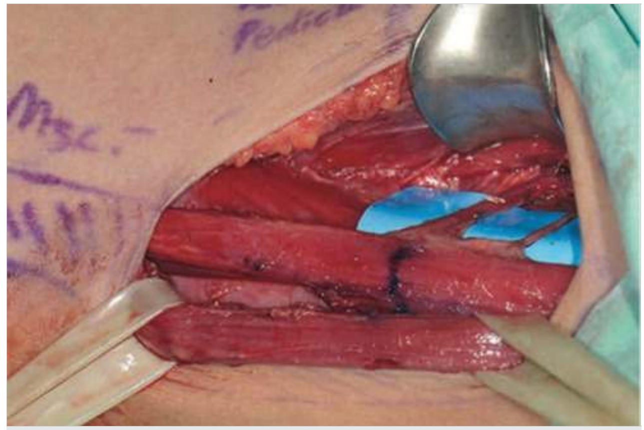

Fig. 22.12 Tailoring of the gracilis muscle.

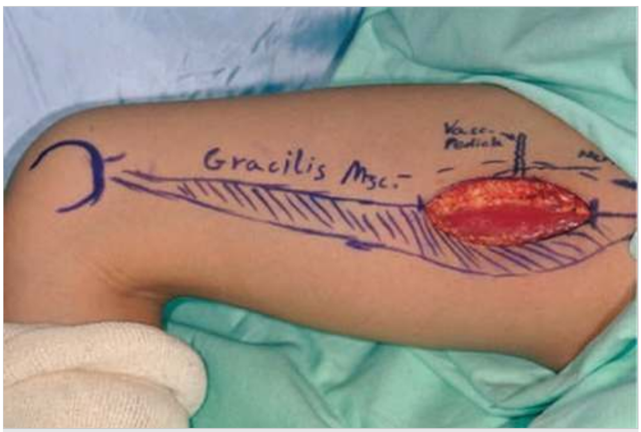

Fig. 22.10 Identification of the gracilis muscle in the thigh.

Fig. 22.13 Flap vessels are transected following placement of blocking stitches along muscle edge.

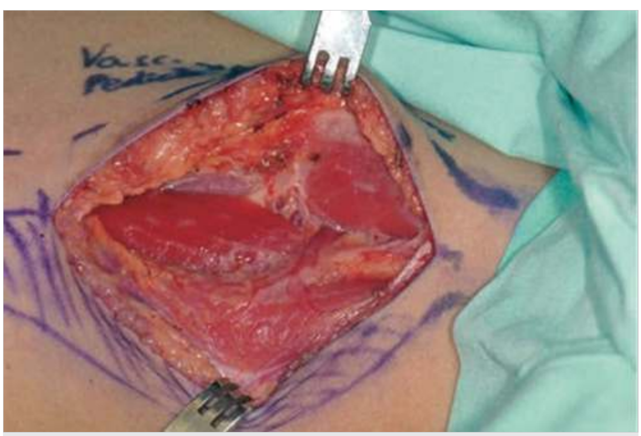

Fig. 22.11 Dissection of the neurovascular pedicle.

muscle is then tailored by splitting it longitudinally to fit the narrow space of the cheek (▶ Fig. 22.12). The muscle strip that is harvested may occasionally weight no more than 10 g. The length of the needed muscle unit is measured in the cheek from the oral modiolus to the superficial temporal fascia superior to the auricular helix take-off and marked in the thigh when the knee is stretched. The knee is then flexed. And the muscle transected caudally and cephalically.

Along the transected muscle edge to be sutured to the modiolus, five 4/0 Vicryl sutures are aligned to create a blocking point to the main stitches that will later connect the muscle to the modiolus.

Only when the cheek recipient vessels are fully dissected and flow verified, the gracilis vessels are transected (▶ Fig. 22.13).

On the affected side of the face: A modified face lift incision is marked with an upward extension of 5 cm superior to the helix take-off and a short 2 cm curved neck extension, about 1 cm caudal to the mandible angle (▶ Fig. 22.14a). The incision line is infiltrated with lidocaine 2% and adrenalin 1:100,000 solution.

Subcutaneous dissection is carried out, leaving thin fatty layer under the skin flap (▶ Fig. 22.14b). The dissection area covers a fan-shaped space from the full length of the skin incision to the modiolus and 1.5 cm along the upper and lower lips. It is important to notice the facial/angular artery near the oral commissure as a landmark for the appropriateness of the level of dissection.

At that stage, the facial artery and vein are dissected at their cross-over point with the mandible where the artery will usually go anteriorly toward the commissure and the vein cephalically toward the anterior border of the masseter muscle. By

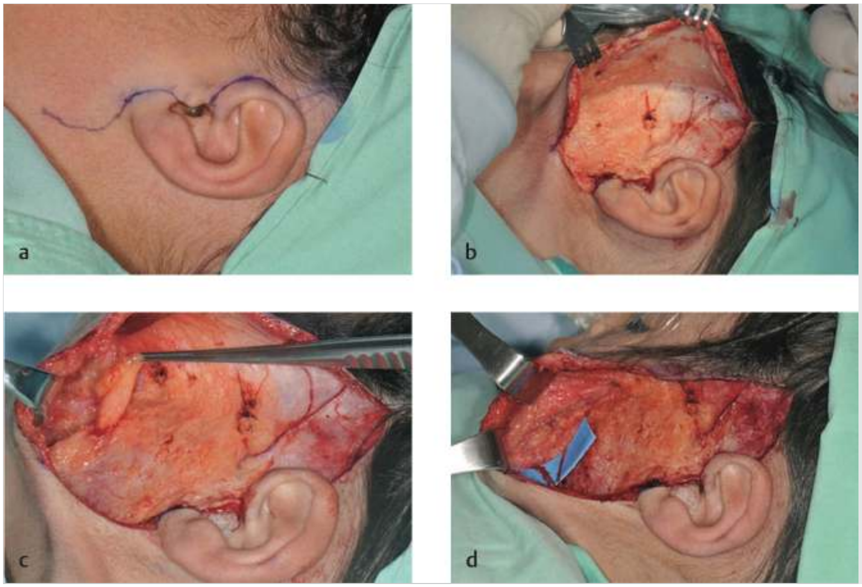

Fig. 22.14 Dissection of recipient paralyzed cheek. **(a)** Incision landmarks; **(b)** subcutaneous flap dissection; **(c)** resection of fat pad; **(d)** facial vessels dissected.

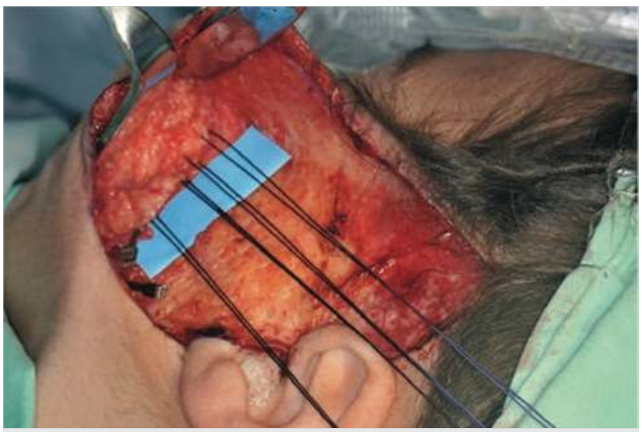

Fig. 22.15 Placement of anchoring Vicryl sutures at the modiolus.

compressing the cheek bulk from the inside, the buccal fat pad is identified, dissected, and resected to free space for the gracilis (► Fig. 22.14c, d).

Four 0 white Vicryl sutures are looped through the remnants and fibrotic layer of the orbicularis oris: One at the modiolus, two (0.5 apart) at the upper lip, and one at the lower lip. Careful placement of these stitches will determine the right natural pull of the mouth at motion and the accurate creation of the nasolabial fold (► Fig. 22.15).

The intraoral upper buccal sulcus old scar from the cross-face procedure is reincised carefully, revealing the marking stitch and the nerve ending of the cross-face nerve graft (► Fig. 22.16). The very end of the cross-face graft is transected and sent for frozen section identification of viable peripheral nerve axons. A tunnel is created between the facial to the intraoral dissections and a vessel loop is transferred from one space to the other.

The gracilis muscle after being detached from the thigh is transferred to the face. The 0 Vicryl sutures are looped twice through it and through the old orbicularis to serve as a pulley that will help in mobilizing the flap to the modiolus and for securing it properly into place.

Only after arterial and venous anastomosis in the face and neural anastomosis in the buccal sulcus, the muscle is stretched to reach its origin in the temporal region above the auricle (► Fig. 22.17 and ► Fig. 22.18). It is secured by four or five 0-Vicryl sutures that are placed by pulling the muscle and fixating the muscle at the point where the lip or modiolus move just slightly with the muscle pull. At the end of that part, the oral commissure should be slightly pulled obliquely and upwards exposing the lateral upper teeth (► Fig. 22.19).

At the end of the procedure, a Penrose drain is left in the operated cheek and a vacuum drain in the donor site in the thigh (► Fig. 22.20).

The skin is closed meticulously and a protecting sticker and a hook-splint is sutured to the patient's scalp and its hook is inserted to the oral commissure to protect the cheek from extra external pressure.

22.4.3 Clinical Pearls

Contraindications

- Current oncologic disease.
- Medical status not permitting long anesthesia.
- Major depression.
- Unrealistic expectations.

Complications

- Injury to functioning facial nerve.
- Recipient or donor site wound infection.
- Recipient or donor site hematoma.
- Failure to achieve facial motion or symmetry.
- Facial bulge over gracilis muscle.
- Inadequate motion or spastic transplanted muscle.

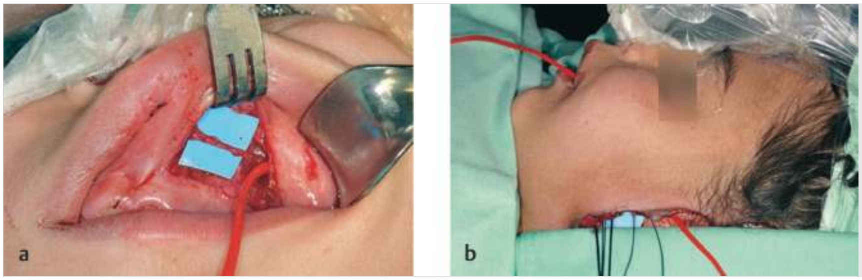

Fig. 22.16 (a, b) Dissection of the cross-face nerve graft.

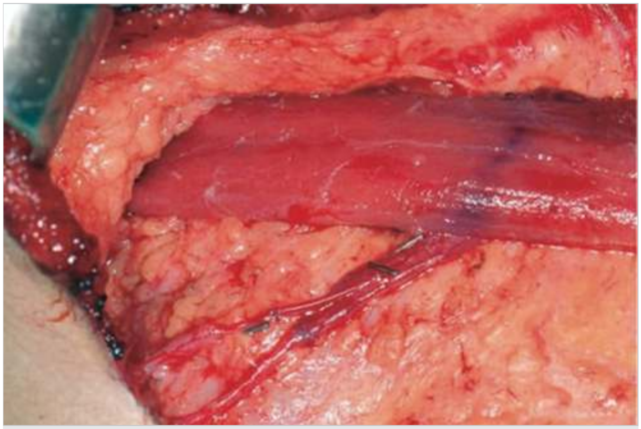

Fig. 22.17 Vessels and nerve anastomoses.

Fig. 22.18 Positioning and tension measurement of the gracilis muscle.

Fig. 22.19 (a, b) Muscle flap secured with correct tension.

Special Preoperative Considerations

- Assess whether there is a viable facial nerve stump on the paralyzed side.
- If there is no viable ipsilateral facial nerve, is there a functioning facial nerve on the contralateral side.
- Assess whether there are viable facial muscles on the paralyzed side.
- Choose the appropriate surgical approach for patients over 60 years.
- Ensure that the patient understands the nature of those long procedures and the long time lag until the final result shows. Ensure reasonable expectations of the final results.

Special Intraoperative Considerations

- At first stage—cross-face nerve graft: Pick a reasonably large nerve branch, but ensure it does have a stronger nerve that does the same action.
- Make sure that the selected normal branch to be sacrificed does not play a major role in orbicularis oculi action.
- Bank the cross-face nerve stump in a constant location and mark it with a thick (3/0) nylon suture—for the ease of retrieving it in the second stage.
- At the second stage, treat the muscle gently and preserve its epimysium. Tailor the muscle to be transferred, to make it as thin, gentle, and long as possible and needed, while not compromising the neurovascular pedicle that penetrates it.
- Place the muscle obliquely from the modiolus to the fascia superior to the auricle.

Special Postoperative Considerations

- Immediate extubation.
- Admit the patient to a step-down unit for 24 hours after surgery.
- Protect the operated cheek by proper signaling and with the designated splint.
- When motion starts, several months after the procedure, the patient should practice daily, in front of a mirror, to strengthen the muscle action and create more symmetry with the healthy side smile

Fig. 22.20 A Penrose drain is left in the operated cheek.

22.5 Conclusion

- Even though it remains impossible to correct long-standing facial paralysis completely, facial nerve paralysis surgery presents with a very high success rate.
- Most operated patients even with a near-normal or even weak smile results are relatively satisfied only from the subtle presence of slight motion in their paralyzed faces.[12]
- Immediate facial nerve neurorrhaphy yields the best reanimation results. Reinnervation of the mimetic muscles on the affected side either with an ipsilateral facial nerve stump or a cross-cranial nerve innervation with a simultaneous cross-face nerve graft followed by a free muscle transfer is the gold standard for treatment of recent paralysis. Reinnervation of the BZMC should not be attempted beyond 12 months of paralysis without muscle transfer. Reinnervation based on facial nerve should be aspired for, even at the cost of conducting a cross-face procedure and the two-stage cross-face nerve graft and gracilis muscle transfer. That procedure is a validated reliable procedure and plays a pivotal role in dynamic reanimation of facial paralysis.

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Section II

Breast

Subsection IIA

Macromastia

II

23 Breast Reduction in the Female Patient: General Considerations

Rodney Cooter

Abstract
Breast reduction is performed to reduce volume and to reshape the breast. Prior to embarking on the operation, an appropriate preoperative consultation should address the risks and complications as delineated in this chapter. The risk profile of each individual patient must be assessed to ensure that the patient gives fully informed consent. Perioperative management planning must take into consideration a regimen of thromboembolic prophylaxis. Longer term issues such as breast screening, lactation, and scar management need to be discussed where appropriate.

Keywords: breast reduction, complications, lactation, mammography, reduction mammoplasty, risks

23.1 Introduction

Breast reduction is a common plastic surgical procedure and can be a very gratifying operation for patients because it alleviates the weight and drag on the neck and shoulders. Most are happy with the shape of their reduced breasts and nearly all patients will report overall significant improvements in their activities of daily living.

There are a plethora of operations described under the umbrella of "breast reduction"; each of these procedures usually has two components: reduction of the skin envelope and reduction of the breast gland. Breast reduction nomenclature, often eponymous, can be reduced to two main skin reduction techniques, namely, "the Wise pattern"[1] and "the vertical scar" techniques, and for the gland reduction, we refer to the anatomical orientation of the pedicle of tissue supporting the neurovascular supply to the nipple-areolar complex. The generous blood supply of the normal breast comes from a number of different source arteries on the chest wall, so a breast reduction can be successfully performed with an inferior pedicle,[2] a lateral pedicle,[3] a central mound,[4] a medial pedicle,[5] or even by double pedicles orientated superiorly[6] or transversely.[7]

One of the commonest breast reduction techniques that has been a "standard" operation for several decades is the combination of a Wise pattern skin resection and an inferiorly based pedicle. The Wise pattern of skin reduction, however, has also been used with almost every other type of pedicle orientation. Proponents of the Wise pattern cite the ease of reproducibility as its greatest strength. However, there is a growing enthusiasm for alternative skin reduction techniques that have less scarring because the Wise pattern's inframammary crease scar is quite lengthy and can be unsightly. The historically popular inferior pedicle technique of gland reduction has also been challenged because it does tend to "bottom out" after about 12 months and newer techniques using a superomedial or medial pedicle orientation have been shown to hold the shape in the longer term.

While recognizing the matrix of options available for breast reduction, the two operative techniques described in this section will be the Wise pattern skin resection combined with an inferior pedicle, and the short vertical scar reduction mammoplasty combined with a medially orientated pedicle. In many ways, these procedures are mutually exclusive in the sense that the inferior pedicle technique resects the breast tissue preserved by the superomedial and medial pedicle technique and vice versa; the medial pedicle technique resects the tissue from the inferior aspect of the breast. It is important, therefore, that whichever technique is used, the operating surgeon must document it clearly because any subsequent re-hypertrophy of the breasts that require further reduction may inadvertently transect the original pedicle supporting the nipple-areolar complex. As re-hypertrophy is more common after young women have a breast reduction, the redo reduction may be many years later and as mentioned above, the skin's scar pattern may not be an accurate indicator of the glandular pedicle's orientation.

23.1.1 Relevant Anatomy

Blood supply: The predominant blood supply is from perforators of the internal mammary artery, the lateral thoracic artery, the thoraco-acromial axis, and vessels from the subscapular system via the serratus and thoraco-dorsal systems and the intercostal perforators. The venous drainage does not necessarily follow the arterial pattern and is more superficial.

Nerve Supply

The nerve supply of the breast is from the anterolateral and anteromedial branches of the intercostal nerves with T4 being the predominant nerve supply to the nipple-areolar complex. There are also contributions from the supraclavicular nerves to the upper aspect of the breast.

Lymphatic Drainage

This is predominantly to the axillary region plus parasternal drainage as well as some inferior drainage.

23.2 Operative Technique

Choice of operative technique should consider each patient's unique anatomy. Chapters 24 and 25 detail commonly used operative techniques for the reduction of the female breast. Two main considerations are choice of pedicle and choice of skin incision pattern.

Pedicle

A multiplicity of pedicles have been described for transposition of the nipple-areola complex, including superior, inferior, medial, lateral, superolateral, and inferolateral. The inferior pedicle technique described in Chapter 24 is a popular choice. If pedicle length is very long, for example exceeding a 2:1 ratio of length:width, nipple-areola vascularity may be questionable and require free nipple grafting.

Skin Incision

Choice of skin incision depends on the extent of skin excess present on examination. In cases where skin excess and the distance for nipple-areola transposition are more limited, a short-scar technique as discussed in Chapter 25 may be chosen. For patients with very large breasts with excess skin in addition to breast tissue, a modified Wise pattern may be required as discussed in Chapter 24.

23.2.1 Preoperative Considerations

In preparing for a breast reduction, it is important that the following areas are discussed as part of the process of a fully informed consent:

Breast Screening

A mammogram is performed for patients over 40 years of age or those with a significant history.

Lactation

Women with very large breasts often struggle to breast feed successfully due to risk of smothering and difficulty of the baby latching on to the nipple-areolar complex. Although the rearrangement and reduction of breast tissue would seem theoretically to risk the ability to breast feed, lactation is usually possible with any type of pedicled breast reduction.[8] This should be therefore discussed with patients but is rarely a factor which decides them against proceeding to surgery.

23.2.2 Risks

Loss of sensation to the nipple-areolar complex and even nipple death must be discussed. Other surgical risks include hematoma, infection, scarring, and asymmetry.

23.2.3 Caution must be Exercised in Patients with

- A cardiac history.[9]
- A history of smoking.[9]
- Previous breast surgery.[9]
- A high body mass index (BMI).[10]
- A large weight loss.[11]
- Diabetes.[12]
- Previous radiotherapy.
- A history of deep vein thrombosis or pulmonary embolus, especially those carrying other risks such as treatment with estrogen-based therapies, and particularly tamoxifen therapy.
- Wound healing issues with steroids.

23.2.4 Documentation

Other than a thorough history and examination, it is almost imperative that preoperative photography is performed with the patient upright, and anterior, oblique, lateral, and supine views are fairly standard. It is useful from a medicolegal point of view to take photographs of all of the preoperative markings with the dimensions clearly legible.

23.2.5 Operative Considerations

- Prophylaxis—antibiotics,[13] thromboembolic.
- Weigh the best resected specimen and lateralize it, preferably with marking sutures.
- Document accurately the technique used for the reduction.

23.2.6 Postoperative

- Drainage tubes.[14]
- Garment wearing.
- Scar management.
- Breast screening.[15]

23.2.7 Long-Term Results

- Shape.
- Scarring.
- Fat necrosis.[16]
- Nipple-areolar complex sensation.[17]
- Patient-reported outcome measures.[18]

23.3 Conclusion

Achieving a successful result from breast reduction surgery requires a thorough work up of the patient. Several risk factors may increase the risk of surgical complications that can include hematoma, infection, asymmetry, poor scarring, nipple-areola necrosis, and fat necrosis. Choice of pedicle type and skin incision should be tailored to the individual patient's anatomy. With careful risk factor mitigation and choice of operative technique, long term outcomes can be very favorable for the breast reduction patient.

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24 Wise Pattern, Inferior Pedicle Reduction Mammoplasty

Rodney Cooter

Abstract

The Wise pattern, inferior pedicle, breast reduction technique can give very predictable results, particularly for the skin envelope. It is an easier technique to learn than vertical mammoplasty techniques but it does have the down side of quite long scarring and the risk of a "boxy" shape after about 12 months postoperatively.

Keywords: breast reduction, inferior pedicle, Robbins technique, Wise pattern

24.1 Introduction

The Wise pattern skin reduction and inferior pedicle technique of gland reduction are still commonly used techniques for reduction mammoplasty globally.[1,2] Although many different parenchymal resections have been defined with the Wise pattern skin reduction, the technique described here will involve an inferior pedicle in what is commonly referred to as the Robbins technique. This gives predictable early results but some may argue that there is too much reliance on the viscoelastic properties of the lower pole skin envelope and that by 12 months, postoperatively, there can be a flattening of the lower pole with some glandular descent. The skin scarring is much longer than with vertical short scar techniques.

24.2 Indications

Almost any breast can be reduced using this combination of techniques. One limiting factor is the length of the glandular pedicle in women with gigantomastia because the limited length of the vertical limb of the soft tissue envelope may be insufficient to allow a very long inferior pedicle to fit comfortably. An absolute indication for this technique is when performing a redo breast reduction which has originally been performed with this method. The techniques described for this operation are usually also useful for augmentation mastopexy procedures where there is excess lower pole skin.

24.2.1 Preoperative Markings

Breast operation planning is best performed with the patient standing in front of the chaperoned surgeon who sits in front of the patient with the breasts at eye level. For breast reduction planning, the newly proposed nipple position is set on the breast meridian at 21 cm from the sternal notch (▶ Fig. 24.1a). It should be at or just above the level of the inframammary fold (IMF). Once the new nipple position is determined, some surgeons use a template for their Wise pattern markings. A 13 cm long open circle is drawn around the proposed new nipple point such that when the circle is closed at operation, the new areolar diameter will be approximately 42 mm. The breast meridian line is drawn inferiorly from the midclavicular point (MCP) and then projected through the new nipple position and onto the abdomen where a vertical arrow is drawn up to the IMF (▶ Fig. 24.1a). The breast is then swept laterally and a 5-cm line drawn from the medial end of the open circle down toward the fixed arrow on the abdomen (▶ Fig. 24.1b). In a similar fashion, the breast is then swept medially and a 5-cm line is drawn from the lateral end of the open circle toward the fixed abdominal arrow (▶ Fig. 24.1c). The IMF is then drawn and the lower ends of the 5-cm limits are connected to each end of the IMF line (▶ Fig. 24.1a). Actually, each end of the IMF line is curved upwards onto the breast to achieve more aesthetically pleasing

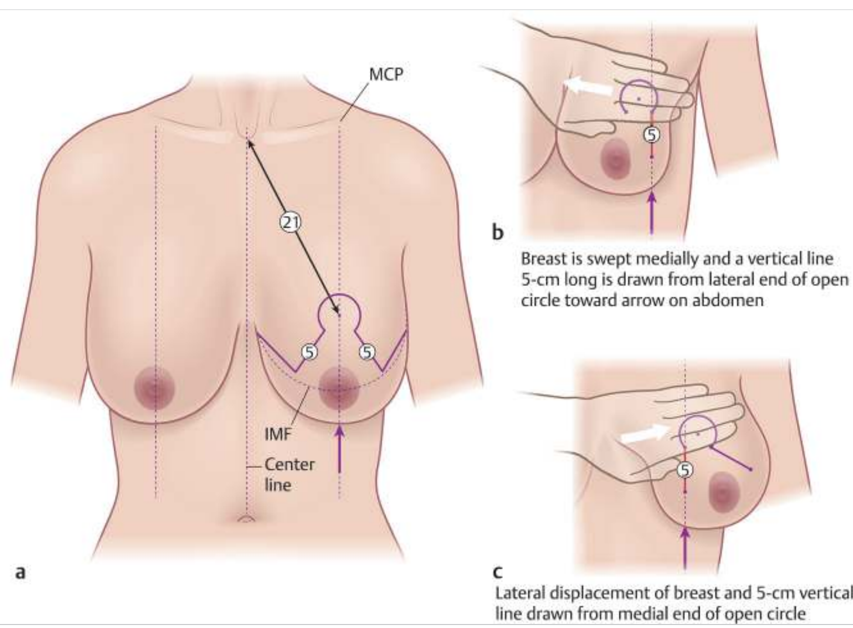

Fig. 24.1 Planning the Wise pattern: **(a)** New nipple position set at 21 cm. **(b)** To determine skin resection, breast is swept laterally, then medially. **(c)** Inframammary fold (IMF) markings are then connected to skin flap markings.

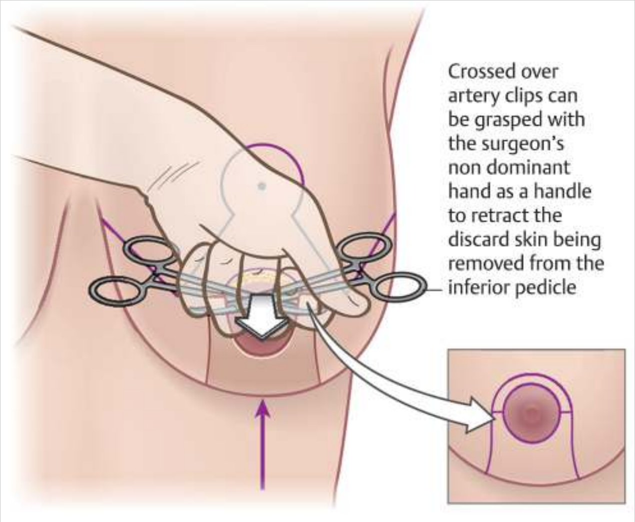

Fig. 24.2 De-epithelializing the inferior pedicle. Two artery clips can be crossed over to form an effective handle to assist accurate de-epithelialization.

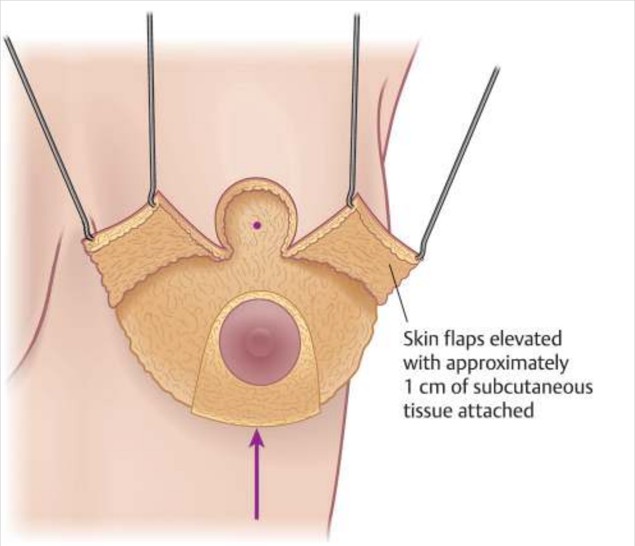

Fig. 24.4 Elevating the skin flaps in the Wise pattern breast reduction.

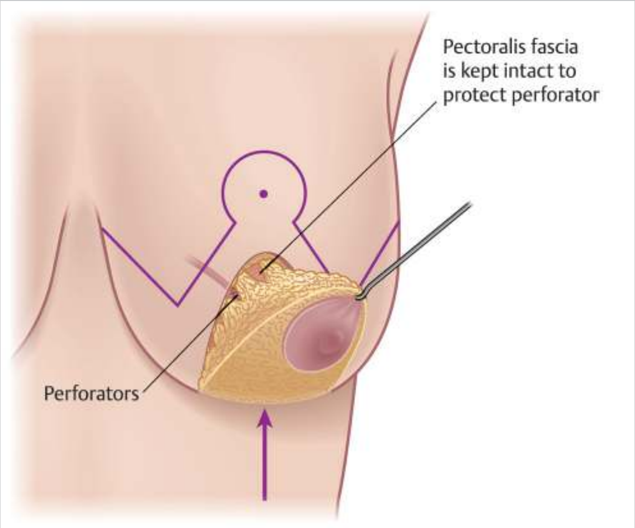

Fig. 24.3 Dissecting the inferior pedicle. Care must be taken to preserve the pectoralis fascia and protect the dominant perforator entering the pedicle from the internal mammary system.

scars postoperatively. Ideally, the IMF length of the incision should equate to the sum of the interconnecting incisions to avoid scar rucking at closure. The new nipple areolar diameter is marked on the areola and the pedicle is designed to straddle the IMF arrow that had been drawn below. Original descriptions suggest a 3:1 ratio of length to width of the pedicle.

24.3 Operative Technique

The patient is supine but with the head up to give a degree of ptosis to the breasts, otherwise large breasts will be displaced too far laterally. Local anesthesia with adrenaline (epinephrine) is injected subcutaneously into the proposed incisions. The nipple-areolar complex is incised and the skin of the inferiorly based pedicle is removed down to the IMF by first elevating the periareolar redundant skin down to the 9 o'clock level on one side and 3 o'clock on the other side of the areolar; artery clips are then used in a crossed-over fashion to act as a handle to facilitate the removal of the remaining skin down to the IMF (▶ Fig. 24.2). Some surgeons leave a triangle of skin at the level of the T-junction of the IMF to help improve healing at that point. The pedicle is then elevated taking care not to breach the pectoralis fascia and leaving enough thickness in the deeper aspect of the pedicle to include the dominant internal mammary perforator entering the medial side of the pedicle about 4 to 6 cm above the IMF at about the level of T4 (▶ Fig. 24.3). Now the skin flaps are elevated by placing skin hooks in each flap and having the surgical assistant lift it away from the breast so the surgeon can use a nondominant hand to palpate the constant flap thickness as the dissection proceeds toward, but not through, the underlying pectoralis fascia. Having elevated both flaps, the two flap dissections are joined at the breast meridian region to completely release any central attachments and to ensure flap mobility (▶ Fig. 24.4). The breast gland reduction is now performed by removing the tissue between the elevated flaps (the new breast's envelope) and the pedicle. This is the horseshoe-shaped glandular resection (▶ Fig. 24.5); a nonabsorbable marking suture is placed at the level of the original areolar's upper border (i.e., at 12 o'clock) so that the examining pathologist can orientate the specimen. Various suturing techniques can now be used to maintain the position of the pedicle on the chest wall and also to "shorten" the pedicle to ensure it fits comfortably within its new envelope.

Wound closure is now performed in two layers with the interrupted dermal sutures being over-sewn by a subcuticular absorbable suture in three elements: around the areola's perimeter, the vertical wound, and the horizontal IMF wound (▶ Fig. 24.6). Care must be taken to ensure that on either end of the vertical wound the inferior element of the areola is not dragged down into a tear shape and that the junction with the IMF is closed comfortably without tension as T-junction wounds can be slow to heal and then scarring may be

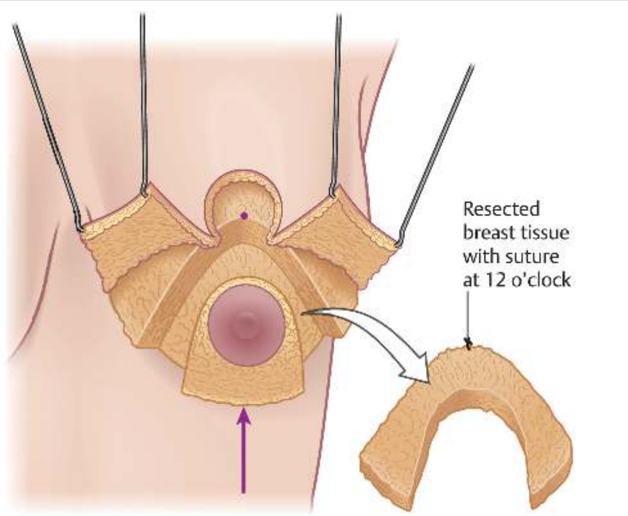

Fig. 24.5 Resection of the parenchyma from the inferior pedicle breast reduction.

unacceptable. Wound drains are optional but can give good access to the wound for retro-filling with a long-acting local anesthetic for postoperative comfort.

24.4 Conclusion

The Wise pattern, inferiorly pedicled breast reduction is a workhorse procedure that is safe and reliable with predictable results. Drawbacks include the long anchor-type scars and the reliance on the skin envelope to support the shape which it does so with some limitations as reflected in the subsequent glandular ptosis in the long term in many cases.

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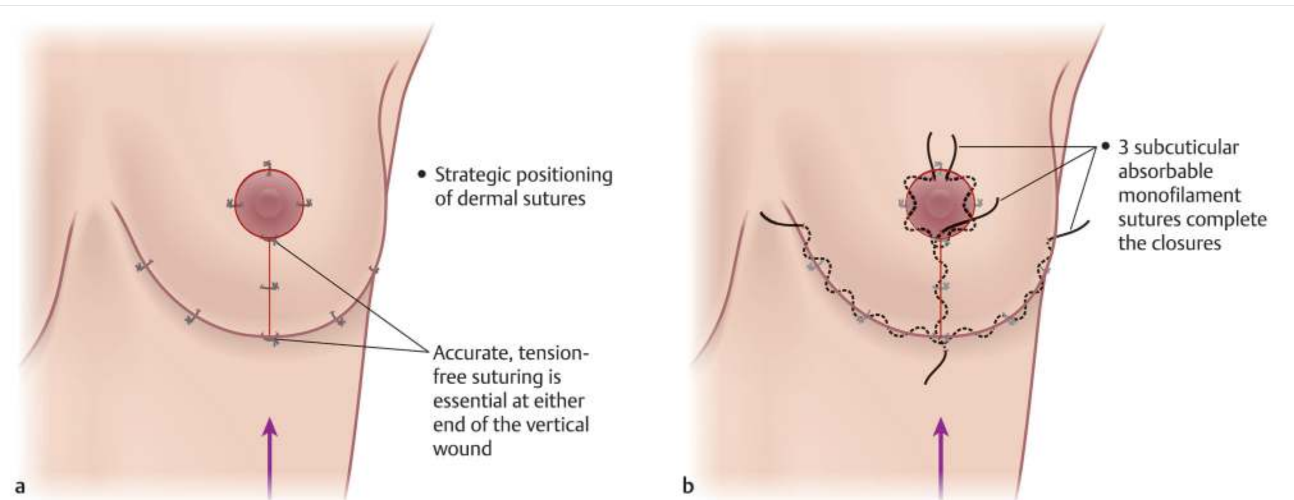

Fig. 24.6 (a, b) Closure of the Wise pattern breast reduction.

25 Vertical Scar Reduction Mammoplasty

Rodney Cooter

Abstract
The vertical scar reduction mammoplasty is an excellent technique once it is mastered. It is useful to start with smaller breasts when embarking on this procedure's learning curve because it is not as logical in surgical execution as some of the other techniques for breast reduction. However, the longer term results are well maintained and dealing with the excess skin can be initially challenging but it is remarkable how much of it restitutes over time.

Keywords: breast reduction, reduction mammoplasty, vertical mammoplasty

25.1 Introduction

Breast reduction is a very popular operation but one of the major downsides is the scarring postoperatively. Traditionally described techniques produce an inverted T-scar or anchor scar, and it has become the focus of many efforts to reduce the horizontal component or eliminate it entirely to leave only a vertical scar. The short scar vertical mammoplasty can not only achieve markedly reduced scar length but also can produce results that maintain breast shape longer than the traditional inferior-pedicled Wise pattern techniques.[1,2] After performing traditional procedures such as the Wise pattern, inferior pedicle technique, the vertical scar reduction mammoplasty can be somewhat counterintuitive to surgeons as it resects tissue that is preserved in the inferior pedicle procedure, and the wound closure, especially at the lower end of the vertical scar, can leave quite a gathered dog-ear of skin. However, once mastered the vertical scar technique can be performed within a shorter operating time than the more traditional technique. In the long term, the shape is retained owing to the parenchymal support from the shaping of the breast gland so that the lower pole of the breast is less prone to bottoming out.

25.2 Indications

The vertical scar reduction mammoplasty is ideal for smaller breast reductions, especially when surgeons are in the early phase of their career because the large residual skin envelope can be daunting to manage in large breast reductions using this technique. As confidence grows with the use of this technique, almost any size breast can be successfully reduced. Some preoperative counseling may be required to alert patients to the possibility of a lumpy scar at its inferior end, and in some patients, there is the requirement of a touch-up procedure postoperatively.

25.2.1 Preoperative Markings

With the patient standing in front of the seated surgeon, operative markings are performed in the presence of a chaperone. The new nipple position is lower than traditionally used for inferior pedicle techniques. As a general rule, the sternal notch to nipple distance is set at 23 to 24 cm (▶ Fig. 25.1a). An open circle is drawn around this point with a circumference of 13 cm which, when closed, will produce an areolar diameter of 42 mm. The breast is then swept medially and a vertical line drawn down from the lateral end of the open circle and this maneuver is repeated in the opposite direction by sweeping the breast laterally and drawing a line from the medial end of the open circle vertically (▶ Fig. 25.1b). These "vertical" limbs can be 7 to 8 cm long and they are then joined by a curvilinear line sweeping down to within 2 to 4 cm of the existing inframammary crease (▶ Fig. 25.1b). The medial or superomedial pedicle is now drawn with the patient lying down; it should be at least

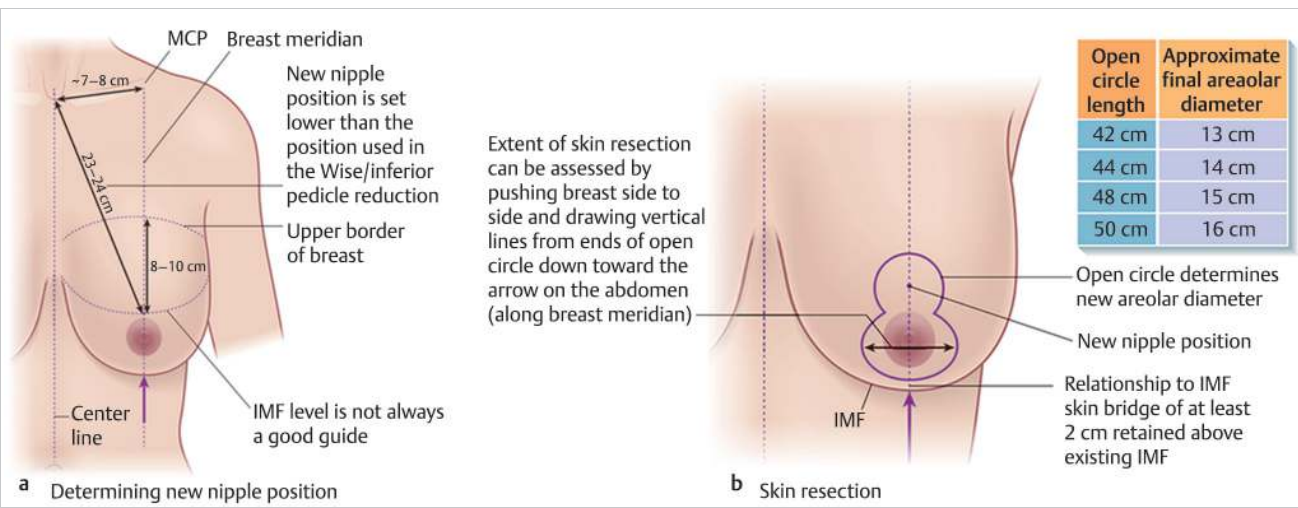

Fig. 25.1 Planning a vertical breast reduction: **(a)** New nipple position at 23 to 24 cm. **(b)** To determine skin resection, breast is swept to each side and a vertical line is drawn toward a breast meridian marking on the abdomen. The vertical lines are connected with a curved line sweeping down to within approximately 2 cm of the inframammary fold (IMF).

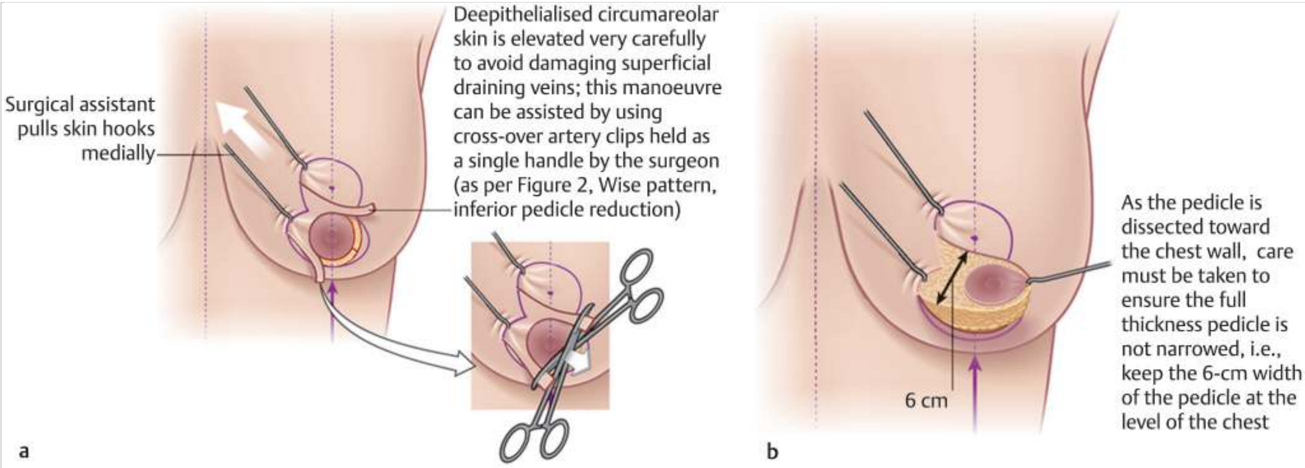

Fig. 25.2 Dissecting the pedicle: **(a)** De-epithelialization technique. **(b)** Isolating the pedicle.

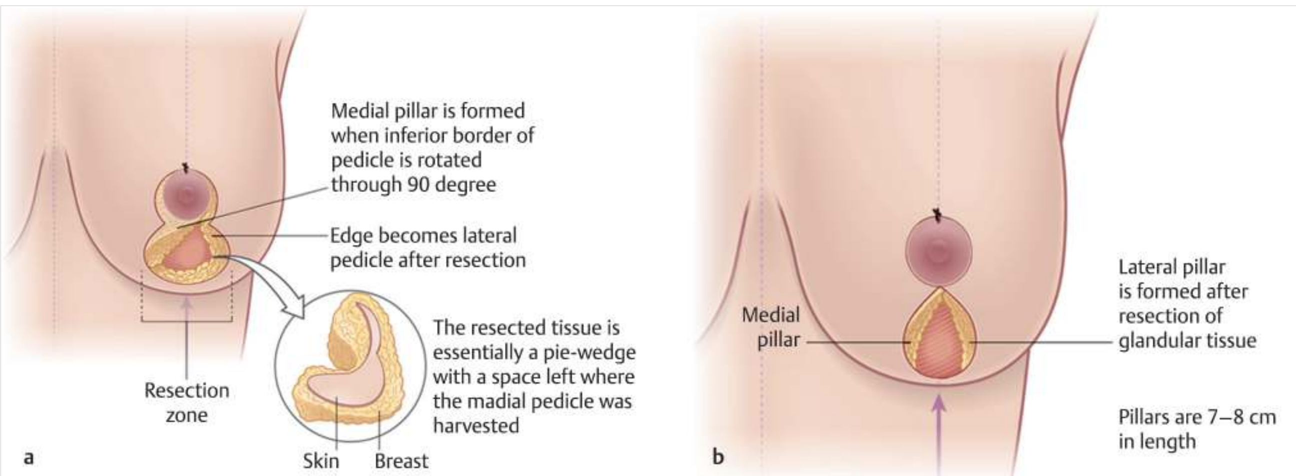

Fig. 25.3 Forming the pillars: **(a)** The medial pillar is formed by the originally inferior border of the pedicle after it has been rotated through 90 degrees. **(b)** The lateral pillar is formed by removal of the reduction specimen.

6-cm wide and include about 1 to 2 cm of tissue cuff around the perimeter of the proposed areola.

25.3 Operative Technique

With the breast skin compressed and the nipple-areolar complex stretched radially, the areolar skin incision is made while taking care to preserve as many underlying superficial veins as possible. Next, the pedicle is incised and de-epithelialized from the areolar region, from lateral to medial; this is made easier if the surgical assistant pulls the skin hooks placed medially. The surgeon elevates redundant skin around the areolar until two strips of discard skin can each be clasped with artery forceps that can be overlapped as a useful hand retraction tool for the surgeon to put counter-traction on the skin (▶ Fig. 25.2a). These simple techniques facilitate accurate intradermal epithelialization of the pedicle and help to preserve the underlying veins. Now the pedicle dissection is deepened toward the chest wall down to, but not through, the pectoral fascia taking care not to inadvertently reduce the base width of the pedicle as the dissection progresses toward the chest wall (▶ Fig. 25.2b). The remaining skin excision pattern is now incised and the gland resection commences beneath the proposed new areolar position; here the tissue removal is minimal so that a shelf is left to support the nipple-areolar complex in its new position. The nipple-areolar complex can now be sutured into position with a solitary stitch at 12 o'clock; this helps define the medial pillar, which is formed by the lower edge of the pedicle becoming vertical once transferred (▶ Fig. 25.3a). A similar length lateral pillar is now formed by resecting the lateral glandular tissue but leaving sufficient tissue on the lateral skin flap for shape retention (▶ Fig. 25.3b). To facilitate this dissection, have the surgical assistant use skin hooks to elevate the skin flap vertically while the surgeon dissects redundant glandular tissue from underneath the lateral flap; this is usually the bulk of the resected specimen. Now the inferior resection is performed and this must be extended subcutaneously medially and laterally to "empty" the inferior breast below the two pedicles, thereby avoiding dog-ears (▶ Fig. 25.4). Some surgeons favor liposuction to contour the inferior pole regions. In any event it is wise to

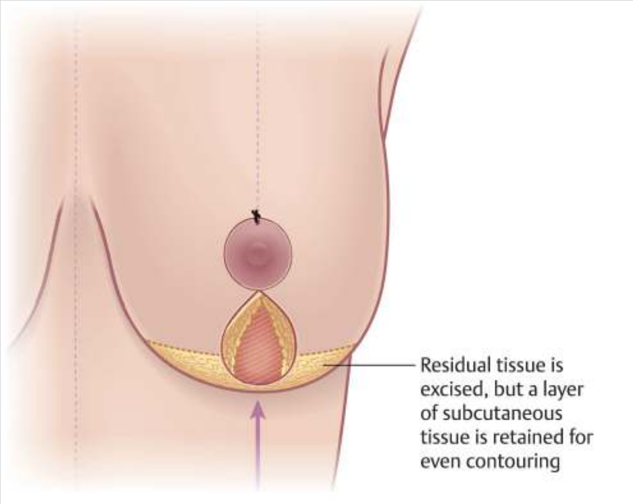

Fig. 25.4 Inferior level dissection. Tissue is removed from the inferior pole and from the medial and lateral potential "dog-ears."

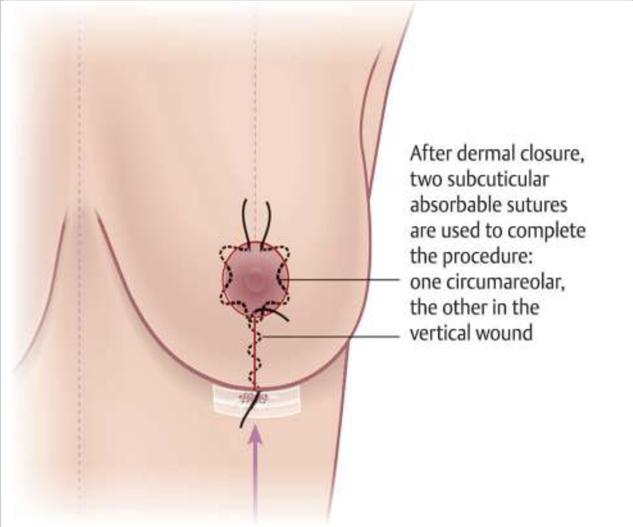

Fig. 25.6 Closure of the vertical scar breast reduction.

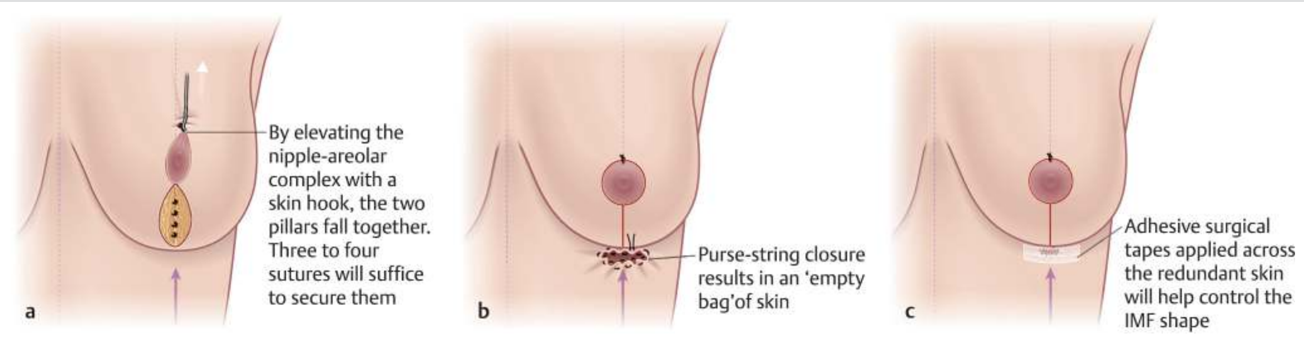

Fig. 25.5 Shaping the breast: **(a)** Closing the pillar. **(b)** Gathering redundant skin in inframammary fold (IMF) region. **(c)** Surgical taping can give early control of excess skin.

leave a uniform layer of adipose tissue on the lower skin to avoid any subsequent contour irregularities.

With a skin hook placed adjacent to the 12 o'clock areolar suture and retracted upward, the pillars are now sutured together with three to four stitches but avoiding any undue tension that could lead to subsequent fat necrosis (▶ Fig. 25.5a). The inframammary crease is usually elevated with this procedure and this leaves a "pouch" of redundant skin that is gathered in a purse-string fashion (▶ Fig. 25.5b). Efforts to reef this lengthy wound into a shorter vertical scar are futile because ultimately it re-stretches. By gathering the excess skin at the level of the newly elevated inframammary crease and then applying adhesive surgical tapes horizontally across it for compression (▶ Fig. 25.5c), the gathered skin will shrink significantly over time and may not need further adjustment. Some do, however! The new breast shape will now emerge and the skin edges are now approximated vertically and the circumareolar skin is closed (▶ Fig. 25.6).

The use of drainage tubes is controversial because they do not prevent hematomas and a seroma is probably inevitable but subsides naturally. Some surgeons do use drains to back-fill with a long-acting local anesthetic after wound closure.

25.4 Conclusion

The vertical scar reduction mammoplasty with a medially or superomedially based pedicle is an excellent procedure for two principal reasons. In the long term, the shape is maintained because the internal pillars, when sutured together, provide good support of the breast mound without requiring the skin envelope to hold the shape as is required in the inferior-pedicled technique. The shorter scars have the obvious advantage over the long anchor pattern scars of the Wise pattern reduction.

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26 Reduction of the Male and Transmale Breast

Paul R. Weiss

Abstract
The subject of reduction of the male and transmale breast has expanded over recent decades because of the evolution of surgical techniques including liposuction. The early classification and description of surgical techniques have evolved with improved techniques and "new" conditions. Anabolic steroids used by body builders, postbariatric deformities, and the transgender male have dramatically increased the number of patients and diversity of anatomic conditions. The techniques employed include liposuction alone or combined with excision through a limited (periareolar) incision, various circumareolar incisions, and "double" incision with management of the nipple-areola on a pedicle or as a free nipple graft.

Keywords: breast reduction, free nipple graft, gynecomastia, pedicle, subcutaneous mastectomy, transgender

26.1 Introduction

The surgical principles for reduction of the male and transmale breast are similar and often the same. The obvious goal is to achieve a normal male chest contour, male-appearing nipple-areola, and remove the breast parenchyma as completely as possible to reduce future cancer risk, particularly in transmale subjects, and do so with the shortest scars. Understanding of the application of the many techniques will enable the surgeon to assist the patient in choosing the correct surgery. For example, liposuction alone may be accomplished with minimal scars and would be appropriate for small gynecomastia conditions. The result may be suboptimal but reasonable for the patient who cannot accept scars. Likewise, the obese male or transmale patient will be counseled to accept long scars to achieve an acceptable contour with few alternatives. Where choices are available between a limited periareolar scar and a double incision with a long scar along the pectoral fold, the surgeon will discuss the benefits and disadvantages of each technique and provide an opinion to assist in decision-making. Plastic surgery principles provide guidelines for planning and execution of skin flaps, understanding blood supply to pedicles, management of skin grafts, and respect for skin tension lines. It is expected that the operative techniques and results discussed in this chapter will provide the knowledge to achieve desirable outcomes.

26.2 Indications

All of the patients presenting for treatment share a common problem: they are embarrassed by their appearance. This anatomic condition carries a diagnosis of gender dysphoria in the transgender patient. A contributing cause of the dysphoria is the presence of breasts. Selection of surgical procedures should consider safety, correction in a single procedure, and minimal scarring. Earlier classification and design of surgical techniques by Letterman and Schurter[1] and Simon et al[2] are the precursors of the current techniques and are appropriate for many patients today. The scar should preferably be placed in an anatomic location, that is, inframammary (pectoral) fold. The procedure should preserve normal appearance and sensibility of the nipple-areola and restore or create a masculine appearance (▶ Fig. 26.1). Postbariatric patients and those with large, pendulous breasts require longer incisions and usually free nipple grafts (FNGs). If there is a large amount of subcutaneous tissue and/or redundant skin, the incision may be extended to the posterior axillary line or onto the back in extreme cases. Webster[3] and Pitanguy[4] performed excision through the areola. Davidson[5] described a concentric circle periareolar technique for skin removal, which can be adjusted to allow elliptical skin excision. As periareolar-only incisions to eliminate redundant skin result in marked spreading of scars, the technique is

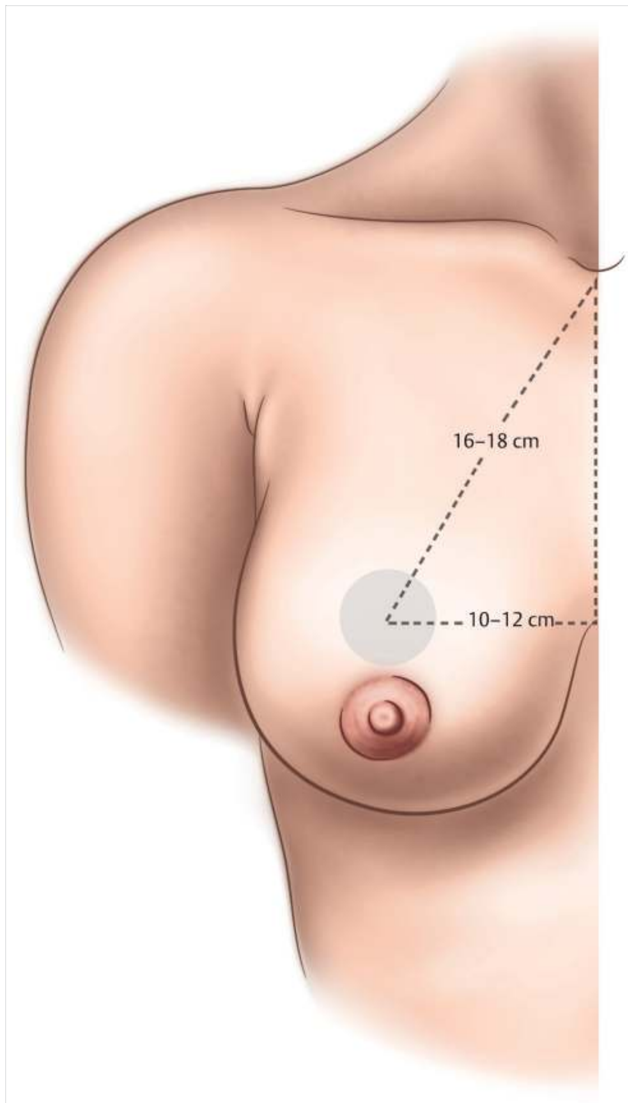

Fig. 26.1 Nipple position for a male chest—a guide for surgical marking.

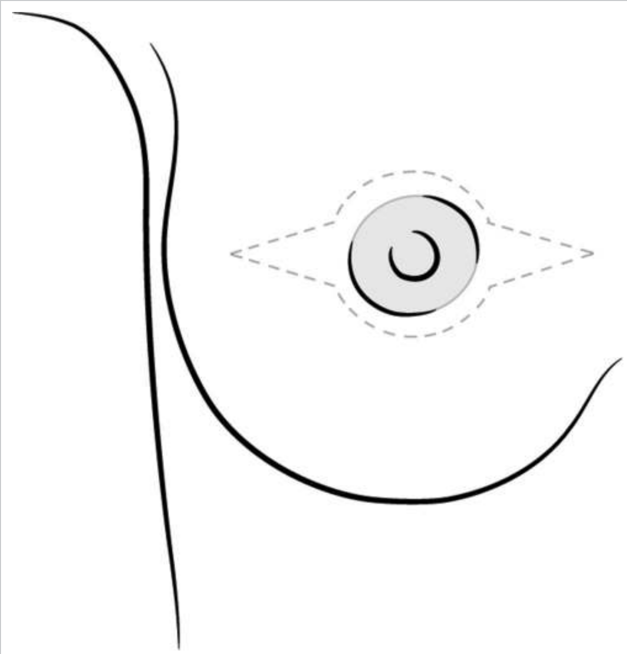

Fig. 26.2 Incision for breast reduction when skin excision and nipple repositioning are minimal.

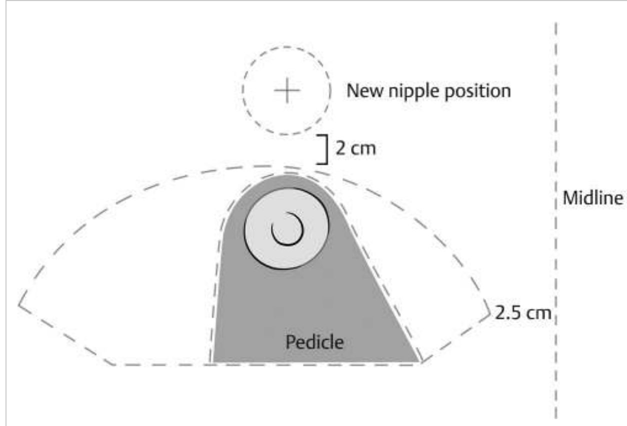

Fig. 26.3 Skin incision for inferior pedicle procedure with pedicle design.

avoided. Extended incisions to remove excess skin with various skin incisions are described by Hammond[6] and Hurwitz.[7] The boomerang approach advocated by Hurwitz for the postbariatric patients addresses both vertical and horizontal skin excess medially and laterally, respectively. An algorithm for chest wall contouring is described by Monstrey et al who addressed the transmale condition of more excess skin resulting from ptosis and/or macromastia.[8] The vertical limb of the anchor scar is unnecessary as a conical shape is not desired and skin redundancy is corrected by modifying the inframammary incisions to lengthen the inframammary fold (IMF) incision by adding a superomedial and superolateral extension and careful wound closure.

26.3 Operative Technique

Liposuction as the sole procedure reported by Courtiss[9] is less effective in physiologic gynecomastia which usually presents with dense subareolar tissue requiring excision through a periareolar incision.[10] Instillation of tumescent solution using a blunt tipped cannula or needle can be through the periareolar incision or remotely when the same alternate incisions are utilized for liposuction. The approach is best through the medial and/or lateral IMF.

To remove redundant skin, a periareolar incision may be employed with a long-axis, vertically-oriented ellipse if the nipple position requires elevation. However, if more than a minimal skin excision is needed, as noted above, this technique should be avoided as spread scars and enlargement of the areolar diameter will result even with a permanent purse-string suture closure. Extending the incision medial and/or lateral to the areolar region will reduce scar spreading but results in scars in a more prominent and less aesthetic position than the IMF (▶ Fig. 26.2).

In male patients with larger tissue volume and redundant skin including postbariatric individuals and transmales, correction of skin excess requires a long incision in the IMF, which becomes the pectoral fold. This facilitates excision of redundant skin as necessary extending the scar laterally in a horizontal or vertical direction and/or across the midline (▶ Fig. 26.3). The decision to extend the incision across the midline is made preoperatively or at the time of wound closure when the need is questionable. Here, the central excision avoids a midline contour deformity. A discontinuous incision is preferred as it is more aesthetically pleasing and healing of a midline scar may be problematic. The nipple-areolar complex is ideally managed with a thin inferior pedicle to preserve appearance and sensibility. However, when the distance from the IMF to the nipple is long, an FNG is necessary to achieve a satisfactory contour because the folding of the pedicle on itself produces a bulky contour. An alternative method creates a pedicle to carry the nipple-areolar complex, leaving the fullness of a folded pedicle and requiring return at a later time to remove excess tissue. Few patients will choose an option requiring two planned surgeries. When an FNG procedure is chosen, a short pedicle is employed to provide fullness under the nipple in its new position to avoid a hollow contour (▶ Fig. 26.4).[11]

Nipple placement markings are made in a standing position at the preoperative office visit and re-marked prior to entering the operating room (OR) (▶ Fig. 26.1). There are many opinions about placement of the nipple-areolar complex.[12,13] Placement falls within the parameters suggested in ▶ Fig. 26.1 and medial to the border of the pectoralis major, but this is difficult to assess in the obese or those with large breasts. Symmetry is vital and final adjustments are made after wound closure to place the inferior areolar border 2 to 2.5 cm above the incision.

If liposuction is to be performed, markings are placed in the subaxillary region to define the area to be treated. Once the patient is prepped and draped, the remaining markings are made (▶ Fig. 26.3). The incision must be made at the IMF, otherwise breast tissue will be left below the incision and leave a residual deformity. Tumescent solution is injected in the areas which will be liposuctioned through incisions within the proposed

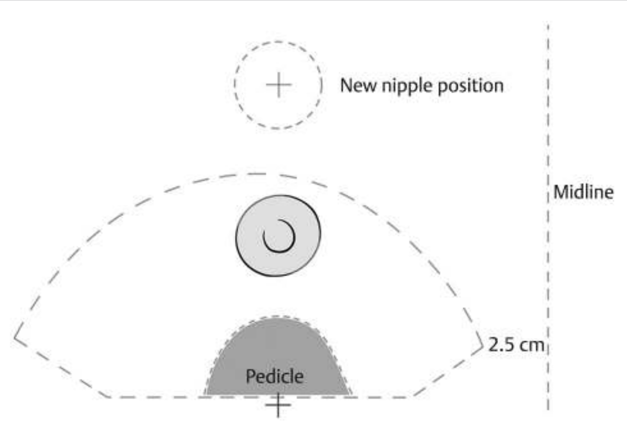

Fig. 26.4 Skin incision for free nipple graft procedure with de-epithelialized pedicle to provide contour under the graft.

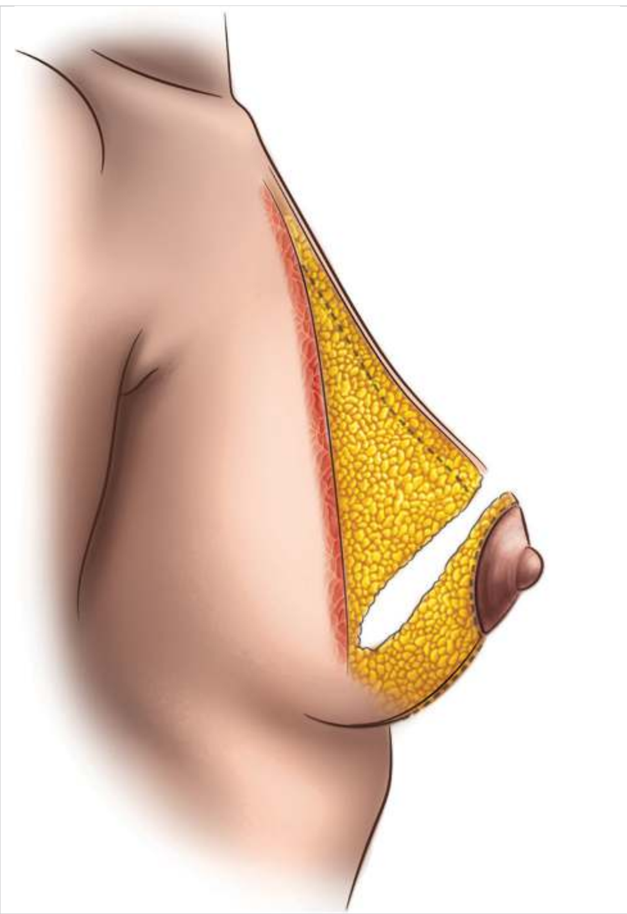

Fig. 26.5 Cross-section of developed inferior pedicle de-epithelialized and cut from remaining breast.

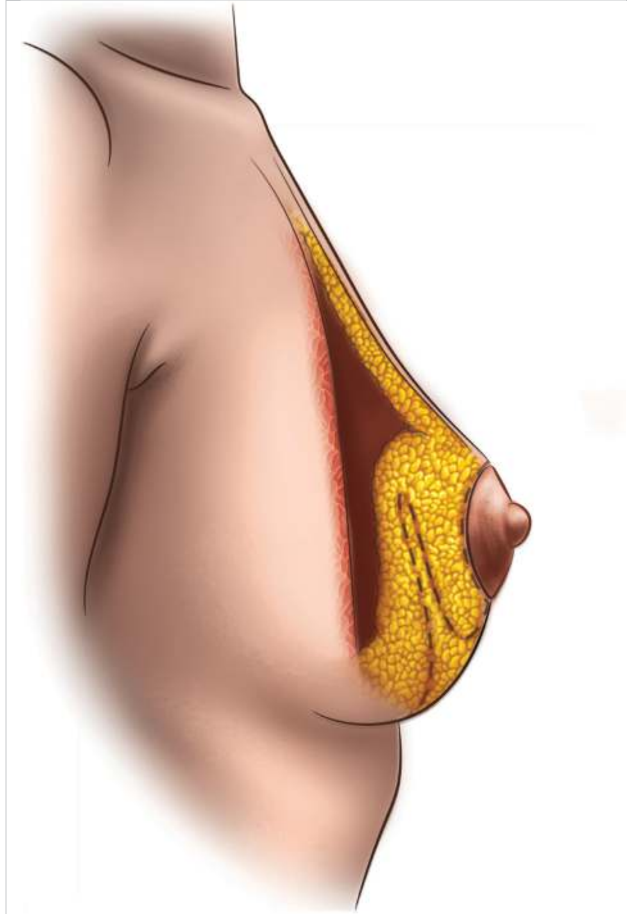

Fig. 26.6 Folded inferior pedicle inset in new position.

resection. If FNGs are planned, the nipples are removed full thickness and placed in labelled containers. A short pedicle is designed centered under the new nipple position and constructed by de-epithelialization and dissection at the level of the breast capsule (▶ Fig. 26.4). It is then sutured to the pectoralis fascia. If the nipple is to be transposed on a pedicle, the surface of the pedicle is first de-epithelialized leaving a 25-cm diameter areola and then dissected just deep to the breast capsule leaving the base in continuity with the underlying fascia without disrupting the IMF (▶ Fig. 26.5 and ▶ Fig. 26.6). This is contrary to Monstrey who opines that disruption of the IMF is essential to achieve the desired contour.[6] Next, the upper incision is made down to the breast capsule and the dissection proceeds superiorly and medially to the pectoralis fascia and laterally to the chest wall fascia. The breast is then resected from the underlying pectoralis fascia leaving it intact. After securing hemostasis, a key suture is placed bringing the skin flap to the IMF at the nipple position. A suction drain is placed and brought out laterally at the end of the incision.

Closure of the incision is now accomplished with subcutaneous and subcuticular sutures. If a bulge is present in the midline after closure commences, it is corrected by extending the incision across the midline. Because of discrepancy in the upper and lower incision lengths, the closure must be adjusted to compensate and dog-ear excision may be necessary medially and/or laterally. If liposuction is planned, it is done before completing the subcuticular repair. If necessary, nipple position is altered to place the inferior border 2 to 2.5 cm above the IMF. Equal distance from the midline and sternal notch is also

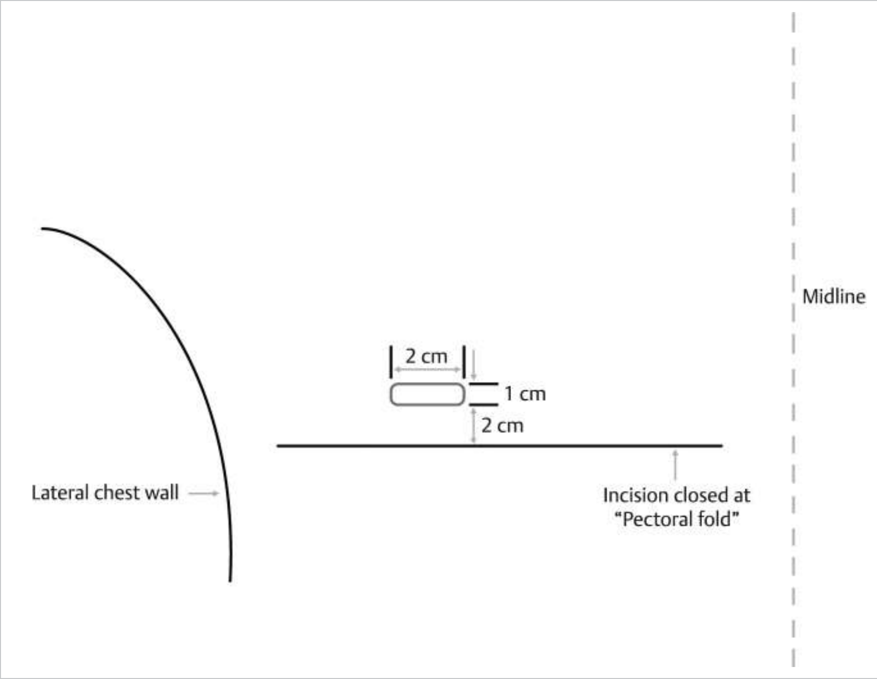

Fig. 26.7 Incision design for nipple-areola pedicle in the skin flap (flap tension creates a circle).

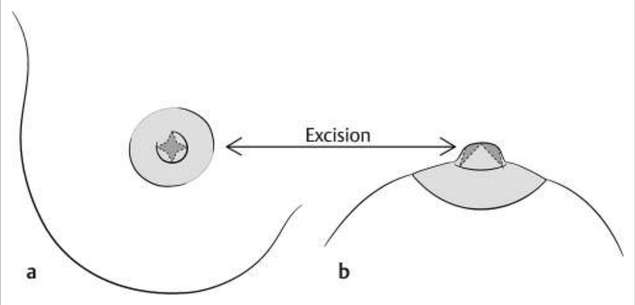

Fig. 26.8 Nipple reduction technique with four-pointed star: **(a)** left lateral view, **(b)** right top view.

checked. A 2.0-cm wide by 1-cm high ellipse is cut full thickness through the flap, which becomes a circle because of flap tension (▶ Fig. 26.7). The nipple-areolar complex is brought out through the opening and sutured with one layer of interrupted buried absorbable sutures. For FNGs, the tissue is thinned to a thick split graft and applied to a 2-cm diameter de-epithelialized circle with the inferior border placed the same as for a pedicled transfer. Because the dermis is not violated, a 2-cm diameter circle is designed rather than the ellipse for a pedicle. Fixation of the FNG is accomplished with a bolster constructed with 12 4–00 nylon sutures tied over a Xeroform gauze and absorbent cotton pad. Three oval eye pads with the gauze upper and lower leaves removed provide a satisfactory amount of material. Cyanoacrylate is used to complete IMF closure and Xeroform gauze is applied over the nipples when pedicles are employed. A circumferential dressing of gauze and ace bandages are applied.

For periareolar approaches with or without liposuction, markings are made preoperatively with an infraareolar incision if there is no skin excess. When skin excision is required, the incision is extended medial and/or lateral to the areola with hemicircular incisions for inset (▶ Fig. 26.2). It is difficult to perform an adequate symmetric excision through this limited access this limited access and difficult to disrupt the IMF to prevent to a this limited access and difficult to disrupt the IMF to prevent to a residual contour simulating a female breast.

In pedicle procedures, nipple reduction is always performed as a secondary procedure utilizing a three- or four-pointed star excision, repairing the residual points and allowing adjustments before final closure (▶ Fig. 26.8).

Postoperative pain is usually minimal and controlled with nonnarcotic analgesics. Drains are not removed until their volume is less than 30 mL in a 24-hour period. FNG bolsters are removed on the third or fourth postoperative day and redressed. Scar evaluation and management requires surveillance and routine management for hypertrophic scars.

26.3.1 Results

Patient satisfaction is high with restoration of self-confidence and self-esteem and relief of dysphoria in transgender patients. Dog-ears are a common problem, which is addressed in the primary surgery by more aggressive resection and combined with liposuction when indicated to reduce or eliminate lateral deformities. Likewise, medial dog-ears are addressed with liposuction or excision crossing the midline when more significant. Bulky pedicles leaving residual fullness in the subareolar region has led to more FNGs, the procedure chosen for the questionable cases. If in doubt, a pedicle is created and inset to judge the contour, converting to FNG when necessary. Careful planning and experience improve results. Hematomas have occurred despite careful dissection and hemostasis but seromas are rare with strict criteria for drain removal.

26.4 Conclusion

The individuals presenting for gynecomastia surgery are well served by the wide variety of surgical techniques and can

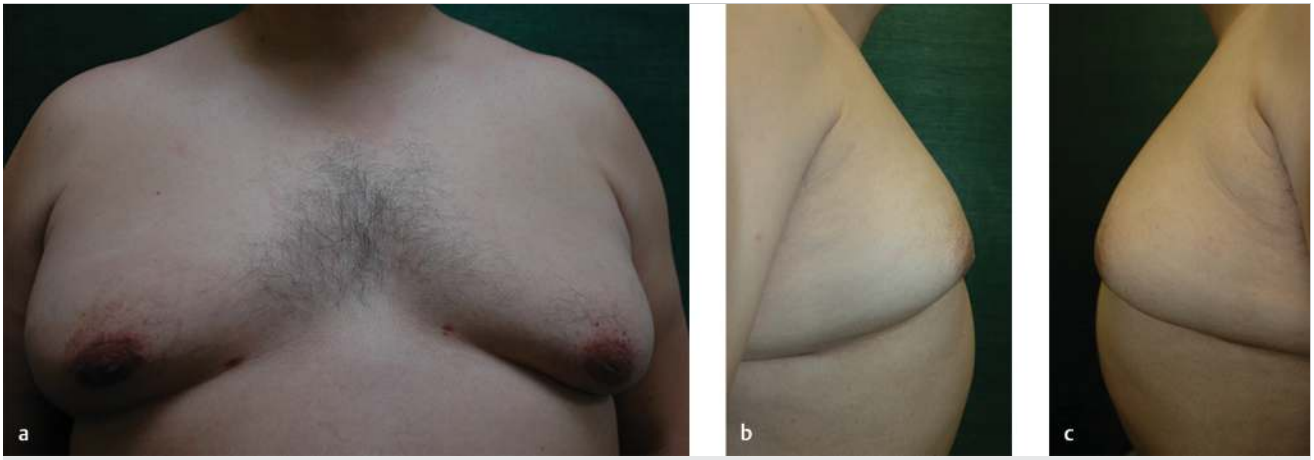

Fig. 26.9 (a–c) Preoperative postbariatric patient after preliminary liposuction.

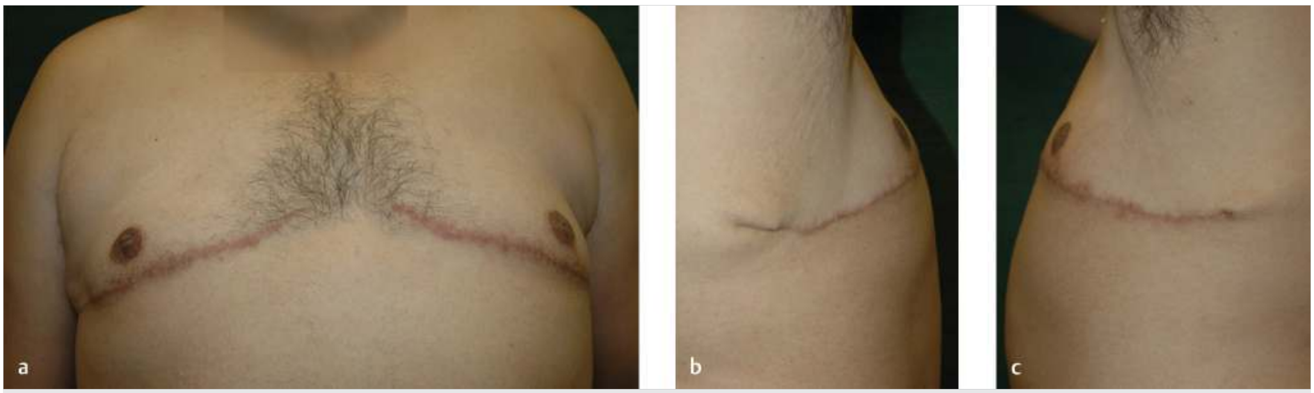

Fig. 26.10 (a–c) After breast reduction with pedicles and liposuction.

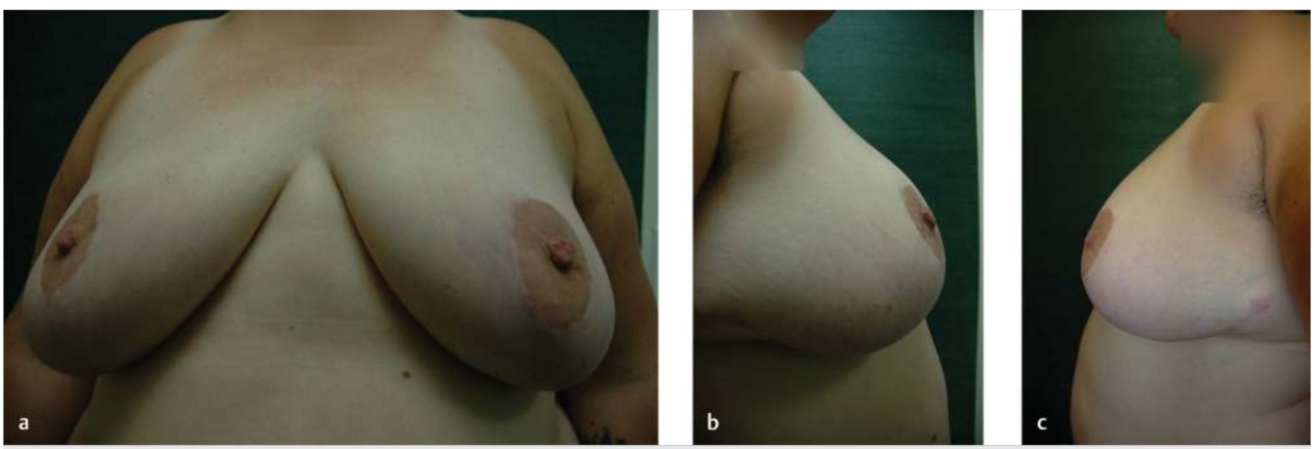

Fig. 26.11 (a–c) Transgender man with prior breast reduction, preoperative.

expect satisfying results. Likewise, the large number of transgender males and nonbinary individuals have emerged as a group of patients who are well served by the procedures that contribute to the resolution of their dysphoria.

The following examples illustrate the results obtained with the techniques described: ▶ Fig. 26.9 shows a 30-year-old man after bariatric surgery and preliminary liposuction with significant redundant of the skin and subcutaneous tissue. In ▶ Fig. 26.10, the result is shown 6 months following nipple transposition on pedicles and lateral liposuction, illustrating satisfactory contour and nipple position. ▶ Fig. 26.11 shows a morbidly obese transgender man who had a prior breast reduction as he was unable to have the procedure which would achieve the desired male appearance. The 3-month postoperative result after a breast reduction with FNG and extended lateral excision and liposuction is shown in ▶ Fig. 26.12. The next

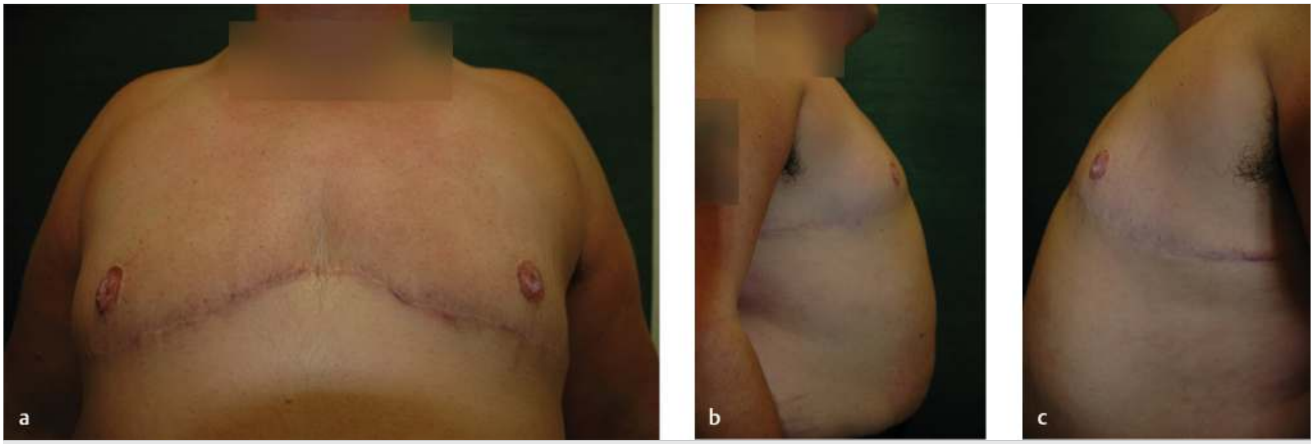

Fig. 26.12 (a–c) Following breast reduction with free nipple grafts and liposuction.

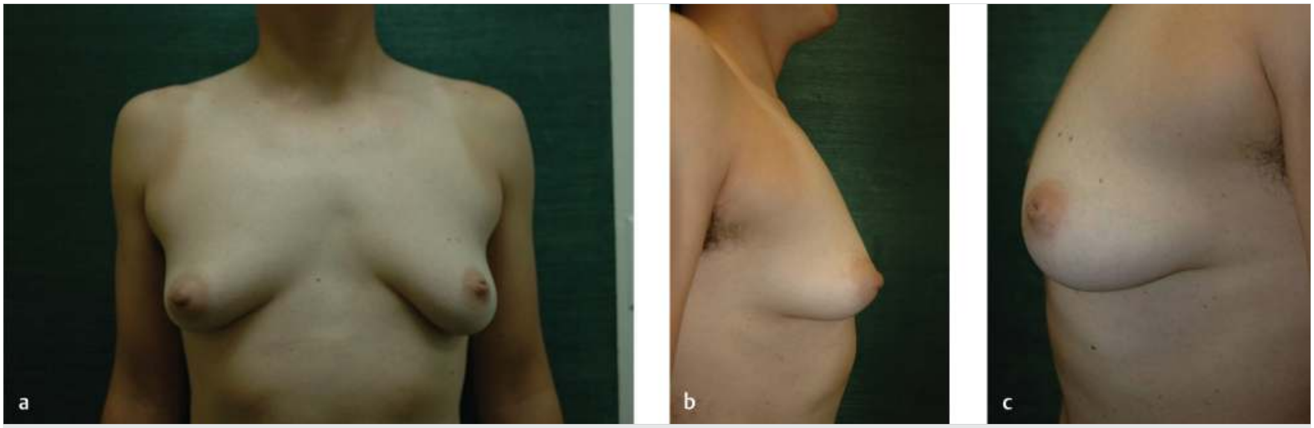

Fig. 26.13 (a–c) Transgender man preoperative.

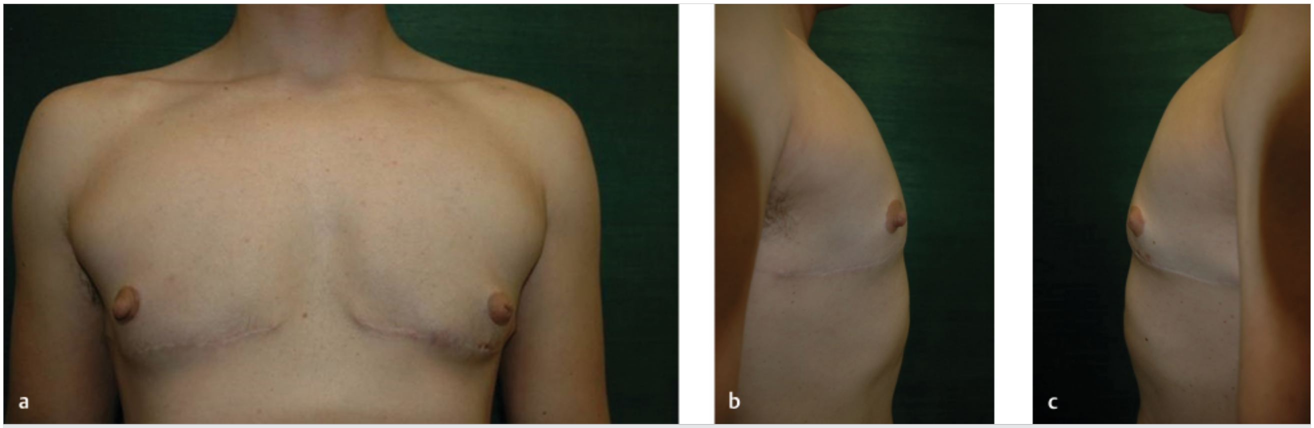

Fig. 26.14 (a–c) Postoperative breast reduction with pedicles.

example is a 40-year-old transgender man before (▶ Fig. 26.13) and 1 year after breast reduction with nipples transferred on pedicles (▶ Fig. 26.14).

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Subsection IIB

Absent Breast

II

27 Breast Reconstruction—General Considerations

Melissa Mueller, Emily Grace Clark, and Gregory R.D. Evans

Abstract
This chapter will focus on a general approach to breast reconstruction. Although not meant to provide specifics of techniques or procedures, the chapter allows an overview of possible options we employ for breast reconstructive surgery. More specific details of these procedures can be found in other chapters. Our techniques in reconstruction have improved along with our ability to treat breast cancer options with newer procedures. As we continue to evolve in breast reconstructive surgery, options for reconstruction will change based on the new demands of adjuvant and neoadjuvant therapy.

Keywords: acellular dermal matrix (ADM), breast implant, breast reconstruction, complications, latissimus dorsi flap, mastectomy, microsurgery, perforator flap, tissue expander, TRAM flap

27.1 Introduction

This chapter focuses on an overview of common breast reconstructive procedures.[1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22] It is not intended to focus on any one procedure which will be covered in subsequent Chapters 28–33.

- Mastectomy: The removal of breast tissue through various means while preserving the skin and/or nipple.
- Timing: Timing can include immediate, delayed, or staged procedures depending on autogenous or implant-based reconstruction.
- Tissue expanders: The use of a device that can expand the soft tissues over time to allow the placement of larger implants.
- Implants: The use of a device to replace breast tissue. These can be various forms of silicone as well as saline.
- Acellular dermal matrix: The use of this biologic property has changed how we approach breast reconstruction allowing large expansion for tissue expanders (TEs) and sooner, larger implants, and placement of the inframammary fold.
- Latissimus dorsi flaps: The use of skin and/or muscle with or without an implant from the back for autogenous breast reconstruction.
- Pedicle transverse rectus abdominis muscle (TRAM) flaps: The use of a pedicled rectus abdominis muscle along with skin perforators for autogenous reconstruction.
- Free TRAM flaps: The use of muscle-sparing free tissue transfer for breast reconstruction with the use of the rectus abdominis muscle.
- Perforator flaps: The use of deep inferior epigastric perforator (DIEP)/superficial inferior epigastric artery (SIEA) flaps or other flaps in other locations for breast reconstruction as a free tissue transfer without the use of muscle.
- Secondary procedures: Fat grafting, nipple-areolar reconstruction, and TE to implant exchange are all secondary procedures.
- Neoadjuvant therapy: The use of therapeutic agents used before definitive surgical resection.
- Complications: Areas of concern in breast reconstruction.

27.2 Indications

27.2.1 General Considerations for Selecting the Appropriate Reconstruction

Autologous (flap-based) reconstruction should be strongly considered in patients who have a history of radiation or even if it is known that they will require adjuvant radiation. Though not an absolute contraindication, implant-based reconstruction in the setting of radiation requires a thorough preoperative discussion with the patient regarding risks and benefits.

Flaps are also ideal options in patients undergoing delayed reconstruction, in smokers, or other patients with risk factors for implant exposure, and when patients would like to achieve a larger size reconstructed breast or match a contralateral large or ptotic breast. Certain benefits can also accompany flap reconstruction, such as the ability to provide an abdominoplasty with a rectus abdominis flap. Local and locoregional flaps can be useful as well such at the thoracodorsal artery perforator (TDAP) and the superior pedicle rectus/external oblique (SPREO).

Certain risks are also higher in flap reconstruction and must be weighed against the potential benefits. For instance, with a latissimus dorsi myocutaneous flap, there are the accompanying donor site scar along the back, a substantial risk of back seroma, and even a risk of shoulder dysfunction postoperatively. Further harvest of the flap creates seromas formation requiring prolonged drain placement. This operation also requires at least one patient repositioning and surgical preparation and may not allow for simultaneous work by both the oncologic and reconstructive teams.

27.3 Operative Technique

27.3.1 Mastectomy

Our reconstructive options have changed with approaches for mastectomies. As the amount of tissue excised continued to decrease, better aesthetic results with more reliable implant/TE-based reconstruction ensued. Traditional horizontal incisions inclusive of nipple resection often did not allow for appropriate medial fullness. As adjuvant therapy became more prevalent and as our understanding of the disease process grew, newer techniques have allowed us to adjust surgical excision leading to overall better aesthetic results. One option that has changed our approach is sentinel node biopsy. Now, surgical excision of the breast tissue can be performed with nipple/areolar resection in a circular pattern with a separate incision in the axilla. This maintains the shape of the breast while obviating the need to elevate a latissimus dorsi flap and also helps to prevent lateral displacement of implant/TE reconstruction.

Finally, newer techniques such as nipple preservation have led to improved aesthetic results. Mastectomy is approached through an inframammary incision (preferred method) or periareolar incision, which has the risk of compromising nipple perfusion. Inframammary approach with nipple preservation and direct-to-implant reconstruction can create a one-stage operative procedure that allows patients to complete their surgical approaches to the cancer and their reconstructive options in one sitting. Naturally, adjuvant therapy may alter or compromise this technique in breast surgery.

Regardless of the technique employed, preservation of the inframammary fold, or its reconstruction, is critical in maintaining appropriate shape and symmetry in breast reconstruction.

27.3.2 Tissue Expanders

Variability in height, width, shape, texture, degree of projection, and maximum volume for expansion are all possible with TE reconstruction. Contour expanders allow for greater lower pole expansion and, unlike previous external port requirement for filling the expander, the integrated valve has allowed a more contained unit for patient comfort. Many expanders have reinforced orientation tabs that allow suturing the expander in place, preventing internal rotation. Although a variety of expanders exist, there is a greater diversity in the range available outside the US where regulations are more lenient.

Recent studies have looked at other opportunities for expansion including a self-filling osmotic expander manufactured in Germany, which consists of an osmotic active hydrogel, vinyl pyrrolidone and methyl methacrylate.

A permanent expander/adjustable implant is a double lumen implant consisting of an outer lumen containing silicone gel with an inner adjustable lumen filled with saline from a remote adjustable port. Although they have been on the market for years, they are not used as frequently as normal expanders due to the inability to adjust the pocket on expander/implant exchange and the concern about possible contamination from expander fill.

27.3.3 Implants

Both saline and silicone implants are available for reconstruction. However, the majority of implant-based reconstruction in the US is performed with silicone. Contributing factors include less rippling, less edge scalloping, and a more natural, softer feel. Anatomic-shaped silicone implants made with a more cohesive gel are particularly useful in creating a natural-appearing reconstructed breast. Despite historical risks associated with outdated generations of silicone implants, patients should be assured that saline and silicone are equally safe. The only major risk that is currently showing a correlation to breast implant is the risk of anaplastic large cell lymphoma (ALCL), which has been linked to both saline and silicone *textured* implants. Silicone filling has been designed with varying silicone polymer length and crosslinking to create a more cohesive "form-stable" implant, which maintains the shape better. More accurate placement with precise pocket dissection is critical to prevent malposition and malrotation. Base width is the principal determinant of implant size, and other metrics for implant selection would include breast height, projection, weight of the mastectomy specimen, and anticipated contralateral breast reconstruction.

Outside the US, polyurethane-coated silicone gel implants consist of a gel-filled silicone elastomer shell coated with polyurethane and are available in the UK since their production in 2005 and in Australia since 2008. Although less prone to capsular contracture, removal is more problematic requiring capsulectomy or even excision of surrounding breast tissue. In 1991, the implant was removed from the market in the US due to concerns over the carcinogenic degradation product.[1]

27.3.4 Acellular Dermal Matrix

Another development in TE/implant reconstruction is the use of acellular dermal matrix (ADM), which can be derived from human, bovine, or porcine tissue. It is decellularized to produce a scaffold that allows cellular ingrowth and revascularization without inciting rejection. A variety of products are available, and they vary in thickness, time of "soaking", shelf life, cost, and ease of inset. ADM provides lower pole soft tissue support, creates a slightly more ptotic and natural-appearing breast, and creates a well-defined inframammary fold with further prevention of superior migration.[2,3] Compared to total muscle coverage, it produces less breast distortion and morbidity by reducing the need for extensive muscle dissection. It also allows for greater operative fill volume, decreasing clinic visits and perhaps shortening any delay in adjuvant therapy. There is some evidence that it may decrease the risk of capsular contracture.[4,5]

ADM is quite versatile and can be used in other types of breast surgery, including in the treatment of capsular contracture, pocket adjustments for implant malposition, onlay graft for rippling, prepectoral placement of implants, and potentially nipple reconstruction.[3] Recently, there has been interest in prepectoral implant reconstruction. ADM is critical in these instances, allowing an additional layer of protection and the elimination of animation deformity. Naturally, the thickness and viability of the mastectomy skin flaps would have to be assessed.[6,7] Symmastia along with implant bottoming out can also be corrected with ADM placement. In the US, the use of ADM is usually covered by insurance for breast reconstruction.

The use of ADM, however, does increase the risk of seroma formation.[8] A recent meta-analysis found a higher overall complication rate with ADM compared to submuscular reconstruction, although other studies have refuted this.[5,9] Caution is also required in patients receiving postoperative irradiation therapy as the ADM may not be fully incorporated due to compromised vasculature in the irradiated field.

Synthetic and biologic (SERI ® Surgical Scaffold – Sofregen Medical Cambridge, MA) inferolateral sling alternatives have been proposed, which may be less costly with a better safety profile.[10]

27.3.5 Autogenous Reconstruction

A pedicled TRAM flap is a fast and reliable autologous option but does include a risk of abdominal wall laxity or hernia, distal flap necrosis (especially in patients with a high body mass index [BMI] or in smokers), and cosmetically unsatisfactory "bulge" in the epigastric region. Blood supply is less robust and caution should be exercised in smokers and those with previous abdominal surgery. Recently, the superiorly based partial rectus abdominis and external oblique flap has been utilized for breast asymmetry following partial or complete breast resection.[11]

Among free flaps, the free TRAM and DIEP flaps are the workhorses for breast reconstruction. These flaps require surgical expertise with the use of a microscope, a longer operative time, and more stringent postoperative monitoring. Although the biggest concern is failure of the venous or arterial anastomosis, the increased vascularity and reliability of the skin paddle may decrease overall postoperative complications.

Additional free flaps are being utilized more recently for breast reconstruction, including the SIEA perforator flap, the TDAP flap, and the superior gluteal artery perforator (SGAP) flap. There is a learning curve associated with these alternate procedures that must be anticipated. SIEA flaps may require preoperative imaging to ensure adequate perforators or the ability to easily convert to a DIEP or TRAM flap. SGAP flaps also require multiple patient positions and surgical preparations. Fat necrosis may be more frequent owing to the decrease in blood flow. The TDAP allows sparing of the latissimus dorsi muscle with or without an implant.[21]

27.3.6 (Neo)Adjuvant Therapy

Radiation or other therapeutic options may be administered immediately following mastectomy but prior to reconstruction or coincident with TE or implant placement. While expanding criteria for postmastectomy radiation, consideration of the timing of radiation therapy with TE/implant reconstruction is critical. If radiation therapy is given prior to mastectomy, consideration should be given to having the patient proceed with some type of flap reconstruction. In direct implant reconstruction, direct implant radiation may occur. There are some recent suggestions that radiation of the implant following tissue expansion may yield an improved result.[13,15,18] The presence of a TE during radiation does not negatively impact recurrence-free survival.[12,13] Regardless of whether the implant or TE is irradiated, complications are higher when radiation therapy is employed with this form of reconstruction.[16]

27.3.7 Complications

A variety of standard postoperative complications can occur. These include bleeding, hematoma and seroma, mastectomy flap necrosis, and late complications such as asymmetry, implant rippling, capsular contracture, and mastectomy flap thinning. A recent meta-analysis revealed a higher rate of reconstructive failure and surgical site infection but lower rates of skin or flap necrosis with prosthesis-based reconstruction compared to autogenous.[22]

Preoperative risk factors can help stratify risk and inform patients as to the appropriate reconstructive option. BMI > 30 is an independent risk factor for overall morbidity, reoperation, prosthesis failure, and wound infection.[12] Smoking also increases risk by 1.5 times along with age over 60 years.

Finally, recent studies have demonstrated a relationship between ALCL and textured breast implants. Although infrequent, late presentation of seroma formation, palpable lymphadenopathy or other potential unusual findings should be explored. Any late seroma fluid should be aspirated under ultrasound control and sent for cytological evaluation to check for CD30 and ALK status because the diagnostic profile for ALCL is CD30 + , ALK-.

27.4 Conclusion

This chapter aimed to examine options for breast reconstruction. Plastic surgeons will continue to be called upon to be on the forefront of innovation for achieving a more aesthetic breast. It is our duty to examine these innovations and see what works best in our reconstructive patients.

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28 Breast Reconstruction with Implants or Tissue Expanders

Melissa Mueller, Emily Grace Clark, and Gregory R.D. Evans

Abstract
Implant-based breast reconstruction has become the predominant type of breast reconstruction, consisting of two-stage immediate, two-stage delayed, and direct-to-implant reconstruction. Both preoperative and intraoperative considerations guide appropriate choice among these reconstructive options. Outside of the US, greater diversity exists for both tissue expanders and breast implants. Techniques including total submuscular and partial subpectoral pocket creation, acellular dermal matrix (ADM) use, SPY Elite use, pocket and inframammary fold revisions, and timing of reconstructive steps are discussed. With expanding criteria for postmastectomy radiation, consideration of effects and timing of radiation treatment is essential. Other risk factors associated with complications, such as obesity, smoking, and age, should be utilized for risk stratification and reconstructive decision-making. The future of implant-based breast reconstruction will rely on minimizing costs without sacrificing aesthetics, as well as continued research on fat grafting and biologic scaffolds.

Keywords: acellular dermal matrix (ADM), adjuvant therapy, breast implant, breast reconstruction, complications, cost analysis, tissue expander

28.1 Introduction

Implant-based reconstruction has become the predominant type of reconstruction in the United States. Newer implants and more options for adjusting shape and size have expanded the use of implant/tissue expander (TE) reconstruction. Although traditionally performed in two stages, discussion with the patient and the surgical oncologist is changing the way we approach reconstruction. In 2013, two-stage and direct-to-implant reconstructions comprised 72 and 8% of breast reconstructive procedures, respectively.[1] In 2011, prosthetic-only reconstruction comprised 37% of immediate reconstructions and 16% of delayed reconstructions. This difference is likely related to the higher rates of pedicle flap reconstruction with and without implants in the United Kingdom.[2] Delayed reconstruction is performed on patients who initially declined reconstruction, whose mastectomy skin flaps have compromised perfusion, or who cannot tolerate a delay in adjuvant therapy. Direct-to-implant reconstruction is only considered if the mastectomy skin flaps are viable and the initial pocket is of appropriate final size. Ideal candidates have small to medium size breast, good skin quality, and a desire for similar size or smaller breasts.

28.2 Indications

Reconstruction of the breast begins with a thorough evaluation of the patient. Preoperative communication is vital and should be offered to all patients (national breast group). Adequate measurement of the inframammary fold is critical. Shape of the breast needs to be determined. Is the breast more ptotic or is it wider? It will help select TE or implant reconstruction. Is the patient projecting or is she more flat and inclusive of the chest width? Tissue expansion and implant reconstruction are more viable options in immediate reconstruction. Patients presenting with previous mastectomy, neoadjuvant therapy, or excessive scarring on the chest wall may not be good candidates for TE/implant reconstruction. Skin thickness needs to be assessed along with its suitability for nipple preservation or immediate implant reconstruction. Relationship to the opposite breast must be determined, which allows adequate placement of incisions for optimal results.[21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40]

28.3 Operative Technique

The following general techniques are available for reconstruction:

- Surgical resection of any poorly perfused skin is critical to prevent complications related to implant/TE reconstruction. Maintaining adequate blood supply including perforators from the medial chest wall is critical in helping to assess skin viability. As indicated previously, nipple-sparing or nipple-preserving surgery requires careful assessment of skin perfusion. Large ptotic breasts may have more compromised skin vascularity than smaller or medium size breasts. Incision selection balances scar cosmesis, accessibility for surgery, and nipple viability. Common incisions include radial, periareolar with or without lateral extension, inframammary, and inferolateral. Surgical access and thus placement of the TE or implant is more difficult with periareolar incisions in patients with small nipple-areolar complexes and with inframammary incisions. A vertical component helps with better exposure, tightening of the lower pole, placement of the TE or implant, and better medial fullness. In both skin-sparing and nipple-sparing, the decision between one- and two-stage reconstruction is made based on the thickness of the mastectomy flaps, and an assessment of flap and nipple perfusion. Skin viability is assessed based on color, temperature, dermal edge bleeding, and capillary refill. If perfusion is equivocal, indocyanine green dye-based imaging technology (SPY Elite, Novadaq, Ontario, Canada) may be used to provide real-time assessment of tissue perfusion. Perfusion numbers and color correlate well with actual skin perfusion and poorly perfused skin can be removed. This may alter the proposed plan of direct implant reconstruction. The use of the SPY apparatus is not cost-effective for routine use; however, in those circumstances where adequate perfusion is questionable or in patients with large ptotic breasts, increased body mass index (BMI), and a history of smoking, it may help prevent future complications.
- Traditionally, an adequate pocket was created by elevating the pectoralis and serratus muscles for implant placement. The pocket required adequate medial release and often resuturing of the latissimus dorsi muscle laterally to prevent lateral displacement. Once the TE or implant was placed, release

of the rectus fascia was often required to allow for adequate lower pole filling with the implant or TE. Adequate hemostasis is required under the pectoralis muscle to prevent hematoma formation and frequently the medial pectoralis perforators must be coagulated or clipped to prevent potential bleeding. Alternative use of a subfacial pocket also allowed placement of the TE or implant. However, this traditional method was challenged by difficult lower pole expansion with a high riding reconstruction, distortion of the inframammary fold with the serratus use, and inadequate inferior muscle coverage.[26,41]

- The use of acellular dermal matrix (ADM) has facilitated improved lower pole expansion. As in the development of a submuscular pocket without ADM, the lower portion of the pectoralis muscle is released and a submuscular pocket created in a similar manner. The ADM midportion is aligned with the median parameter of the breast. The inframammary fold is inset first; this is performed by placing 2–0 Vicryl along the inframammary fold taking care to suture the ADM as low as possible. Different ADMs have different ways to inset the tissue, and the correct side of the tissue along with the correct orientation must be ensured prior to suture placement. In most cases the more porous dermal side is placed against the skin flaps allowing for adequate revascularization. Excessive release can create lateral displacement, bottoming out, or symmastia. It is critical that the ADM is adequately sutured laterally to prevent lateral displacement of the TE or implant. Different sizes of ADM may be required but normally a 6 × 16 cm or 8 × 16 cm piece is selected. There are certain products that take into account the bilateral nature of breast reconstruction, using an appropriate size and orientation for the left and right breasts. Once the inferior portion of the ADM is sutured to the fascia along the inframammary fold, TE or implant can be placed under the pectoralis muscle. Sutures in a parachute fashion can be placed prior to placement of the TE or implant along this superior boarder, or sutures can be placed following insertion of the TE/implant. If this is performed, care must be taken to prevent injury to the reconstructive device. If using TE with tabs, then the tabs should be securely sewn into place ensuring fixity of TE placement. In obese patients with larger base widths a larger sheet of ADM (6 × 20 cm) and pectoralis alone may not provide complete expander coverage. In this instance, serratus muscle and/or fascia is elevated and the ADM used as an interposition graft between the pectoralis and serratus.[15,30] In creating the pocket, it should be of optimal size and position to allow for precise expansion and to minimize pocket modifications at the time of TE/implant exchange. Expanders are filled at least 50% to create a breast mound and decrease dead space while avoiding excess tension on the mastectomy skin flaps. Depending on surgeon's preference, one or more drains are used for egress of fluid (▶ Fig. 28.1).
- Expansion resumes approximately 2 to 3 weeks following the initial surgery. With the use of ADM, it is not unreasonable that only one or two more expansions may be required in the clinic. If chemotherapy coincides with tissue expansion, expansion is coordinated between cycles with measurement of the absolute neutrophil count, which should be above 1.5 thousand/μL. Overexpansion may be required and often overexpansion prior to TE/implant exchange allows the skin to nicely drape over the implant when exchange occurs. Final expansion and timing of exchange are dependent on a variety of factors including patient's desire, adjuvant therapy, and patient's postoperative recovery.
- TE exchange for an implant occurs following adequate expansion and filling. During this procedure, there are several approaches that can be taken. One is the excision and complete removal of the previous mastectomy scar. If the tissue

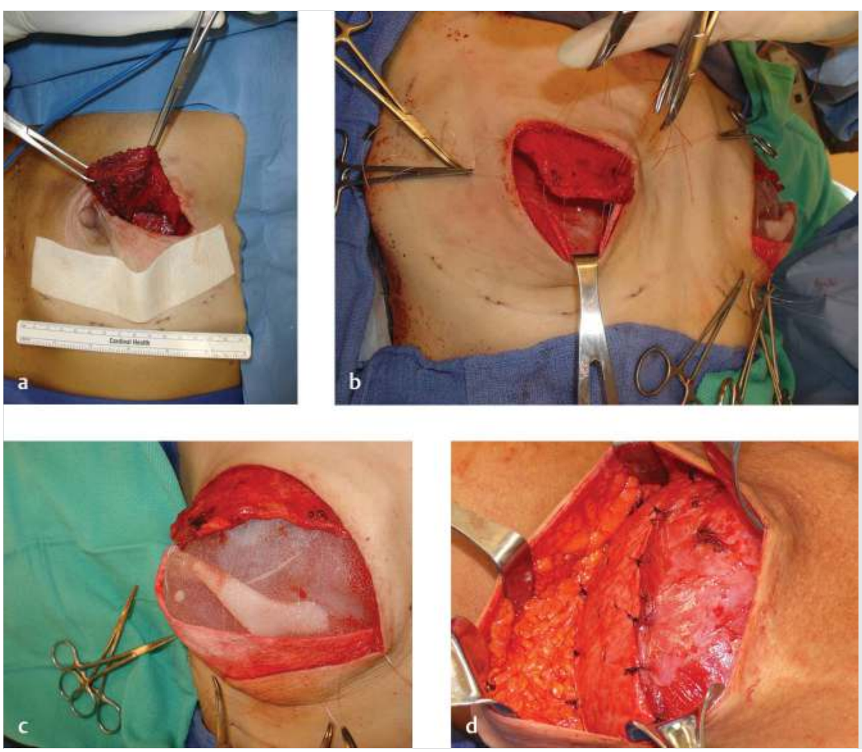

Fig. 28.1 Insertion of acellular dermal matrix (ADM). **(a)** The pectoralis muscle is released from the chest wall along its inferior and medial aspects and the submuscular plane is dissected. **(b, c)** The inferior border of the ADM is sutured to the superficial fascia near the inframammary fold and then the superior edge of the ADM is tacked to the free edge of the pectoralis. **(d)** After the expander is inserted, the ADM-pectoralis tacking sutures are tied.

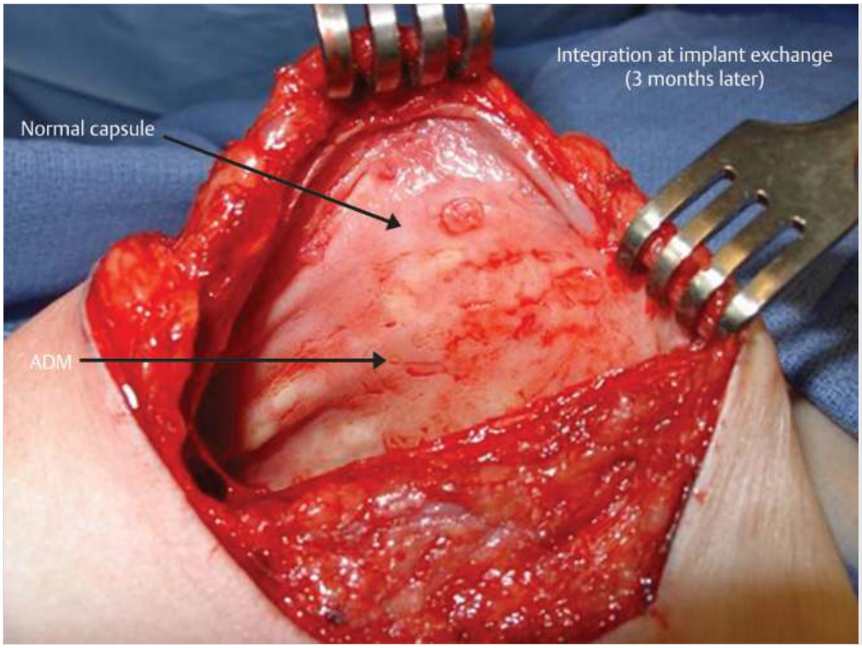

Fig. 28.2 Acellular dermal matrix (ADM) incorporation. At the time of expander to implant exchange, typically 1 to 2 months of completion of expansion, the ADM should be fully incorporated with the capsule and mastectomy flap. Any unincorporated ADM should be excised.

around the scar is thin then excision of this thin skin should be performed. Frequently, this occurs in previously irradiated tissue and reinforcement with additional ADM may be required. Once the mastectomy skin is excised, an inferior incision can be made through the capsule entering the pocket of the TE. The ADM should be fully integrated. If for some reason the ADM has not been fully integrated, then its removal is required. Second, some practitioners believe that making another incision along the inframammary fold potentially prevents further complications than along the mastectomy incision following implant exchange. During this procedure, modifications to manipulate or define the inframammary fold including internal placement of capsulorrhaphy sutures, external marionette sutures, and liposuction can occur. Lateral displacement of the implant can be adjusted by placing 0-ethibond sutures to decrease the implant pocket. In some cases, internal scoring and release of the capsule may be required to adequately open the pocket. Although the appropriate implant should have been selected preoperatively, it should be re-confirmed in the operating room by placement of implant sizes. Once placed in the correct orientation, the capsule, as well as the dermis and the skin, is closed. Typically drains are not required during this exchange, unless there is extensive dissection of the capsule (▶ Fig. 28.2).

- Nipple reconstruction is considered 2 or more months after TE/implant exchange. This allows for the tissue to settle and for the implant to begin taking its location in the new pocket. A variety of nipple techniques are available.[1–38] Some create more of a flattening of the breast, which can alter the overall aesthetic results. Recently, tattooing the nipple-areolar complex in a three-dimensional fashion has gained some momentum. Each patient is an individual and desires and timing of nipple reconstruction or tattooing are variable.
- Direct implant reconstruction follows a similar pattern. Future revisions of the pocket, liposuction, or fat grafting may be necessary in order to adjust the aesthetic result.
- Suprapectoral TE/implant placement may also be performed. It should be noted that patient selection is critical in these circumstances. Knowing the oncologic surgeons and how they develop their mastectomy flaps will ensure less morbidity. Larger patients with large ptotic breasts may not be the best candidates for these procedures, along with patients who may require adjuvant therapy postoperatively. ADM is used to cover the implant or TE anteriorly or circumferentially, which allows additional tissue to be incorporated into the mastectomy skin flaps increasing the thickness. The advantage of suprapectoral placement is elimination of the animation deformity that can occur with placement of TE/implants under the pectoralis muscle.

28.4 Conclusion

With the growing costs of modern healthcare and progressive shift to managed care systems, attention is focusing on total, relative, and reimbursed costs of breast reconstruction.

With current pricing of ADM, two-staged implant-based reconstruction is more costly with ADM even when accounting for complication-associated costs and reduction in expansion visits.[23,24] The cost comparison between two-stage and direct-to-implant reconstructions is less consistent.[24,25,28,38]

In the UK, key differences in reimbursement affect reconstruction cost analysis. For example, direct-to-implant reconstruction may be less costly only for unilateral reconstruction. This is because only primary procedures are covered in the setting of combined or bilateral operations and for operations performed during the same hospital admission.[31]

The future of prosthesis-based reconstruction will undoubtedly be shaped by pressures of modern healthcare and reimbursement to minimize costs of reconstruction. The balance will lie in performing cost conscious reconstruction while not sacrificing aesthetic outcome. The future of implant-based reconstruction also lies in the application of fat grafting to improve soft tissue coverage, contour deformities, and asymmetries following reconstruction.

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29 Breast Reconstruction with Pedicled Latissimus Dorsi Flap

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Abstract
The pedicled latissimus dorsi (LD) is a workhorse flap for immediate, delayed, or salvage breast reconstruction. It provides reliable, well-vascularized tissue coverage that avoids an abdominal donor site and the complexity of microsurgery. The flap is typically harvested in the lateral decubitus position and requires a position change. While performing LD flap breast reconstruction, the thoracodorsal nerve should be divided, the skin paddle must be carefully designed, and the final scar should lie in the relaxed skin tension lines. When used appropriately, the LD flap results in excellent breast contour and shape.

Keywords: autologous breast reconstruction, breast reconstruction, latissimus dorsi, pedicled flap

29.1 Introduction

Breast cancer is the most common cancer of women in the US. Almost 300,000 cases of invasive disease are diagnosed annually.[1] An increasing number of women are having mastectomies. Of those who choose autologous reconstruction, abdominally based flaps are most common, but the latissimus dorsi (LD) flap remains a workhorse flap for breast reconstruction.

Originally described in 1906 by Iginio Tansini, the LD flap has experienced waxing and waning popularity.[2,3] Halsted aggressively discounted the "autoplastic" flap due to his strong beliefs in radical cancer eradication.[4] In the late 1970s, the anatomy, vascular territories, and use in breast reconstruction were again popularized, but the advent of the pedicled transverse rectus abdominis musculocutaneous (TRAM) flap overshadowed the LD flap.[5,6,7,8]

More recent microsurgical variations from the abdomen such as the deep inferior epigastric perforator (DIEP) and superficial inferior epigastric artery (SIEA) flaps have gained utility while offering lower abdominal donor site morbidity than pedicled TRAM flaps.[9] However, the LD flap maintains a role in breast reconstruction because of reliability, ease of dissection, and absence of complex microsurgery.

29.2 Indications

The LD flap can be used for immediate, delayed, or salvage breast reconstruction. For patients with small breasts, it can be used in a purely autologous fashion. Women bearing larger breasts typically need either augmentation with an implant or an extended LD flap to achieve a larger breast size.

The latissimus flap is an excellent choice if there is any question about the viability of the mastectomy skin flaps. Radiation damage is commonly encountered and increases the risk of complications in breast reconstruction. Attempting to expand irradiated tissue that is tight, inelastic, and thickened portends a high rate of expander extrusion.[10] LD flaps bring reliable skin, fat, and muscle with a robust blood supply that can replace threatened, ischemic tissue and allow expansion.

Prior abdominal surgeries may disqualify some patients from receiving a TRAM, DIEP, or SIEA flap. Risk of a hernia, bulge, or prolonged recuperation time may also make the LD flap a more attractive option. Furthermore, patients who smoke, are obese, or have other comorbidities such as diabetes may present an elevated risk of complications from abdominal based flap reconstruction.[9] Contraindications to the LD flap include a prior thoracotomy scar or an axillary dissection damaging the thoracodorsal pedicle, although rare.

29.3 Operative Technique

29.3.1 Preoperative Planning

Planning the skin island will vary based on the chest wall defect and any adjunctive therapy such as previous or anticipated radiation. In a patient with prior radiation, the inferior pole can be replaced to aid in expansion, or the skin paddle can replace the mastectomy scar. The LD skin paddle design is predicated on the quality and quantity of mastectomy flap skin preserved.

In delayed reconstructions where large areas of mastectomy skin must be replaced, such as an irradiated chest wall, donor LD flap and overlying skin of the back can be tissue expanded prior to transfer to the breast. Conversely, when more mastectomy skin is preserved, the LD paddle can be designed for nipple-areolar reconstruction alone, or de-epithelialized entirely and used for bulk as a buried flap beneath total skin and nipple sparing mastectomies.

The orientation of the scar on the back should ideally follow the relaxed skin tension lines or be concealed within the bra strap. A horizontally oriented scar, while camouflaged medially, may create tethering and result in rolled adipose tissue in the axilla or lateral chest wall. If performing bilateral breast reconstruction, the scars should also be symmetric.

29.3.2 Surgical Marking

Surgical marking should be accomplished with the patient standing upright, hands at her side (▶ Video 29.1 and ▶ Fig. 29.1). Anteriorly, the midline, inframammary fold (IMF), and planned skin excision on the breast should be outlined. Posteriorly, with the patient forcefully contracting the latissimus by pressing hands on hips, the lateral edge of the latissimus can be palpated and traced down to the posterior iliac crest. Contraction of the muscle also reassures the likelihood that the thoracodorsal nerve and vascular structures are intact. The scapular tip marks the superior margin of the latissimus. The skin paddle is then designed overlying the latissimus in an orientation as described above and tailored to the needs of the mastectomy defect (▶ Fig. 29.2).

Fig. 29.1 Preoperative view of Patient 1, a 44-year-old woman who had bipedicled transverse rectus abdominis musculocutaneous (TRAM) reconstruction of the right breast after modified radical mastectomy and radiation who now presents for prophylactic left mastectomy.

Fig. 29.2 Preoperative markings.

Fig. 29.3 Lateral decubitus position. A moldable padding is used with left arm elevated to allow a two-team approach.

Fig. 29.4 Superior incision taken down to latissimus dorsi (LD) muscle illustrating the distinct fascial layer with subfascial fat on the LD muscle and subcutaneous fat on the skin flap *(arrow)*.

Video 29.1 Preoperative markings

29.3.3 Positioning

This flap is easily harvested in the lateral decubitus position with the arm abducted and positioned above the head (▶ Fig. 29.3), or in the prone position in cases of bilateral LD flaps. The skin island is incised and the first fascial layer encountered is the superficial fascia. This fascial layer separates the deep and superficial fat (▶ Fig. 29.4). Dissection typically occurs just under this layer leaving the deep fat on the latissimus and the superficial fat on the skin flaps. Laterally, the edge of the latissimus is encountered and marks the most lateral aspect of the flap. Work in a clockwise or counter-clockwise fashion to raise the skin flaps. Inferomedially, dissection is carried to the lumbosacral fascia. The inferior border of the muscle is identified and transected above the posterior superior iliac crest. Care is required when raising the latissimus from the paraspinous muscles as the fibers of both muscles can be intertwined. Be wary of the minor blood supply to the latissimus from the intercostal perforators. These should be identified and clipped or tied off to minimize risk for subsequent hematoma. Moving medially and superiorly, the inferior aspect of the trapezius is encountered and dissected from the latissimus. The trapezius is superficial to the latissimus and the fibers run in a perpendicular orientation. Beneath trapezius, the latissimus origin is purely fibrous and quite thin. The scapular tip marks the superior border of the muscle flap. Superolaterally, the teres major fibers must also be teased away from the LD. Near the axilla, visualization of the thoracodorsal neurovascular pedicle on the posterior surface of the LD is aided by a lighted retractor or headlight (▶ Fig. 29.5). Doppler can also be utilized, but the pedicle is typically easily seen.

The flap is elevated toward the axilla creating a tunnel toward the breast incision. Care must be taken if dissecting from a medial to lateral direction on the posterior surface of the LD, as the serratus muscle can be inadvertently raised with the latissimus muscle. It helps to make this distinction through the mastectomy wound as the serratus and latissimus muscles are more easily delineated anteriorly. A branching vascular pedicle to the serratus is typically encountered and should be preserved until the status of the thoracodorsal artery and venae comitantes are confirmed. In cases of prior surgery or trauma near the dominant pedicle, identification and preservation of the branch to the serratus muscle may ensure viability of the flap. The serratus branch can otherwise be divided.

Division of the musculotendinous insertion to the humerus is performed to achieve adequate transfer to the anterior chest wall. It is often desirable to preserve some attachment to prevent excessive stretch and compression of the pedicle. The thoracodorsal nerve accompanying the pedicle should be divided to minimize muscle bulk and limit unsightly muscle contractions. Identification of the thoracodorsal nerve is confirmed by gently pinching it between forceps and seeing the LD muscle contract in an unparalyzed patient ▶ Video 29.2. In the lateral decubitus position, the ipsilateral breast dissection can be simultaneously initiated. The flap may then be delivered through the tunnel incision and tucked into the lateral mastectomy space temporarily and sterile occlusive dressing placed for the position change to supine for flap insetting.

29.3.4 Closure of Donor Site

The donor site should be adequately drained because of the relatively high rate of seroma formation.[11] We typically use two 15 French round closed suction drains, placing one toward the axilla and the other in the dependent position. The risk of seroma formation can be significantly reduced with the use of both fibrin glue and quilting sutures.[11] 3–0 dissolvable monofilament suture is used to close the dermal layer, and the skin can be closed in a running subcuticular fashion. After the wound is dressed, the patient can be placed into a supine position.

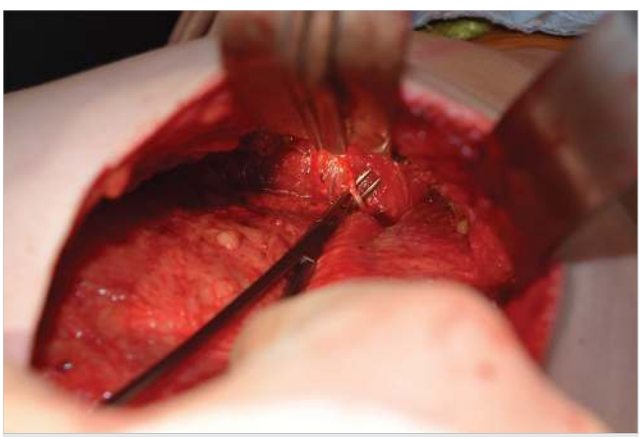

Fig. 29.5 Left-sided latissimus dorsi (LD) displaying the neurovascular bundle. With the flap already passed through the tunnel to the breast space, the right angle clamp has isolated the thoracodorsal nerve from the vascular pedicle on the posterior LD muscle near its insertion to the humerus prior to division.

29.3.5 Inset of Flap

Once supine, the pectoralis major may also be elevated if necessary to provide medial coverage over an implant. The LD flap is used most commonly to fill the lateral and inferior aspect of the breast, providing the implant with total muscle coverage. The LD is secured both inferiorly at the IMF and laterally at the anterior axillary line with 2–0 dissolvable suture. This provides a window between the pectoralis major and LD to place a submuscular tissue expander or implant.

29.3.6 Results

When used appropriately the LD flap results in excellent breast contour and shape with or without implants (▶ Fig. 29.6, ▶ Fig. 29.7, and ▶ Fig. 29.8).

29.3.7 Commonly Used Current Procedural Terminology (CPT) Codes

- 19361: Breast reconstruction with LD flap, without prosthetic implant.

Video 29.2 Isolation of the thoracodorsal nerve

Fig. 29.6 Patient 1 fully expanded to match right breast.

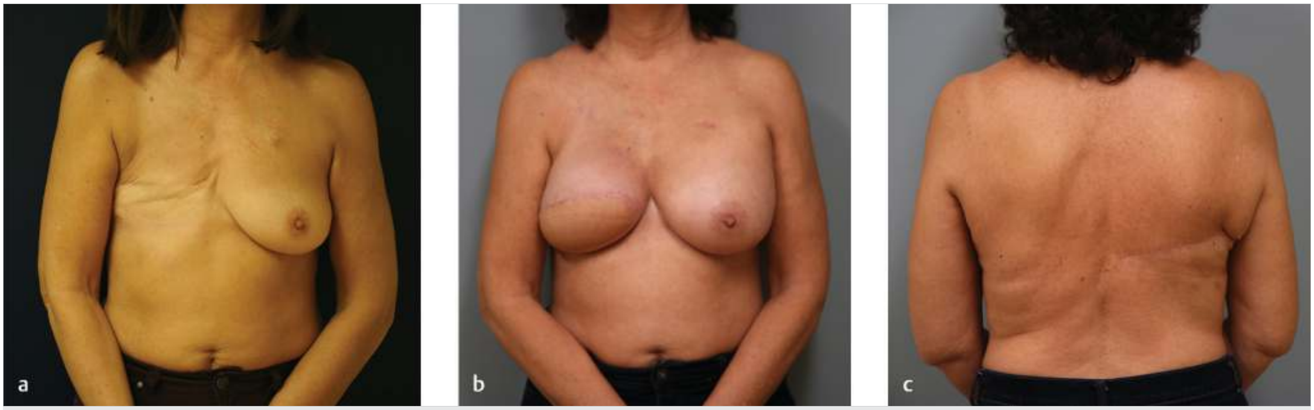

Fig. 29.7 A 60-year-old woman who had prior right skin-sparing mastectomy presents for delayed reconstruction. **(a)** Latissimus dorsi (LD) flap and expander were placed as she wished to be larger than her native breast. **(b)** One month following exchange of tissue expander for permanent implant and left side dual plane augmentation with implant. The donor site healed well with some rolling of the adipose tissue in the axilla **(c).**

Fig. 29.8 A 57-year-old woman who had breast conservation therapy including bilateral radiation, following completion mastectomies and submuscular tissue expander placement with mastectomy flap necrosis **(a).** Salvage reconstructions with removal of implants and bilateral extended latissimus dorsi (LD) flaps **(b).** Due to the amount of tissue recruited and tension on the donor site, she had widening of the back scars **(c).**

- Modifier 50: Identifies a procedure performed identically on the opposite side of the body (mirror image).
- 19340: Immediate insertion of breast prosthesis following mastopexy, mastectomy, or in reconstruction.
- 19342: Delayed insertion of breast prosthesis following mastopexy, mastectomy, or in reconstruction.
- 19350: Nipple/areola reconstruction.

29.4 Conclusion

The LD flap is a workhorse flap for immediate, delayed, and salvage breast reconstructions. It provides reliable, well-vascularized tissue coverage that avoids an abdominal donor site and the complexity of microsurgery. While performing LD flap breast reconstruction, the thoracodorsal nerve should be divided, the skin paddle must be carefully designed, and the final scar should lie in the relaxed skin tension lines.

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30 Breast Reconstruction with Pedicled Transverse Rectus Abdominis Flap

Steven M. Sultan and Mark R. Sultan

Abstract

The pedicled transverse rectus abdominis flap remains an important tool in the armamentarium of plastic surgeons throughout the world. The flap is particularly useful in clinical situations that preclude microsurgery or where microsurgery is unavailable. When properly elevated, the flap will reliably perfuse the ipsilateral hemiabdomen and a portion of the contralateral hemiabdomen. The authors favor the use of the ipsilateral hemiabdomen so that the better-perfused zones I and II will be positioned medially in the reconstructed breast. Successful outcomes are dependent upon preserving and capturing the maximum number of perforators, recreating the footprint of the breast, and carefully considering the donor site closure.

Keywords: breast reconstruction, pedicled flap, TRAM

30.1 Introduction

Despite recent advances in perforator-based microsurgical breast reconstruction, the pedicled transverse rectus abdominis muscle (TRAM) flap remains a mainstay in breast reconstruction throughout the world. This flap provides an autologous tissue option for women with appropriate donor abdominal tissue who may prefer a more expeditious method of autologous reconstruction or where microsurgical techniques are not available.[1] The pedicled TRAM flap also provides a valuable failsafe when microsurgical reconstruction must be aborted because of complications related to unfavorable vascular anatomy or even hemodynamic instability.[2] Therefore, this flap remains an essential part of the armamentarium of the well-rounded plastic surgeon.

30.2 Indications

It is widely recognized that free TRAM flaps and, to a lesser degree, deep inferior epigastric perforator (DIEP) flaps provide better perfusion to the pannus than pedicled TRAM flaps.[3] It is also believed that the short-term donor site morbidity of the microvascular methods of flap transfer is lower than that of its pedicled counterpart.[4,5] This may not be true of long-term morbidity. However, there are instances when a pedicled TRAM flap is an excellent reconstructive option. These include those patients whose volume requirement for unilateral breast reconstruction is 50 to 60% of the total TRAM paddle volume (representing zones I and II of the flap). Pedicled TRAM flaps, harvested properly, can reliably perfuse zones I, II, and a portion of zone III.[6] Other than patients with abdominal wall fascial laxity in whom the TRAM flap harvest site can be securely repaired. In addition to patients who remain excellent candidates for pedicled TRAM flaps.

Relative contraindications to pedicled TRAM flaps include active cigarette smoking, diabetes, and patients in whom zones I and II alone may not be adequate to achieve symmetry with the contralateral breast.[7,8]

30.3 Operative Technique

30.3.1 Markings

The patient is marked in the upright position. The midline of the chest and abdominal wall are outlined as is the meridian of each breast. Each inframammary fold is also clearly marked along with the remaining borders of the breast. The TRAM flap is marked as a long ellipse, generally from just beyond one anterior superior iliac spine (ASIS) to the other and from just above the umbilicus to a low groin crease (▶ Fig. 30.1). Confirmation that the donor site closure can be achieved without undue tension is obtained by having the surgeon grasp the pannus while the patient is flexed at the waist and then asking the patient to stand upright.

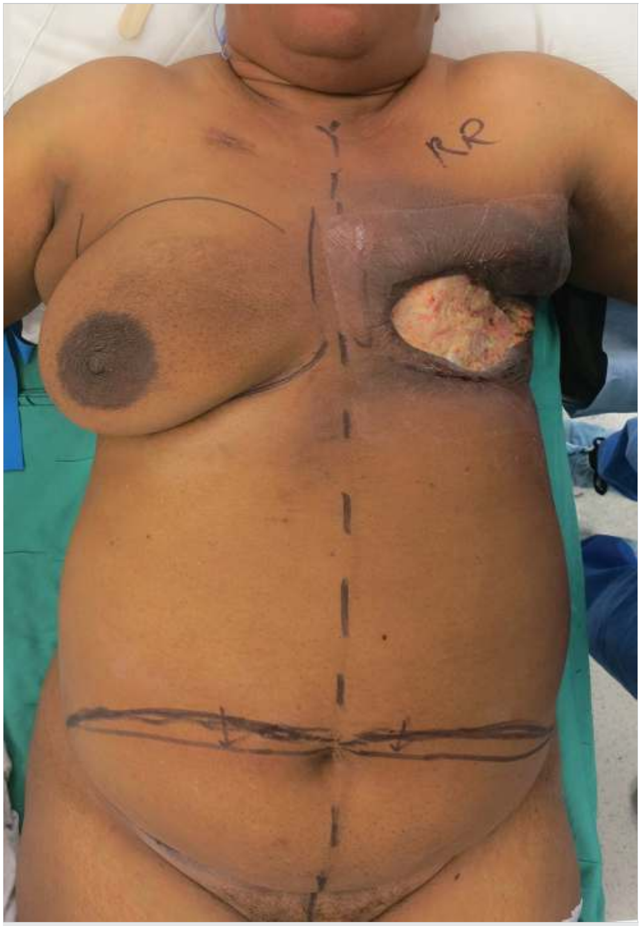

Fig. 30.1 Markings for a pedicled transverse rectus abdominis (TRAM) flap in a 55-year-old woman who presented with a chronic wound of her left chest following simple mastectomy and radiation 10 years prior. Note the flap markings and the markings of the borders of the normal contralateral breast for reference when insetting and shaping the flap.

The incisions for the mastectomy are drawn in conjunction with the oncologic surgeon. If a balancing procedure on the contralateral breast is planned, these markings are also drawn at this time. A location for the subcutaneous tunnel from the abdominal wound into the mastectomy for transfer of the TRAM flap is outlined on the upper abdominal wall as well.

30.3.2 Positioning

The patient is positioned supine on the operating table with all pressure points carefully padded. A pillow is placed below the knees to improve flexion at the waist, which will expedite the donor site closure. In a unilateral mastectomy case, the contralateral arm is positioned adjacent to the trunk. The ipsilateral arm is prepped into an arm bag so that during the sculpting phase it can be adducted and positioned symmetrically to the contralateral arm.

30.3.3 Harvesting

We generally favor use of the ipsilateral rectus in pedicled TRAM flap breast reconstruction. This is because with a turn of 180 degrees, zones III and IV of the flap are positioned near the axilla while the better-vascularized zones 1 and 2 are in the more critical medial aspect of the breast.

The superior skin incision for the harvesting of the TRAM flap is generally made first. Once the dermis is traversed, the incision is beveled superiorly through the subcutaneous tissue toward the abdominal wall fascia in order to capture supraumbilical perforators, which may emanate 2 to 3 cm above the umbilicus, then running obliquely through the subcutaneous fat.

The inferior flap incision is made and carried directly down to the abdominal fascia. The umbilicus is isolated with care taken not to devascularize it.

The flap is elevated off the fascia on the contralateral side first with attention paid to the size and caliber of the perforating vessels, which require release and cauterization. As the midline is reached, the dissection slows to carefully elevate the flap off the ipsilateral rectus fascia until the major medial row perforators are identified and preserved. A similar approach is useful to spare the lateral fascia. The upper abdominal dissection continues, elevating the pannus of the facscia off the costal margins and to the xyphoid.

A Doppler probe may be used to outline the course of the superior epigastric vessels, and a thin width of fascia is planned to be included on the rectus while the remainder is spared, ensuring a solid donor site fascial repair.

Below the level of the TRAM flap the fascia is incised vertically. The rectus muscle is split laterally in the direction of its fibers to identify the inferior epigastric vessels below the muscle. The vessels are followed retrograde toward their origin where they are ligated (veins first) after isolating a length, which can be utilized for “super-charging” should that prove necessary. The rectus muscle must now be released from its medial, lateral, and posterior fascial attachments. The most critical areas are at the tendinous inscriptions because of the hazard of transecting the muscle excessively in which case the choke vessels are subject to injury.

The muscle is released above and below each inscription. The muscle is then encircled and retracted away from the remaining attachment of the muscle to the fascia at the inscription. This is then detached carefully while protecting the muscle. A full vertical fascial release is performed before transecting the rectus muscle at the level of the arcuate line.

The final dissection of the flap superiorly near the costal margin is performed with the superior epigastric vessels identified and in view on the undersurface of the rectus. This allows lateral fascial release just above the costal margin. The eight intercostal perforator is generally ligated. These maneuvers improve the arc of rotation of the flap (▶ Fig. 30.2).

Before the transfer of the TRAM flap into the mastectomy defect, the inferior, medial, and lateral borders of the breast should be re-established, if needed, with imbricating sutures. A subcutaneous tunnel just wide enough to pass the flap into the mastectomy defect is created (▶ Fig. 30.3). The flap is then drawn through this tunnel with a 180 degrees turn, bringing zones 3 and 4 into the wound first so that they are positioned laterally toward the axilla. The flap is then secured to the defect as the donor site defect is repaired (▶ Fig. 30.4). This begins with horizontal mattress sutures to repair the fascial defect with all the knots left medially. The lateral fascia can then be used as a second layer of repair over the initial line of repair. This also centralizes the umbilicus. Superiorly, care must be taken to repair the fascia without placing tension upon the superior epigastric vessels. The patient is then placed to 60 degrees of an upright position to allow primary closure of the abdominal skin defect.

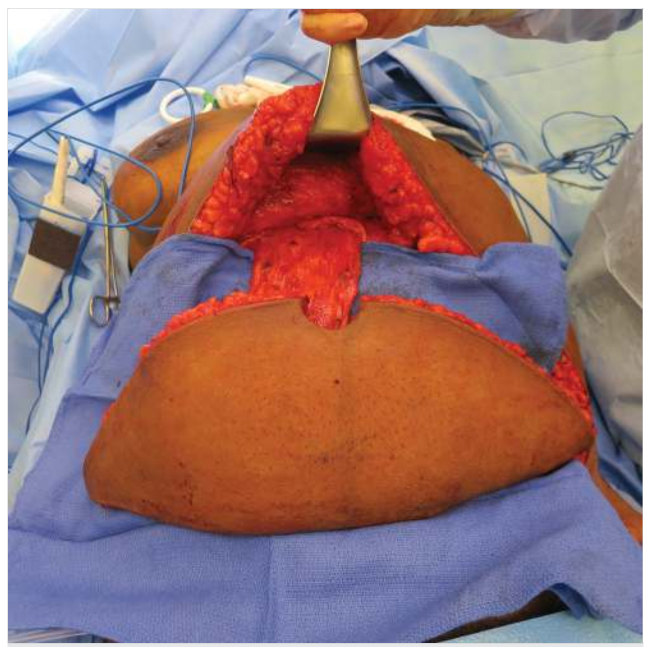

Fig. 30.2 The pedicled transverse rectus abdominis (TRAM) flap elevated on the right rectus muscle. The authors generally prefer to use an ipsilateral flap in such cases in order to align zone 1 in the medial breast. However, this patient’s left internal mammary artery was occluded on preoperative imaging obtained to evaluate her ribs for osteoradionecrosis. She was therefore not a candidate for left pedicled TRAM.

Fig. 30.3 A tunnel is developed just wide enough to rotate the flap from the abdominal donor site to the chest defect.

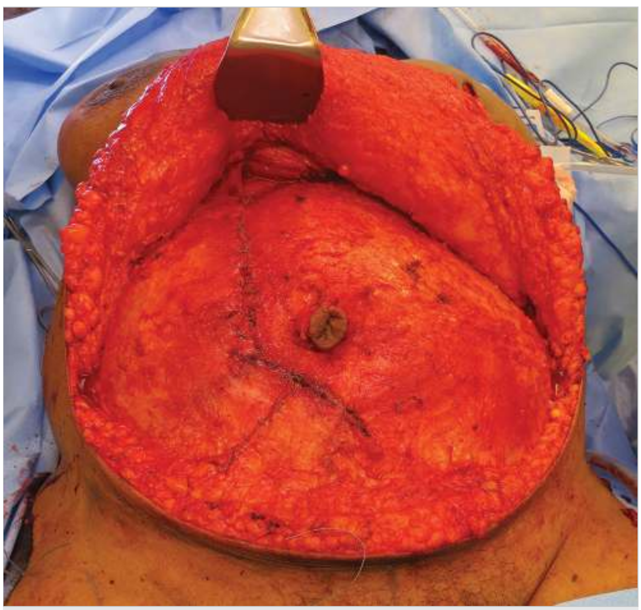

Fig. 30.4 The donor site fascia is closed primarily with dissolvable suture. The initial suture line is then reinforced with a further plication of the fascia, which both strengthens the closure and centers the umbilicus.

30.3.4 Insetting

Sculpting of the flap is performed with the patient in the upright position. The general orientation of the flap depends on the appearance of the contralateral breast. For a narrower breast, the flap is oriented vertically or obliquely. For a wider breast, the flap is oriented more horizontally (▶ Fig. 30.5). Superiorly, the edge of the flap is de-epithelialized and anchored to the detached free edge of the mastectomy fascia to prevent inferior migration of the flap postoperatively. Medial fixation sutures may also be necessary. The lateral excess flap volume is excised. The portion of the flap beneath the skin flaps is then marked and de-epithelialized. Final insetting is then completed.

Fig. 30.5 The flap is inset vertically for a narrower breast or, as in this case, horizontally for a wider breast. Tacking sutures are used superiorly to prevent downward migration of the flap postoperatively.

30.4 Conclusion

Use of an ipsilateral pedicled TRAM flap allows favorable insetting with the better-vascularized portion of the flap in the more critical medial and central reconstructed breast. Fascial sparing allows for a secure two-layer fascial repair. The most critical aspect of TRAM flap harvesting is prevention of rectus muscle injury at the tendinous inscriptions.

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31 Breast Reconstruction with Free Transverse Rectus Abdominis Muscle Flap

Rodney Cooter

Abstract

The free transverse rectus abdominis muscle (TRAM) flap is reliable for breast reconstruction, affording good volume and a favorable donor scar. Intraoperatively, it is important to have a warm and fluid-filled patient throughout the procedure and also postoperatively. Excellent results can be achieved with good operative planning and surgical technique; having two teams and performing the microsurgical anastomoses with the bulky flap outside the operative zone can reduce operating time significantly. Although there can be some abdominal muscle function compromise if a full TRAM flap is harvested, some of the functional deficits can be alleviated with appropriately planned muscle-sparing procedures, particularly in bilateral cases. Although there is an increasing tendency toward free perforator flaps, the free muscle TRAM flap is still quite reliable if appropriate attention to detail is given to every step of the operative plan and the postoperative monitoring.

Keywords: breast reconstruction, deep inferior epigastric, internal mammary, microsurgical, rib resection, TRAM flap

31.1 Introduction

The evolutionary pathway of breast reconstruction with the transverse rectus abdominis muscle (TRAM) flap closely parallels advances in our understanding of the arterial blood supply and venous drainage of the abdominal wall's composite tissues. The early delineation of angiosomes and choke vessels[1] helped us to appreciate the limitations of pedicled TRAM flaps based on the superior epigastric vessels compared with the more robust "free muscle" TRAM flaps based on the inferior epigastric vessels; and further refinement of perforasomes has led to the pursuit of "muscle free" perforator flaps.[2]

Along this advancing spectrum, the transition from pedicled flaps to free flaps heralded a new horizon in breast reconstruction[3] and, although perforator flaps have less donor site morbidity, the free TRAM flap remains a mainstay in many practices.

31.2 Indications

The free TRAM flap breast reconstruction technique can be used for immediate or delayed postmastectomy reconstruction. It can be employed for unilateral or bilateral reconstructions so long as the abdominal panniculus has a sufficient repository of adipose tissue. The free TRAM is particularly favored by patients whose preference is to avoid implant-based reconstruction. Contraindications include a prior abdominoplasty or other significant abdominal scarring, or poor patient physiology due to concomitant diseases. Relative contraindications include smokers,[4] nulliparous woman who intend to have future pregnancies, and athletic individuals who may be compromised by any reduced rectus abdominis muscle function postoperatively,[5] and also patients with a high body mass index may be unsuitable because of the increased operative risks.[6]

As an operation, it bears all the hallmarks of plastic and reconstructive surgery and to execute it well is to be able to raise most flaps, but the management of these patients is more than just an elegant operation. Thoughtful planning is imperative and an understanding of the physiology of both the patient and the flap intraoperatively and postoperatively is paramount.[7] Any breast reconstruction should never be viewed simply as an operation because the procedure is part of the continuum of care of a patient who has had a mastectomy.

31.3 Operative Technique (for a Unilateral Delayed Reconstruction)

31.3.1 Preoperative Planning

Efficient operative techniques require good planning. After a thorough history and examination and photographic documentation, free TRAM flap preparation may also include a computed tomography (CT) angiogram of the abdominal wall to assess whether the patient is suitable for a muscle-sparing procedure.[8] For a unilateral reconstruction, one key factor in determining the dimensions of the TRAM flap is the patient's preference of size for the contralateral breast; some may wish to have it reduced in size, others may desire a reconstruction of equivalent size and shape. If a match is requested, the following sequence can be followed to achieve symmetry in a delayed reconstruction. Measure the coordinates of the mastectomy scar from the sternal notch and the midclavicular point. Then transfer those points accurately to the contralateral breast and draw in a "sham" mastectomy scar and measure the surface area of breast tissue beneath the "sham" scar down to the inframammary fold (IMF). In this way the transverse and vertical dimensions of the skin component of the proposed flap can be ascertained. Then measure the height from the mid-mastectomy scar to the superior point of the upper pole of the normal breast to calculate the subcutaneous tissue required to reproduce the superior pole element of the flap (▶ Fig. 31.1).

In planning the flap on the abdomen in unilateral cases it is useful to have the reconstruction straddling the contralateral rectus abdominis muscle (▶ Fig. 31.2a). If possible, avoid the umbilical region, which, if included in the skin paddle, mandates a vertical scar on the flap. Preference is given to the contralateral muscle because one of the favored recipient vessel sites is the internal mammary system[9] and if this is considered unsuitable, or indeed damaged during preparation, the contralateral muscle can still be pedicled on the contralateral superior epigastric system as a fallback option. To recruit the further volume required for the upper pole, it is useful to plan for beveling of the adipose tissue superiorly from the abdominal flap skin paddle (▶ Fig. 31.2a) and indeed, to increase overall flap

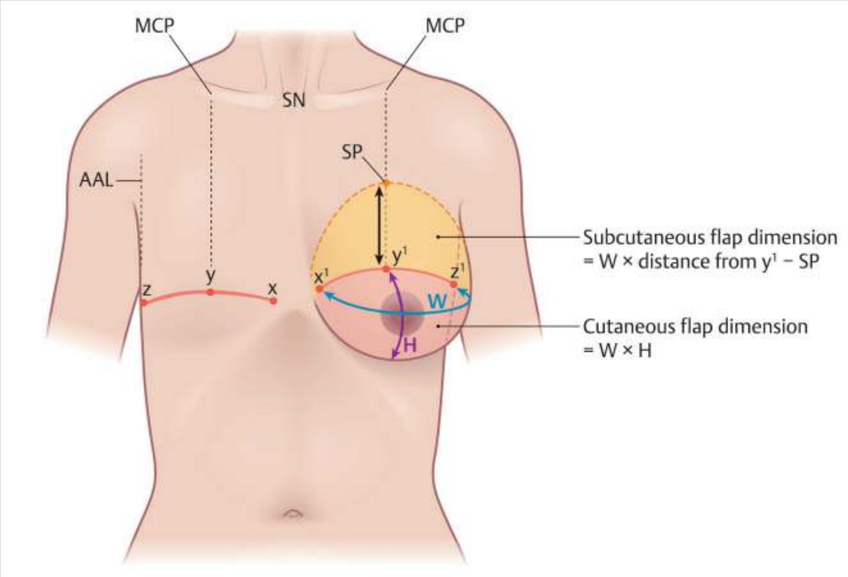

Fig. 31.1 Determining free transverse rectus abdominis muscle (TRAM) flap dimensions: Establish x, y, and z coordinates of mastectomy scar: x = medial end of scar measured from sternal notch (SN), y = meridian point of scar measured from mid-clavicular point (MCP), z = lateral end of scar at anterior axillary line (AAL). Transfer x, y, and z coordinates onto breast and draw a "sham" mastectomy scar with coordinates x^1, y^1, and z^1. The required cutaneous component of the flap is measured as the area between the "sham" scar and the inframammary fold (IMF). The required adipose tissue for the superior pole is measured from y to the uppermost limit of the superior pole (SP). W, flap width; H, flap height.

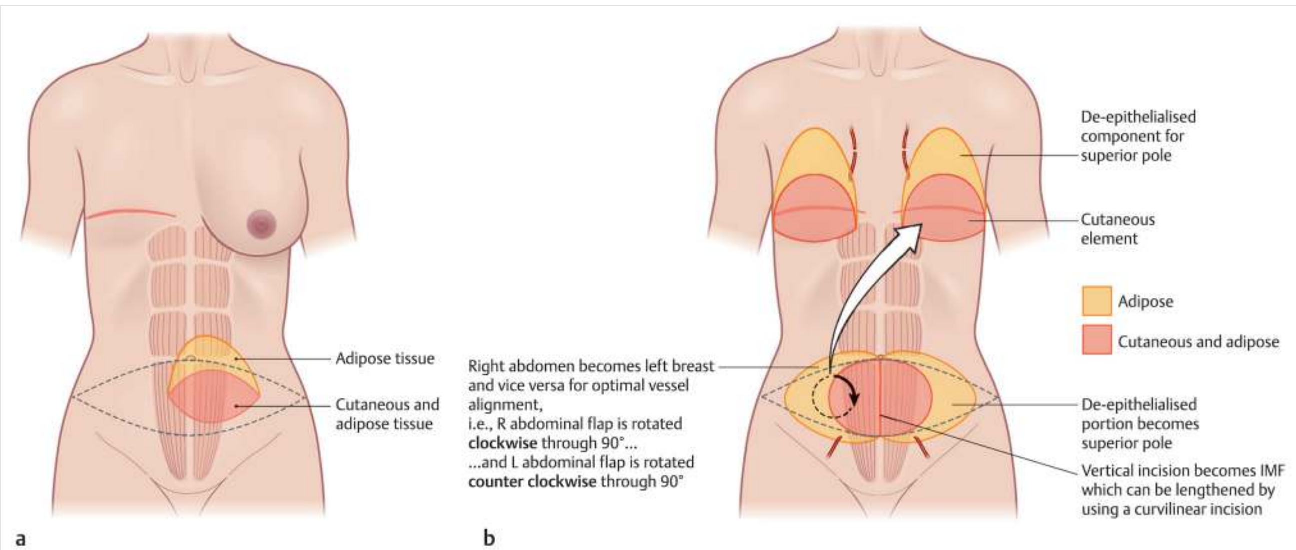

Fig. 31.2 Planning of free transverse rectus abdominis muscle (TRAM) flaps on abdomen. **(a)** Unilateral: (1) Straddle contralateral rectus abdominis muscle. (2) Try to avoid umbilical region in cutaneous component. (3) Plan to bevel edge of flap to harvest extra adipose tissue for superior pole. **(b)** Bilateral: (1) Each hemi-panniculus is elevated. (2) Midline incision becomes inframammary fold (IMF) on each side.

volume an inferior cuff of adipose tissue can be included if there are no scars to limit such a dissection. In bilateral cases, the whole intraumbilical abdominal panniculus is elevated and some peripheral beveling will augment the reconstructed breasts' volumes. If possible, the vertical midline abdominal incision can become the IMF for the reconstructed breast and the lateral tissues become the de-epithelialized superior poles (▶ Fig. 31.2b).

31.3.2 Operative Considerations

Intraoperatively, it is important to prevent hypothermia by using adequate patient warming, fluid warming, and continuous monitoring of the patient's core temperature.[10] Appropriate measures are also necessary for adequate antibiotic[11] and thromboembolic prophylaxis.[12] Control of fluid management is facilitated by having an indwelling urinary catheter.

The operation commences with incisions around the proposed flap donor site, taking care to avoid damage to the superficial inferior epigastric artery and vein, which should be preserved, if present. The dissection through the adipose layer of the abdomen is now beveled down to the abdominal wall by harvesting the predetermined superior pole's cuff of adipose tissue outside the boundary of the skin component of the TRAM flap. Once the abdominal wall is reached circumferentially, the lateral regions of the flap are elevated in turn by dissecting medially toward the chosen rectus abdominis muscle. If a muscle-sparing TRAM flap has been planned then the appropriate amount of muscle is preserved along with the motor branches of nerves which enter the muscle posterolaterally[13]

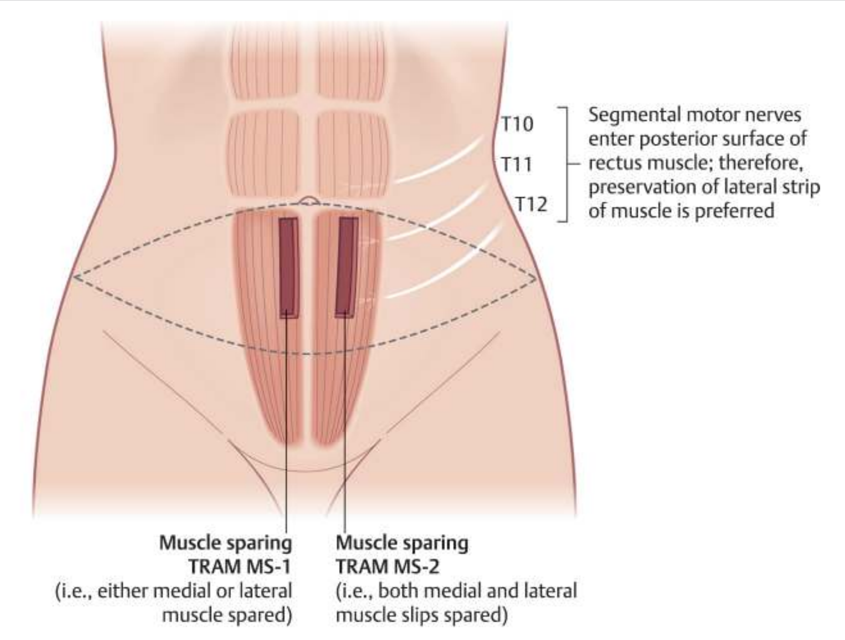

Fig. 31.3 Preserving motor nerves to rectus abdominis muscle. Segmental motor nerves enter the posterior aspect of the rectus abdominis muscle. Elevation of medial segment of rectus abdominis muscle, i.e., sparing the lateral segment, is an MS-1. Elevation of a middle segment of muscle but sparing both the lateral and medial segment is an MS-2.

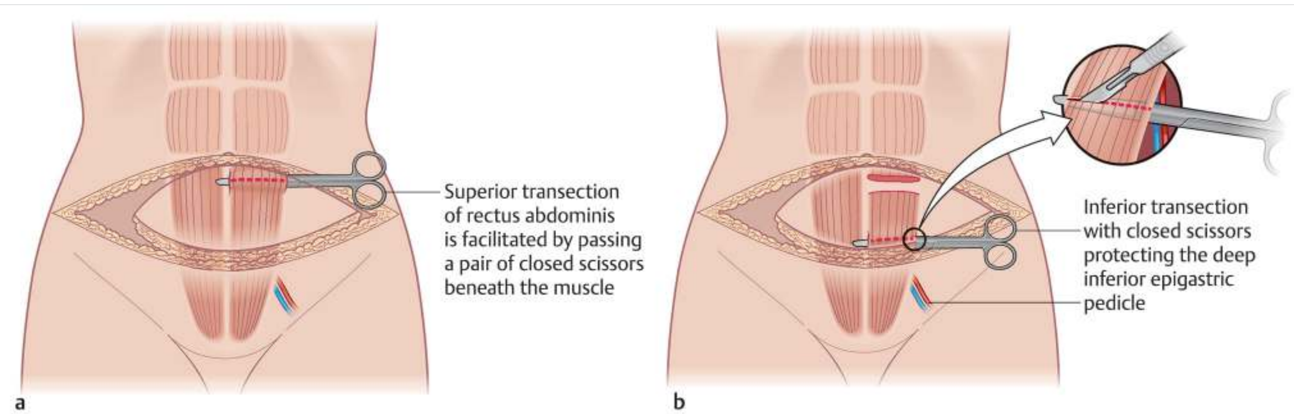

Fig. 31.4 Transecting the rectus abdominis muscle. **(a)** Superior transection—above periumbilical perforator. **(b)** Inferior transection—taking care to avoid damage to deep inferior epigastric pedicle.

before the flap is rendered a free flap (▶ Fig. 31.3). Before transecting the upper rectus abdominis muscle, it is also now important to ensure that the recipient vessels are appropriate at the chest level because in the unlikely event that the recipient vessels are damaged, or rendered unsuitable, the flap can still be transferred as a pedicled flap. At this stage incisions are made in the anterior rectus sheath to expose the underlying rectus muscle around the base of the flap; a cuff of the anterior sheath is preserved to cover the mesh hernioplasty edges. Having isolated the rectus abdominis muscle, instruments such as a closed large pair of scissors are then passed transversely beneath the fibers of the rectus abdominis muscle, which is then cut transversely down to the metal scissors which serve to protect underlying tissue (▶ Fig. 31.4a), taking care to maintain immaculate hemostasis. The cut edge of the rectus muscle is then sutured to the flap to avoid any shear complications during the further dissection or during the transfer to the chest wall. Now the whole flap is raised from superior to inferior and the dissection proceeds quite swiftly to clear any small vessels from the posterior surface of the rectus muscle. Care is taken to preserve the deep inferior epigastric vessels at the lower lateral border of the rectus muscle and the pedicle is dissected away from the lateral border of the muscle so that the inferior aspect of the muscle can be transected safely (▶ Fig. 31.4b), thereby completing the islanding of the TRAM flap. Much care must be taken to avoid any damage to the primary pedicle during the inferior transection of the rectus abdominis muscle. Again, it is best to use a protecting instrument placed behind the muscle but in front of the pedicle (▶ Fig. 31.4b) and to avoid any diathermy in the proximity of the pedicle. Once isolated, the whole flap can be elevated above the abdomen, and the deep inferior epigastric pedicle is then easily dissected straight down toward the external iliac vessels. This dissection is facilitated by the assistant placing a hand over the abdominal contents and gently applying compression as well as superior traction while the lower remnant of the rectus muscle and the inguinal ligament

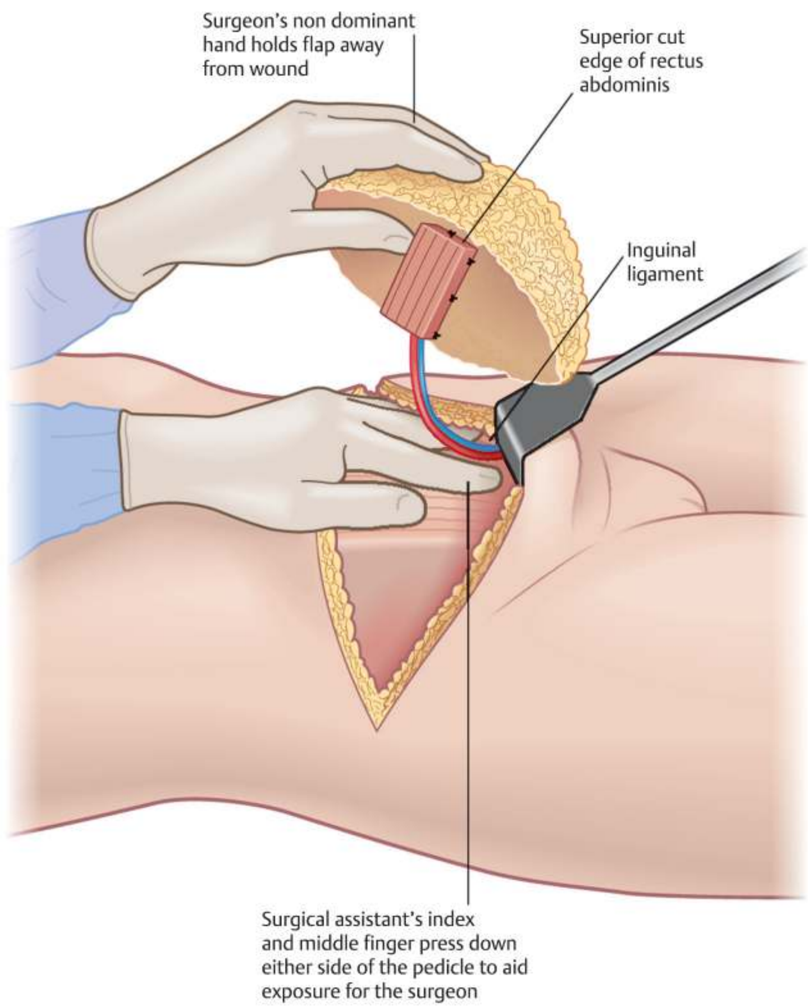

Fig. 31.5 Facilitating dissection of the free transverse rectus abdominis muscle (TRAM) flap's deep inferior epigastric pedicle. Surgical assistant places hand over abdominal content and gently compresses and pulls superiorly. Broad metal retractor is used to retract inguinal ligament and inferior remnant of rectus abdominis muscle. Flap is lifted away from wound by the surgeon to facilitate clipping of redundant branches from pedicle.

region are retracted inferiorly with a broad metal retractor (▶ Fig. 31.5). Once the pedicle is dissected by clipping minor branching vessels, and about 8 to 10 cm of length has been achieved, it is usual practice to place the free flap back on the abdominal region and allow it to perfuse naturally while the recipient vessels are further prepared.

31.3.3 Chest Preparation

After the mastectomy scar is excised and sent for histopathology,[14] the upper skin flap is elevated superiorly enough to accommodate the planned de-epithelialized adipose flap segment used to reconstruct the superior pole. During this flap elevation, take note of any medial perforators as they can give an indication of the position of the underlying internal mammary vessels. At this stage it is useful to elevate a superomedially based pectoralis major muscle flap by incising the muscle transversely at the level of the fourth costal cartilage and then making a vertical incision at the level of the costo-chondral junctions (▶ Fig. 31.6), to lift it away from the proposed site for the micro anastomoses at the third costal cartilage level.[15] Such exposure will allow the flap pedicle to gently curve away from the anastomotic site rather than risking kinking of the pedicle, if only the third costal cartilage is removed through an incision directly over it. The third costal cartilage is then removed, ensuring all the medial cartilage is excised from the sternum to expose the recipient vessels; bone nibblers can be helpful here. Some surgeons prefer to preserve integrity of the rib and advocate an interspace approach to the internal mammary vessels.[16]

31.3.4 Flap Transfer

The abdominal flap is then prepared for transfer to the chest by first clamping the deep inferior epigastric artery, noting the time of clipping as the start of flap ischemia, and then subsequently clamping the veins. Each vessel is clipped with a different size clip to ensure that each can be identified appropriately after transfer; some surgeons leave the flap vein to be anastomosed without a clip as it will be the first vessel to be connected. The time is recorded when the flap vessels are clipped as this is the start of the ischemia period. The flap is then placed upside down on the chest opposite the mastectomy site (▶ Fig. 31.7) and wrapped in a moist surgical pack; the pedicle is then draped into the wound in preparation for the micro-anastomoses. As a general rule, the first anastomosis to be performed is the venous side after which the arterial anastomosis is completed; the time is then recorded as the end of the flap ischemia time. The pectoralis muscle flap is then laid back over

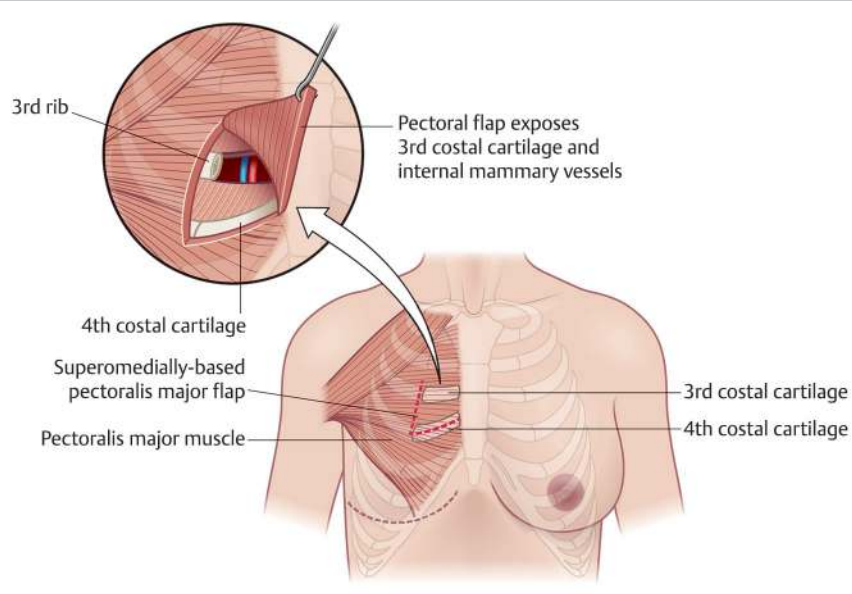

Fig. 31.6 Exposing the internal mammary recipient vessels by elevating the flap of pectoralis muscle from the fourth costal cartilage allows the pedicle to drape smoothly from the third intercostal interspace.

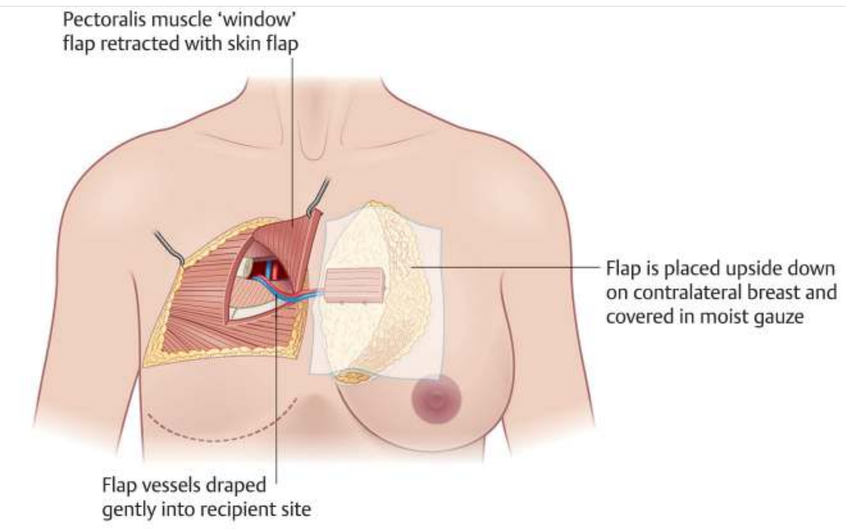

Fig. 31.7 Preparing for the micro anastomoses of the free transverse rectus abdominis muscle (TRAM) flap. To avoid restricting access to the recipient vessels, the flap is placed on the contralateral chest and the pedicle draped into the recipient site.

the anastomoses and tacked back into place, avoiding any tension or compression on the underlying anastomoses. The flap is then transferred into the defect, placing sufficient volume superiorly to give a superior pole projection, and the chest skin between the mastectomy scar and the proposed inframammary crease is then removed while retaining the underlying subcutaneous tissue attached to the chest wall; this helps to define the inframammary crease and to camouflage the inferior scar of the reconstruction. As the flap is sutured into place it is very useful to medialize it as much as possible to maintain future projection. A drainage tube is placed beneath the flap but every effort is taken to avoid any risk of damage or suction to the pedicle region.

The donor site is then closed as an abdominoplasty with a mesh hernioplasty[17] at the site of any muscle harvest, and the retained cuff of anterior rectus sheath is sutured over the larger sutures securing the perimeter of the mesh (▶ Fig. 31.8). It is useful to have two teams working synchronously such that the abdomen can be closed over suction drains while the microsurgical anastomoses are being performed at the chest level.

Variations to this "standard" description include muscle-sparing techniques, bilateral flaps, and stacked flaps.

31.4 Conclusion

The free TRAM flap remains a mainstay of breast reconstruction. Indications for surgery include unilateral or bilateral mastectomy defects after breast cancer resection. Patients desiring muscle preservation or those requiring bilateral flaps may opt for muscle-preserving operations such as perforator flaps. The surgical technique typically involves anastomoses of the deep inferior epigastric vessels to the internal mammary vessels. A two-team approach in which one team performs the microsurgical anastomoses while the other team closes the abdominal donor site can reduce operative time significantly. A mesh is used to close the abdominal wall. Careful placement of the flap

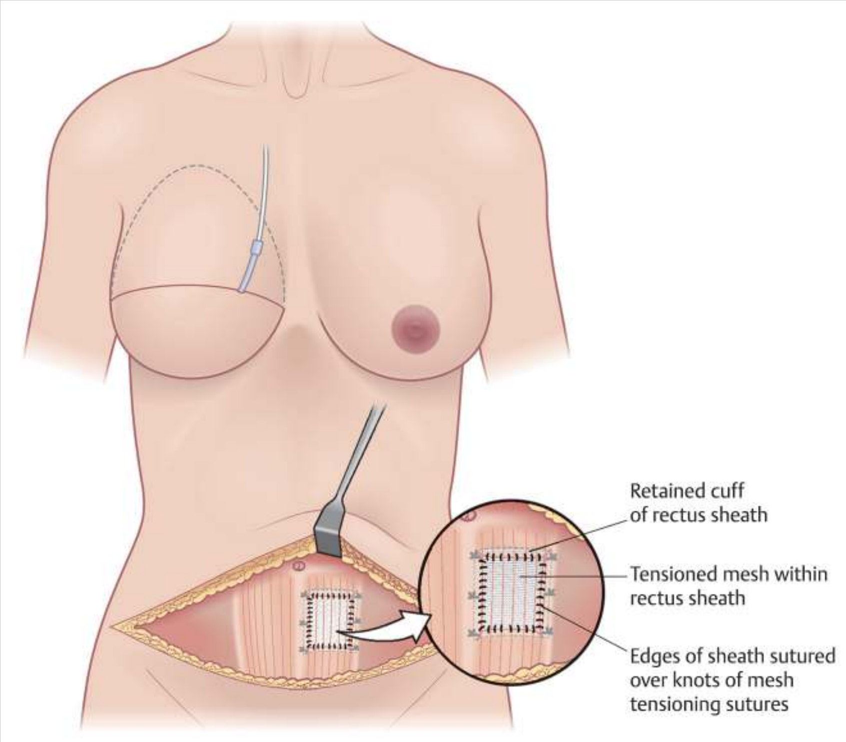

Fig. 31.8 Closure of the free transverse rectus abdominis muscle (TRAM) flap donor site. **(a)** Mesh is tensioned while it is sutured into the muscle-harvest defect. **(b)** A cuff of retained anterior rectus sheath is secured over the perimeter of the mesh with a running suture.

along the chest wall is important to create desirable superior and medial pole fullness.

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32 Breast Reconstruction with Free Perforator Flaps

Edward I. Chang

Abstract
Autologous tissue reconstruction following a mastectomy for cancer or for (risk reducing) prophylactic reasons represents the pinnacle of reconstructive options. The use of perforator flaps minimizes the donor site morbidity following flap harvest and affords patients the most optimal result with long-term durable outcomes and the most natural feeling and appearing breast. The deep inferior epigastric perforator (DIEP) flap from the abdomen represents the most popular donor site with a favorable donor site profile and often provides adequate tissue that mimics the consistency of the breast. Multiple perforators should be included with the flap to maximize success rates while minimizing fat necrosis and flap failure. The internal mammary vessels are the recipient vessels of choice and careful consideration should be given to previously irradiated vessels, particularly on the left side where the vein is smaller than the right side. Diligent postoperative monitoring and a low threshold for re-exploration are also critical for optimizing flap survival.

Keywords: breast reconstruction, DIEP flap, free flap, perforator

32.1 Introduction

Breast reconstruction has been revolutionized with the increasing popularity and comfort using autologous perforator flaps. The evolution of perforator flaps coincided with increasing comfort with free tissue transfer and success rates are well above 95% at high volume institutions. Since the description of the transverse rectus abdominis myocutaneous (TRAM) flap, advancements in our knowledge of perforator anatomy, surgical technique, and perfusion physiology have propelled perforator flaps to the gold standard for postmastectomy breast reconstruction due to reliable outcomes, improved donor site morbidity, and higher satisfaction and improvements in quality of life with autologous reconstruction compared to implant-based reconstruction.[1,2,3]

32.2 Indications

With the passage of the Women's Healthcare and Rights Act, all patients who have undergone mastectomy are eligible for breast reconstruction. The decision to undergo breast reconstruction is a personal decision for the patient, although studies have demonstrated high satisfaction and improved psychosocial well-being with breast reconstruction compared to patients who do not undergo reconstruction.[4] Aside from significant medical comorbidities that may increase perioperative complications, there are no definitive contraindications that preclude a patient from reconstruction.

However, in the setting of prior radiation, autologous tissue is recommended rather than an implant-based reconstruction because of the high risk of complications associated with implants in the setting of prior radiation.[5] The risks of infection, delayed wound healing or wound dehiscence, and capsular contracture are all increased in the setting of prior radiation. However, the indications for a perforator flap are largely based upon the reconstructive microsurgeon's experience and preference and patient factors such as body habitus, perforator anatomy, and prior surgery.

The most common free perforator flap performed for autologous breast reconstruction is the deep inferior epigastric perforator (DIEP) flap (▶ Fig. 32.1). The DIEP flap was popularized and is now the standard of care for many reconstructive microsurgeons. The DIEP flap can be performed using a single perforator if a dominant perforator is identified; however, this has been associated with a higher risk for flap loss and therefore taking an additional perforator is recommended.[6] However, taking additional perforators not only reduces the risk of flap failure, but also limits the risk of developing fat necrosis.[7] The use of a computed tomography angiogram (CTA) has also been touted as providing significant benefit in the preoperative planning of DIEP flaps. Again the indication and potential benefit for obtaining a CTA is dependent on a number of different factors including surgeon's preference and radiology technician as the ability of the CTA to identify the perforators and the branching pattern of the deep inferior epigastric vessels is dependent on the timing of the injection and acquisition of images (▶ Fig. 32.2).[8,9,10]

If a patient has had a formal abdominoplasty, the patient is not a candidate for any abdominal based free flap for breast reconstruction. Under these circumstances, the patient would need an alternate free perforator flap such as a superior gluteal artery perforator (SGAP) flap, inferior gluteal artery perforator (IGAP) flap, or profunda artery perforator (PAP) flap to reconstruct the breast.[11,12,13] In patients who are quite thin and do not have sufficient abdominal tissue, the abdominal donor site may also not be ideal for a perforator flap for breast reconstruction. However, if the patient has limited abdominal tissue, poor perfusion across the midline, or has had a prior midline laparotomy, a bipedicle from the abdomen is indicated whereby the entire abdominal tissue is harvested as a free flap to reconstruct a unilateral mastectomy defect (▶ Fig. 32.3).[14]

Fig. 32.1 Deep inferior epigastric perforator (DIEP) flap harvested from the abdomen without harvesting of any of the rectus abdominis muscle with the flap.

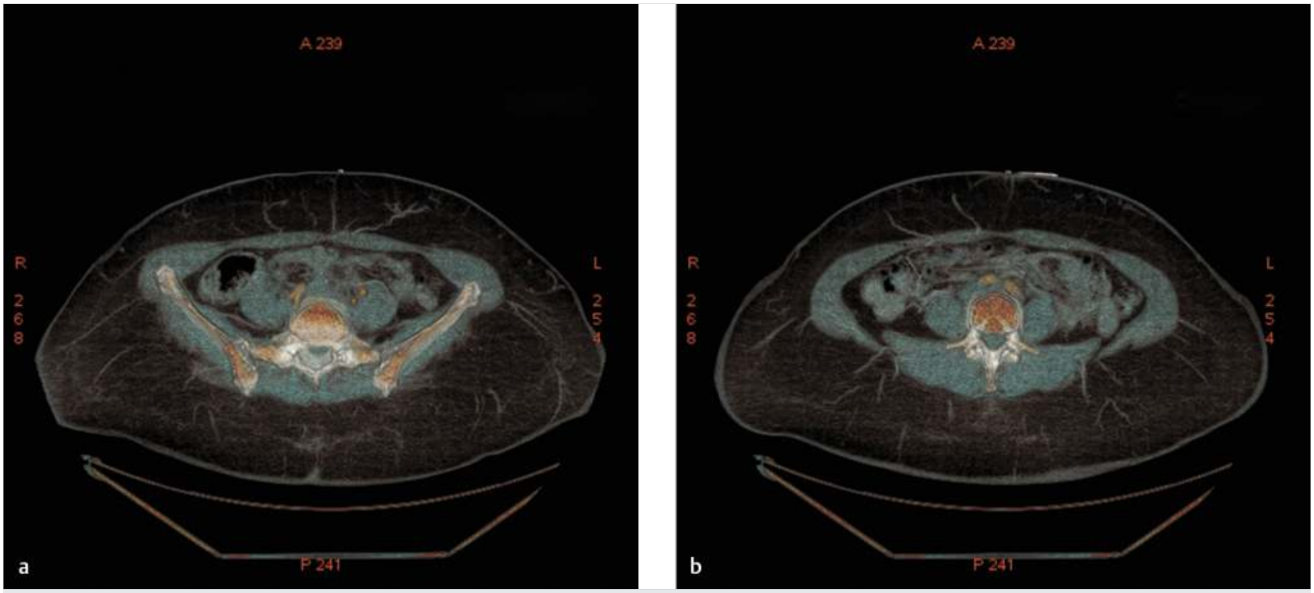

Fig. 32.2 (a, b) Computed tomography (CT) angiogram demonstrating perforators arising from the deep inferior epigastric vessels passing through the rectus abdominis muscle, supplying the overlying soft tissue.

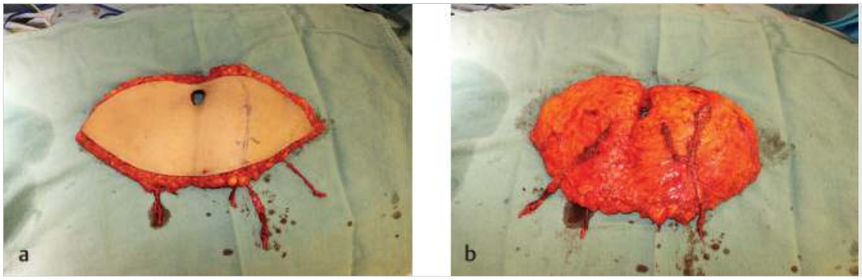

Fig. 32.3 (a, b) Free bipedicled deep inferior epigastric perforator (DIEP) flap where the entire abdominal donor site is harvested based on the deep inferior epigastric vessels on both sides, which used to reconstruct a unilateral mastectomy defect.

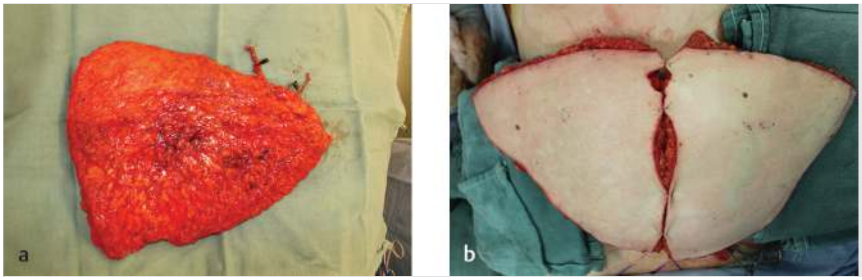

Fig. 32.4 (a) Superficial inferior epigastric artery (SIEA) flap harvested from the abdomen without violation of the rectus fascia, and **(b)** deep inferior epigastric perforator (DIEP) flap demonstrating mottling consistent with superficial dominance of the venous outflow.

32.3 Operative Technique

The patient should be marked preoperatively to identify the appropriate amount of tissue that can be harvested which will allow a tension free closure of the donor site. Careful attention should be paid toward any prior surgical scars or hernias that may impact the flap harvest and may indicate the need for preoperative imaging. Typically, the umbilicus is incised first, and the stalk is dissected to the fascia, preserving sufficient fat around the umbilical stalk to minimize risks of umbilical necrosis. The inferior incision is then made and the superficial epigastric vessels should be identified and preserved during the dissection, especially in the setting of superficial dominance (▶ Fig. 32.4).[15] The superior incision is then made and dissection proceeds to the fascia and then from a lateral to medial direction, paying careful attention to identify all the perforators.

Once the perforators have been identified, the microsurgeon must decide which perforators to include with the flap. A preoperative CTA can sometimes be helpful or alternatively indocyanine green (ICG) angiography can also be helpful in perforator selection. The remaining perforators should be clamped or ligated. The perforator dissection then commences with incising the fascia around each perforator and then tracing each perforator to the main pedicle. The main pedicle should be identified lateral to the rectus abdominis muscle to make certain it is patent, and the main pedicle can then be dissected as proximally as possible in order to maximize pedicle length and caliber (▶ Fig. 32.5).

Fig. 32.5 The deep inferior epigastric vessels isolated and dissected proximally to the takeoff in order to maximize the pedicle length and caliber of the vessels for the microvascular anastomosis.

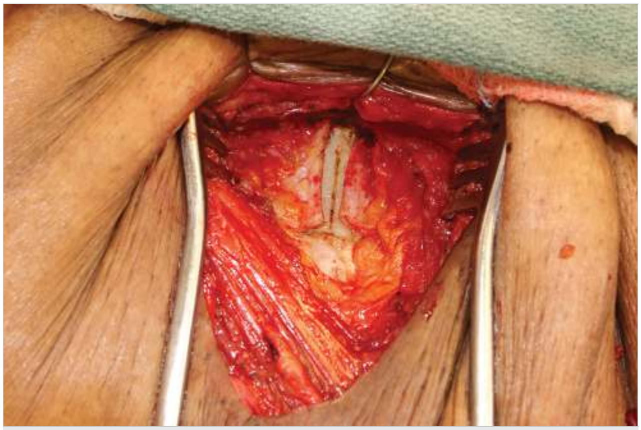

Fig. 32.6 Isolation of the internal mammary vessels typically occurs at the third interspace with removal of the third rib.

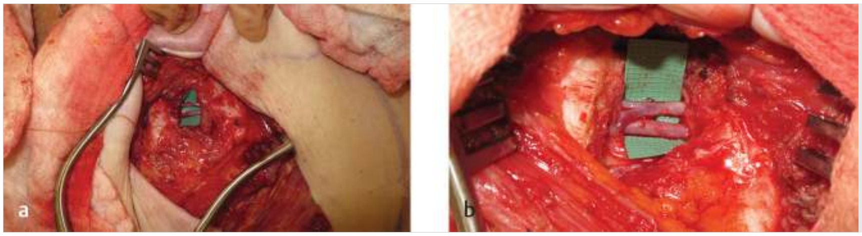

Fig. 32.7 Internal mammary vessels on the right and the left side, demonstrating a smaller internal mammary vein on the left side compared to the right side. Note the internal mammary vein is larger on the right **(a)** compared to the left side **(b),** which is also more likely to branch compared to the right side.

The internal mammary vessels have become the recipient vessels of choice in the modern era. In the setting of prior radiation, the internal mammary vessels should be isolated and deemed suitable to use for free tissue transfer prior to dividing the superior epigastric vessels. In the setting that the internal mammary vessels are not usable, a pedicled TRAM can still be performed or the microsurgeon may wish to evaluate other recipient vessels like the thoracodorsal vessels. In general, however, many would prefer to preserve the thoracodorsal vessels in the setting that the flap fails, so that the latissimus dorsi flap can still be used.

Isolation of the internal mammary vessels is typically performed in the third interspace (▶ Fig. 32.6). Dissection proceeds through the pectoralis major muscle to the third rib. The perichondrium is scored and then elevated to expose the cartilage. The cartilage is then removed with a Rongeur or en bloc with a scalpel. The remaining perichondrium can then be removed paying careful attention to avoid injuring the internal mammary vessels deep to the perichondrium. The remaining soft tissue and intercostal muscles can be removed in order to obtain the maximal length of the vessels. Of note, the internal mammary vein on the left side is significantly smaller than the right side and extreme caution should be used if the vein is less than 2.0 mm (▶ Fig. 32.7). In the setting when the vein is smaller than 2.0 mm, alternative recipient veins such as the cephalic vein or perhaps the external jugular vein should be considered.[16,17]

Once adequate recipient vessels have been confirmed, the flap is rendered ischemic and can be transferred to the chest for the microvascular anastomoses. An operating microscope is recommended, although using only loupe magnification has also been described.[18] The recipient artery should be tested for adequate inflow. The microvascular anastomosis should be performed meticulously making certain that a full-thickness suture is placed with equal spacing and without back walling the vessel. A venous coupler (Synovis, Inc.) is often used for the venous anastomosis and has demonstrated reliable outcomes (▶ Fig. 32.8). Following completion of the anastomoses, patency should be confirmed and the flap should be inspected for adequate perfusion by either documenting bleeding or via ICG angiography.

The donor site should be closed carefully reapproximating the muscle and then the fascia. If the patient has a noticeable diastasis, this should be corrected as well at the time of closure. The use of mesh is indicated when a larger amount of fascia is sacrificed as occurs in when both the lateral and medial rows of perforators are harvested (▶ Fig. 32.9).[19] Closed suction drains should be placed prior to skin closure. The umbilicus is finally delivered through the abdominal skin and inset.

Postoperative care should include thorough flap checks to confirm adequate perfusion of the flap. Signs of compromised perfusion would include loss of the Doppler signal, poor turgor, loss of capillary refill, poor bleeding on pinprick, and a cool pale flap. Conversely, signs of venous congestion include brisk capillary refill, dark rapid bleeding on scratch test, increased swelling, and mottling and darkening color of the flap (▶ Fig. 32.10). If there is any concern for compromised flap perfusion, an immediate re-exploration is warranted.[20]

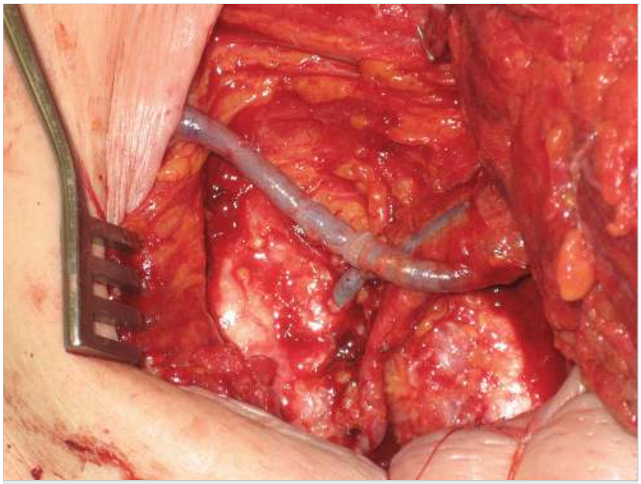

Fig. 32.8 Venous anastomosis completed with a venous coupler device rather than the hand-sewn technique that is used to perform the arterial anastomosis.

Fig. 32.10 Congested flap secondary to poor venous outflow. Note the swelling of the flap and increasing discoloration of the flap. Multiple scratch marks demonstrating dark bleeding.

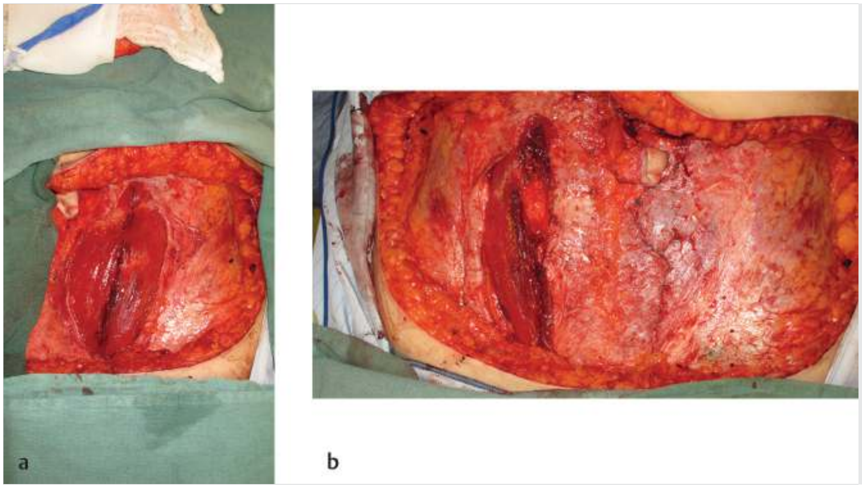

Fig. 32.9 Closure of the abdominal donor site should be performed to close the fascia primarily, which is typically done in the setting of a deep inferior epigastric perforator (DIEP) flap harvest because very little, if any, of the fascia is sacrificed during the flap harvest. Minimal muscle defect **(a)** following flap harvest allows primary closure of the donor site. **(b)** Note the muscle defect on the contralateral side following a muscle-sparing transverse rectus abdominis myocutaneous (TRAM) harvest.

32.4 Conclusion

Although a number of different perforator flaps have been described for autologous free flap breast reconstruction, the abdominal donor site remains the most popular choice. In order to maximize success rates in free DIEP flap breast reconstruction, careful preoperative planning, meticulous surgical technique, and diligent postoperative monitoring and management are critical.

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33 Secondary Procedures of the Reconstructed Breast

Sameer A. Patel, Marilyn Ng, and Douglas S. Wagner

Abstract
Breast reconstruction marks the beginning of restoring a natural-appearing breast mound. The patient may choose either an implant- or autologous-based breast reconstruction. The astute surgeon will recognize the need for secondary procedures after careful assessment of the reconstructed breast to refine the shape of the breast and reconstruct a nipple-areolar complex. The operative techniques outlined provide tools to correct volume asymmetries and contour deformities through fat grafting, implant replacement, capsulorrhaphy, and judicious use of biologic mesh.

Keywords: acellular dermal matrix, biologic mesh, breast deformity, breast reconstruction, breast reconstruction revision, capsuloplasty, capsulorrhaphy, implant replacement, nipple reconstruction

33.1 Introduction

Restoring the natural breast aesthetics after breast reconstruction improves patient satisfaction. For many patients, this may require secondary procedures to refine the breast mound and correct acquired postreconstructive deformities. Secondary procedures may include cutaneous standing deformities excision, nipple reconstruction, implant replacement, implant capsuloplasty, inframammary fold creation, and newer modalities of revision including use of acellular dermal matrix (ADM) and autologous fat grafting. To avoid poor results in patients, it is very important to recognize patient's history of adjuvant chemoradiation therapy and smoking and then develop a plan after careful analysis of reconstructed breast. Preoperative and postoperative photographs are taken for reference.

33.2 Indications

- Secondary procedures may be used after completion of primary breast mound reconstruction and at an appropriate time following adjuvant therapy. At our institution, we recommend delaying reconstructive procedures by 4 to 6 weeks after adjuvant therapy and 6 to 12 weeks after the last surgical procedure.
- Nipple reconstruction is performed as the last stage of breast restoration in patients with athelia, amastia, and nipple-sacrificing oncologic procedures (▶ Fig. 33.1 and ▶ Fig. 33.2).
- Fat grafting may be employed at any stage after initial reconstruction to address challenging asymmetries and contour deformities after lumpectomy, implant breast reconstruction, and autologous breast reconstruction (▶ Fig. 33.3 and ▶ Fig. 33.4).
- For implant-based reconstruction, implant replacement and capsuloplasty are important revision modalities. Implant replacement is indicated for exchange of a tissue expander, volume adjustments, and removal of ruptured or malpositioned implants (▶ Fig. 33.5). In the case of irradiated patients, the expander exchange to a permanent implant is delayed for 6 months.
- Capsuloplasty, with capsulotomy, capsulorrhaphy, or capsulectomy, is reserved for implant repositioning, controlling, and shaping in the setting of malposition and/or capsular contracture (▶ Fig. 33.6).
- Use of biologic meshes offer an alternative to complete muscle coverage of a tissue expander or permanent implant, repair compromised pectoralis major muscle, reconstruct the inframammary fold, mechanically protect implant exposure under thin skin, minimize capsular contracture, and camouflage implant rippling. An additional use of biologic mesh is as an internal bra during contralateral breast symmetry procedures (▶ Fig. 33.7).

Fig. 33.1 Nipple reconstruction. **(a)** Mark the patient in upright position and identify the new nipple location from a fixed point. **(b)** Mark the nipple reconstruction pattern away from previous scars. **(c)** Postoperative lateral view of reconstructed nipple with maintenance of projection.

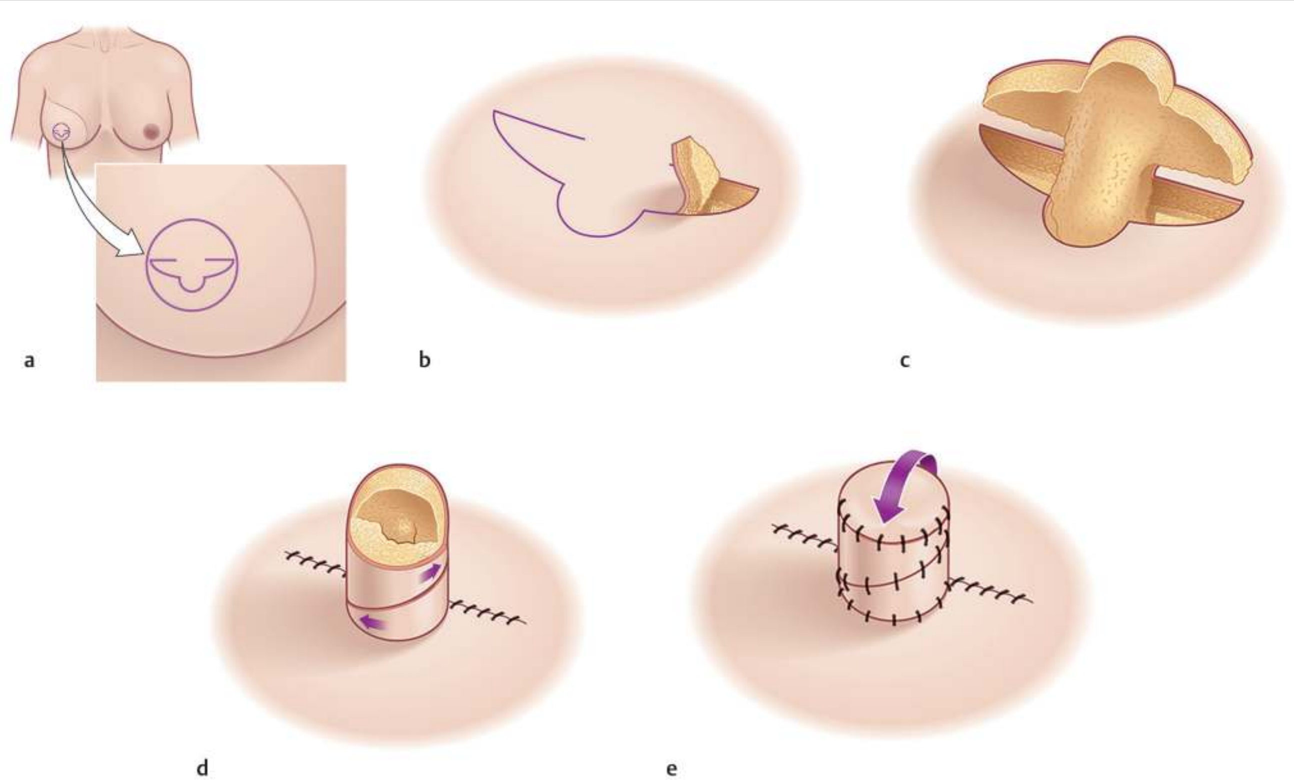

Fig. 33.2 Nipple reconstruction sequence. **(a)** Nipple reconstruction markings. **(b)** Raise lateral and C-flap segments. **(c)** Approximate donor skin edges. **(d)** Rotate and secure opposing lateral segments. **(e)** Secure C-segment.

33.3 Operative Techniques

33.3.1 Anesthesia

General anesthesia combined with laryngeal mask airway or endotracheal intubation is usually satisfactory. Local anesthesia without epinephrine infiltration is sometimes advisable in poor-risk patients. Additional anesthetic adjuncts may include thoracic paravertebral blockades.[1]

33.3.2 Position

The patient is placed in semi-Fowler's position and arms are abducted.

33.3.3 Nipple Reconstruction: Modified C-V Flap

Operative Preparation

Bilateral breasts are prepared in the routine manner (▶ Fig. 33.1a–c).[2,3,4,5]

Preoperative Markings

The patient is marked in the standing or seated position. Identify the apex of reconstructed breast mound along the breast meridian from a fixed point and its distance from the midline (▶ Fig. 33.1a). Consider the position of the contralateral nipple-areolar complex. A transverse line bisects the proposed nipple and determines the base of the flap, which is directed away from mastectomy scars. The central approximately 1 cm base is preserved for perfusion and determines the nipple width. Lateral V-segments are created by extending 21 mm lateral from each side of the central base. Nipple projection is determined by the distance of the base to midpoint of the arc connecting the endpoints of the lateral V-segments. Amount of projection may be determined by the patient's unaffected contralateral nipple or patient–surgeon preference in the case of bilateral breast reconstruction. A 1 cm C-segment is marked away from the central arc and will become the cap for the newly constructed nipple (▶ Fig. 33.1b, c).

Details of the Procedure

The procedure begins with raising of each of the lateral segments from lateral to the flap base in the subdermal level to include 5 mm of subdermal fat (▶ Fig. 33.2a, b). Avoid dissecting past the central flap base. The donor site is approximated in two layers (4–0 and 5–0 Monocryl) (▶ Fig. 33.2c). The lateral segments are rotated in double opposing fashion and secured with simple suture (6–0 Monocryl) and its base is sutured to the skin edge (▶ Fig. 33.2d). The C-segment is secured to the superior edge of the lateral segment (▶ Fig. 33.2e). (*Alternative modification*: The C-segment is de-epithelialized and will be the platform for the reconstructed nipple. The superficial edge of the lateral segment is then loosely approximated with a purse-

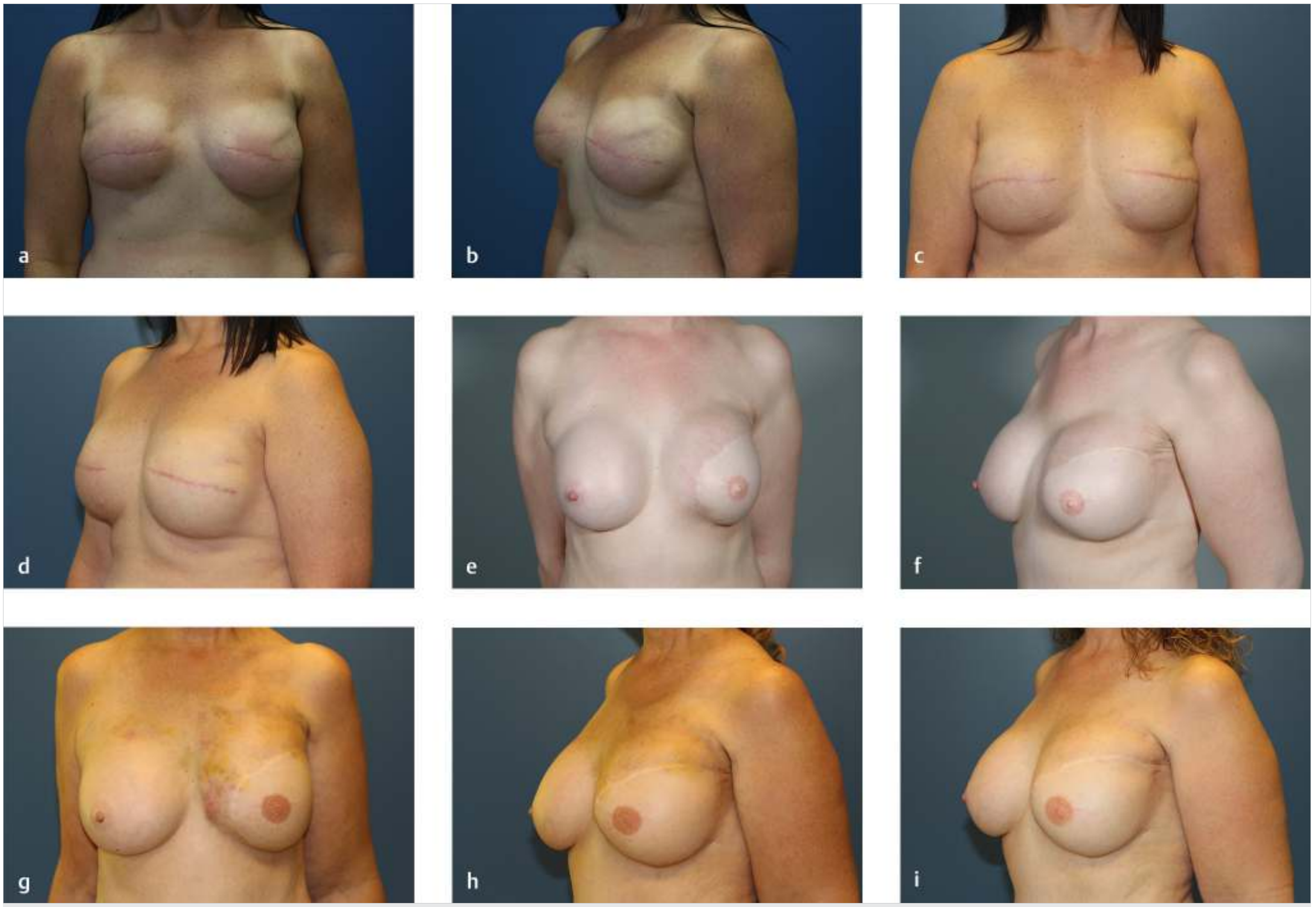

Fig. 33.3 Fat grafting. **(a, b)** Contour deformities on 39-year-old woman following bilateral mastectomy and submuscular implant and AlloDerm mesh reconstruction for invasive cancer. **(c, d)** Appearance of breasts 6 months after bilateral fat grafting with 200 cc fat to each breast. **(e, f)** A 60-year-old woman with mastectomy and radiation therapy for left breast cancer. She underwent left pedicled transverse rectus abdominis muscle (TRAM) flap reconstruction and right breast augmentation. Subcutaneous fat deficiency in upper poles. **(g, h)** Appearance at 2 weeks and then **(i)** 6 months after fat grafting with good graft retention (112 mL fat to left breast and 50 mL to right breast).

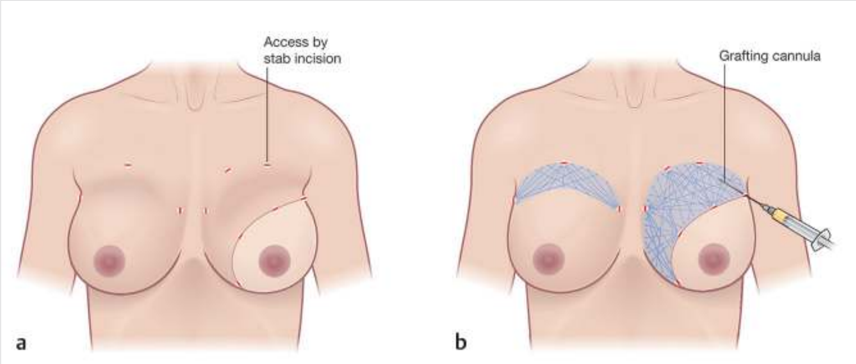

Fig. 33.4 Fat grafting sequence. **(a)** Peripheral radial access creation around marked contour deformity. **(b)** Harvested fat is injected upon withdrawal in a fanning pattern.

string suture and allowed to heal secondarily.) A protective dressing with a central cut-out is placed over the nipple and the donor site is dressed as per surgeon's preference. Three-dimensional nipple-areolar tattooing is performed 6 to 12 weeks after nipple reconstruction.

33.3.4 Fat Grafting

Operative Preparation

Bilateral breasts and donor sites are prepared in the routine manner.

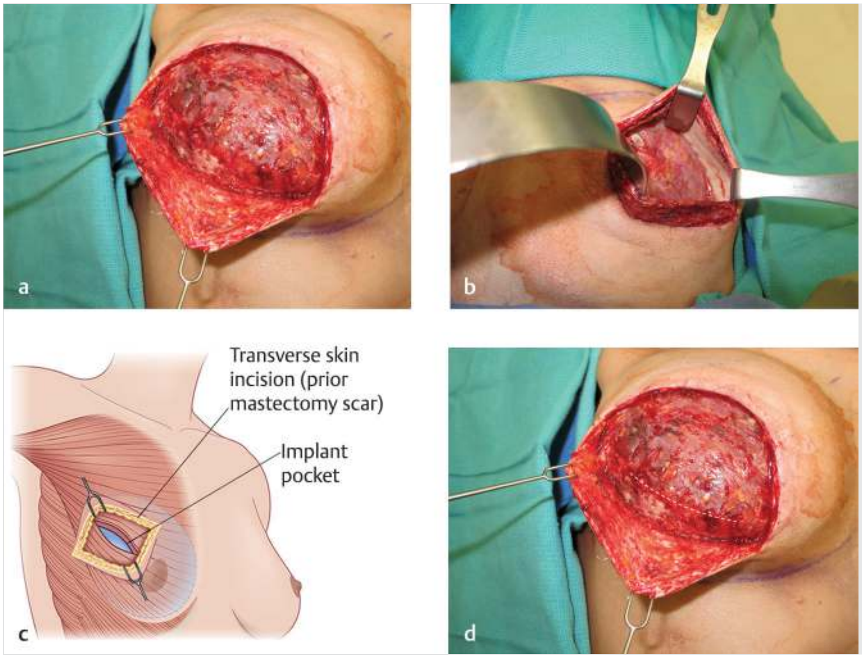

Fig. 33.5 Implant replacement sequence. **(a, b)** Raise inferior and superior soft tissue flaps. **(c)** Divide pectoralis major muscle parallel to it fibers to enter implant pocket cases of total submuscular coverage. **(d)** Alternatively, when biologic mesh has been used previously, separate the inferior pectoralis major muscle from the biologic mesh to enter the implant pocket.

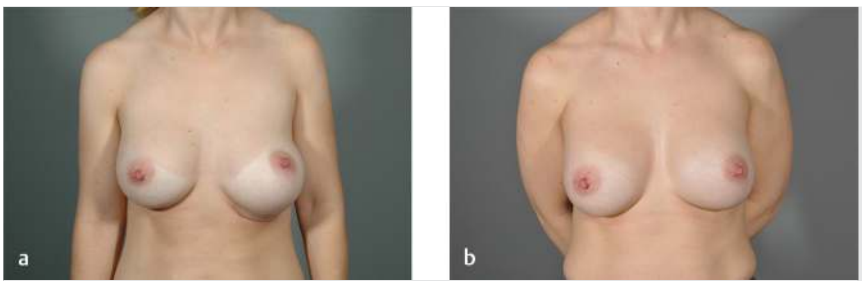

Fig. 33.6 Capsuloplasty. **(a)** Bottoming out of left breast implant reconstruction. **(b)** Inferior mammary fold re-established with capsulorrhaphy, and the shape and projection improved with superior capsulotomies.

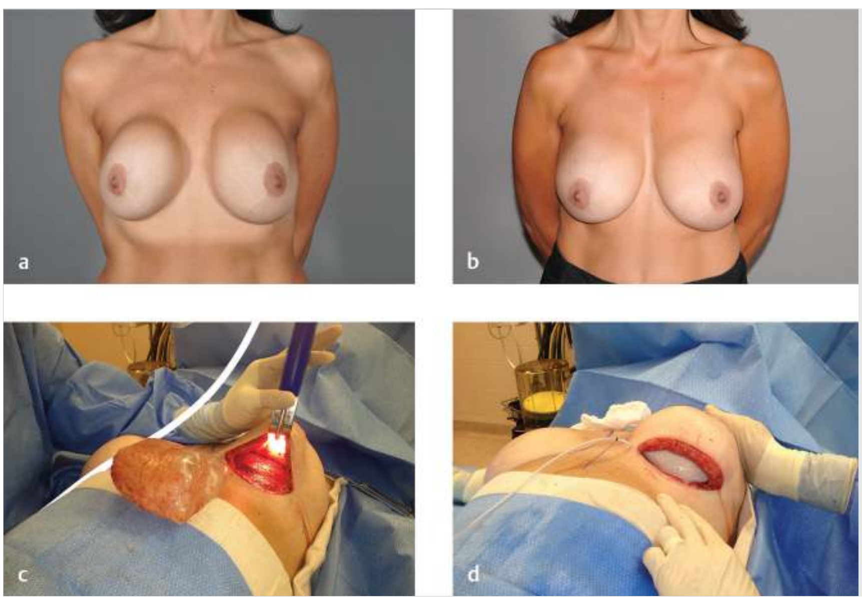

Fig. 33.7 Biologic mesh. **(a, b)** Bilateral capsular contracture treatment with Strattice Placement Implant Removal, Capsulectomy and Exchange (SPICE) procedure. **(c)** Total capsulectomy. **(d)** Implant replaced in the subpectoral position with acellular dermal matrix inferior sling placement.

Preoperative Markings

Mark breast contour deformities and areas of asymmetrical volume deficiency with the patient in standing position (▶ Fig. 33.3a–i). Estimate the amount of fat needed to correct the contour defect; then mark appropriate donor site. Separately mark the normal boundaries of the breast footprint including the inframammary fold.

Details of Procedure

Prepare donor site with tumescent (wetting solution, for example: 30 mL of 1% lidocaine, 1 mL of 1:1000 ephinephrine in 1,000 mL of lactated Ringer's solution at 21 °C). Allow 7 to 10 minutes for maximal vasoconstrictive effect. Meanwhile, mark multiple injection sites peripherally around the contour deformity (▶ Fig. 33.4a). This may range from four to eight sites for a lumpectomy deformity, or more for larger asymmetries. Injection sites are created with careful superficial stab incisions with a #15 scalpel or 19-gauge needle. Perform sterile fat harvesting (e.g., handheld vs. closed-system suction-assisted liposuction) and processing (e.g., rolling, centrifugation, gravity separation, washing, and filtration) as per surgeon's preference.[6,7] Use sharp cannula "pickle fork" to release scar tissue prior to grafting, using the same injection sites. Avoid injury to underlying implant or nearby flap pedicle.

Follow principles of the Coleman injection and "structural fat grafting" to maximize surface area contact of the fat graft to surrounding vascularized tissue.[6,7] Transfer fat into open barrel of 10 mL or 60 mL injection syringes depending on anticipated volume correction. Attach a blunt-tip 7 or 9 cm cannula (19-gauge lumen). Advance cannula into previously incised access sites and inject upon withdrawal. Placing small aliquots in a multiplanar crosshatch pattern is key to optimize graft viability (▶ Fig. 33.4b). Large volume fat injection of up to 200 to 300 mL per site is not uncommon to correct volume asymmetries. Use digital manipulation to smooth out grafting irregularities. Injection sites are closed and dressed in routine manner. Surgical bra is applied and instruction is given to avoid sleeping on side or prone.

33.3.5 Implant Replacement

Operative Preparation

Review breast magnetic resonance imaging (MRI) in procedures for ruptured permanent implant. Bilateral breasts are prepared in the routine manner.

Preoperative Markings

Bilateral breasts are marked while the patient is in the standing position for normal boundaries of the breast footprint including the inframammary fold.

Details of Procedure

Layered technique (▶ Fig. 33.5a, b) begins with sharp excision of mastectomy scar. Raise inferior and superior skin/subcutaneous flaps away from underlying pectoralis major muscle (PMM). Split the muscle longitudinally along its fibers as well as the underlying capsule as inferiorly as possible (▶ Fig. 33.5c, d). This approach permits a multilayer closure to minimize wound and implant complications.

Bluntly dissect and explant the implant without tearing the capsule. Inspect the implant for rupture. In the setting of a known implant rupture, evacuation of all silicone material is critical to reduce risk of infection and capsular contracture. In a similar fashion, the tissue expander is freed from the capsule and deflated for removal. Capsule procedures are performed for breast shaping as needed (see Implant Capsuloplasty section). Perform circumferential capsulotomy at the base to improve projection. The implant pocket is inspected for hemostasis and is followed by copious antibiotic-impregnated irrigation.[8,9] Confirm that new implant is the correct profile, volume, and base width. (Tip: The equivalent permanent implant is approximately 100 cc larger than the tissue expander volume to account for its rigid shell construct and port. Reference to official final tissue expansion volume and intraoperative use of sterilizable silicone implants aids in accurate selection of a permanent silicone implant suitable for the patient's desired outcome.) Using a "no-touch" technique, the implant is correctly orientated and delivered into the implant pocket. Assess bilateral breasts for symmetry before layered closure. Dressing and surgical bra as per surgeon's routine.

33.3.6 Implant Capsuloplasty

Operative Preparation

Bilateral breasts are prepared in the routine manner.

Preoperative Markings

Bilateral breasts are marked with the patient in the standing position for normal boundaries of the breast footprint including the inframammary fold. Assess skin envelope thickness and Baker classification of capsular contracture. Identify and mark areas of asymmetry related to implant malposition.

Details of Procedure

Perform a layered approach to the implant as previously described (▶ Fig. 33.5) or through an inframammary incision. Use a lighted retractor or a headlight for optimal exposure. The implant is removed and inspected for defects before proceeding with capsule corrections (▶ Fig. 33.6a).

Capsulorrhaphy is performed in loss of implant pocket control by plication of capsular tissue with interrupted absorbable sutures along the periprosthetic border where needed.[10] Inframammary fold position may be raised with capsulorrhaphy. In general, suture capsulorrhaphy reduces the periprosthetic capsular volume. An alternative technique is strip capsulectomy in which an elliptical strip of capsular tissue is resected and the raw edges are approximated.

Perform open capsulotomy for mild/moderate capsular contracture.[11] The release and expansion of the soft tissue envelope occurs by scoring the capsule with electrocautery until overlying soft tissue bulges. This usually involves circumferential scoring at the base for projection and radial scoring elsewhere as needed for tissue expansion.

For severe noncalcified capsular contracture with adequate soft tissue coverage, perform an anterior capsulectomy of the subpectoral implant leaving the posterior capsule on the chest wall.[12] Using electrocautery, carefully separate the overlying soft tissue or pectoralis major muscle while keeping the capsule intact, if possible. The capsule is easily identified by its slightly bluish hue. Explant the implant and capsule. Consider interposition of ADM to prevent capsular contracture recurrence (see Biologic Meshes, ▶ Fig. 33.7a). In cases with calcified capsular contracture or a grossly contaminated pocket, a complete capsulectomy is performed with site change or neosubpectoral pocket creation[12] (▶ Fig. 33.6b).

The 14-point plan is employed to reduce risk of implant infection and capsular contracture.[9] The implant pocket is irrigated with triple antibiotic-impregnated solution (50,000 U of bacitracin, 1 g of cefazolin, 80 mg of gentamicin, and 500 mL of normal saline); then inspect for hemostasis. A closed suction drain is placed and secured. A new and appropriate-volume implant is replaced using a no-touch technique. The soft tissue is approximated in a three-layer fashion.

33.3.7 Biologic Meshes

Operative Preparation

Bilateral breasts are prepared in the routine manner.

Preoperative Markings

Bilateral breasts are marked while the patient is in the standing position for normal boundaries of the breast footprint including the inframammary fold. Identify and mark areas of wrinkling, rippling, and thin skin.

Details of Procedure

Perform a layered approach to the implant pocket as previously described (see Implant Replacement, ▶ Fig. 33.5) or through an inframammary incision. Use a lighted retractor or a headlight for optimal exposure. The expander or implant is removed and inspected for defects before proceeding with capsule corrections. Select ADM of surgeon's choice and prepare as per the manufacturer instructions.

Create inferior pole suspension or extend existing tissue for implant coverage by dividing the pectoralis major muscle inferomedial insertion. This may be performed during the first or second stage of breast reconstruction. A contoured or elliptical ADM is inset with dermal side abutting the mastectomy flap. The inferior border is secured along the proposed inframammary fold with three insetting sutures followed by a 2–0 monofilament absorbable running suture. An implant is delivered under the pectoralis major muscle, and the inferior fascial edge is approximated to the free ADM edge with 3–0 interrupted sutures (▶ Fig. 33.7).

Interposition of an ADM (patch technique) proceeds with placement of simple sutures around the ADM to the underlying soft tissue. This technique is an option to repair pectoralis major muscle injury. Similarly, there is an onlay technique with the ADM placed directly between the thin capsule/skin and implant. The dermal side is in direct contact with the mastectomy flap and its periphery is secured with interrupted sutures. The implant is reinserted into the breast and the ADM is redraped over the implant and approximated to the capsule. At our institution, we advocate the use of fenestrated ADM to reduce rate of infection, seroma, and capsular contracture risk.[12,13,14,15]

Following ADM placement, the pocket is irrigated with antibiotic solution. Closed suction drains are inserted and monitored. The incision is closed in layers.

33.4 Conclusion

The discerning plastic surgeon will restore the appearance of the breast mound and nipple-areolar complex following reconstruction. Selection of the appropriate secondary procedure(s) begins with clinical examination and appraisal of preoperative photographs to identify breast asymmetry, implant position, contour irregularities, and capsular contracture. Techniques including the modified C-V flap for nipple reconstruction, implant replacement, capsuloplasty, fat grafting, and biologic mesh use are important tools for achieving excellent reconstructive results.

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Subsection IIC

Other Deformities of Breast

II

34 Tuberous Breast Deformity

David A. Sterling, Michael Grimaldi, and Charles K. Herman

Abstract
The tuberous breast deformity is a congenital abnormality with unclear etiology and prevalence. Although the underlying cause is not known, constricting bands that prevent proper development of breast tissue appear to play a role. Ultimately, there is constriction of the breast base with hypoplasia of parenchyma and/or breast skin envelope, elevation of the inframammary fold (IMF), and enlargement of the areola with possible herniation. The deformity can be difficult to correct: the surgical technique generally involves release of constricting bands, lowering of the IMF, volume restoration typically with implants, and reduction of areolar size.

Keywords: asymmetry, congenital, constriction, hypoplastic, tuberous breast

34.1 Introduction

The tuberous breast deformity, first described by Rees and Aston in 1976, is a congenital anomaly that can be challenging to correct.[1] The deformity represents a spectrum of pathology, from mild to severe and unilateral or bilateral, and can result in significant psychological stress to the patient. The etiology is unknown, although some surgeons postulate the abnormal development of the breast fascial envelope. As the problem is developmental, tuberous breasts often present during puberty.[2,3,4] Its prevalence is unknown; however, it is a common finding in women presenting for mammoplasty, seen in 20 to 50% of patients.[5]

34.2 Indications

Correction of the tuberous breast deformity is indicated in patients who are unhappy with the size and/or shape of their breasts, and have characteristics consistent with the deformity. Common features seen in tuberous breasts include a constricted breast base with reduced vertical and horizontal dimensions, skin envelope deficiency, breast tissue hypoplasia, a malpositioned inframammary fold (IMF), herniation of breast parenchyma through the areola with resultant areolar enlargement, and breast asymmetry.[1,2,3,4,5,6,7,8,9,10] Patients can present with various combinations and severities of these characteristics.

Several classification schemes have been developed that define the spectrum of tuberous breasts and help guide treatment decisions.[4,6] In 1999, Grolleau et al developed a popular classification based on the location of breast hypoplasia and skin envelope deficiency, where Type I involves lower medial quadrant hypoplasia, Type II involves entire lower pole hypoplasia, and Type III involves hypoplasia of all four quadrants (▶ Fig. 34.1).[4]

It is worth noting that failing to identify the anomaly and treating with volume expansion alone can yield unsatisfactory

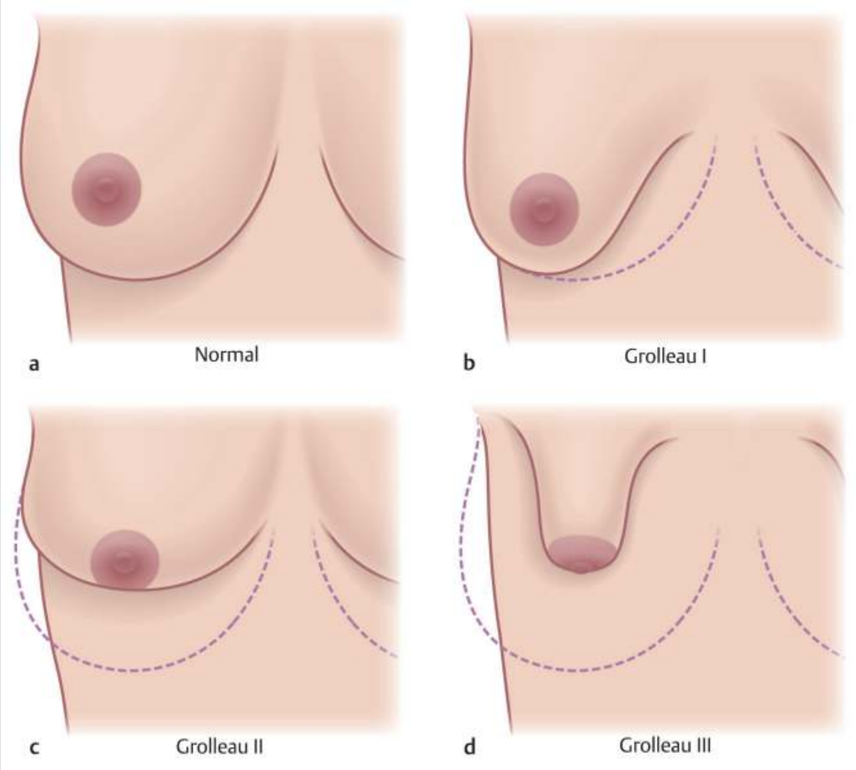

Fig. 34.1 Classification of the tuberous breast deformity according to Grolleau et al. **(a)** Normal. **(b)** Type I with hypoplastic lower medial quadrant. **(c)** Type II with hypoplastic lower pole. **(d)** Type III with upper and lower pole hypoplasia.

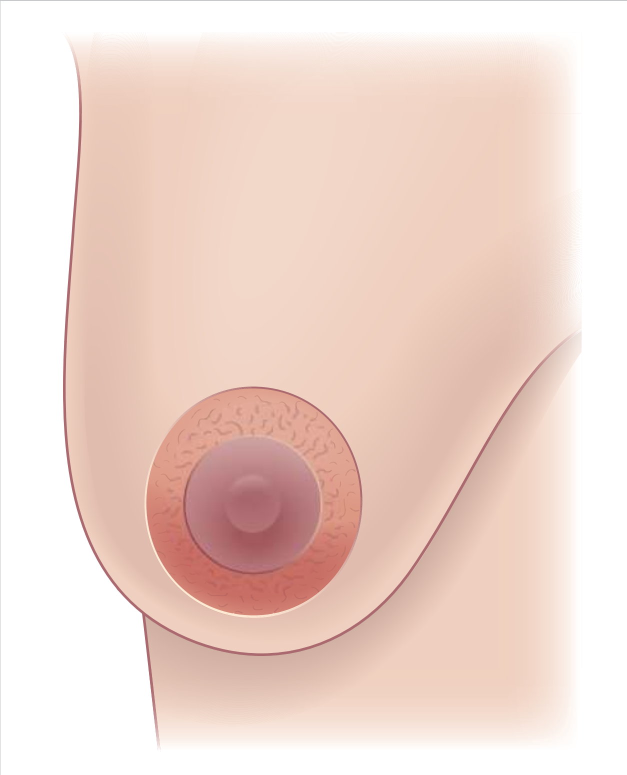

Fig. 34.2 Periareolar donut-type skin de-epithelialization.

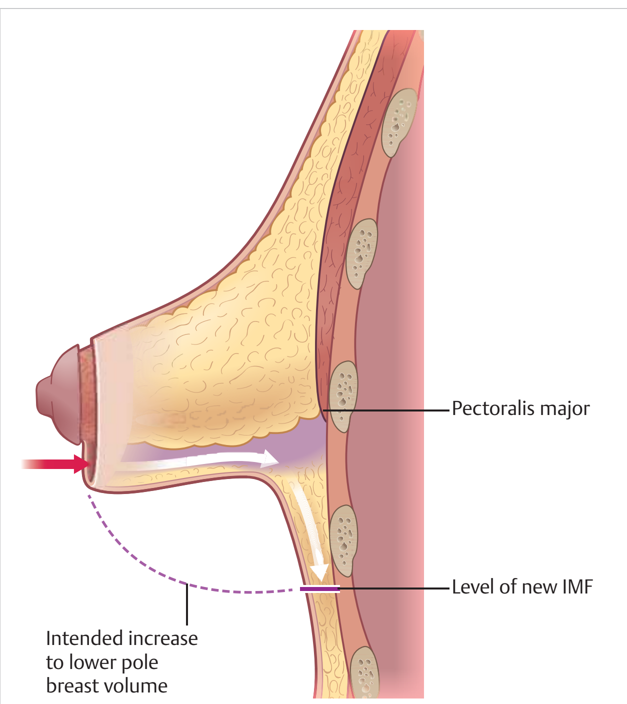

Fig. 34.3 Subcutaneous dissection over breast parenchyma down to fascia overlying pectoralis major muscle. Dissection is extended to desired level of new inframammary fold (IMF).

aesthetic results. As the deformity is likely more prevalent in patients seeking breast surgery, it is important to have a high index of suspicion in this population.[1,3]

34.3 Operative Technique

- The goals of surgery include:
  - Restoration of breast volume and expansion of constricted areas.
  - Lowering of the IMF.
  - Reduction of areolar size and reduction of herniated breast tissue.
  - Establishment of symmetry.
- Examine and mark the patient preoperatively to clearly identify degree of ptosis, current and desired IMF, hypoplastic quadrant(s), and suspected borders for the implant pocket.
- Perform a periareolar incision with dissection down to deep fascia at the current IMF (▶ Fig. 34.2). The dissection can be either transglandular or subcutaneous (▶ Fig. 34.3). Some surgeons prefer an IMF incision.[2]
- Dissect from the current IMF inferiorly to the desired height of the new IMF (▶ Fig. 34.3).
- Perform a superior dissection above the pectoralis major muscle fascia to access the posterior aspect of the breast, and radially score the gland to release any constricting bands (▶ Fig. 34.4 and ▶ Fig. 34.5).
- Incise the inferior border of pectoralis major muscle and dissect below the muscle superiorly and laterally to create a subpectoral implant pocket (▶ Fig. 34.6).
- Place an implant in a dual plane pocket with the superior aspect covered by the pectoralis major muscle and the inferior aspect covered by glandular tissue (▶ Fig. 34.7). Some

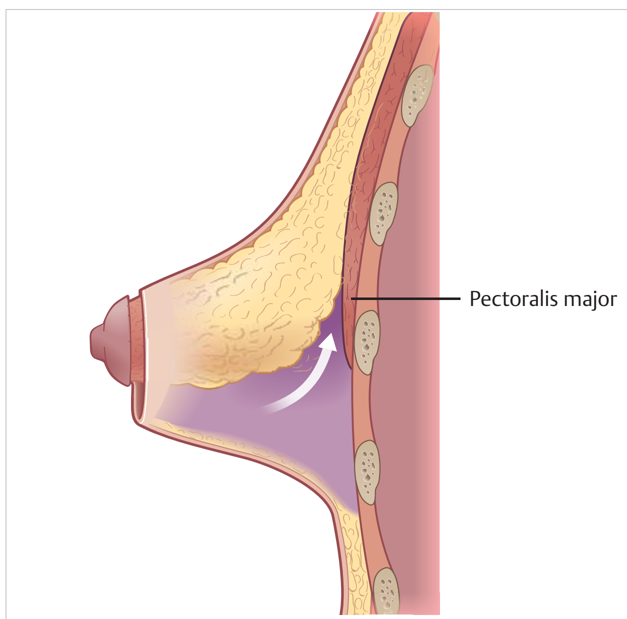

Fig. 34.4 Superior dissection above pectoralis major muscle fascia to mobilize lower pole of gland.

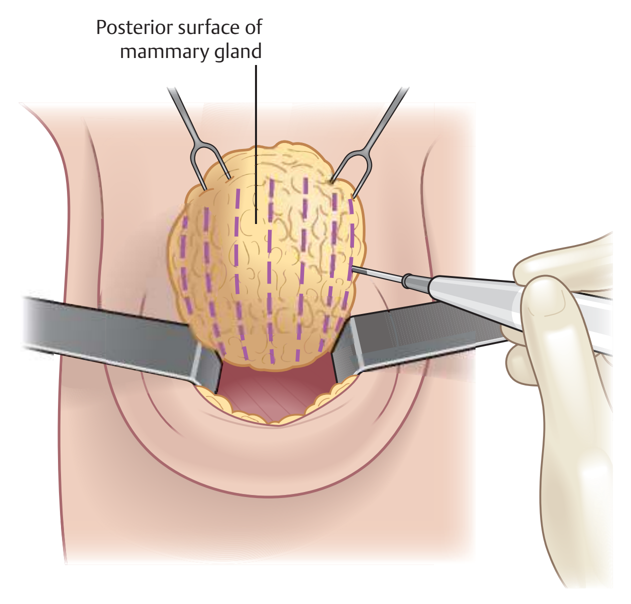

Fig. 34.5 Exteriorization of lower pole and radial incisions to release constricting bands.

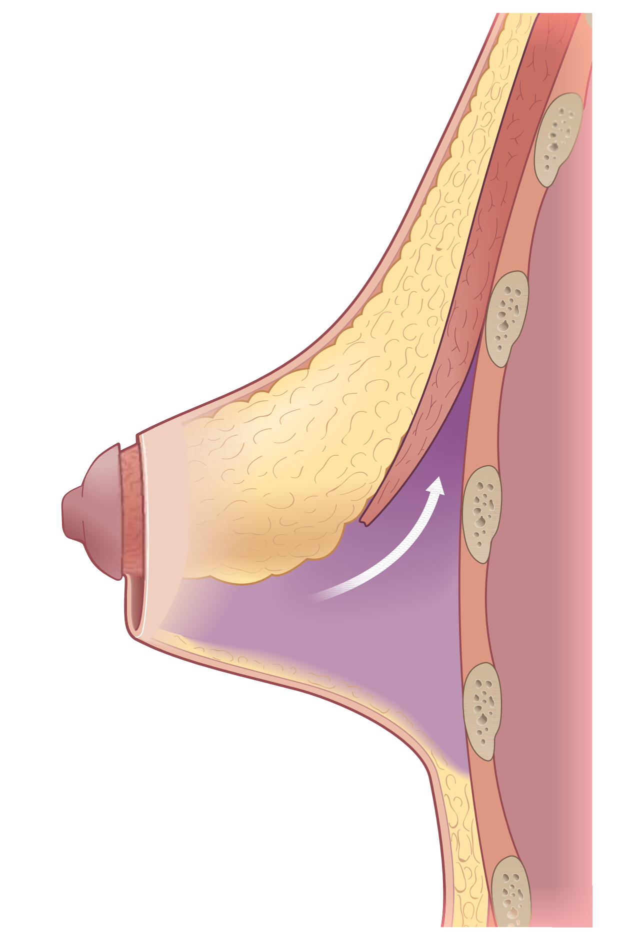

Fig. 34.6 Incision of lower border of pectoralis major muscle and dissection below muscle superiorly and laterally to create implant pocket.

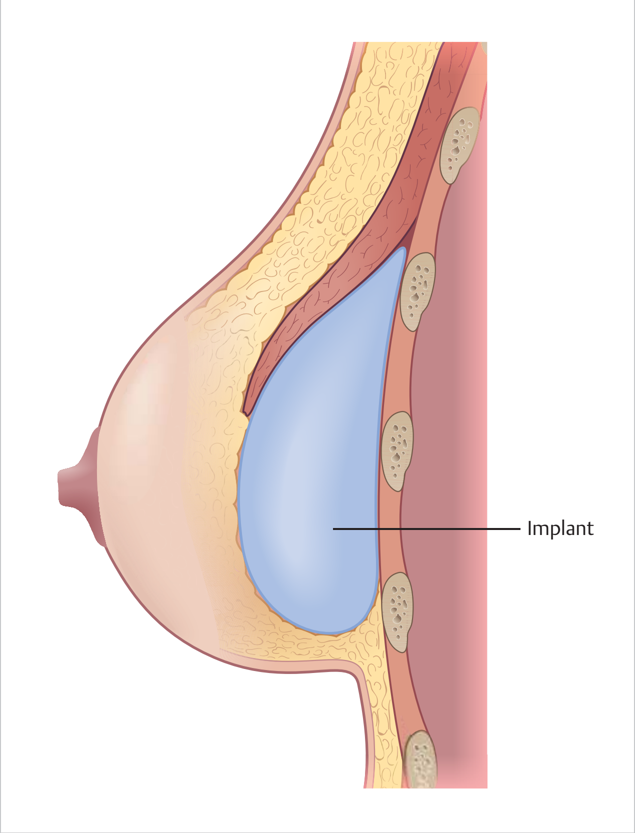

Fig. 34.7 Placement of an implant below the pectoralis major muscle superiorly and breast parenchyma inferiorly.

surgeons place an implant in a subglandular pocket, or use a tissue expander in a two-stage procedure. In particular, tissue expansion may be necessary if there is a severe skin envelope deficiency.[4,6,7,8]

- If necessary, reduce the areola through a periareolar donut-type skin de-epithelialization. Herniated breast tissue can be telescoped toward the chest wall before closure.
- Other techniques are described in the literature or are indicated based on the characteristics of the breast:
  - Riggotomies (the subcutaneous puncturing of scar tissue with multiple passages of a fine needle) and fat grafting for volume and contour deformities.[2,11,12,13]
  - Various internal glandular flaps and/or local flaps to restore volume and/or skin deficiency; Z-plasties, thoracoepigastric flaps, and myocutaneous serratus anterior transposition flaps have been used by various authors.[2,3,4,6,9,10]
  - Mastopexy and reduction mammaplasty for ptosis and volume correction.[2,7]

34.4 Conclusion

The tuberous breast deformity is a congenital abnormality that encompasses several key features including hypoplasia, elevation of the IMF, and herniation of parenchyma into the nipple-areolar complex. Surgical correction involves releasing abnormal fibrous constricting bands, lowering the IMF, reducing the areola if necessary, and placing a prosthesis for augmentation.

Failing to identify the deformity preoperatively and inadequate correction can lead to unsatisfactory results.

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35 Poland's Syndrome

Ian C. Sando and Paul S. Cederna

Abstract

Poland's syndrome is a rare congenital disorder characterized by chest wall hypoplasia, breast aplasia or hypoplasia, ipsilateral hand anomalies, and a variety of associated anomalies. The degree of both the chest wall deformity, breast deformity, and muscular deficiency must be considered when planning reconstruction. Multiple stages are required, and contralateral chest procedures may be needed to achieve symmetry. Tissue expansion addresses the hypolastic and constricted soft tissue envelope when performing implant-based reconstruction. Transfer of the latissimus dorsi muscle recreates the anterior axillary fold, provides soft tissue, and may be used for provision of pectoralis major function.

Keywords: breast, chest wall deformity, congenital, hypoplasia, pectoral agenesis, Poland's syndrome, reconstruction

35.1 Introduction

- Poland's syndrome, originally described in 1841, is a rare congenital anomaly characterized by unilateral absence of the costosternal head of the pectoralis major muscle and a constellation of hypoplastic components of the ipsilateral chest and upper extremity, including breast hypoplasia or aplasia, hypothelia/athelia, brachysyndactyly, thoracic skeletal defects, neurovascular anomalies, axillary alopecia, and absent sweat glands.
- The incidence of Poland's syndrome ranges from 1 in 30,000 to 1 in 100,000 live births.[1,2] It affects men more commonly than women, and most frequently involves the right side of the body. The exact cause of the condition is unknown.

35.2 Indications

- Poland's syndrome most commonly presents as unilateral absence of the costosternal head of the pectoralis major muscle, hypoplastic or absent breast parenchyma, and chest wall structural anomalies.
- For patients with milder forms, the syndrome may manifest as only slight chest asymmetries noticed during childhood. The syndrome may go unrecognized until adolescence when muscle and breast development occurs. The deformity adversely impacts adolescents' social functioning and emotional well-being as they attempt to conceal their deformities from family and friends.
- More severe forms, including those with gross chest wall anomalies and brachysyndactyly, are readily recognized in infancy. Limb anomalies are often corrected early in childhood to optimize function and appearance; exact timing is individualized so that growth restriction, flexion contractures, and rotational deformities are minimized.
- Chest surgery is indicated for the following reasons[3]:
    - Unilateral depression or paradoxical movement of the chest wall.
    - Lack of adequate protection of the heart and lungs.
    - Hypoplasia or aplasia of the female breast.
    - Cosmetic defects due to lack of the pectoralis major muscle, chest wall anomalies, soft tissue atrophy, or absence of the anterior axillary fold.

35.3 Operative Techniques

35.3.1 Preoperative Assessment

- Reconstructive options for chest wall reconstruction vary based on gender, severity of the deformity, and patient's preference.
- Patients should be counseled that reconstruction may require multiple stages and may be an ongoing process that extends from adolescence to adulthood.
- The presence or absence of the serratus anterior and latissimus dorsi muscles should be documented since these muscles may be used for reconstruction.
- The degree of pectoralis major hypoplasia, as well as the sternal notch-to-acromion, acromion-to-olecranon, and olecranon-to-ulnar styloid distances, should be compared to the contralateral side to evaluate for chest wall asymmetries.
- In women, the size of the breasts, degree of ptosis, position and size of the nipple-areolar complexes (NACs), location of the inframammary folds, and breast base diameters should all be assessed.
- In men, the most noticeable deformity is infraclavicular concavity and loss of the anterior axillary fold, which is more prominent in thin, athletic patients. Surrounding muscles, such as the pectoralis minor, clavicular head of the pectoralis major muscle, and trapezius, may be hypertrophied, particularly in men who weightlift in attempts to disguise their asymmetries. There may be transverse narrowing of the hemithorax, hypoplasia, hypopigmentation, and superolateral displacement of the NAC, and displacement of axillary hair onto the proximal medial arm.

35.3.2 Approaches

- Options for chest reconstruction include the use of tissue expansion with implants, latissimus dorsi muscle transfer, custom chest wall implants, transverse rectus abdominis musculocutaneous flaps, sternal/rib reconstruction, fat grafting, free tissue transfer, or a combination of methods.[1,3,4,5,6,7,8,9,10]
- Contralateral procedures, including mastopexy, breast reduction, breast augmentation, NAC reduction, suction-assisted lipectomy, inframammary fold repositioning, and fat grafting, are often required to achieve symmetry.
- The most commonly utilized techniques, including tissue expansion with implants, latissimus dorsi muscle transfer, and fat grafting, are described below.
- Both implant-based and latissimus dorsi muscle transfer reconstructions can be performed with an endoscopic approach to minimize scarring.[1]

35.3.3 Techniques

Tissue Expansion with Implants

- Tissue expansion is ideal for the female patient with an aplastic or hypoplastic breast when there is a restrictive soft tissue envelop precluding primary augmentation with a breast prosthesis.
- The fibrotic breast tissue requires radial scoring prior to expander placement to allow for adequate expansion.
- The degree of muscle coverage depends of the amount of pectoralis major muscle that remains. When the clavicular head is present, partial superior coverage may be achieved; however, in case of complete absence of the pectoralis major muscle, the expander is placed in a complete subglandular or subcutaneous pocket.
- The expander is positioned on the chest wall to ensure adequate expansion of the lower pole, ensuring that the inframammary fold is symmetric with the contralateral side.
- The breast is typically over-expanded by 20 to 30% to account for skin elasticity, and to ensure that a natural breast shape is ultimately achieved.
- In adolescent females, a subcutaneous tissue expander is placed during early breast development and intermittently expanded to match the changing contralateral breast volume. Expanders are exchanged for the permanent implant years later after breast development is complete. The ability to maintain symmetry during puberty helps psychological development and improves overall psychosocial well-being.

Latissimus Dorsi Muscle Transfer

- Transfer of the ipsilateral pedicled latissimus dorsi muscle is the best method to recreate the anterior axillary fold in patients with Poland's syndrome.
- In men, it also adds additional muscle bulk and helps create a symmetric chest contour. At times the muscle does not provide sufficient bulk to achieve symmetry with the contralateral chest. In this situation, fat grafting can be used as an adjunctive procedure to improve the overall outcome.
- In women, the latissimus dorsi muscle is transferred at the time of tissue expander exchange for permanent implant to provide additional tissue bulk over the implant, minimize visible implant wrinkling, and minimize infraclavicular hollowness.
- Care should be taken to preserve the innervation of the muscle to minimize denervation atrophy over time; however, patients should be counseled about the potential for animation deformity, contour asymmetries on the back, and the potential for decreased shoulder function.
- The muscle is accessed through an incision at the lateral border of the muscle. The authors prefer an endoscopic approach where a 5 to 6 cm incision is placed within the axilla to minimize scarring.[1]
- The skin and subcutaneous tissue is elevated off the muscle fascia to expose the entire superficial surface, taking care to cauterize the lumbosacral perforators. The muscle is then elevated in a submuscular plane and the muscle and fascial attachments to the chest wall are divided.
- The ipsilateral chest skin is undermined using an endoscopic approach (through the axillary incision), or through a periareolar, inframammary, or presternal incision. The tissue expander is removed and any capsulectomies and/or capsulotomies are performed.
- The posteromedial humeral insertion is detached at the periosteum and the muscle is interpolated on the anterior chest wall after dissection.[6]
- The appropriate position for normal pectoralis major muscle insertion is identified on the anteromedial aspect of the proximal humerus and the tendon of the latissimus dorsi is secured to the deep fascia and periosteum at the bicipital groove using 3–0 Ethibond suture to recreate the anterior axillary fold.
- In men, the muscle is tailored to the appropriate size, position, and tension after it is rotated to the anterior chest:
  - The lumbosacral fascia of the latissimus dorsi is perfectly aligned with the ipsilateral border of the sternum.
  - The lateral border of the latissimus dorsi is aligned with the inferior border of the clavicle after rotation to the anterior chest.
  - The medial and superior borders of the latissimus dorsi are positioned along the new anterior axillary fold, recreating the position of the pectoralis major muscle if it was present.
  - The latissimus dorsi muscle is secured into its new position with interrupted sutures of 3–0 Ethibond placed between the lumbosacral fascia and the sternum, and the epimysium and the inferior clavicle.
  - The tension of the muscle is optimized during the anchoring process to allow maximal generation of force after transfer.
- In women, the muscle is secured to the chest wall with enough laxity to ensure symmetric ptosis and sufficient space for the required breast implant. Implant sizers are often used to guide final implant size and muscle tension.

35.3.4 Fat Grafting

- Fat grafting has become a preferred technique to augment the anterior axillary fold, address contour irregularities, and increase soft tissue volume to achieve chest symmetry, particularly in men where custom chest wall implants may have traditionally been used.
- Patients should be counseled that multiple fat grafting procedures might be required to achieve an optimal outcome.
- Fat is harvested from the abdomen, flank, back, thighs, or multiple sites.
- The authors prefer to harvest fat using manually generated low negative pressure to minimize loss of adipocytes from shear.[11]
- Fat is centrifuged at 3,000 revolutions per minute for 3 minutes, and the sanguinous and oily supernatant fractions are discarded.
- Fat is grafted using the Coleman technique[11] with small aliquots delivered in each tunnel in a grid-like fashion at multiple depths to optimize graft survival and minimize fat necrosis.

35.4 Conclusion

- Poland's syndrome represents a constellation of clinical presentations in both males and females including chest wall, breast, nipple, extremity, neurovascular, and muscle anomalies.

- Correction of the aesthetic and functional anomalies requires a comprehensive assessment of the deficits and a tailored, individualized approach to the reconstruction.
- Shared decision-making with the patients will allow an optimal functional restoration and aesthetic correction for every patient.

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Subsection IID

Trunk

II

36 Treatment of Pressure Ulcers

Mamtha S. Raj and Robert X. Murphy Jr.

Abstract

The most vital step in the treatment of pressure ulcers is adequate surgical excision of devitalized tissue. Described in this chapter are effective techniques to aid in adequate debridement of pressure ulcers for infection source control and preparation for reconstruction. In brief, the ulcer is explored for undermining and tunneling, and the pseudobursa is coated with methylene blue dye. Necrotic tissue and biofilm are then excised. Hemostasis is achieved. Immediate options then include a surgical dressing, negative pressure wound therapy (NPWT), or surgical reconstruction.

Keywords: debridement, negative pressure wound therapy, pressure ulcer, source control, surgical excision

36.1 Introduction

Pressure ulcerations are exceedingly difficult conditions to treat. Appropriate workup includes an understanding of the etiology of the wounds, the patient's nutritional status, laboratory evaluation including albumin and prealbumin values, and radiological evaluation. Plain films, computed tomography (CT), triple phase bone scan, and magnetic resonance imaging (MRI) to evaluate for the presence of osteomyelitis may be utilized in the radiological evaluation of pressure ulcers. Although authors some have found fistulograms with radiopaque dye helpful in determining the extent of the pseudobursa, in our experience, assessing the wound with intraoperative usage of dyes such as methylene blue has been beneficial in elucidating the contours of the pseudobursa and regions to excise.

Chemical debridement may be a useful modality in pressure ulcer treatment. Papain and urea ointment, collagenase, and fibrinolysin DNase are some of the chemical debridement options available to the reconstructive surgeon.[1] However, the most vital step in treatment of pressure ulcers remains adequate surgical excision of devitalized tissue.[2] Surgical debridement consists of exposing the extent of the ulcer and removing all infected or devitalized tissue.

One option for management of the freshly debrided surgical wound is to employ negative pressure wound therapy (NPWT). NPWT was introduced in the Roman era with direct suction of wounds by mouth. By the 19th century, this had evolved into glass cups attached to suction tubing. Modern NPWT surfaced in the 1990s and utilizes polyurethane foam and a mechanical vacuum device to remove infectious wound exudate, draw wound edges together, and increase perfusion to the wound, thereby stimulating formation of healthy granulation tissue.[3]

36.2 Indications

Surgical debridement is the mainstay of treatment of Stage III (full-thickness skin loss) and Stage IV (full-thickness skin and tissue loss) pressure ulcers. Indications for treatment are as follows: removing the source of infection in a septic patient, decreasing bacterial load in the ulcer, which would in turn decrease evolution of bacteria into antibiotic resistant strains, obtaining uncontaminated tissue specimen for future antibiotic therapy and establishment of potential osteomyelitis, and preparing wound for healing and secondary reconstruction with a skin graft or flap.[1] As many patients have multiple comorbidities, limited debridement when carried out for source control of sepsis may be performed in the coagulopathic patient.

Chemical debridement with papain/urea debridement ointment or collagenase can be used when surgical debridement is not possible, but generally cannot replace thorough surgical debridement.

NPWT may be indicated in the treatment of Stages III and IV pressure ulcer wounds. Important contraindications are as follows: inadequate debridement with continued presence of infection/necrotic tissues in the wound, osteomyelitis, cancerous cells in the wound, an open fistula to an organ or body cavity in or around the wound, and a bleeding wound due to anticoagulation status.[4] A major advantage of NPWT is fewer dressing changes, thereby reducing wound contamination by the environment. Disadvantages include difficulty in maintaining a good seal, inability to assess the wound daily by a physician, and potential for wound tracts being missed.

Immediate reconstruction with a myocutaneous or fasciocutaneous flap is used when wound conditions are optimal and the patient is stable enough to tolerate additional operative time and risk. Addressing any nutritional deficiencies and offloading any pressure from the wound are critical to successful treatment of pressure ulcerations prior to reconstruction.

36.3 Operative Technique

The following procedure can be viewed in the accompanying video (▶ Video 36.1):

1. Exploration of pressure ulcer: The degree of tissue involvement of the pressure ulcer must be evaluated by either digital palpation or swab probing of exposed tissues including subcutaneous fat, muscle, and bone with careful attention to the extent of undermining. In the cases of sacral decubitus and ischial ulcers, digital rectal examination should be performed to assess involvement of anal sphincters and the level to which excisional debridement may be performed without

Video 36.1 Debridement of Stage IV sacral pressure ulcer in preparation for bilateral glueteal flaps

Fig. 36.1 Sacral pressure ulcer. The extent and depth of the sore including degree of involvement of anal sphincter must be performed prior to debridement.

Fig. 36.2 Coating the pseudobursa with methylene blue.

leading to a functional compromise of sphincter tone. Skin overlying the rectum should be marked and avoided in debridement. If the patient is a candidate for a diverting colostomy, this is best performed prior to debridement (▶ Fig. 36.1).

2. Wide sterile prepping: In cases of debridement, wide prepping of the ulcer region should be performed as ulcer may extend far beyond the visible dermal margins.
3. Coating the entire pseudobursa: Dyes such as methylene blue or gentian violet can be put onto a sponge or cotton applicator and wiped within the borders, tunnels, and crevasses of the wound to help elucidate the borders of the pseudobursa and the extent of resection (▶ Fig. 36.2). It can also be allowed to pool in the ulcer, allowing the dye to diffuse and reveal deeper tracts.

Fig. 36.3 Resection of the entire extent of the marked pseudobursa.

4. Use of epinephrine: Chronic wounds are inflamed and have a significant risk of bleeding. In a relatively small wound, peribursal injection of a 1:100,000 to 1:200,000 epinephrine solution with 1% lidocaine helps to mitigate this risk. For larger wounds, a solution of one ampule (1:1,000) of epinephrine in 100 mL of normal saline may be used to avoid potential lidocaine toxicity.
5. Exposure of the wound and removal of biofilm: Initially in debridement, skin overlying areas undermined by ulcer should be excised. Resection should include both healthy and necrotic subcutaneous tissue and epidermis. Electrocautery is the preferred method of resection as it simultaneously controls bleeding.
6. Sharp excisional debridement: Once the pressure ulcer has been exposed, debridement of remaining necrotic muscle and subcutaneous tissue can be accomplished with usage of an Allis clamp to hold tissue and a scalpel or electrocautery to remove it. Alternatively, a heavier Rutherford-Morison tissue grabbing forceps may be used for stronger retraction. The entire extent of the marked pseudobursa should be resected. With debridement of bone, a Rongeur, curette, or osteotome should be used. Soft, easily removed bone can be a sign of osteomyelitis, which may be identified with preoperative imaging. Bleeding from tissue edges and bone suggests healthy tissue and marks adequate debridement. Once the contaminated exposed wound and biofilm are removed, a true bone culture can be taken with fresh sterile equipment to determine the accurate extent of bone infection with quantitative bacteriology (▶ Fig. 36.3).
7. Hemostasis: After debridement, hemostasis should be achieved with electrocautery and all large bleeding vessels ligated. Fibrin-based glue products or epinephrine-soaked sponges can aid in this effort. The surgeon must ensure the anesthetized patient is normotensive at this stage.
8. Application of an NPWT if indicated: After adequate debridement and hemostasis, the wound can be temporized with the application of NPWT if immediate reconstruction is not planned. Black polyurethane sponge should be cut to the size of the pressure ulcer. Adequate seal with adhesive films

should be achieved and continuous suction at 125 mm Hg should be maintained.

36.4 Conclusion

Success in treatment of pressure ulcers hinges upon both patient optimization and adequate debridement of devitalized tissue. Preoperatively etiology of the wounds, the patient's nutritional status, laboratory evaluation including albumin and prealbumin values, and potential radiological evaluation should be addressed. Intraoperatively, the ulcer is explored for undermining and tunneling. To aid in determining the extent of the crevasses and complex tunneling of the pressure ulcer, the pseudobursa is coated with methylene blue dye. Necrotic tissue and biofilm are then excised. Hemostasis is achieved. Immediate options then include application of a surgical dressing, NPWT, or surgical reconstruction.

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37 Treatment of Pressure Ulcers with Flaps

Hyunsuk Peter Suh and Joon Pio Hong

Abstract
Using a flap is the most efficient and reasonable method to cover a defect and fill the dead space resulting from pressure ulcers. Compared to other soft tissue reconstructions with flap surgery, the recurrence rate in pressure ulcer coverage is extremely high in many reports. As most of the chronic ulcer treatment starts from the debridement, complete debridement of pressure ulcers of nonviable tissue including bursa, necrotic bone, and the abnormal bony protrusion is needed. After cleaning up the wound bed, various flaps can be used to cover the defect. The flap covering the defect should fit the defect without the excessive tension of the margin of the flap. Before selecting the flap to cover the defect, the surgeon should prepare for secondary flap surgery and leave some tissue to manage potential recurrence.

Keywords: perforator flap, pressure sore, pressure ulcer

37.1 Introduction

- Treatment of pressure ulcers must take into account the multiple risk factors.
- Complete debridement is essential before covering the wound.[1,2,3,4]
- Muscle flap, fascial flap, and propeller flaps are options to close the wound.
- Tension-free suturing at the area of direct pressure is essential to prevent recurrence.[2,4,5]

37.2 Indications

- Superficial wound (Stages I and II) will heal with conservative care.
- Correction of risk factors such as pressure, friction, shear, moisture, and malnutrition is essential before operative treatment.
- Stages III and IV ulcers require flap surgery (▶ Fig. 37.1).[3,4,6]
- As pressure ulcers are not life-threatening, surgery is often delayed until the risk factors are corrected.
- Risks and benefits of surgery must be considered and nonsurgical treatments should be also considered in high-risk patients.[4,5]

37.3 Operative Technique

- Basic principles
  - Excision of ulcer, underlying bursa, and scarring[1,2,3,4]
    - Debridement.
    - Complete debridement of the following is essential: ulcer, bursa, scar tissue, and calcification.
  - Only healthy, pliable tissue should be left before flap surgery.
  - Incomplete debridement will cause flap failure and wound dehiscence.
  - Radical removal of any involved bone and heterotopic ossification.
  - Obliteration of dead space.
  - Nonviable underlying bone should be debrided and biopsy should be sent.

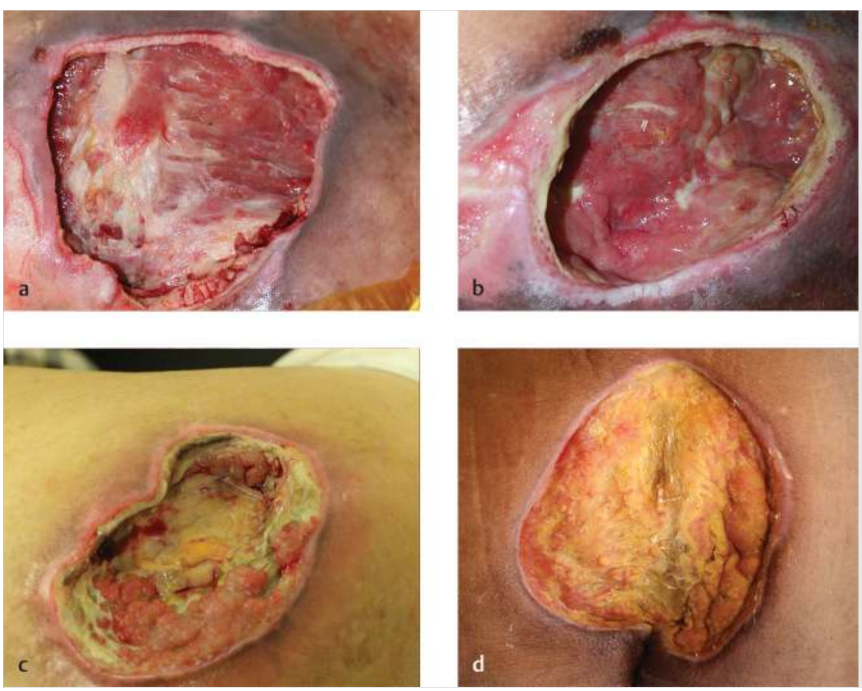

Fig. 37.1 (a–d) Pressure ulcer in sacral lesion. Stages III and IV ulcers, which need flap coverage.

- Minimize pressure points from areas of bony prominence.
- A wound containing contaminated foci with $> 10^5$ colony-forming unit (cfu) per gram of tissue cannot be closed, as the incidence of complications such as dehiscence and persistent infection is 50 to 100%.[2,4]
- There has been no study to compare the effectiveness of musculocutaneous and fasciocutaneous flaps; when we think about the likelihood of recurrence, careful attention is needed to select the suitable patient and perform adequate surgical procedures.
- Flap preference has changed over the past decade from muscle flaps to perforator flaps.
- By using perforator flaps we can preserve muscle and conserve additional surgery options.
- Surgeon should think ahead regarding the recurrence and secondary flap surgery before selecting the first flap for pressure ulcer reconstruction.

- Options for surgical coverage:
  - Random skin flap.
  - Muscle flap with skin graft.
  - Myocutaneous flap.
  - Fascial/Fasciocutaneous flap.
  - Propeller flap.
- Reconstruction by anatomic site[4,6,7,8,9,10]:
  - Sacral lesion:
    - Most common area of abnormal pressure and ulceration in supine position.
    - Myocutaneous gluteal flaps can be advanced by: Rotation, V-Y advancement, and island.
    - Perforator based flaps: Rotation or V-Y advancement flap.
    - Propeller flap.
  - Ischial lesion:
    - Inferior gluteus maximus myocutaneous flap: Rotation, V-Y advancement, and island.
    - V-Y hamstring advancement.
    - Gracilis myocutaneous flap.
    - Tensor fascia lata musculocutaneous flap.
    - Gluteal thigh flap.
    - Perforator based rotation or V-Y advancement flap.
    - Propeller flap.
  - Trochanteric lesion:
    - Tensor fascia lata musculocutaneous flap.
    - Rectus femoris myocutaneous flap.
    - Vastus lateralis muscle flap with skin graft.
    - Gluteal thigh flap.
    - Perforator based rotation or V-Y advancement flap.
    - Propeller flap.

37.3.1 General Surgical Principles of Propeller Flaps

Preoperative Imaging and Vessel Evaluation

- Computed tomography (CT) angiography:
  - Preoperative mapping of perforators is possible and preferable.[11,12]
  - It can evaluate size and the course of the perforator. If the source vessel is located between the point where the perforator penetrates the deep fascia and the pressure ulcer, there is more possibility of flap advancement.
  - Evaluate the source vessel of two separate perforators and decide preoperatively whether to dissect two vessels.
- Handheld Doppler.
- Magnetic resonance imaging (MRI):
  - Accurate and noninvasive method to evaluate underlying osteomyelitis in chronic pressure ulcer.

Intraoperative

Patient Position

- For sacral ulcers, prone position with hip flexion (30~45 degrees) and for ischial ulcers, prone position with hip flexion of nearly 90 degrees is needed. In this position, there should be no abnormal tension on the wound after flap coverage.[2,4,7]
- In trochantic ulcer surgery, a lateral position with the leg freed is needed to check the tension of closure during the operation (▶ Video 37.1).

Complete Debridement

- Complete removal of nonviable tissue is essential (▶ Fig. 37.1 and ▶ Fig. 37.2).
- Leave fresh skin and wound bed with no scar tissue.
- To excise the bursa completely, apply the methylene blue solution to the surface of the entire pocket with cotton swab (▶ Fig. 37.3 and ▶ Video 37.2).
- Bursa itself and the scarred tissue around it should be removed completely.
- After soft tissue debridement, abnormal bony protrusion and nonviable bone should be removed by using osteotomes, rongeurs, and surgical rasps, leaving healthy bone with pinpoint bleeding.
- Flap surgery can be delayed if there is inflammation or complete debridement is not possible in a single operation. Between debridement and covering surgery, negative pressure wound therapy can be used.

Video 37.1 Key procedures of propeller flap for covering pressure ulcer

Video 37.2 Painting the pocket of sore with methylene blue

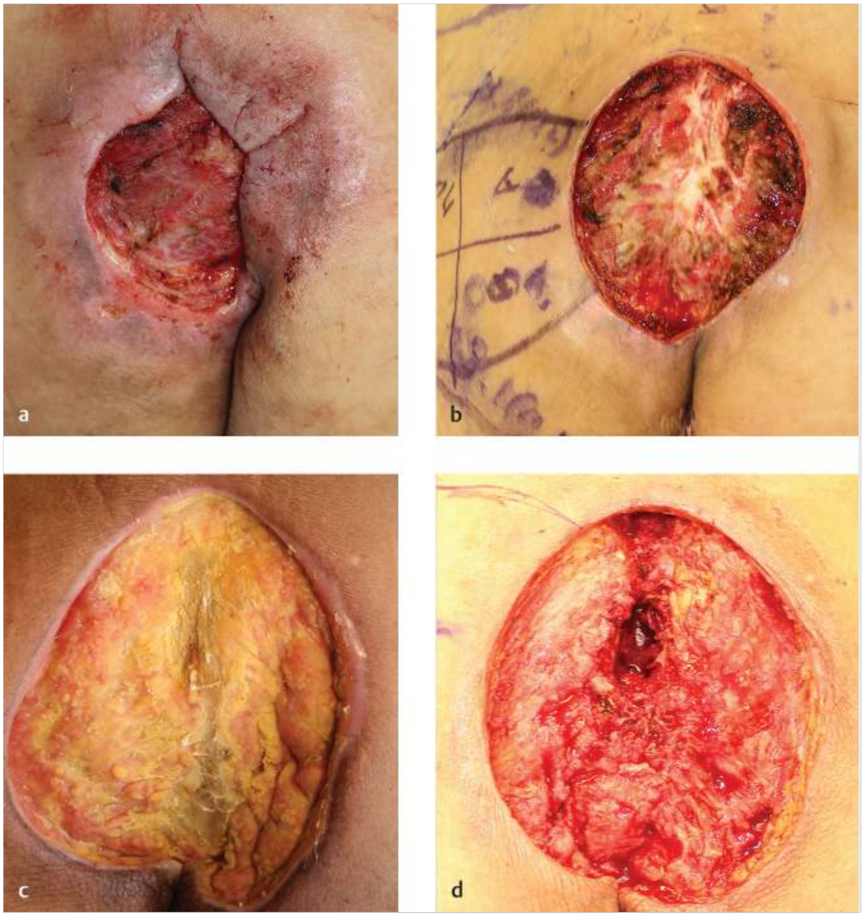

Fig. 37.2 (a–d) Complete debridement. Bursa itself and scarred tissue around it should be removed completely. Abnormal bony protrusion and nonviable bone should be also removed.

Fig. 37.3 Identifying wound surface. To excise the entire surface of the wound, paint the entire pocket with the mixture of methylene blue with H_2O_2 (1:1) and scrub with cotton swab.

Perforator Identification

- One dominant perforator in close proximity to the defect is sufficient.
- If the marked perforator is very close to the margin of the defect, it can be visualized by dissecting just above the deep fascia toward the perforator before designing the flap.
- Pedicle dissection is performed under loupe magnification (2–3.5 times magnification).

Flap Design

- Traditional length-to-width ratio of 1:3 is not definite in propeller flap.[2]
- Based on the location of the perforator on the flap, axiality of flap is more important.
- In the trunk, it is more reasonable to design transverse flaps.
- In the thigh region, it is better to design vertically.
- Tension on the donor site should also be considered and minimized.
- Flap is designed based on axiality and tissue abundance.[14]

Perforator Dissection and Selection

- Use loupe magnification and microsurgical instruments.
- Make an incision on a border of initial design.
- Flap design can alter depending on the condition of the feeding vessel after pedicle dissection.

- Elevate flap with meticulous hemostasis.
- Elevate flap in the suprafascial plane.
- After a sizable perforator is identified ensure that flap rotation is sufficient to cover the defect.
- The distance from the perforator to the tip of the flap should be longer than the distance from the perforator to the margin of the defect.
- Adjust the flap design before elevating the flap.
- Make an incision on the other side of the flap.
- Skeletonize the perforator above the fascia.

Pedicle Dissection

- Perforator is dissected to minimize the kinking of the pedicle.
- Make an incision in the deep fascia.
- Intramuscular dissection or direct septal dissection is needed.
- Dissection must extend from the perforator back to the source vessel.
- Depending on the angle of rotation or the amount of advancement required, the length of the pedicle must be adequate to accommodate flap inset.
- If the pedicle runs toward the defect, dissection helps in the required advancement of the flap.

Insetting

- After rotation or advancement, flap viability should be checked.
- Check for kinking of the vessel or traction on the pedicle.
- Rotate clockwise or counter-clockwise to check which is better.
- If there is kinking or tension on the pedicle, dissect the pedicle more or make an incision in the muscle to eliminate tension.
- After thorough hemostatsis, use suction drainage to minimize hematoma and seroma collection.
- Suture the flap without any residual dead space beneath it.
- There should be no tension on the flap margin.

37.3.2 Postoperative Care

- Deep vein thrombosis (DVT) prophylaxis is recommended during the postoperative immobilization.
- There is no sufficient evidence to show definite postoperative care for pressure ulcer surgery.
- Traditionally patients were kept in bed for up to 6 to 8 weeks until the wounds reach maximal tensile strength.[14]
- In recent regimens, early sitting 2 to 3 weeks after surgery for 15-minute interval is shown to be safe.
- Active and passive range-of-motion exercise of unaffected limbs should be started just after surgery.
- Postoperative education should be emphasized.

37.3.3 Complications

- There are wide variations in recurrence rate from 3 to 100%.
- Thorough evaluation of patients' risk factors and care must be taken for patients who initially seem like poor candidates.

37.4 Conclusion

- Using a flap is the most efficient and reasonable method to heal pressure ulcers.
- Successful reconstruction is possible after completing every step of surgery:
  - Proper debridement of necrotic, less viable tissue including bursa, necrotic bone, and the abnormal bony protrusion.
  - Proper flap coverage with dead space obliteration and without excessive tension on the margin of the flap.
  - Postoperative management and education.

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38 Management of Deep Sternal Wound Infections

Hinne A. Rakhorst

Abstract

Deep sternal wound infections pose a significant challenge to patient, plastic surgeon, and thoracic surgeon. Patients often suffer from significant comorbidities and wounds typically are complex. The role of the plastic surgeon is to cover the defect as soon as possible, reducing in hospital stay and improving quality of life in a multidisciplinary team approach.

Solutions are customized to individual patients by choosing the right technique from the armamentarium of today's plastic surgeon. This book chapter describes patient populations, principles, and pearls of treating deep sternal wound infection. Treatment algorithms ranging from healing by secondary intention to local or free perforator flaps are discussed in a practical way.

Keywords: deep sternal wound infection, free flap, mediastinitis, microsurgery, perforator flap, vacuum assisted closure, wound

38.1 Introduction

Deep sternal wound infection, often referred to as mediastinitis, is a severe complication following sternotomy. In 2001, an estimated 760,000 sternotomies were performed in the USA.[1] Approximately, 2% of these were complicated by deep sternal wound infections or mediastinitis.[2] Mortality rates of this complication are reported to be as high as 50%. Treatment is a complex and challenging task that often involves a multidisciplinary team approach to obtain optimum results.

Deep sternal wound infections are either acute or chronic. The mediastinitis can involve soft tissue, sternal bone, or the combination of both. Sternal infections can also present after healing of soft tissues and bone, oftentimes as fistulas arising from surgical hardware.

It is hypothesized that the primary cause is a bacterial infection of bone. After removing the internal mammary vessels, sternal perfusion is decreased and the risk of bacterial invasion increased. Infection can spread and result in infected hardware or wound dehiscence and sternal dehiscence. Nonsurgical treatment involves dressings and antibiotics, but surgery is often required to debride avascular bone and provide soft tissue coverage.

38.2 Indications

Patients are often American Society of Anesthesiologist (ASA) Class III to IV and surgery is frequently in an acute setting. Factors that are typically encountered include:

- Obesity.
- Smoking.
- Poor vascular and microvascular status.
- Pulmonary disease, resulting in coughing which puts tremendous stress on the sternotomy site.
- Diabetes.
- Poor general condition and feeding status.
- Radiation therapy after previous breast cancer treatment.

Even under these conditions, 98% of patients heal without developing mediastinitis. This means that the 2% that develop a deep sternal wound infection typically have severe comorbidities.

38.2.1 Clinical Course

Early referral to a plastic surgery unit is vital to enhance the chances of early cover of the wound, and reducing morbidity and mortality.

Of foremost importance is close collaboration with thoracic surgical colleagues who should be made aware of the possibilities and limitations of the plastic surgical management of this condition. The role of the plastic surgeon is to close the wound in a skillful and timely manner in a multidisciplinary approach.

Good collaboration will enhance surgical management and reduce morbidity, mortality, and costs to the health care system by reducing the number of procedures, days in hospital, and visits to clinic.[3] It is advisable to monitor outcome indicators and take photos to illustrate your results and to review such cases regularly in an effort to improve your surgical efficiency and thereby improve patient outcomes.

Upon referral, several factors need to be assessed:

- Thoughts of the patient and family.
- Operability of the patient.
- Prognosis of the patient.
- Comorbidities, pressure ulcers.
- Pulmonary status.
- Earlier surgeries; internal mammary vessel harvest, pectoralis and rectus abdominis perfusion status, and local perforators.
- Previous radiation therapy to chest wall, especially in women who have had breast cancer.

38.3 Operative Technique

Typically, patients have multiple comorbidities; these are likely to have contributed to the problem in the first place. These factors, for example, smoking, obesity, and lung problems with severe coughing, oftentimes cannot be changed and therefore are a "given." As these are not factors to optimize prior to surgery, it is our challenge to pick customized solutions.

There is little evidence-based literature in sternal wound care. Therefore, there is no single protocol available as a gold standard. However, van Wingerden et al published a helpful algorithm combining wound classification with treatment strategies[4] using an evidence-based approach.

Treatment involves two aspects: bone and soft tissue.

A helpful way to analyze the problem is to divide the sternal region into thirds from cranial to caudal to help with flap selection.

Fundamental questions to ask include:

- Is the problem limited to soft tissue?

- Is there bony involvement?
- Is the bony involvement leading to bony nonunion and instability?

A treatment plan is then formulated by taking the aforementioned factors into consideration. Sometimes just a simple first debridement can be helpful to assess the extent of the wound and the tissue viability to help decide on a strategy to follow.

38.3.1 Bony Union

It is important to decide with the thoracic surgeon what to do with bony stability. This matter can be addressed using wiring or plating following aggressive wound debridement. Rigid plating seems to have better results than conventional wiring of the sternum,[5] especially in complicated cases. The condition of the bone may be a challenge when it is soft due to inflammation, and infection of the hardware is a serious risk. Also, patients may suffer from pulmonary problems with coughing and increased tension on the osteosynthesis resulting in mechanical failure.

Alternatively, bony fixation can be addressed after the infection has been treated by soft tissue coverage, reducing risks of infecting hardware. The flap can be raised later to enable plating of the sternum if the patient has sternal instability. Oftentimes, scar tissue provides some form of stability and patients' complaints may be mild as their daily activities can be limited.

38.3.2 Soft Tissue Closure

Goals of soft tissue closure include obliterating dead space, adding vital tissue to enhance effective antibiotic treatment, and delivering wound healing factors into the region. Using suction drains subcutaneously and between flaps and sternum to obliterate dead spaces is also important.

Finally, closure without tension is important. On the other hand, any type of closure should be rigid and reliable. It should be designed to withstand stresses caused by coughing and involuntary and voluntary movements. Postoperatively, harnesses can be used such as orthoses for supporting the sternum, although in any type of bandaging and harnessing, compression of pedicles should be avoided.

Final closure can be achieved by selecting from a wide array of flaps. Flap choice should be based on what a surgeon is familiar with and what best suits the patient.

38.3.3 Timing

The initial choice is made between early debridement and early flap cover and debridement and vacuum assisted closure (VAC) treatment, to be followed by soft tissue reconstruction at a later stage.

Similar to complex lower limb fractures, mounting evidence supports early debridement and soft tissue cover.[6] Aggressive treatment is usually required for a successful outcome. However, several issues are considered (as in Section 38.3.1 above). Earlier cover reduces morbidity and mortality, reduces hospital stay, and improves outcome. Therefore, the primary aim is for early referral and early cover of the defect.

38.3.4 Bacterial Cultures

Negative bacterial cultures are not required to proceed to closure or cover of the defect.[7] Oftentimes, a way to treat positive bacterial swabs is by coverage with vital tissues. Of course, extensive debridement is done to remove all necrotic tissue prior adding vital tissue.

38.3.5 Debridement

As a first stage, debridement is key. The debridement removes infected hardware, and necrotic soft tissue, bone, and cartilage and should be quite aggressive. Oftentimes, half the sternum is debrided and rib cartilage is removed leading to extensive defects with sternal instability. Here, bony fixation is cumbersome and may be better delayed until soft tissue healing and infection control are achieved.

At the end of debridement, a plan should be made for:

- Bony union.
- Soft tissue coverage.

For both tissues a plan is made in terms of techniques as well as timing.

38.3.6 Vacuum-Assisted Closure (VAC)

Wounds are covered with VAC systems. VAC systems provide not only cover for the wound, but also allow ease of care for nursing staff and patient. They also offer sternal stability by means of stabilizing the sternum by vacuum. As VAC provides stability it oftentimes improves respiratory function.

VAC can be used in stable patients and mild defects as a conservative wound closure strategy. After a number of weeks of treatment, secondary closure can be an option or even skin grafting. In case of progressive necrosis or in patients too unstable to go through longer surgical procedures, VAC is used as a bridge between major necrotic tissue resections and definitive flap cover.

38.3.7 Definitive Closure Strategies and Flaps

When closing a sternal defect, start by wide undermining of the wound edges. Extensive scar tissue can restrict the mobility of the prepectoral skin. Dissect through the scar tissue until fresh tissues are found and any scar is adequately released to mobilize the skin. Ensure the dissection proceeds in a subcutaneous plane to allow a pectoral muscle turn-over flap, preserving medial perforators.

Next, necrotic bone is resected. If no bony fixation is performed, aim for maximum contact between scar or bone and the planned flap. This is done by having all wound edges freed from any prominences of bone and scar. In addition, when a flap is used, make an opening where the flap can sink onto the mediastinum while lying snugly on bone. Place suction drains between the flap and the wound bed to enhance contact and reduce dead space and hematomas. One can return after healing of the wound to perform bony fixation after lifting the flap to approach the bone.

38.3.8 Secondary Closure

In selected cases, secondary closure may be an option. Wounds that are granulating after weeks of wound care or defects over an intact sternum may be closed or grafted as some patients don't want to undergo more complex surgery involving flaps.

After wide undermining and extensive scar release, sometimes tension can be reduced adequately. Skin can be closed in many layers over a suction drain. Make sure there is no dead space. Extensive subcutaneous suturing may be required, sometimes with polydioxanone (PDS) and nonresorbable sutures that are left in for weeks to support the healing wound.

Random flaps can be used to fill up dead space or reduce tension in the midline. Consider doing simple Z-plasties or alternative flaps when these issues are encountered. Another option is to de-epithelialize a local flap and use it for filling small subcutaneous cavities. Considering the fact that patients generally have poor wound healing qualities, a surgeon should have the skills and be able to move to more complex strategies.

38.3.9 Perforator Flap

Perforator flap is an option, and should be considered to use to reduce midline tension and to fill dead space. Perforator flaps are typically quick to dissect, reliable, and preserve the option of using muscle flaps later. The surgeon should be comfortable in perforator surgery.

If the internal mammary vessels are available, excellent options include internal mammary artery perforator (IMAP) flaps. If the right or left internal mammary artery (R/LIMA) are used, a computed tomography angiography (CTA) gives information on the status of the peristernal perforators arising from the internal mammary artery. Doppler can also be helpful.

Internal Mammary Artery Perforator (IMAP) Flap

The second intercostal space is a typical location of a large perforator that can be used to design a large fasciocutaneous flap.[8,9] A flap can be designed up to the deltopectoral groove laterally. If a longer flap is needed, one could consider a delay procedure to go beyond the deltopectoral groove or choose an alternative flap.

The perforator is located using Doppler. Start the incision cranially identifying the perforator. After this, incise the full flap and raise it from lateral to medial. The flap can be propellored if required, for which the perforator can be mobilized further by dissecting it from the intercostal muscles. Alternatively, leave the base of the flap to be divided in a second stage and transpose with the perforator in a cutaneous pedicle.

Superior Epigastric Perforator Flap

More caudally, a superior epigastric artery perforator can be Dopplered, typically between 1 and 10 cm caudal to the xiphoid and 1 and 6 cm lateral to the midline.[10] This flap can be used to fill dead space or reduce tension at the caudal one-third of the presternal area where pectoral flaps typically are less suitable options. Distal tip necrosis can be an issue.

38.3.10 Planning and Dissection

The angiosome of the perforators is up to approximately the anterior axillary line.[11]

Using Doppler, a perforator is localized in the subxiphoid area and used as pivot point. Design your fasciocutaneous flap with the inframammary line as the superior margin and the anterior axillary line as a lateral boundary with a maximum of approximately 20 cm in length and 5 cm in width.[11]

While dissecting it to its base, transpose it to check the design and reach of the flap. Subsequently, decide to island it or to leave the cutaneous connection to be divided in a second stage. The last option might be safer in patients with poor vascular status and in smokers.

38.3.11 Muscle Flaps

Rectus Abdominis Flap

The rectus flap covers full-sternal defects reliably. It is a workhorse flap for defects involving the lower half of the sternum. It reaches the sternal notch and is thin, facilitating draping of the flap into the small gutter-shaped defects found in sternal dehiscence wounds.

Planning and Dissection

Design the flap by determining the subcostal area as a pivot point, three fingers laterally from the midline. The rectus insertion to the pubic bone is the caudal landmark. Typically, the length from subcostal to pubic bone is the same as the length from the subcostal area to the suprasternal notch.

First, make a laparotomy incision. Move down to the linea alba in its full length and undermine slightly laterally. Now identify the medial aspect of the muscle. In this, perforators of the inferior epigastric artery can be of use as they arise from the muscle.

Incise the anterior rectus sheet leaving enough fascia medially to place secure sutures when closing. Incise it in full length. The anterior rectus sheet is not part of the flap, so next dissect the anterior fascia from the muscle at the intersections where it is connected. Bipolar dissection is used. When this is done, go deep to the muscle. Here the muscle can be dissected by blunt dissection as it is not connected to the fascia cranial to the semilunate line and the peritoneum caudal to this line.

Identify the inferior epigastric artery and ligate it as caudal as possible as it can be used to supercharge or connect the artery if the superior epigastric artery proves to be insufficient. Typically, the caudal aspect of the flap needs some time to be perfused by the superior epigastric artery. When there is doubt about the superior vascular supply, one can also test its supply by first placing a temporary microvascular clamp on the pedicle prior to clipping it.

After this, dissect the insertion from the pubic bone and flip the muscle into the defect. The cranial connection of the muscle to the ribs can be narrowed slightly from laterally to increase reach. Using Doppler or direct visualization the superior pedicle can be identified and preserved.

Place suction drains under the muscle and suture it into place. The muscle is made to fill all defects including defects cranial to the sternum. Oftentimes, the mobilized skin can be closed under slight tension if all dead space is obliterated with the flap. Cranially, a small monitoring window to the flap can be left. Here the muscle can be grafted with a small skin graft. If the skin cannot be closed, it can be sutured onto the flap. The muscle is grafted with a skin graft.

Donor site closure is performed by suturing the anterior rectus sheet. As the anterior rectus sheet is not part of the flap, this should be without much tension. If tension is too much, a mesh repair can be considered. However, sterility in the circumstance of an infected sternal wound might be a factor in opting for secondary mesh repair if indicated in a minority of cases.

Summarizing the use of a rectus abdominis muscle flap:

- First choice if more than two-thirds of sternal defect.
- Easy, quick operation.
- Can be based on the eight intercostal artery.[12]
- Flip over the flap, rotation reduces reach of the flap.
- Ligate inferior epigastric as caudal as possible to keep length for potential supercharging.
- Drain under the flap to promote flap approximation to bone.
- Mesh: Decide prior to surgery when to use, typically anterior rectus fascia is closed.
- Leave a small part for monitoring at the cranial aspect of the wound, which is the distal part of the flap.
- Skin graft the flap.

38.3.12 Pectoralis Flap

For defects of the cranial two-thirds of the sternum, cover can be provided using pectoralis flaps. Pectoralis major is a Mathes Type V flap and is perfused by both internal mammary artery perforators and the thoracoacromial vessels. It can be used as a turn-over flap based on internal mammary artery perforators or based on the thoracoacromial vessels.

The thoracoacromial pedicle originates at the midclavicular level where it runs beneath the clavicle. The muscle can be divided from the humeral insertion and released further up to the pedicle to gain length, using an extra incision for exposure. Its pivot point is therefore at the midclavicular level. This means that its reach is usually limited to the upper two-thirds of the sternum. Typically, the more severe wound problems occur at the inferior one-third of the sternum making it a helpful flap only in select cases.

Bilateral pectoralis flaps can be used to increase cover. Wide subcutaneous undermining typically gains reach to close the skin over the flaps that are used to reduce dead space and introduce well-vascularized tissue for infection control.

38.3.13 Visceral Flaps

Omentum Flap

The omental flap is an option for coverage of sternal wounds. The flap reaches up to the sternal notch covering a full sternal defect and filling all the irregularities and grooves. Some authors consider this flap the second choice for sternal cover, especially in irradiated chests. Harvesting of the flap can be done laparoscopically and it reaches to cover a full sternal defect.

Its advantages include its pliability and ability to cover irregular surfaces. Also, it has great anti-inflammatory qualities. However, a disadvantage is that it is in the abdominal cavity, and using it connects a sterile cavity to the contaminated presternal area leading to a potential risk of contamination of the abdominal cavity. Literature shows this risk is minor. Another caveat of this flap includes herniation of the abdominal wall.

The omentum is supplied by the gastroepiploic arteries, which arise from the omental artery, and is generally harvested on the right gastroepiploic artery. The stomach is connected to the transverse colon by the gastrocolic ligament, which is the anterior portion of the lesser sac. This ligament is part of the suspension system of the omentum.

Raising of the flap is done by first detaching it from the transverse colon and secondly from the greater curvature of the stomach dividing the short gastric arteries. After this the flap can be transferred to the chest wall. The tunnel is made in the epigastric region. After inset of the flap with a drain between flap and chest wall, skin can be closed after wide undermining or a skin graft is placed on top.

38.3.14 Free Flaps

In severe cases where pedicled options are limited, free tissue transfer should be considered.

Flap selection is done mainly based on personal preference and required tissues. In flap selection a long pedicle is a great advantage. Flaps that have been used are numerous including latissimus dorsi, vastus lateralis, anterolateral thigh, and even fibular flaps.

Preoperatively, the surgeon should be aware of possible recipient vessels for both artery and vein. The surgeon should have a plan A, B, and C and be prepared to use vein grafts if required. Preoperative imaging might be of assistance using CTA or magnetic resonance angiography (MRA). Acceptor vessels include the internal mammaries, thoracoacromial artery, thyrocervical plexus, and neck arteries and veins.

38.4 Conclusion

Treatment of deep sternal wound infections exemplifies the benefits of a plastic surgery service in a hospital. It combines multidisciplinary working, anatomy, and creativity. In addition, it reduces morbidity, mortality, and costs.

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39 Reconstruction of Thoracic and Abdominal Defects

Rei Ogawa

Abstract
For reconstruction of thoracic and abdominal defects, various types of flaps can be planned depending on the condition of the recipient site. In any case, it is important to identify and examine the blood vessels that will nourish the flap before surgery commences. Multidetector-row computed tomography (MDCT) is useful if the vascular pedicle is a perforator. After flap elevation, efforts to rotate the flap onto the recipient site are made frequently: separation of the tissues around the perforator pedicle continues until the distal end of the flap can be rotated onto the recipient site without tension.

Keywords: free flap, island flap, local flap, pedicled flap, perforator flap, propeller flap, regional flap

39.1 Introduction

Thoracic and abdominal walls are important because they cover vital organs. In many cases, wounds in these walls can be reconstructed by using the surrounding tissue as local or regional flaps. This is because the skin surface area in the body trunk is relatively large. Flap design flexibility is improved by including perforators. Propeller flaps can be easily moved to the recipient site. Muscle can be included in these flaps (i.e., a myocutaneous flap) if thicker tissues are needed, and artificial materials can be added if supporting structures are needed. As a last resort, free flaps can be used.

39.2 Indications

Thoracic wall defects mainly arise from mediastinitis, empyema, radiation ulcer, malignant tumor resection, and keloid removal. For thoracic wall reconstruction, latissimus dorsi (LD) muscle flap[1]/thoracic artery perforator (TAP) flap,[2] rectus abdominis muscle (RAM) flap[3]/deep inferior epigastric artery perforator (DIEP) flap,[4] pectoralis major (PM) muscle flap[5]/internal mammary artery perforator (IMAP) flap,[6] deltopectoral (DP) flap,[7] and omentum flap[8] can be used.

Abdominal wall defects mainly arise from trauma, peritonitis, radiation ulcer, malignant tumor resection, and hernia. For abdominal wall reconstruction, RAM flap[9]/DIEP flap,[10] abdominal external oblique muscle flap,[11] groin flap[12]/superficial circumflex iliac artery perforator (SCIP) flap,[13] tensor fascia lata (TFL) muscle flap,[14] rectus femoris (RF) muscle flap,[15] and anterolateral thigh (ALT) flap[14] can be used. Fascia lata or artificial membranes such as polypropylene, polydioxanone, and teflon meshes can be used as supporting structures.

39.3 Operative Technique

39.3.1 Conventional Myocutaneous Pedicled Flap

Even when an established conventional flap is planned, it is necessary to preoperatively examine the main vessels by methods such as angiography (▶ Fig. 39.1). Sometimes, the most optimal vessel is not available. For example, in patients with mediastinitis-induced thoracic wall defects, the internal mammary artery has been used previously for coronary artery bypass graft (CABG).[3,16,17] In such cases, the flap can be changed to an intercostal artery-based pedicled vertical rectus abdominis musculocutaneous (VRAM) flap.[3]

In the case of conventional myocutaneous flaps, a relatively large flap can be harvested safely. Thus, the size and volume of the attached muscle can be adjusted depending on the condition of the recipient site.

In general, flap elevation starts under the muscle from the distal end. Elevation then continues to the area around the rotation axis. Efforts to rotate the flap onto the recipient site are made frequently: separation of the tissues continues until the distal end of the flap can cover the recipient site without tension. This is important because if the tension is high, the risk of congestion increases. Thus, careful preparation of the perforator pedicle is necessary.

To avoid flap congestion, it is also necessary to ensure that (1) the cutaneous vein is attached to the distal edge of the flap and is anastomosed with the vessel in the recipient site, and (2) the skin pedicle is maintained around the vascular pedicle.

The donor site is closed first. Thereafter, the flap is sutured to the recipient site. The muscle and deep and superficial fascia of the flap are sutured to the corresponding tissues in the recipient site by using absorbable sutures. The dermis and superficial layer are then sutured.

39.3.2 Perforator Pedicled Propeller Flap

Before surgery, the perforators around the wound should be identified. One method is Doppler flowmetry, which is simple and quick. However, it is difficult to follow the perforator course after it penetrates the fascia with this method. Color Doppler scanning with a 10 MHz high-resolution probe yields better results. Moreover, to elucidate the precise anatomical detail of individual perforators, computed tomography angiography (CTA) with multidetector-row computed tomography (MDCT) is useful, although it will expose the patient to radiation.[18]

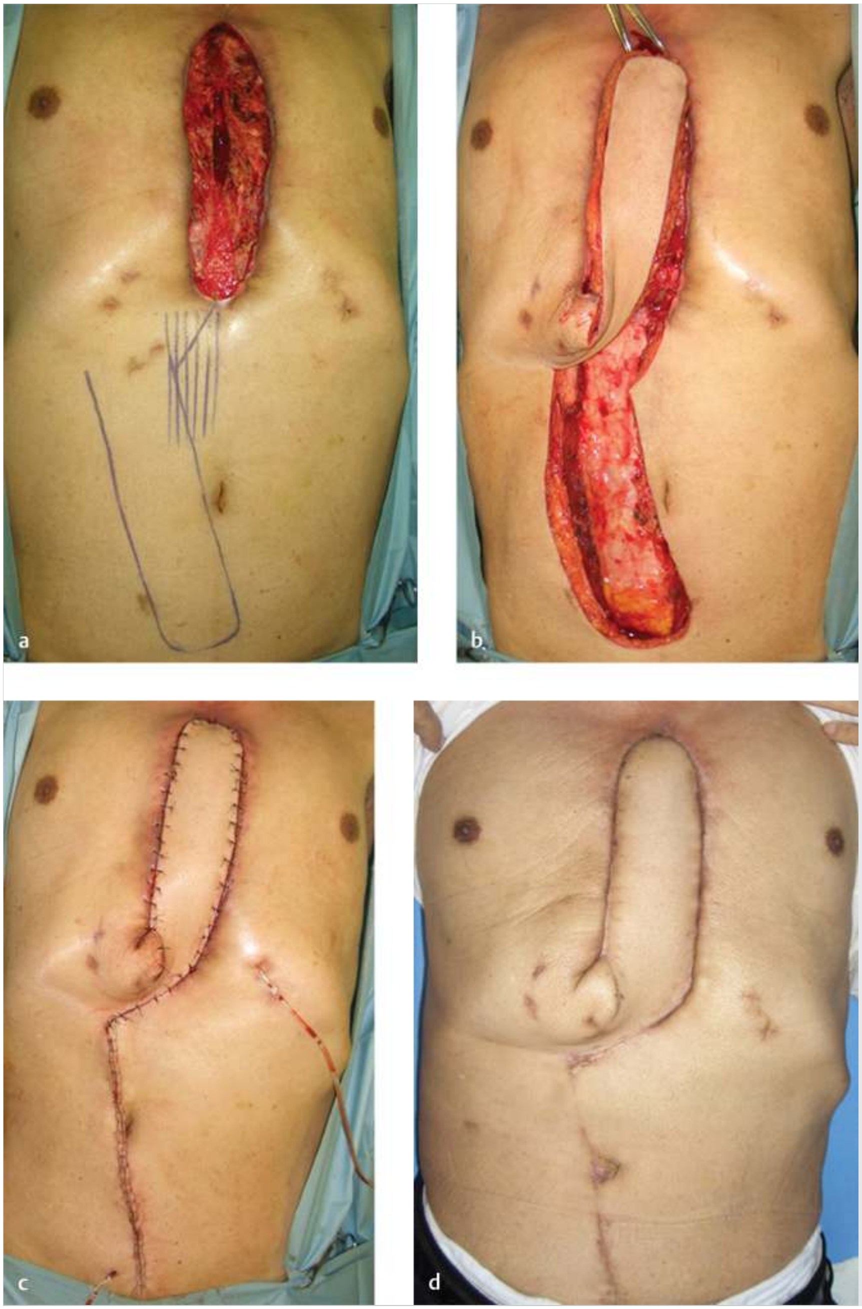

Fig. 39.1 Thoracic wall reconstruction using a modified superior based rectus abdominis myocutaneous flap. This 72-year-old man presented with recurrent severe poststernotomy mediastinitis for over 2 years. The patient had previously undergone coronary artery bypass grafting in which both internal mammary arteries were harvested for revascularization. Despite the absence of the internal mammary arteries, it was thought that enough time had passed to allow the superior-based collateral blood supply to develop adequately to the point that it could fully support the viability of the rectus abdominis sans inferior blood supply. Accordingly, a decision was made to reconstruct the chest wall with an intercostal artery-based pedicled vertical rectus abdominis musculocutaneous (VRAM) flap. The skin pedicle was designed in an oblique fashion to maintain adequate blood flow to the skin pedicle itself, in addition to improving venous drainage. The oblique design also allowed a longer flap to be harvested. For easy rotation of the skin pedicle, the skin incision line was designed oblique to the alignment of the rectus abdominis muscle (RAM). The distal edge of the skin flap was elevated and the distal end of the muscle was dissected. Postoperative evaluation revealed a viable flap with adequate coverage of the sternal defect in addition to good donor site outcome. **(a)** Flap design, **(b)** flap rotation, **(c)** immediately after the operation, and **(d)** 3 months after operation.

The flap is designed according to the perforator course (▶ Fig. 39.2). After the recipient site is prepared, elevation starts from the periphery.[6] The indication for perforator pedicled flap is reconstruction of relatively shallow defects; thus, the thickness of the flap should be adjusted intraoperatively to match recipient site thickness. In general, elevation starts at the fat tissue layer and continues around the superficial fascia. The area around the perforator pedicle is then elevated.

The perforator is then identified. It is easy to find the perforator under the deep fascia if the diameter of the perforator is predicted to be small. Efforts to rotate the flap onto the recipient site are made frequently: separation of the tissues around the perforator pedicle continues until the distal end of the flap can cover the recipient site without tension. The perforator pedicle can be skeletonized if flap rotation is difficult. If the tension is high, the risk of congestion increases. Thus, careful preparation of the perforator pedicle is necessary.

To avoid flap congestion, it is also necessary to ensure that (1) the cutaneous vein is attached to the distal edge of the flap and is anastomosed to the vessel in the recipient site and (2) the skin pedicle is maintained around the vascular pedicle.

The donor site is closed first. Thereafter, the flap is sutured to the recipient site. The deep or superficial fascia of the flap is sutured to the corresponding tissue in the recipient site by using absorbable sutures. The dermis and superficial layers are then sutured.

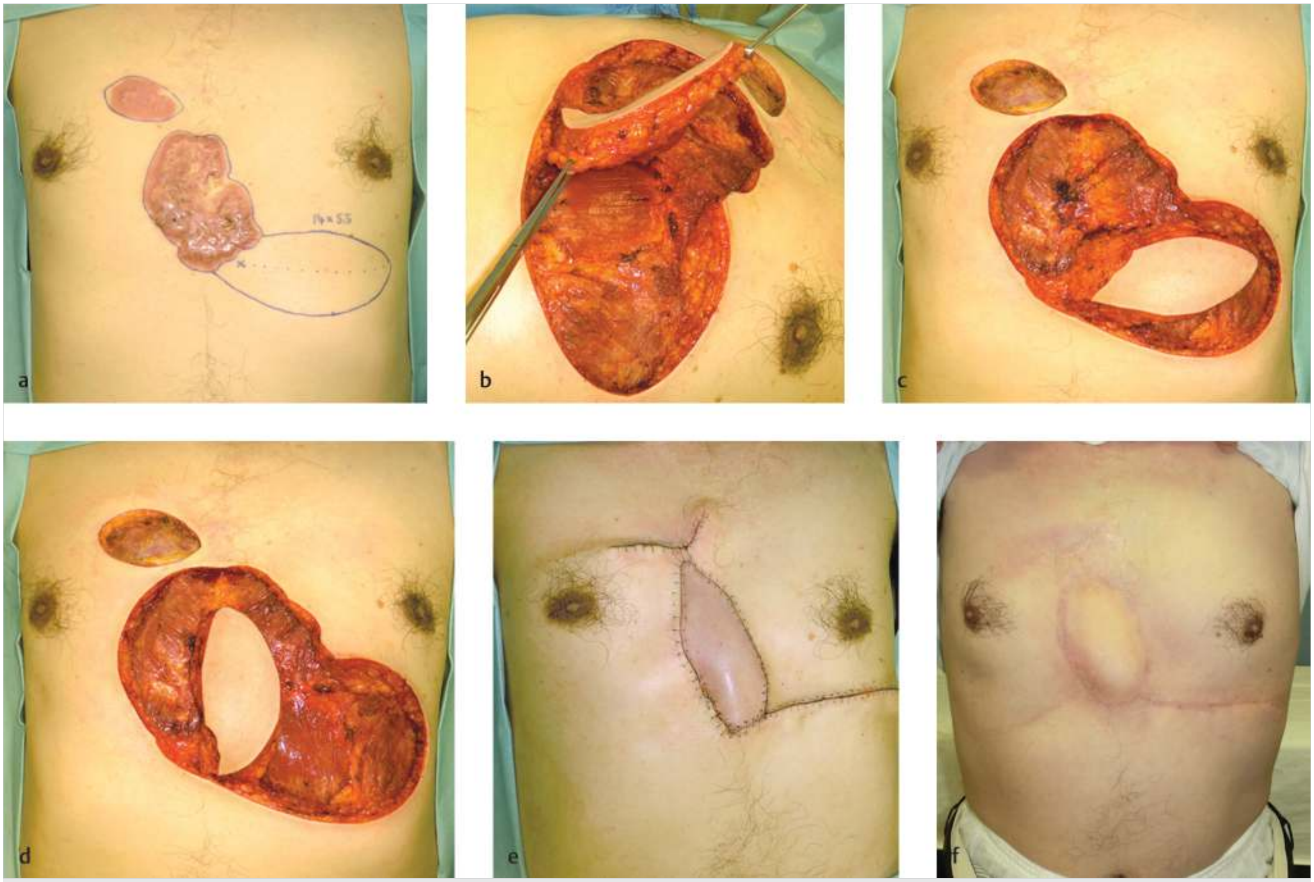

Fig. 39.2 Thoracic wall reconstruction using a perforator-pedicled propeller flap. (The case has been cited from Nguyen et al[3] with permission from the publisher.) This 53-year-old patient had a chest wall keloid that started growing 20 years ago. The keloid was removed along with the fat tissues under the keloid. The seventh internal mammary artery perforator was detected by preoperative multidetector-row computed tomography (MDCT). The 14 cm × 5.5 cm flap was elevated from the periphery and a perforator was detected. An island flap was generated and rotated 100 degrees to cover the recipient site. Immediately after surgery, the flap exhibited some congestion. Nevertheless, it survived completely. Postoperative radiation therapy (20 Gy) was delivered in four fractions over 4 days. Two years after the operation, the keloid has not recurred. **(a)** Flap design, **(b)** identification of the perforator pedicle, **(c)** creation of the island flap, **(d)** rotation of the flap, **(e)** immediately after the operation, and **(f)** 2 years after the operation.

39.4 Conclusion

For reconstruction of thoracic and abdominal defects, various types of flaps can be planned depending on the condition of the recipient site. In any case, it is important to identify and examine the blood vessels that will nourish the flap before surgery commences. MDCT is useful if the vascular pedicle is a perforator.

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40 Vascularized Lymph Node Transfer

David W. Chang and Rebecca M. Garza

Abstract

Vascularized lymph node transfer is a form of physiologic surgical treatment for lymphedema, used in patients with primary or secondary lymphedema that is refractory to nonsurgical management. Lymph node donor sites include the groin, neck, omentum, mesentery, and lateral thorax, and recipient sites commonly used include the proximal or distal extremities. In cases of secondary lymphedema that results from tumor ablation or lymph node dissection, lymph node transfer is often accompanied by scar release and replacement of soft tissue deficits. In this chapter, a practical approach to surgical decision-making and a step-by-step guide to harvest and transfer of common lymph node flaps are presented. Intraoperative photos from a variety of flaps and a video guide to supraclavicular lymph node harvest are provided.

Keywords: groin lymph node transfer, lymphedema, supraclavicular lymph node transfer, thoracic lymph node transfer, vascularized lymph node transfer

40.1 Introduction

Vascularized lymph node transfer (VLNT) is one form of physiologic surgical treatment of lymphedema.[1] VLNT has gained popularity since early clinical studies showed efficacy in reducing affected limb girth and decreasing reliance on decongestive therapy.[2] The first donor sites described included the groin and axilla.[3,4] As concern for iatrogenic lymphedema at the donor site grew,[5] new donor sites were explored, including harvest of submental and supraclavicular lymph nodes that carry lower risk of donor site lymphedema.[6,7,8,9]

40.2 Indications

VLNT may be employed in cases of either primary or secondary lymphedema involving upper or lower extremities. VLNT should be used as an adjunct to decongestive therapy in patients with International Society of Lymphology (ISL) stages II–IV lymphedema.[10] In cases of trauma or the surgical resection of malignancy, patients may have significant soft tissue deficiency and/or large amounts of scar tissue in the groin or axilla. Extensive scar release is recommended, and flap tissue should be used to replace soft tissue deficits.[1,8] In contrast, patients with primary lymphedema or lymphedema of the lower extremities secondary to previous abdominal/pelvic surgery with lymph node dissection (LND) will not have scar tissue in the groin or axilla. Therefore, there is no role for scar release, and lymph nodes may be transferred alone without accompanying free flap. Finally, in patients with acquired amastia, VLNT may be combined with autologous breast reconstruction with either pedicled or free flaps.[11] Importantly, patients with active malignancy should not undergo VLNT. An algorithmic approach to VLNT in the upper and lower extremities is presented in ▶ Fig. 40.1.

40.3 Operative Technique

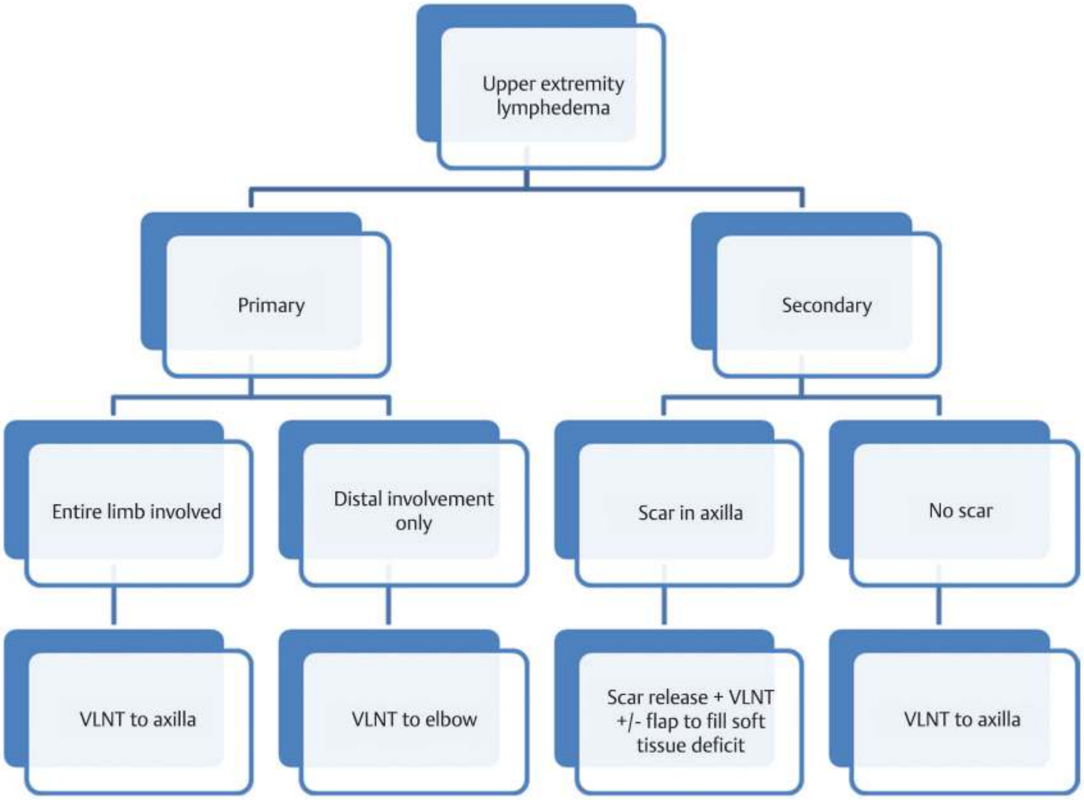
Discussion of all possible lymph node transfer donor and recipient sites is beyond the scope of this chapter. Transfers most frequently performed are presented, and transfer of omental, mesenteric, and submental nodes is not included.

40.3.1 Supraclavicular Lymph Node Transfer

The right neck donor site is preferred over the left, given the presence of the thoracic duct on the left. In cases of right upper extremity lymphedema, however, the left neck is used to avoid any further disruption of lymphatic drainage on the affected side (▶ Video 40.1).

1. A transverse skin incision is made 1 to 2 cm above the clavicle within an anatomic triangle bordered by the sternocleidomastoid muscle (SCM) (medial), external jugular vein (EJV) (lateral), and clavicle (inferior) (▶ Fig. 40.2).
2. Platysma is divided transversely.
3. At the medial aspect of the incision, the lateral border of the SCM is identified. Dissection along the edge of the SCM is performed. The omohyoid muscle is transected, and the internal jugular vein is identified and retracted (▶ Fig. 40.3).
4. Dissection is carried deep medially until the anterior scalene muscle is visualized. Care is taken to avoid injury to the phrenic nerve. The proximal portion of the transverse cervical artery (TCA) is then identified inferiorly, usually traveling superolaterally. An accompanying vein is identified.
5. A cluster of deep cervical lymph nodes (level Vb) is dissected from surrounding tissue, with care taken to avoid disruption of connections between the vascular pedicle and the nodes. Lymphatic vessels are clipped on the "stay" side to prevent leak and left open on the flap side (▶ Fig. 40.4).
6. The distal end of the arterial pedicle is identified, clipped, and divided.
7. Once recipient site and vessels are prepared, the proximal TCA and flap vein are ligated and transferred to the recipient site for microvascular anastomosis.
8. The donor site is closed in layers (platysma, skin) over a closed-suction drain.

Video 40.1 Supraclavicular lymph node flap harvest



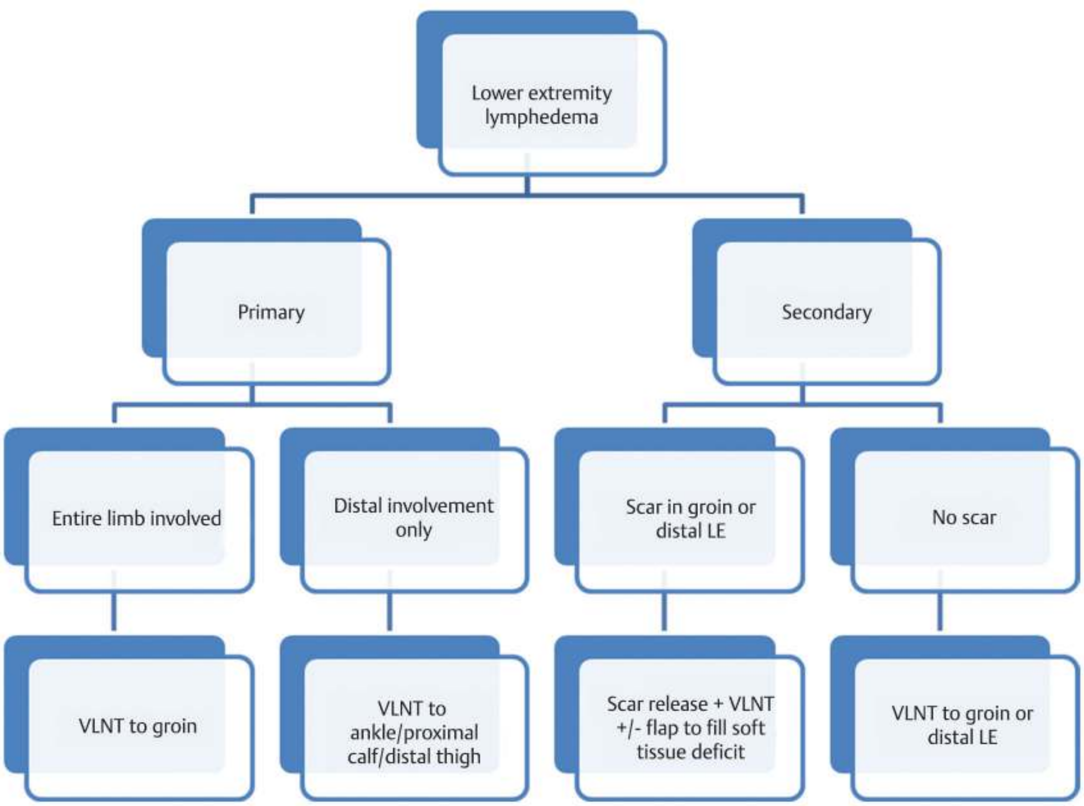


Fig. 40.1 (a) Algorithmic approach to vascularized lymph node transfer (VLNT) in the upper extremity. **(b)** Algorithmic approach to VLNT in the lower extremity.

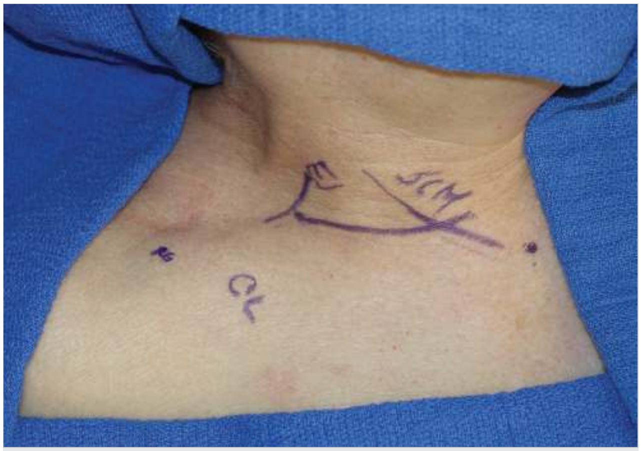


Fig. 40.2 Landmarks for planned harvest of supraclavicular lymph node flap: SCM, sternocleidomastoid muscle; EJ, external jugular vein; CL, clavicle.

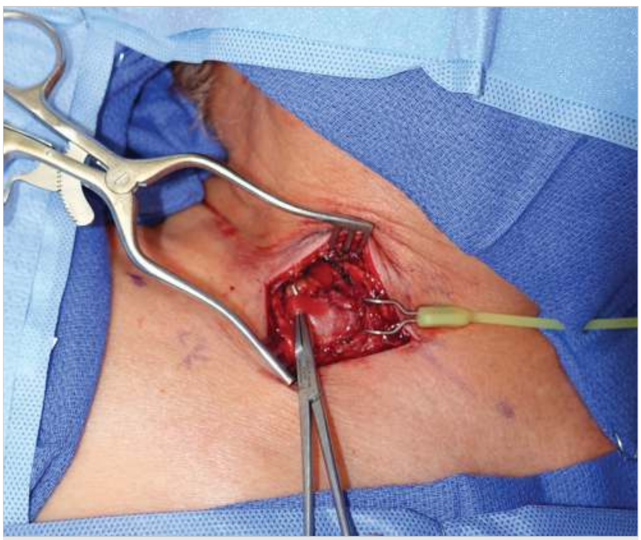


Fig. 40.3 Omohyoid muscle is divided and sternocleidomastoid muscle (SCM) is retracted medially to provide access to supraclavicular lymph nodes.

40.3.2 Lateral Thoracic Lymph Node Transfer

1. Indocyanine green (ICG) is injected along the lateral thorax, and infrared camera is used to identify lymph node basins.
2. Longitudinal incision is made overlying the nodes.
3. Lateral thoracic artery is identified with accompanying vein, and nodes are harvested based on this pedicle.
4. If combined with either pedicled or free latissimus dorsi (LD) flap, the thoracodorsal artery and vein serve as the vascular pedicle. The nodes are harvested through extended medial dissection off the LD muscle and included in the flap. Skin only, partial muscle, or entire muscle can be included depending on recipient site defect (▶ Fig. 40.5).
5. Incision is closed in layers over a closed-suction drain.

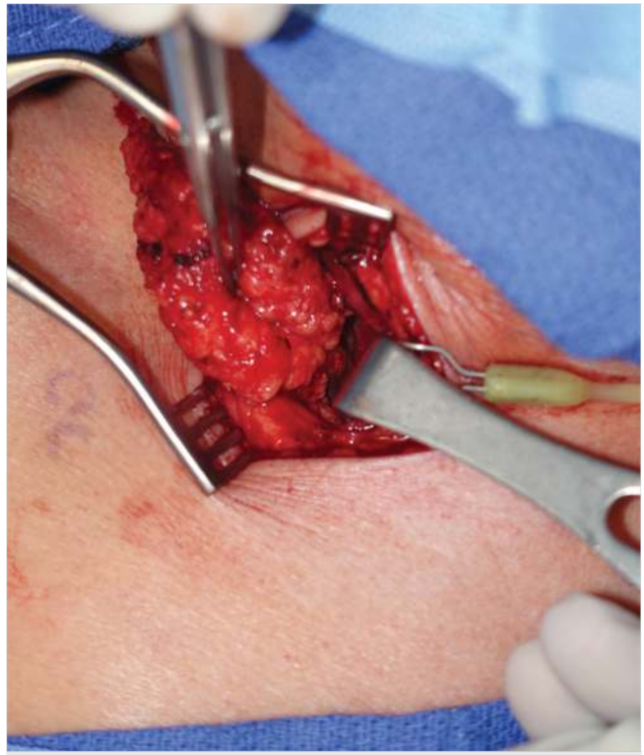


Fig. 40.4 Harvested supraclavicular lymph node flap based on the transverse cervical artery (TCA) and accompanying vein.

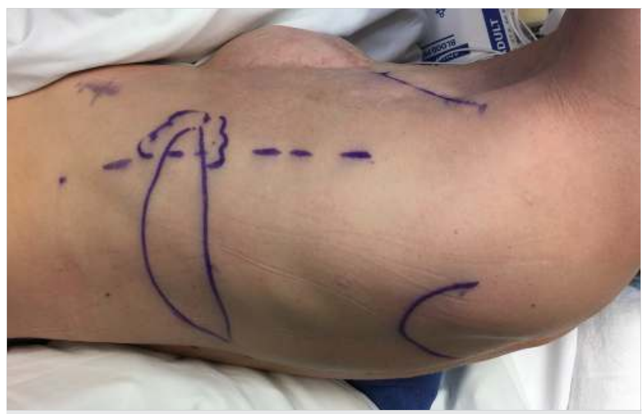


Fig. 40.5 Design of combined pedicled partial myocutaneous latissimus dorsi (LD) flap with vascularized lymph node transfer (VLNT).

40.3.3 Groin Lymph Node Transfer

1. To minimize risk of iatrogenic lower extremity lymphedema, reverse lymph node mapping is done. The legs are injected intradermally with technetium-99 labeled albumin.
2. Transverse groin incision is made above the inguinal ligament, and dissection is carried inferiorly in a superficial plane in order to identify the superficial inferior epigastric (SIE) or superficial circumflex iliac (SCI) vessels.
3. Lymph nodes are identified deep to Scarpa's fascia, lateral to the superficial inferior epigastric vein (SIEV), and around the SCI vessels.[12,13]

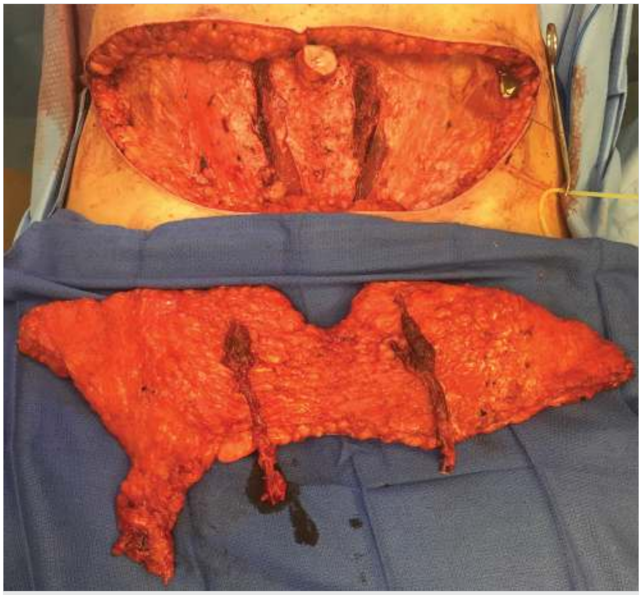


Fig. 40.6 In this case, combined abdominal free flap and bipedicled deep inferior epigastric perforator (DIEP) flap is harvested, for breast reconstruction with groin vascularized lymph node transfer (VLNT) including superficial inferior epigastric vein (SIEV).

4. Gamma probe is used to identify and exclude the sentinel nodes in the groin that typically lie medial to the SIE vessels and inferior to the inguinal ligament.[14]
5. Nodes are harvested based on either an SIE or SCI pedicle.
6. If combining groin lymph node transfer with abdominally based free flap for breast reconstruction, tissue superior to the nodes is left in continuity with the abdominal fat. The abdominal flap is harvested in the standard fashion, based on the deep inferior epigastric (DIE) vessels (▶ Fig. 40.6). If ipsilateral DIE vessels are used, only venous anastomosis is required for the lymph node flap, as nodes receive arterial supply through the flap.
7. The flap is transferred to the chest, and anastomosis of DIE vessels and internal mammary vessels is performed. Venous anastomosis between the SIEV or superficial circumflex iliac vein (SCIV) is performed to a branch of the thoracic duct vein, placing the nodes in the axilla.
8. Groin donor site should be obliterated with quilting sutures or an adipose flap from the abdomen to decrease risk of seroma.[15]

40.3.4 Recipient Site Preparation

Common recipient sites in the upper extremity include the axilla, elbow, or wrist, and groin, distal thigh, proximal leg, or ankle in the lower extremity. Skin paddles can be unsightly and require revision for debulking or removal. In general, the senior author prefers more proximal recipient sites because incisions can be camouflaged, scar can be released and replaced with vascularized tissue that may facilitate lymphatic drainage, and because VLNT is thought to result in lymphangiogenesis.[8] Others advocate distal placement of lymph nodes in more depended areas of the limbs typically free of scar, where VLNT acts as a lymphatic "pump."[16]

In cases of previous trauma or surgical resection where soft tissue deficit and scar are present, extensive scar release is recommended. In these cases, lymph nodes may be harvested with an accompanying muscle, myocutaneous, or fasciocutaneous flap. Flap soft tissue bulk may be used to correct deficiency, as seen in previous axillary or groin dissection. Skin paddles may be required if there is insufficient tissue to allow for primary closure of skin at the recipient site, or flaps may be buried. In cases of primary lymphedema or previous abdominal or pelvic LND without significant scar tissue at the recipient site, recipient artery and vein of appropriate caliber to match the flap pedicle should be identified. The recipient site should be selected based on proximal extent of lymphedema. For example, if a patient has primary lymphedema that affects only the foot and calf, VLNT may be placed in the distal thigh. But if the entire limb is involved, VLNT to the groin is recommended.

40.4 Conclusion

Vascularized lymph node transfer is an effective treatment for either primary or secondary lymphedema of the upper or lower extremity, typically for patients with moderate to severe disease. Multiple donor sites for lymph node harvest are available, and selection of the most appropriate donor site depends on the patient's medical or surgical history, qualities of the recipient site, and patient's preference. In this chapter, practical step-by-step guides to safe lymph node harvest and transfer have been presented.

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Section III

Hand and Upper Extremity

III

41 Hand Infections

M. Shuja Shafqat, Bharat Ranganath, Nathan Miller, and Robert X. Murphy Jr.

Abstract

Hand infections are a common problem encountered by the plastic surgeon and understanding of the diagnosis and treatment are of paramount importance. Many different types of infections are seen. However, knowledge of basic principles is key to the treatment of these processes. This chapter aims to outline these principles both inside and outside the operating room. In addition, acute and chronic paronychia/eponychia, felon, purulent flexor tenosynovitis, collar button, and deep space abscesses are reviewed as well as how to diagnose and deal with these infectious processes.

Keywords: abscess, collar button, deep space, eponychia, flexor tenosynovitis, hand infections, paronychia

41.1 Introduction

41.1.1 General Principles

Hand infections are a commonly encountered problem by the plastic surgeon. These infections, even when properly treated, can lead to stiffness, disability, or amputation. Modern advances in antibiotic therapy have significantly decreased the morbidity from hand infections but should never replace surgical drainage when indicated.[1] One should have adequate knowledge of the spaces of the hand where pus can collect and how to adequately examine them.[2]

41.1.2 Epidemiology

The most common infections encountered are cellulitis, paronychias/eponychias, felons, and purulent flexor tenosynovitis. The most common mechanisms are human and animal bites, intravenous drug use, and other traumatic inoculations.[2] Patients who are immunosuppressed are most susceptible and one should have a heightened awareness and a lower threshold for surgical intervention.[2,3,4]

41.1.3 Treatment

All patients with infections of the hand should be treated with elevation of the hand above heart level, immobilization with a resting hand splint, antibiotics tailored to the most likely causative organism and the type of infection or cultures if available, and early therapy and range of motion to prevent functional deficit.[2] All patients with pus confined to an enclosed space should undergo surgical drainage.[4,5]

41.1.4 General Surgical Principles

Preoperative

- Patients should be positioned with extremity on a hand table so that exposure will be adequate.
- Lights should be placed proximally and distally along the extremity and at 90 degrees to the field of view of the surgeon and the assistant. They should not be oriented parallel to the field of view or radial/ulnar to the extremity to prevent shadowing.
- Tourniquet should be placed. Adequate cast padding can be used with an upper arm pneumatic tourniquet or rubber Penrose drain can be wrapped at the base of the finger and secured with a hemostat.
- **Exsanguination (Esmarch) is contraindicated** because of the chance of forcing the infection into new tissue planes. The extremity should be elevated for several minutes before inflating the tourniquet.[1] Some may occlude the radial and ulnar artery during this time before the tourniquet is inflated.
- Tourniquet is set to 100 mm Hg over the patient's systolic blood pressure, commonly at 250 mm Hg.

Intraoperative

- Large incisions should be used to expose the entirety of the area in question and allow for adequate drainage[1]:
  - Incisions should be designed to be extended if necessary.[1]
  - Avoid exposure of critical structures if unnecessary.[1]
  - Avoid incisions directly across flexion creases to prevent long-term contracture.[1]
- Cultures and gram stain should be taken upon the encounter of pus. If multiple different spaces are encountered, separate cultures should be taken. In addition, tissue cultures and biopsies can be taken for quantitative culture and diagnosis of abnormal tissue. Fungal and mycobacterial cultures should be considered in the appropriate setting (chronic infections, immunosuppressed, etc.).[1,4]
- Necrotic tissue should be adequately debrided to prevent propagation of infection.[1,2]
- Irrigation via syringe, gravity, or pulse lavage should be done prior to dressing application.[1]

Postoperative

- Incisions can be left open with moist dressings to prevent desiccation and premature closure of any wounds.[1,6]
- Pieces of strip packing should be left in small wounds to allow for drainage and prevent closure.
- Soft and loose dressings should be applied to allow for swelling of the hand and to avoid strangulation.[1]
- Consistent and frequent re-evaluation is of paramount importance. Should the patient fail to resolve, repeat drainage or debridement may be necessary and should not be delayed.[6]
- Amputation may be required if the digital vessels become occluded and the finger is not viable.[1]

41.1.5 Acute Paronychia/Eponychia

A paronychia is an infection beneath the eponychial or paronychial folds.[1] They may develop as a result of disruption between the nail and the underlying tissues. They can occur in both acute and chronic forms.[2] Diagnosis is made by physical examination demonstrating an area of erythema and fluctuance dorsal to the nail, which may spread superficially around to the contralateral side of the nail. The infection may also progress to the volar aspect of the finger and involve the pulp.[5] Patients will complain of pain, redness, and swelling around the nail and may also report drainage of pus.

41.1.6 Chronic Paronychia

Chronic paronychias are associated with diabetes or chronic exposure to moisture as seen in dishwashers or cafeteria workers.[3] Patients may complain of occasional drainage of cheesy exudate.[6] Cultures often demonstrate a fungal infection (*Candida albicans*), and occasionally pseudomonas, or atypical mycobacterium.

41.1.7 Felon

A felon is an abscess of the pulp in the thumb or the fingertip.[1] The fingertip is composed of a series of fascial bands that run from the distal phalanx to the skin, defining separate compartments within the finger pulp.[4] An infection in these small, closed spaces results in a rapid development of pain. Physical examination reveals a red, swollen, fluctuant fingertip which is exquisitely tender. Patients often complain of throbbing at night.[3] These infections often result from a puncture wound to the finger pulp or progression of a severe paronychia.

41.1.8 Flexor Tenosynovitis

One should be familiar with the diagnosis of flexor tenosynovitis (FTS) and **Kanavel's four cardinal signs**[1,2,3,4,5,6]:

- Fusiform and symmetric swelling of the entire digit.
- Flexion posturing.
- Tenderness along the flexor sheath.
- **Pain on passive extension**—this is the most reliable sign that is seen earliest and commonly present[2]:
  - Pitfall: A common pitfall seen is accidentally putting pressure on a tender area of cellulitis, abscess, or septic joint while performing this maneuver. Ensure that as you examine the patient you carefully watch where you place pressure on the patient's digit.
  - A sign that we commonly see is the patient will try to actively extend the wrist as the examiner attempts to passively extend the finger. This is in effort to prevent finger extension and elucidating pain. We find this to be a reliable adjunct to this cardinal sign.

Beware if two of these signs are present.[2] FTS is most commonly caused by a penetrating trauma leading to inoculation of the tendon sheath.[1,4] Patients usually present at least 2 to 3 days after the inciting event.[3] This is a surgical emergency and expeditious diagnosis and treatment is the goal.[1,2] X-ray should be obtained before going to the operating room looking for foreign bodies or bony irregularity.

41.1.9 Deep Space and Collar Button Abscess

There are four anatomic deep spaces of the hand: the first webspace, the midpalmar space, the thenar space, and the hypothenar space. In the setting of overlying cellulitis, foreign body, or penetrating wounds, these spaces can become infiltrated by infection and develop abscesses.[1,2]

Diagnosis is clinically based on erythema, fluctuance, and extreme pain on palpation and flexion/extension. The fingers may be abducted in the setting of a collar button abscess, or there may be loss of the normal palmar concavity in midpalmar space abscess. Radiographs are useful to identify foreign bodies and may show associated bony destruction. Magnetic resonance imaging (MRI) or computed tomography (CT) can be used to define presence of fluid collections suggestive of abscess.[1,2,3]

The term "collar button abscess" is used to describe an abscess in the webspace that involves both the volar and dorsal aspects with communication through the deep transverse metacarpal ligament. Pain on abduction and adduction of the metacarpophalangeal (MCP) joint is a hallmark of this diagnosis.[2,7]

41.2 Indications

41.2.1 Acute Paronychia/Eponychia

Indications

- Indications for operative intervention include acute paronychia or eponychia with evidence of abscess.[3]

Contraindications

- Contraindications to surgery include an early infection without abscess formation.

Conservative Treatment

- Conservative treatment involves appropriate antibiotic selection for the most common causative organisms, soaks, elevation, and splinting.[2,3,4,6]

41.2.2 Chronic Paronychia

Contradictions

Contraindications for surgery include failure to treat with conservative treatment first, including topical and oral treatments.

Indications

- Indications for surgical intervention are failed conservative treatment.

Conservative Treatment

- Conservative treatment includes topical antifungals, followed by oral antifungals if topical treatment fails.
- Gentian Violet applied twice daily has also been shown to be effective in managing chronic paronychial infections.

41.2.3 Felon

Indications

- Indications for operative intervention include an acute felon with pus.

Contraindications

- Contraindications include an early infection without pus formation.[1]

Conservative Therapy

- Conservative management includes elevation, warm soaks, and oral antibiotics.[5]

41.2.4 Flexor Tenosynovitis

Indications

- At least three of the Kanavel signs.

Contraindications

- A relative contraindication is early FTS.

Conservative Treatment

Patients rarely seek treatment early.[1,2,3] However, if they present within the first 24 hours with mild symptoms and only expression of one or two Kanavel signs, they can be treated conservatively with intravenous (IV) antibiotics, elevation, and splinting.[1,3,5,6] The tendon sheath can also be aspirated with a needle to obtain fluid for culture before antibiotics are given. Do not aspirate in any areas of acute cellulitis to avoid inoculating a sterile tendon sheath. If pus is encountered on aspiration, proceed to surgical treatment.[1]

Nonsurgical treatment should not be considered in the immunocompromised patient (see Introduction section).[1] Patients treated conservatively need frequent reassessment and if infection fails to resolve or improve significantly within 24 hours, surgical treatment should be quickly initiated.[1,3,6]

41.2.5 Deep Space and Collar Button Abscess

Diagnosis of an abscess necessitates operative drainage.

Conservative Treatment

- Nonoperative treatment is only indicated if there is no discrete abscess.
- IV antibiotics, elevation, warm compresses, and immobilization are the mainstays of conservative treatment.

41.3 Operative Technique

41.3.1 Acute Paronychia/Eponychia

- Adequately anesthetize finger with digital nerve or tendon sheath block.
  - This is routinely performed with 1% plain lidocaine and a 30-gauge needle. Lidocaine with epinephrine is also acceptable.
- Elevate nail fold with a blade, pointing tip away from nail bed to avoid iatrogenic injury (▶ Fig. 41.1a).[1,3]

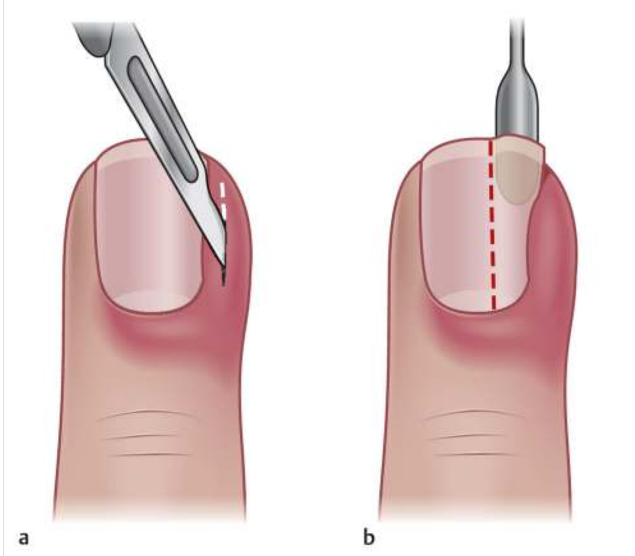

Fig. 41.1 Acute paronychia: **(a)** Incision to drain a paronychia with blade pointed away from the nail bed. **(b)** Partial nail plate removal if subungal abscess is present.

- Culture, irrigate thoroughly, and place a small wick of gauze under nail fold.
- If subungual abscess is noted, the involved portion of the nail is removed after it is carefully separated from the nail bed with a periosteal elevator (▶ Fig. 41.1b).[1,2,3,5,6]
- Incisions in the eponychial fold are rarely indicated and should be avoided.[6]
- Dressings are removed in 24 hours, and warm soaks are begun, followed by nonadherent gauze and dry, sterile dressings two to three times daily.[1]
  - Our preferred dressing is Telfa and compressive gauze wrap.
- Continue oral antibiotic coverage for 5 to 7 days.[6]

41.3.2 Chronic Paronychia

- Adequately anesthetize finger with digital nerve or tendon sheath block.
  - This is routinely performed with 1% plain lidocaine and a 25-gauge needle.
- A crescent-shaped portion of skin (1 mm proximal to the eponychial fold and 3 to 5 mm in width) is excised proximal to the eponychial fold, taking care not to disturb the underlying matrix (▶ Fig. 41.2).[1,2]
- Any granulation tissue is removed.
  - Tissue is sent for bacterial, including mycobacterial, and fungal cultures and pathology.[1]
- Sterile dressings are applied.
- Warm soaks are started twice daily.
- Wound is allowed to heal by secondary intention.[1,2]

41.3.3 Felon

- Adequately anesthetize finger with digital nerve or tendon sheath block.

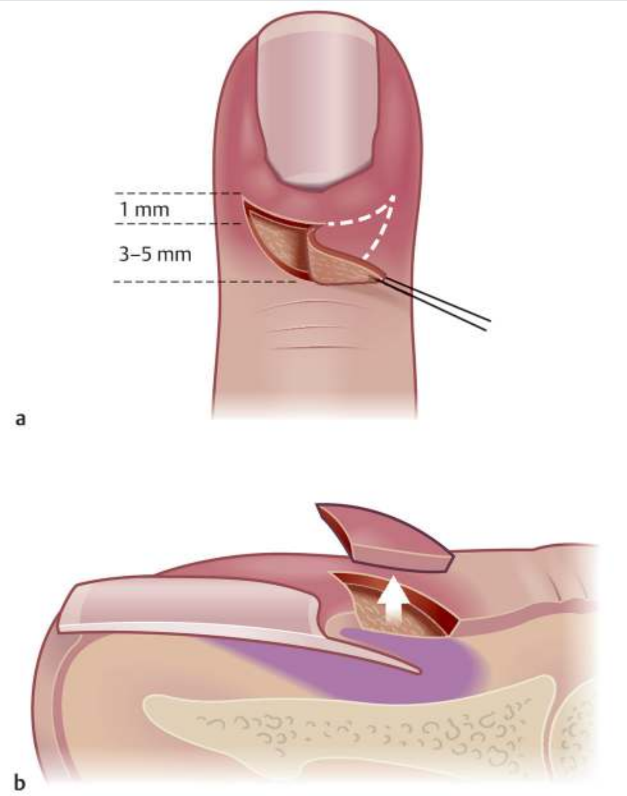

Fig. 41.2 (a, b) Chronic paronychia: Dorsal and lateral views of removal of the eponychial skin without disturbance of the underlying germinal matrix.

- This is routinely performed with 1% plain or with epinephrine lidocaine and a 30-gauge needle.
- If infection is "pointing" on the volar surface, an oblique incision directly over that area of the finger pad is most effective.
  - Incisions for drainage are otherwise placed on the midaxial, longitudinal axis on the ulnar side for the index, long, and ring fingers, and on the radial side for the small finger and thumb (▶ Fig. 41.3).[1]
- Branches of the neurovascular bundle are avoided by using a fine clamp or scissors, and the fibrous septa are dissected just volar to the volar periosteum.[1,2]
  - Enter the incision with the instrument until you encounter the distal phalanx.
  - Gently slide the tip of the instrument volar until you can pass it palmar to the distal phalanx.[1]
  - Spread with some degree of pressure to open all of the fibrous septa.[5]
- Must ensure that all compartments are decompressed.
- Culture exudate, irrigate thoroughly, and pack loosely with gauze.[2,6]
- Apply sterile dressings and apply protective splint over distal digit.
- Warm soaks are started twice daily and applied until the wound is closed by secondary healing.[2,6]

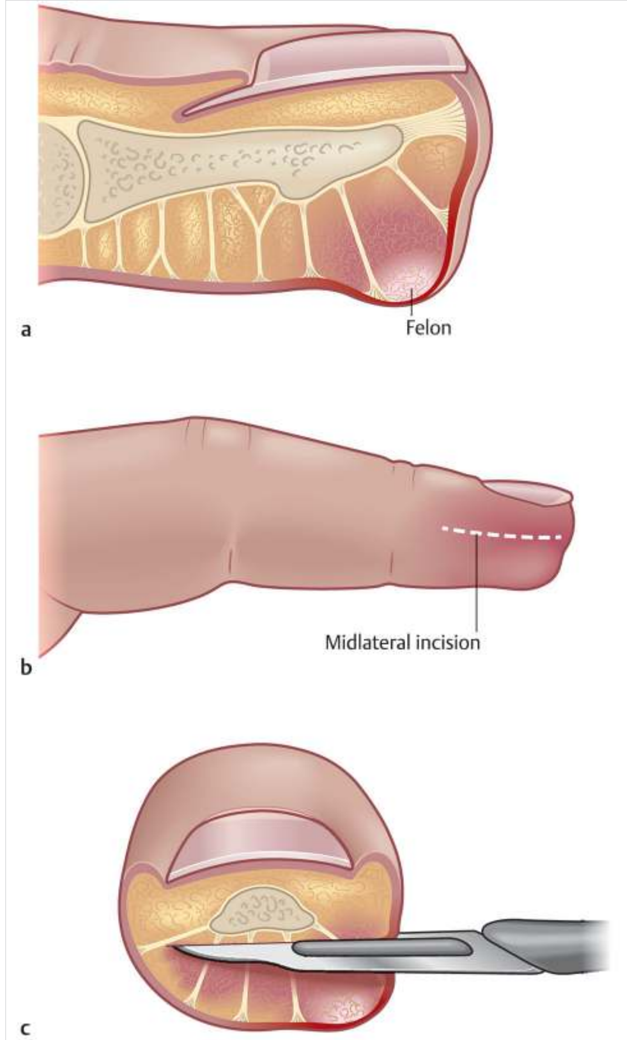

Fig. 41.3 Felon: **(a)** Pus can collect within pockets between fibrous bands of the fingertip. **(b)** Midaxial approach. **(c)** Necessary extent of drainage for a felon.

41.3.4 Flexor Tenosynovitis

- See ▶ Video 41.1 for an example of the operative technique.
- There are multiple techniques described that allow for adequate decompression of the sheath.
- Incisions at the level of the A1 pulley and at the distal interphalangeal (DIP) joint volar crease will allow exposure to the flexor sheath. Releasing the A1 pulley permits access to the interval between the flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) tendons where an angiocatheter can be introduced easily. Normal saline can be flushed distally from the proximal incision out of the distal incision (▶ Fig. 41.4).
  - The wide exposure approach through a midlateral approach is preferred for patients with advanced stages of infection and likely tendon necrosis (▶ Fig. 41.5).[3] *Bruner zig-zag incisions could lead to exposed tendons and desiccation and therefore should be avoided.*

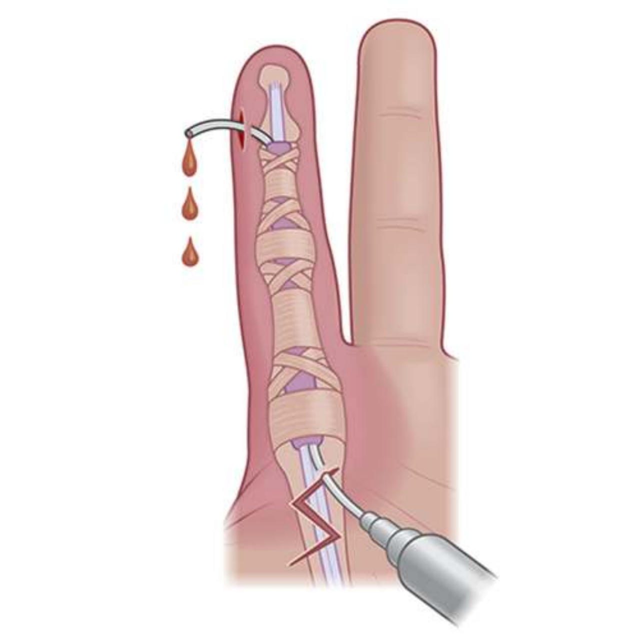

Fig. 41.4 Closed tendon sheath irrigation method for drainage of flexor tenosynovitis.

Video 41.1 Flexor tenosynovitis: Incision and drainage

- Irrespective of the technique, the key goals are accessing the tendon sheath, complete drainage, and irrigation until effluent is clear.

Wide Exposure Technique

- After tourniquet is inflated, a midlateral incision can be made.
- Zig-zag incision:
  - *Advantages*: Better exposure of the tendon sheath in its entirety and can be extended proximally and distally with ease.
  - *Disadvantages*: Create scars on pinching surfaces and if dehiscence occurs, the tendon and neurovascular structures may be exposed and desiccate. This is the main reason this technique is seldom used.
  - Can extend proximally into palm and into carpal tunnel if infection tracks proximally (▶ Fig. 41.5).
- Midlateral incision:
  - *Advantages*: Avoids scars on volar surfaces and will not risk tendon exposure and desiccation.
  - *Disadvantages*: May result in some numbness on the dorsum of the digit.

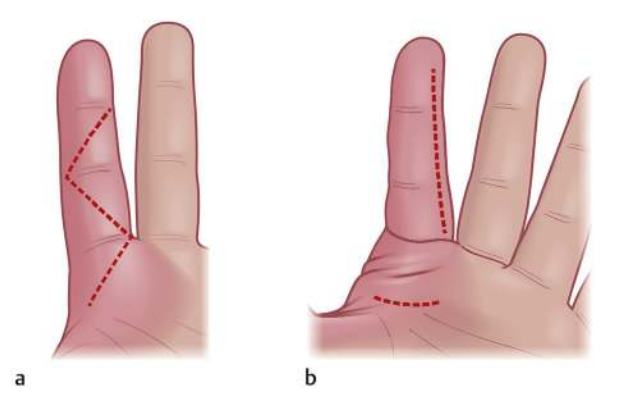

Fig. 41.5 Flexor tenosynovitis: **(a)** Design of a Bruner zig-zag incision. **(b)** Design of a midlateral incision with palmar A1 counter-incision.

  - Should be made on the ulnar border of the index, long, and ring fingers to avoid the pinching surface and on the radial border of the thumb and small fingers to avoid the exposed surface (▶ Fig. 41.5).[1]
  - Incision designed from mid-distal phalanx to the web-space.[1]
  - The incision can be extended proximally through zig-zag incisions in the palm.
  - Alternatively, a counter-incision can be made at the level of the A1 pulley.
  - Tendon sheath is accessed dorsal to the neurovascular bundles.[1]
  - After the incision is created, the sheath is opened proximal to A1 and distal to A4.[1]
  - Culture the pus that is present and debride any wounds and necrotic tissue including tendons if they too are necrotic.
  - Perform a synovial biopsy for fungus and mycobacterium if the synovium is excessively inflamed.[1]
  - Carpal tunnel release is indicated if infection tracks this far proximally.
  - Consider insertion of an angiocatheter antegrade into the tendon sheath for at least 1 cm and copious irrigation of the sheath with saline or antibiotic solution until effluent via the distal sheath is clear.
  - **Tip**: Be extremely careful of neurovascular structures when creating these large incisions. As in Dupuytren's disease, the structures can be displaced from their normal anatomic locations. In addition, they can be friable from excess inflammation. Be on the lookout for Pacinian corpuscles to mark these structures.
  - If there is significant necrosis of critical structures or a large percentage of the soft tissue, amputation may be necessary. Pang et al showed 17% amputation rate in their population.[8]

Through and Through Technique

- Make an incision in a zig-zag fashion over A1. Identify and open the tendon sheath.[1]
- Make a counter-incision just proximal to the DIP flexion crease and distal to A4. Again, identify and open the tendon sheath.

- Insert an angiocatheter antegrade into the tendon sheath between the FDS and FDP tendons and then copiously irrigate the sheath with saline or antibiotic solution until effluent via the distal incision is clear. The catheter does not need to remain in place.

Closed Tendon Sheath Technique

- Make an incision over the A1 pulley. Identify and open the tendon sheath (▶ Fig. 41.4).[1]
- Make a counter-incision on the ulnar midaxial side of the digit over the distal phalanx. Identify the neurovascular bundle and access the tendon sheath dorsal to it. Resect the sheath distal to the A4 pulley.
- Insert an angiocatheter antegrade into the tendon sheath and copiously irrigate the sheath with saline or antibiotic solution until effluent via the distal incision is clear. The catheter is removed and the wounds are not closed but allowed to heal by secondary intent.

Postoperative Care

- Wounds can be left open and packed with moist gauze, loosely closed with strip packing between the sutures to allow for drainage, or can be loosely reapproximated to allow adequate drainage.
- Lille et al published evidence that postoperative irrigation is **not** necessary as there was no significant difference between these and those that received only intraoperative irrigation.[9]
- Splint the hand.
- Elevate the hand.
- First dressing change should be done at 12 hours and then dilute soaks should be done.[1,2] We prefer warm dilute chlorhexidine soaks in our institution.
- Another excellent adjunct we have found is whirlpool therapy especially for patients undergoing wide exposure drainage or with tissue necrosis/open wounds.
- Packing may be discontinued when infection is resolved.
- Volar incision heals quickly.[1,6]
- Midlateral incision will heal by secondary intention.[1,6]
- As stated in the Introduction, consistent and frequent re-evaluation is of paramount importance. Should the patient fail to resolve by 24 to 48 hours, repeat drainage or debridement may be necessary and should not be delayed.[1]

Risk Factors for Poor Outcomes

- Above 43 years old, diabetes mellitus, peripheral arterial disease, renal failure, presence of subcutaneous purulence, digital ischemia, polymicrobial infection.[8]

41.3.5 Deep Space and Collar Button Abscess

- A tourniquet is generally used, but use of an Esmarch to exsanguinate the hand is contraindicated as this may force bacteria proximally through the tissue planes or lymphatic systems.
- Open incision and drainage and packing or placement of a drain.

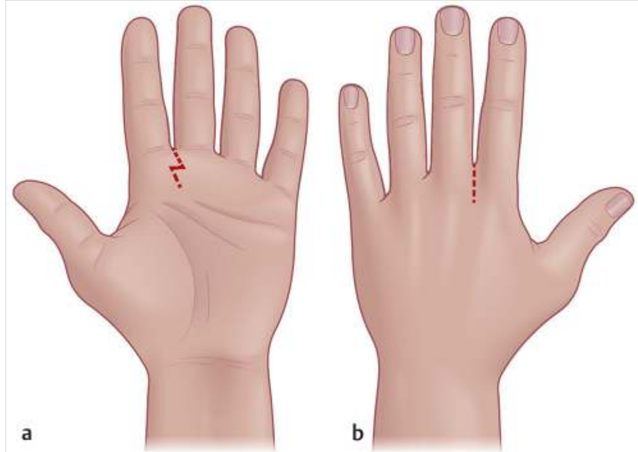

Fig. 41.6 (a) Volar and **(b)** dorsal approaches for drainage of collar button webspace abscesses.

- A large enough, longitudinal incision should be made to adequately drain the abscess cavity.[2,7,10,11,12]
- The wound should be probed to open up and drain all cavities.

Collar Button Abscess

- Intraoperative
  - Approach: Landmarks and marking
    - Both dorsal and volar incisions should be made (▶ Fig. 41.6).[7,10]
    - Do not create incision in the webspace as this could lead to contracture and webspace creep.
- Procedure
  - Volar incision
    - Zig-zag incision is made from just proximal to the apex of the webspace down to distal palmar crease.
    - Subcutaneous tissue is spread with a tenotomy scissor or mosquito clamp until abscess cavity is entered.
      - Care is taken to avoid injury to the common digital artery and nerves.
    - Abscess cavity is opened fully and drained, irrigated, and packed open with plan for serial packing changes.
      - Wound can be closed over an irrigation catheter or Penrose drain.
  - Dorsal incision
    - A longitudinal incision is made on the dorsal hand between the metacarpal heads from the just distal to the apex of the webspace and extending proximally over the area of fluctuance.
    - Subcutaneous tissue is spread until abscess cavity is entered and opened.
    - Abscess cavity is opened and drained, irrigated, and packed, a wick inserted, or closed over an irrigation catheter or Penrose drain.
      - If irrigation catheter is placed, this can be flushed with a continuous infusion of normal saline solution (NSS) or LR at 10 to 50 mL/hour.
- Postoperative
  - Packing or wicks are changed daily until resolution of infection.

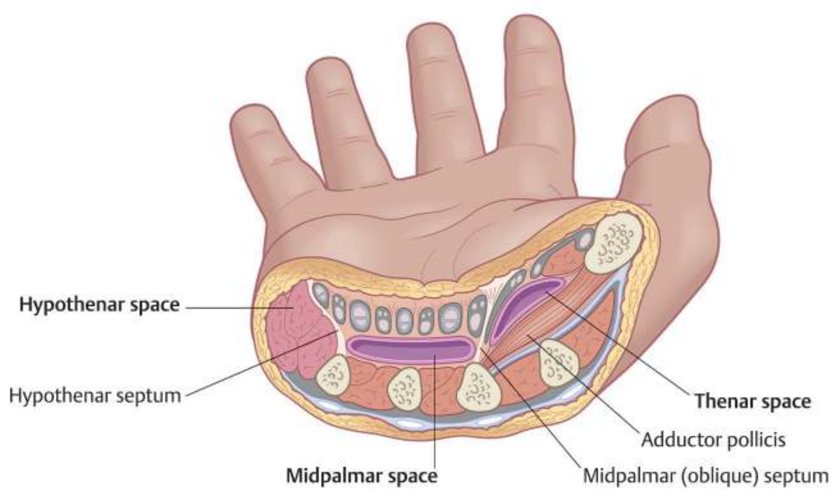

Fig. 41.7 Thenar, hypothenar, and midpalmar spaces of the hand and their boundaries.

- ◦ A second look procedure can be performed after 24 to 48 hours if clinical signs do not improve.
- Complications
  - It is key to avoid injury to the common and proper digital vessels and nerves as they bifurcate in this area and normal anatomy can be distorted.
  - Continuous irrigation can be uncomfortable for the patient and is therefore used less frequently.

Thenar Space

- Intraoperative
  - Approach: Landmarks and marking
    - The thenar space is bounded by the adductor pollicis (dorsal border), the index finger tendons (volar border), and the midpalmar septum (ulnar border) (▶ Fig. 41.7).
    - A volar incision is always performed, and consideration is made for an additional dorsal incision if there is further extension of the abscess cavity in this direction that cannot be drained from a volar approach.[10,11]
- Procedure
  - A curved longitudinal incision is made over the thenar space from the metacarpophalangeal (MP) crease distally extending proximally over the thenar space.
  - The subcutaneous tissue is spread taking care to avoid injury to cutaneous nerves, and in particular the recurrent motor branch of the median nerve.
  - Abscess cavity is opened fully and drained.
  - The first dorsal interosseous compartment is often released.
  - The wound is then irrigated and packed open with plan for serial packing changes or can be closed over an irrigation catheter or Penrose drain.
- Postoperative
  - See above for collar button abscess.
- Complications
  - The recurrent motor branch of the median nerve and the superficial palmar arch are within the vicinity and should be identified and protected.

Midpalmar Space Abscess

- Intraoperative
  - Approach: Landmarks and marking
    - The midpalmar potential space is defined by the distal extent of the transverse carpal ligament proximally, the 2nd, 3rd, and 4th metacarpals dorsally, the flexor tendons and lumbricals volarly, the midpalmar septum/thenar eminence radially, and the hypothenar eminence ulnarly (▶ Fig. 41.7).[1,3,12]
- Procedure
  - A transverse incision over the distal palmar crease or a curved longitudinal incision between affected metacarpals can be made.
  - Dissection is carried down past the flexor tendons.
  - The abscess cavity/palmar space is entered and the cavity is opened and drained, copiously irrigated, and packed or closed over a Penrose drain.
- Postoperative
  - See above for collar button abscess.
- Complications
  - Care must be taken to avoid injury to branches of the median nerve and the superficial palmar arch.

Hypothenar Space Abscess

- Intraoperative
  - Approach: Landmarks and marking
    - The hypothenar space is volar to the 5th metacarpal and dorsal/radial to the hypothenar septum/midpalmar space (▶ Fig. 41.7).[1,7,10,11,12]
- Procedure
  - A curved longitudinal incision over the hypothenar eminence or 5th metacarpal is made.
  - Dissection is carried down to the fluctuant abscess cavity, which is opened and drained, copiously irrigated, and packed, wicked, or closed over a Penrose drain.
- Postoperative
  - See above for collar button abscess.

41.4 Conclusion

A thorough understanding of hand infections is of great importance to plastic surgeons as they are a commonly encountered problem. Various infections are possible, and knowledge of basic principles is key to the treatment of these processes. The principles outlined in this chapter allow a comprehensive approach to manage these issues inside and outside the operating room.

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42 Fingertip and Nail Bed Injuries

Sean J. Wallace, Robert M. Teixeira, and Robert X. Murphy Jr.

Abstract
Revision amputation should be discussed with every patient undergoing fingertip or nail bed injury reconstruction. Fastidious removal of the nail plate is necessary when nail bed lacerations have been identified. The nail plate is often replaced under the eponychial fold to prevent syncytial adhesions, to splint the nail bed, and to act as a dressing for the nail bed. Loupe magnification is strongly encouraged when repairing nail bed injuries and many fingertip injuries.

Keywords: fingertip amputation, fingertip anatomy, fingertip injury, heterodigital flap, homodigital flap, nail bed anatomy, nail bed injury, nail bed laceration, revision amputation

42.1 Introduction

42.1.1 Fingertip Injuries

Overview and Anatomy

- The fingertip refers to the region of the digit distal to the distal interphalangeal (DIP) joint, which includes the nail plate, nail bed, hyponychium, eponychium, the distal phalanx, and the insertions of the extensor and flexor tendons (▶ Fig. 42.1).[1,2]
- Injury to this region of the digit is a common ailment seen in the emergency department by the plastic surgeon with the long and ring fingers being the most commonly injured.[1,2]
- Neurovascular considerations at the fingertip include trifurcation of proper digital nerves and arteries just distal to the DIP joint.

Initial Evaluation

- Perform a full history and physical examination, but with a focus on the particular injury.

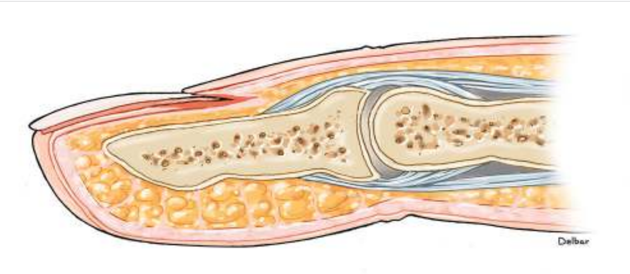

Fig. 42.1 Fingertip and nail bed anatomy. The fingertip and nail bed are anatomically described as distal to the distal interphalangeal (DIP) joint. Pertinent anatomy includes the nail plate, nail bed, hyponychium, eponychium, distal phalanx, and the insertions of the extensor and flexor tendons. From Bentz ML, Bauer BS, Zuker RM. Principles and Practice of Pediatric Plastic Surgery. 2nd ed. New York: Thieme Medical Publishers; 2016.

- Document age, gender, hand dominance, mechanism, level of injury, nicotine use, previous hand injuries, occupation, hand hobbies, comorbidities, and patient expectations.[1,2]
- Document physical examination findings prior to anesthetizing the area of injury, which should include neurovascular status, size of the defect, level of the injury, geometry of the defect, and presence of exposed bone.[1,2]
- Anteroposterior (AP) and lateral digital or hand radiographs can be utilized to evaluate for fractures and/or the presence of foreign bodies.

42.1.2 Nail Bed Injuries

Overview and Anatomy

- The nail plate and nail bed are made up of the germinal matrix, lunula, sterile matrix, eponychium, and hyponychium (▶ Fig. 42.1).[3,4]
- The germinal matrix produces approximately 90% of the nail, while the sterile matrix contributes approximately 10%. Regeneration of a complete nail takes approximately 3 to 4 months but up to 12 months for a final nail.[3,4]
- As with fingertip injuries, damage to this region is a common ailment seen in the emergency department by the plastic surgeon and is commonly associated with distal phalanx fractures.[3]
- Neurovascular considerations of the nail bed include terminal branches of volar-digital arteries and dorsal branches of digital nerves.

Initial Evaluation

- Perform a full history and physical examination, but with a focus on the particular injury.
- Document age, gender, hand dominance, mechanism, level of injury, tobacco smoking status, previous hand injuries, occupation, hand hobbies, comorbidities, and patient expectations.[3,4]
- Document a complete hand examination prior to anesthetizing the area of injury, being sure to include fingertip sensation, capillary refill, and flexor/extensor function.[3,4]

AP and lateral digital or hand radiographs can be utilized to evaluate for fractures and/or the presence of foreign bodies.

42.2 Indications

42.2.1 Fingertip Injuries

Goals of Reconstruction

- Restoration of form and function while minimizing donor site morbidity.[2]
- Preservation of joint function, sensation, and digital length.[2]
- Provide an aesthetically acceptable outcome and avoid common complications.[2]

- ∘ Treatment options may include direct closure, healing by secondary intent, skin grafting, reconstruction with local or regional flaps, revision amputation, or microsurgical replantation.

42.2.2 Nail Bed Injuries

Goals of Reconstruction

- Restoration of form and function while minimizing donor site morbidity.[3,4]
- Preservation of sensation, as two-point discrimination is dependent on nail function.[3,4]
- Provide aesthetically acceptable outcomes and avoid common complications.[3,4]

42.3 Operative Technique

42.3.1 Fingertip Injuries

Preparation

- Surgical loupe magnification.
- Digital block versus need for conscious sedation versus general anesthesia.
- Irrigation and debridement of devitalized tissue and foreign bodies.
- Digital tourniquet can be achieved with the use of a small Penrose drain and hemostat clamp or with the use of a Tourni-Cot.

Treatment Modalities

- Direct closure
  - Indicated in instances of minimal soft-tissue loss with remaining dorsal or volar skin flap.[2,5] Note: Volar skin flap provides better sensate option.
  - If exposed bone is present in the wound, utilize bone cutter or Rongeur to shorten bone and mobilize skin flap for tension-free closure.[2,5]
  - Wound care: Dressing changes with antibiotic ointment and nonadherent gauze until healed.
  - Close wounds with a resorbable suture such as small caliber Chromic or Vicryl Rapide. Nonabsorbable suture can be painful upon removal.
- Healing by secondary intent
  - Traditionally indicated in instances of soft-tissue defect ≤ 1 cm^2 without exposed vital structures.[2,5]
  - Larger wounds (2.5 cm) can also heal by secondary intent even if a small amount of bone is exposed.[2,5]
  - Provides a better option for near-complete sensate recovery.[2,5]
  - Wound care: Dressing changes with antibiotic ointment and nonadherent gauze until healed.
- Skin grafts
  - Split-thickness skin graft (STSG)
    - Rarely indicated due to high complication rate including graft failure, graft contracture, cold sensitivity, and poor sensibility.[2,5]
    - A vascular bed is required (no exposed tendon or bone).[2,5]
    - Donor sites include hypothenar eminence or extremity.[2,5]
    - Wound care: Bolster dressing with nonadherent petroleum-based gauze for 5 days followed by antibiotic ointment and nonadherent gauze until healed.
  - Full-thickness skin graft (FTSG)
    - Indicated in instances of need for wound closure sooner than closer by secondary intent can provide.[2,5]
    - Must have periosteum or peritenon present for graft-take.[2,5]
    - Donor site includes hypothenar eminence, wrist crease, antecubital fossa, and medial arm.[2,5]
    - Wound care: Bolster dressing with petroleum-based gauze for 5 days followed by antibiotic ointment and nonadherent gauze until healed.
  - Composite graft
    - Indicated in pediatric population with small volar soft-tissue defects and exposed bone.[2,5]
    - Nonmicrosurgical replantation of amputated portion to serve as biologic dressing to allow underlying wound to heal by secondary intent.[2,5]
    - Wound care: Dressing changes with antibiotic ointment and nonadherent gauze until healed.
- Local flaps
  - Homodigital
    - Atasoy-Kleinert (single volar V-Y advancement) (▶ Fig. 42.2)
      - ■ Indicated in dorsal-oblique and transverse injury geometries of < 1 cm.[2,5,6]
      - ■ Reconstruction by incorporating donor tissue from proximally on the injured digit.
      - ■ Provides a better option for near-complete sensate recovery.
      - ■ Mobilize a full-thickness volar triangular V-Y advancement flap along distal phalanx from DIP flexion crease to terminal component of injury along nail bed, granting up to 1 cm advancement coverage.[2,5,6]
      - ■ Commonly requires a degree of bone shortening with bone cutter or Rongeur.
      - ■ Flap can be designed to cross DIP flexion crease and include neurovascular bundles to allow increased advancement.[2,5,6]
      - ■ Donor site is closed loosely in standard V-Y fashion.
      - ■ Wound care: Dressing changes with antibiotic ointment and nonadherent gauze until healed.
      - ■ Kutler (bilateral lateral V-Y advancements) (▶ Fig. 42.3)
      - ■ Indicated in transverse and lateral oblique injury geometries of < 1.0 cm.[2,5,6]
      - ■ Reconstruction by recruiting donor tissue from laterally on the injured digit.
      - ■ Provides a better option for near-complete sensate recovery.
      - ■ Mobilize full-thickness bilateral lateral triangular V-Y advancement flaps to the terminal component of injury along nail bed. The dorsal incision is carried down to the level of the periosteum, while the volar incision is limited to the dermal layer.[2,5,6]
      - ■ Commonly requires a degree of bone shortening with bone cutter or Rongeur.
      - ■ Donor site closed in standard V-Y fashion.
      - ■ Wound care: Dressing changes with antibiotic ointment and nonadherent gauze until healed.

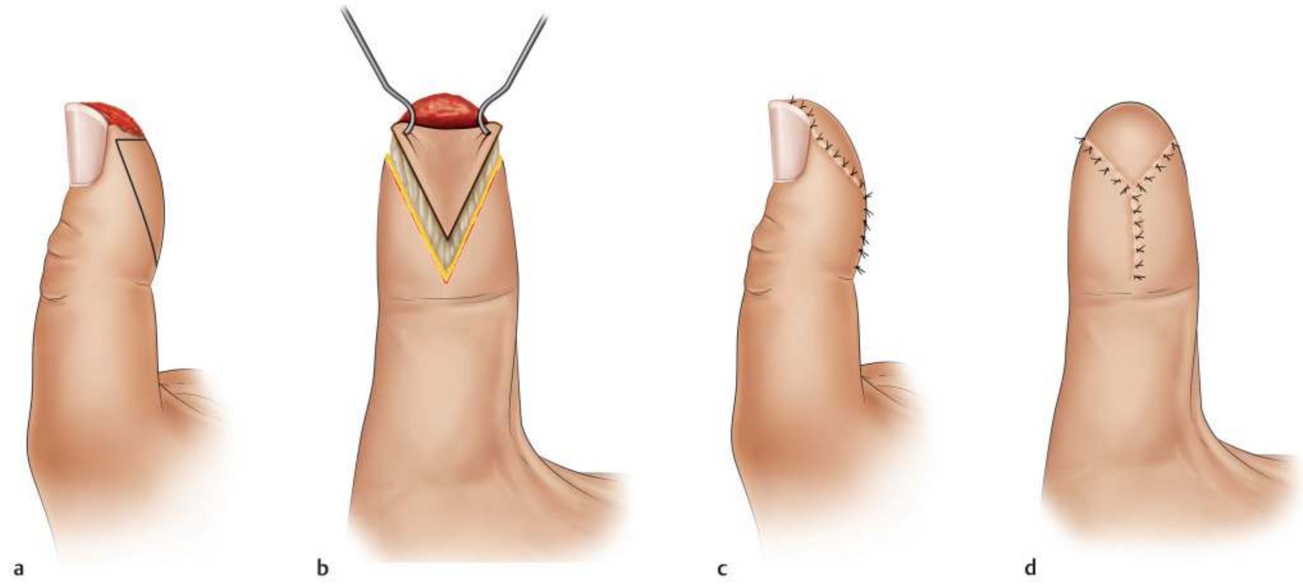

Fig. 42.2 (a–d) The Atasoy-Kleinert flap. A full-thickness volar triangular V-Y advancement flap is raised along distal phalanx from the distal interphalangeal (DIP) flexion crease to terminal component of injury along nail bed. This grants up to 1 cm advancement coverage. The donor site is closed in standard V-Y fashion. From Germann G, Levin LS, Sherman R. Reconstructive Surgery of the Hand and Upper Extremity. New York: Thieme Medical Publishers; 2017.

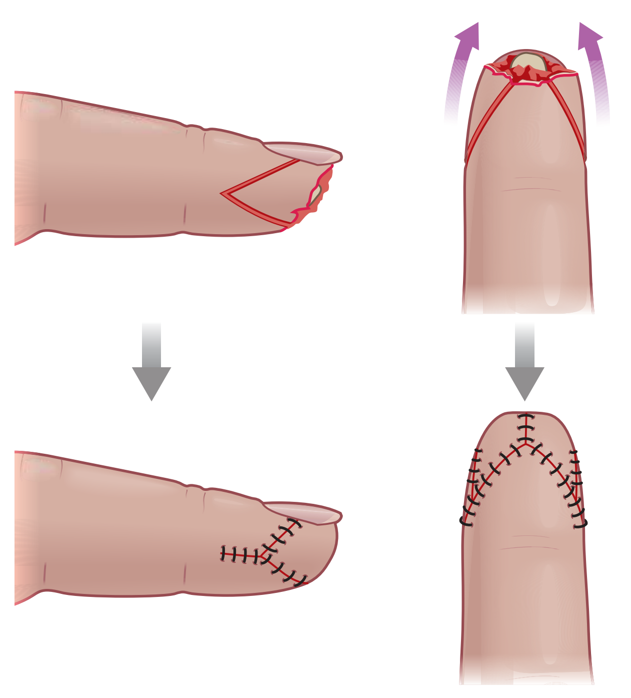

Fig. 42.3 The Kutler flap. A full-thickness bilateral lateral triangular V-Y advancement flap is raised to provide coverage to the terminal component of the injury. The dorsal incision is carried down to the level of the periosteum, while the volar incision is limited to the dermal layer. The donor site is closed in standard V-Y fashion.

- Moberg (volar advancement) (▶ Fig. 42.4)
  - ■ Indicated most commonly for volar-oblique distal thumb injuries.[2,5,6]
  - ■ Reconstruction supplied by bilateral volar-digital arteries, granting up to 1 to 2 cm advancement coverage.[2,5,6]
  - ■ Provides a better option for near-complete sensate recovery.
  - ■ Mobilize full-thickness volar flap by making radial-axial and ulnar-axial incisions, dissecting down to the level of flexor tendon, and advancing recruited tissue to terminal component of injury.[2,5,6]
  - ■ The volar tissue can be advanced further by creating a V incision at the base of the flap and advancing it in a V-Y fashion.[2,5,6]
  - ■ Alternatively, greater advancement can be made by creating a transverse incision at the base of the flap and skin grafting the proximal defect following advancement.[2,5,6]
  - ■ Wound care: Dressing changes with antibiotic ointment and nonadherent gauze until healed. Consider a volar-based protecting splint.
- Reverse homodigital island flap
  - ■ Utilizes an island of skin from the proximal finger with the digital vessel in continuity.
  - ■ The flap is a reverse flow based on consistent communications between the radial digital and ulnar digital vessels.[2,5,6]
  - ■ The donor site is closed with a bolstered skin graft.
  - ■ Wound care: Dressing changes with antibiotic ointment and nonadherent gauze until healed. Consider a volar-based protecting splint.

• Regional flaps
  ○ Heterodigital
    – Allows for coverage of larger defects than homodigital flaps; however, they often require cortical relearning and have overall less sensory recovery.[2,5,6]

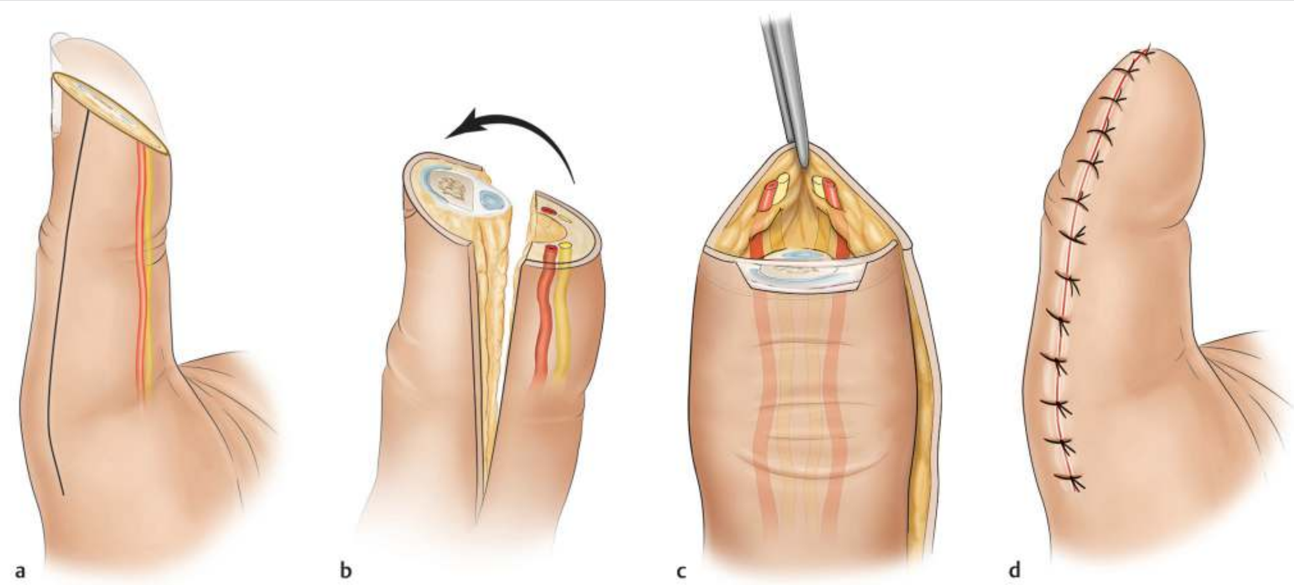

Fig. 42.4 (a–d) The Moberg flap. A full-thickness volar flap is raised by making radial-axial and ulnar-axial incisions, dissecting down to the level of flexor tendon, and advancing recruited tissue to terminal component of injury. From Germann G, Levin LS, Sherman R. Reconstructive Surgery of the Hand and Upper Extremity. New York: Thieme Medical Publishers; 2017.

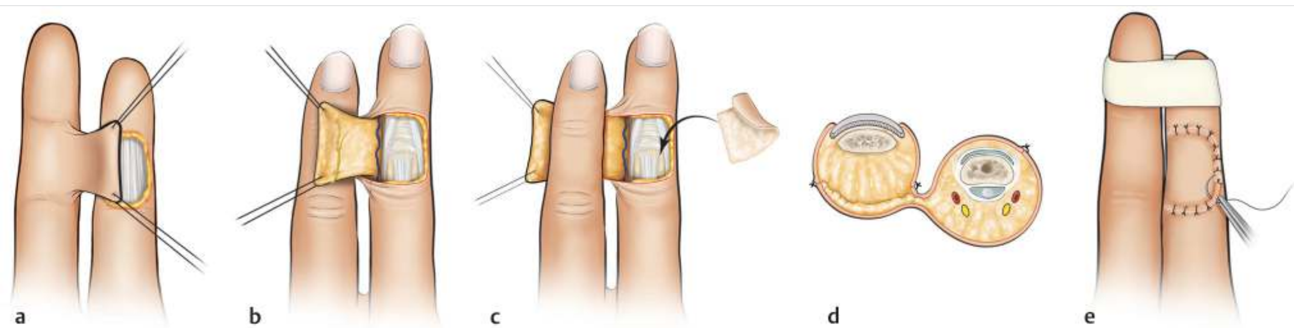

Fig. 42.5 (a–e) Cross finger flap. A full-thickness flap is raised superficial to extensor paratenon and secured to the injured digit. The donor site is skin grafted. The flap is then divided 2 to 3 weeks later. The most common donor site is the dorsum of the long finger middle phalanx. From Germann G, Levin LS, Sherman R. Reconstructive Surgery of the Hand and Upper Extremity. New York: Thieme Medical Publishers; 2017.

– Cross finger flap (▶ Fig. 42.5)
  - Indicated in volar oblique injuries.[2,5,6]
  - Reconstruction is supplied with digital neurovascular bundle of donor finger.
  - Provides an insensate reconstruction.[5,6]
  - Requires skin grafting of donor site and two separate operative procedures.
  - Raise a full-thickness flap superficial to the extensor paratenon on the dorsum of middle phalanx of the adjacent donor digit. The flap is secured to the recipient site with Chromic suture. The donor site is reconstructed with a full- or split-thickness skin graft. The fingers are then immobilized.[2,5,6]
  - The pedicle of the flap is divided after 2 to 3 weeks and the flap is inset.[2,5,6]
  - Wound care: Antibiotic ointment and nonadherent gauze for the flap itself. The skin graft will require a bolster dressing for 5 days, then antibiotic ointment and nonadherent gauze. Consider volar-based protecting splint prior to the flap pedicle being divided.

– Littler (pedicled neurovascular island) (▶ Fig. 42.6)
  - Rarely used.
  - Indicated for volar thumb defects.[2,5,6]
  - Can be applied as a regional heterodigital flap to other fingers.[2,5,6]
  - Donor site is usually the ulnar, nondominant side of the long finger.[2,5,6]
  - Provides stable soft tissue coverage for larger defects that provides sensation.[2,5,6]
  - Cortical relearning may occur otherwise the patient will have donor sensations at the recipient sites.[2,5,6]
  - Preoperatively, verify that both digital vessels are patent in the donor finger otherwise the digit may be rendered ischemic.
  - A distal skin flap is raised from the lateral/volar aspect of the finger creating darts at the DIP crease to prevent scar contractures.

- The neurovascular pedicle is dissected proximally to the common digital artery and the tethering branch is ligated. The donor nerve is left in continuity to maintain sensibility.[2,5,6]
- The digital nerve from the recipient can be coapted to the flap nerve in an end-to-side fashion to improve sensation.[5,6]
- The flap is then tunneled through a subcutaneous plane or transposed through a Bruner incision. The donor site is skin grafted.[2,5,6]

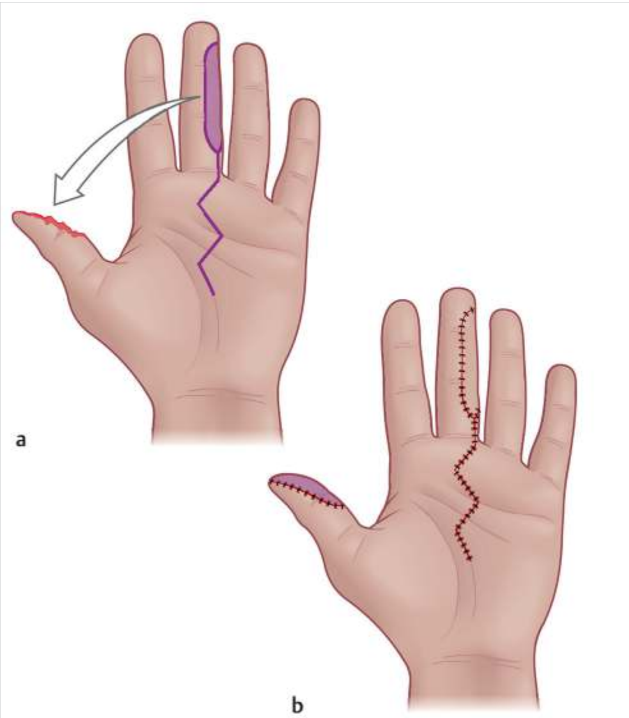

Fig. 42.6 (a, b) Littler flap. A full-thickness flap is raised and the pedicle is dissected to the common digital artery. The flap is then transposed either through a subcutaneous tunnel or through a Bruner zig-zag incision. The donor site is skin grafted. The donor site can be either the ulnar aspect of the long finger or the radial aspect of the ring finger.

- Wound care: Antibiotic ointment and nonadherent gauze for the flap itself. The skin graft will require a bolster dressing for 5 days, then antibiotic ointment and nonadherent gauze. Consider volar-based protecting splint.

– Kite flap (first dorsal metacarpal artery) (▶ Fig. 42.7)
- Indicated for distal thumb defects.[2,5,6]
- The arterial supply is the first dorsal metacarpal artery.
- Vena comitantes and the superficial veins on the hand provide venous outflow.
- Sensation is provided by a superficial sensory branch of the radial nerve.[2,5,6]
- Durable soft tissue coverage that provides protective sensation.
- The digital nerve from the recipient can be coapted to the flap nerve in an end-to-side fashion to improve sensation.[2,5,6]
- Cortical relearning is possible otherwise the patient will have donor sensations at the recipient sites.[2,5,6]
- A full-thickness flap superficial to extensor paratenon is raised on the dorsum of the proximal index finger.
- The proximal incision over the dorsal index finger is made only through the dermis as the superficial vein is needed for flap venous return.
- The pedicle is harvested with a 1 to 1.5 cm wide area of fascia.
- The pedicle is dissected off the fascia of the first dorsal interosseous muscle and the flap is transposed through a subcutaneous tunnel or a Bruner incision. The donor site is skin grafted.[2,5,6]
- Wound care: Antibiotic ointment and nonadherent gauze for the flap itself. The skin graft will require a bolster dressing for 5 days, then antibiotic ointment and nonadherent gauze. Consider volar-based protecting splint.

– Quaba flap (first dorsal metacarpal artery perforator)
- Usually indicated for coverage of dorsum of hand and fingers to proximal interphalangeal (PIP) joint.[2,5,6]
- If the reverse flap is used, it can cover past the PIP joint and even dorsal or volar fingertips.
- Provides durable soft tissue coverage with low donor site morbidity.

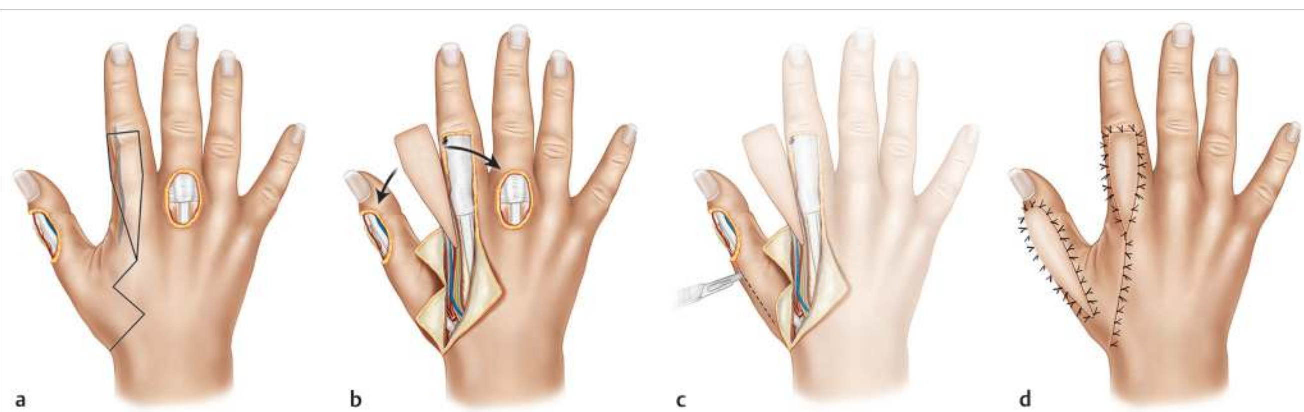

Fig. 42.7 (a–d) Kite flap. A full-thickness flap on the dorsum of the proximal index finger is raised superficial to extensor paratenon. The pedicle is dissected and the flap is transposed through a subcutaneous tunnel or a Bruner incision. The donor site is skin grafted. From Germann G, Levin LS, Sherman R. Reconstructive Surgery of the Hand and Upper Extremity. New York: Thieme Medical Publishers; 2017.

    - Reconstruction supplied by first dorsal metacarpal artery perforator, which is distal to junctura tendinum nearby the metacarpophalangeal joint.[2,5,6]
    - The skin paddle is elevated from the dorsal hand proximally. The flap is elevated off the fascia of the interosseous muscles and transposed either via subcutaneous tunnel or Bruner incision. The perforator is not skeletonized, as the surrounding tissue contains the draining veins. The donor site can often be closed primarily.[2,5,6]
    - Wound care: Antibiotic ointment and nonadherent gauze. Volar-based protective splint for 1 week.
  - Thenar flap
    - Indicated for injuries of the volar pulp of the index through small fingers.[2,5,6]
    - The flap can be elevated with a width of 1 to 1.5 cm and a 2.5 cm length.
    - The donor site is closed primarily.
    - The injured finger must be flexed as the flap is inset.
    - The flap is divided and inset after 2 to 3 weeks.
    - Older patients may develop flexion contractures because of the flexed position of the DIP and PIP joints of the injured finger.
- Revision amputation
  - Indicated in patients eager to return to work and activities as quickly as possible.[2,5]
  - Indicated in injuries proximal to lunula, flexor, or extensor tendon insertions.[2,5,6]
  - Heavily contaminated wounds and human bites should be staged: initial debridement followed by revision amputation.
  - Commonly requires a degree of bone shortening/contouring with bone cutter or Rongeur.
  - Perform traction neurectomies to digital nerves 1 cm proximal to zone of injury to prevent neuroma formation.[2,5,6]
  - Cauterize digital arteries and veins to prevent hematoma.
  - Completely ablate the nail bed (including dorsal hood).[2,5,6]
  - Wound care: Antibiotic ointment and nonadherent gauze dressing. Splinting is optional and depends on patient compliance.

Postoperative Care

- Bolster dressings from skin grafts typically removed on postoperative day 5. The wounds are redressed with antibiotic ointment and a nonadherent gauze dressing until healed.[2,5,6]
- Consider volar-based splinting in any reconstruction crossing a joint or webspace or in an unreliable patient or child.[2,5,6]
- Desensitization therapy and occupational hand therapy can be started after soft tissue heals.[2,5,6]

Complications

- Neuroma
  - Results from irritation of distally injured digital nerve.[2,5]
  - Causes chronic pain at repaired wound weeks to months following injury.
  - Prevent by pulling nerve out to tension and sharply transecting proximally to allow for retraction into wound bed and sequestrating away from direct contact to surfaces.[2,5]
- Lumbrical plus
  - Results from transection to flexor digitorum profundus (FDP) tendon insertion site on the distal phalanx and subsequent tendon retraction with additional pull on lumbrical origin.[2,5]
  - The lumbrical contracts first to draw the PIP joint into extension.
  - Prevent by securing FDP tendon distally to DIP volar plate or proximally to A4 pulley in affected digit.[2,5]
- Quadriga effect
  - Results from over-advancement of FDP tendon or tendon adhesions from previous procedures.[2,5]
  - Causes limiting of flexion of neighboring noninjured digits secondary to common proximal muscle origin.[2,5]
  - Prevent by avoiding over-advancement and inset of FDP tendon during repair.[2,5]
- Hook nail deformity
  - Results from traumatic loss of volar tissue support.
  - The nail plate grows out and curves volarly over the distal finger.
  - Causes curved and possibly painful nail bed.[2,5]
  - Prevent by ablating the entire or distal nail bed prior to definitive repair.[2,5]
  - Alternatively, adding soft tissue and bony support will prevent the hook nail.

42.3.2 Nail Bed Injuries

Preparation

- Surgical loupe with magnification of 2.5 × or 3.5 ×.
- Digital block versus need for conscious sedation versus general anesthesia.
- Irrigation and debridement of devitalized tissue and foreign bodies.
- Digital tourniquet can be achieved with use of a small Penrose drain and hemostat clamp or with the use of a TourniCot.

Treatment Options

- Trephination
  - Indicated for very painful subungual hematomas of any hematoma size.[3,4]
  - Contraindicated when there is nail plate or margin disruption, or displaced distal phalanx fracture.
  - Utilize battery-powered cautery or heated paper clip to pierce the nail plate and allow hematoma evacuation. Irrigate wound thoroughly with normal saline.
  - Wound care: Antibiotic ointment, nonadherent gauze dressing, and a protective finger splint for 1 week.
  - Antibiotics are only indicated if there is an associated distal phalanx fracture.[3,4]
- Primary repair of laceration
  - Indicated in simple or stellate nail bed lacerations.[3,4]
  - Remove the nail with Freer elevator or tenotomy scissors. Examine the laceration—if it involves the germinal matrix, the nail fold should be elevated using two radial incisions to improve exposure. Utilize running or interrupted small caliber Chromic or Monocryl suture to repair the laceration.

Alternatively, simple nail bed lacerations may be repaired with surgical skin glue.[3,4]
- ◦ Replace the nail plate in the nail fold. If not available, use sterile foil or silicone sheeting as replacement.[3,4]
- ◦ The nail plate can be secured with a simple suture distally or a horizontal mattress suture proximally using a Chromic suture.
- ◦ It is not necessary to suture the nail plate in place for sterile matrix lacerations. The dressing will hold the nail plate in place for the week that it is required.
- ◦ Wound care: Antibiotic ointment, nonadherent gauze dressing, and a protective finger splint.

- Nail bed avulsion repair with retained segment
  - ◦ Indicated when primary repair is not possible, and the avulsed nail bed segment is retained on the nail plate.[3,4]
  - ◦ Full exposure of nail bed with removal of remaining nail plate.
  - ◦ Carefully remove the retained nail bed from the avulsed segment and place directly on the periosteum as a free graft. Secure with small caliber Chromic or Monocryl suture.
  - ◦ Use sterile foil or silicone sheeting as replacement for the nail plate and place in the nail fold.
  - ◦ Wound care: Antibiotic ointment, nonadherent gauze dressing, and a protective finger splint.
- Nail bed avulsion repair with lateral bipedicled advancement
  - ◦ Rarely indicated.
  - ◦ Indicated in < 2 mm germinal or sterile matrix avulsions.[3,4]
  - ◦ Expose the nail bed by removing the nail plate as previously described.
  - ◦ The nail bed is undermined laterally on both sides of the defect with a Freer or Cottle periosteal elevator and the tissues advanced medially. The repair is sutured in a tension-free manner with small caliber Chromic or Monocryl suture.[3,4]
  - ◦ Use sterile foil or silicone sheeting as replacement for the nail plate and place in the nail fold.
  - ◦ Wound care: Antibiotic ointment, nonadherent gauze dressing, and a protective finger splint.
- Nail bed avulsion repair with split-thickness nail bed graft
  - ◦ Indicated when a large amount of sterile matrix is irreparable or avulsed and not available.[3,4]
  - ◦ Either digital or regional blocks are used and the nail bed is exposed as previously described.
  - ◦ A template of the defect is made using sterile foil.
  - ◦ If the defect is < 50% of the nail bed, a split-thickness graft may be harvested from the same digit using the sterile foil template. If the defect is > 50%, harvest a split-thickness graft from the great toe.[3,4]
  - ◦ Harvest to be obtained underneath an operating microscope with a #15 blade scalpel.
  - ◦ Graft thickness should be 0.007 to 0.010 inch.[3,4]
  - ◦ Secure graft with small caliber Chromic or Monocryl suture. Proper longitudinal orientation does not need to be maintained.[3,4]
  - ◦ Replace the nail plate in the nail fold. If not available, use fine mesh gauze or silicone sheeting as replacement. Utilize a half-buried horizontal mattress with small caliber Chromic or nylon suture to secure the nail plate/plate replacement to the nail fold.
  - ◦ Wound care: Antibiotic ointment, nonadherent gauze dressing, and a protective finger splint.
- Nail bed avulsion with full-thickness nail bed graft
  - ◦ Indicated in germinal matrix avulsion injuries not amenable to closure with bipedicled advancement.[3,4]
  - ◦ Either digital or regional blocks are used and the nail bed is exposed as previously described.
  - ◦ A template of the defect is made using sterile foil.
  - ◦ The great toe is often the best donor site. Remove the toenail, elevate the nail fold, and harvest the lateral nail bed as a full-thickness graft from the distal margin to the proximal germinal matrix. Advance the lateral margin to close the toe wound primarily.
  - ◦ Trim the graft to the template and secure the graft using small caliber Chromic or Monocryl suture. Proper longitudinal orientation must be maintained.[3,4]
  - ◦ Replace the nail plate in the nail fold. If not available, use fine mesh gauze or silicone sheeting as replacement. Utilize a half-buried horizontal mattress with small caliber Chromic or nylon suture to secure the nail plate/plate replacement to the nail fold.[3,4]
  - ◦ Wound care: Antibiotic ointment, nonadherent gauze dressing, and a protective finger splint.
  - ◦ The donor toe will have a subsequent nail deformity.

Postoperative Care

- For both split- and full-thickness nail bed grafts, the nail plate/nail plate replacement will be pushed forward and off by the newly generating nail.[3,4]
- Remove initial dressings approximately 5 to 7 days postoperatively.
- Continue protective splinting for 2 weeks postoperatively unless other associated injuries require prolonged immobilization. Consider plaster in children or noncompliant patient.[3,4]
- Provide antibiotics if there is an associated distal phalanx fracture.[3,4]
- Desensitization therapy and occupational hand therapy can be started after soft tissue heals.[3,4]
- Inform patient that nail growth is stunted for up to 21 days, and that it will take about 1 year or three nail cycles before the assessment of the final nail appearance.[3,4]

Complications

- Hook nail deformity
  - ◦ Results from loss of bony support to nail bed.[3,4]
  - ◦ Causes curved and painful nail bed.
  - ◦ Prevent by preserving bony support and avoiding excessive tissue tension on wound closure.[3,4]
  - ◦ Can also prevent by shortening the nail bed back to level of the remaining distal phalanx.[3,4]
- Nail ridges, split nail, nonadherence
  - ◦ Results from scarring at various places of the nail and may require scar excision.[3,4]

42.4 Conclusion

42.4.1 Fingertip Injuries

- Properly categorizing the injury in the initial evaluation will guide reconstructive options, which may include direct closure, healing by secondary intent, skin grafting, reconstruction with local flaps, revision amputation, or microsurgical replantation.
- Primary goals of reconstruction should include preservation of joint function, sensation, and digital length.
- Revision amputation is indicated in patients who wish for a faster recovery and return to daily activities; however, shortening should be avoided, if possible, in the long and ring fingers.
- Homodigital flaps have better postoperative sensibility than heterodigital flaps.
- Prevent neuroma formation by performing traction neurectomies when nerve is visible in the wound bed.
- Composite grafting is not recommended for patients age 6 or older.

42.4.2 Nail Bed Injuries

- Consider trephination for symptomatic subungual hematomas.
- Antibiotics are indicated for distal phalanx fractures with associated nail bed lacerations.
- Full exposure of the nail bed laceration is vital to successful nail healing. Use a Freer or scissor to atraumatically dissect the nail plate from the nail bed. Utilizing radial incisions along the nail fold will allow for exposure of the germinal matrix. Repair the nail bed laceration with fine absorbable suture.
- Stent the nail fold with the avulsed nail plate, sterile foil, or a silicone sheet.
- Avulsed sterile matrix may be placed onto the wound bed as a graft, assuming there is adequate periosteum over the distal phalanx.
- If there is < 2 mm loss of germinal or sterile matrix, consider a lateral bipedicled advancement flap. Otherwise, consider split- versus full-thickness nail bed grafts from the adjacent nail bed or the great toe.
- Prevent the hook nail deformity by shortening the nail bed to the level of the remaining distal phalanx and performing a tension-free closure.

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43 Local Flaps for Finger and Hand Reconstruction

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Abstract
Traumatic injuries to the digits and hand are common phenomena seen by plastic and orthopaedic surgeons. Although some injuries can be treated with primary closure or secondary intention with serial dressing changes, exposure of vital structures such as the neurovascular bundles, tendons, and bone necessitates the use of soft tissue coverage. There are several local flap options available for reconstruction of traumatic defects based on anatomic location. The goals of hand and finger reconstruction should include early coverage after debridement, preservation or restoration of sensation if available, and initiation of motion and therapy to maximize function. For injuries that involve multiple structures such as bone, tendon, and nerves, in addition to soft tissue, a staged approach may be considered with placement of allograft, silicone rods, or external fixators while stable soft tissue coverage is obtained prior to reconstruction of deeper structures.

Keywords: digital, dorsal metacarpal, fingertip, flap, hand, local, pedicled, volar advancement

43.1 Introduction

43.1.1 Fingertip Injuries

Fingertip injuries are those distal to the insertion of the flexor and extensor tendons. They are the most common injuries of the hand.[1,2] Injuries can occur to the glabrous volar pulp or the dorsal nail. A knowledge of the relevant anatomy includes an understanding of the nail structure. The lateral skin of the nail is referred to as the paronychium with the proximal portion termed the eponychium. The nail bed is comprised of the germinal matrix proximally, which is seen as the lunula under the nail plate and the sterile matrix distally. The germinal matrix under the nail fold creates the nail plate. The most distal extent of the nail bed is the hyponychium.[2,3,4] Local flap options for closure of fingertip defects include the volar V-Y advancement flap, the thenar flap, and for the thumb, the Moberg palmar advancement flap. With fingertip injuries, however, if there is no exposure of vital structures, secondary intention is the preferred treatment method.[3]

43.1.2 Volar and Dorsal Digital Injuries

Injuries proximal to the distal interphalangeal (DIP) joint on the fingers can often present with exposed tendon, bone, or neurovascular structures. Exposure of these structures requires the use of vascularized tissue for coverage.[5] Often, distant coverage options are bulky and do not provide good color match or sensibility. Local options include the cross finger flap, dorsal metacarpal artery perforator flaps, and digital neurovascular island pedicle flaps. Although these options provide similar tissue to the defect, it does create a wound on a digit or portion of the hand that was previously unaffected. Additionally, recovery from these defects can be challenging due to the development of joint stiffness if prolonged immobilization for healing is needed.[5,6] Appropriate patient selection for these procedures is important as is patient participation in therapy postoperatively.

43.1.3 Volar and Dorsal Hand Injuries

Volar and dorsal hand defects can present as a challenging task. The tissue used for coverage should be thin, pliable, and allow access for further reconstructive procedures that may need to be performed in a staged approach.[7,8] Often, free tissue transfer will provide an excessive amount of tissue than is needed for the reconstruction. This extra tissue, especially on the volar surface, can sometimes make the rehabilitation process difficult. Most local options include flaps based on the radial or ulnar arteries and communications between the two. The posterior interosseous artery and reverse radial forearm flaps can provide tissue that has a better contour and color match and are mainstays for reconstruction of these defects.[8,9,10]

43.2 Indications

43.2.1 Fingertip Injuries

Volar V-Y Advancement Flap (Atasoy)

- Exposed distal phalanx.
- Transverse or dorsal oblique fingertip amputations.
- Not useful for volar oblique amputations.

Thenar Flap

- Volar fingertip injuries involving index, long, and ring fingers.
- Young patients as this can cause stiffness at the proximal interphalangeal (PIP) and DIP joints.[11]
- Patient is able to tolerate, and is agreeable to, a two-step procedure.

Moberg Palmar Advancement Flap

- Volar or transverse thumb defects, distal to DIP joint crease (▶ Fig. 43.1).
- Defects involving exposed bone or tendon at the base requiring vascularized tissue coverage.
- Allows for use of glabrous, sensate coverage.
- The flap is based on the radial and ulnar neurovascular bundles of the thumb.
- Allows for 2 cm of wound coverage with flap advancement.[12]

43.2.2 Volar and Dorsal Digital Injuries

Cross Finger Flap

- Utilized for clean volar digit defects where tendons or neurovascular structures may be exposed in the wound bed (▶ Fig. 43.2).

Fig. 43.1 Volar thumb defect.

- Use of the cross finger flap should be minimized in elderly patients as this can contribute to joint stiffness of the injured digit as well as the donor digit.
- Depending on the location of the defect, the flap can be designed around the middle phalanx or the proximal phalanx of the donor digit. The donor digit is usually radial to the injured digit except for the index finger; the long finger is used as the donor digit.[6]
- The patient is able to tolerate a multistage procedure.

Dorsal Metacarpal Artery Perforator Flap

- The arc of rotation of the flap allows for coverage of volar and dorsal thumb defects as well as dorsal hand or digit defects of the index or long fingers at about the level of the PIP joints.[7,13]
- Either the first or second dorsal metacarpal arteries can be used as the pedicle and the flaps can be proximally or distally based.[6]
- This can be performed in a single-stage procedure, and provides similar skin to the defect.

Neurovascular Digital Island Pedicle Flap

- Used for midaxial or volar defects distal to the PIP joint crease, generally for the radial side of the index finger or ulnar side of the small finger where protective sensation may be required.[14]
- The island flap can be taken from the same finger, as a homodigital flap, or from a neighboring finger as a heterodigital flap.[7,15]
- The patient is able to tolerate altered sensation of the previously uninjured donor digit.

43.2.3 Volar and Dorsal Hand Injuries

Posterior Interosseous Artery Fasciocutaneous Flap

- Can be used for dorsal hand defects, some proximal volar wrist defects, and first webspace defects.
- This provides a relatively thin flap with good color match and minimal donor site morbidity.

Fig. 43.2 Volar thumb defect.

- Retrograde flap based on watershed communications between anterior interosseous artery and posterior interosseous artery.[16]
- There should be no history of trauma to the volar or dorsal forearm or deep wrist injuries to minimize any complications to the pedicle.

Reverse Radial Forearm Flap

- Useful for volar and dorsal hand, wrist, and distal forearm defects (▶ Fig. 43.3).
- Consider for extensive multidigit defects as a staged procedure where coverage is obtained in the first stage and then subsequent stages are performed with flap sectioning and division.[9]
- There should be an intact ulnar artery as it is the main blood supply to the flap via communication through the palmar arch.[12] A preoperative Allen's test should be performed.
- There should be no history of trauma to the proximal volar forearm or to the palmar arch to minimize any complications to the pedicle.

43.3 Operative Technique

43.3.1 Fingertip Injuries

Volar V-Y Advancement Flap (Atasoy)

- Provide a digital block for the patient.

Fig. 43.3 Traumatic dorsal hand wound.

- A finger tourniquet, such as a Penrose drain, can be placed to allow for minimal blood loss.
- The wound should be thoroughly irrigated and debrided of any devitalized tissue or bone fragments.
- The distal phalanx may need to be shortened with a Rongeur. Care must be taken to allow for enough distal phalanx to support the remaining sterile matrix.
- If there is a nail bed laceration, the nail plate will need to be removed, the nail bed can be repaired with a 5–0 Chromic or other absorbable suture, and the nail plate should be replaced with the native nail plate or other materials such as petroleum gauze, foil from the suture packet, or plastic intravenous (IV) tubing.
- The flap is designed as a triangle in the volar pulp with the base as the distal cut edge of the amputation site.
- The apex of the triangle can be placed in the distal joint flexion crease.
- A full-thickness incision is made through the skin only.
- Dissection is then made in a distal to proximal direction from the wound bed to mobilize the fibrofatty soft tissue off the periosteum and flexor tendon sheath. This allows for advancement of the flap over the cut edge of the finger.[17]
- The base of the triangle is sutured to the sterile matrix using 5–0 Chromic or other absorbable suture.
- The volar incision is converted from a V to a Y with the advancement of the flap.[17] This can be closed with absorbable or nylon suture.

Fig. 43.4 Elevation of Moberg flap.

Thenar Flap

- Template the defect and draw the proposed flap in the middle of the thenar eminence with the thumb abducted.
- Place the base of the flap proximally and ensure a wide base to allow for adequate blood supply.
- Incise the edges of the flap and dissect proximally, including a layer of subcutaneous fat.
- The donor site may be closed primarily with some minimal undermining or a skin graft should be placed prior to flap inset.
- Flex the affected digit to allow the wound to come into contact with the flap.
- Inset the flap onto the defect working in a distal to proximal direction.[11] This can be done with resorbable or permanent sutures.
- Dress the exposed undersurface of the flap and most proximal portion of the defect with moistened or Vaseline-impregnated gauze and change daily.
- Splint the wrist dorsally.
- The flap can be divided in approximately 2 to 3 weeks.
- Incise the base of the flap and divide. Inset the proximal part onto the defect with resorbable or permanent sutures.
- The final donor site can be closed primarily.
- Provide the patient with hand exercise instructions or formal occupational therapy to work on range of motion exercises to prevent stiffness.

Moberg Palmar Advancement Flap

- Place midaxial incisions on both the radial and ulnar sides of the thumb.
- Dissection should be taken down deep to the neurovascular bundle to the anterior surface of the tendon sheath. The neurovascular bundle is kept within the flap.
- The dissection progresses proximally to the metacarpophalangeal (MCP) flexion crease to allow for flap advancement (▶ Fig. 43.4).
- Several maneuvers can be done to increase flap advancement including flexing the interphalangeal (IP) joint, making a V-Y incision at the proximal base of the flap, and creating a transverse incision at the base of the flap, dissecting through the

Fig. 43.5 Inset of Moberg flap with mild flexion at the interphalangeal (IP) joint.

Fig. 43.6 Cross finger flap donor site from index finger with full-thickness skin graft for donor site coverage.

subcutaneous tissue with protection of the neurovascular bundles and then advancing.[1] The resulting defect at the base of the thumb would then require a skin graft for closure.

- The flap is then advanced and inset with either permanent or resorbable sutures. If the distal edge of the wound involves the nail bed, minimize the use of sutures for the inset of the distal edge to prevent hook nail deformity (▶ Fig. 43.5).

Fig. 43.7 Cross finger flap inset in volar thumb defect.

- The thumb can then be placed in a soft padded dressing and thumb spica splint.
- If the IP joint was flexed for the closure, this can slowly be extended with therapy after the incision heals.

43.3.2 Volar and Dorsal Digital Injuries

Cross Finger Flap

- Create a template of the defect to place on the dorsum of the donor digit to allow for planning of the distal and proximal incisions.
- If needed, harvest of the flap may extend over the dorsal PIP joint crease.
- For defects distal to the DIP joint in the injured digit, the flap can be designed over the middle phalanx and the injured digit would be flexed at the PIP joint and extended at the MCP joint to allow for the flap to reach the defect.
- The incision of the flap should be made at or just dorsal to the midaxial line of the donor digit, on the surface away from the injured digit.
- When designing incision placement, take into consideration the need for an additional few millimeters of tissue for a skin bridge between the two digits.
- Dissection should be taken through the subcutaneous tissue. The neurovascular bundles should still be volar to the incision.
- The flap should be elevated off the extensor mechanism, but the paratenon should be left intact to allow for skin grafting.
- Dissection continues dorsal to the neurovascular bundle on the side closest to the injured digit.
- Harvest a full- or split-thickness graft to cover the donor defect. Inset this first with Chromic sutures. The suture tails can be kept long on the cut and hinged edges of the digit to allow for a tie-over bolster dressing (▶ Fig. 43.6).
- The flap can then be inset with resorbable or permanent sutures (▶ Fig. 43.7).
- Place a bolster dressing over the skin graft.
- Consider placement of a Kirschner wire between the two digits if the injured digit requires some flexion for flap inset.
- A soft dressing can be applied and supported with a splint.

- The secondary procedure can be performed in approximately 2 weeks.
- The flap is detached sharply and the cut edges are inset. The skin bridge can be trimmed accordingly such that the edge falls within the midaxial position.
- The patient should immediately engage in therapy and passive and active range of motion exercises to regain mobility.

Dorsal Metacarpal Artery Perforator Flap

- Mark the course of the vessel with a Doppler ultrasound.
- Dissection of the flap can be done with tourniquet, but deflate the tourniquet prior to inset to check perfusion of the flap.
- Create a template of the defect to identify the size of the flap.
- The flap is designed over the dorsal-radial aspect of the proximal phalanx of the index finger or proximally around the distal index metacarpal or MCP joint.
- The incision at the base of the flap is extended proximally in a sinusoidal or zigzag shape to allow for further dissection of the pedicle. These skin flaps are raised in a subdermal plane to capture the subcutaneous tissue around the pedicle.[12]
- Incision is made around the edges of the flap taking care of the proximal incision to just go through the skin to avoid damage to the underlying vascular bundle.
- Dissection is made in a distal to proximal direction, above the paratenon.
- A wide margin of tissue is left around the pedicle to prevent damage to draining veins.
- At the level of the first dorsal interosseous muscle, proximal to the MCP joint, the dorsal interosseous fascia is harvested with the flap to allow for adequate rotation of the pedicle.
- On the radial side, the fascia of the adductor pollicis muscle is incised and the dissection is performed in the subfascial plane.
- Branches of the superficial radial nerve can be harvested with the flap to provide sensation.
- A tunnel can be created from the wound to the base of the dissected pedicle, or counter-incisions can be made to deliver the flap to the wound.
- The flap is inset and incisions are closed with permanent sutures.
- The donor site of the flap may be closed primarily or require a full- or split-thickness skin graft for closure.
- A soft padded dressing can be placed, with loose areas around the pedicle and a window cut out of the dressing for monitoring the flap. This can be supported with a volar splint.

Neurovascular Digital Island Pedicle Flap

- Dissection of the flap can be performed under tourniquet.
- Create a template of the defect and design the flap distally on the donor digit, usually centered around the neurovascular pedicle.
- Incise the flap margins and extend the incision proximally onto the digit and palm in a zigzag or midaxial approach.
- Locate the neurovascular bundle at the base of the flap and continue the dissection proximally, leaving some tissue around the pedicle to avoid damage to draining veins.

Fig. 43.8 Harvest of neurovascular island flap from ulnar long finger for reconstruction of volar thumb defect.

- The dissection continues to the pivot point of the flap, which will be at the origin of the digital artery of the superficial arch (▶ Fig. 43.8).[15]
- Divide the skin paddle and artery distally.
- The flap can then be draped onto the wound and the course of the neurovascular bundle should be marked where there would be no tension on the bundle.[14]
- A tunnel can be created from the wound to the pivot point, or alternatively an incision can be created from the wound to the midpalm.
- The flap is then delivered to the wound through the tunnel or placed onto the wound with the counter-incision closed around the pedicle.
- Secure the flap with permanent sutures and close the remaining incisions. The donor site defect can be closed primarily or a full-thickness skin graft can be placed (▶ Fig. 43.9).

43.3.3 Volar and Dorsal Hand Injuries

Posterior Interosseous Artery Fasciocutaneous Flap

- This should be performed under general anesthesia with tourniquet.
- A skin paddle is designed on the dorsal forearm, based on the dimensions of the wound requiring coverage.
- The incision is extended distally to allow for pedicle dissection.
- The skin paddle is centered around the junction of the proximal and middle thirds of the extensor forearm.

Fig. 43.9 Neurovascular island flap inset into thumb defect with full-thickness skin graft coverage on long finger donor site.

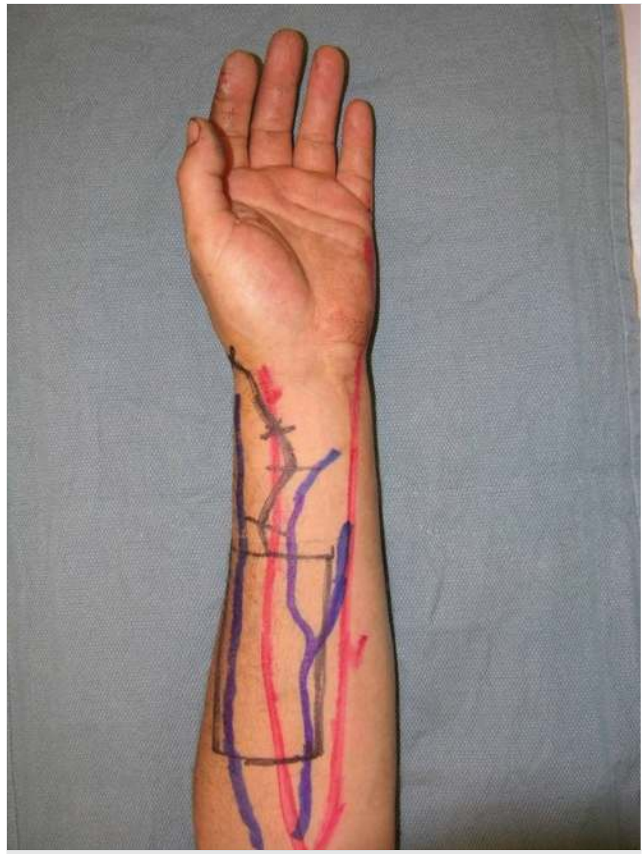

Fig. 43.10 Planned reverse radial forearm pedicled flap for coverage of dorsal hand wound.

- The ulnar incision is performed first to identify the extensor carpi ulnaris.
- Proximally, the posterior interosseous artery lies on the interosseous membrane between the extensor carpi ulnaris and extensor digiti minimi muscles.
- The fascia of the extensor carpi ulnaris is incised and dissected off the muscle to find the septum between this muscle and the extensor digiti minimi. Within this septum lies the posterior interosseous artery.[10,16]
- The radial incision is made and then the septum is approached from this direction with identification of the extensor digiti minimi and a subfascial dissection is performed.
- Perforators to neighboring muscles should be ligated with dissection of the pedicle.
- Branches of the posterior interosseous nerve should be identified and preserved.
- The proximal origin of the posterior interosseous artery is identified, approximately 6 cm distal to the lateral epicondyle and ligated.
- The septum is harvested with the flap as it will contain septocutaneous perforators to the skin paddle.
- Pedicle dissection is taken to 2 to 5 cm from the dorsal wrist crease.
- A subcutaneous tunnel can be created from the pivot point of the flap to the wound, or the dorsal forearm incision can be extended to the wound and opened to allow for guiding the flap to the defect without placing any tension on the pedicle.[18]
- The flap is inset with deep absorbable sutures and permanent or absorbable sutures at the skin level. The forearm incisions are closed.
- The donor site may be closed primarily or a split-thickness skin graft can be placed.
- A loose soft padded dressing is placed and the wrist can be splinted in slight extension to minimize skin and pedicle tension.

Reverse Radial Forearm Flap

- This should be performed under general anesthesia with tourniquet.
- Prior to tourniquet inflation, a Doppler ultrasound can be used to trace the course of the radial artery.
- A skin paddle is designed based on a template of the defect on the proximal forearm centered around the drawn course of the radial artery, taking care to note the proper orientation of the skin paddle after the flap would be rotated (▶ Fig. 43.10).
- The incision is extended from the skin paddle distally to allow for continued pedicle dissection.
- The skin and subcutaneous tissue are incised and dissected down to the muscular fascia.
- The fascia is incised and a subfascial dissection is performed in an ulnar to radial direction under the skin paddle.[10]

Fig. 43.11 (a, b) Final appearance of radial forearm flap reconstruction with split-thickness skin grafting of donor site several months postoperatively.

- The fascia can be secured to the subcutaneous tissue with resorbable sutures to prevent shearing.
- The dissection continues until the radial artery is identified in the fascial septum between the flexor carpi radialis and brachioradialis.
- Identify and protect the cephalic vein and the radial sensory nerve branch, and the lateral antebrachial cutaneous nerve.
- Preserve the paratenon over the brachioradialis and flexor carpi radialis tendon.
- The proximal pedicle and venae comitantes are identified and ligated. An on-table Allen's test can be performed prior to ligation and after releasing the tourniquet to ensure hand perfusion via the ulnar artery.[9,18]
- The dissection is then made on the radial side along the radial artery coursing distally. Perforating branches to adjacent muscles are identified and divided.
- The dissection is done to the level of the wrist crease.
- A subcutaneous tunnel is then made to the wound to allow for delivery of the flap without placing tension on the pedicle.[8,18]
- The flap is inset with deep absorbable sutures and permanent or absorbable sutures at the skin level. The forearm incisions are closed.
- The donor site may require a skin graft (▶ Fig. 43.11).
- A soft bulky dressing can be applied with a window for flap monitoring.

43.4 Conclusion

43.4.1 Fingertip Injuries

Volar V-Y Advancement Flap (Atasoy)

- Keep the incision through the level of the skin and dermis to allow for the blood supply through the fatty tissue to remain.
- Stay in the plane right above the periosteum to decrease trauma to the blood supply to the flap.[17]
- Adequate distal phalanx is required to prevent hook nail deformity.

Thenar Flap

- The flap dissection should not be too deep so that the underlying neurovascular bundles to the thumb do not become exposed or damaged.[19]
- This is a multistage procedure and should only be considered for younger patients as this has a high risk of PIP and DIP joint stiffness. Aggressive therapy is required.

Moberg Palmar Advancement Flap

- Consider this flap for coverage of thumb defects 2 cm or less.
- This technique should not be used on the other digits of the hand as it may cause joint contracture. Addition of a V-Y portion of the proximal segment allows for limiting the amount of flexion needed at the thumb IP joint.
- This technique allows for coverage with sensate, native tissue in a single-stage procedure.[20]

43.4.2 Volar and Dorsal Digital Injuries

Cross Finger Flap

- This flap is useful for volar defects requiring thin, pliable tissue.
- Nerve coaptation can be performed with the dorsal digital nerve, making this a sensate flap. However, the traditional flap harvest does not involve the neurovascular bundles; therefore, the flap is insensate.[6]
- Flexion of the PIP joint may be required for flap inset and this can lead to stiffness, which may be difficult to overcome in elderly patients.

Dorsal Metacarpal Artery Perforator Flap

- The design of the radial margin of the flap should extend to the midaxis of the digit to capture the connections of the pedicle to the skin.[13]
- Extend the proximal incision to the interval between the metacarpal bases of the thumb and index finger.

- Avoid skeletonizing the pedicle to prevent damage or injury to the venous system.
- Creating distally based, reverse flaps can increase the arc of rotation and coverage options.[7,13]

Neurovascular Digital Island Pedicle Flap

- The flap preferentially should be harvested from the long or ring finger; the digital vessels in these fingers are codominant.[15]
- In distal fingertip defects, distally based homodigital island flaps can be created, with harvest of tissue from the base of the finger, dissection distally of the neurovascular bundle, and reliance on the communicating vessels between the radial and ulnar digital arteries to provide perfusion of the flap.[1,15]

43.4.3 Volar and Dorsal Hand Injuries

Posterior Interosseous Artery Fasciocutaneous Flap

- A line can be drawn from the lateral epicondyle to the distal radioulnar joint, which can represent the course of the posterior interosseous artery.[15]
- The artery becomes more superficial on the distal forearm.
- The pivot point is at the communication between the posterior and anterior interosseous arteries, which is approximately 2 cm proximal to the distal radioulnar joint.[16]
- The most distal extent of the flap has been described to be at the level of the metacarpal phalangeal joints.
- Primary closure can usually be obtained with flap widths of 4 cm or less but a flap that has widths of 5 to 7 cm can be harvested.[10,18]

Reverse Radial Forearm Flap

- The flap can also be harvested as an adipofascial flap with skin graft and primary closure of the donor site, or as an osteocutaneous flap for reconstruction of bony defects in the thumb and hand.[12]
- The lateral antebrachial cutaneous nerve can be included for flap innervation.[10]

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44 Extensor Tendon Injuries and Repair

James Nolan Winters and Brian Mailey

Abstract

This chapter highlights the dorsal hand anatomy and complex extensor tendon biomechanics.

Provocative physical examination maneuvers, common mechanisms of injury, and extensor tendon zones are reviewed in detail. Conservative and operative treatment options are listed for each zone of injury including: technical pearls, splinting, and rehabilitation protocols.

Keywords: anatomy, extensor tendon, injury, repair, zones

44.1 Introduction

An intricate balance exists between the soft tissue and bony elements of the hand. The extensor tendons, flexor tendons, and intrinsic muscles create a normal resting cascade for the bony skeleton. The extensor tendons are superficial, visible under the skin, and easily exposed to injury in the setting of dorsal hand trauma. Variable anatomy, inter-tendon connections, and lack of suspicion by the examiner can mask injury to the extensor mechanism. During the evaluation, it is important to have a high index of suspicion for injury based on any differences between the injured and noninjured hands. This chapter will highlight conservative and operative treatment options in extensor tendon repair.

44.2 Indications

Extensor tendon injuries occur from two primary mechanisms: closed ruptures (e.g., mallet finger, ▶ Fig. 44.1a) or open sharp lacerations (▶ Fig. 44.1b). Appropriate repair and reconstruction are dictated by location of the injury (e.g., zone 1, 2, 3, etc.), and time elapsed to presentation (acute vs. chronic). Important variables to obtain from the history include: handedness, occupation, prior hand injuries, mechanism, and position of hand during injury. Flexion of the hand during laceration injury results in a tendon laceration located more proximally, in relation to the skin laceration site.

Recognition and treatment of injuries should be performed as soon as possible following initial injury. Acute, clean transection injuries can be repaired primarily within the first 2 to 3 weeks. Chronic injuries, contaminated wound beds, or traumatic degloving with significant skin and soft tissue loss require additional reconstructive considerations: tendon grafts, tendon transfers, additional soft tissue coverage, etc. This chapter will focus on the acute management and repair of extensor tendon injuries.

44.2.1 Anatomy and Biomechanics

Finger extension occurs through an intricate mechanism involving the extrinsic and intrinsic musculature. The radial nerve and posterior interosseous branch innervate the extensor musculature. The extensors are subdivided into superficial and deep groups, at the forearm level. The superficial group contains the following muscles: extensor carpi radialis longus and brevis (ECRL and ECRB), extensor digitorum communis (EDC), extensor digiti minimi (EDM), and extensor carpi ulnaris (ECU). The deep group contains the following muscles: abductor pollicis longus (APL), extensor pollicis brevis (EPB), extensor pollicis longus (EPL), and extensor indicis proprius (EIP).

The extensor tendons traverse six dorsal compartments at wrist level, numbered radial to ulnar (▶ Fig. 44.2). The first dorsal compartment contains APL and EPB tendons. ECRL and ECRB compromise the second compartment. Palpation of Lister's tubercle over the distal radius allows identification of the third

Fig. 44.1 **(a)** Closed mallet finger of the small finger. Extensor lag is noted at the distal interphalangeal (DIP) joint, with inability to extend actively. There are no lacerations or soft tissue defect noted. **(b)** Dorsal view of a type 2 mallet finger of the long finger with sharp laceration in extensor tendon zone 1. **(c)** Lateral view demonstrating extensor lag and inability to perform active extension at DIP joint. **(d)** Lateral radiograph of soft tissue mallet finger.

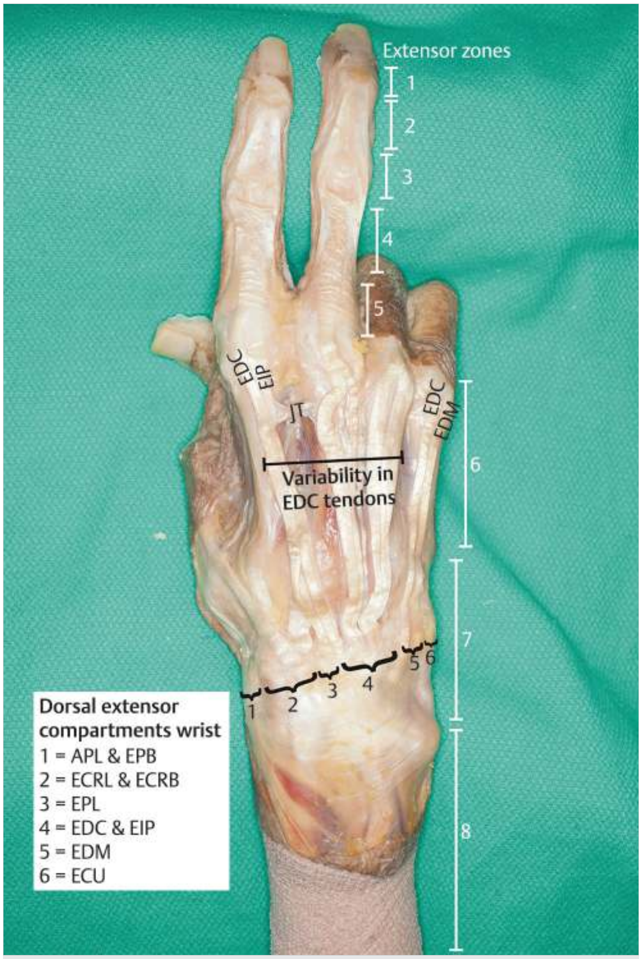

Fig. 44.2 Extensor tendon zones are numbered 1 to 9 (white text): zone 1: distal interphalangeal (DIP) joint of digits, interphalangeal (IP) joint of thumb; zone 2: middle phalanx of digits, proximal phalanx of thumb; zone 3: proximal interphalangeal (PIP) joint of digits, metacarpophalangeal (MCP) joint of thumb; zone 4: proximal phalanx of digits, metacarpal of thumb; zone 5: MCP joint of digits, carpometacarpal (CMC) joint of thumb; zone 6; metacarpals; zone 7: wrist level; zone 8: distal forearm; zone 9: extensor muscle belly. The dorsal extensor compartments are numbered 1 to 6 (black text): 1. APL = abductor pollicis longus and EPB = extensor pollicis brevis. 2. ECRL = extensor carpi radialis longus and ECRB = extensor carpi radialis brevis. 3. EPL = extensor pollicis longus. 4. EDC = extensor digitorum communis and EIP = extensor indicis proprius. 5. EDM = extensor digiti minimi. 6. ECU = extensor carpi ulnaris. JT, junctura tendinae.

compartment, EPL, which lies immediately ulnar. The fourth compartment houses EDC and EIP. The fifth and sixth compartments contain EDM and ECU, respectively. In general, the extensor tendons have consistent anatomy with some degree of variability. They become thin, flat, and superficial at the metacarpal level. Interconnections exist amongst EDC tendons, known as juncturae tendinae (JT), disguising injuries as distal pull from the neighboring EDC tendons creating movement, if the injury is proximal to the JT. EPL and EPB power extension of the thumb.

The biomechanical complexity increases distal to the metacarpophalangeal (MCP) joint (▶ Fig. 44.3) with involvement of the intrinsic musculature.[1] The sagittal bands attach to the MCP volar plate and create a sling for the extensor tendon. This prevents subluxation of the extensor tendon and aids in MCP extension. The extensor tendon trifurcates over the proximal phalanx into a central slip and two lateral slips. The central slip inserts onto the base of the middle phalanx, creating proximal interphalangeal (PIP) extension. Interossei and lumbricals also provide contributions to the extensor mechanism allowing for MCP flexion with PIP extension (▶ Table 44.1). The lateral components join the lumbricals on the radial side and interossei on both sides to form the conjoined lateral bands. The lateral bands coalesce dorsally to form the terminal tendon inserting on the base of the distal phalanx and creating DIP extension. The extensor mechanism and lateral bands receive additional stabilization from two important retinacular ligaments. The triangular ligament arises at the middle phalanx, preventing volar subluxation of the lateral bands during PIP flexion. The transverse retinacular ligament arises from the PIP volar plate and attaches to the lateral bands to prevent dorsal subluxation with extension. Comprehensive knowledge of this detailed system is advantageous in evaluating and treating extensor tendon injuries.

44.2.2 Extensor Tendon Injuries

Injuries to the extensor tendons are classified by location into nine separate zones, starting distally (▶ Fig. 44.2). Odd number zones are mainly joints (e.g., zones 1 and 3 are over the DIP and PIP joints, respectively) and even number zones are mainly bones (e.g., zones 2 and 4 lie over the middle and proximal phalanges, respectively). The thumb is classified into five zones.

44.3 Operative Technique

44.3.1 Zone 1

Injury to the terminal tendon, overlying the DIP joint, is commonly termed a mallet finger. This injury pattern manifests following forced flexion during times of active extension. Doyle classification system describes four types of mallet fingers (▶ Table 44.2).[2] Type 1 represents closed injury with loss of tendon continuity (with or without small avulsion fracture). Type 2 injuries are open lacerations with loss of tendon continuity at/or proximal to DIP. Type 3 injuries are open with loss of overlying skin, subcutaneous tissue, and tendon substance. Type 4 injuries have large mallet fractures (▶ Fig. 44.4a).

Closed mallet fingers are generally treated nonoperatively with DIP splinting in full extension for 6 to 8 weeks (▶ Fig. 44.4b).[3,4] PIP joint should be left free. Additional splinting and night-time splinting may be required for up to 12 weeks. If the patients' occupation prevents them from splinting (e.g., surgeon, dentist) or incapable of compliance (e.g., child), then percutaneous pinning may be considered. DIP joint is pinned in full extension for 6 to 8 weeks with K-wire tips buried under skin (▶ Fig. 44.4c).

Open mallet fingers require surgical repair to approximate the tendon ends or fixate the tendon to the base of the distal phalanx. Clean type 2 mallets may be repaired in the emergency department. The terminal tendon is quite thin and differential suturing of the skin and tendon may not be possible. Tenodermodesis may be performed with running of horizontal

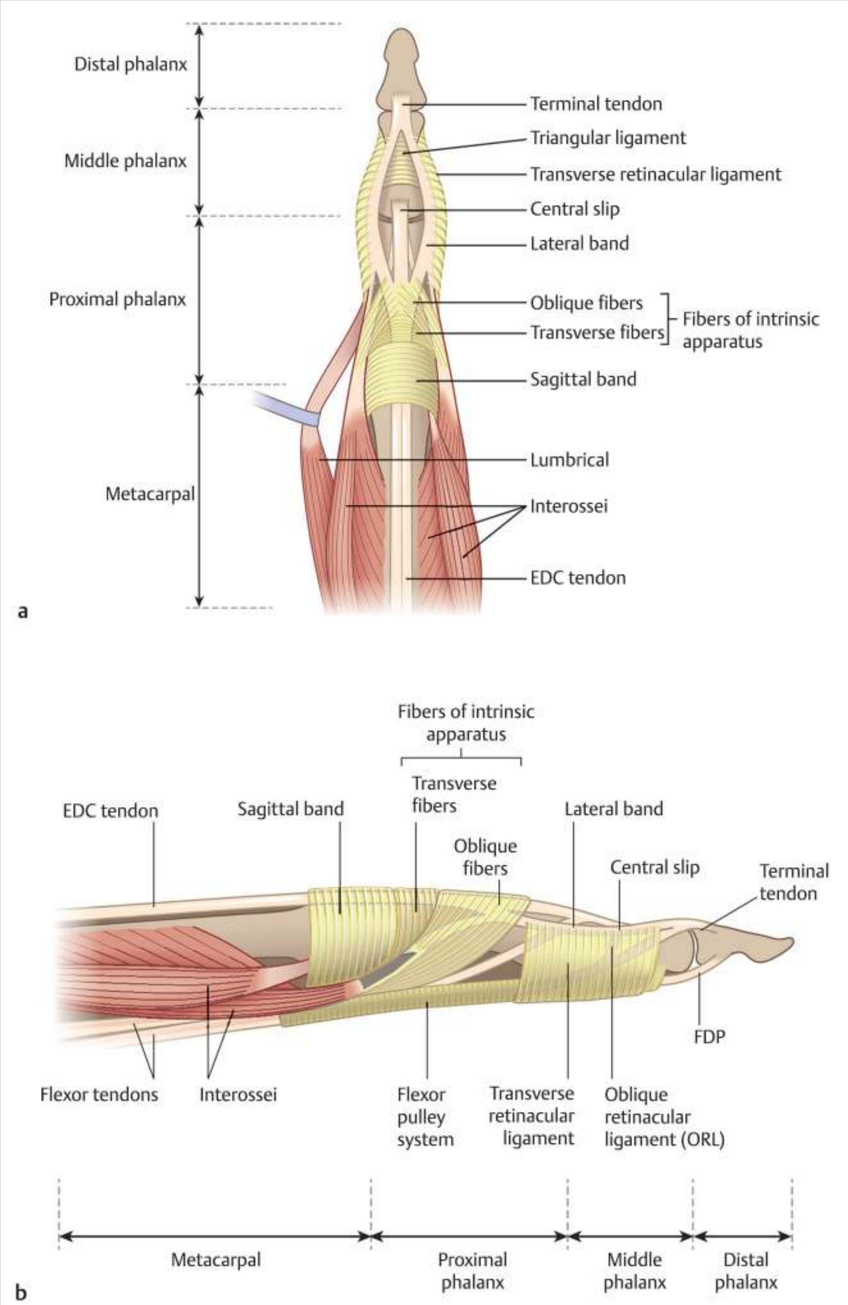

Fig. 44.3 (a, b) Dorsal and lateral views of the distal extensor mechanism composed of the extensor tendon, stabilizing ligaments, and intrinsic musculature. Note the common extensor tendon trifurcation into central slip and two lateral bands, which join to form the terminal tendon. Stabilizing ligaments include: sagittal band, transverse retinacular ligament, oblique retinacular ligament, and triangular ligament. Intrinsic musculature includes: lumbricals, dorsal interossei, and palmar interossei. The lumbricals insert onto the oblique fibers of the radial side of the extensor expansion. The dorsal interossei insert onto transverse fibers of the extensor expansion and base of the proximal phalanx. The palmar interossei insert onto the lateral band on the adductor side of digit.

mattress sutures to incorporate skin, tendon, and periosteum in one bite for reapproximation.[5] This should be followed by DIP placement in full extension with splinting or pinning for 6 to 8 weeks.

Grossly contaminated, unstable DIP joint, type 3 and type 4 injuries require a greater degree of operative attention and in most cases should be repaired in the operating room. Type 3 injuries with loss of tendon and overlying tissue may require flap coverage for reconstruction (e.g., cross finger, homodigital, hatchet, etc.). Secondary reconstruction of the terminal tendon can then be performed with tendon graft or oblique retinacular ligament. Reconstruction of a type 4 mallet finger may be treated in a number of different ways.[6] Closed reduction and percutaneous K-wire fixation may be performed if fragment is easily reduced. Open reduction may be required for difficult fracture fragments. This is performed by first slightly flexing the DIP joint. A dorsal blocking K-wire is inserted to prevent proximal migration of the fracture fragment. The finger is the then extended completely reducing the distal phalanx to the fracture fragment and an additional K-wire is passed across the DIP joint to immobilize the fracture and tendon injury for 6 weeks.

Closed mallet thumbs may be treated the same as fingers with full-extension splinting for 6 to 8 weeks (▶ Table 44.3). Open injuries should be treated surgically with direct repair followed by full-extension splinting for 6 to 8 weeks. The EPL tendon is more substantial and can tolerate a core locking suture.

Table 44.1 Insertions of intrinsic muscles

Short intrinsic muscles	Origin	Insertion	Innervation	Action
Lumbricals				
• 1st and 2nd	Radial two FDP tendons (unipennate muscles)	Oblique fibers on radial side of extensor expansion (dorsal prox. phalanx) IF and LF	Median nerve	Extend IP joint of IF and LF
• 3rd and 4th	Ulnar three FDP tendons, cleft between tendons (bipennate muscles)	Oblique fibers on radial side of extensor expansion (dorsal prox. phalanx) RF and SF	Deep branch of ulnar nerve	Extend IP joint of RF and SF
Dorsal interossei (1–4)	Adjacent metacarpals as bipennate muscle 1 (MC 1 & 2) 2 (MC 2 & 3) 3 (MC 3 & 4) 4 (MC 4 & 5)	Transverse fibers of extensor expansion (lateral tendon of deep belly) and base of proximal phalanx (superficial belly of medial tendon) Percentage insertion into bone/EM: 1st DIO: 100/0; 2nd: 60/40; 3rd: 6/94; 4th: 40/60	Deep branch of ulnar nerve	Abduct IF, LF, RF, and SF from axial line of LF; flexion of MCP
Palmar interossei (1–3)	Palmar surface of metacarpals 2, 4, and 5 as unipennate muscles	Lateral band on adductor side of IF, RF, and SF Approximate insertion into bone/EM: 1st PIO: 0/100; 2nd: 0/100; 3rd: 10/90	Deep branch of ulnar nerve	Adduct IF, RF, and SF toward axial line of LF; MCP flexion

Abbreviations: DOI, dorsal interossei; EM, extensor mechanism/expansion; IF, index finger; IP, interphalangeal; LF, long finger; MC, metacarpal; MCP, metacarpophalangeal; PIO, palmar interossei; RF, ring finger; SF, small finger.

Table 44.2 Doyle classification of mallet fingers

Injury	Description
Type 1	Closed injury (with or without small dorsal avulsion fracture)
Type 2	Open laceration
Type 3	Open injury (deep abrasion resulting in loss of skin, subcutaneous tissue, and tendon substance)
Type 4	Mallet fractures a) Transphyseal injury of distal phalanx (pediatric population) b) Avulsion fracture involving 20–50% of articular surface c) Avulsion fracture involving > 50% of articular surface

44.3.2 Zone 2

Typically, tendon injuries over the middle phalanx result from sharp transection. Partial lacerations involving less than 50% of the tendon and no extension lag do not require repair. In this instance, the wound should be irrigated, skin closed, and extension splint placed for 2 weeks, followed by restricted strength use for the following month. Lacerations greater than 50% may be repaired with figure of eight suture or horizontal mattress sutures. Epitendinous sutures are time consuming and not necessary. Repair should be followed by DIP extension splinting for 6 weeks. If significant tendon and soft tissue loss is present, then flap coverage and secondary tendon repair will be required to span the defect. Tendon graft (e.g., palmaris longus) or tendon sharing techniques have been described.

Laceration to EPL in zone 2 should be repaired with core-type suture (e.g., modified Kessler), if possible. Splinting with thumb IP extension and MCP free for 6 weeks is necessary. Short-arm thumb spica with thumb in extension may also be used postoperatively.

44.3.3 Zone 3

Injury to the central slip can result in a boutonniere deformity presenting as DIP hyperextension and PIP flexion (▶ Fig. 44.5).[7] This results from lateral band volar migration. Patients are often misdiagnosed on presentation as a jammed finger with PIP swelling, tenderness, and weak PIP extension against resistance. Clinical suspicion requires performance of Elson test, which is performed by holding the PIP joint of affected finger in flexion and asking the patient to extend DIP.[8] Normal patients cannot extend DIP due to slack in lateral bands. Disruption of central slip results in DIP hyperextension on testing and no force felt by the patient in attempting to extend the PIP joint.

Closed injuries should be treated with PIP extension splinting for 6 to 8 weeks, followed by night-time splinting. The DIP joint should be left free and actively flexed to help pull the lateral bands dorsally.

Open injuries should be explored operatively due to potential for PIP joint violation. Surgical treatment options depend upon laceration site of central slip and bony fracture fragment size. Proximal lacerations with adequate distal tendon stock should be repaired with a core suture. Avulsions and distal central slip injury with adequate tendon quality can be repaired using a bony suture anchor driven into the middle phalanx. Avulsions with larger fracture fragments may require K-wire or screw fixation.

Three surgical procedures have been described for central slip injuries not amenable to primary repair. If adequate proximal central slip tendon persists, then it can be reattached to the middle phalanx via suture anchor. The base of the middle phalanx is prepared and the bone roughened up to promote tendon healing. The 2-mm suture anchor is inserted and then reattached to the proximal extensor tendon via a turndown procedure, popularized by Snow (▶ Fig. 44.6a).[9] This is performed by exposing the intact extensor tendon over the proximal phalanx and designing a distally based extensor tendon flap in a rectangular or triangular fashion. A few millimeters of distal tendon is left attached to the lateral bands, and one or two sutures are placed in the corners of each base to prevent the flap from pulling through. It is then turned over onto itself and attached to the base of the middle phalanx via a suture anchor or pull-out button. If inadequate remaining central slip exists, then centralization of the lateral bands described by Aiache et al is an

Fig. 44.4 **(a)** Bony mallet. The lateral radiograph demonstrates the proximally retracted fracture fragment of distal phalanx base due to terminal tendon pull proximally. Fractures at this location involve varying degrees of articular surface. **(b)** Stack splint for mallet finger injuries. The splint keeps the distal interphalangeal (DIP) joint held in extension, while allowing proximal interphalangeal (PIP) joint flexion. This splint is kept in place for 6 to 8 weeks without removing. **(c)** Closed reduction and percutaneous fixation of bony mallet. The lateral radiograph shows a dorsal blocking K-wire placed within the head of the middle phalanx to prevent proximal migration of fracture fragment from terminal tendon pull. A longitudinal K-wire is placed through the distal and middle phalanx to pin the DIP joint in hyperextension. **(d)** Right index finger mallet following removal of K-wires. Clinically, the patient has loss of hyperextension at DIP, but without flexion deformity. This is considered an acceptable outcome.

Table 44.3 Extensor tendon rehab protocols

Week	Immobilization (zones 1–3: 6 weeks; zones 4–6: 4 weeks)	Dynamic splinting and early passive motion	Early active motion
1–2	• Volar-based resting splint • Wrist: 40 degrees extension • MCP: 0–20 degrees flexion • Ips: 0 degree extended	• Dynamic splint with cable dorsally placed • Wrist immobilized in 40 degrees extension • MCP: 0 degree • Palmar block allowing 30–40 degrees MCP active flexion • Early active MCP flexion and passive extension with IP extended • 20x/hour in splint	• Volar-based splint • Wrist immobilized in 30 degrees extension • MCP blocked in 45 degrees flexion • IP joints free • Active MCP flexion and extension, with IPs extended in week 1 • Active MCP flexion and extension, with IP flexion and extension in splint in week 2 • 10x/hour in splint
3–4	• Splint continued • Graded joint mobilization in hand therapy	• Splint modified removing palmar block and allowing for full MP active flexion	• Splint modified with MCP blocked in 70 degrees • Active EDC glide
5	• No change	• Discontinue splint • Graded joint mobilization in hand therapy	• Discontinue splint • Graded joint mobilization in hand therapy
6–12	• Discontinue splint • Continue graded joint mobilization with increase in resistance • Further night-time splinting dependent on zone of injury	• Completion of graded joint mobilization • Start light ADLs • Gradually increase resistance in ADLs	• Completion of graded joint mobilization • Start light ADLs • Gradually increase resistance in ADLs
> 12	• Return to normal activities without restrictions	• Return to normal activities without restrictions	• Return to normal activities without restrictions

This chart is to serve as a general overview to each rehabilitation plan. Variations exist based on extensor tendon zone of injury, duration of splinting, and between individual surgeon preferences.
Abbreviations: ADLs, activities of daily living; EDC, extensor digitorum communis; IP, interphalangeal joint; MCP, metacarpophalangeal joint.

option.[10] This is performed by releasing the transverse retinacular ligaments, which are pulling the lateral bands volar. The lateral bands are then relocated dorsally over the digit and sutured to each other over the PIP joint with braided nonabsorbable sutures (▶ Fig. 44.6b). Ahmad and Pickford described a third reconstructive option by using a slip of flexor digitorum superficialis (FDS) tunneled through a volar-dorsal hole at middle phalanx base and reattachment to the extensor proximally.[11]

Fig. 44.5 Boutonniere deformity of the right small finger showing classic hyperextension at distal interphalangeal (DIP) joint and flexion at proximal interphalangeal (PIP) joint. Elson test can be performed to diagnose central slip injury: PIP flexed to 90 degrees over the edge of table. Patient asked to extend middle phalanx against resistance. If central slip injury is present, the patient will be able to extend the DIP joint with the PIP joint in flexion. This is caused by the pull of the lateral bands.

44.3.4 Zone 4

Injury to the extensor tendon overlying the proximal phalanx most commonly results from sharp laceration. The tendon is broad and flat here (▶ Fig. 44.7), with partial lacerations being quite common. Focused physical examination testing with isolation of fingers will show reduced strength with extension. Exploration and repair may be performed in the emergency department for clean lacerations. Relaxing incisions and recreating the position of the hand at time of injury will help identify the lacerated edges. Lacerations less than 50% do not require repair; however, a figure of eight suture or horizontal mattress can be used for repair.[12] Safety position splinting for 2 weeks followed by early motion is recommended. Total transection of the extensor tendon requires repair. Multiple suture techniques have been shown to provide adequate strength for early range of motion protocols including: Kleinert modification of Bunnell, modified Kessler, modified Becker, and running, interlocking horizontal mattress.[13,14,15] Generally, two or three horizontal mattress sutures are placed. The broad flat extensor tendon has progressively less excursion over the digit and can therefore tolerate less changes in length. Care is taken to avoid bunching and over-shortening of the tendon. The amount of tendon excursion is approximately 11 mm at the MP joint, 6 mm at the PIP joint, and 3 mm at the DIP joint.[16] Slight changes in length can affect tendon function.

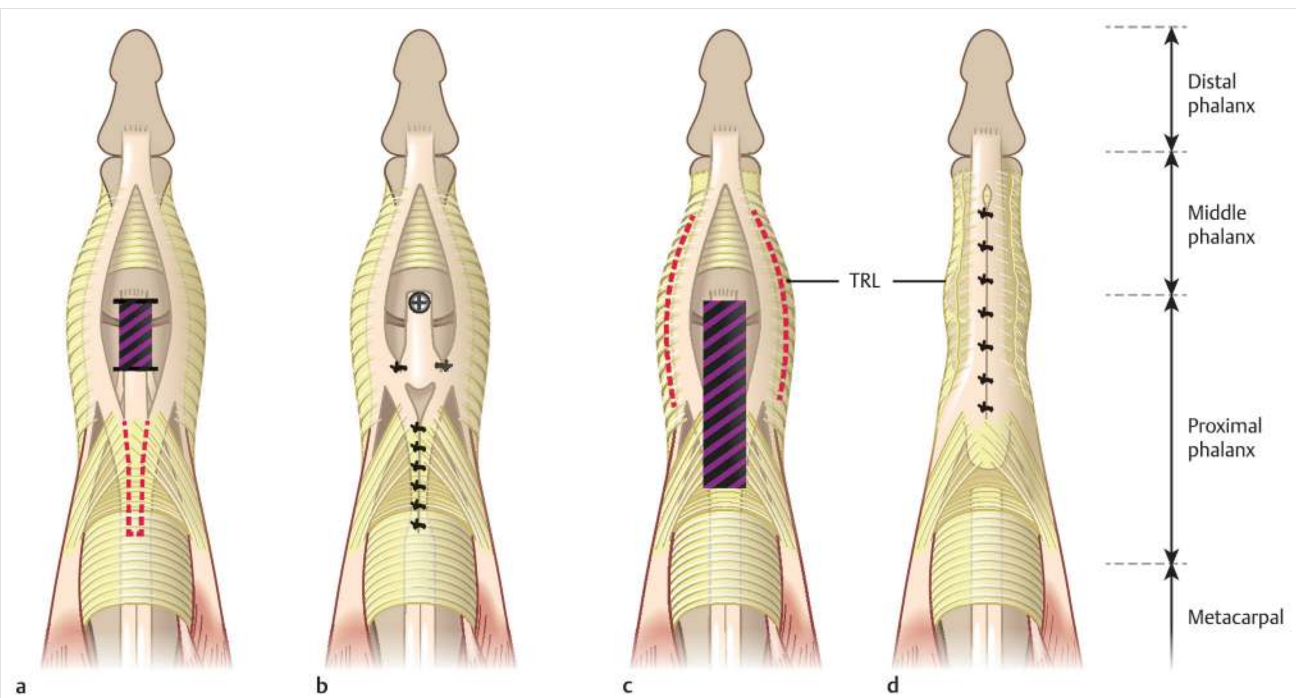

Fig. 44.6 (a, b) Central slip reinsertion with extensor tendon turnover (black box = extensor defect). Distally based rectangular flap denoted by dashed lines. Sutures at base of flap connected to lateral bands to prevent pull-through. Note suture anchor placed through tendon to secure to middle phalanx. **(c, d)** Relocation of lateral bands (black box = extensor defect). Release of transverse retinacular ligament (TRL) on radial and ulnar side to free lateral bands denoted by dashed lines. Lateral bands then brought dorsally and sutured in midline overlying proximal interphalangeal (PIP) joint.

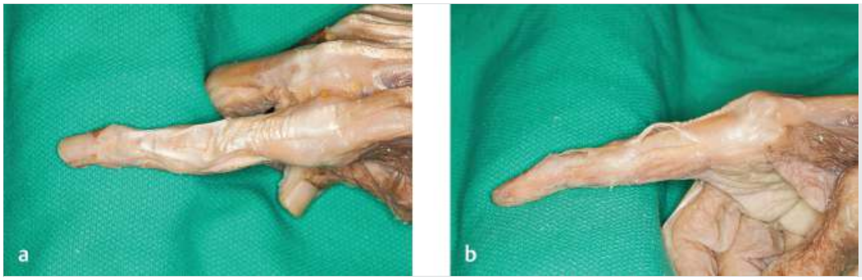

Fig. 44.7 A cadaver extensor tendon zone 4 is shown here. **(a)** Dorsal view with a broad, flat tendon. **(b)** The thin and flat tendon from a lateral view. The extensor tendon has minimal excursion in this zone and does not tolerate changes in length. Care should be taken to approximate tendon edges, avoiding over-tightening or bunching.

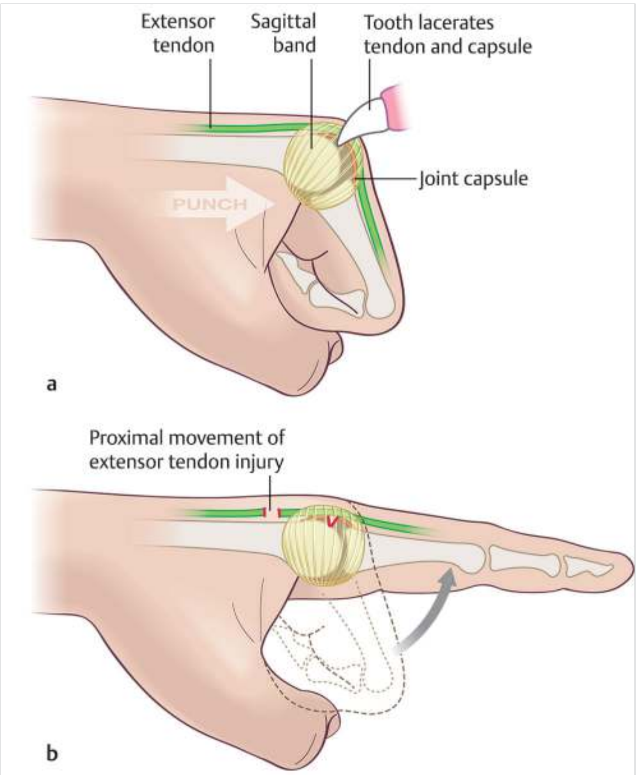

Fig. 44.8 (a, b) Fight bite injury occurs in a flexed position while the hand is clenched in a fist. When examined in extension, these injuries may be missed as the tendon and joint capsule have moved more proximally. To appropriately determine if the violation of the joint capsule has occurred, the examiner should have the patients flex their digits to recreate the position of the hand during the injury. *Green*: extensor tendon. *Blue*: joint capsule. *Yellow*: sagittal band. *Red arrow* denotes path of injury. Note the different alignment of injured structures with finger extended.

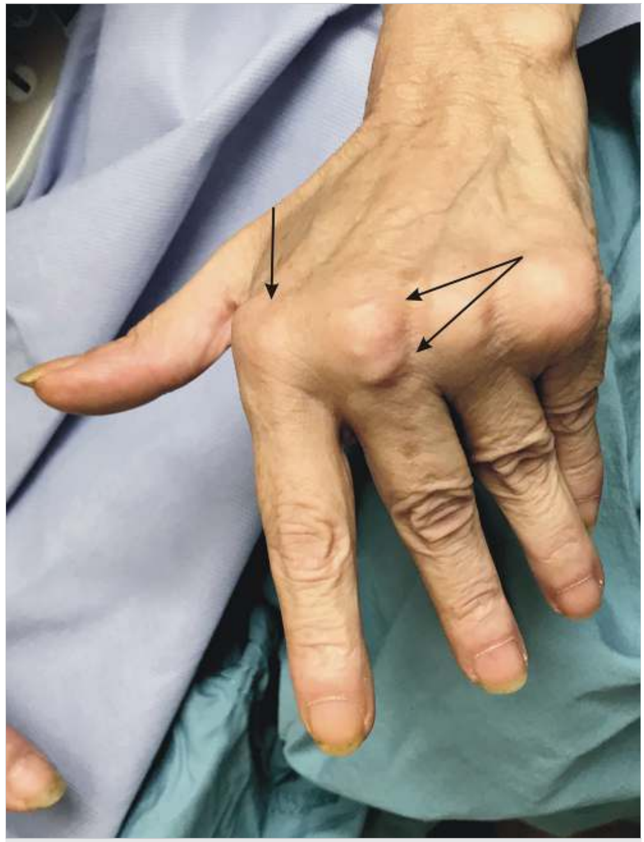

Fig. 44.9 Sagittal band rupture. Preoperative photo of left hand showing sagittal band injury of the long finger resulting in ulnar subluxation of extensor digitorum communis (EDC) tendon into webspace with flexion at metacarpophalangeal (MCP) joint. Sagittal band rupture is usually due to radial sided involvement of sagittal band, commonly referred to as boxer's knuckle. Sagittal band injury can be clinically confused with Vaughan-Jackson syndrome, rupture of extensor tendons. Note index finger extensor tendon remains centralized over MCP joint.

44.3.5 Zone 5

Injuries overlying the MCP joint can result from altercations (fight bite, ▶ Fig. 44.8), sharp laceration, or closed sagittal band rupture. In fight bites, tendon lacerations are of secondary concern in the initial evaluation. Violation of the MCP joint and infection from oral flora is the primary concern and should be managed first.[4] These injuries should be washed out and surgically debrided. Wounds may be left open for dressing changes, intravenous (IV) antibiotics, and splinting. Repair of extensor lacerations can be done as in zone 4 acutely or at a later date. It is important to evaluate the MP joint capsule through a range of motion, as the injury typically occurs with the finger in flexion and the joint inoculation may be missed if the finger is only examined in extension.

Sharp lacerations and closed trauma can injure the sagittal band. This will result in extensor tendon subluxation in the ulnar direction (▶ Fig. 44.9a). Sharp laceration should be thoroughly irrigated and repaired with interrupted figure out eight sutures. Patients should be splinted with MP joints in full extension for roughly 1 week followed by flexion and extension exercises. Buddy taping should be applied following splint removal to limit abduction and adduction. Closed ruptures presenting within 2 weeks should be treated with MCP extension

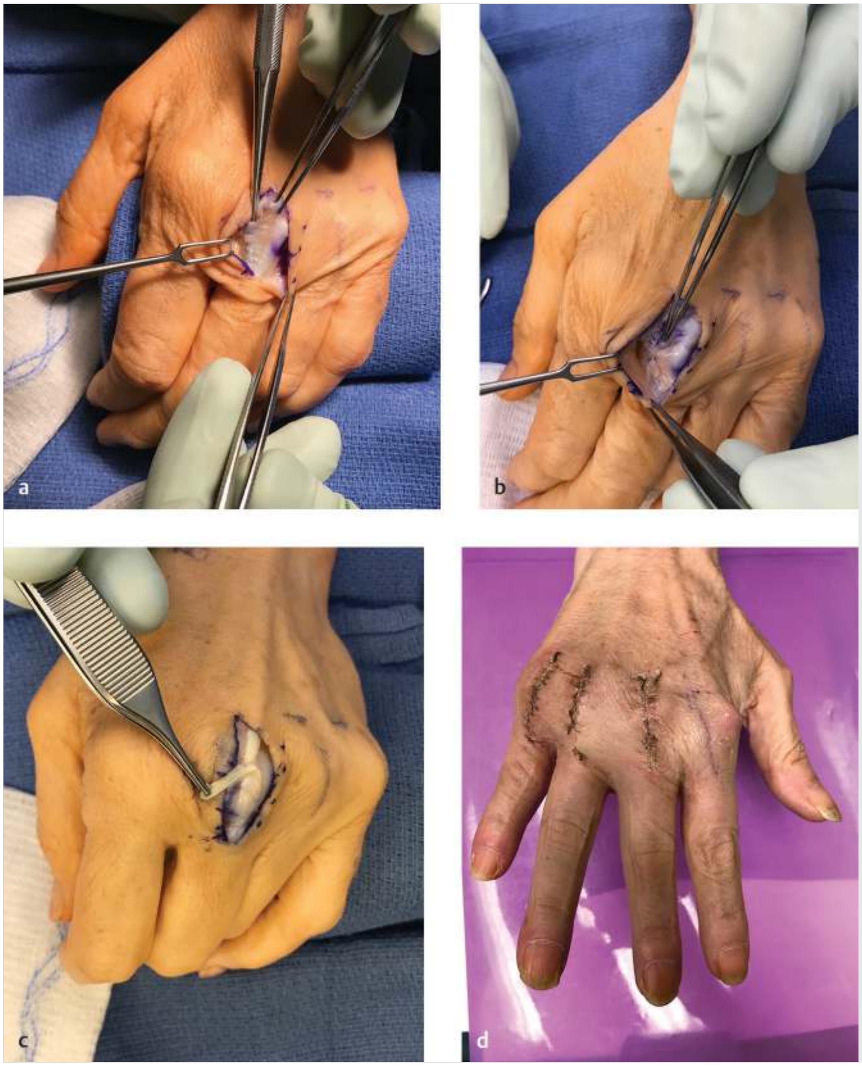

Fig. 44.10 These photos represent a patient undergoing sagittal band reconstruction. **(a)** Intraoperative photo of left long finger with ulnar subluxation of extensor digitorum communis (EDC) tendon following radial sided sagittal band rupture. Freer elevator demonstrates the defect in the radial sided sagittal band. **(b)** Demonstration of utilization of a sagittal band step cut for repair. This is performed by lengthening the ulnar side of the sagittal band, in combination with radial sided sagittal band imbrication shown here. **(c)** Centralization of the extensor tendon over the metacarpophalangeal (MCP) joint is shown. This can be done using a proximally based slip of EDC (McCoy repair) or junctura tendinae (Wheeldon repair). **(d)** Postoperative photos of the same patient's right hand status post reconstruction of long, ring, and small finger sagittal bands showing extension at proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints without subluxation of EDC tendons during MCP flexion.

splinting for 6 weeks. Chronic ruptures or failed conservative treatment should be taken back to the operating room for surgical repair. Primary repair of the native sagittal band is the preferred method.[6] A C-shaped incision is made on the MCP joint with proximal and distal extensions. The skin is then retracted to identify the edges of the sagittal bands. A 4–0 suture is then used in an interrupted figure of eight fashion for repair. The contralateral side may need to be released in a step-cut method, if the injury is chronic and the tissues shortened (▶ Fig. 44.10). The skin is closed and patient splinted in MCP extension as above. A yolk splint can be used to allow the other digits to move while off-loading the injured digit.

44.3.6 Zone 6

Extensor tendon injuries overlying the metacarpals are often difficult to recognize on examination due to interconnections through junctura tendinae. A high index of suspicion should be present with any dorsal hand laceration given the superficial location. Asking the patients to recreate the position of their hand during the time of injury may help identify lacerated tendon edges prior to surgical exploration. Extensor tendons can be adequately explored and repaired in the emergency department in this location. They have adequate bulk for core sutures and develop fewer adhesions.[1] Extending the laceration may help identify the proximal and distal ends. A 25-gauge hypodermic needle can be used to hold the transected ends in close proximity without tension during repair. Multistrand core locking sutures are appropriate if feasible, otherwise horizontal mattresses will suffice. The hand is splinted in 20 degrees of wrist extension with 20 degrees of MP flexion, and neutral PIPs.[17,18,19]

44.3.7 Zone 7

Injury to extensor tendons at the wrist innately involves the extensor retinaculum. Knowledge of the six dorsal compartments is critical when identifying and realigning multiple transected tendons. The extensor retinaculum can be opened in a stair-step fashion to assist in later repair. Additional proximal and distal exposure may be required for correct identification of tendons. Core sutures are used to repair tendons, as above. The retinaculum is then closed with figure of eight sutures to prevent bow-stringing of the extensor tendons. Splinting ensues for 4 weeks, as in zone 6.

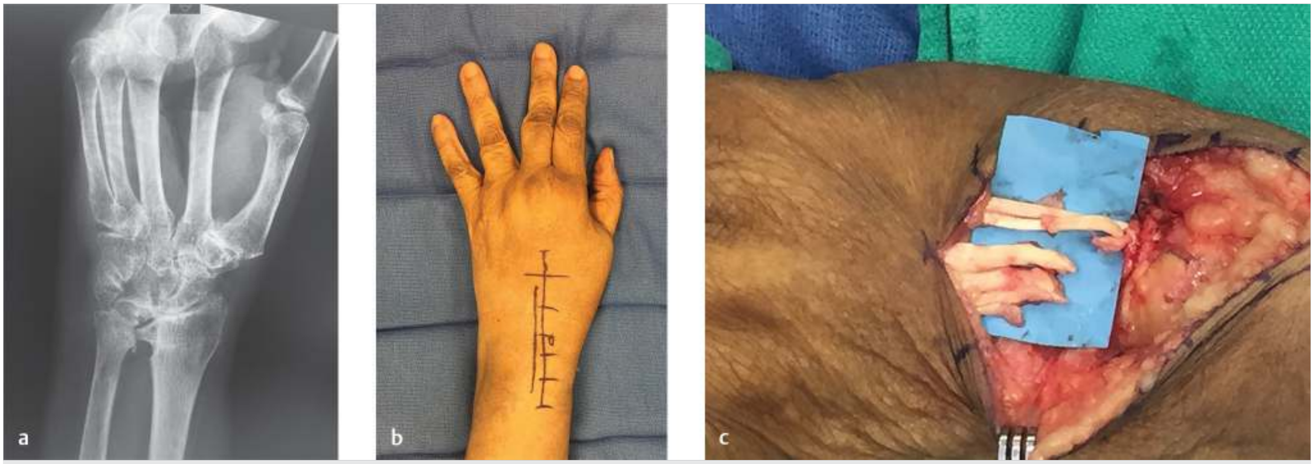

Fig. 44.11 Vaughan-Jackson syndrome. Inability to extend fingers due to rupture of digital extensor tendons from ulnar to radial sided fashion. Results from distal radioulnar joint (DRUJ) instability with dorsal ulnar head creating friction point for extensor tendon glide, eventually causing rupture. **(a)** Radiograph of rheumatoid arthritis patient showing erosions, carpal space narrowing, ankylosis, and DRUJ involvement. **(b)** This patient had inability to extend small, ring, and long fingers. Scheduled to undergo extensor reconstruction and Darrach's procedure (ulnar head resection). **(c)** Intraoperative photo of same the patient demonstrating all extensor tendons ruptured except extensor indicis proprius (EIP) and extensor digitorum communis (EDC) to index finger. These tendons were used to reconstruct the other extensor defects.

Patients may also undergo rupture of extensor tendons in this zone from thumb spica splints, distal radius hardware, or rheumatoid arthritis deformities (e.g., von Jackson, ▶ Fig. 44.11). These injuries frequently require tendon transfers or tendon grafting, along with tendon transfers.

44.3.8 Zone 8/9

Damage in these regions usually involve the musculotendinous junction and the muscle belly itself. The superficial radial sensory nerve, posterior interosseous nerve (PIN), and radial nerve can also be damaged in this region depending on the depth of laceration. The strength of repairs is limited by lack of tendon or fibrous septa to reapproximate. When tendons are present in adequate stock proximally and distally, core sutures should be placed. Multiple figure of eight sutures should be used to reapproximate the muscle belly itself. Tendon transfers may be used as salvage procedures, if the tendon repairs rupture. Postsurgical splint should be placed with wrist in 40 degrees of extension, MCP joint in 20 degrees of flexion, and IP joints free for 4 to 6 weeks.[17]

44.4 Conclusion

The extensor mechanism is a complex interrelation between the extrinsic and intrinsic musculatures. Astute knowledge of anatomy and high clinical suspicion help in identifying injury. Appropriate splinting should be utilized in closed injuries to prevent mallet finger, boutonniere deformity, and ulnar subluxation at the MCP joint from sagittal band rupture. Partial lacerations less than 50% do not require repair. Total transection injuries should be repaired according to zone of injury. The more proximal tendons are amenable to core sutures. Distal extensor tendon injuries tolerate less shortening or bunching in the repairs. Postoperative splinting and motion protocols are imperative to regain function and prevent adhesions.[17,18,19,20] Chronic ruptures or large degloving injuries may require secondary repair with tendon grafts or transfers.

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45 Flexor Tendon Repair

Austin Michael Beason, James Nolan Winters, and Brian Mailey

Abstract
Repair of flexor tendon injuries of the hand requires an understanding of the anatomy, biomechanics, and characteristics of the flexor tendon zones as well as potential complications and rehabilitation protocols. The operative techniques to repair flexor tendon injuries of the hand are specific to each zone and careful consideration of timing of injury, surgical approach, and method of repair are critical to ensuring successful outcomes. Rehabilitation protocols after repair are aimed at restoring pre-injury motion and strength to the affected digit and typically involve early progressive range of motion exercises starting at 1 to 2 weeks post repair.

Keywords: flexor digitorum profundus, flexor digitorum superficialis, flexor tendon repair, flexor tendon zones, hand rehabilitation protocol

45.1 Introduction

The flexors, extensors, and intrinsic muscles create natural, balanced C-shaped curvatures to the hand. In repose, the fingers lie in a cascade with a progressive composite flexion curvature from the index finger to the small finger. If there is loss of any one of these counterbalancing elements to one or multiple digits, it is immediately apparent to the naked eye (▶ Fig. 45.1). However, loss of a finger flexor is usually the most obvious and immediately functionally limiting.

45.2 Indications

Flexor tendon injuries occur from closed ruptures (e.g., jersey finger) or open sharp transections.[1,2,3,4] Repair and reconstruction of flexor tendons vary by the location of injury (e.g., zones 1, 2, 3, etc., ▶ Fig. 45.2) and time elapsed to presentation.[1,5,6,7] It is important to obtain from history the handedness of the patient, the occupation, and the position the hand was in during injury. For example, if the fingers were flexed during injury, the distal tendon stump is always much shorter than expected by site of laceration and amount of distal tendon available for repair is limited, many times creating a weaker repair.[8,9]

Repair should be performed as soon as possible after initial transection.[10,11] Within 3 weeks, the injury is considered acute and can be done primarily. After this time, the surgeon should prepare for the possibility of using secondary reconstructive measures, including tendon grafts, flexor tendon sheath and pulley creation, and two-staged reconstruction with silicone (hunter) rods.[10,11,12,13] This chapter will focus on the acute repair of flexor tendon injuries.

45.2.1 Anatomy and Biomechanics

Finger flexion occurs through tendon excursion created by the flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) muscle bellies. Each finger is powered by a separate tendon from each muscle belly. Thumb flexion occurs independently via the flexor pollicis longus muscle and tendon.

The FDS tendons have a common muscle belly in the forearm and each FDP tendon has its own individual muscle belly. The FDS muscle is entirely innervated by the median nerve. The FDS and FDP tendons insert on the middle and distal phalanges, respectively. Each FDS tendon divides into two halves at the metacarpal head; this is known as Camper's chiasma (▶ Fig. 45.3). The two halves rotate dorsally around the FDP tendon and insert onto the middle phalanx separately. The FDP tendon provides the origin for the lumbrical muscles, as they arise from the radial side of each FDP tendon at the palm level. These profundus tendons eventually insert onto the distal phalanx. The index finger (IF) and long finger (LF) FDP muscle bellies are innervated by the anterior interosseous nerve of the median nerve. The ring finger (RF) and small finger (SF) FDP muscle bellies are innervated via the ulnar nerve. The flexor pollicis longus powers flexion of the thumb interphalangeal joint and is innervated by the anterior interosseous nerve of the median nerve.

Each tendon lies within a synovial-lined tendon sheath that allows smooth tendon gliding and tendon nutrition (▶ Table 45.1). Thickened areas of the sheath are known as pulleys (▶ Fig. 45.4). There are five annular and three cruciate pulleys. Odd numbered annular pulleys are at the joint levels (e.g., A1 at MCP joint, A3 at proximal interphalangeal [PIP] joint, and A5 at distal interphalangeal [DIP] joint) (▶ Table 45.2). The A2

Fig. 45.1 **(a)** Illustration of abnormal finger cascade consistent with a small finger flexor tendon injury, **(b)** intraoperative visual of flexor tendon after repair, and **(c)** postoperative hand in repose with restored normal finger cascade.

and A4 pulleys lie in the middle portion of the proximal and middle phalanges, respectively, and are considered to be the most important at preventing bow-stringing of the tendons and should be preserved, whenever possible (▶ Table 45.3).

45.2.2 Flexor Tendon Injuries

Injuries to the tendons are classified by location as separate zones.[1]

45.3 Operative Technique

45.3.1 Zone 1

FDP injuries distal to the insertion of the FDS tendon are commonly termed rugger jersey fingers and imply inadequate distal tendon stumps for soft tissue repair alone.[4,7] These injuries require repair to bone.[14,15] This was classically accomplished using a sterile pull-out button. The introduction of readily available suture-bone anchors has evolved this procedure and obviated the use of buttons sutured to the nail plate.[10,14] The Leddy and Packer classification[7] separates these injuries based on the retraction of the proximal tendon end (▶ Table 45.4). Type 1 injuries (▶ Fig. 45.5) retract into the palm as both vinculae (▶ Fig. 45.6) rupture, and earlier repair (preferably within 1 week) is required to ensure the myotendinous unit has not shortened too much. Type II injuries avulse with a small fragment of distal phalanx. The long vincular remains intact and the tendon retract to the A3 pulley at the PIP joint. Repair can be delayed to 6 weeks. Type III injuries have a large bony fragment and do not retract beyond the middle phalanx. This can be repaired primarily with bony fixation. Type IV injuries can be the most challenging with separate bony and tendon avulsion as the tendon frequently retracts into the palm.

Flexor tendon repair should be performed in the operating room under loupe magnification. Incisions should be created to maintain viability of skin flaps, permit adequate exposure, and minimize skin scar contractures. The flexor tendon is exposed incorporating any lacerations and the distal and proximal stumps are identified. If any distal stump is present, it can be used to buttress the repair. The site for attachment on the distal phalanx is prepared to create a roughened-up area of bone to provide an adequate healing surface. A bone anchor is inserted into the distal phalanx and the proximal tendon end is tied down to bone in a horizontal mattress fashion. If a distal tendon end is present, it is tied over the top of the repair. A limited running-locking, crackow-type suture can be used to strengthen the repair. It is important obtain adequate purchase with the bone anchor, but not to completely puncture the dorsal cortex to avoid creating a nail bed injury and nail plate irregularities. A sagittal preoperative radiograph is used to determine the maximum screw length that can be used.

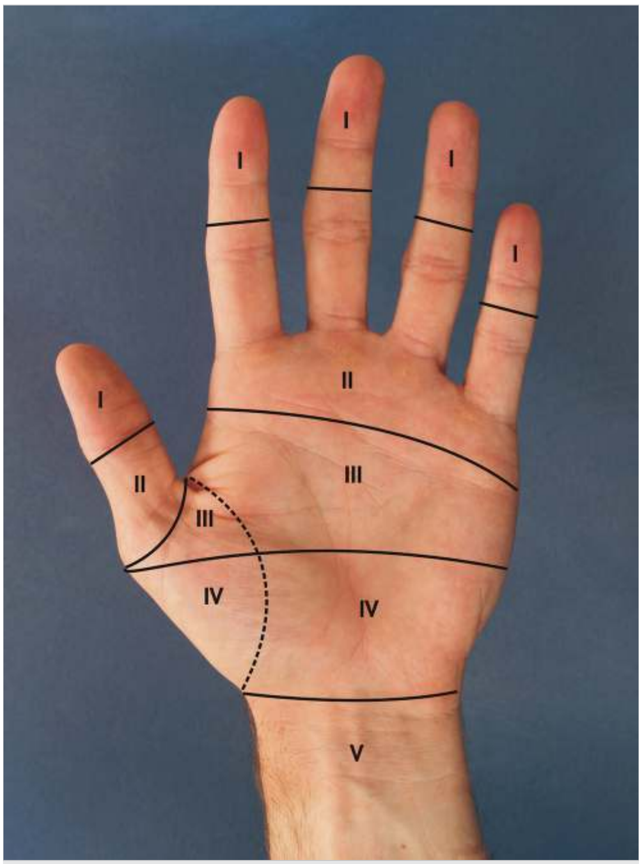

Fig. 45.2 Palmar view of the hand demonstrating the flexor tendon zones as described by Kleinert et al.[1]

45.3.2 Zone 2

These injuries occur between the A1 pulley and the insertion of the FDS tendon. Up until the landmark presentation by Dr. Kleinert in 1970,[1] acute repair was not recommended in these patients. Experience in repairing acute zone 2 flexor tendon injuries has demonstrated that these patients can do very well if a strong repair is performed and an early flexor tendon rehabilitation protocol is adhered to.[16]

The same technical considerations are performed as described in zone 1 injuries. Ultrasound can be used to identify the tendon ends and assist with creation of incisions.[17] Once

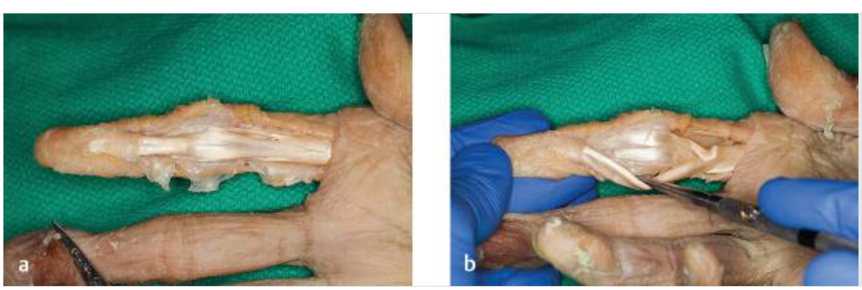

Fig. 45.3 **(a)** Image demonstrating Camper's chiasma with flexor tendon sheaths released and **(b)** insertion sites of the flexor digitorum superficialis (FDS) tendon insertion at the middle phalanx with the flexor digitorum profundus (FDP) tendon retracted ulnarly.

Table 45.1 Gross, histologic, and functional anatomy of the flexor pulley system

	Gross/Histologic anatomy	Functional anatomy
A5	Arises from palmar plate of the DIPJ	
C3		Thin and condensable allowing collapse and approximation of annular pulleys with flexion
A4	Superficial oblique fibers overlay the deeper annular fibers and distally merge with C3 fibers	
C2		Thin and condensable, allowing collapse and approximation of annular pulleys with flexion
A3	Arises from palmar plate of the PIPJ	
C1		Thin and condensable, allowing collapse and approximation of annular pulleys with flexion
A2	Superficial oblique fibers overlay the deeper annular fibers and form a proximal, prominent leading edge; distally oblique fibers merge with C1	**Strength**: A2 > A4 > A1 > A3 **Stiffness**: A2, A4 > A1, A3, A5 **Length**: A2 > A1 > A4 > A5 > A3
A1	Arises from palmar plate of the MCPJ Single annular band most common (59%) Double and triple annular bands also seen A1 and A2 are separate structures in 95% *(separated by 0.4–4.1 mm)*	
PA	Composed of transverse and vertical fibers of palmar fascia; the vertical fibers extend dorsally on each side of the tendons to insert on the deep transverse intermetacarpal ligament	Clinically important when other proximal components of the flexor sheath (A1 + /– A2) are lost

Abbreviations: DIPJ, distal interphalangeal joint; MPJ; PIPJ, proximal interphalangeal joint.
Source: Adapted from Doyle JR. Anatomy of the finger flexor tendon sheath and pulley system. J Hand Surg Am 1988;13(4):473–484.

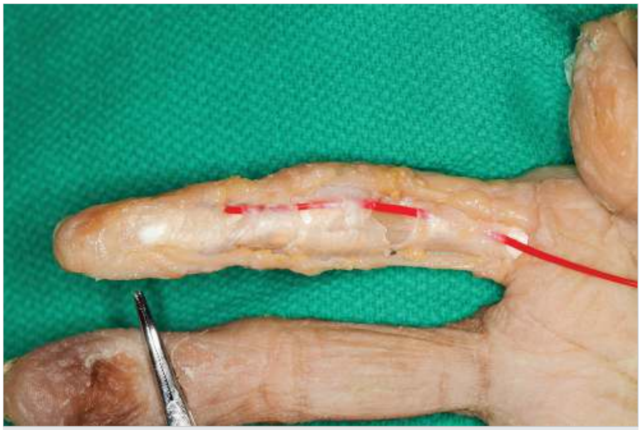

Fig. 45.4 Image demonstrating a red rubber catheter running longitudinally underneath the flexor tendon sheaths on the palmar aspect of the index finger.

the skin flaps are created, it is imperative to plan the location of the repair prior to opening the flexor tendon sheath. Based on the distal tendon stump, the surgeon should mentally decide where the final repair will be located. Next, the pullies and flexor tendon sheath are opened. The A2 and A4 pullies should be preserved if possible; however, if the tendon repair will be located at one of these locations, the neighboring pullies should be left undisrupted to prevent bow-stringing.

The proximal tendon end can be retrieved by flexing the wrist and milking proximal to distal. Alternatively, a small hook, tendon passer, or small caliber hemostat clamp can be used to blindly fish out the tendon stump. Generally, my preferred technique is to attempt one or two blind passes with a clamp. If unsuccessful, I prefer to create a small separate counter-incision at the A1 pulley and retrieve the tendon(s) in the palm. The tendon is then passed through the sheath using an 8 French red rubber catheter or a sterile respiratory catheter under anesthesia (▶ Fig. 45.7). This technique limits incision length and disruption of the pulley system in the fingers.

The proximal tendon is speared with a hypodermic needle, the wrist held in flexion by the assistant or with a towel bump, and the tendon is repaired. A 5–0 monofilament epitendinous running suture is created on the dorsal aspect of the tendon; a knot is not generally created until the end. A locking core repair is performed with a minimum of four strands.[18] I prefer to use a looped 4–0 FiberWire suture using six strands with the knot buried in the repair. The epitendinous suture is then completed over the volar aspect and tied to its tail.

45.3.3 Zones 3–5

Operative techniques are similar to zone 2 but the prognosis is better for zones 3-5 (▶ Fig. 45.8). The repair bulk is less important and the postoperative adhesions are less constricting. For zone 4 injuries within the carpal tunnel, excess tendon bulk can become problematic if multiple tendons are injured. The transverse carpal ligament can be repaired, if bow-stringing is anticipated. Zone 5 injuries commonly occur in the setting of a "spaghetti wrist" with concomitant neurovascular injuries (▶ Fig. 45.9).[19] The tendon repair does not require epitendinous sutures. Outcomes are generally positive; however, patients can develop very significant adhesions restricting motion. We have used Kenalog in the postoperative period for softening of recurrent scar adhesions prior to performing tenolysis. Associated nerve injuries (▶ Fig. 45.10) are frequently more disabling than the tendons.

Table 45.2 Anatomic description of pulley system

	Level and attachment	Length *(avg. in mm from Doyle, 1988)*	Thickness *Annular pulleys range from 0.25 to 0.75 mm and is usually proportional to length of the pulley* A2 > A1 > A4	% Present Doyle, 1988 (*N* = 61)
A5	Palmar plate at DIPJ	4	Despite length, is quite thin	93%
C3		2.5		
A4	Periosteum at midportion of P-2 *(middle phalanx)*	7	Thickest at mid aspect	98%
C2		2.9	0.1 mm	
A3	Palmar plate at PIPJ	3	0.33 mm	87%
C1		4.2	0.1–0.2 mm	
A2	Periosteum of proximal half of P-1 *(proximal phalanx)*	16.8	Thickest distally (varies from 0.25 to 0.75 mm)	100%
A1	Palmar plate at MCPJ *(prox. two-thirds of A1 fibers)* Proximal aspect of P-1 *(distal one-third of A1 fibers)*	8	0.5 mm	100%
PA	Proximal edge is 1–3 mm distal to the beginning of the synovial sheath (pouch)	9.3		100%

Abbreviations: DIPJ, distal interphalangeal joint; MCPJ, metacarpophalangeal joint; PIPJ, proximal interphalangeal joint.
Source: Adapted from Doyle JR. Anatomy of the finger flexor tendon sheath and pulley system. J Hand Surg Am 1988;13(4):473–484.

Table 45.3 Deficit of fingertip to palm distance in millimeters as measured after pulley release. Demonstrates that A2 and A4 pulleys are most critical pulleys for flexor tendon function.

Deficit of fingertip to palm distance in mm	Pulley(s) released *(denoted by X)*				
	A1	A2	A3	A4	A5
0	X				
12–15		X			
2–5				X	
0	X		X		X
12–15	X		X	X	X
20–25	X	X	X		X
25–30	X	X	X	X	X

Source: Adapted from Doyle JR. Anatomy of the finger flexor tendon sheath and pulley system. J Hand Surg Am 1988;13(4):473–484.

Table 45.4 Zone 1 flexor tendon injuries (jersey finger) are defined according to the classification system as described by Leddy and Packer[7] and amended by Smith

Zone 1 flexor tendon injury type	Description
Type I	No bony fragment, rupture of both vinculae and tendon retraction into palm
Type II	Small bony fragment, with proximal tendon end held by vincula longa at the level of PIPJ
Type III	Large bony fragment caught at A4 pulley with both vinculae intact
Type IV	Intra-articular fracture of the distal phalanx with avulsion of the FDP tendon from the avulsed bony fragment

Abbreviations: FDP, flexor digitorum profundus; PIPJ, proximal interphalangeal joint.
Source: Adapted from Smith JH, Jr. Avulsion of a profundus tendon with simultaneous intraarticular fracture of the distal phalanx—case report. J Hand Surg Am 1981;6(6):600–601.

Fig. 45.5 Image series demonstrating zone 1 injury with loss of distal interphalangeal joint (DIPJ) flexion **(a–c)** preoperatively and proximal harvest of the **(d, e)** retracted tendon.

Fig. 45.6 Image demonstrating the vincula brevia connecting the head of the proximal phalanx to the flexor digitorum superficialis (FDS) tendon and a portion of vincula longa attaching to the inferior aspect of the flexor digitorum profundus (FDP) tendon to the superior aspect of the FDS distal to Camper's chiasma.

45.3.4 Postoperative Protocol

The patient is splinted with wrist and fingers flexed at the end of the repair. This prevents the patient from making a tight fist and relieves tension off the tendon. Early controlled mobilization protocols are standard of care for cooperative adult patients.[16] These rehabilitation programs are started 1 to 2 weeks after surgery with progressive increases in motion followed by strength. Many protocols have been developed that use various degrees of active and passive motion. We begin at 2 weeks postoperative with place and hold activities for 2 weeks followed by 2 weeks of active motion with the wrist in neutral or flexed along with fingers in a fist with wrist motion. At 6 weeks, strength training is initiated and progressed until 12 weeks, at which time the patient is allowed to do normal full-strength activities.

45.4 Conclusion

The greatest challenge in flexor tendon repair continues to be regaining complete return of motion. Incomplete flexion after tendon repair results from two primary factors, namely, bow-stringing from over release of the pulley system and tendon adhesions. Early range of motion protocols have dramatically limited stiffness from tendon adhesions and improved zone 2 flexor tendon outcomes; however, access to certified hand therapists is limited in rural communities, which contributes to the persistence of this issue. Bow-stringing results from release of the flexor tendon sheath—some element of release is necessary to retrieve the tendon ends, perform the repair, and limit the repair catching during gliding. A number of factors can assist the surgeon in focusing the dissection of the tendon sheath and limiting the amount of tendon sheath that is sacrificed. Foremost, obtaining specific history from the patient on

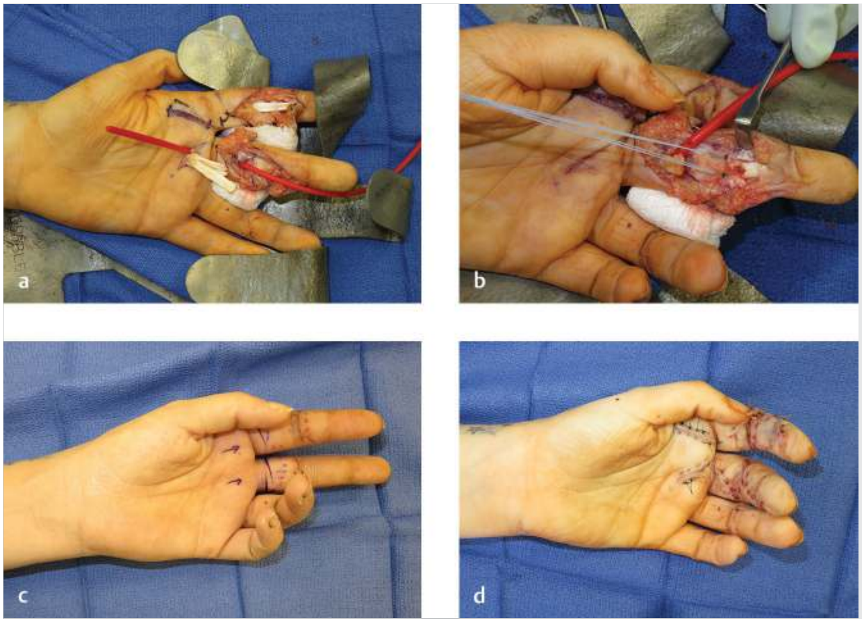

Fig. 45.7 Image series demonstrating a zone 2 flexor tendon repair of the third digit and the use of a red rubber catheter to retrieve retracted flexor digitorum superficialis (FDS) tendon through a separate incision over the **(a)** A1 pulley at the distal aspect of the palm. The successful retrieval of the FDS tendon and a **(b)** suture loop passed around the flexor digitorum profundus (FDP) tendon in preparation for primary repair, and the **(c)** preoperative and the **(d)** postoperative visuals of the repaired flexor tendon injury demonstrating improved cadence are shown.

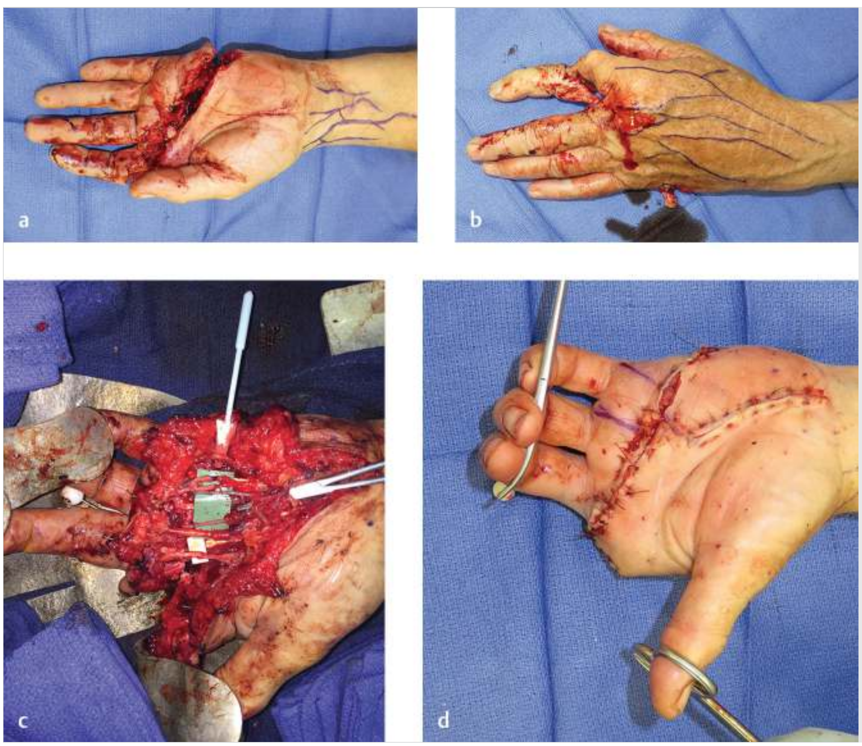

Fig. 45.8 Image series of **(a, b)** zone 3 injury preoperatively; it is important to identify the venous blood supply on the ventral forearm and dorsal hand prior to tourniquet placement as has been done with purple marker in the images. Intraoperative dissection and identification of **(c)** neurovascular structures and **(d)** postrepair image; index finger metacarpophalangeal joint (MCPJ) was disrupted and digit was sacrificed.

the position of the finger during injury greatly helps in knowing which tendon end is retracted, thereby indicating where the repair will be located with the finger in extension. Ultrasound can also assist in identifying the tendon ends for retrieval. Finally, use of catheters to retrieve tendon ends can limit incision lengths, trauma to the tendon, and sheath dissection. Future directions for tendon repair include methods for creating less bulky repairs and identifying agents that decrease postoperative edema and/or improve tendon healing (e.g., polydeoxyribonucleotide).

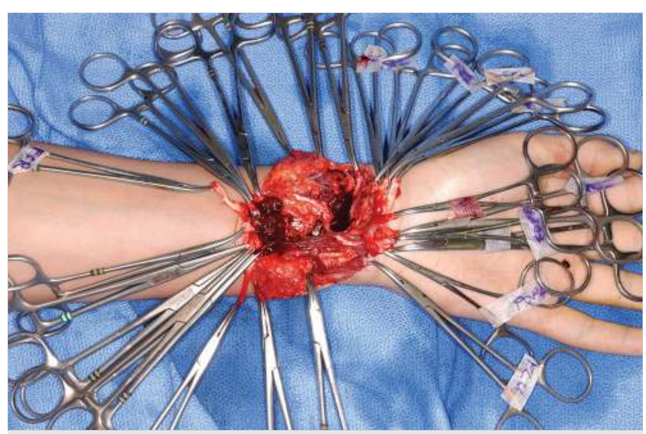

Fig. 45.9 Illustration of spaghetti wrist.

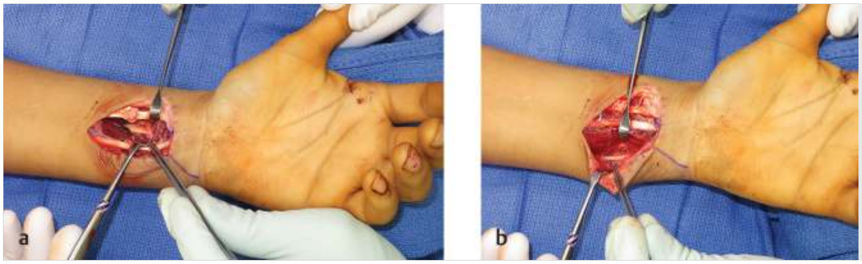

Fig. 45.10 It is critical to intraoperatively assess for nerve injuries in cases of spaghetti wrist; visual of **(a)** median nerve assessment and **(b)** ulnar nerve assessment.

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46 Tendon Transfers

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Abstract

Tendon transfers are used to restore function of joint flexion, or extension, or digit adduction and abduction. In this chapter we are going to review the main tendinous transfers used for paralyses of the radial, median, and ulnar nerves, their indications, surgical technique, and complications.

Keywords: median, nerve, paralysis, radial, tendon transfer, ulnar

46.1 Introduction

46.1.1 General Principles in Tendon Transfer

It is essential to know the fundamental principles of muscle contraction, amplitutude, synergy, and alignment before embarking upon tendon transfers. There have been many pioneers who have described these principles including Steindler, Boyes, Littler, Bunnell, Brand, and Curtis. Essentially, we borrow from the expendable and give to the necessary. The recipient tendon's function must be more important than the donor function. Idealy the transfer has adequate strength and uses synergistic motion. The transferred tendon should perform one function. Crossing multiple joints to create composite functions only weakens the transfer. The more the transfer can be performed in a straight line in a path of least resistance, the better the function.

Avoid Joint Contracture

After a nerve injury or loss of tendon/muscle in the upper extremity, the patient must enter into a rehabilitation program that prevents joint contracture and maintains supple joints. Patients with stiff fingers with fixed contractures are poor candidates for tendon transfers because they will not be able to mobilize a rigid joint after surgery.

Muscle Strength

The transferred tendon must be strong enough to perform the intended function. It is important to know the relative work capacity of the forearm muscles to optomize the type of transfer[1] (▶ Table 46.1).

Generally, muscles having a strength of MS 4 or 5 are chosen for functional recovery.[2] Muscles that have been reinnervated following a trauma should be avaoided for transfer as they will not have apporiate strength.

Excursion

The tendon amplitude or excursion must be sufficient to restore the lost function of the recipient muscle and be similar to the tendon that is replacing. The resting fiber length is directly related with the amount of excursion that can be expected from tendons and can be estimated with the Boyes 3, 5, and 7 rule.[3]

1. Wrist flexors and extensors: 33 mm.
2. Finger extensors and extensor pollicis longus (EPL): 50 mm.
3. Finger flexors: 70 mm.

A wrist flexor cannot substitute fully for a finger extensor, because wrist flexor has less excursión. We, therefore, optomize the effective amplitude through the tenodesis effect and by providing an easy gliding plane.

One Tendon One Function

A single tendon cannot be expected to perform two functions, for exemple, to flex and extend the same joint. Similarly, a transfer cannot be expected to flex finger and oppose the thumb. However, one tendon may be used to restore the function of multiple fingers; for example, transferring the flexor carpi radialis to extensor digiti communis tendons for extesion of all digits together.[3]

Straight Line of Pull

The maximization of muscle contraction efficiency and force of a transferred tendon is accomplished by creating a direct line of muscle pull from its own origin to the insertion of the tendon being substituted. Redirectional pulleys may be required for specific function but this does diminish the muscle's efficiency and force of contracture.[4,5]

Table 46.1 Work capacity of forearm muscles

Donor muscle	MKg	Recipient muscles	MKg
BR	1,9	EPL	0,1
PT	1,2	APL	0,1
FCR	0,8	EPB	0,1
FCU	2,0	EDC	1,7
PL	0,1	EIP	1,1
FDS	4,8	ECRL	1,1
FDP	4,5	ECRB	0,9
FPL	1,2	ECU	1,1

Abbreviations: APL, abductor pollicis longus; BR, brachioradialis; ECRB, extensor carpi radialis brevis; ECU, extensor carpi ulnari; EDC, extensor digitorum communis; ECRL, extensor carpi radialis longus; EIP, extensor indicis proprius; EPB, extensor pollicis brevis; EPL, extensor pollicis longus; FCR, flexor carpi radialis; FCU, flexor carpi ulnaris; FDP, flexor digitorum profundus; FDS, flexor digitorum superficialis; PL, palmaris longus; PT, pronator teres.
Source: Data from Cheah et al.[9]

Tissue Equilibrium

This term infers that maturation of the tissue bed has ocurred before the tendon transfer. Tissue maturation means that the inflammation and edema are limited to prevent increased scarring of the transferred tendon surrounding the tissue. It is important to keep in mind that the tendon transfers work best when passed between deep fascial layer and subcutaneous fat. The motion is hindered if there is an inadequate gliding surface due to a scar tissue, residual joint stiffness, or residual edema.[1]

Synergism

The concept was advocated by Littler and it refers to a transferred tendon's normal contractile period which should be the same as the contractile period of the tendon that is being augmented. A synergistic transfer allows the muscle to contract during the expected motion, in a contraction sequence that is in phase with the recipient muscle.[6]

Timing of Tendon Transfers

There is no consensus about time from injury to transfer. If a radial nerve is regenerating, it may take 9 to 12 months to realize the extent of the deficit. Some authors advocate a limited transfer (pronator teres [PT] to extensor carpi radialis brevis [ECRB]) to supplement any return in the reinervated extensor muscles and to act as an internal (baby sitter) splint preventing contractures and enabling some intermediary function.[5] If the radial nerve injury has a very poor prognosis in reinervating the muscles, it is better to proceed directly to the tendon transfers or distal nerve transfers.[5]

Tendon transfers for ulnar and median nerve palsy are performed several months after the injury.

46.1.2 Radial Nerve Palsy

- Radial nerve palsy causes limitation in wrist extension, loss of thumb and finger extension, and weakness in grip strength.
- The radial nerve gives off the posterior interosseous branch, at the level of the radial capitellum. This branch innervates all extensors except the extensor carpi radialis longus (ECRL). The radial nerve palsy can be divided into high palsy and low or posterior interosseous palsy. In low radial nerve palsy, the wrist extension is preserved with radial deviation.
- The inability to stabilize the wrist leads to grip strength loss of up to 50%, causing a significant functional imbalance.

Anatomy

- The radial nerve has its origin in the posterior chord of the brachial plexus, and runs along the humerus in its posteromedial surface.
- At the level of the middle third of the humerus diaphysis, in the spiral groove, the radial nerve heads laterally and just before the elbow it gives branches to the brachioradialis (BR) and ECRL.
- At the radial capitellum it divides into the posterior interosseous nerve (PIN) and the radial sensitive branch.
- The PIN gives branches to muscles in the following order:

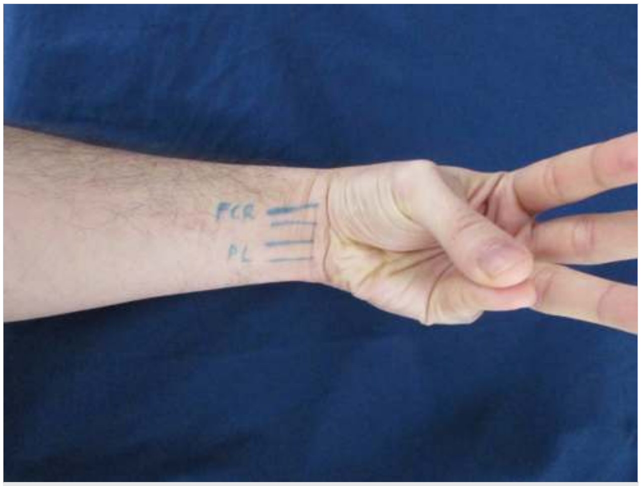

Fig. 46.1 Checking for the presence of the palmaris longus (PL).

  ECRB, supinator, extensor digitorum communis (EDC), extensor carpi ulnaris (ECU), extensor digiti minimi (EDM), abductor pollicis longus (APL), extensor pollicis brevis (EPB), EPL, and extensor indicis propius (EIP).[7,8]
- The radial sensitive branch becomes subcutaneous about 9 to 10 cm proximal to the radial styloid process in its path toward the hand.

Physical Examination

- Stiff contracted joints are a contraindication to tendon transfer.
- The presence of residual muscular activity is examined.[9,10]
- Make a list of the available normal contracting muscles. Identify what function needs to be restored. Then match up expendable tendons to those that require restoration of function.
- Assess all muscles individually including the presence of the palmaris longus (PL) (▶ Fig. 46.1).

46.1.3 Opponensplasty

- The EIP, PL, and flexor digitorum superficialis (FDS) have all been employed to create opposition when redirected toward the thumb from the ulnar side of the palm through a fascial pulley. The location of the pulley as well as the distal insertion of the tendon to the thumb vary according to the needs of the patient to obtain different degrees of palmar abduction, pronation, and flexion of the thumb.[11]

Burkhalter Transfer

- EIP transfer.

Camitz Transfer

The PL opponensplasty is usually performed for loss of abduction and opposition in severe carpal tunnel syndrome. We perform a Camitz procedure at the same time as carpal tunnel release in patients with severe thenar wasting.[12]

Table 46.2 Anatomy and function of innervated ulnar nerve muscles

Muscle	Origin	Insertion	Function
FCU	Medial epicondyle* Medial border of the olecranon and upper posterior ulna†	Pisiform Hamate hook	Carpal flexion and ulnar deviation Grip stabilization
FDP to 4th and 5th fingers	Upper anterior ulna, IOM, and anterior radial shaft	Anterior base of the distal phalanx of 4th and 5th fingers	Primary flexion of the distal phalanx Secondary flexion of medial and proximal phalanxes
ADM	Pisiform, tendon of the FCU and pisohamate ligament	Ulnar border of the proximal phalanx in the 5th finger and extensor hood	Fifth finger abduction MCP flexion IP extension
ODM	Hook of the hamate Flexor compartment	Distal and proximal fifth metacarpal shaft	Fifth metacarpal flexion and opposition
FDM	Hook of the hamate Flexor retinaculum Pisiform bone	Fuses with ADM	Primary flexor MCP Secondary abductor of fifth finger
Lumbricals to 4th and 5th digits	Correspondent FDP muscle tendon	Radial side of extensor hood, MCP volar plate, and proximal phalanx	IP extension and MCP flexion
Dorsal interosseous (bipenate)	Opposite surface of adjacent metacarpals	Base of its proximal phalanx and extensor aponeurosis	Abduction of fingers Dynamic and static finger stabilizers IP extension and MCP flexion
Palmar interosseous (unipenate)	Ulnar shaft of 1st and 2nd and radial shaft of 4th and 5th metacarpals	Extensor expansion of its correspondent finger	Adduction of fingers Dynamic and static finger stabilizers IP extension and MCP flexion
Adductor pollicis	Capitate, 2nd or 3rd metacarpals Distal 3rd metacarpal	Medial side of the thumb proximal phalanx base	Adduction of the thumb metacarpal Extension of the IP
Flexor pollicis brevis**	Trapezoid, capitate, and volar ligament of the distal carpal row	Radial thumb sesamoid and base of the proximal phalanx	Flexion of the thumb MCP, distal phalanx extension, pronation

Abbreviations: ADM, abductor digiti minimi; FCU, flexor carpi ulnaris; FDM, flexor digiti minimi; FDP, flexor digitorum profundus; IOM, interosseous membrane; IP, interphalangeal; MCP, metacarpophalangeal; ODM, opponens digiti minimi.
Note: *: Humeral head; †: Ulnar head; **: Deep transverse head.

46.1.4 Ulnar Nerve Paralysis

- Ulnar nerve originates from the anterior division of the lower components of the brachial plexus; besides its sensitive innervation of the ulnar border of the hand and digits, it shares with the median nerve motor innervation of carpal and digital flexor tendon extrinsic muscles in the forearm and provides most of the intrinsic muscle innervation in the hand (▶ Table 46.2).
- The knowledge of its normal anatomy and the anatomy and biomechanics of its innervated muscles allows the surgeon to understand the consequences of its paralysis and helps him or her to design functional surgical plans according to individual patient deficits and donor availability.[13]
- Ulnar nerve paralysis can be divided into high and low types. High paralysis involves functional deficit of both extrinsic and intrinsic muscles causing sensory loss in its territory, paralysis of the flexor carpi ulnaris (FCU), absence of fourth and fifth distal interphalangeal (DIP) joint flexion, debilitated lateral pinch, abduction of the small finger, and asynchronous movement of the fingers. Low paralysis spares extrinsic muscles but presents all the intrinsic deficits including muscle atrophy and clawing of fourth and fifth fingers. Clinical findings in ulnar nerve palsy are summarized in ▶ Table 46.3.

46.2 Indications

46.2.1 Radial Nerve Palsy

- Chronic, incomplete, or irreparable radial nerve paralysis or extensor muscle/tendon loss. The objective is to restore wrist, thumb, and finger extension.
- Radial nerve injuries are treated with neurorraphy or nerve reconstruction, where a tendon transfer could be utilized as an internal splint.

46.2.2 Ulnar Nerve Paralysis

Pathophysiology of Deformities

- Normal hand function is achieved through perfect balance between intrinsic and extrinsic muscles. Each of them separately has a small size but collectively they represent almost 50% of grip strength, and ulnar paralysis leads not only to loss of grip precision, but also causes loss of grip and pinch strength (38 and 77% of normal respectively), impairs the ability to manipulate medium and large size objects and in time it leads to well-known deformities that are also a frequent complaint in these patients.[14]

Table 46.3 Clinical findings in ulnar palsy

Sign	Description
Andre-Thomas	Wrist flexion when IP extension is attempted due to tenodesis effect
Bouvier	Loss of full IP extension with MCP hyperextension Can extend IP joints with blocked MCP extension
Bunnell	Inability to make an "O" between thumb and index (tip pinch)
Duchenne	Fourth and fifth MCP hyperextension and IP flexion exacerbated when finger extensión is attempted
Earle-Vlastou	Inability to cross the third finger over the index
Egawa	Inability to abduct/adduct third finger when MCP is flexed
Froment	Compensatory flexion of the thumb IP when key pinch is attempted
Jeanne	Compensatory thumb MCP hyperextension when key pinch is attempted
Masse	Flattening of the transverse metacarpal arch, loss of hypothenar bulk, and inability to make a concave palm
Pitres-Testut	Decrease in the transverse diameter of the hand and inability to abduct the middle finger with the MCP extended
Pollock	Inability to flex the fourth and fifth DIP joints (high palsy)
Sunderland	Inability to oppose the little finger toward the thumb
Wartenberg	Persistent abduction of the fifth finger due to unopposed extensor pull
Inverted Pyramid	Atrophy of the transverse head of the AP with a hollow in the distal thenar eminence

Abbreviations: AP, adductor pollicis; DIP, distal interphalangeal; IP, interphalangeal; MCP, metacarpophalangeal.
Source: Data from Draeger RW, Stern PJ. The inverted pyramid sign and other eponymous signs of ulnar nerve palsy. J Hand Surg Am 2014;39 (12):2517–2520.

- Ulnar nerve palsy produces complex deficits and its clinical significance varies depending on age, joint laxity, and individual functional demands.

Ulnar Clawing and Alterations in Finger Motion

- In normal conditions midpalmar intrinsic muscles (lumbricals and interosseous) contribute to metacarpophalangeal (MCP) flexion and interphalangeal (IP) extension (known as "*intrinsic plus*" position); this last action occurs through its extensor mechanism insertion (▶ Fig. 46.2).
- In case of intrinsic palsy (low ulnar nerve palsy), the predominant action of extrinsic flexors overpowers the DIP and proximal interphalangeal (PIP) joints while the extrinsic extensors overpower the MCP joint.
- The MCP is drawn into extension and the PIP and DIP into flexion creating the claw appearance of the little and ring fingers.
- The finger flexion sequence normally starts with the initiation of intrinsic MCP flexion and finger extension. Loss of the intrinsics and contraction of the FDS and flexor digitorum profundus (FDP) produce a distal to proximal rolling of the fingers, which brings finger tips to their base, rather than to the center of the palm.
- This flexion pattern impairs the ability to grasp large objects because fingers are not capable of sweep around and tend to push them out of grasp.
- Motor imbalance causes clawing of fourth and fifth fingers; MCP volar plate laxity, unopposed MCP extension, and unopposed IP flexion ("*intrinsic minus*" deformity), all contribute to this deformity which worsens when the patient tries to open the hand (▶ Fig. 46.3). If there are anatomical variations in the innervation of radial lumbricals, this deformity can also be seen in the second and third fingers.
- Ulnar clawing may be less noticeable in high ulnar nerve palsy as the fourth and fifth FDPs are also paralyzed producing less imbalance (known as the ulnar paradox), although this can be variable depending on anatomical variantion of the patient. With persistent deformity, soft tissues around the MCP and IP joints contract and the extensor mechanism attenuates leading to fixed deformity.

Key Pinch

- Paralysis of the adductor pollicis (AP), half of the flexor pollicis brevis (FPB), and the first dorsal interosseous muscle, further debilitated by the unopposed extrinsic extension, causes loss of the thumb–index pinch strength so that it is usually compensated by the activation of the flexor pollicis longus (FPL) and, in chronic cases, hyperextension of the thumb MCP.[7]

Transverse Metacarpal Arch

- When normally innervated, interosseous muscles tone maintain palm in a "cup type" rotation toward the center of the hand.
- When paralyzed, unopposed extrinsic extension rotates metacarpals out and the passive action of the transverse metacarpal ligaments holds metacarpal heads in a more parallel position; patients complain of the inability to cup water in the hand, loss of the hypothenar bulk, and difficulty in grasping because of their inability to normal contour their palm around objects.

Fifth Finger Abduction

- Normal function of the EDM is to pull or draw the proximal phalanx of little finger proximally and into abduction. These forces are countered by the intrinsic muscles.
- With paralysis of the third palmar interosseous muscle, this leads to unopposed abduction of the little finger at the MCP joint (▶ Fig. 46.4).

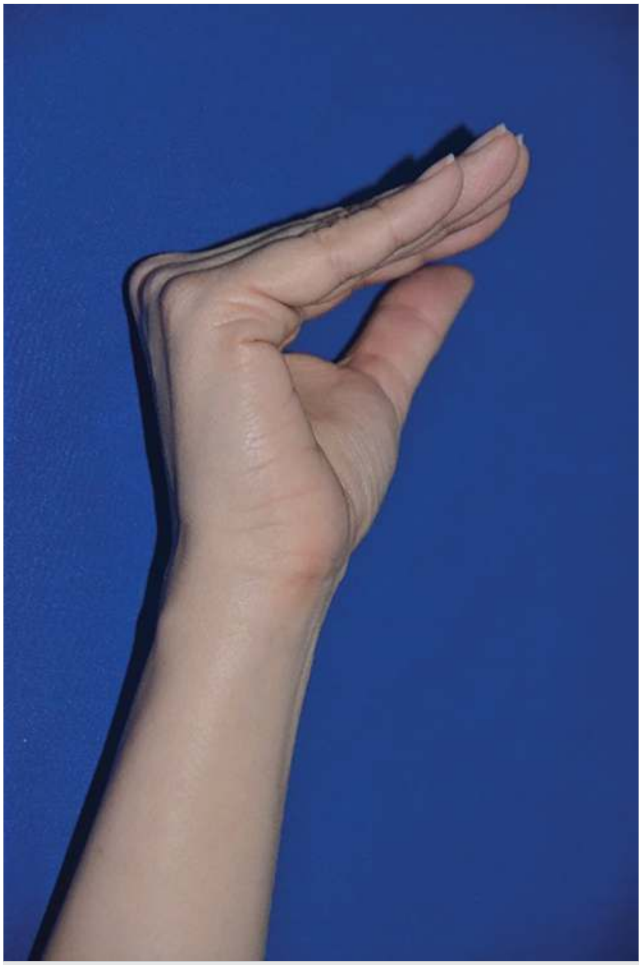

Fig. 46.2 "Intrinsic plus" position. Metacarpophalangeal (MCP) full flexion and interphalangeal (IP) full extension due to normal function of lumbrical and interosseous muscles.

Fig. 46.3 "Intrinsic minus" deformity. Inability to flex the MCP and extend the interphalangeal (IP) of the fourth and fifth fingers due to intrinsic muscle paralysis and unopposed extrinsic function.

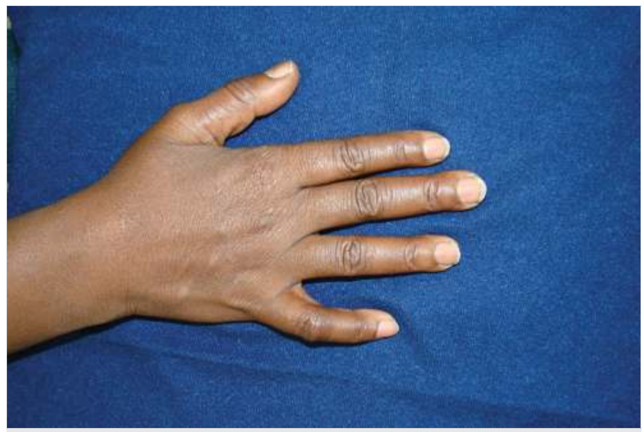

Fig. 46.4 "Wartenberg sign." Permanent abduction of the little finger due to the extensor digiti minimi (EDM) unopposed function.

High Ulnar Nerve Palsy

- Loss of FCU activity does not affect wrist motion notably and reconstruction is normally not required. Loss of fourth and fifth DIP joint flexion due to paralysis of FDP of these two fingers can contribute to weakness of grasp, and the inability to close the ulnar palm produces debilitated holding on to objects.[7]

Timing

- Tendon transfers are reconstructive palliative procedures used to improve hand function in patients in whom nerve reconstruction failed to reinnervate, those who have persistent muscle strength deficit after recovery, or in patients presented late, when muscle atrophy and fibrosis have occurred and one cannot expect further improvement.[8]
- With the advances in microsurgical techniques and rehabilitation protocols, motor recovery from ulnar nerve trauma has been described to be achieved by up to 2 and 3 years after repair for high and low injuries respectively.
- Normal hand function is rarely achieved and patients (especially manual laborers) experience limitations at work.[8] It is widely accepted that dysfunction that is still present after 1 year will not regain normal strength and secondary procedures can improve those deficits; but the surgeon should consider not only time but age, etiology, patient occupation, and soft tissue stability to decide whether a tendon transfer is indicated.
- Some authors advocate that early reconstruction can prevent chronic deformity and if one decides to pursue secondary reconstruction before 1 year, the benefit should exceed the risk of potential deficits and only fully expendable motors are used.

46.3 Operative Technique

46.3.1 Radial Nerve Palsy

- Preserve the FCU if possible, as it is the principal wrist flexor.
- Numerous tansfers have been described, but the most common includes:
  - PT to ECRB, which restores wrist extension.

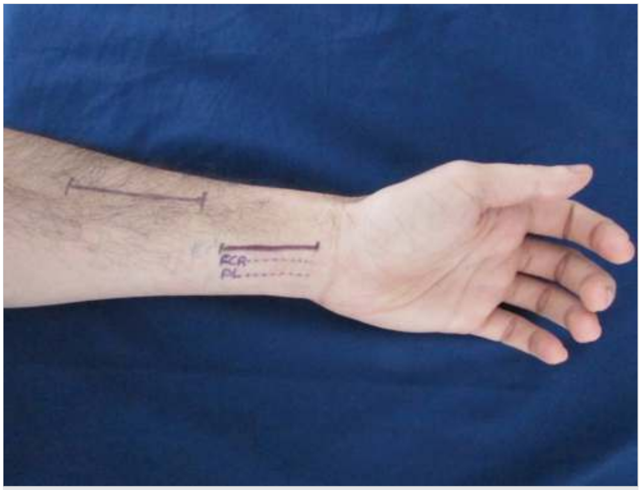

Fig. 46.5 Volar incisions.

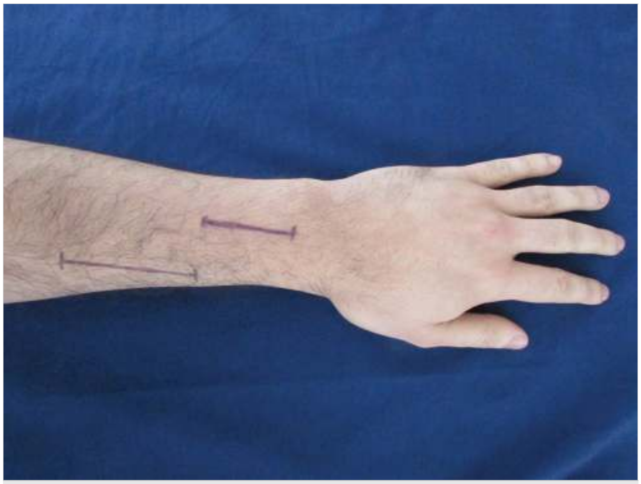

Fig. 46.6 Dorsal incisions.

- Flexor carpi radialis (FCR) to EDC, which restores digital extension. As an alternative, the FDS of the fourth finger can be transferred to EDC.
- PL to EPL, which restores extension/abduction of the thumb. As an alternative, the FDS of the third finger can be transferred to the EPL.

- The patient is set in supine position, the upper extremity on a surgical table and under proximal pneumatic tourniquet.
- It is recommended to release the tourniquet and check hemostasia before incision closure to prevent hematomas.

Pronator Teres (PT) to Extensor Carpi Radialis Brevis (ECRB)

- A 5 to 6 cm incision is made in the radial border of forearm and middle third, BR, and ECRB are identified (▶ Fig. 46.5).
- Deep to the BR, which is ulnarly retracted, the insertion of the PT is identified. The radial sensitive branch must be recognized and preserved.
- The PT is desinserted along with a periosteal strip extension.
- Tenorrhaphy between PT and ECRB is performed under wrist extension of 45 degrees. If recovery of the ECRB is not expected in time, it is completely divided and a side to side tenorrhaphy is performed, with 3–0 polypropylene or polyester suture and at least 5 cm of tendon overlaying, with a continous crossed suture in both borders of the overlaped tendons, as described by Friden (2). When an internal splint is intended the ECRB is not divided.
- An adequately executed transfer guarantees 45 degrees pasive wrist extension without any support.

Flexor Carpi Radialis (FCR) to Extensor Digitorum Communis (EDC)

- A 5 to 6 cm incision in the dorsal forearm is made, immediately proximal to Lister's tubercle (▶ Fig. 46.6). The EDC and EPL are identified.
- A second 5 cm long palmar incision over the FCR is performed (similar to Henry's approach), through which the FCR and PL tendons are located.
- The FCR is distally divided and followed proximally until an adequate length for tendon excursion is obtained.
- FCR is passed from palmar to dorsal through a subcutaneous tunnel that communicates both incisions in the radial border of the forearm. It is important to avoid compression of the sensitive cutaneous nerves. The FCR is passed through each EDC, while fingers and the MCP are mantained in full extension. Tenorrhaphy is completed with 3–0 polypropylene or polyester suture.

Palmaris Longus (PL) to Extensor Pollicis Longus (EPL)

- Through the palmar incision previously described, the PL is distally divided and followed proximally until an adequate length is obtained.
- Through the same subcutaneous tunnel previosly used, the PL is transferred dorsally.
- A side-to-side tenorrhaphy with the EPL is performed, with a double-crossed suture. As mentioned before, if no recovery is expected, the EPL is completely divided. Tendons are overlayed and sutured with 3–0 polypropylene or polyester. Lister's tubercle continues to act as a natural pulley for the EPL.
- When PL tendon is absent an alternative is the use of the FDS of the third finger transferred to the EPL. In this case the median nerve must be identified and protected.

Postoperative Care

- Wounds are covered with antiobiotic ointment-impregnated gauze and splinted, maintaining wrist in 45 degrees extension and all fingers and MCP in full extension.
- Splintage lasts 4 weeks, with wound observation and cleansing every week. Stitches are removed between the second and third postoperative weeks.
- The position of the splint must be adequately maintained and checked to ensure satisfactory outcomes.
- If possible, after second week, it is recommended to use a custom-made thermoplastic splint.
- After removing the splint at 4 weeks, the patient begins physiotherapy using a resting splint in the safe position (MCP at

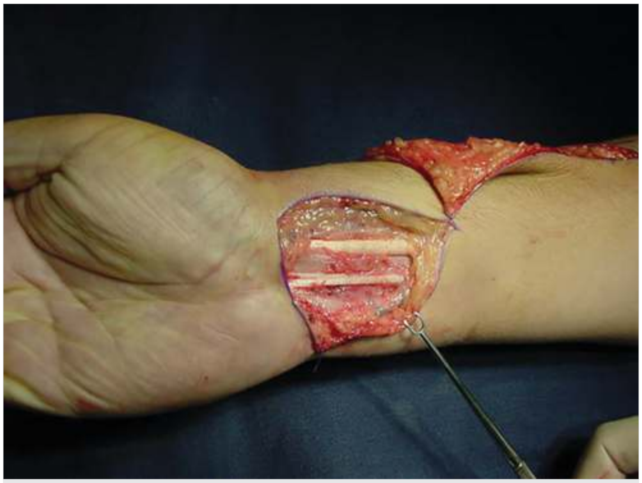

Fig. 46.7 Flexor carpi radialis and palmaris longus tendons.

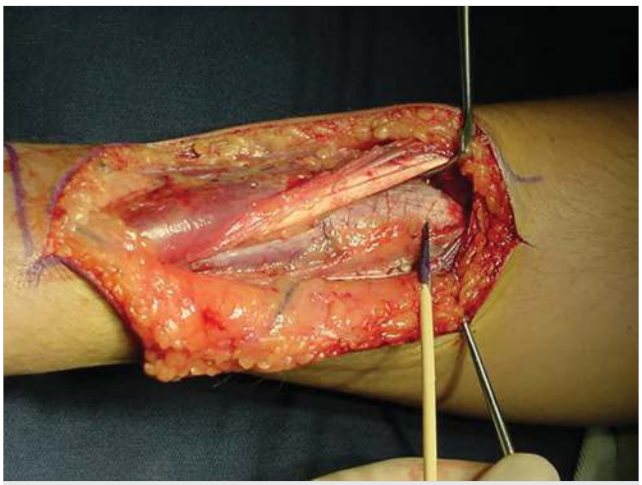

Fig. 46.8 Pronator teres tendon.

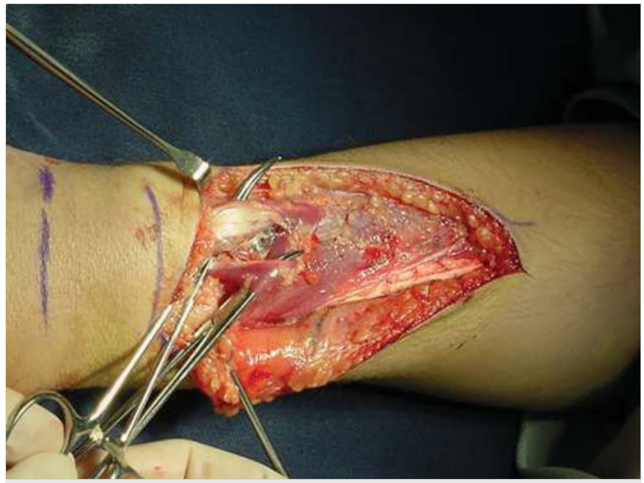

Fig. 46.9 Extensor carpi radialis brevis and pollicis longus tendons.

Fig. 46.10 Flexor carpi radialis to extensor digitorum communis.

40 degrees of flexion) for 2 weeks. This should allow active protected movements.

- After 6 weeks the patient begins muscular strengthening.

Results and Evidence

- Reports in the last 20 years are heterogeneous and hard to compare; nevertheless, these techniques continue to be standard of treatment.
- Common complications include loss of wrist and digital flexion, problematic scarring, and bulging at the tenorrhaphy site.

Tendon Transfer for Radial Palsy: Case Example

The surgical steps used for tendon transfer for radial nerve palsy.

- Through palmar incision at the distal forearm we identified the FCR and PL tendons (▶ Fig. 46.7).
- We also identified the PT tendon (▶ Fig. 46.8) and through the dorsal incision two of the receptor tendons: ECRB and EPL (▶ Fig. 46.9).
- For finger extension we transfer the FCR to EDC tendons (▶ Fig. 46.10).
- In ▶ Fig. 46.11, the PL to EPL transfer through the volar incision is shown.
- During the surgery in lateral view we test the wrist extension recovery with the PT to ECRB tranfer (▶ Fig. 46.12).
- In the next figures we can see the functional results of the tendon tranfers made: Anteroposterior view (▶ Fig. 46.13), lateral view with finger flexion (▶ Fig. 46.14), lateral view with finger extension (▶ Fig. 46.15), lateral view with wrist flexion (▶ Fig. 46.16), and excellent result with EPL (▶ Fig. 46.17).

46.3.2 Median Nerve Palsy

- The median nerve is responsible for multiple actions including opposition of the thumb, key pinch, and sensitivity to the most dextrous part of the hand.[11]

Fig. 46.11 Palmaris longus to extensor pollicis longus tendon.

Fig. 46.12 Intraoperative result.

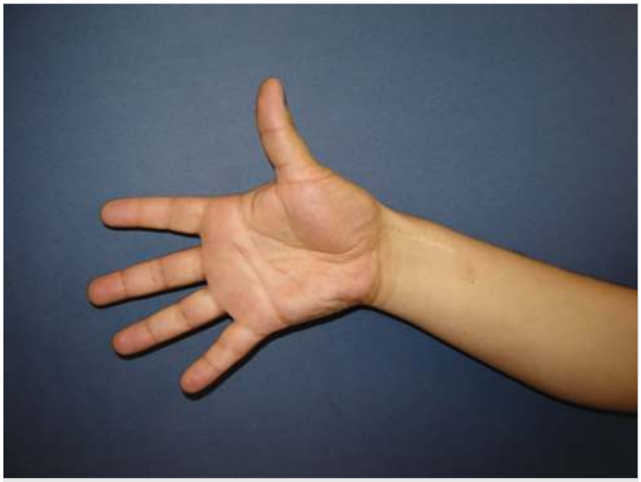

Fig. 46.13 Postoperative result: anteroposterior (AP) view.

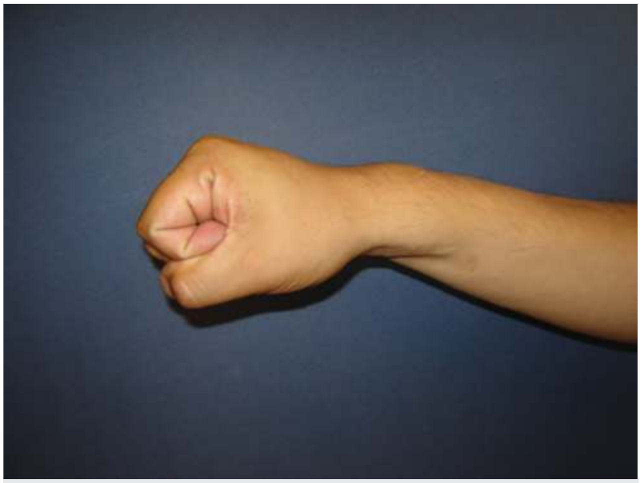

Fig. 46.14 Postoperative result: lateral view in flexion.

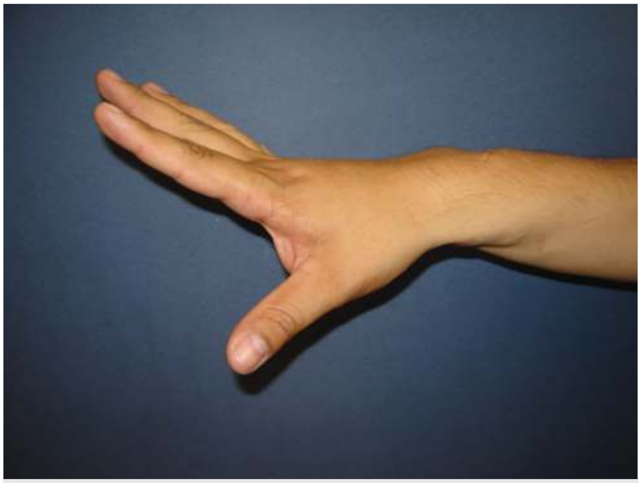

Fig. 46.15 Postoperative result: lateral view in extension.

Fig. 46.16 Postoperative result: lateral view in wrist flexion.

Fig. 46.17 Postoperative result: thumb extension.

Fig. 46.19 Design of the approaches to obtain access to extensor indicis propius (EIP) tendon.

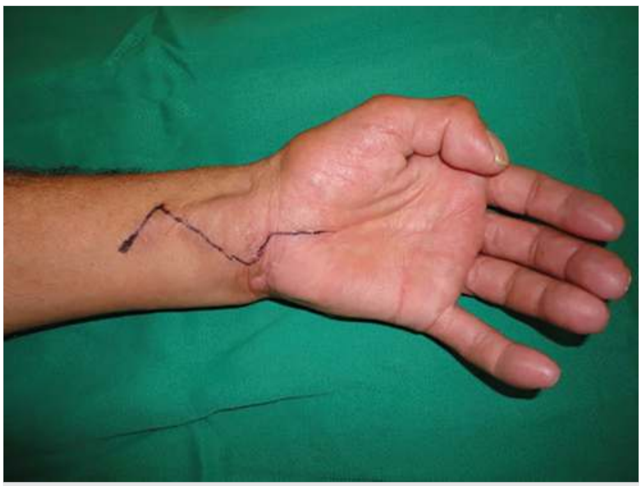

Fig. 46.18 Design of the approaches to obtain access to the carpal tunnel and thenar region.

Fig. 46.20 Tendon of extensor indicis propius (EIP) is divided immediately proximal to the extensor hood.

- The main objective is to restore lost motor function, in particular thumb opposition and flexor pollicis longus and index and long finger profundus function.

46.3.3 Opponensplasty

Burkhalter Transfer

- A small incision is made over the index finger MCP joint where the EIP is identified ulnar to the EDC (▶ Fig. 46.18, ▶ Fig. 46.19, and ▶ Fig. 46.20).[15]
- A longer incision is made on the dorsal ulnar aspect of the distal forearm and the muscle belly of the EIP is mobilized and placed on the ulnar aspect of the wrist, and its tendon is passed through a subcutaneous tunnel around the wrist, through the palm, to an incision over the MCP joint (▶ Fig. 46.21, ▶ Fig. 46.22, and ▶ Fig. 46.23).[15]
- The tendon is transfixed to the MCP joint.

Camitz Transfer

- The presence of the PL is confirmed by opposing the thumb to the little finger with the wrist flexed.
- A small incision is performed proximal to the distal wrist.[12]
- The PL is freed in the forearm and into the palm. It is elongated with a strip of palmar aponeurosis which is dissected out in continuity with the tendon (▶ Fig. 46.24 and ▶ Fig. 46.25).

Fig. 46.21 Use the flexor carpi ulnaris (FCU) tendon as pulley.

Fig. 46.22 Extensor indicis propius (EIP) tendon is passed through a subcutaneous tunnel to an incision over the thumb MP joint, at abductor pollicis brevis (APB) insertion.

- The transverse carpal ligament is realeased.
- The radial part of the ligament can function as a pulley to create the desired direction of pull.
- A second incision is made over the dorsal radial aspect of the thumb MP joint. A subcutaneous tunnel is developed between this joint and the carpal tunnel.
- The PL tendon and its aponeurotic extension are passed through this tunnel (▶ Fig. 46.26, ▶ Fig. 46.27, and ▶ Fig. 46.28).
- The palmar skin incision is closed, and the tendon transferred is usually attached to the abductor pollicis brevis (APB) insertion.
- Different techniques of distal attachment were described by Brand, Littler, Riordan, and Royle-Thompson. Tendon transfers are most efficient when they perform only one active function[12] (▶ Fig. 46.24, ▶ Fig. 46.25, ▶ Fig. 46.26, ▶ Fig. 46.27, and ▶ Fig. 46.28).

Fig. 46.23 Opposition of the thumb is verified before definitive insertion of the extensor indicis propius (EIP) tendon.

Fig. 46.24 Volar approach to palmaris longus tendon.

Postoperative

- The patient is immobilized for 5 weeks with a thumb spike, with blockage of the MCP joint, and thumb in slight abduction and opposition.
- After removing the splint, mobilizations are carried out and controlled by a physiotherapist for 2 weeks; then active mobilizations and progressive resistance are initiated.

Fig. 46.25 The palmaris longus is elongated with a strip of palmar aponeurosis.

Fig. 46.26 Palmaris longus tendon goes through a pulley in the radial remnant of annular ligament in subcutaeous tunnel.

Opponensplasty may not be as beneficial if sensory recovery is not expected.[12]

46.3.4 Ulnar Nerve Paralysis

"Clawing" or Intrinsic Minus Deformity

- There are a variety of techniques described over the years to correct ulnar clawing which use extrinsic tendons of the wrist and fingers.[7,8]
- Selection of individual technique depends of time, associated deficits, available donors, and deformity type.
- Clawing can be classified as simple or complex using Bouvier's maneuver. Simple type clawing is recognized because patients can extend IP joints when MCP extension is blocked (positive Bouvier) and only MCP flexion needs to be reanimated. The most common static procedure is Zancolli's capsulodesis. Complex clawing needs "dynamic transfers," which use an active motor unit to correct deformities and produce movement.[8,16]
- Simple clawing can be corrected by preventing MCP hyperextension, thus allowing secondary IP extension through the integrity of the extensor mechanism with "*static procedures.*" They include MCP arthrodesis or capsulodesis, A1 or A2 pulley release, and tenodesis. These procedures are relatively simple, and they produce more predictable results in high combined injuries, when donor options are scarce. They don't improve grip strength (although there are some authors who

Fig. 46.27 Palmaris longus tendon goes in the direction of abductor pollicis brevis (APB) insertion.

affirm they can, since they put the MCP in flexion) and they cannot restore synchronous flexion of the fingers.
- Static procedures can stretch and weaken with time resulting in recurrence of the deformity.
- The most common static procedure, Zancolli's capsulodesis, modified by Omer complex clawing needs *"dynamic*

Fig. 46.28 The opposition is verified by pulling gently the palmaris longus (PL) tendon proximally.

transfers," which use an active motor unit to correct deformities and produce movement. In isolated ulnar nerve injuries, the preferred donors are finger flexors or wrist tendons through tendon grafts. They can restore synchronous movement and some can improve grip strength. The dynamic transfers have been used in simple clawing with insertion in the proximal base phalanx.[8,16] Static and dynamic transfers are listed in ▶ Table 46.4.

Zancolli's Capsulodesis

- A palmar incision parallel to the distal palmar crease of the affected MCP joints is done and the flexor mechanism is exposed; the A1 pulley is excised and the flexor tendon retracted to either side to expose the palmar plate (▶ Fig. 46.29 and ▶ Fig. 46.30).
- A distal based volar plate flap is developed and advanced proximally and fixed over the metacarpal neck with a transosseous suture or a bone anchor to maintain the MCP in 20 degrees of flexion. The same procedure is repeated in each finger from radial to ulnar and incision is closed (▶ Fig. 46.31).
- Immobilization for 5 weeks avoiding MCP extension (20 degrees of flexion prefered) with IP joints free is indicated.

Dynamic Tendon Transfers

- There are several extrinsic muscles used to restore complex hand clawing; they can be classified by the muscle donor or the insertion they use.
- No matter which donor is selected, the most important principle is that its tendon must pass volar to MCP axis of rotation to produce its flexion.
- All dynamic transfers are amplified by the tenodesis effect of wrist motion.
- The choice of distal insertion depends on patient indications and can be done at the MCP joint, the proximal phalanx, the A1 or A2 pulleys, or the extensor mechanism. The most used by the authors are described in detail.

Superficialis Tendon Techniques

- They can be used in low palsy types; however, in high ulnar palsy only third finger FDS is available for transfer and it should be used with caution.
- It doesn't need extension with tendon grafts and they are relatively easy to perform. But they can further debilitate grip strength and the IP extension obtained is not strong, so they are indicated only in selected simple clawing cases and the most used technique is Zancolli's lasso procedure. However, some authors prefer these donors over the wrist extensors.
- For the lasso, a palmar transverse distal incision across the distal palmar crease or several Bruner type incisions can provide access to all the digits. A1 and proximal A2 pulleys are exposed (▶ Fig. 46.32).
- A transverse incision in the flexor sheath or through the A2 pulley is made to retrieve the FDS proximal to its insertion. Both slips are detached of the insertion and its proximal end is looped around the pulley and sutured back to itself creating an MCP flexion of approximately 30 degrees.
- Evolution of the technique has diminished donor site morbidity because one tendon can be used to activate two fingers (▶ Fig. 46.33).

Wrist Motors Techniques

- BR, ECRL, ECRB, and wrist flexors can theoretically improve hand strength without the sacrifice of flexor tendons and can reanimate IP extension but they have the disadvantage of requiring a tendon graft to reach the insertion site.
- Depending on the associated deformities, patient requirements, and surgeons' preferences, extensor or flexor muscles are used and the route of transfer can be dorsal or volar.
- The most popular technique is the ECRL technique through a volar approach because it has proven to be the most mechanically efficient, easy to reeducate, and it preserves the ECRB, which is the most powerful wrist extensor.[16] Other described techniques are listed in ▶ Table 46.4.

Table 46.4 Tendon transfer options for clawing reconstruction

Transfer	Procedure	Comments
	STATIC PROCEDURES	
Bunnell (1942)	Proximal flexor tendon release to produce bowstring at the MCP	Not used in current practice Only historical relevance
Fowler (1949)	One or two tendon grafts sutured to the extensor retinaculum and to the radial lateral band of affected finger*	To be functional, patient must have normal wrist flexion and extension
Riordan (1953)	Half of ECRB and ECU attached to its insertion and to the radial lateral band of affected finger*	Indicated only when there are no motors for dynamic transfers Needs wrist extension
Zancolli (1957)	Palmar capsulodesis	Recurrences reported No progression of deformity
Mikhail (1964)	Bone blocks to prevent MCP hyperextension	Not used in current practice Flexion deformity
Parkes (1973)	Tendon graft between the flexor retinaculum and the radial lateral band of affected finger*	Omer modified the technique by attaching the proximal tendon graft end to the MCP volar plate
	DYNAMIC PROCEDURES	
Littler (1949)	Middle finger FDS split into four equal slips passed through the lumbrical canal of each finger sutured to the corresponding lateral band*	Modified Stiles-Bunnell transfer (1942) to diminish the donor morbidity Not indicated in manual laborers or combined palsies
Fowler (1949)	EIP and EDM divided and passed through interosseous spaces and sutured to the radial lateral band of affected finger*	Can lead to intrinsic plus deformity; modified by Riordan using only the EIP divided in ulnar isolated palsy
Brand I (1958)	ECRL/ECRB elongated with tendon grafts through the lumbrical canal and to the radial lateral band of affected finger*	Dorsal route Initially described by Littler but popularized by Brand
Brand II (1951)	Same as Brand I but by a volar route through the carpal tunnel	Mechanically more efficient and easy to reeducate than Brand I
Riordan (1969)	Use of the FCR as motor Distal insertion as Brand I through a dorsal route	Indicated in patients with positive Andrew-Thomas sign Contraindicated in high palsies
Antia (1969)	Palmaris longus as the motor source Rest of the procedure same as Brand II	Indicated in young patients with supple hands and a big PL Weak donor
Burkhalter (1973)	Distal insertion to the proximal phalanx	Avoid the risk of PIP hyperextension risk
Zancolli (1974)	FDS tendon slips looped around the A1 pulley and sutured back to itself	Zancolli's lasso

Abbreviations: ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; EDM, extensor digiti minimi; EIP, extensor indicis propius; FCR, flexor carpi radialis; FDS, flexor digitorum superficialis; MCP, metacarpophalangeal; PIP, proximal interphalangeal; PL, palmaris longus.
Note: * For the index finger the insertion is made on the ulnar lateral band.

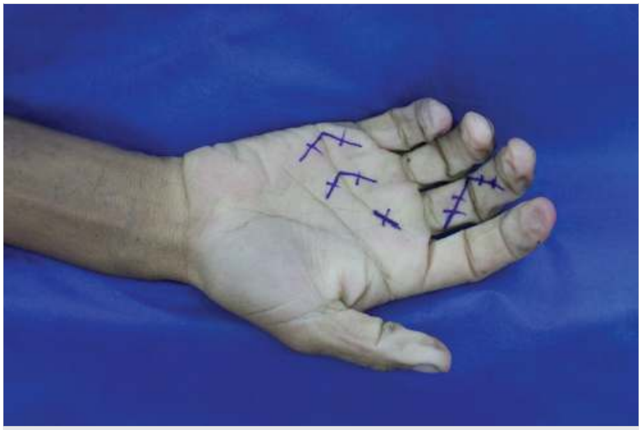

Fig. 46.29 Zancolli's capsulodesis. Bruner type incisions at the metacarpophalangeal (MCP) of ulnar digits.

Fig. 46.30 Metacarpophalangeal (MCP) volar plate exposed with flexor tendons retracted.

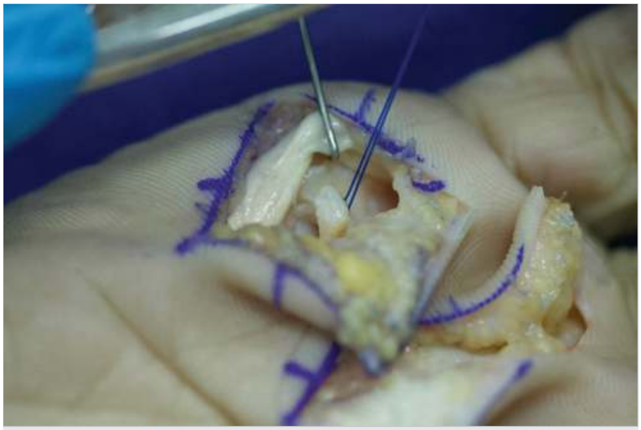

Fig. 46.31 Capsular flap ready to fix.

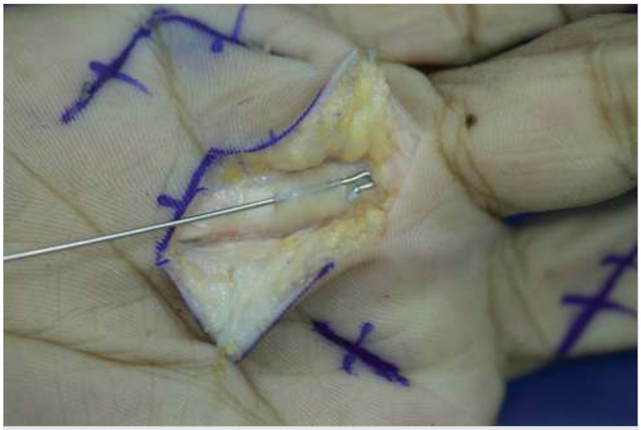

Fig. 46.32 Zancolli's lasso. A1 pulley dissected.

Flexor Route ECRL Transfer (Modified Brand or Brand II)

- A short transverse incision over the second metacarpal base to identify and disinsert the tendon and a second incision more proximally in the middle forearm are used to reroute muscle; the tendon is passed deep to the BR muscle into an incision on the volar aspect of the distal forearm and a tendon graft (plantaris or palmaris) is harvested and attached to the distal ECRL tendon and distally splited into two or four tails according to the deficits (▶ Fig. 46.34).
- An additional incision in the thenar crease is made and the extended ECRL is passed dorsal to the superficial arch and through the carpal tunnel. Dorsoradial incisions at the base of the affected 3rd, 4th, or 5th digit and dorsoulnar at the base of the 2nd digit are made and the corresponding lateral bands in each digit are identified.
- A tunnel is made from the finger incisions and each tail of the tendon graft is passed through the lumbrical canal to the distal incisions. Before tensioning, proximal incisions are closed. Split grafts are sutured to the lateral bands of each finger in 45 degrees wrist flexion, 70 degrees of MCP flexion, and IP extension (▶ Fig. 46.35 and ▶ Fig. 46.36).

Fig. 46.33 Flexor digitorum superficialis (FDS) sutured back to itself (close-up).

Fig. 46.34 Brand's modified technique of extensor carpi radialis longus (ECRL) through flexor route incisions.

Fig. 46.35 Extensor carpi radialis longus (ECRL) elongated with a palmaris longus (PL) tendon graft.

- The hand is immobilized in *intrinsic plus* position. In simple clawing, grafts can be sutured to the proximal phalanx base in order to augment grip strength (▶ Fig. 46.37 and ▶ Fig. 46.38).

Fig. 46.36 Tendon passed through the carpal tunnel and lumbrical canal and retrieved at the dorsoradial incision of the fifth finger.

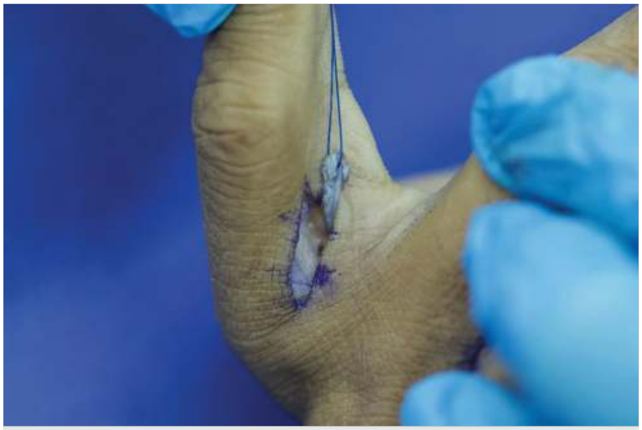

Fig. 46.37 Close-up of the radial lateral band prepared to fix the transfer.

Key Pinch Restoration

- ECRB/ECRL, ring (or middle) finger FDS, and EIP tendons are used to reanimate thumb adduction and most of the time the results more than compensate for the loss of movement.
- Wrist extensors need tendon grafts, and the most used motors are FDS tendons.
- The tendons are transected through a Bruner type incision proximal to its decussation to avoid swan-neck deformity; the tendon is pulled through a transverse palmar incision at the MCP joint.
- The vertical septum of the superficial palmar fascia acts as a pulley and a subcutaneous tunnel is made to the ulnar border of the thumb MCP joint where the distal tendon is retrieved and sutured to the AP tendon with the thumb adducted to the index finger.
- Neviaser[20] described the stabilization of index MCP with the transfer of an accessory slip of the APL. Littler[21] used both the EDM and the EIP to restore function of the AP and first IO muscle, respectively, and finally PL has been used for the same purpose with variable results (▶ Table 46.5).[17,18,19]

Fig. 46.38 Final position in MCP flexion and interphalangeal (IP) extension.

High Isolated Ulnar Nerve Palsy

- The additional loss of the ulnar FDP tendons in high palsy is addressed by suturing to the third profundus tendon in the distal forearm.
- This will not increase strength, but can improve flexion and patients should be aware that an ulnar clawing can be noticeable or worsen after the FDP tenodesis.
- FCU reanimation is not usually performed.

Complications

- The most commonly described complications are deformity recurrence, mainly in static procedures, soft tissue contractures and tenodesis, loss of grip strength when FDS are used in some patients, and swan-neck deformities in very distal FDS tenotomy.

46.4 Conclusion

Tendon transfers for the management of peripheral nerve paralysis are surgical procedures performed for several decades, have a very good functional prognosis, and following the recommendations given in this chapter will not leave further sequelae in the function of the hand when using donor tendons to transfer.

When we are confronted with a patient with sequelae due to nonrecoverable nerve injuries, the tendon transfers allow us to rehabilitate the patient, giving him or her, for example, extension to the fingers, or to the wrist, recovering the opposition of the thumb, and improving the function of clamp or grip.

For each of the nerve injuries of the upper extremity, radial, median, and ulnar paralysis, we have shown the surgical possibilities to recover the lost function. They are surgical techniques with good functional prognosis and variable complexity, but easily reproducible.

Table 46.5 Key pinch restoration

Transfer	Procedure	Comments
DYNAMIC PROCEDURES		
Edgerton (1965)	FDS as the motor and the palmar fascia as a natural pulley passed subcutaneously and inserted to the adductor pollicis tendon	For combined palsies, can be inserted in the APB expansion to improve pronation
Brown (1974)	EIP as the motor donor passed dorsal to volar through the second intermetacarpal space	Weak donor
Neviaser (1980)	Accesory slip of the APL to the first dorsal interosseous tendon	Needs tendon graft Improves index stability
Smith (1983)	ECRB extended with a tendon graft through the space between middle and index metacarpals and inserted to the adductor pollicis tendon	Omer passed the tendon between the middle and ring metacarpals Insertion over the abductor can also improve thumb pronation
Robinson (1992)	EIP to the radial base of the index proximal phalanx and EDC to the fifth finger to the adductor tubercle of the thumb	Addresses both thumb adduction and index abduction

Abbreviations: APB, abductor pollicis brevis; APL, abductor pollicis longus; ECRB, extensor carpi radialis brevis; EDC, extensor digitorum communis; EIP, extensor indicis propius; FDS, flexor digitorum superficialis.
Sources: Data from Pasquella and Levine,[17] Palti and Vigler,[18] and Liss.[19]

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47 Nerve Repair

Megan P. Lundgren, Waseem Mohiuddin, and Patrick J. Greaney Jr.

Abstract

Nerve injuries can be devastating to the quality of life of patients who sustain them. Three categories of nerve injuries are described within the Seddon and Sutherland classification systems: neurapraxia, axonotmesis, and neurotmesis. Recent advancements in nerve repair surgery include nerve conduits, nerve allografts, and nerve transfers. The primary goal of nerve repair is to allow reinnervation of the target organs by guiding axons into the environment of the distal nerve. Success of nerve repair depends on knowledge of the distinct types of nerve injury, the feasibility and timing of surgical repair to the type of injury, and good microsurgical technique with tension free results. Ideally, the technique described in this chapter will provide repair with minimal loss of nerve fibers, especially at the suture line. In all repairs, nerves need to be handled with extreme care. Nerves should be retracted with very fine skin hooks in the epineurium or with plastic slings. They should not be mobilized over such a length that the blood supply is impaired. Use of a tourniquet should be minimized while also maintaining a tension free, well-vascularized repair.

Keywords: axonotmesis, nerve conduit, nerve graft, nerve injury, nerve repair, nerve transfer, nerve tube, neuropraxia, neurotmesis

47.1 Introduction

The first nerve repair surgery was described by Cruikshank in 1795.[1] In 1942, Seddon classified nerve injuries into three categories: neurapraxia, axonotmesis, and neurotmesis.[2] The mildest form of nerve injury, neurapraxia, refers to a transient block in conduction from temporary neural ischemia or demyelination. Axonotmesis is a lesion wherein the axons and myelin are disrupted, causing the distal stump to undergo Wallerian degeneration.[3] Neurotmesis, the most severe type of injury, describes a completely transected nerve. In 1951, Sunderland expanded these categories (▶ Table 47.1).[4] Recent advancements in nerve surgery include nerve conduits, cold preservation of nerve allografts, and nerve transfers.[5]

Table 47.1 Categories of nerve injuries as explained by Seddon and Sunderland

Seddon classification	Sunderland classification	Tissues injured
Neurapraxia	1	Myelin sheath
Axonotmesis	2	Axons
	3	Axons, endoneurium
	4	Axons, endoneurium, perineurium
Neurotmesis	5	Complete transection—axons, endoneurium, perineurium, epineurium

Source: Data from Sunderland.[4]

47.2 Indications

Nerve repairs are performed in all areas of the body, but most commonly in the upper and lower extremities, face, and breast.[3,6] Penetrating trauma producing neurologic deficits should be considered neurotmetic and surgically repaired. However, closed injuries can be observed under the assumption that neurapraxic and axonotmetic lesions will recover without surgical intervention. Lack of spontaneous recovery within 3 to 6 months is an indication for surgical exploration.[3,7]

Neurotmetic lesions necessitate surgical repair. End-to-end neurorrhaphy can be used in sharp transections with a well-vascularized nerve bed.[8] If a tensionless primary repair cannot be achieved, nerve conduits, grafts, or transfers can be employed. Nerve conduits can be used for nerve gaps of up to 3 cm, although the quality of repair increases with shorter gaps.[9] Nerve grafting is the preferred management for gaps ranging from 3 to 50 cm, with the sural nerve as the most commonly chosen donor graft.[7] Alternatively, nerve transfers are indicated in proximal peripheral nerve injuries when other techniques are not possible. They are also indicated to avoid operating in scarred areas, when partial injuries present with well-defined functional deficits, when nerve injuries present in a delayed fashion, or when the level of injury is unclear.[3,10]

47.3 Operative Technique

47.3.1 Techniques of Nerve Repair

Success of nerve repair depends on knowledge of the distinct types of nerve injury, the feasibility and timing of surgical repair to the type of injury, and good microsurgical technique with tension free results. The various techniques include end-to-end repair, nerve grafting, nerve transfer, and nerve conduit.

End-to-End Repair

Remove all necrotic material at the level of the injury. Obtain normal, healthy-appearing fascicles at proximal and distal ends with careful sharp dissection using either microscissors or a surgical blade (▶ Fig. 47.1a). Ensure adequate length for tension free repair by flexing the joint above the injury (▶ Video 47.1).

Video 47.1 End-to-end neurorrhaphy: Ensure adequate length for tension free repair by flexing the joint above the injury (courtesy of Sidney M. Jacoby, MD)

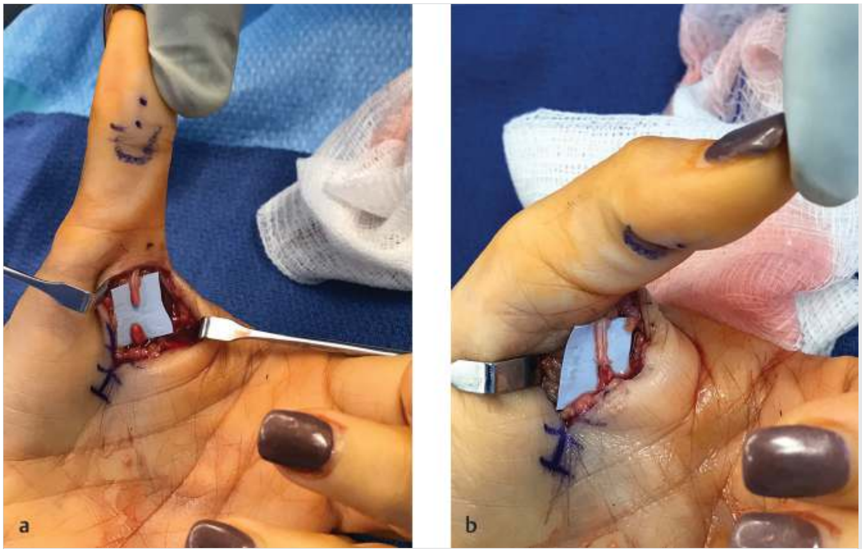

Fig. 47.1 **(a)** The proximal and distal ends of the recurrent branch of the median nerve are exposed, mobilized, and brought together leaving minimal gap. **(b)** 9–0 sutures are used in an interrupted fashion to approximate the two ends, maintaining fascicular alignment, with no tension on the repair. Photo courtesy of Sidney M. Jacoby, MD.

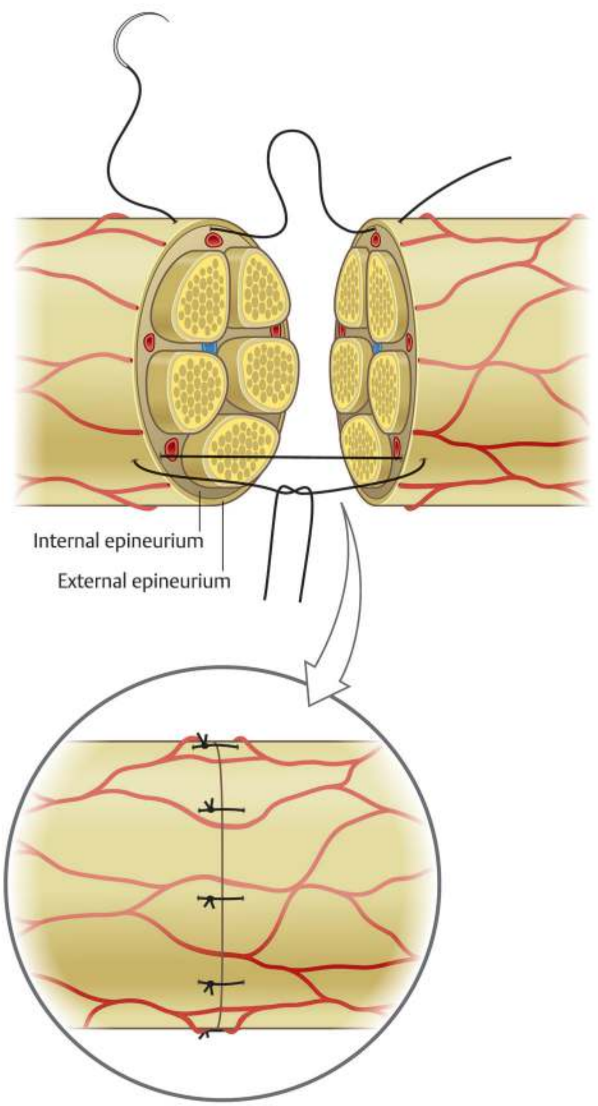

Fig. 47.2 Schematic representation of end-to-end neurorrhaphy.

Video 47.2 End-to-end neurorrhaphy: Positioning and exposure of nerve ends, with suturing technique (courtesy of Sidney M. Jacoby, MD)

The nerve ends are mobilized and brought together leaving minimal gap. This may require dissection proximally or distally, or transposition. Utilizing a monofilament suture usually ranging from 7–0 to 10–0, maintenance stitches are placed in an interrupted fashion (▶ Fig. 47.1b, ▶ Fig. 47.2, and ▶ Video 47.2). The needle can be passed through the epineurium, the perineurium, or both, with increasing levels of fascicular alignment.[11]

Nerve Grafting

Excise the zone of injury. The ends of the nerves should be inspected for a normal fascicular pattern. Measure the defect. Based upon the size of the defect, and with consideration of donor site morbidity, the donor nerve is chosen. An easily accessible graft, with a proper diameter for most injuries, is the sural nerve. In addition, the only morbidity of removal is a decrease in lateral foot sensation which improves with time. Other graft sources include the anterior branch of the lateral or medial antebrachial cutaneous nerve, or the lateral femoral cutaneous nerve. Reverse the graft. Approximate the ends of the donor graft to the exposed ends of the injured nerve, using suturing technique as described in the "End-to-End Repair" section[11,12] (▶ Fig. 47.3).

Nerve Transfer

Expose the recipient nerve. Assess the recipient nerve with electrical stimulation before proceeding. Choose the donor

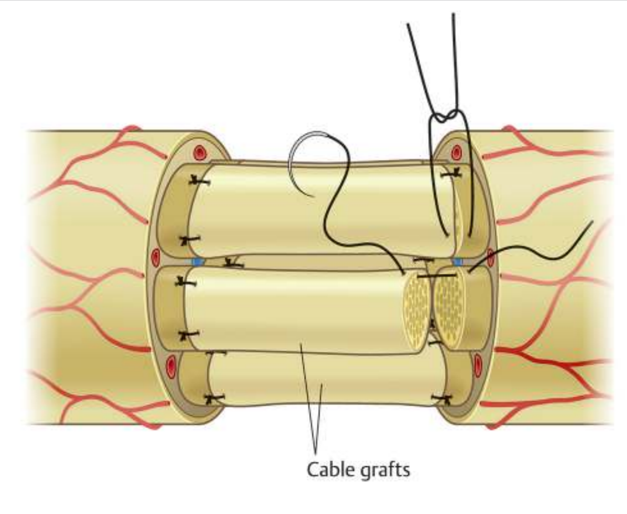

Fig. 47.3 Schematic representation of nerve grafting.

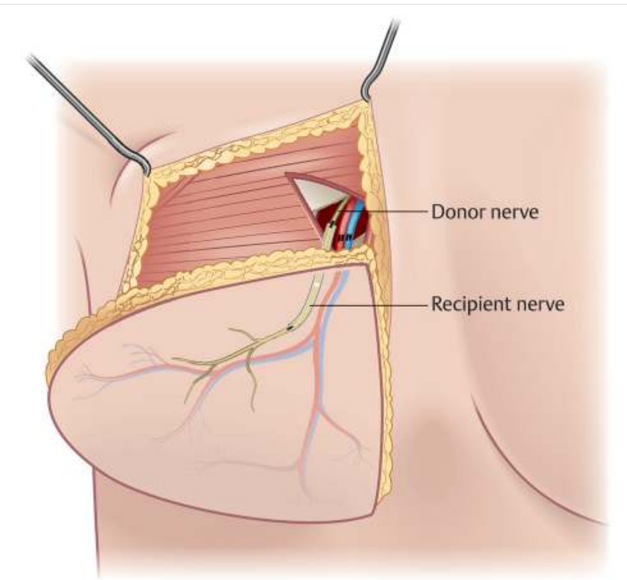

Fig. 47.4 Schematic representation of deep inferior epigastric perforator (DIEP) flap neurotization, a type of nerve transfer.

nerve. The choice is qualified by the percentage of motor axons and the closeness to the muscle to be innervated. The donor nerve should innervate a relatively expendable muscle distal to the target of the recipient nerve. In addition, the target muscles should ideally have synergistic function. This relieves postoperative tension on the repair, and makes rehabilitation easier. Transect the recipient nerve and perform preferably end-to-end repair using the microsurgical techniques described in the preceding sections[13,14] (▶ Fig. 47.4 and ▶ Video 47.2).

Nerve Conduit

The basic concept of a nerve conduit or nerve tube is that of a cylindrical substance used to connect two free nerve ends. The

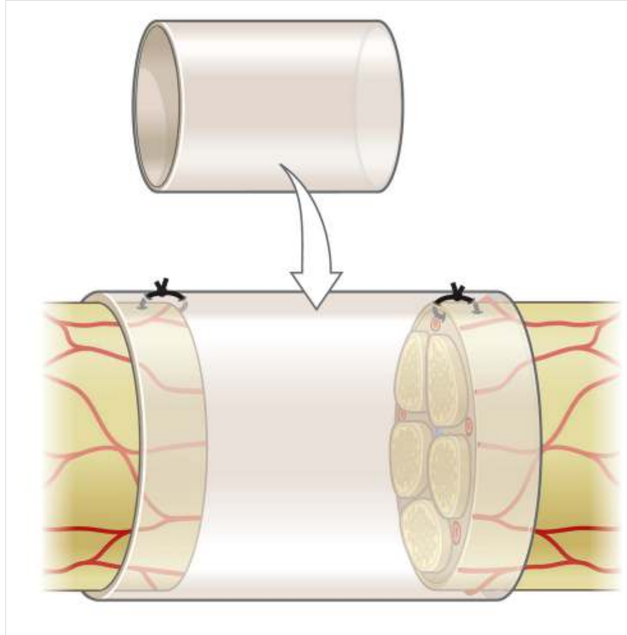

Fig. 47.5 Schematic representation of neurorrhaphy using a nerve conduit.

use of a conduit obviates the need for microsurgical alignment of fascicles. It also relieves the morbidity of donor nerve graft dissection and use.[15] An ideal nerve conduit should be pliable, maintain its shape during regeneration, and resist collapse during activity. Options include natural or synthetic tubes that will direct axonal sprouting from a regenerating proximal nerve and provide a path for diffusion of factors that are secreted by damaged nerve endings.[16] Collagen tubes such as NeuraGen® and Neuramatrix® are biologics. In addition, Axogen® biologic conduits are made of acellular nerve. Synthetic tubes, such as Neurolac® and Neurotube®, are made of poly(D,L-lactide-caprolactone) and polyglycolic acid, respectively. Choose a conduit with a slightly large diameter than the injured nerve. As with the above repairs, remove all necrotic tissue in the nerve bed and excise the damaged ends of the nerves to normal-appearing fascicles. Approximate the free ends of the nerves as much as possible, ensuring a less than 3 cm gap. Use several U-sutures to approximate the tube to the nerve ends proximally and distally. Insert the ends of the nerves into the tube, with an overlap of 2 mm. Utilizing 8–0 nylon suture, in a horizontal mattress fashion, secure the epineurium of the nerve to the conduit, either microsurgically or with 3.5 × magnification.[17] Ensure healthy soft tissue coverage of the conduit upon closure[15] (▶ Fig. 47.5).

47.4 Conclusion

Advances in nerve repair have allowed for substantially improved recovery in surgical patients over the past several decades. Both proper selection of the best method of repair as well as precise surgical technique are necessary for optimal recovery.

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48 Hand Fractures/Dislocations

Randy M. Hauck

Abstract
The major principles in treating hand fractures and dislocations are the same as treating fractures and dislocations elsewhere—restoring and maintaining the anatomy that has been disrupted. The majority of fractures are not displaced and can be treated nonoperatively. If there is significant displacement suggested by rotational or angular deformity of the digit, then reduction is indicated. The reduction may or may not be stable and may be lost without fixation (open or percutaneous). Early motion is critical to good outcomes when treating phalangeal or metacarpal fractures.[1] Flexor and extensor tendons occur in close proximity to the phalanges and metacarpals and will become adherent to the callus if some range of motion (ROM) is not initiated during fracture healing.

For nondisplaced fractures this requires protecting the affected digit(s) until stability can be retained by callus. Nondisplaced fractures that are stable can be protected by buddy taping and with removable splints. Patients are educated to remove the splint on a daily basis to do ROM exercises. Displaced fractures are reduced and pinned or plated if necessary and then begun on a program of protected motion exercises.

It is best to obtain three different views as the fracture or displacement may not be seen in just one or two views. The standard is a posterior-anterior, lateral, and oblique of the digit or hand. It is also wise to look at a joint above and below the injured area to be sure nothing is missed.

Keywords: finger dislocation, finger fracture, hand dislocation, hand fracture, metacarpal fracture, metacarpal-phalangeal dislocation, phalanx fracture, proximal interphalangeal dislocation

48.1 Introduction

48.1.1 Phalanx Fractures/Dislocations

Distal Phalanx (P3)

• Tuft nail bed
Nondisplaced P3 tuft fractures are held in place by the very strong periosteum dorsally which has the germinal and sterile matrices. These may benefit from hematoma drainage by placing a hole in the nail plate if there is greater than 50% of the nail occupied by hematoma.

• Shaft
Displaced fractures of the short shaft of the distal phalanx of the finger or thumb can be either transverse or oblique.

• Base or distal interphalangeal (DIP) joint—mallet or Seymour
Dislocations or subluxations at the DIP joint from a P3 fracture usually occur with a rupture of either the flexor or extensor with a piece of bone at the base of the distal phalanx.

• Seymour fractures
Seymour fracture is usually a Salter-Harris 1 involving the distal phalanx. The nail bed is interposed in the fracture site and may interfere with reduction. This is almost always an open fracture.

Middle Phalanx (P2)

• Distal—condylar
Nondisplaced fractures of the proximal and middle phalanges are best treated with buddy taping, a removable splint, and range of motion (ROM) exercises. Displaced diaphyseal fractures may require reduction and may need fixation. However, there are fractures that seem displaced yet the patient can fully extend and flex the fingers without scissoring or angulation. If the fractures cause scissoring or angulation fixation is necessary. This is usually best accomplished by manipulation and percutaneous pinning.

• Shaft
Fractures of the shafts of the middle and proximal phalanges are treated the same as the distal phalanx for reduction.

Base-Proximal Interphalangeal (PIP) Fracture/ Dislocations—Volar or Dorsal Base

Intra-articular fractures of the base of P2 usually have a volar fragment that remains attached to the strong volar plate of the PIP joint. The P2 base fracture may be comminuted as well.

PIP Dislocations

Dislocation of the PIP joint requires injury to at least two of the following: volar plate, central slip, and collateral ligaments. The direction of the middle phalanx in relation to the proximal is a clue to what is torn. If P2 is volar, at least one collateral ligament and the central slip are disrupted. If P2 is dorsal to P1, then the volar plate and collateral ligament(s) are damaged.

Proximal Phalanx (P1)

• Head
Fractures of the head or most distal aspect of the proximal phalanx are intra-articular and can be either unicondylar or bicondylar.

• Neck
Fractures that involve the neck of the proximal phalanx are often transverse.

• Shaft
Displaced fractures of the shaft of the proximal phalanx are usually unstable and require reduction and fixation.

• Base
Fractures of the base of the phalanges involve the metacarpal-phalangeal (MP) joint.

48.1.2 Thumb Metacarpal-Phalangeal Collateral Ligament Injury

Injury to the ulnar collateral ligament of the thumb MP joint occurs with forceful deviation of the thumb in a radial direction. The ligament may just rupture or pull off with a piece of bone. It is important to differentiate between a partial ulnar collateral ligament (UCL) disruption and a complete disruption. The partial disruption will have a distinct end point of radial deviation. Partial injuries, albeit rare with a bony component, can be treated with prolonged splinting.

48.1.3 Metacarpal Fractures

- Head

Intra-articular fractures of the head of metacarpals often require open reduction and fixation because of the injury to the cartilage bearing surface.

- Neck/Shaft

Nondisplaced fractures of the metacarpals or displaced fractures of the neck of the small metacarpal (boxer's fracture) do best with buddy taping, a removable splint, and early ROM (▶ Fig. 48.1).[2,3]

- Base

Base fractures of the thumb and small finger metacarpals require precise reduction because of the motion required at the carpal metacarpal joints.

48.2 Indications

48.2.1 Phalanx Fractures/Dislocations

Distal Phalanx (P3)

- Tuft nail bed
  - Displacement of the fracture causing angular or rotational deformity of the digit.
- Shaft
  - Displacement of the fracture causing angular or rotational deformity of the digit.
- Base or DIP joint—mallet or Seymour
  - Displaced fractures of the volar base of the distal phalanx that include the flexor tendon insertion.
  - Subluxation of the distal phalanx on the lateral radiograph.
- Seymour fractures
  - Displacement of the epiphysis.

Middle Phalanx (P2)

- Distal—condylar
  - Displacement of the condyle(s).
- Shaft
  - Displacement causing angular or rotational deformity.

Base-PIP Fracture/Dislocations—Volar or Dorsal Base

- Displacement of the articular surface.
- PIP dislocations
  - Inability to reduce without opening.

Fig. 48.1 (a–c) Boxer's fracture (neck of small metacarpal).

Proximal Phalanx (P1)

- Head
  - Displacement involving the articular surface or displacement causing rotational or angular deformity.
- Neck
  - Displacement causing rotational or angular deformity.
- Shaft
  - Displacement causing rotational or angular deformity.
- Base
  - Displacement involving the articular surface.

48.2.2 Thumb Metacarpal-Phalangeal Collateral Ligament Injury

The complete disruption will allow the MP joint to deviate greater than 45 degrees. If the ligament is completely disrupted or displaced above the adductor aponeurosis (Stener lesion), the ligament should be repaired.

48.2.3 Metacarpal Fractures

- Head
  - Displacement involving the articular surface

- Neck/Shaft
  - Displacement causing rotation or angular deformity

- Base
  - Displacement causing rotational or angular deformity
  - Disruption of the articular surface

48.3 Operative Technique

48.3.1 Phalanx Fractures/Dislocations

Distal Phalanx (P3)

- Tuft nail bed.

Displaced tuft fractures are treated by repairing the nail bed and then splinting it with the nail or a nail substitute.[1]

- Shaft

Transverse fractures are reduced by accentuating the deformity (e.g., a dorsally displaced distal fragment is moved further dorsally) and then placing traction on the digit and moving back into the correct anatomical position. Oblique fractures can often be reduced with traction and rotation. Reduced and stable fractures do not require fixation and early motion can proceed. Unstable fractures with angulation or scissoring require fixation but motion can also proceed despite internal or external methods of fixation.

- Base or DIP joint—mallet or Seymour

Volar base fractures require open reduction and internal fixation (ORIF) with stabilization of the fragment, which is attached to the profundus tendon using pins, a small screw, or button. Dorsal fractures of the base can be treated with splinting if they remain reduced in a splint or pinned in extension if the joint is subluxated (▶ Fig. 48.2).[1]

- Seymour fractures

This usually requires operative intervention to remove the tissue interfering with reduction. This is done by opening the nail fold at the base of the nail and visualizing the nail bed and fracture to reduce it. If unstable with skin closure it should be pinned (▶ Fig. 48.3).

Middle Phalanx (P2)

- Distal—condylar

Displaced fractures of the distal aspect of the middle phalanx involve the condyles. Transverse fractures proximal to the head can be reduced and pinned as described above for distal phalanx fractures by placing a percutaneous pin (0.045 K-wire) down the medullary canal of the distal phalanx through the DIP joint and the distal fragment and then reducing the fracture and pushing the pin across the fracture site. If there is comminution or rotational stability, another pin is necessary to prevent rotation.

Fig. 48.2 (a–c) Fracture of base of distal phalanx.

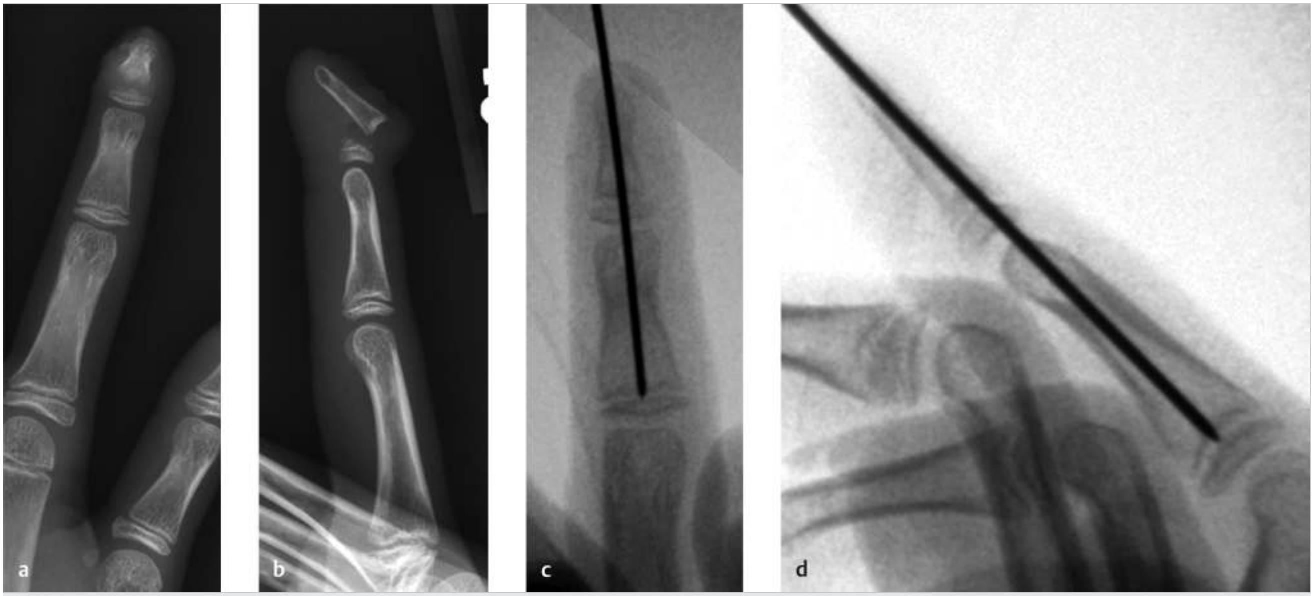

Fig. 48.3 (a–d) Seymour fracture.

Many transverse fractures will have interdigitating fragments to be stable enough with one longitudinal pin.[1,2]

Unicondylar fractures are intra-articular and have an oblique configuration. These are best distracted and pinned or held in place with a transverse or oblique pin or screw (open or percutaneous) (▶ Fig. 48.4). Soft tissue attachments to the condyle may prevent closed reduction mandating open reduction with a pin or lag screw to maintain the reduction. Early motion is imperative after fixation of these injuries or stiffness and loss of motion will often result.

- Shaft

For transverse fractures pins can be placed obliquely to keep them out of the joints and allow motion while healing (▶ Fig. 48.5 and ▶ Fig. 48.6).

Base-PIP Fracture/Dislocations—Volar or Dorsal Base

If comminuted with subluxation, this fracture responds best to treatment with external fixation with K-wires that provide mild distraction to align the fragments and allow motion of the joint. If the volar base is severely comminuted, a hamate graft may be necessary to reconstruct the joint (▶ Fig. 48.7 and ▶ Fig. 48.8).[4]

- PIP dislocations

Treatment usually involves reduction by extreme dorsiflexion and traction if P2 is dorsal to P1. Conversely, if P2 is volar to P1, the reduction requires extreme PIP flexion and traction. If such maneuvers are successful and the joint is stable, simple buddy taping will suffice. If unstable, which usually occurs with dorsal dislocation of P2, splinting or pinning in the least amount of flexion that holds the joint congruent is performed. The joint is then extended to normal ranges over several weeks. If closed reduction is unsuccessful then open reduction is necessary as a flexor tendon or collateral ligament may be stuck in the joint blocking reduction.[4] Dislocations with the middle phalanx volar to the proximal phalanx should make one look for a central slip injury. These can be treated with splinting of the PIP joint in extension or pinning for 6 to 8 weeks.

Proximal Phalanx (P1)

- Head

These fractures are unstable and require reduction and pinning or screw fixation. This can be done percutaneously or open (▶ Fig. 48.9).

- Neck

These are reduced by accentuating the displacement, distracting the finger, and then pulling it back to its anatomic position. This reduction can be held with longitudinal pins placed percutaneously (▶ Fig. 48.10).

- Shaft

The same reduction maneuver as above for the middle phalanx is employed and then the fragments can be usually pinned percutaneously. If the fragments cannot be reduced closed, the bone is exposed and then the fragments can be either pinned or plated with small plates and crews. Opening these fractures induces a great deal of scar around the tendons and if the patient is not motivated to move very soon after the surgery the fingers can be quite stiff. The flexor and extensor tendons are intimately associated with the middle and proximal phalanges and often scar down to the fracture if early motion is not initiated (▶ Fig. 48.11 and ▶ Fig. 48.12).[1,2] Fractures at the junction of the shaft and the base of the proximal phalanx tend to angulate in a volar direction. This may interfere with the normal mechanics of the finger motion and therefore may need reduction and fixation. Slight angulation is acceptable and will not interfere with function.

Fig. 48.4 (a–d) Condylar fracture of distal middle phalanx.

- Base

If displaced, they are unstable and require reduction and pinning or wiring usually through a volar approach.

48.3.2 Thumb Metacarpal-Phalangeal Collateral Ligament Injury

If the fragment is large it can be pinned or held with a screw. This fracture is reduced by distraction and pronation of the thumb. If the ligament is avulsed from the bone it can be reattached with an anchor. The ligament repair can be protected with a pin across the joint (▶ Fig. 48.13).[2]

48.3.3 Metacarpal Fractures

- Head

The fragment(s) can be fixed with small screws, pins, or interosseous wires through a dorsal approach (▶ Fig. 48.14).

- Neck/Shaft

Neck and diaphyseal fractures that present with rotational malalignment or scissoring can be treated with reduction and pinning. Neck fractures are reduced with the Jahs maneuver. This involves holding the fingers in flexion including all joints while placing traction on the digit containing the fracture. Long oblique diaphyseal fractures may require open reduction and can be held with several compression screws. Transverse fractures can be percutaneously pinned or plated if closed reduction is unsuccessful (▶ Fig. 48.15 and ▶ Fig. 48.16).[2,3]

- Base

Bennet's fractures (intra-articular fractures at the base of thumb P1) can be usually reduced with traction and pronation of the thumb and then pinned in position. The abductor pollicis longus tendon pulls the metacarpal proximally while the ulnar fragment remains distal. The fixation can be maintained by a pin through the first metacarpal to the second metacarpal to maintain the reduction. The fracture fragments do not require individual pin fixation in this case unless displacement persists. Larger fragments or Rolando's fractures may require ORIF. The small finger metacarpal base fracture can usually be reduced closed with traction and pinned to allow early motion. Similar to the first metacarpal base fractures, the pin can simply maintain the metacarpal out to length countering the pull of the extensor carpi ulnaris. Dislocations of the bases of the index, long, or ring metacarpal bases involve a large transfer of energy and may require opening to reduce and if unstable are best pinned after reduction (▶ Fig. 48.17).[2,3]

Fig. 48.5 (a–c) Transverse fracture of diaphysis of middle phalanx.

Fig. 48.6 (a–d) Comminuted diaphyseal fracture of middle phalanx.

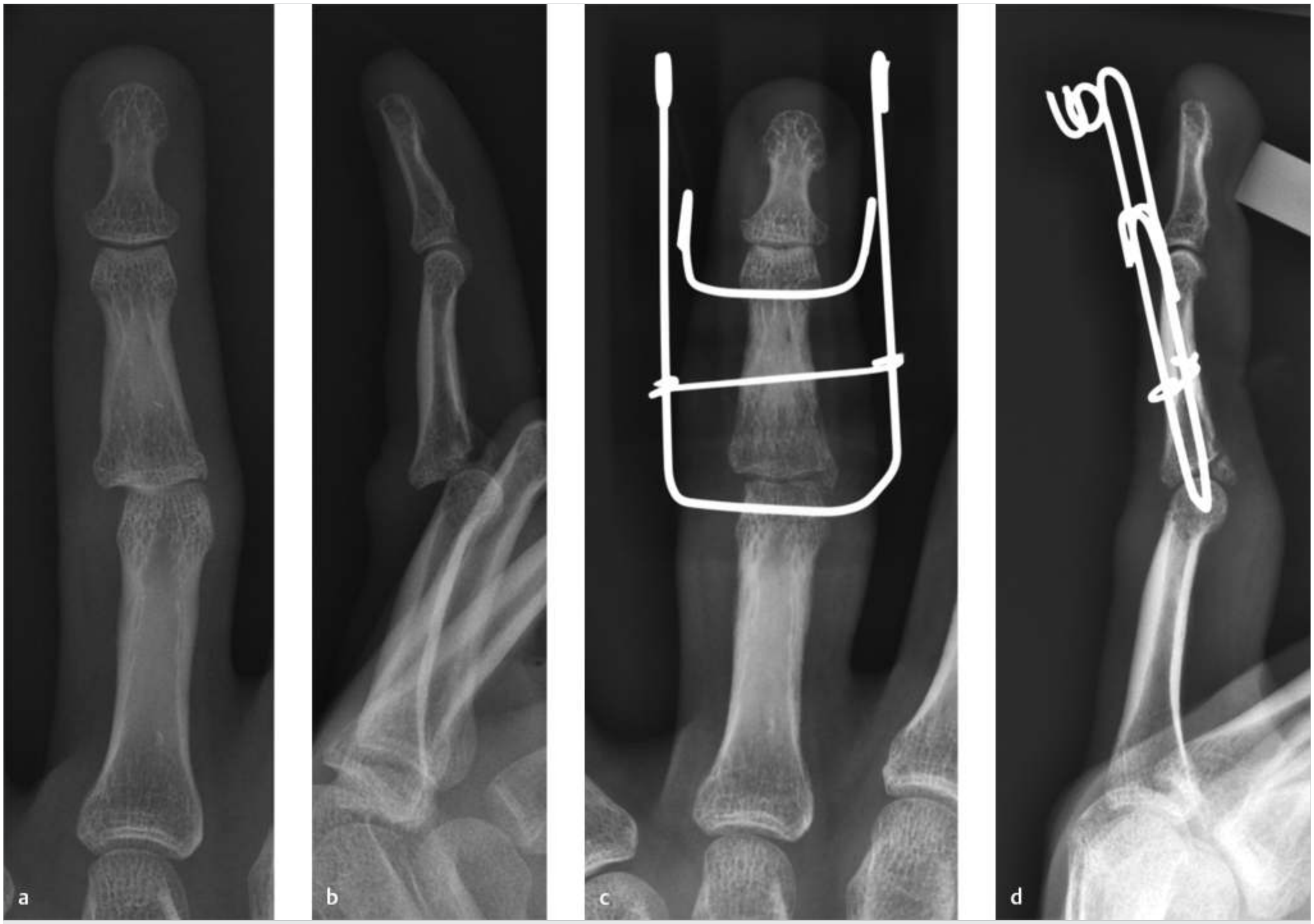

Fig. 48.7 (a–d) External fixation for fracture dislocation of proximal interphalangeal (PIP) joint.

Fig. 48.8 (a–d) Base fracture of middle phalanx.

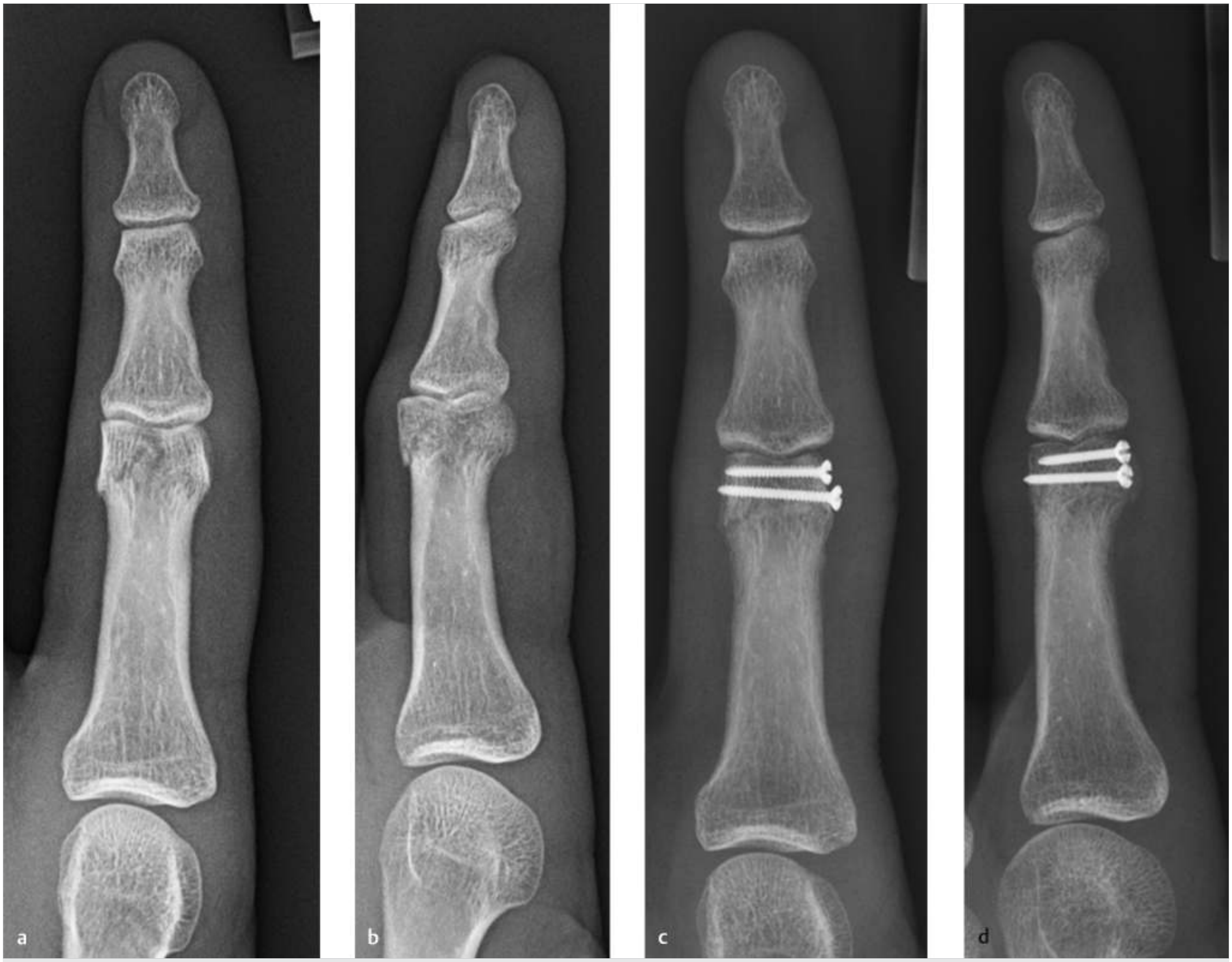

Fig. 48.9 (a–d) Condylar fracture of head of proximal phalanx.

48.4 Conclusion

48.4.1 Phalanx Fractures/Dislocations

Distal Phalanx (P3)

• Tuft nail bed
Most tuft fracture of the distal phalanx are treated nonoperatively. If tuft fractures are displaced with destruction of the nail bed, nail deformities may result.

• Shaft
Shaft fractures of the distal phalanx are rare but can result in significant angulation if displaced and not addressed correctly.

• Base or DIP joint—mallet or Seymour
Fractures of the base of the distal phalanx require consideration of the insertion of the flexor and extensor tendons.

• Seymour fractures
If unreduced, a Seymour fracture will usually result in osteomyelitis of the distal phalanx as the bone is exposed at the base of the nail.

Middle Phalanx (P2)

• Distal—condylar
Reduction and early motion are necessary to maintain position and prevent scarring with loss of motion of fingers with joint injuries.

• Shaft
If reduction is inadequate, subsequent rotational or angular deformity will occur.

Base-PIP Fracture/Dislocations—Volar or Dorsal Base

Injuries involving the articular surface of the base of the middle phalanx require concise reduction and early motion to prevent stiffness and loss of motion.

PIP Dislocations

Dislocations of the PIP joint require attention to determine the exact structures that have been disrupted so that ligaments can be protected during healing.

Fig. 48.10 (a–d) Transverse fracture of neck of proximal phalanx.

Proximal Phalanx (P1)

- Head

As with most fractures involving a joint, adequate reduction is necessary to prevent long-term deformity and loss of motion.

- Neck

As with most intra-articular fractures, reduction and early motion are necessary to maintain position and motion.

- Shaft

Proximal and middle phalangeal shaft fractures are treated similarly.

- Base

Fractures of the base of phalanges involve the MP joint and require articular congruity and early motion.

48.4.2 Thumb Metacarpal-Phalangeal Collateral Ligament Injury

Thumb instability from MP ligament causes loss of grip strength and requires adequate repair of the ligament.

48.4.3 Metacarpal Fractures

- Head

As with most intra-articular fractures, reduction of the joint surface is required to prevent the development of joint degeneration over time.

- Neck/Shaft

Most metacarpal neck fractures can be treated without surgery unless there is rotational or angular deformity of the finger.

- Base

The bases of the metacarpals of the border digits (thumb and small finger) perform more motion for hand function that other digits. These joints require adequate reduction to prevent later degeneration of the joint involved.

48.4.4 Fractures in Children

Fractures in children are treated similarly to those in adults with the caveat to protect the epiphyses. Also, their fractures will heal more quickly than adults and need to be treated urgently to avoid malunion. The Salter–Harris classification is commonly used to describe the bony deformity in children in relation to the growth plate (▶ Table 48.1). More often than not, Salter 1 and 2 types can be reduced closed and early motion started early with the aid of buddy tape.

Fig. 48.11 (a–d) Oblique diaphyseal fracture of proximal phalanx.

Fig. 48.12 (a–d) Oblique diaphyseal fracture of proximal phalanx with plate and screw fixation.

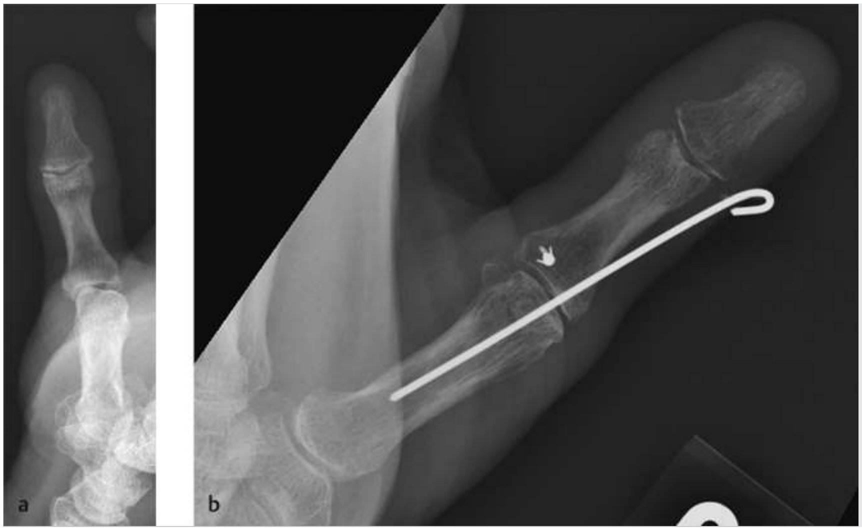

Fig. 48.13 (a, b) Ulnar collateral ligament injury with transarticular pin and anchor.

Fig. 48.14 (a–d) Fracture of metacarpal head.

Fig. 48.15 (a–d) Displaced oblique diaphyseal fracture of ring metacarpal.

Fig. 48.16 (a–d) Displaced oblique diaphyseal fracture of small metacarpal.

Fig. 48.17 (a, b) Bennet's fracture of thumb.

Table 48.1 Salter–Harris classification

Classification	Mnemonic
S-H 1 Separation of the entire physis without surrounding fracture	Slip of physis
S-H 2 Fracture along the physis extending above the physis	Above physis
S-H 3 Fracture along the physis and below the physis	Lower than physis
S-H 4 Fracture through the physis	Through physis
S-H 5 Crush of physis	Rammed physis

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49 Dupuytren's Contracture

Catherine de Blacam, Billy Lane-O'Neill, Patricia A. Eadie, and Seán Carroll

Abstract
Dupuytren's disease is a benign fibroproliferative disease of the hand, which is characterized by contracture of the palmar and digital fascia and can lead to disabling flexion contracture of the small joints of the hand. Surgical options include open fasciectomy procedures, open fasciotomy, needle fasciotomy, and enzymatic fasciotomy. Currently there is insufficient evidence to support one surgical intervention over another. Recurrence rates remain significant and while surgery can release contractures, it cannot cure the disease.

Keywords: collagenase injection, Dupuytren's contracture, enzymatic fasciotomy, needle fasciotomy, open fasciotomy, open limited fasciectomy, Xiaflex injection

49.1 Introduction

Dupuytren's disease is a benign fibroproliferative disease of the hand, which is characterized by contracture of the palmar and digital fascia and can lead to disabling flexion contracture of the small joints of the hand. Dupuytren's disease is an autosomal dominant condition, which demonstrates variable penetrance[1] and is most frequently observed in individuals of northern European ancestry, with prevalence as high as 10% in certain populations.[2]

The palmar fascia comprises discreet transverse, longitudinal, and vertical systems.[3] Dupuytren's disease starts with a palpable nodule in the palm, with pathologic cords then extending along the anatomical pathways of the palmar fascia, in proliferative, involutional, and residual phases.[4] As the cords thicken and shorten, they cause symptomatic flexion contractures, usually of the ulnar side of the hand and, potentially, volar displacement of digital neurovascular bundles.[5]

49.2 Indications

The primary indication for surgery is the extent of the patient's functional disability. Patients may describe discomfort shaking hands, difficulty wearing gloves, putting hands in pockets, and washing their face or interference with leisure activities such as playing golf or piano. Contractures of this degree are easily detected on examination by a positive table top test (▶ Fig. 49.1).[6]

Commonly accepted objective indications for surgery include metacarpophalangeal (MCP) joint contracture of more than 30 degrees and any proximal interphalangeal (PIP) joint contracture of 20 degrees with documented progression. Patients with longstanding PIP joint contracture will likely have collateral ligament shortening and underlying articular changes, making correction of the contracture difficult. However, with a persistent surgical approach these too can be corrected, which is also underappreciated.

In our experience pain is an often under-recognized indication for surgery in Dupuytren's disease. Patients may describe discomfort as a result of the inability to fully extend or stretch out their hand. Persistent pain can also be a feature in the presence of a palmar nodule in a manual worker. We consider both of these situations an indication for surgery, even in the absence of contracture.

Associated factors such as Dupuytren's diathesis, recurrent disease, the patient's age, the presence of comorbid osteoarthritis or rheumatoid arthritis, a history of complex regional pain syndrome, and comorbidities which may impair wound healing should all be evaluated when considering surgical intervention. Patients must all be counseled about the pathophysiology of Dupuytren's disease, the rehabilitation following surgery and the significant likelihood of recurrence. For patients who may not be suitable for operation under general anesthetic, fasciectomy under regional anesthetic or local anesthetic with epinephrine may be considered.[7]

49.3 Operative Technique

The aim of surgery is to provide symptomatic relief by contracture release. Elimination of Dupuytren's disease is not possible. Any procedure undertaken must address the skin, the fascia, and any residual joint contracture after excision of involved fascia.[8] A summary of operative techniques, together with indications and outcomes, is provided in ▶ Table 49.1. Pearls and pitfalls to bear in mind in any surgical approach are presented in the text box.

Fig. 49.1 Table top test.

Table 49.1 Summary of surgical techniques and the authors' indications for each

Technique	Indication	Outcome
Needle fasciotomy	Isolated MCPJ contracture with good overlying skin	Recurrence 58–84%[9,10]
Enzymatic fasciotomy	Isolated MCPJ contracture with good overlying skin	Recurrence 47%[11]
Open limited fasciectomy	Suitable for most patients	Recurrence 20–63%[10,12]
Dermofasciectomy	Severe contracture involving skin; recurrent disease in a young patient; Dupuytren's diathesis	Recurrence 12%[13]
Open segmental fasciectomy	Authors rarely use; advanced age or comorbidity that precludes a more extensive procedure	Recurrence 38%[14]
Open fasciectomy without skin closure	Anticoagulation	20% "residual contracture"[15]
Open fasciotomy	Authors rarely use	Recurrence 43%[12]

Abbreviation: MCPJ, metacarpophalangeal joint.

Pearls and Pitfalls to Bear in Mind in Any Surgical Approach

- Pearls
  - General
    - Normal fascial anatomy determines the pattern of pathologic cords.
    - Surgery can release contracture; it cannot cure the disease.
    - Frank communication with patient about outcomes, recurrence, and potential complications.
  - Surgical approach
    - Midline straight incision.
    - Dissect proximal to distal.
    - Early identification of neurovascular bundle is key to preservation, whether in palm or in finger.
    - Early intraoperative open segmental cordotomy in severe contracture assists further dissection.
    - Preserve transverse (Skoog's) fibers of palmar aponeurosis.
    - Placement of Z-plasties as close to flexion creases as possible, incorporating any buttonholes.
    - Counsel patients to return early in case of recurrence (failing table top test).
- Pitfalls
  - Intraoperative arterial insufficiency:
    - If operating on recurrent disease, obtain information on previous surgery if possible preoperatively.
    - Determine cause—spasm due to acute extension versus division of vessel.
    - Flex finger to alleviate traction.
    - Warm finger with warm irrigant solution.
    - Apply topical papaverine (30 mg/mL).
    - Explore and repair at least one artery if both are damaged.
  - Divided digital nerve
    - Repair immediately to reduce potential neuroma formation.
    - Counsel patient about likelihood of recovery.

49.3.1 Authors' Preferred Procedures

Needle Fasciotomy

Needle fasciotomy (aponeurotomy/cordotomy) is in our opinion an excellent procedure for a discrete palmar cord causing MCP joint flexion. The procedure is performed following direct infiltration of local anesthetic, using a 23-gauge needle and with the finger held extended so that the cord is prominent. Our approach is to use multiple passes in multiple directions to cause three-dimensional expansion and gradual release of the cord. It is recognized and explained to the patient that the recurrence rate is higher than other procedures but most patients appreciate the benefit of the shortened recovery time. Recurrences can be addressed by repeat needle fasciotomy. Furthermore, the effect of a needle fasciotomy does not affect the outcome of subsequent open procedures. In our hands, the incidence of permanent digital nerve injury has been extremely low using this approach. Incidence of tendon or nerve damage is similarly low in reported series, with long-term recurrence of 58 and 24% reoperation rates reported.[9]

Enzymatic Fasciotomy

Clostridium collagenase histolyticum causes local dissolution of type I and type III collagen present in the pathological cords of Dupuytren's disease. In the collagenase option for reduction of Dupuytren's I and II trials, 64% of injected cords met the defined endpoint of contracture reduction to within 0 to 5 degrees of full extension at 30 days after last injection, compared with 7% of placebo injected cords.[16] Collagenase is marketed as Xiaflex (Endo Pharmaceuticals Inc., Malvern PA) and is approved for the treatment of adult patients with Dupuytren's contracture and a palpable cord. The injection solution comprises 0.58 mg of clostridial collagenase diluted in 0.25 mL (MCP joint) or 0.20 mL (PIP joint) of sterile diluent. Under aseptic conditions, the cord is palpated and the solution is injected in three adjacent aliquots with a 27-gauge needle (▶ Video 49.1). Care is taken to avoid the underlying flexor tendons and adjacent neurovascular bundles. Up to two injections of the full 0.58 mg dose can be given in the same hand in a single visit. The patient is advised to keep the hand elevated prior to manipulation of the contracture 24 to 72 hours later. If the cord has not spontaneously ruptured, the contracted joint is passively manipulated under local anesthetic. Frequently reported adverse outcomes include edema (73%), bruising (51%), and pain at the injection site (32%).[16] Skin tears are not uncommon and are managed with simple dressings. If the procedure is unsuccessful, a 1-month interval is allowed before repeat injection is attempted. Recently published 5-year follow-up data reported an overall recurrence rate of 47%.[11]

Open Fasciectomy

The procedure is carried out under loupe magnification, with a hand fixation device providing adjustable assistance as the contracted digits are released (▶ Fig. 49.2). Several skin incisions have been described, all following the basic principle that resultant scars must not cross flexion creases at right angles. The authors' preference is always a straight line incision. In our experience, this approach causes minimal devascularization of the skin, is the least likely to damage neurovascular structures, and allows tailoring of Z-plasties to the flexor creases. A frequently changed, size 15 scalpel blade is used to sweep skin and subcutaneous tissue off diseased fascia. In order to avoid thin, avascular skin flaps, dermofasciectomy (see below) should be considered if the diseased fascia is intimately attached to the skin—a common feature of recurrent Dupuytren's disease. Bipolar diathermy hemostasis is undertaken judiciously, avoiding damage to digital vessels or nerves.

The approach of open radical fasciectomy, as historically advocated by McIndoe and Beare,[17] has now largely been abandoned in favor of a more limited fasciectomy (also referred to as regional or partial fasciectomy). This approach removes pathological pretendinous, central, natatory and spiral cords, while leaving uninvolved fascia in situ. Skin flaps are raised and dissection of the diseased fascia starts in the palm. The common digital arteries and nerves bifurcate at the level of the palmar digital junction and should be identified here by blunt dissection with a tenotomy scissors. Dissection in the finger is the most challenging part of the procedure, with neurovascular bundles often unpredictably displaced due to spiral cords.

Video 49.1 Enzymatic fasciotomy with collagenase

Neurovascular bundles should be identified distally outside the zone of disease before proceeding with dissection of the termination of the pretendinous cord. Natatory and retrovascular cords are then removed before addressing residual contracture, checking hemostasis and closing skin.

Following any open fasciectomy, residual contracture must be addressed in a stepwise manner, bearing in mind that mild residual PIP joint deformity is more functionally tolerable than a stiff or hyperextensible straight finger. Shortening of the tendon sheath is addressed by making transverse incisions in the sheath at PIP joint level, taking care to preserve the pulley system. Selective division of the volar plate checkrein ligaments achieves limited arthrolysis of the contracted PIP joint.[18] Gentle passive manipulation of the joint may also be performed.[19]

Open limited fasciectomy is the most common operation for Dupuytren's contracture. Recorded recurrence rates vary from 20 to 63%[10,12]; it has been suggested that recurrence of up to 100% is observed if patients are followed for long enough.[8]

Dermofasciectomy

Dermofasciectomy involves excision of the overlying skin together with the diseased fascia of the palm and fingers. The volar surface of the digit and palmar defect are then reconstructed with a full-thickness skin graft, harvested from the groin or medial arm. The skin graft can reduce the risk of recurrence by acting as a "firebreak" of uninvolved tissue, though this theory was not borne out in a randomized controlled trial.[8,20,21] Recurrence rates lower than other procedures have been reported.[13]

49.3.2 Other Procedures

Needle Fasciotomy and Fat Grafting

Hovius et al have proposed that extensive percutaneous needle fasciotomy followed by fat grafting (so-called "percutaneous aponeurotomy and lipofilling" or "PALF") may help to decrease adhesions and separate strands of cord scar.[22] A volume of 10 mL of fat per ray is injected subcutaneously into the palm

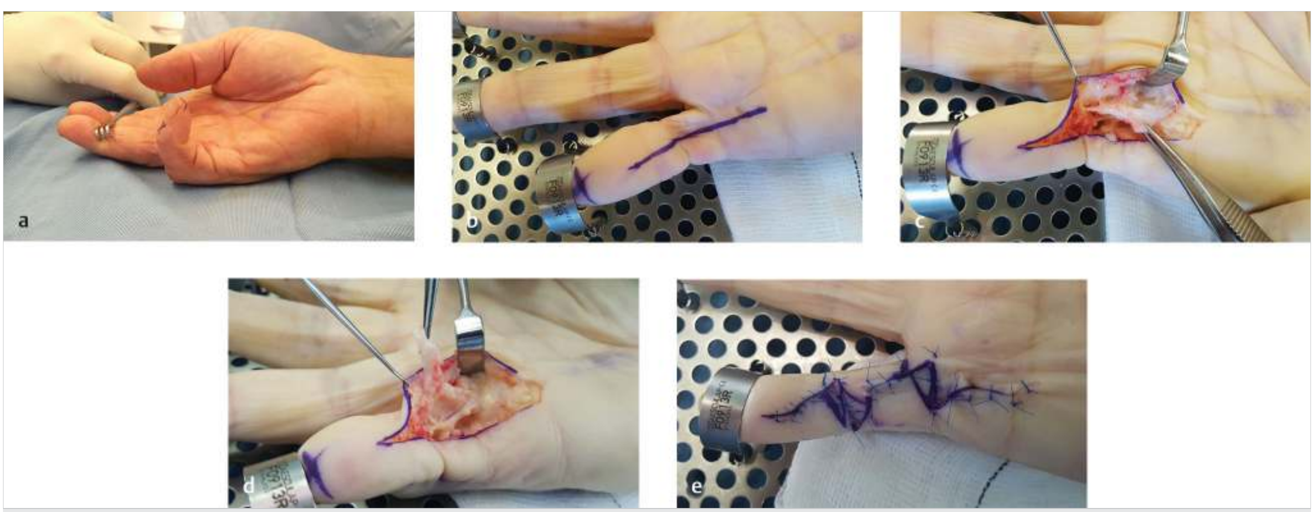

Fig. 49.2 Open limited fasciectomy: **(a)** Right little finger Dupuytren's disease with approximately 45 degrees of proximal interphalangeal (PIP) joint flexion. **(b)** Straight line incision marking. **(c)** Dupuytren's fascia superficial and radial to radial neurovascular bundle. **(d)** Excision of Dupuytren's fascia from proximal to distal. **(e)** Closure with Z-plasties.

and digit along the tracks of the ruptured cords. Although early results are encouraging in terms of side effects and contracture correction, long-term outcome data is awaited.

Open Fasciotomy

Fasciotomy procedures involve division but not removal of pathologic cords. Open fasciotomy was initially described by Dupuytren[23] and consists of division of the pathologic cord at a single point, usually in the palm. A longitudinal incision is made over the cord, which is then divided transversely under direct vision with a scalpel blade. The procedure avoids extensive dissection and is particularly effective in correcting MCP joint contracture. Recurrence sufficient to warrant reoperation has been reported in 43% of patients.[12]

Open Segmental Fasciectomy

This approach was described by Moermans and involves removal of limited segments of diseased cord via a series of short curved incisions.[14] The procedure can be considered intermediate between open fasciectomy and fasciotomy procedures. It avoids extensive palmar and digital dissection, removes only portions of the diseased tissue but breaks the continuity of the cord.

Open Fasciectomy without Skin Closure

This technique, described by McCash,[24] allows skin defects following contracture release to heal by secondary intention. In patients with longstanding contracture and inadequate skin, a series of transverse incisions are used to expose and excise the Dupuytren's cords. Benefits of the procedure include decreased risk of postoperative hematoma and edema, avoidance of a skin graft donor site, and the ability to commence active mobilization immediately. The compromise is wounds that take 6 to 8 weeks to heal. Favorable results in terms of sustained range of motion and postoperative complications have been reported.[15] Apart from occasions where hematoma is anticipated, it is our observation that the technique is not widely used in contemporary practice. A modified open palm approach, whereby transverse limbs of Bruner or Z-plasty closures are left open, has also been described.[25] This "modified McCash" approach is used in our practice, in order to avoid strangulation of Z-plasty flaps.

49.3.3 Postoperative Management

The hand is elevated until the dependent position is not accompanied by throbbing pain, usually 48 hours. The patient is seen by a hand therapist within 1 to 3 days of surgery to start range of motion exercises. Skin sutures should be removed at 14 days postoperatively and routine bathing and incisional site massage commenced. Splinting regimes vary between units and while the use of a thermoplastic extension splint at night is frequently recommended, a recent Cochrane review suggests that this may be of little benefit in preventing recurrence.[26] Functional recovery is highly variable; a guideline of 3 to 6 weeks for return to work and sports is reasonable.

49.4 Conclusion

Dupuytren's disease can lead to disabling flexion contracture of the small joints of the hand and the primary indication for surgery is the extent of the patient's functional disability. The aim of surgery in Dupuytren's disease is to provide symptomatic relief by contracture release. The authors' preferred treatment options include needle fasciotomy, enzymatic fasciotomy, open fasciectomy, and dermofasciectomy. The patient must understand that surgery cannot cure Dupuyren's disease. No matter which approach is undertaken, frank communication about outcomes, recurrence, and potential complications is essential.

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Section IV

Nerve Compression

IV

50 Median Nerve Compression

Jarom Gilstrap, Bharat Ranganath, M. Shuja Shafqat, and Robert X. Murphy Jr.

Abstract
The most commonly encountered peripheral nerve compression syndrome is carpal tunnel syndrome, or compression of the median nerve at the wrist. This chapter will focus on sites of compression of the median nerve and describe standard treatment options as well as detailed surgical steps for decompression of the median nerve at the wrist.

Keywords: carpal tunnel, carpal tunnel release, carpal tunnel syndrome, endoscopic carpal tunnel release, median nerve, nerve compression

50.1 Introduction

- **Entrapment neuropathies** are disorders of the peripheral nerves, characterized by pain and/or loss of function as a result of chronic compression.
- The most common of the compression neuropathies is the **carpal tunnel syndrome** (CTS) (▶ Fig. 50.1).[1]
- The median nerve can also less commonly be compressed in the forearm from lacertus fibrosus (bicipital aponeurosis), pronator teres muscle, the flexor digitorum superficialis fascial arch, vascular leashes, aberrant muscle of the flexor pollicis longus, or tumors.
- The less common site of median nerve compression is in the upper arm at the ligament of Struthers (fibrous band between humeral supracondylar spur or bony process and medial epicondyle).
- The first carpal tunnel release was performed in 1924 by Herbert Galloway.

50.1.1 Epidemiology

- Most common nontraumatic diagnosis seen by hand surgeons.[2]
- Prevalence of CTS estimated to be as high as 3.72%.[3]
- The male to female ratio of CTS is 1:3.[4]
- Most common age group is 45 to 60 years.
- There is an increased risk for CTS in pregnancy.[5]
- Although CTS in patients less than 30 years old is seen, the risk in this age group is less than 10%.

50.1.2 Risk Factors

- Diabetes mellitus, alcohol abuse, smoking, generalized edema, pregnancy, thyroid disease, and various inflammatory conditions have all been associated with CTS.[6]
- **Repetitive activity** and **position/posture** have been associated with the development of CTS.
- CTS is also associated with the use of vibrational tools.

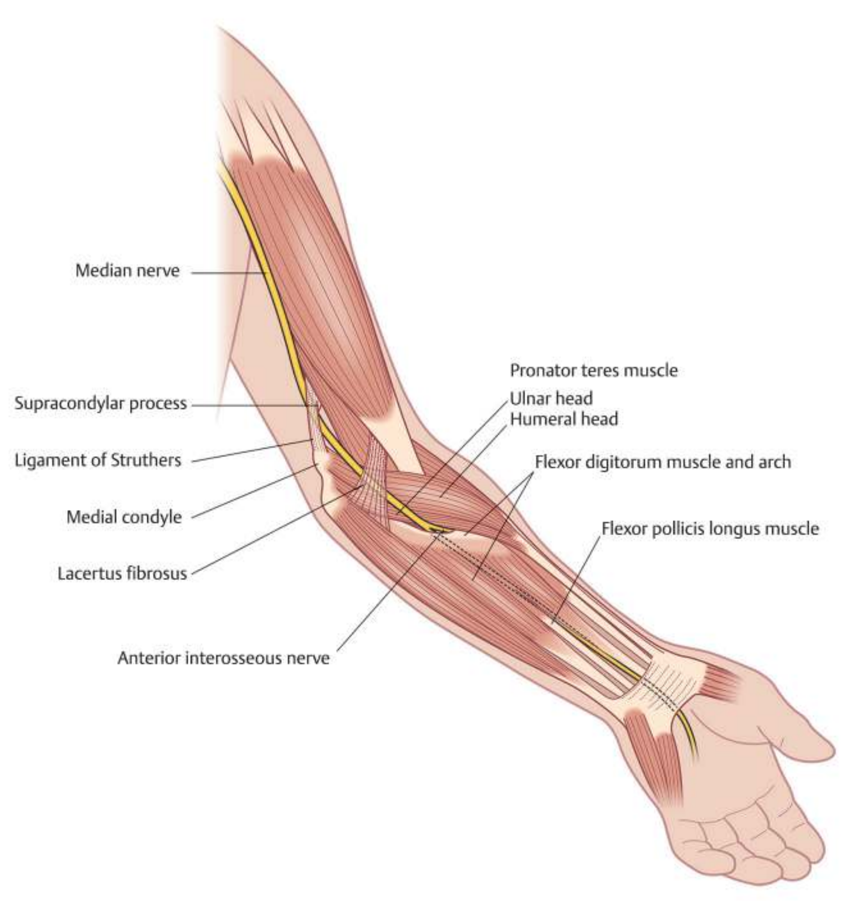

Fig. 50.1 Drawing of course of median nerve from arm to hand, *arrows* pointing to common sites of compression.

50.1.3 Diagnosis and Imaging

- Most common cause of continued symptoms after carpal tunnel release is incorrect diagnosis.
- Compression at more proximal sites alone or in conjunction with carpal tunnel ("Double Crush Phenomenon") should be evaluated as failure to treat proximal compression, which can cause continued or prolonged symptoms after carpal tunnel release.
- Often times, diagnostic tests in addition to history and physical examination are required.[7]
- History
  - Early CTS symptoms include:
    - Nocturnal symptoms.
    - Paresthesias.
    - Numbness in median nerve sensory distribution (radial three and a half digits).
  - Later symptoms include:
    - Lack of coordination and weakness, usually described as "clumsiness."
    - Pain at wrist and/or thenar area.
    - Atrophy of the thenar musculature in advanced disease.
- Physical examination:
  - Appearance: Skin changes, muscle atrophy, thumb resting in adducted position (late stages).
  - Motor: Measurable weakness in grip and thumb abduction.
  - Sensory: Decreased light touch, decreased two-point discrimination of thumb, index, long, and radial side of ring finger.
  - Evocative tests:
    - **Tinel/Hoffman sign**: Tingling in nerve distribution on percussion of the skin over the nerve at the carpal tunnel.
    - **Phalen's test**: Tingling with prolonged flexion at wrist.
    - **Durkan's test**: Dysesthesia in the nerve distribution on compression of the median nerve over/or just proximal to the carpal tunnel.
- **Electromyography** (**EMG**) and **nerves conduction studies**: Motor latencies are usually greater than 4.5 ms and sensory latency is greater than 3.5 ms.[8]
- Magnetic resonance imaging (MRI): Less often needed for diagnosis; may aid occurrences of relapsing or recurrent symptoms.[9]
- Ultrasound: High resolution needed for accurate imaging
  - A given upper extremity nerve can be compressed at more than one point along its course from the thoracic outlet to the hand, giving rise to the "double crush" phenomenon,[10] whereby a proximal point of compression worsens the symptoms and presentation of concurrent distal compression.[11]

50.1.4 Treatment

Nonoperative Approach: Splinting

- Generally, conservative treatment is trialed first.[12] Indications for surgical intervention include recalcitrant or recurrent symptoms, or if there is evidence of progression or advanced disease. Conservative management can include:
  - Splinting with the wrist in neutral position, usually nighttime.[13]
  - Activity modification—limit flexion/extension and vibratory activities.
  - Antivibration gloves.
  - Postural and ergonomic modification.
  - Nonsteroidal anti-inflammatory drugs (NSAIDs).
  - Physical therapy.
  - Steroid injections (often a diagnostic aid).[14]

50.2 Indications

- Failure of conservative management after weeks to months.[15]
- Severe symptoms limiting daily activity (persistent loss of feeling or coordination, decreased thumb strength, disturbed sleep caused by nocturnal pain).
- Evidence of severe disease and irreversible nerve damage such as muscle wasting or continuous numbness.

50.3 Operative Technique

- WALANT (**W**ide **A**wake **L**idocaine with **A**drenalin **N**o **T**ourniquet).[16]
- Use of tourniquet is most common.
- Anesthesia: Sedation (MAC) with local anesthetic block, rarely Bier block or general anesthesia.

50.3.1 Open Carpal Tunnel Release

- See ▶ Video 50.1.
- Induction of anesthesia (MAC, Bier, general) and administration local anesthetic.
- Markings are made to include the following: Kaplan's cardinal line (indicating the location of the palmar arch) and longitudinal line drawn from radial border of ring finger down to wrist. Typically, a flexion crease is located just ulnar to or can be made within the thenar crease and can be used as a line of incision. Should the flexion crease at the wrist need to be crossed, this should be done in a nonperpendicular (Bruner-type) fashion (▶ Fig. 50.2).

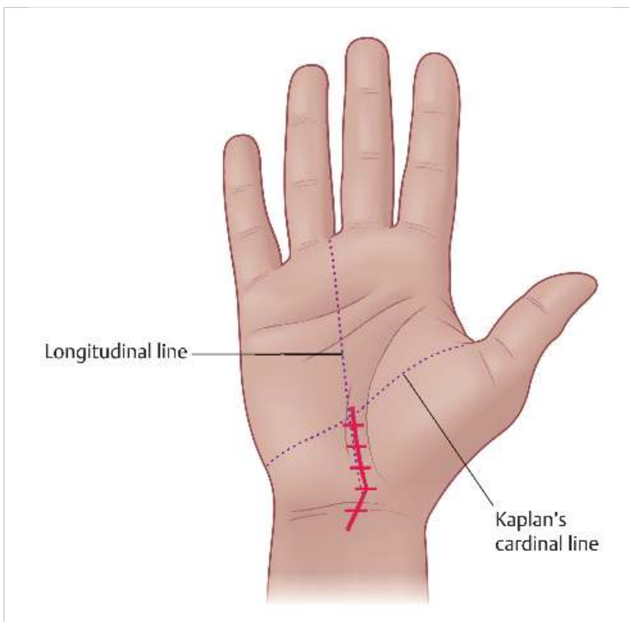

Fig. 50.2 Open carpal tunnel release (CTR) markings.

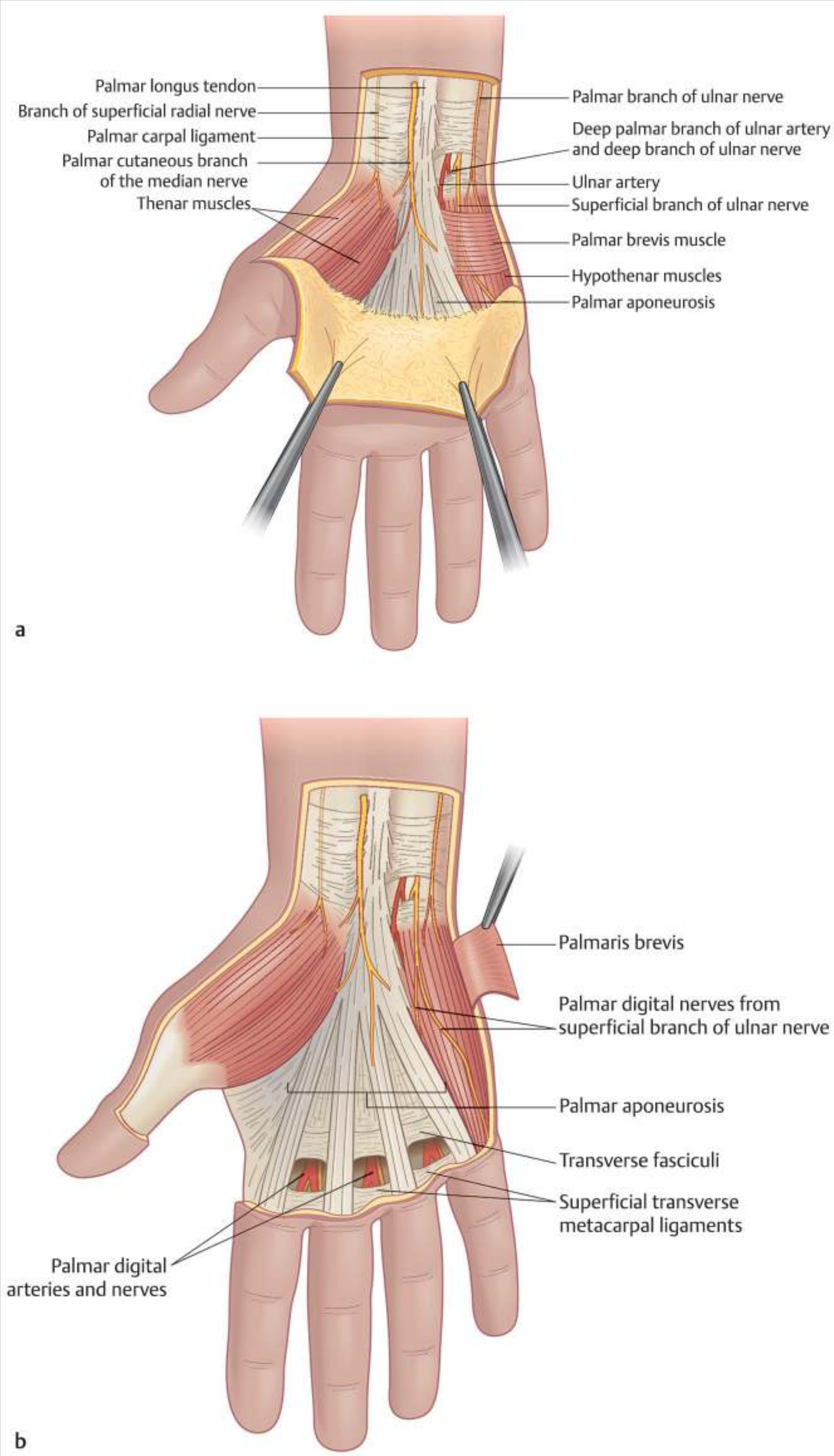

Fig. 50.3 (a, b) Fascial layers of the palm.

- The tourniquet is inflated after the arm is exsanguinated with an Esmarch.
- Usually, a 2-cm incision will suffice.
- Incision is made and carried down to the palmar fascia sharply. The palmar fascia is identified and incised (▶ Fig. 50.3).
- Deep to this the palmaris brevis will be often identified and incised or could be cauterized with bipolar electrocautery in order to avoid bleeding when the tourniquet is released.
- The transverse carpal ligament is identified and entered sharply. The median nerve will be immediately visible. Care should be taken to protect this during release of the carpal ligament.

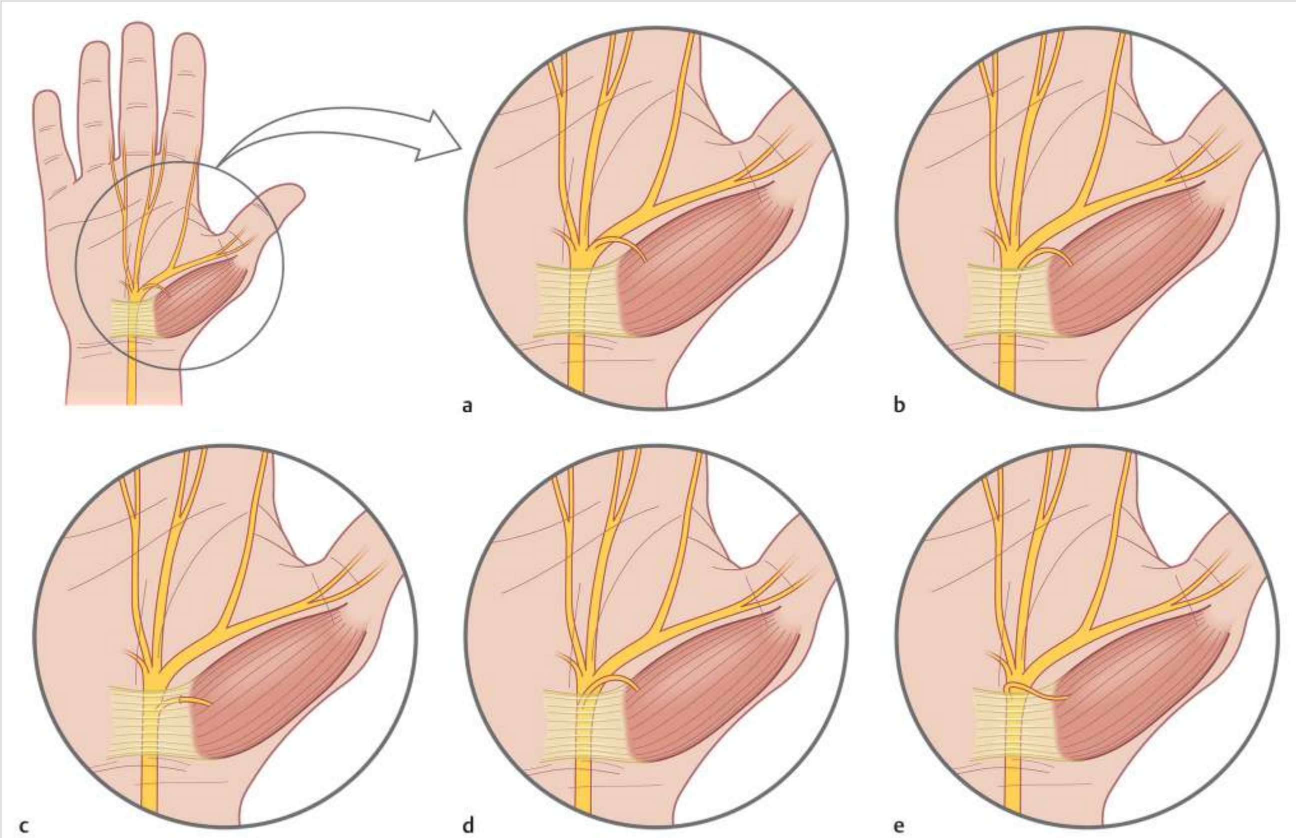

Fig. 50.4 (a–e) Median nerve variants.

Video 50.1 Open carpal tunnel release

- Release should be carried out proximately and distally with scalpel or tenotomy scissors. Complete release can be verified by passing a blunt instrument proximally and distally. Any compressing bands should be released under direct visualization.
  - Always be on the lookout for the recurrent motor branch of the median nerve that innervates the thenar musculature. There is a variable branching pattern to this nerve (▶ Fig. 50.4).
- Completion of distal release of the carpal ligament is signaled by appearance a fatty layer surrounding the superficial palmar arch. Care should be taken when this becomes visible.
- The tourniquet is released.
- Hemostasis is achieved. Incision can be closed in one or two layers.
- The hand is then wrapped in a **soft dressing**. Note: Splinting is not necessary.

50.3.2 Endoscopic Carpal Tunnel Release (One Port)

- Induction of anesthesia and administration of local anesthetic.
- The arm is exsanguinated with an Esmarch and a tourniquet is inflated to 250 mm Hg.
- A 1-cm incision is made at the proximal wrist flexion crease and dissection is carried down through the subcutaneous tissue.[17]
- The antebrachial fascia is incised and the transverse carpal ligament is identified. Dilators and a synovial elevator are then passed into the carpal tunnel.
- A 30-degree endoscope is then passed and the transverse carpal ligament is identified to the distal edge.
- An endoscopic knife is passed and the blade is deployed.
- The knife and endoscope can then be drawn from distal to proximal while visualizing the release.
- Visualization of the fat or superficial palmar fascia fibers which are volar to the transverse carpal ligament confirms complete decompression.

- Dilators may be passed to confirm release as well.
- Incisions are closed in one or two layers.
- The hand is then wrapped in a soft dressing. Note: Splinting is not necessary.

50.3.3 Postoperative Considerations

- Soft dressings.[19]
- Resume light activity at 2 weeks and increase activity as per patient comfort.

50.3.4 Complications

- Infection.
- Persistent pain, pillar pain.
- Persistent symptoms.
- Recurrent symptoms.
- Major nerve injury/numbness.

50.3.5 Outcomes and Prognosis

- Open and endoscopic surgical techniques are equally effective in relieving symptoms.[19]

50.4 Conclusion

- CTS (median nerve compression at the wrist) is the most common peripheral nerve compressive neuropathy encountered by the plastic surgeon.
- A thorough understanding of the anatomy (including various sites of median nerve compression), workup, and nonoperative treatment modalities is essential.
  - It is just as important to know when not to operate as it is when to operate!
- Good knowledge of the anatomy will allow for a safe and effective carpal tunnel release no matter what the modality used.

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51 Ulnar Nerve Compression from Wrist to Elbow—Cubital Tunnel and Guyon's Canal Release

Bharat Ranganath and Nathan Miller

Abstract

Ulnar nerve compression in the upper extremity is a commonly encountered diagnosis that causes notable morbidity to patients and is therefore of interest to plastic surgeons. The most common location of ulnar nerve compression is at the elbow, followed by the wrist. Treatment of ulnar nerve compression begins with conservative measures and progresses to surgical decompression.[1] This chapter provides an overview of the nature of ulnar nerve compression at these locations, diagnostic modalities, and the mainstays of treatment with a specific focus on surgical decompression by release of the ulnar nerve at the cubital tunnel at the elbow and Guyon's canal in the wrist.

Keywords: cubital tunnel syndrome, entrapment neuropathy, Guyon's canal, hand paresthesias, hand weakness, nerve compression, nerve compression, nerve entrapment, surgical decompression, ulnar nerve compression

51.1 Introduction

Entrapment neuropathies are a group of disorders of peripheral nerves that are characterized by pain, paresthesias, and/or loss of function (motor and/or sensory) of the affected nerves as a result of chronic compression. In the upper extremity, the three major nerves (median, ulnar, and radial) can be compressed at classically described locations as they traverse various tunnels and anatomic locations.[1]

Early symptoms of nerve compression include paresthesias and numbness in the sensory distribution of the affected nerve. Later symptoms include lack of coordination, muscle weakness, and atrophy and indicate advanced disease. Diagnosis is clinical based on symptom pattern and classic evocative physical examination findings such as the Tinel's sign, but can be aided by nerve conduction studies, electromyography (EMG), and occasionally imaging such as magnetic resonance imaging (MRI) or ultrasound. Often times a given upper extremity nerve can be compressed at more than one point along its course from the thoracic outlet into the hand, giving rise to the "double crush" phenomenon whereby a proximal point of compression worsens the symptoms and presentation of concurrent distal compression.[2,3,4]

51.1.1 Risk Factors

Risk factors for upper extremity compression syndromes are widely described but still poorly understood. These can be loosely classified into associated systemic diseases and patient-specific conditions/activities. Diabetes mellitus, alcohol abuse, smoking, generalized edema, pregnancy, thyroid disease, and various inflammatory conditions have all been associated with compression neuropathy.[2,4]

Repetitive activity and body position/posture have also been associated with the development of compression neuropathy. Studies have also found association between the use of vibrational tools and upper extremity nerve compression symptoms.[5]

Generally, conservative treatment is trialed first via modalities such as rest, oral analgesics, and especially splinting. Surgical decompression is warranted if symptoms persist or if there is evidence of progression or advanced disease.[1,2]

51.1.2 Relevant Anatomy of Ulnar Nerve

- C8–T1 cervical nerve roots.[1,2,3,4]
- Formed by medial cord of brachial plexus.[1,2,3,4]
- Course[1,2,3,4]
  - Arm
    - Becomes superficial beside the medial intermuscular septum in arm 10 cm proximal to medial epicondyle.
    - Covered by arcade of Struthers 8 cm proximal to medial epicondyle.
    - At elbow passes medial to medial head of triceps and posterior to medial epicondyle.
  - Forearm
    - Passes through the cubital tunnel.
    - Roof—flexor carpi ulnaris (FCU)/Osborne's band (leading edge of FCU).
    - Floor—medial (ulnar) collateral ligament.
    - Passes distally between flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) muscle bellies.
  - Wrist
    - Radial to FCU tendon and ulnar to hook of hamate to enter Guyon's canal.
    - Roof—volar carpal ligament.
    - Floor—transverse carpal ligament.
    - Ulnar border—pisiform/FCU, pisohamate ligament, abductor digiti minimi.
    - Radial border—hook of hamate.

51.1.3 Symptoms of Ulnar Nerve Compression/Palsy

- Early—paresthesias/numbness/tingling in ulnar distribution (ulnar half of forearm/hand/small and ring fingers), wrist pain.[1,4]
- Later—motor deficits[1,4]:
  - Weakness of abduction and adduction of digits.
  - Weak grasp.
  - Intrinsic wasting.
  - Possible clawing of little and ring fingers.
  - Possible Wartenberg's sign (abduction of little finger).

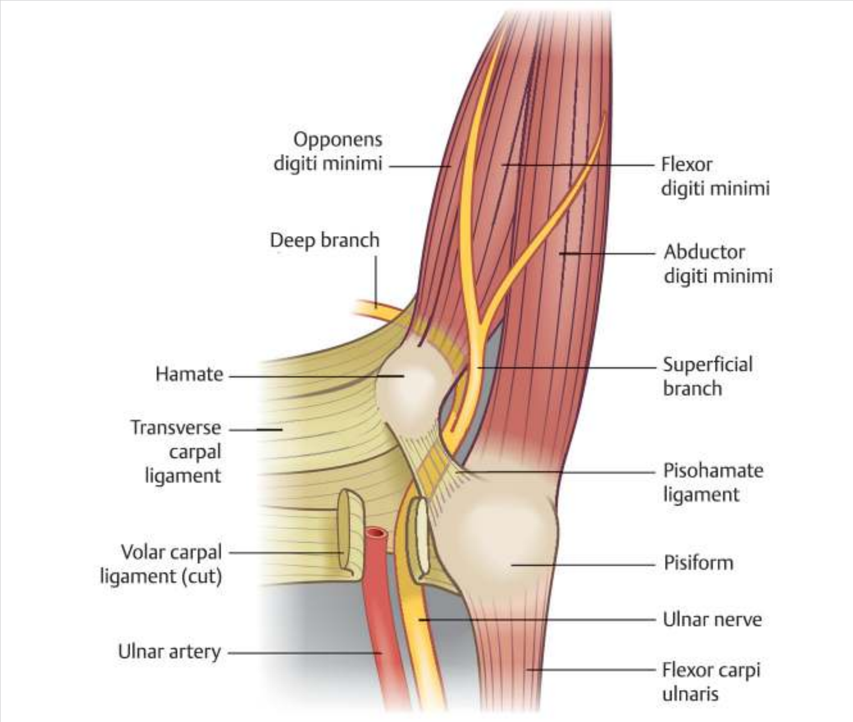

Fig. 51.1 Guyon's canal shows the course of the ulnar nerve as it crosses the wrist through Guyon's canal and branches into the deep motor and superficial sensory branches.

51.1.4 Sites of Compression

- At elbow = "cubital tunnel syndrome"[1,3,4]
  - Arcade of Struthers.
  - Medial intermuscular septum.
  - Medial epicondyle.
  - Osborne's band (tendinous edge of FCU).
- At wrist/Guyon's canal = "ulnar tunnel syndrome" (▶ Fig. 51.1)[1,3,4]
  - Usually caused by space-occupying lesion.
    - Ganglion cyst.
    - Trauma/carpal fracture.
    - Vascular thrombosis of ulnar artery ("hypothenar hammer syndrome").
    - Compression categorized into three zones[4]:
      - Zone 1 is proximal to ulnar nerve bifurcation by volar carpal ligament and results in sensory and motor deficits.
      - Zone 2 is at the deep motor branch as it passes hook of hamate by pisohamate ligament/proximal edge of hypothenar musculature and results in motor weakness only.
      - Zone 3 is around superficial sensory branch of ulnar nerve and results in sensory deficits only.

51.2 Treatment Options

- Conservative:
  - Rest.
  - Splinting.
  - Nonsteroidal anti-inflammatory drugs (NSAIDs).
  - Steroid injection.
- Operative
  - Surgical decompression
    - At elbow there are several options:
      - In situ decompression.
      - Medial epicondylectomy and in situ release.
      - Subcutaneous transposition.
      - Submuscular transposition.
      - Intermuscular transposition.
      - No strong data to support anything more than in situ decompression unless there is subluxation of the ulnar nerve about the medial epicondyle where a medial epicondylectomy should be performed as well. Some surgeons may opt for a transposition if the nerve subluxates.[4,6]
    - At wrist:
      - Guyon's canal release.
      - Identify and excise any space-occupying lesions.

Indications

- Indications for operative treatment:
  - Failed nonoperative management.
  - Refractory life/occupation limiting symptoms.
  - Wrist fracture with ulnar distribution neuropathy.
- Contraindications:
  - Patient is not a surgical candidate.
  - Relative contraindication is when the patient has had multiple releases of the same nerve in the past.

51.3 Operative Technique

- At elbow[1,2,3,4]:
  - Preoperative planning and special equipment:
    - Upper arm tourniquet.

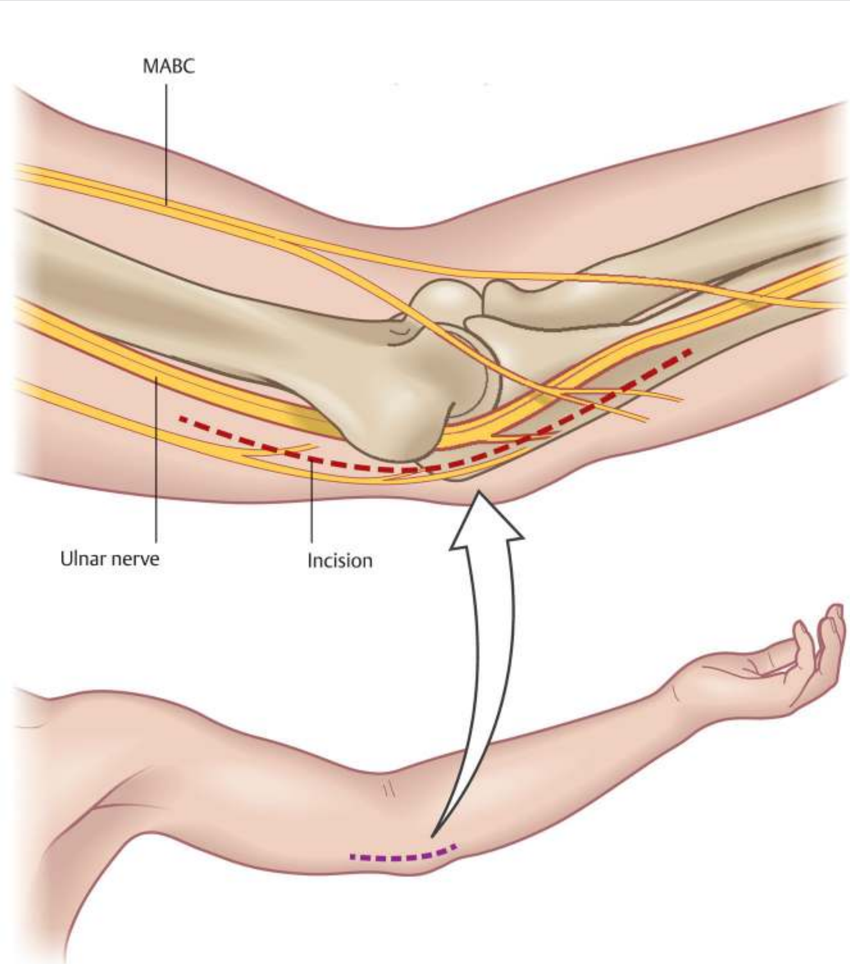

Fig. 51.2 General incision placement for ulnar nerve release at the elbow. The course and branches of the ulnar nerve and the more superficial medial antebrachial cutaneous (MABC) nerve can be seen in relation to each other and the operative field.

- Key steps of the procedure:
  - Markings (▶ Fig. 51.2):
    - Medial epicondyle and olecranon.
    - MABC generally 3 to 4 cm distal to medial epicondyle.
  - Incision—longitudinal between medial epicondyle and olecranon over ulnar nerve.
- Key steps of in situ decompression at the elbow (cubital tunnel release)[4]:
  - Palpate ulnar nerve and expose it by dividing overlying fatty tissue.
  - Proximally dissect and decompress ulnar nerve up to medial intermuscular septum, which should be transected or partially resected.
  - Run finger more proximally for any other points of compression at arcade of Struthers.
  - Continue decompression and neurolysis distally to tendinous edge of FCU "Osborne's band."
  - Be sure to release superficial and deeper fascia in this area.
  - Release the nerve 2 to 3 cm into the FCU muscle to remove intramuscular septa.
  - Complete neurolysis and feel up and down to ensure nerve is free of other points of compression.
- If also performing submuscular transposition[2,4]:
  - Proximally open and resect medial intermuscular septum of arm.
  - Expose fascia of flexor pronator muscle group.
  - Mark and open fascia of flexor pronator in a fashion that will allow for Z-plasty like step-lengthening closure (▶ Fig. 51.3).
  - Divide and open flexor pronator muscle origin to create new submuscular tunnel for nerve after transposition.
  - Ensure ulnar nerve is fully neurolyzed and mobilized.
  - Transpose ulnar nerve anterior to medial epicondyle.
  - The nerve should have a gentle curve from the anterior to the posterior compartments.
  - Loosely close flexor pronator fascia in Z-plasty/step-lengthening fashion over ulnar nerve[4] (▶ Fig. 51.4).
  - Ensure no other areas of compression or kinking remain or have been newly created.
  - Closure.
- Avoidances/Hazards/Risks:
  - Identify and protect MABC.
  - Avoid creating new points of compression.

• At wrist—Guyon's canal release[1,2,4]:
- Preoperative planning and special equipment:
  - Arm tourniquet.
- Key steps of the procedure:
  - A curvilinear incision is made over the ulnar wrist extending distally into the palm.

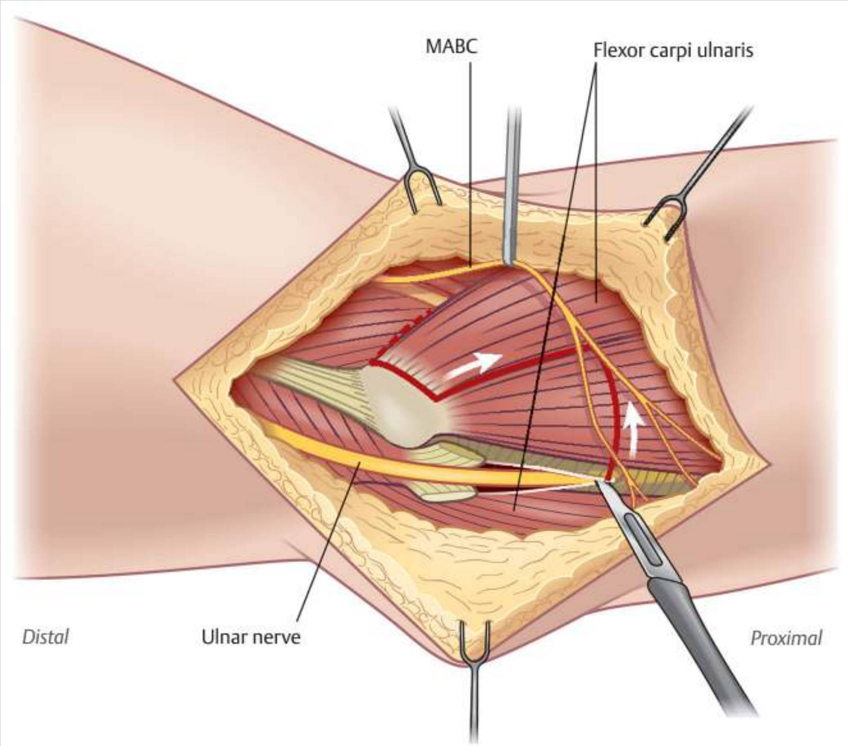

Fig. 51.3 Fascial release step lengthening shows the incision pattern in the flexor pronator fascia to perform the step-lengthening to create new course for decompressed ulnar nerve during submuscular transposition. MABC, medial antebrachial cutaneous.

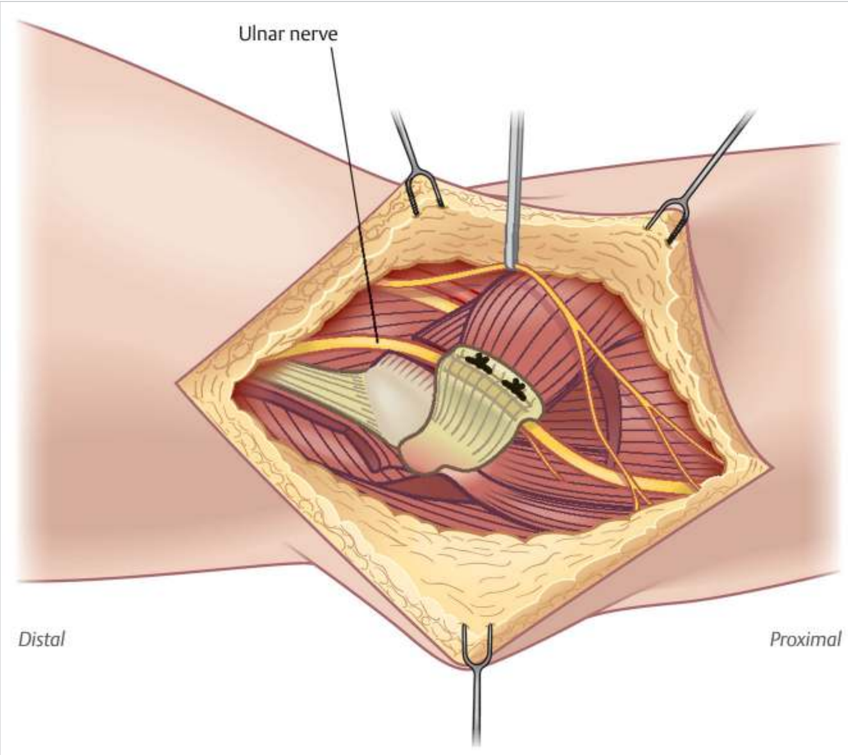

Fig. 51.4 Fascial closure over transposed ulnar nerve shows position of the ulnar nerve after completed submuscular transposition. Note the loose lengthened fascial closure over nerve with no tension or points of further compression.

– Dissection is carried down through the palmaris brevis to expose the volar carpal ligament/palmar aponeurosis.
– This is opened and the ulnar nerve and artery are identified.
– Decompression is continued distally to release the tendinous edge of the hypothenar musculature (to release the deep motor branch of the ulnar nerve), which can be found around the area of the hook of the hamate, and proximally to release the antebrachial fascia.
– The artery is inspected for any signs of thrombosis or aneurysm.
– The field is inspected for any space-occupying lesions.

- Hemostasis is assured, skin is closed, and a bulky soft dressing is applied.
  - Avoidances/Hazards/Risks:
    - Care should be taken to avoid injury to any cutaneous nerves that cross the operative field.

51.4 Conclusion

Ulnar nerve compression in the upper extremity is a commonly encountered diagnosis treated by plastic surgeons. The most common location of ulnar nerve compression is at the elbow, followed by the wrist. Diagnosis is clinical and aided by EMG/nerve conduction velocity (NCV) test. Treatment algorithm begins with conservative measures and progresses to surgical decompression by release of the ulnar nerve at the cubital tunnel at the elbow and/or Guyon's canal in the wrist depending on the location of compression.

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52 Pronator Syndrome

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Abstract

This chapter discusses proximal compression neuropathy of the median nerve, known as pronator syndrome. Common presentations, symptoms, physical examination findings, and treatment options are reviewed in detail. The anatomical sites of compression and surgical pearls for complete decompression are highlighted for educational and instructional purposes.

Keywords: median nerve proximal compression, pronator syndrome

52.1 Introduction

- First described by Seyffarth in 1951 as a compression neuropathy of the median nerve as it passes between the heads of the pronator teres.[1]
- Definition:
  - Compression neuropathy of the median nerve in the proximal forearm causing vague aching pain and/or distal paresthesias.
  - The diagnosis of pronator syndrome results from compression of the median nerve in the forearm by any of the following anatomic structures[2]:
    - Superficial and deep heads of pronator teres.
    - Bicipital aponeurosis (lacertus fibrosus).
    - Fibrous arch of flexor digitorum superficialis (FDS).
    - Ligament of Struthers (often present with a supracondylar exostosis of the humerus)—pain notable usually 8 to 12 cm above the medial epicondyle over the median nerve path.
    - Vascular leashes.
    - Gantzer's muscle (accessory flexor pollicis longus [FPL] muscle).
    - Tumors.
    - Fibrous condensation of flexor carpi radialis (FCR), pronator, and FDS tendons.
- Risk factors:
  - Manual labor with repetitive motion can exacerbate symptoms but causation is yet unproven.
  - Common comorbidities:
    - Diabetes mellitus.
    - Depression/anxiety.
    - Thyroid disease.
    - Obesity.
  - Smoking.
- Often occurs in the setting of other compression neuropathies of the upper extremity:
  - Specifically with carpal tunnel syndrome (CTS) as a double crush of the median nerve.
- Controversial topic within hand and peripheral nerve surgery[3]:
  - Electromyography (EMG)/nerve conduction studies often negative.
  - Diagnosis made primarily based on clinical signs and symptoms.

52.2 Indications

52.2.1 Symptoms

- Pain or aching in proximal volar forearm or just above the medial elbow.
- Paresthesias in radial three and half digits of hand (like CTS).
- Paresthesias in the palmar cutaneous branch of the median nerve distribution (unlike CTS).[4]
- Worsened by repetitive wrist and finger flexion, pronation/supination, and elbow flexion.[5]

52.2.2 Physical Examination

- Compression test[6,7]:
  - Compression of proximal volar forearm with thumb reproduces the paresthesias.
  - Reproduction of paresthesias in radial three and half digits as well as palm in involved extremities approximately 30 seconds.
- Positive Tinel's sign of the proximal forearm (not often present).
- Compression site specific tests [8,9]:
  - Pronator teres:
    - Resisted pronation with elbow in flexion.
  - Lacertus fibrosus:
    - Resisted elbow flexion and forearm supination.
  - Sublimis arch of the FDS:
    - Resisted flexion of middle finger.
  - Ligament of Struthers originating from a supracondylar process:
    - Tenderness to palpation along anteromedial aspect of the distal humerus.
- Differentiating from CTS[10]:
  - *Decreased sensation over the palm* (palmar cutaneous nerve distribution which branches proximal to the carpal tunnel).
  - *Does NOT typically produce nocturnal symptoms.*[11]
  - Provocative tests at the wrist will be negative.

52.2.3 Preoperative Testing

- Two radiograph views of distal humerus if supracondylar process is suspected.
- Magnetic resonance imaging (MRI) if there is palpable mass in forearm.
- EMG and nerve conduction study (NCS):
  - Useful to rule out CTS or cervical radiculopathy.
  - Identification of double crush of the median nerve.
  - Limited utility and unreliable in pronator syndrome alone.

52.2.4 Conservative Treatment[8]

- Avoidance of symptom aggravating activities.
- Ice/heat.
- Immobilization with removable long arm splint.
- Nonsteroidal anti-inflammatory drugs (NSAIDs).

- Oral steroids.
- Local steroid injections.[4]

52.2.5 Operative Indications

- Failure of conservative treatments for 3 to 6 months.
- Debilitating pain or numbness preventing activities of daily living or work.
- Space-occupying lesion.

52.3 Operative Technique

52.3.1 Preoperative Preparation

- Upper arm tourniquet.

52.3.2 Key Steps of the Procedure

- Markings
  - Design 4 cm straight incision in the mid volar forearm 2 cm distal to the antecubital fossa[12] (separate incision 8 cm above medial elbow needed if ligament of Struthers is suspected/documented).
- Key steps
  - Dissection down to volar forearm fascia.
    - Care is taken to avoid any branches of medial antebrachial cutaneous nerve.
  - Lacertus fibrosus will be encountered and divided completely.
  - Identify interval between pronator and brachioradialis:
    - Radial artery retracted radially.
  - Median nerve identified on undersurface of pronator teres as it passes between the superficial and deep heads.
  - Decompress median nerve by releasing all tight overlying structures along the course of median nerve:
    - Superficial head of pronator teres,
    - Sublimis arch of FDS,
    - Vascular leashes—small branching veins will be encountered and should be clipped as they are fragile and will bleed easily in this area,
    - Palpate nerve course distally to identify any further potential sites of compression such as Gantzer's muscle,
  - Dissection is not routinely carried above the elbow, unless supracondylar process is identified on physical examination or imaging preoperatively.
- Postoperative management:
  - Steri-Strip and dry gauze wrap over incision,
  - Remove gauze in 48 hours and shower,
  - No heavy lifting or strenuous activity,
  - Follow-up in the office in 2 weeks,

52.4 Conclusion

- Clinical diagnosis based on constellation of symptoms with or without EMG findings:
  - Aching pain in proximal volar forearm,
  - Paresthesias in radial three and half digits:
    - Numbness in the palmar cutaneous branch distribution will differentiate from CTS,
  - Worsens with repetitive pronation and supination,
  - Symptom reproduction with compression and provocative tests,
  - Often occurs with CTS as a double crush of the median nerve,
- Limited utility of EMG and imaging studies.
- Conservative therapy with activity limitations, splints, and NSAIDs remain mainstay of treatment.
- Surgical intervention reserved for refractory and debilitating symptoms.
- Full release of all potential compression sites in proximal forearm provides relief for most patients.

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53 Radial Nerve Syndrome

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Abstract

Radial tunnel syndrome (RTS) describes compression of the radial nerve in the proximal forearm. This syndrome occurs infrequently compared to more common upper extremity compression neuropathies and presents a diagnostic and therapeutic challenge. RTS has a propensity to occur concomitantly with other compression neuropathies. The careful examiner will be able to recognize the specific constellation of symptoms comprising this syndrome and offer appropriate surgical intervention when indicated. This chapter aims to provide the foundational knowledge needed for plastic and hand surgeons to be able to appropriately recognize and treat RTS.

Keywords: anatomy, arcade of Frohse, compression neuropathy, diagnosis, leash of Henry, radial nerve, radial tunnel syndrome, treatment

53.1 Introduction

- Definition:
  - Compression neuropathy of the radial nerve in the proximal forearm causing vague aching pain.
  - Late stages develop extensor weakness or paralysis.
  - Pathophysiology is less straightforward than other compression:
    - Initial irritation of the nerve is thought to be not severe enough to cause sensory/motor symptoms.
    - Perceived as pain in proximal extensor musculature as the posterior interosseous nerve (PIN) carries unmyelinated and small myelinated fibers that can perceive pain.[1]
- Radial tunnel syndrome (RTS) results from compression of the radial nerve in the proximal forearm by any of the following anatomic structures:
  - Arcade of Frohse (leading edge of the supinator muscle fascia).
  - Extensor carpi radialis brevis (ECRB).[2]
  - Vascular leash of Henry (often a branch of the radial recurrent artery).
  - Distal supinator muscle fascia.
  - Ganglion cyst of the radiocapitellar joint (rare).[3]
  - Tumors.
  - Bone mass from radius (exostosis, tumor, callus, malunion).
- Relevant anatomy:
  - Components of the radial tunnel:
    - Floor—radiocapitellar joint.
    - Roof—brachioradialis (BR) and then supinator muscle distally.
    - Medial—biceps tendon and brachialis.
    - Laterally—extensor carpi radialis longus (ECRL) and ECRB fascia.
- Risk factors:
  - Manual labor with repetitive rotational motions of the wrist can exacerbate symptoms.
  - Overhead use of extensor muscle.
  - Lifting with extensor muscles instead of flexors:
  - Common comorbidities:
    - Diabetes mellitus.
    - Depression/anxiety.
    - Thyroid disease.
    - Obesity.
  - Smoking.
- Often occurs in the setting of other compression neuropathies of the upper extremity.
- Controversial topic within hand and peripheral nerve surgery:
  - Electromyography (EMG)/nerve conduction study (NCS) often negative.
  - Diagnosis primarily made on clinical signs and symptoms.

53.2 Indications

53.2.1 Symptoms

- Pain or aching in the proximal dorsal forearm:
  - Can be prominent at night.
  - Radiation of pain proximally in line with course of radial nerve around the humerus.
- Paresthesias and/or muscle weakness are characteristically absent.
- Worsened by movements that place the nerve on stretch:
  - Elbow extension.
  - Pronation.
  - Wrist flexion.

53.2.2 Physical Examination

- Compression test:
  - Compression applied by the examiner in the interval between the BR and the ECRL over the radial tunnel in the dorsal proximal forearm 4 to 5 cm distal to the lateral epicondyle produces severe pain.
- Resisted extension of the long finger can also reproduce the pain:
  - This has been shown to be not universally present in the literature.
  - Note: This test is of very limited value.

53.2.3 Differential Diagnosis

- Lateral epicondylitis (tennis elbow):
  - Pain in lateral epicondylitis is typically more proximal than in RTS.
    - Pain will be at the origin of the mobile wad just distal to the lateral epicondyle as opposed to the pain in RTS, which is located in the interval between the BR and ECRL about 4 to 5 cm distal to the lateral epicondyle.[1]
  - The two syndromes can occur simultaneously.
- PIN syndrome:
  - PIN syndrome is a pure motor neuropathy with weakness of the extensor muscles of the hand and wrist.
    - It will show up with EMG and NCS.

- ◦ RTS does not have a prominent motor component and EMG/NCS is typically negative.
- ◦ Some clinicians do not differentiate RTS from posterior interosseous syndrome.

53.2.4 Preoperative Testing

- MRI if palpable mass in forearm.
- EMG and NCS:
  - Useful to rule out PIN neuropathy or Wartenberg's syndrome (compression of the superficial radial nerve in the distal forearm).
  - Less utility for diagnosis of RTS, often negative.[4]
  - Helpful to evaluate for compression neuropathies of other nerves in the upper extremity as these often occur concomitantly with RTS.

53.2.5 Conservative Treatment

- Activity modification.
- Physical therapy.
- Ice/heat.
- Splinting of the wrist.
- Nonsteroidal anti-inflammatory drugs (NSAIDs).
- Local steroid injections.

53.2.6 Operative Indications

- Failure of conservative treatments for 3 to 6 months.
- Debilitating pain preventing activities of daily living or work.
- Space-occupying lesion in the radial tunnel.

53.3 Operative Technique

53.3.1 Preoperative Preparation

- Upper arm tourniquet.

53.3.2 Key Steps of the Procedure

Markings

- Design 5 cm straight incision on the dorsal forearm starting 3 cm distal to the lateral epicondyle.
- Center the incision over the palpable interval between the BR and ECRL.

Key Steps

- Dissection down to dorsal forearm fascia:
  - The posterior cutaneous nerve of the forearm should be protected.
- The interval between the BR and ECRL is identified and blunt dissection is used to separate the muscles.
  - The BR muscle is always a darker red than the ECRL and this aids in identification.
- The first nerve encountered will be the superficial branch of the radial nerve.
  - This is traced proximally and deep until the branching of the PIN is identified.
- At this point all overlying compressive structures are released:
  - Proximally the fascial condensation on the deep surface of the ECRB is often compressive and should be released.
  - Any compressive vascular leashes should be clipped and divided:
    - Ensure that there are no small accompanying nerve branches with the vessels before clipping.
  - The nerve is then traced distally to where the PIN dives under the arcade of Frohse and released throughout the entire length of the supinator muscle as there can be compressive fascial bands throughout the muscle:
    - In order to trace the nerve through the entire supinator occasionally requires switching to a more posterior interval to visualize the entire course of the nerve in the distal supinator.[5]

Postoperative Management

- Steri-Strips and dry gauze wrap over incision.
- Remove gauze in 48 hours and shower.
- No heavy lifting or strenuous activity.
- Follow-up in the office in 2 weeks.
- NSAIDs for postoperative discomfort.

53.4 Conclusion

- Clinical diagnosis is through exclusion based on ruling out other causes of similar pain and symptoms which include:
  - Aching pain in proximal dorsal forearm.
  - The absence of sensory or motor symptoms of the radial nerve.
  - Worsened resisted extension of the long finger.
  - Symptom reproduction with compression over the radial tunnel.
  - Often occurs in the setting of other compression neuropathies of the upper extremity.
- Limited utility of EMG/NCS except to rule out other syndromes or neuropathies—usually negative in RTS.
- Conservative therapy with activity modification, splints, and NSAIDs remain mainstay of treatment.
- Surgical intervention reserved for refractory cases with debilitating symptoms.
- Full release of all potential compression sites provides symptom relief for most patients.

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54 Arterial Insufficiency, Reconstruction, and Amputation

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Abstract

Arterial insufficiency in the hand and upper extremity can be broadly categorized into of vaso-occlusive and vasospastic origins, with symptoms arising secondary to systemic disease, atherosclerosis, acute or chronic trauma, idiopathic vasospasm, or hypercoagulable states. Pharmacologic therapy can mitigate symptoms when mild, and catheter-based sympathectomy and botulinum toxin injection offer hope for avoiding surgery in some patients. However, although nonsurgical treatment can be effective, operative intervention is often necessary in the form of vascular sympathectomy, vascular reconstruction, or amputation of nonsalvageable fingers. The presentation of arterial insufficiency is varied with patients often presenting a complex clinical picture. This chapter aims to equip surgeons with the foundational knowledge necessary to recognize, evaluate, and appropriately treat patients with vaso-occlusive and vasospastic disorders of the hand and upper extremity.

Keywords: amputation, botulinum toxin, hypothenar hammer syndrome, radial artery, Raynaud's phenomenon, vasospastic disease, ulnar artery

54.1 Introduction

54.1.1 Vaso-occlusive Disease

- Arterial insufficiency occurs when blood flow fails to meet metabolic demand, which results cell ischemia, injury, and eventual death:
  - Clinically this manifests as pain, cold intolerance, and distal numbness and digital ulceration.
- Chronic arterial insufficiency from vaso-occlusive disease of the upper extremity can stem from a variety of etiologies and present with a wide array of symptoms.
- Etiology
  - Trauma:
    - Hypothenar hammer syndrome—chronic trauma to the ulnar artery causing eventual occlusion.
    - Thenar hammer syndrome[1]—rare, secondary to chronic trauma to the radial artery with subsequent occlusion.
    - Cannulation injuries—trauma over time to the arterial lumen from repeated attempts at cannulation during cardiac catheterization, arterial lines, or blood gas sampling which increases the likelihood of aneurysm, pseudoaneurysm, arteriovenous (AV) fistula, and chronic thrombosis over time.
  - Atherosclerosis:
    - Less common in the upper extremity than the lower extremity.
  - Embolic events.
  - Hypercoagulable states.
  - Systemic vascular disease:
    - Thromboangiitis obliterans (Buerger's disease).
    - Polyarteritis nodosa.
    - Takayasu's arteritis.
    - Granulomatosis with polyangiitis (formerly Wegener's granulomatosis).
    - Giant cell arteritis.
- Pathophysiology:
  - Mechanism of injury to the vessel may vary, but the pathologic, histologic, and clinical manifestations are comparable:
    - Chronic inflammation and repetitive trauma cause injury to all layers of the artery.
    - Adventitial scarring contributes to occlusion.
    - Media and intimal damage cause weakening of the vessel wall and aneurysm/pseudoaneurysm formation.
    - Exposure of subendothelial collagen activates the clotting cascade resulting in localized thrombosis and eventual distal embolization.
    - Atherosclerosis and chronic disease increase the susceptibility of vessels to damage.
  - Thrombosis causes local and distal ischemic symptoms:
    - Thrombosis increases sympathetic vascular tone and therefore the likelihood of vasospasm distal to the thrombosed segment is increased, further worsening the ischemia.[2]
    - Angiogenesis triggered by ischemia leads to collateralization.
  - Hemodynamics distal to the occlusion change and increase the risk of propagating the clot further by increasing stasis and turbulent blood flow.
- Relevant anatomy:
  - Radial and ulnar arteries branch from the brachial artery just distal to the antecubital fossa.
  - Radial artery:
    - Courses through the forearm under the bicipital aponeurosis and brachioradialis and superficial to the biceps tendon, pronator teres, flexor digitorum superficialis, and flexor pollicis longus as it proceeds distally.
    - Smaller caliber than the ulnar artery in the proximal forearm.
    - In the distal forearm runs between the brachioradialis and flexor carpi radialis.
    - Usually of larger caliber than the ulnar artery as it reaches the hand.
  - Ulnar artery:
    - Courses deeper in the forearm, under the pronator teres and flexor digitorum superficialis.
    - Superficial to the flexor digitorum profundus.
    - Found deep and radial to the flexor carpi ulnaris running with the ulnar artery in the distal forearm.
  - Vascular supply to the hand is an exceedingly complex anatomic and physiologic arrangement which often precludes the definitive determination of vessel dominance:
    - Significant anatomic variability exists with rich anastomotic connections between arches.
  - Superficial palmar arch:
    - Predominantly supplied by the ulnar artery with minor contribution from the superficial volar branch of the radial artery.

  - Deep to the palmar fascia and distal to the deep palmar arch.
  - Gives off the three common digital arteries which course distally to bifurcate into the proper digital arteries that supply the fingers.
- Deep palmar arch:
  - Predominantly supplied by the radial artery with minor contribution from the deep branch of the ulnar artery.
  - Deep to the flexor tendons at the level of the metacarpal bases.
  - Commonly gives off the princeps pollicis which is the primary blood supply to the thumb running between the first dorsal interosseous and adductor pollicis.

- Risk factors:
  - Peripheral vascular disease.
  - Atherosclerosis:
    - Hyperlipidemia, hypertension, diabetes mellitus, and obesity increase risk.
  - Manual labor with repetitive trauma to the hypothenar or thenar eminence over time.
  - Repeated arterial cannulation.
  - Smoking.
  - Genetic disorders:
    - Ehlers-Danlos and Marfan syndromes.
  - Hypercoagulability:
    - Inherited clotting disorders.
    - Neoplasm-induced prothrombotic states.
  - Collagen vascular disorders.

54.1.2 Vasospastic Disease

- First described by Raynaud in 1862 in his doctoral dissertation as a phenomenon of "local asphyxia of the extremities" in a young French woman.
- Definition[3]:
  - Primary vasospasm:
    - Termed Raynaud's disease or primary Raynaud's phenomenon.
    - Vasospasm without an identifiable anatomic or systemic etiology.
  - Secondary vasospasm:
    - Termed Raynaud's syndrome or secondary Raynaud's phenomenon.
    - Encompasses all other vasospastic conditions of the hand that are secondary to: collagen vascular disorders, occlusive disease, hematologic disorders, pharmacologic, or infectious etiologies.
- Etiology—primary vasospasm:
  - Raynaud's disease:
    - By definition this is a primary vasospasm without an identifiable etiology.
- Etiology—secondary vasospasm:
  - Termed Raynaud's syndrome or secondary Raynaud's phenomenon.
  - Vaso-occlusive disease (see above section):
    - Secondary vasospasm distal to the occlusive lesion.
  - Systemic vascular disease:
    - Systemic sclerosis.
    - Systemic lupus erythematosus.
    - Dermatomyositis.
    - Sjogren's syndrome.
    - Mixed connective tissue disease.
    - Vasculitis.
    - Thromboangiitis obliterans (Buerger's disease).
    - Atherosclerosis.
  - Anatomic:
    - Thoracic outlet syndrome (unilateral symptoms).
  - Pharmacologic:
    - Ergot alkaloids.
    - Beta-blockers.
    - Amphetamines.
    - Vinblastine/Vincristine.
    - Interferon alpha.
    - Cisplatin.
    - Cyclosporine.
    - Bleomycin.
  - Hematologic:
    - Cryoglobulinemia.
    - Associated with hepatitis B and C.
    - Factor V Leiden.
    - Cold agglutinin disease.
    - Polycythemia vera.
    - Cryofibrinogenemia.
    - Homocysteinemia.
    - Protein C, protein S, or antithrombin III deficiency.
    - Paraproteinemia.
  - Infectious:
    - Hepatitis B and C.
    - Parvovirus B19.
    - Mycoplasma (associated with cold agglutinins).
- Pathophysiology—competing theories:
  - Central:
    - Central nervous system (CNS) changes causing hyperactivity of the sympathetic response peripherally.
    - Supported by patients that have symptoms related to emotional stress.[4]
  - Peripheral:
    - Exaggerated response of peripheral vasculature to circulating catecholamines, temperature, and trauma.
  - Neuropeptide dysregulation:
    - This could encompass both central and peripheral mechanisms.
    - Neuropeptides are made in the CNS but can be excreted either there or in peripheral nerve endings.
    - Substance P, calcitonin gene-related peptide (CGRP), neuropeptide Y, and vasoactive intestinal peptide (VIP) are all vasoactive causing either vasodilation or vasoconstriction when secreted in response to temperature changes.
  - Reperfusion injury:
    - Intimal fibrosis and vessel wall thickening found in the peripheral vasculature of postmortem patients with digital vasospasm.
    - Thought to be a result of the repeated ischemia/reperfusion that occurs during and after vasospasm rather than the inciting event causing the vasospasm.
  - Clinical manifestations of vasospasm[5]:
    - Inadequate nutritional perfusion.
    - Insufficient oxygen delivery.
    - Anaerobic metabolism causing an acidotic local environment.

- Relevant anatomy:
  - See Vaso-occlusive Disease section above.
- Risk factors:
  - Gender:
    - Women are more susceptible than men at a ratio of 9:1.
  - Smoking.
  - Collagen vascular disorders.
  - Cold environment.
  - Medications.
    - See above list under in Section 54.2.2.

54.2 Indications

54.2.1 Vaso-occlusive Disease

Symptoms

- Pain with activity progressing to rest pain with disease progression.
- Distal paresthesias and/or muscle weakness.
- Cold intolerance.
- Edema.
- Increased fatigability and decreased exercise tolerance.

Physical Examination

- Delayed capillary refill.
- Evaluation of skin turgor.
- Digital ulceration:
  - Evaluate any areas of skin breakdown and note which fingers are most severely affected.
- Detailed sensory examination.
- Palpating pulses.
- Allen's test:
  - Can be crucial to localizing occlusive lesions.
- Digital Allen's test.
- Handheld doppler examination can be done in conjunction. with the Allen's and Digital Allen's tests.[3]

Preoperative Testing

- Color duplex ultrasonography:
  - Allows real-time visualization of vessel dynamics.
  - Can measure wall thickness and identify intraluminal thrombi.
  - Best modality for detecting aneurysm and pseudoaneurysm and elucidating their specific anatomy.[2]
- Segmental arterial pressure:
  - Allows calculation of radial brachial and digital brachial indices (RBI, DBI):
    - Normal DBI is 1, 0.7 to 1.0 is decreased but adequate, less than 0.7 is inadequate, greater than 1 is likely due to calcification of vessels.
- Computed tomography angiography (CTA)[6]:
  - Noninvasive imaging modality:
    - Does require injection of intravenous (IV) contrast.
    - Exposes the patient to ionizing radiation.
  - Valuable for imaging pathology proximal to the proper digital arteries.
    - May be preferable in patients unable to tolerate conventional angiography.
- Magnetic resonance angiography:[7]
  - Noninvasive imaging modality:
    - Does not require IV contrast.
    - No exposure to ionizing radiation.
  - Difficulty in visualizing most distal vasculature in the fingers.
  - Initial imaging modality of choice in patients with collagen vascular disorders:
    - Higher risk of vasospasm with conventional angiography and CTA, both of which require radiographic dye.
- Contrast angiography:
  - Gold standard for evaluation of upper extremity vascular anatomy.
  - Allows surgeon to visualize the extent of thrombosis and collateral flow that is present:
    - Caution exercised in patients with collagen vascular disorders as vasospasm in these patients can give the false appearance of occlusion and thrombosis.
  - Tendency to overestimate the extent of the occlusion:
    - Often occluded segments are smaller when visualized intraoperatively.
  - Allows for endovascular interventions in conjunction with the vascular surgeon or interventional radiologist:
    - Angioplasty and/or thrombolysis in select cases.
  - Crucial for operative planning.

Conservative Treatment

- Smoking cessation.
- Avoidance of caffeine.
- Environmental and activity modification:
  - Minimize cold exposure.
- Pharmacologic interventions to treat secondary vasospasm distal to the occlusion by increasing nutritional flow and decreasing sympathetic tone, thereby inducing vasodilation[5]:
  - Calcium channel blockers:
    - Nifedipine, Amlodipine.
  - Tricyclic antidepressants (TCAs):
    - Amitriptyline, Imipramine.
  - Selective serotonin reuptake inhibitors (SSRIs):
    - Fluoxetine, Paroxetine, Sertraline.
  - α_1-adrenergic antagonists:
    - Prazosin, Terazosin.
  - α_2-adrenergic agonists:
    - Clonidine.
  - Phosphodiesterase inhibitors:
    - Sildenafil, Tadalafil.

Operative Indications

- Operative intervention is reserved for patients with occlusive lesions with inadequate collateral flow causing local and distal ischemia.
- Failure of conservative treatments for 3 to 6 months.
- Debilitating pain preventing activities of daily living or work.
- Aneurysms and pseudoaneurysms always require operative intervention given the risk of downstream emboli.

54.2.2 Vasospastic Disease

Symptoms

- Triphasic digital color change (all three not necessary for diagnosis):
  - White—pallor.
  - Blue—cyanosis.
  - Red—hyperemia.
- Pain.
- Numbness/dysesthesias.
- Digital ulcers/gangrene.
- Symptoms occur in response to:
  - Cold temperature.
  - Stress.
  - Pain.

Physical Examination

- Bilateral hand involvement common.
- Capillary refill:
  - Can be delayed.
- Evaluation of skin turgor.
- Digital ulcers:
  - Note location and severity of wounds.
- Palpate pulses.
- Allen's test:
  - Rules out occlusive disease.
  - Can be done in conjunction with handheld doppler.
- Digital Allen's test.
- Full motor examination.
- Detailed sensory examination:
  - Semmes-Weinstein monofilament testing.

Preoperative Testing

- Full rheumatologic workup to rule out collagen vascular disorders:
  - Erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), anti-nuclear antibody (ANA), rheumatoid factor (RF), anti-centromere antibody.
- Cold recovery testing[4]:
  - Place digits in cold water bath for 1 minute:
    - Positive test when digits do not recover their baseline temperature within 20 minutes.
  - Not necessary when diagnosis is obvious or in the presence of digital ulceration.
  - Lacks specificity:
    - Can be positive in smokers without the presence of vasospastic symptoms.
- Color duplex ultrasonography:
  - Can help diagnose occlusive disease when this is suspected.
- Segmental arterial pressure:
  - Allows calculation of RBI and DBI:
    - Normal DBI is 1, 0.7 to 1.0 is decreased but adequate, less than 0.7 is inadequate, greater than 1 is likely due to calcification of vessels.
- CTA:
  - Noninvasive imaging modality:
    - Does require injection of IV contrast.
    - Exposes the patient to ionizing radiation.
  - Valuable for imaging pathology proximal to the proper digital arteries:
    - May be preferable in patients unable to tolerate conventional angiography.
- Magnetic resonance angiography[7]:
  - Noninvasive imaging modality:
    - Does not require IV contrast.
    - No exposure to ionizing radiation.
  - Difficulty in visualizing most distal vasculature in the fingers.
  - Initial imaging modality of choice in patients with vasospastic disease, specifically collagen vascular disorders:
    - Higher risk of vasospasm with conventional angiography and CTA, both of which require IV radiographic dye.
- Contrast angiography:
  - Gold standard for evaluation of upper extremity vascular anatomy.
  - Allows visualization of occlusive lesions if they are present.
  - Best for operative planning if periarterial sympathectomy is to be performed.

Conservative Treatment

- Smoking cessation.
- Avoidance of caffeine.
- Environmental and activity modification:
  - Minimize cold exposure:
    - Use of protective garments even in mild temperatures.
- Discontinue any medications that may be contributing to vasospasm.
- Biofeedback:
  - Develop CNS control over peripheral autonomic functions.
- Pharmacologic management:
  - Increase nutritional flow and decrease sympathetic tone, thereby inducing vasodilation.
  - Calcium channel blockers:
    - Nifedipine, Amlodipine.
  - TCAs:
    - Amitriptyline, Imipramine.
  - SSRIs:
    - Fluoxetine, Paroxetine, Sertraline.
  - α_1-adrenergic antagonists:
    - Prazosin, Terazosin.
  - α_2-adrenergic agonists:
    - Clonidine.
  - Phosphodiesterase inhibitors:
    - Sildenafil, Tadalafil.

Operative Indications

- Failure of conservative measures for 3 to 6 months.
- Nonhealing ulcers.
- Gangrene requiring amputation.
- Debilitating pain/numbness affecting activities of daily living.

54.3 Operative Technique

54.3.1 Vaso-occlusive Disease

Preoperative Preparation

- Upper arm tourniquet.
- If a venous or arterial graft may be necessary; make sure to also prep out the extremity from which this will be harvested if it is not already in the operative field.

Key Steps of the Procedure

- Markings:
  - Incision should be centered over the area of occlusion, aneurysm, or pseudoaneurysm.
    - Incision length should be generous in order to provide wide exposure of the affected area.
- Exposure:
  - Incision is carried down through skin, subcutaneous tissue, and antebrachial and/or superficial palmar fascia.
  - The neurovascular bundle in question is identified deep to the fascia.
- Key steps—embolectomy:
  - If the thrombosis is acute due to arterial cannulation or acute on chronic, the decision can be made to attempt embolectomy instead of a more extensive reconstruction.
    - Proximal and distal control of the vessel is obtained with vessel loops or vascular clamps.
    - Before arteriotomy, 1,000 to 5,000 units of intravenous heparin is given.
    - A transverse arteriotomy is made using a #11 blade scalpel.
    - Fogarty embolectomy catheter is passed proximal and distal from the arteriotomy site to retrieve any clot that is present.
    - Catheters of 2 French size can be used effectively in the hand and wrist.
    - Usually difficult to cannulate the digital vessels; however, embolectomy of the arch is possible.
  - Embolectomy is often performed in conjunction with thrombolytic therapy.
    - Intra-arterial injection of tissue plasminogen activator can resolve any clot unable to be extracted with the Fogarty catheter.
    - Intraoperative angiography can be used with injection of contrast through the arteriotomy site and live fluoroscopy using a C-arm or mini C-arm to visualize any areas yet without flow.
- Key steps—radial/ulnar thrombosis, aneurysm, pseudoaneurysm
  - The diseased vessel is exposed and dissected free from the surrounding tissue.
    - Vessel is examined under loupe or microscopic magnification in order to determine which areas are diseased and require resection and which areas are healthy enough proximally and distally to accept an anastomosis.
  - Proximal and distal control of the vessel is obtained using vessel loops or vascular clamps.
    - At this point 1,000 to 5,000 units of heparin can be given intravenously.
  - Resection of the aneurysm or diseased vessel can be performed at this point.
  - Reconstructive options—end-to-end repair:
    - If after cutting back to healthy vessel there is only a small gap, end-to-end repair is preferable.
    - Mobilization of the vessel proximal and distal to decrease tension.
    - 8–0 or 9–0 nylon interrupted sutures under microscopic magnification used to perform the anastomosis.
  - Reconstructive options—interposition vein grafting:
    - Needed when the gap is too large for primary repair of the vessel.
    - Vein grafts can be harvested from preferred sites with careful ligation of all side branches.
    - Common choices include the cephalic, basilic, greater saphenous, and lesser saphenous veins.
    - In cases where arch reconstruction is necessary, vein grafts with multiple branches can be anastomosed to the common digital arteries as they come off the arch.
    - Vein graft brought onto field and reversed.
    - It is helpful to distend the vessel with heparin saline in order to ensure that the length is correct.
    - End-to-end anastomosis is performed using 8–0 or 9–0 nylon suture.
    - Data in the hand surgery literature shows poor long-term patency of vein grafts; however, patients often remain symptom free despite this.[8]
  - Reconstructive options—interposition arterial grafting:
    - Cardiac literature and some recent studies in the hand literature support the use of arterial grafts, which show better long-term patency rates compared to vein grafts.
    - Artery of choice is the descending branch of the lateral femoral circumflex artery.[9]
    - Lateral intermuscular septum of the thigh is marked with a line from the anterior superior iliac spine (ASIS) to the lateral border of the patella.
    - Incision designed along this line at the junction of the proximal and middle thirds with a medial extension toward the groin crease proximally.
    - Incision through skin, subcutaneous tissue, and muscle fascia.
    - Lateral intermuscular septum is entered between the rectus femoris and vastus lateralis muscles.
    - Medial retraction of the rectus femoris will reveal the artery running with two venae comitantes on the superficial surface of the vastus intermedius and traversing under the vastus lateralis.
    - Vessel can be traced proximally to gain a better size match for the radial/ulnar artery.
    - Artery is ligated and brought onto the field for anastomosis.
    - Arterial grafts do not require reversal.
    - End-to-end anastomosis with 8–0 or 9–0 nylon.
  - Once end-to-end repair or graft inset is complete, clamps and the tourniquet are let down and digital perfusion assessed.
- Skin closure completed with deep dermal and simple interrupted sutures in the forearm, and horizontal mattress sutures in the palm.

Postoperative Management

- Splints can be used for comfort and to prevent excessive range of motion or use.
  - Splint applied with the wrist in 15 degrees of extension, 90 degrees of MCP joint flexion, and interphalangeal (IP) joints in full extension.
  - Splint is wrapped with Kerlix gauze only to prevent excessive compression of the extremity.
- Hand elevated at or above the level of the heart to control swelling.
- Based on intraoperative assessment of vascular disease and difficulty of anastomosis, the surgeon may choose to anticoagulate the patient postoperatively with one of the following protocols:
  - Heparin drip keeping the patient's partial thromboplastin time (PTT) between 60 and 90.
  - Heparin 5,000 units three times a day.
  - Lovenox 40 mg once a day.
  - Aspirin 325 mg once a day.
  - Clopidogrel 75 mg once a day.
- Splint removed at 1 week:
  - Wash hand daily with soap and water.
  - Removable splint placed.
- Hand therapy with gentle active range of motion initiated at 2 weeks.

54.3.2 Vasospastic Disease

Preoperative Preparation

- Anesthesia:
  - Local anesthetic without epinephrine is used to perform complete wrist block:
    - Median nerve block by infiltration between the palmaris longus and flexor carpi radialis tendons 1 to 2 cm proximal to the distal wrist crease.
    - Ulnar nerve block by infiltration deep to the flexor carpi ulnaris tendon 1 to 2 cm proximal to the distal wrist crease.
    - Radial nerve block by infiltration just proximal to the radial styloid.
- Botulinum toxin preparation:
  - Botulinum toxin comes supplied in a vacuum-sealed vial as a dried precipitate:
    - Vial contains 100 units of onabotulinumtoxin A.
  - Botulinum toxin is reconstituted in 20 mL of preservative-free, injectable, normal saline (5 U/mL)[10,11,12]:
    - Can use 10 mL for cases where only one hand requires injection.

Key Steps of the Procedure

- Injection:
  - 20 mL is divided into 10 mL per hand.
    - 2 mL or approximately 10 units of botulinum toxin per neurovascular bundle.
  - Injection is performed in the intermetacarpal valleys around the neurovascular bundles at or just proximal to the level of the A1 pulley.[10,11,12,13]

Postoperative Management

- Gentle pressure held over injection sites with dry gauze for 3 to 5 minutes.
- Normal use of the hand is ok directly after the procedure.
- Vasodilation and pain relief from injection typically occur within 5 to 10 minutes; however, this can take up to several days for the full effect to become evident.

Periarterial Sympathectomy

- Preoperative preparation:
  - Upper arm tourniquet.
- Key steps of the procedure:
  - Markings:
    - L-shaped incision is marked beginning 8 to 10 cm proximal to the wrist crease over the ulnar artery and proceeding distally and angling radially toward the carpal tunnel as it crosses the wrist crease.
    - From there the incision continues along the radial border of the hypothenar eminence into the palm until 1 cm proximal to the finger flexion crease.
    - Finally a transverse L incision extension traveling from ulnar to radial 1 cm proximal to the finger flexion crease is designed.
    - A separate incision is required to access the dorsal branch of the radial artery.
      - Incision designed from the snuffbox to the dorsum of the 1st webspace.
  - Key operative steps:
    - Approach and exposure:
      - Initial dissection is done under tourniquet control and loupe magnification.
      - Incision through skin, subcutaneous tissue, and superficial antebrachial and palmar fascia of the forearm and hand, respectively.
      - Skin flaps are elevated and tacked back with fish hook retractors, sutures, or self-retaining retractors.
      - Identify the ulnar artery proximally and then proceed the dissection distally isolating the superficial palmar arch, and common and proper digital neurovascular bundles.
      - Dorsal radial artery exposed from the snuffbox distally as far as it can be traced until it branches and dives into the first dorsal interosseous muscle.
    - Sympathectomy[4,14]:
      - Tourniquet is let down and the microscope brought in for the remainder of the dissection.
      - Curved or straight microsurgical scissors are used to strip the adventitia from around the arteries, paying special attention to areas of branching as the highest concentrations of sympathetic fibers can be found at these locations.
      - This is best done with the tourniquet down to allow for distension of the vessels so that safe adventectomy can be completed, and this also allows evaluation of flow and identification of any occluded areas that may require simultaneous reconstruction.
    - Wound closure:
      - 3–0 Monocryl deep dermal sutures in the forearm.

- Permanent or absorbable simple interrupted or horizontal mattress sutures for final skin closure in the hand and forearm
  - Dressing:
    - Bulky hand dressing for comfort.
- Postoperative management:
  - Dressing stays in place for 48 hours for comfort.
    - Then it can be removed and hand can be washed with soap and water.
  - Consider aspirin or other anticoagulants if concomitant vascular reconstruction was performed.
  - Hand therapy with active range of motion initiated at 5 to 7 days postoperatively.
    - Edema and stiffness are common after surgery and patients should be maintained in therapy until they regain full range of motion.
  - Temporary neuropraxia is also common.
    - Desensitization therapy helps alleviate symptoms until full sensation is recovered.

Operative Technique—Amputation

- Preoperative preparation:
  - Upper arm tourniquet versus isolated finger tourniquet.
  - Digital block for postoperative comfort:
    - Avoid local anesthetic with epinephrine in patients with vasospastic disorders.
- Key steps of the procedure:
  - Markings:
    - Traditional fish-mouth type incisions are preferred, preserving as much normal skin as possible with the initial dissection.
      - This will depend on the amount and location of the skin necrosis and/or exposed bone.
    - Amputation level should take into consideration the insertion of the flexor digitorum profundus on the base of the distal phalanx and the insertion of the flexor digitorum superficialis on the mid-portion of the middle phalanx.
      - Every attempt should be made to save one or both of these insertions to allow for better function postoperatively.
  - Key operative steps:
    - Incision dorsally is carried down through skin, subcutaneous tissue, and extensor tendon to the level of the bone.
    - Volar incision similarly through skin, subcutaneous tissue to the level of the flexor tendon.
      - If the flexor tendon is to be divided a traction tenotomy should be performed.
    - Neurovascular bundles should be identified and ligated at this point.
      - Traction neurectomies should be performed in order to mitigate the possibility of a painful digital neuroma in the amputation stump.
    - Bony shortening can be completed at this point until tension-free skin closure can be achieved.
      - If the level of amputation is through the distal interphalangeal (DIP) or proximal interphalangeal (PIP) joint, the head of the remaining phalanx should be denuded of all articular cartilage and the condyles contoured in a way that will produce a broad, flat surface to pinch against.
- Postoperative management:
  - Bulky hand dressing applied postoperatively for comfort.
    - Remove on postoperative day 1 and shower.
  - Early active motion can prevent complications such as the quadriga phenomenon or a lumbrical plus finger.
  - Aggressive desensitization exercises with a certified hand therapist can prevent the common complication of a dysesthetic, painful stump.
  - Hand therapy to retrain the patients to use their hand in the absence of the amputated part.

54.4 Conclusion

54.4.1 Vaso-occlusive Disease

- Identify the etiology of the occlusive lesion and treat any underlying systemic conditions.[4]
- Careful physical examination including handheld Doppler.
- Preoperative imaging to identify any aneurysm/pseudoaneurysm and the anatomical site of occlusion.
- Intraoperative assessment to determine whether embolectomy, end-to-end repair, interposition vein graft, or interposition arterial graft is the appropriate treatment.
- Decision for postoperative anticoagulation based on intraoperative vessel quality and ease of anastomosis.

54.4.2 Vasospastic Disease

- Determine if vasospasm is due to primary Raynaud's phenomenon or secondary Raynaud's phenomenon.
- Preoperative testing and imaging to ensure that there is no occlusive component causing downstream vasospasm.
- Conservative measures including pharmacologic measures.
- Botulinum toxin for minimally invasive chemical sympathectomy before attempting open periarterial sympathectomy.
- Periarterial sympathectomy if all other measures fail.
- Revision amputation of any fingers with irreversible gangrenous changes or exposed vital structures.

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55 Acute Compartment Syndrome

Emily Nicole Perez

Abstract
Acute compartment syndrome is a surgical emergency caused by increased interstitial tissue pressure within a closed noncompliant fascial compartment. Tissue ischemia and muscle necrosis progress quickly without emergent surgical release. History and physical examination alone may be sufficient to make the diagnosis but when equivocal measuring compartment pressures may be helpful. A low index of suspicion is required to prevent delay in diagnosis and subsequent irreversible tissue injury. Strategic placement of incision may be utilized to adequately relieve intracompartment pressures while maintaining protective soft tissue covering over vital neurovascular structures. Significant morbidity can be associated with fasciotomy; however, delay in surgical release may lead to devastating functional impairment.

Keywords: acute compartment syndrome, arm, contracture, fasciotomy, forearm, hand, leg, necrosis, perfusion, pressure, release, thigh, trauma, Volkmann

55.1 Introduction

Acute compartment syndrome (ACS) is surgical emergency that requires prompt diagnosis and treatment. It is defined as the increase in tissue pressure within a closed fascial compartment. This increase in pressure leads to tissue ischemia and eventual muscle necrosis.[1] Even with early intervention there is still a high risk of permanent disability and loss of function.[2] The first documentation of this clinical entity was described by Volkmann in 1873[3] with the subsequent literature aimed at early recognition of symptoms and diagnosis. The mainstay of treatment has remained emergent surgical fasciotomy.

55.2 Indications

Acute compartment syndrome of the extremity is treated with emergent surgical decompression; however, at present there is no clear consensus on how to make the diagnosis. Most surgeons proceed with surgery when the diagnosis is even suspected.[4] On initial history and physical examination pain with passive stretch of fingers, paresthesia and hypoesthesias, paralysis, palpable swelling, and eventually absent peripheral pulses all suggest the diagnosis.[5] When the diagnosis is in question or with patients in which high-risk injuries have been identified continuous monitoring of intracompartmental pressures has been employed. An absolute pressure of greater than 30 mm Hg or pressures within 30 mm Hg of either the diastolic blood pressure or mean arterial pressure necessitate fasciotomy.[6] Near-infrared spectroscopy is also useful in identifying elevated compartment pressures.[7]

55.3 Operative Technique

Surgical decompression of the upper extremity for acute compartment syndrome is accomplished from the brachium to the hand with a curvilinear incision from the deltoid insertion to the medial epicondyle then curving radially across the antebrachium and traveling across the carpal tunnel and into the middle of the palm (▶ Fig. 55.1). This technique allows for extending the incision proximally and distally as necessary. In the proximal arm the deltoid should be assessed as it may be

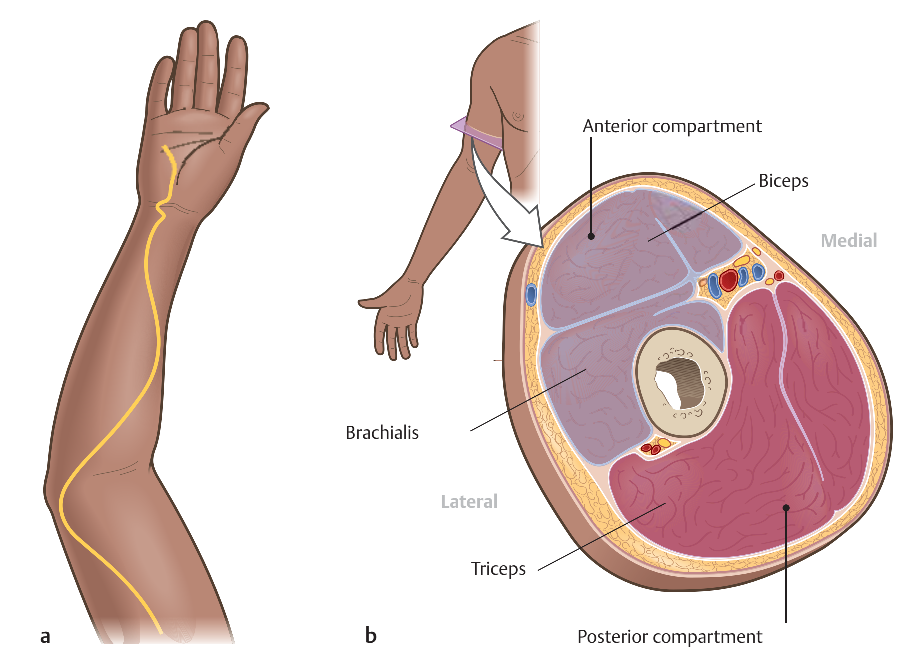

Fig. 55.1 **(a, b)** Forearm volar incision.

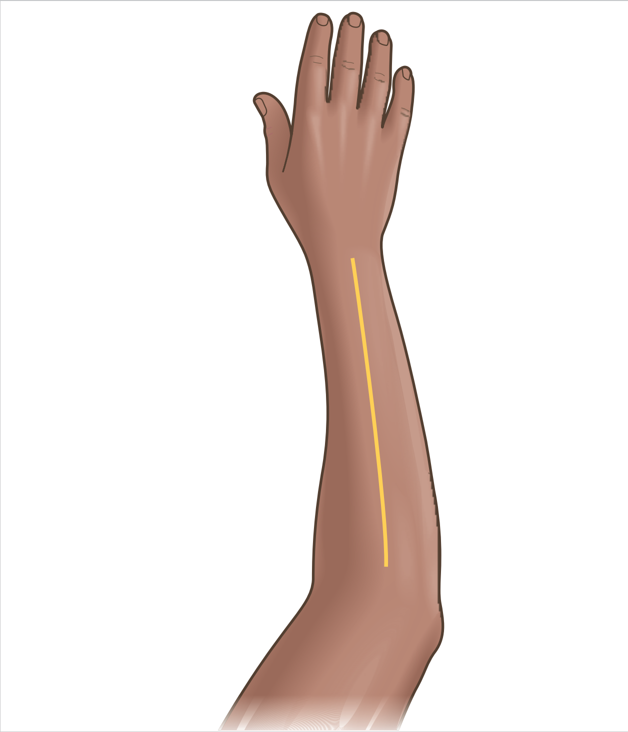

Fig. 55.2 Forearm dorsal incision.

Video 55.1 Upper extremity fasciotomy release

necessary to release the thick epimysium. The anterior and posterior compartments of the arm can both be accessed from this incision and released (▶ Fig. 55.1). Incising the intermuscular septum can provide for additional decompression.

With extension across the elbow and into the forearm the lacertus fibrosus can be released and the brachial artery may be evaluated. In the forearm the antebrachial fascia is incised longitudinally to decompress the superficial flexor compartment (▶ Fig. 55.1b and ▶ Video 55.1). The fascia over the flexor carpi ulnaris (FCU) is opened and the muscle is retracted ulnarly. The flexor digitorum superficialis (FDS) is then retracted radially and the fascia over the deep forearm muscles is opened. If the extensor compartment needs to be released a longitudinal dorsal incision may be made from the lateral epicondyle to the distal radial ulnar joint (▶ Fig. 55.2). To release the extensor compartment and the mobile wad, dissection should be carried forth between the extensor digitorum communis (EDC) and the extensor carpi radialis brevis (ECRB).

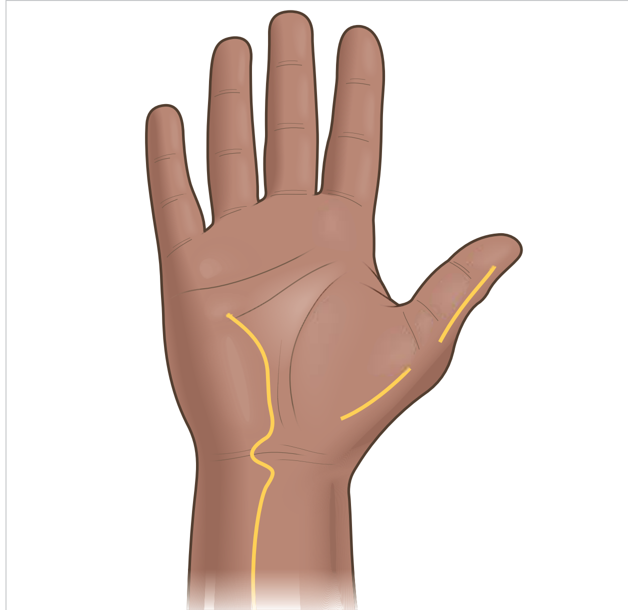

Fig. 55.3 Palmar hand incisions.

Next the hand may be released (▶ Fig. 55.3). It is important to identify which compartments of the hand are compromised as it is often not necessary to decompress all 10 fascial compartments. For a volar release, the forearm incision may be extended across the flexion crease into an extended carpal tunnel incision. Releasing the transverse carpal ligament is usually sufficient to release the carpal tunnel as well as decompress Guyon's canal. The incision can be extended into the second volar webspace where the abductor pollicis fascia and the first volar interosseous may be released. To decompress the thenar and hypothenar compartments longitudinal incisions are made on the radial side of the first metacarpal and the ulnar side of the fifth metacarpal, respectively. On the dorsal side two longitudinal incisions are made over the second and fourth metacarpals to decompress the interossei and adductor compartments.

When there is concern for finger necrosis, fasciotomies can be made through midaxial incisions dorsal to the neuromuscular bundle (▶ Fig. 55.4). Incisions are typically made on the ulnar side of the index and middle fingers and the radial side of the thumb, and ring and small fingers to minimize subsequent irritation.

Compartment release of the thigh starts with a linear incision from the greater trochanter lateral epicondyle of the femur. To release the anterior compartment, incise the iliotibial band and the vastus lateralis can be reflected off the intermuscular septum. Then incise the intramuscular septum the length of the incision to release the posterior compartment. In the lower leg, two incisions are needed to adequately address all four compartments: lateral, anterior, superficial posterior, and deep posterior (▶ Fig. 55.5). To approach the anterior and lateral compartments a longitudinal incision is made 2 cm anterior to the fibular shaft. The fascia of the anterior compartment is opened midway between the septum and tidal crest. From here the fascia is completely released both proximally and distally. The lateral fascial release is made in line with the fibular shaft

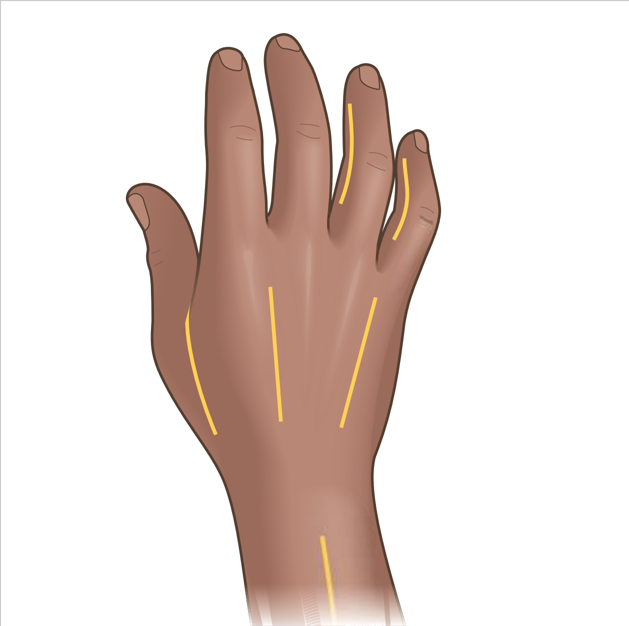

Fig. 55.4 Dorsal hand incisions with digital incisions.

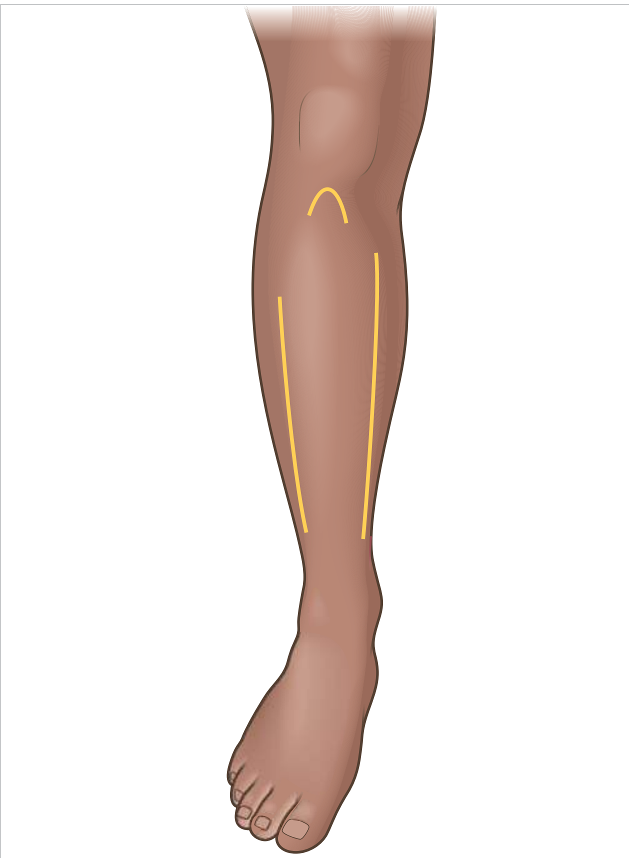

Fig. 55.5 Leg incisions.

toward the lateral malleolus (▶ Fig. 55.6). Care should be taken to avoid the superficial peroneal nerve as it exits the facia. Next a medial incision is made to release the two posterior

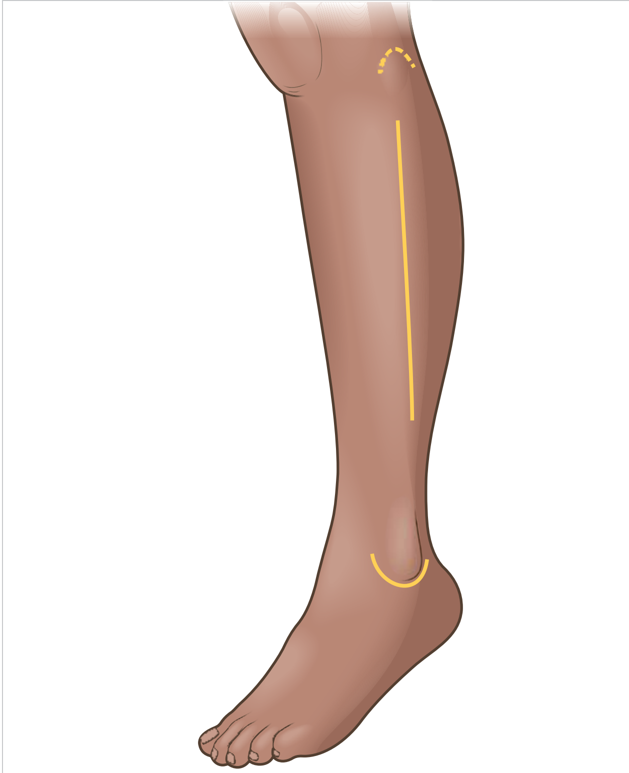

Fig. 55.6 Leg lateral incision.

compartments (▶ Fig. 55.7). The posterior medial edge of the tibia may be palpated and the incision should be centered 2 cm posterior to that. Once the fascia is encountered, undermine anteriorly to the posterior tibial margin. The saphenous vein and nerve should be avoided and retracted. The deep posterior compartment is most superficial here and the fascia should be opened under the soleus muscle. The superficial fascia must also be released, which can be done by undermining slightly posteriorly and in parallel to the incision of the deep compartment.[8]

55.3.1 Discussion

ACS can have devastating and irreversible effects if not treated appropriately and thoroughly. Surgical decompression is the only appropriate therapy for compartment syndrome and elevation of the extremity should be avoided until compartment release can be performed. Fasciotomies are not without morbidity; however, there are several clinical pearls that can help improve outcomes. A Bruner type zig-zag incision over the volar wrist crease can help to prevent flexion contractures instead of simply continuing the forearm incision linearly across the carpal tunnel. Additionally, when deciding skin incisions attention should be paid to ensure that neurovascular structures are covered and protected from desiccation. The median nerve at the carpal tunnel and ulnar nerve at the cubital tunnel are particularly vulnerable. Lastly, fasciotomy incisions should only be closed when all swelling has resolved or skin grafting may be necessary.

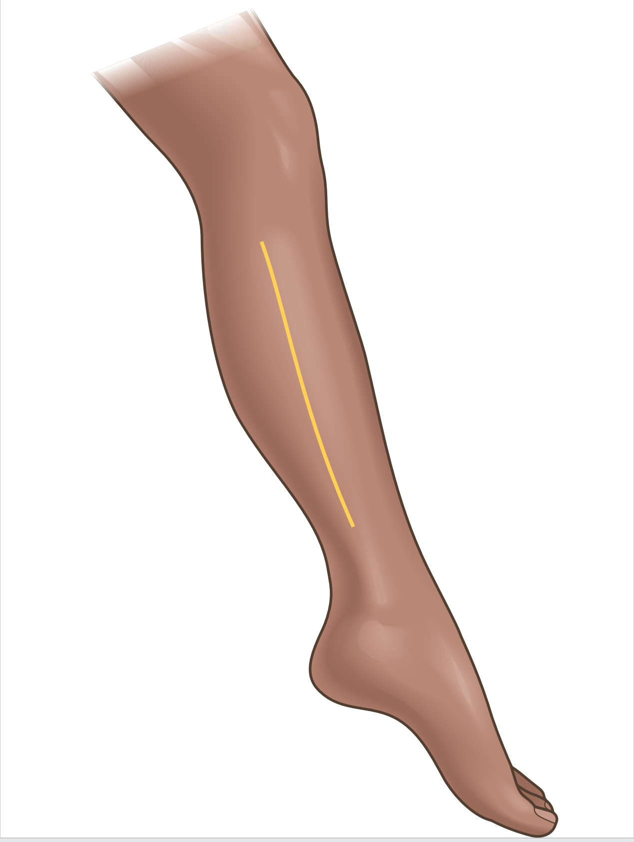

Fig. 55.7 Leg medial incision.

55.4 Conclusion

ACS must be identified quickly and treated expeditiously. Some surgeons only require a clinical suspicion to proceed with surgery whereas others would prefer to obtain intracompartment pressures. Surgical decompression is imperative to prevent irreversible tissue injury. Deliberate placement of incisions is imperative to adequately decompress all compartments while maintaining coverage for vital neurovascular structures. Fasciotomies can be associated with significant morbidity; however, the morbidity associated with a delay or missed diagnosis can be devastating.

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56 Arterial Repair, Revascularization, or Replantation of Digit, Hand, or Upper Extremity

Ajul Shah, Brian Le, and David Chiu

Abstract
Advances in microsurgical techniques and equipment have allowed revascularization of the upper extremity to be reliable in properly selected patients. Injury may be the result of penetrating or blunt trauma. An example of blunt trauma is hypothenar hammer syndrome in which ulnar artery thrombosis can occur. Successful outcomes require a thorough assessment of the zone of injury, tensionless anastomosis, meticulous microsurgical technique, and avoidance of constrictive dressings. Areas that have suffered structural damage, including intimal injury, are unlikely to be successfully repaired and must be resected for an optimal result. Steps involved in restoring ulnar arterial flow to the hand include exposure of the neurovascular bundle, resection of diseased ulnar artery, interpositional grafting, and attentive perioperative management.

Keywords: artery, arterial reconstruction, hypothenar hammer, microsurgery, ulnar artery aneurysm, ulnar artery thrombosis, vein graft

56.1 Introduction

Revascularization of the upper extremity is guided by a number of broad principles, applicable to a wide variety of pathologic conditions ranging from vascular disease to vascular trauma. Blunt trauma has the potential to cause arterial injury throughout the upper extremity, but is commonly evidenced as ulnar artery thrombosis or aneurysm. Patients who suffer from this condition, also known as hypothenar hammer syndrome,[1] often work in professions where the ulnar side of the hand is subject to repetitive trauma[2] and suffer from intermittent ischemic symptoms in the ulnar digits. The revascularization of the hand through restoration of the ulnar artery illustrates the broad range of techniques used when reconstructing the arterial vasculature of the upper extremity, including careful patient selection, vessel grafting, and microsurgery.

56.2 Indications

Repeated blunt trauma to the hypothenar eminence may lead to injury of the ulnar artery, causing thickening of the vessel wall and potentially thrombosis or aneurysmal dilatation.[3] The superficial position of the neurovascular bundle in Guyon's canal makes the vessel susceptible to direct injury and indirect injury when the vessel is driven into the hook of the hamate. Patient who suffers from this disease may also have arterial anatomy that is inherently more susceptible to derangements.[4] Regardless of whether the patient develops aneurysmal dilatation or thrombosis, the patient may suffer from ischemic symptoms of the ulnar sided digits related to the showering of distal emboli, vasospasm, or malperfusion. These symptoms may be limited to cold intolerance, pallor, and discoloration, but can progress to severe symptoms such as uncontrollable pain and tissue necrosis.[3,5,6] Furthermore, the patient may suffer from paresthesias in the ulnar sided digits from direct compression on the nearby ulnar nerve. If the patient has a coincident physical examination, he or she will undergo further diagnostic workup. Imaging modalities include Doppler ultrasonography, multislice computed tomography angiography, magnetic resonance imaging, magnetic resonance angiography, and digital subtraction angiography.[7] When the diagnosis is confirmed by history, physical, and subsequent testing, the patient has an indication for intervention.

56.3 Operative Technique

Although surgical intervention is often the treatment for patients diagnosed with hypothenar hammer syndrome, considerations for medical treatment should be given. Patients who smoke must be counseled for smoking cessation to improve symptoms. Calcium channel blockers can be used to decrease symptoms of vasospasm brought on by the clot,[7,8] and thrombolytic therapy may be considered.[9,10] However, those patients with ulnar artery aneurysm or thrombosis with continued symptoms despite medical intervention need surgical treatment.

The following provides a step-by-step operative technique guide to delineate both the management of ulnar artery thrombosis as well as the principles of arterial reconstruction of the upper extremity.

56.3.1 Technique

- Markings (▶ Fig. 56.1):
  - The hook of the hamate, pisiform, and flexor carpi ulnaris (FCU) are marked.
  - Kaplan's cardinal line is marked, indicating the course of the superficial palmar arch.
  - An incision on the radial side of the FCU is marked with a Bruner incision at the wrist crease; the marking is continued longitudinally on the medial side of the hamate, with an eventual radial angulation at Kaplan's cardinal line.
- Exposure of the ulnar neurovascular bundle:
  - Esmarch bandage is used to exsanguinate the arm and the pneumatic tourniquet is inflated 100 mm Hg above the patient's systolic blood pressure.
  - Incision is made through the skin and the volar carpal ligament is divided sharply to enter Guyon's canal.
    - Proximally, the antebrachial fascia is divided sharply, further exposing the ulnar neurovascular bundle.
  - The ulnar artery will be identified on the radial side of the nerve, and is carefully freed from all surrounding structures.
  - Identify the diseased area of the ulnar artery (▶ Fig. 56.2).

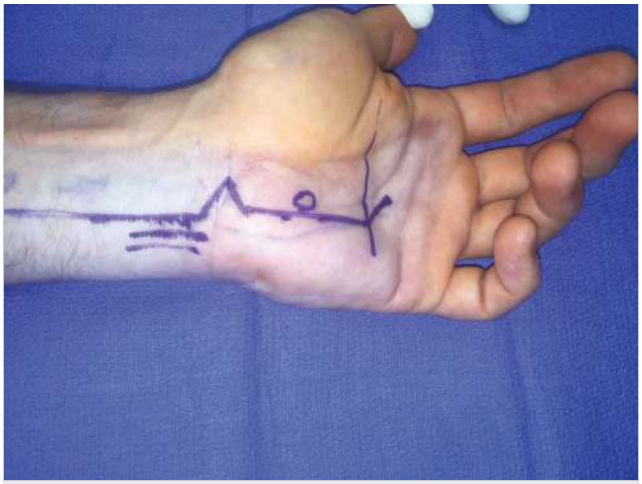

Fig. 56.1 Preoperative markings for exposure of the ulnar neurovascular bundle. Courtesy of Dr. Grant Thomson, Professor of Surgery at Yale Plastic Surgery in New Haven, CT.

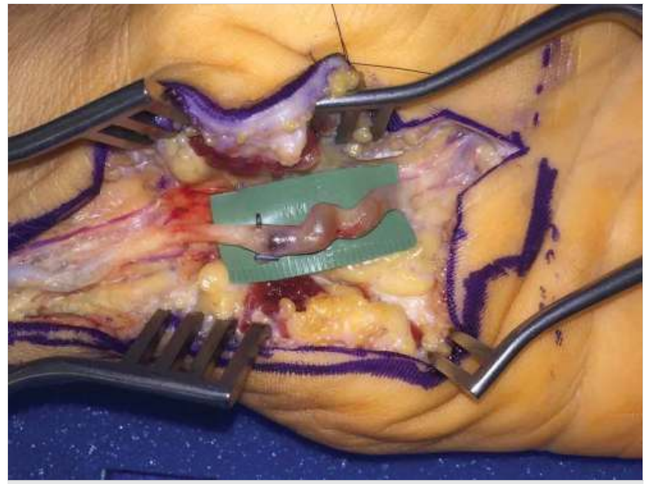

Fig. 56.2 Isolation of the ulnar artery with visualization of the thrombosed segment. Courtesy of Dr. Grant Thomson, Professor of Surgery at Yale Plastic Surgery in New Haven, CT.

    - If an aneurysm is identified, clear the surrounding tissues and use micro-dissecting scissors to clearly identify the point at which the aneurysm emanates from the ulnar artery.
    - If an area of thrombosis is identified, clear the surrounding tissues and identify nondiseased areas both proximal and distal to the area of thrombosis.
    - The pattern of thrombosis is best visualized on imaging studies.
    - Although the injury generally starts in the palm, the thrombus may propagate proximally and distally. The vessel may thrombose distally to the level of the palmar arch, where the common digital artery to the fourth webspace branches.[11]
- Resection of the diseased segment:
  - After normal areas of the artery are identified proximal and distal to the diseased segment, the diseased segment is excised sharply.
  - The proximal and distal lumen must be inspected to ensure a healthy intima without evidence of thrombus or vessel wall damage.
    - There is often a need for continued resection until normal, disease-free artery is encountered, which may leave a large gap.
  - To confirm the adequacy of resection, a “spurt test” is performed.
    - Single vascular clamps are placed on the proximal and distal cut ends.
    - The tourniquet is released, and each clamp is temporarily released to confirm adequacy of flow through the cut ends.
  - The gap between the cut ends is measured.
  - After resection of the diseased segment, a decision must be made as to the method treatment.
    - Some authors advocate for simple ligation of the ulnar artery, but studies have demonstrated superior outcomes with reconstruction.[12,13]
    - If the area of resected artery is small, it may be possible to perform a direct end-to-end anastomosis; however, this is generally less likely than the need to perform arterial reconstruction.
    - There should not be undue tension on the anastomosis in an attempt to facilitate direct coaptation as this will potentiate occlusion of the anastomosis.
- Reconstruction of the ulnar artery—choice of bypass graft:
  - When reconstructing the ulnar artery, the surgeon has the choice between an interpositional reversed vein graft or an interpositional arterial graft.
    - Arterial grafts may have superior patency rates than interpositional vein grafts.[14,15,16]
    - However, these studies may suffer from selection bias and are underpowered as compared to the studies performed on vein grafting.[14]
    - Regardless of which option is chosen, attention to technical detail will allow either technique to achieve high patency rates.
  - When choosing an interpositional vein graft, one may choose between those located locally (basilic or cephalic veins) versus those located at a distance (saphenous vein graft).
- Reconstruction of the ulnar artery—harvest of greater saphenous vein (GSV):
  - In this instance, the GSV is identified along its course on the anterior surface of the medial malleolus.
  - A multitude of small 2 to 3 cm skip incisions are made along the course of the GSV until the desired length is obtained.
  - The GSV is freed from surrounding tissues and all small branches are ligated.
  - In order to accommodate reconstruction of the common digital artery to the fourth webspace, a branch of the GSV is identified proximally and preserved to create a branched vein graft.
  - The proximal and distal ends of the GSV are uniquely marked, as is the “top side” of the vein.

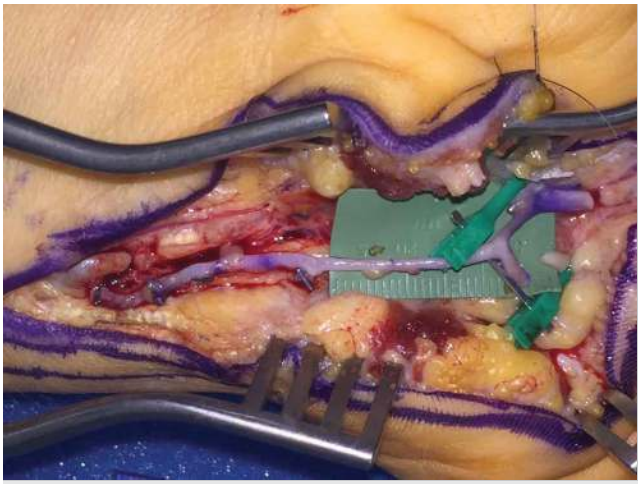

Fig. 56.3 Reversed greater saphenous vein graft is placed in preparation for microsurgical anastomosis. Note the sizable gap between proximal ulnar artery and the distal palmar arch and the distal common digital artery to the fourth webspace—sequential portions of proximal and distal artery were resected due to the continued presence of damaged intima. When obtaining a vein graft, the surgeon must be cognizant of the need to harvest a branched vein to prevent an unnecessary end-to-side anastomosis of the common digital artery into the reconstructed palmar arch. Courtesy of Dr. Grant Thomson, Professor of Surgery at Yale Plastic Surgery in New Haven, CT.

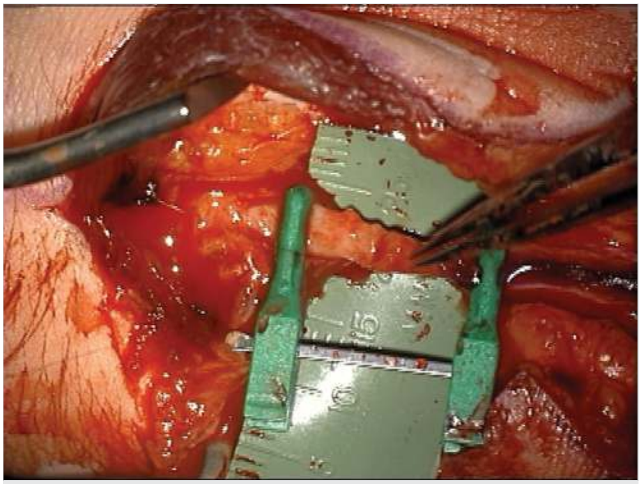

Fig. 56.4 Double approximating clamps are placed to facilitate microsurgical anastomosis. Courtesy of Dr. Grant Thomson, Professor of Surgery at Yale Plastic Surgery in New Haven, CT

- ◦ The GSV is cut, irrigated with heparinized saline to confirm patency, reversed, and brought to the hand (▶ Fig. 56.3).
  - – Vein graft reversal is necessary to prevent impedance of flow by valves; this does not need to be done for an arterial graft.
- Reconstruction of the ulnar artery—microsurgery:
  - ◦ Meticulous technique must be respected in order to preserve patency of the anastomosis.
  - ◦ The proximal cut end of the ulnar artery is irrigated with heparinized saline as is the now proximal end of the GSV.

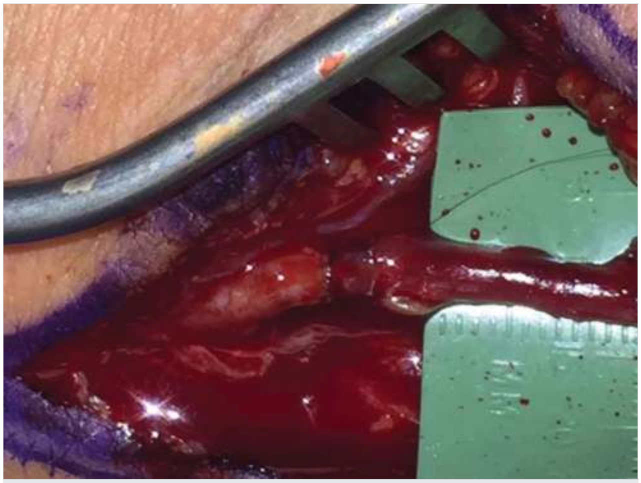

Fig. 56.5 Completion of the proximal anastomosis. Courtesy of Dr. Grant Thomson, Professor of Surgery at Yale Plastic Surgery in New Haven, CT.

  - ◦ A double approximating vascular clamp is placed to bring the two cut ends into close proximity, ensuring that the "top side" of the GSV is visualized anteriorly.
  - ◦ The microsurgical anastomosis is performed using 8–0 nylon sutures:
    - – Two sutures are initially placed 180 degrees from each other in an interrupted fashion.
    - – The double approximating vascular clamp is then flipped 180 degrees in order to access the "back wall" of the vessel (▶ Fig. 56.4).
    - – The back walls of the vessels are then sutured using the de-crescendo spiral technique.[17]
    - – A running suture with multiple loops is placed, with each loop smaller than the previous.
    - – Each individual loop is then cut, and the respective suture is subsequently tied individually.
    - – This technique helps to avoid the placement of a blind suture in a narrow opening between two already tied sutures.
    - – The double approximating vascular clamp is then returned to its original position and the front wall is sutured using the de-crescendo spiral technique.
  - ◦ After completion of the anastomosis, the proximal vascular clamp is released to confirm patency of the anastomosis and to allow any kinks in the GSV to "untwist" (▶ Fig. 56.5).
  - ◦ The GSV is then clamped and the distal anastomoses to the superficial palmar arch (and in this case, the branch to the fourth webspace) are completed in a similar fashion (▶ Fig. 56.6).
  - ◦ All clamps are released to confirm patency of the anastomoses (▶ Fig. 56.7).
- Closure and wound management:
  - ◦ Prior to closure, capillary refill and Doppler signals are checked in the ulnar sided digits and compared to preoperative recordings.
  - ◦ All wounds are irrigated with normal saline.
  - ◦ The lower extremity incisions are closed in a multilayered fashion.

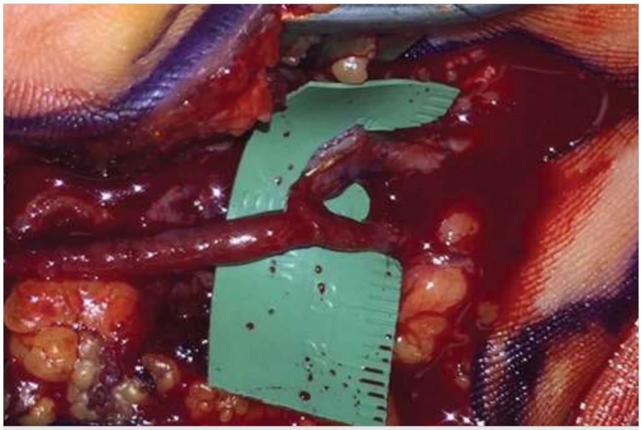

Fig. 56.6 Completion of the distal anastomoses. Courtesy of Dr. Grant Thomson, Professor of Surgery at Yale Plastic Surgery in New Haven, CT.

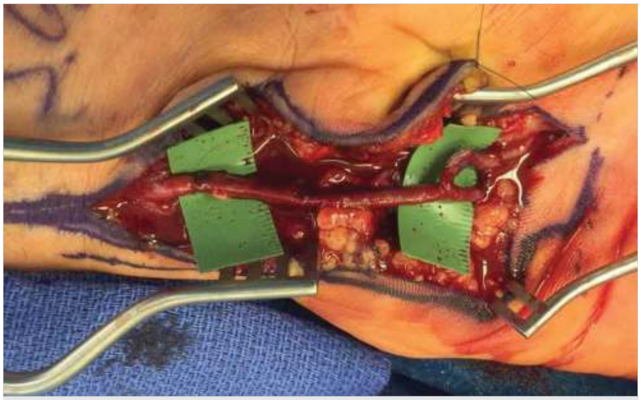

Fig. 56.7 Intraoperative view of the completed reconstruction. Courtesy of Dr. Grant Thomson, Professor of Surgery at Yale Plastic Surgery in New Haven, CT.

  - The upper extremity incisions are closed in a single-layered fashion using 5–0 nylon sutures.
  - Upper extremity incisions are dressed with bacitracin, xeroform, and gauze while taking care to avoid any compressive dressings.
  - The upper extremity is placed in a loose-fitting short-arm volar splint to protect the arterial reconstruction.
  - The patient is administered 81 mg of aspirin postoperatively for 30 days.

56.4 Conclusion

Revascularization of the upper extremity is guided by a number of broad principles, and is well exemplified by reconstruction of the thrombosed or aneurysmal ulnar artery. To achieve a successful outcome, whether for this disease state or others, a few clinical pearls are necessarily identified:

- Zone of injury:
  - When reconstructing arteries in the upper extremity, regardless of whether for digital replantation or vascular disease, the cut ends of the artery must be disease free—an attempt to circumvent interpositional grafting by anastomosing vessels with diseased or damaged intima will likely lead to thrombosis.
- Tensionless anastomosis:
  - An attempt to circumvent interpositional grafting by anastomosing vessels under undue tension will likely lead to complications.
- Attention to meticulous microsurgical technique:
  - The vessels must be handled with the utmost of care, being mindful not to damage the intimal layer.
  - An accurate coaptation without adventitial intrusion must be performed.
  - Interpositional vein grafts must be selected with respect to both size and length to minimize the chance for eddy currents, stenosis, and thrombosis.
    - Graft diameter should match the diameter of recipient vessels as closely as possible; if not, various techniques can be used on either vessel to create a closer match.
    - Grafts should be long enough to prevent tension at the anastomotic sites, but not so long that kinks are created.
- Avoidance of constrictive dressings:
  - The extremity will swell postoperatively; if dressings do not accommodate for this fact, complications more serious than occlusion of the arterial reconstruction may arise.

When these principles of reconstruction are considered, one can expect excellent outcomes in a wide variety of pathologic states.

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57 Rheumatoid Hand

Jessica Billig, Paymon Rahgozar, and Kevin C. Chung

Abstract
Rheumatoid arthritis (RA) is an autoimmune disorder that obliterates joint spaces and damages surrounding soft tissue. Ligamentous laxity and joint destruction cause pain and functional deficits. This chapter will present anatomy of the rheumatoid hand and three effective operative techniques to correct common abnormalities. Rheumatoid hand surgery is not simply a surgical exercise, but requires a holistic view of the disease by considering an individual patient's needs. Although deformity alone is not an indication to operate, appropriately selected patients with pain and functional limitations may benefit from surgical intervention.

The characteristic pathology of RA is an infiltrative synovitis, leading to articular destruction, joint subluxation, fixed finger deformities, and tendon ruptures. Frequently, the metacarpophalangeal joints (MCPJs) of the digits and thumb are affected. In early and flexible digital MCPJ destruction, treatment includes crossed intrinsic transfer and synovectomy. However, soft tissue reconstruction is inadequate in chronic or fixed MCPJ deformities, and management requires silicone arthroplasty. MCPJ hyperextension and interphalangeal joint (IPJ) flexion of the rheumatoid thumb produces boutonniere deformity, which is treated by MCPJ arthrodesis. Successful arthrodesis rests on good bony abutment through removal of synovitis, articular cartilage, and osteophytes. Finally, tendon rupture is common in the RA patient. Treatment is two-fold by applying tendon transfers to restore function and synovectomy in conjunction with bone resection to prevent recurrent rupture.

Adequate treatment of the rheumatoid hand requires a patient-centered focus to provide individualized treatment. Surgery aims to alleviate pain, improve function, and prevent disease progression. Hand surgeons must master the indications and techniques of silicone arthroplasty, thumb arthrodesis, and tendon transfers.

Keywords: metacarpophalangeal joint arthrodesis, metacarpophalangeal joint silicone arthroplasty, rheumatoid arthritis, tendon transfers

57.1 Rheumatoid Hand

57.1.1 Introduction

Rheumatoid arthritis (RA) is a polyarticular inflammatory arthritis produced by a T-cell mediated autoimmune response. An inflammatory synovial pannus develops, leading to cartilage erosion, attenuation of ligaments, and articular destruction. Joint deformities may cause pain and functional limitations, hindering the ability to perform activities of daily living. However, not all patients with severe deformities are symptomatic.

Before disease-modifying drugs were available, arthroplasty and arthrodesis were the primary treatments for RA. Arthrodesis creates a fixed and stable joint but limits the arc of motion. However, owing to the progressive nature of RA, patients often required multiple fusions that restricted motion and impaired function.[1,2] Currently, treatment focuses on a combined medical and surgical approach. This chapter will describe three common rheumatoid hand procedures: silicone arthroplasty, thumb arthrodesis, and tendon transfers.

57.2 Digits

57.2.1 Indications

Volar subluxation and ulnar deviation of the digits characterize the typical deformities of the metacarpophalangeal joint (MCPJ) in RA. Synovitis infiltrates and stretches the joint capsule and ligamentous support structures causing a flexible deformity. In advanced cases, the extensor tendon can rupture near its insertion at the proximal phalanx, weakening the collateral ligaments and exacerbating volar subluxation of the proximal phalanx.[3] Chronic subluxation results in contracture of the ulnar lateral band, leading to a fixed deformity.

The characteristic finger pathology in RA includes boutonniere (▶ Fig. 57.1) and swan-neck deformities (▶ Fig. 57.2). Boutonniere deformity arises from synovitis of the proximal interphalangeal joint (PIPJ) in the digits and the interphalangeal joint (IPJ) in the thumb. Synovitis stretches the extensor mechanism and forces the lateral bands to sublux volarly while the retinacular ligaments shorten. Swan-neck deformity can arise from multiple joints. Volar plate laxity and extensor tendon weakening cause PIPJ hyperextension. Simultaneously, rupture of the extensor apparatus, intrinsic weakness, and dorsal translation of conjoint tendons produce distal interphalangeal joint (DIPJ) flexion (▶ Table 57.1).

When managing the RA patient, surgeons must examine the entire extremity, including the wrist. Priority of reconstruction should proceed in a proximal to distal fashion. Surgeons should

Fig. 57.1 Boutonniere deformity with flexion of metacarpophalangeal joint and hyperextension of interphalangeal joint.

Fig. 57.2 Swan-neck deformity with hyperextension of proximal interphalangeal joint and flexion of metacarpophalangeal joint and distal interphalangeal joint.

Table 57.1 Pathophysiology of swan-neck deformity

Involved structure	Order of aberrations
DIPJ	1. Rupture of terminal tendon of extensor apparatus leading to mallet deformity 2. Volar plate laxity and extensor inequity 3. PIPJ hyperextension
PIPJ	1. Volar plate laxity 2. PIPJ hyperextension 3. Conjoint tendons relax and translate dorsally 3. DIPJ flexion
MCPJ	1. Extensor weakening at proximal phalanx 2. PIPJ hyperextension 3. Attenuation of volar plate and MCPJ subluxation 4. Intrinsic tightness

Abbreviations: DIPJ, distal interphalangeal joint; MCPJ, metacarpophalangeal joint; PIPJ, proximal interphalangeal joint.

address elbow pathology, followed by the wrist, and then the hand. Dorsal subluxation of the ulna at the wrist, caused by destruction of ulnar carpal ligamentous structures, leads to the caput ulna syndrome. Dorsal subluxation is a common usage, but it is understood that the ulna is the fixed unit of the forearm that does not sublux. Rather the radius subluxes volarly, which gives the appearance of relative ulna subluxation. Owing to the unopposed pull of the radial wrist extensors, the caput ulna syndrome causes radial deviation of the metacarpals and ulnar subluxation of the digits at the MCPJ. Therefore, to minimize recurrence of MCPJ ulnar subluxation, wrist pathology should be addressed before treating the MCPJ.

57.2.2 Operative Technique

Silicone Arthroplasty

The degree of joint space destruction and length of time the deformity has been present determine the appropriate treatment of the MCPJ. Flexible deformities are treated with soft tissue reconstruction via crossed intrinsic transfers, whereas fixed deformities are treated with silicone arthroplasty (▶ Table 57.2). Arthrodesis of the MCPJ of the digits severely restricts arc of motion and limits function. However, fusion is commonly performed for the thumb MCPJ, which will be discussed later in this chapter.

Table 57.2 Metacarpophalangeal joint treatment of the digits

Passively correctable	Indications	Treatment
Yes	1. Ulnar deviation of the digits, passively correctable 2. Ulnar subluxation of extensor tendons 3. No arthritis	Crossed intrinsic transfer and synovectomy
No	1. Ulnar subluxation or dislocated digits 2. Not passively correctable 3. Chronic subluxation with soft tissue contraction	Silicone arthroplasty

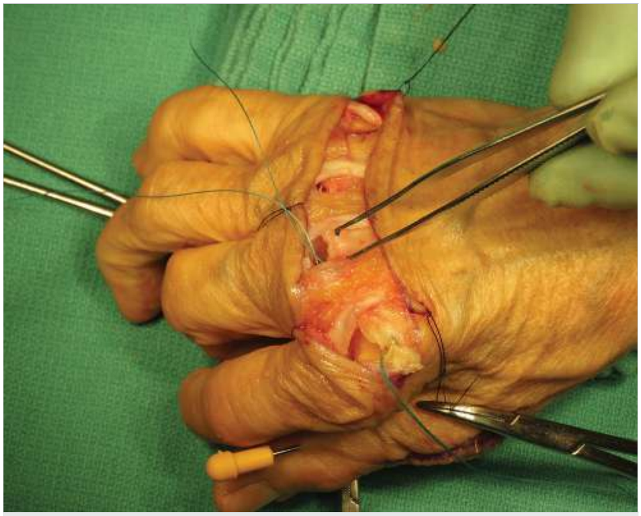

Fig. 57.3 Radial collateral ligament tagged for future reconstruction.

Silicone arthroplasty is the most effective method to treat chronic digital MCPJ destruction in RA. By amplifying arc of motion at the MCPJ, centralizing the digit, and improving extensor lag, silicone arthroplasty reduces pain and improves function.[4] It is important to preserve the radial collateral ligament for reconstruction after placement of the implant (▶ Fig. 57.3) and to select the appropriate size implant (▶ Fig. 57.4).

Thumb Metacarpophalangeal Joint Arthrodesis

Thumb deformities in RA can cause severe disability. In the rheumatoid thumb, grasp and pinch are compromised by impaired thumb abduction and opposition. Ligamentous laxity leads to malalignment of the joint via tendon subluxation and rupture, leading to boutonniere and swan-neck deformities. Treatment is guided by the underlying disease state and the Nalebuff classification (▶ Table 57.3).[5] In the active, high-demand patient, arthrodesis provides long-lasting functional results.[6] Unlike the digits, thumb MCPJ arthrodesis does not impair function because the thumb carpometacarpal joint preserves opposition through its many degrees of freedom.

The goal of arthrodesis is to improve pinch and opposition and alleviate pain. Routinely, the angle of fusion is discussed with the

Fig. 57.4 Silicone arthroplasty placed into joint space.

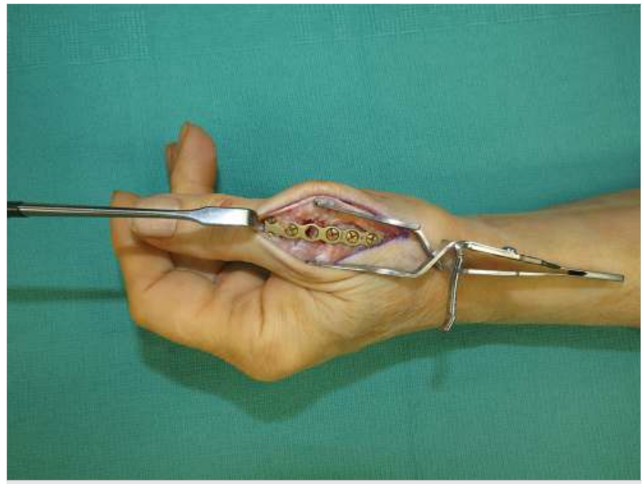

Fig. 57.5 Mini-plate used for arthrodesis.

Table 57.3 Modified Nalebuff classification for rheumatoid thumb deformities

Type	Deformity	Description	Treatment
I	Boutonniere	Flexion of MCPJ and hyperextension of IPJ with passive correction	Synovectomy and EPL rerouting or arthrodesis
II	Boutonniere	Similar to type 1 with CMC joint involvement, no passive correction	Arthrodesis or arthroplasty
III	Swan-neck	MCPJ hyperextension, flexion of IPJ, adduction of metacarpal, CMC dislocation	Arthrodesis of MCPJ and arthroplasty with LRTI for CMC joint
IV	Gamekeeper	Radial deviation of MCPJ due to UCL erosion	Synovectomy with UCL reconstruction
V	Swan-neck	Similar to type III Due to volar plate laxity of MCPJ leading to hyperextension and flexion of IPJ	Arthrodesis or capsulodesis

Abbreviations: CMC, carpometacarpal; EPL, extensor pollicis longus; IPJ, interphalangeal joint; LRTI: ligament reconstruction tendon interposition; MCPJ, metacarpophalangeal joint; UCL, ulnar collateral ligament.

patient preoperatively to customize the treatment to each individual patient. Commonly, the MCPJ is fused in 15 to 20 degrees of flexion, 20 degrees of pronation, and 5 degrees of abduction.[6] Successful arthrodesis relies on adequate debridement of synovitis, removal of articular cartilage, and appropriate abutment of bony edges. Although there are many ways to perform arthrodesis, the common principle is preservation of bone stock and length to facilitate optimal pinch postoperatively. By maintaining length, the thumb can oppose to the ring or small finger. Good bone stock will permit bony union and favorable fusion. Arthrodesis can be performed with mini-plates (▶ Fig. 57.5), interfragmentary screw fixation, tension band wiring, or Kirschner wiring, depending on the surgeon's preference. The main disadvantages of arthrodesis are loss of mobility at the fused joint and increased stress placed on surrounding joints, which may induce disease progression in those joints. Surgeons must appreciate the individual patient's wishes, the patient's activity level, and the pathophysiology of RA when determining the best treatment.

57.3 Tendons

57.3.1 Indications

Tendon rupture in the RA patient is common, resulting from direct synovial infiltration of the tendons and from mechanical irritation of bony prominences. Extensor tendons are affected more often than flexor tendons. Tendon ruptures are not an absolute indication for operative intervention because many RA patients may be completely asymptomatic. The patient's specific complaints and examination should direct treatment.

57.3.2 Operative Technique

Tendon Transfer

Tendon rupture is caused by tendon ischemia from infiltrative synovitis or from mechanical irritation by bony erosions. Possible physical examination findings include sudden loss of digit or thumb flexion or extension. However, patients may preserve some finger extension because of an intact juncturae tendinum. In these cases, the tenodesis effect will not be maintained. Rupture of the small finger extensor is most common with tendon ruptures progressing in an ulnar to radial direction.[3,7]

Management centers on prevention of recurrence through synovectomy and removal of bony prominences and restoration of function through tendon transfers. Tendon transfers are used because often the ruptures are not recognized and many months have passed before a decision is made to reconstruct the lost function. By then, the muscle from the ruptured tendon will retract, leading to contracture. Therefore, transferring a

Fig. 57.6 Extensor digiti quinti to extensor digitorum communis of the ring finger tendon transfer in an end-to-side fashion.

normal expendable tendon unit can restore movement more efficiently. Surgeons should select expendable donor tendons to prevent loss of function at the donor site. Treatment of common tendon ruptures is shown in ▶ Table 57.4.

The exact operative technique depends on the tendon that is ruptured. However, there are unifying fundamentals for all tendon transfers.[8] Principles for successful tendon transfer include placement of the retinaculum under the transferred tendon to shield it from the eroded wrist, complete synovectomy, bony resection, and setting appropriate tension of the repair. Placement of the retinaculum under the tendon transfer protects the repair and helps avoid recurrent rupture. Setting appropriate tension of the tendon transfer avoids postoperative tendon laxity and ensures the best functional outcome. For example, to treat a small finger extensor rupture, the distal end of the ruptured tendon is suture weaved into the extensor digitorum communis of the ring finger with a Pulvertaft tendon weaver in an end-to-side fashion (▶ Fig. 57.6). The tension is set with the wrist slightly flexed. Intraoperative wrist tenodesis can confirm correct tension.

Table 57.4 Treatment of ruptured tendons

Ruptured tendons	Treatment
EDQ	EDQ to EDC of RF end-to-side
EDQ and EDC to SF and RF	EIP to EDC of RF and SF (or EDQ)
EDQ and EDC to SF/RF/MF	1. EIP to EDC of RF and SF (or EDQ) 2. EDC of MF to EDC of RF end-to-side
EDQ and EDC to SF/RF/MF/IF and EIP	1. FDS RF to EDC of RF and SF (or EDQ) 2. FDS MF to EDC of IF and MF
EPL	EIP to EPL
FPL	BR to FPL
FDS	No transfer; synovectomy to prevent additional rupture
FDP and FDS	Flexor tendon reconstruction

Abbreviations: BR, brachioradialis; EDC, extensor digitorum communis; EDQ, extensor digiti quinti; EIP, extensor indicis proprius; EPL, extensor pollicis longus; FPL, flexor pollicis longus; IF, index finger; MF, middle finger; RF, ring finger; SF, small finger.

57.4 Conclusion

RA consists of a progressive and destructive disease process that affects soft tissue and bone. Patients may present with considerable hand deformities. However, not all deformities cause pain and loss of function. Therefore, hand surgeons must consider the patient's concerns and provide tailor treatment for each individual patient. The approach to the rheumatoid patient is not a one-size-fits-all model. Each patient is unique with different goals of treatment. The aims of rheumatoid hand surgery include providing pain relief, enhancing function, and preventing disease progression.

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58 Articular Surgery for the Scleroderma Hand: Arthrodesis and Arthroplasty

Erez Dayan and Charles P. Melone Jr.

Abstract

Classic features of systemic scleroderma are disabling and disfiguring proximal interphalangeal (PIP) and metacarpophalangeal (MCP) joint contractures of the hands. Although surgical correction has often been recommended, seldom has it been employed due to concerns for devitalized wound and compromised healing capacity inherent in the disease process. Nonetheless, despite characteristically ischemic and precarious wound conditions, carefully planned and executed arthrodesis and arthroplasty can prove considerably beneficial to medically stable patients with systemic scleroderma. In the authors' experience, techniques of PIP arthrodesis based on dorsal cutaneous arterial (DCA) network and MCP silicone arthroplasty perfused by the dorsal metacarpal collateral artery (DMCA) plexus have consistently demonstrated uncomplicated wound healing and considerably improved function.

Keywords: arthrodesis, arthroplasty, arthropathy, diffuse cutaneous systemic sclerosis, scleroderma, systemic sclerosis

58.1 Introduction

Systemic scleroderma is a disabling autoimmune disease characterized by an intrinsic fibro-occlusive vascular disorder resulting in extensive tissue ischemia and sclerosis that typically afflict the hands. Raynaud's vasospastic syndrome, invariably associated with the disease, further contributes to the vascular disturbance. In its most frequent and debilitating form, termed diffuse systemic scleroderma (dSSc), classic features are progressively severe proximal interphalangeal (PIP) joint and metacarpophalangeal (MCP) joint contractures, apt to be the major source of painful dysfunction (▶ Fig. 58.1).

Fig. 58.1 Scleroderma hand deformity classically involves extension contractures of the metacarpophalangeal (MCP) joints and flexion contractures of the proximal interphalangeal joints with vascular compromise of adjacent soft tissues.

Although articular reconstruction is generally recommended for these deformities, surgical techniques are infrequently reported and the literature provides minimal guidance for optimal soft tissue and skeletal management. This chapter describes our experience with specific techniques designed to preserve wound vascularity, promote uncomplicated wound healing, and enhance outcomes for PIP and MCP articular reconstruction.

58.2 Indications

For patients with this high-risk diffuse disease process, only those in optimal medical condition are considered for articular surgery. Elective surgery for poorly managed patients with deteriorating health is prone to failure and ill advised. Progressive flexion contracture of the PIP joint, often associated with painful and infected dorsal ulceration, is the hallmark deformity of scleroderma, and the principal indication for reconstructive surgery. The PIP flexion contracture often exceeds 90 degrees, creating excessive tension with severe ischemia of the overlaying dorsal soft tissue that results in a predictable sequence of attenuation, atrophy, and painful ulceration. Previously the deformed PIP joints have been managed by a variety of techniques, including capsulotomy[1], implant arthroplasty,[1] and arthrodesis.[1,2,3,4,5,6,7,8] Because of the deficient, sclerotic soft tissues, and insufficient bone stock, attempts to preserve PIP joint mobility are prone to failure and thus a consensus exists that arthrodesis is the optimal treatment for the dysfunctional PIP joint.[2,3,4,6,7,8,9] The PIP arthrodesis performed by the authors employs specific flap designs for unobstructed exposure, preservation of wound vascularity, and tension-free closure, and is based on consistent proximal and distal dorsal cutaneous arterial branches (DCAB) of the radial and ulnar proper digital arteries (▶ Fig. 58.2).[10] Consistently high fusion rates resulting in a more extended joint posture markedly improve digital function and alleviate dorsal soft tissue tension with its painful ulceration. Moreover, once solid fusion has occurred, the reconstructed joint is relatively protected from osteolysis, secondary infection, pathological fracture, or other detrimental effects of this progressive disease.

MCP joint contractures, usually fixed in hyperextension but occasionally in flexion, are also typical of progressive dSSc, and severely limit both grasping and releasing functions of the hand. In an attempt to improve both functional posture and mobility of the MCP joints, and since soft tissue and skeletal structures are more substantive at this level, the senior author has exclusively employed silicone implant arthroplasty for these deformities. This method has consistently corrected the deformities, alleviated pain, and restored functional mobility of the MCP joints. The characteristic presence of sclerotic collateral soft tissues and the typical absence of recurrent synovitis seemingly enhance both stability and durability of the implants.

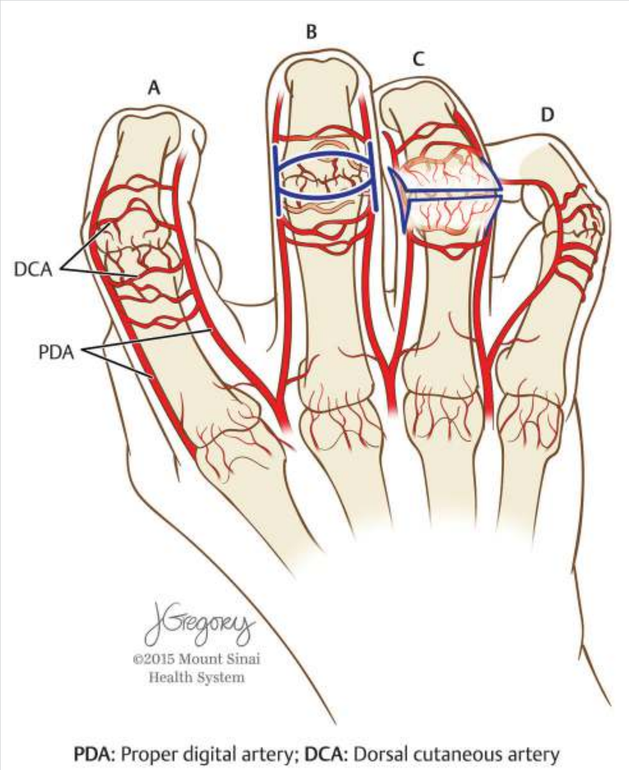

Fig. 58.2 Flap design for proximal interphalangeal (PIP) arthrodesis with apposing dorsal pedicles based on the consistent proximal and distal dorsal cutaneous arterial branches of the radial and ulnar proper digital arteries. Judicious flap elevation provides thorough joint exposure and preserves the delicate cutaneous vasculature. Printed with permission from ©Mount Sinai Health System.

Fig. 58.3 Markings for elliptical excision of devitalized soft tissues and for the apposing bipedicle advancement flaps to expose and resurface the affected proximal interphalangeal (PIP) joints.

58.3 Operative Techniques

For all cases of articular surgery, basic tenants for success are:

Tourniquet control with a bloodless field; balanced regional anesthesia with its vasodilatory effect and its avoidance of intubation; a warm operating environment to limit Raynaud's syndrome; and a tension-free wound closure.

58.3.1 PIP Arthrodesis

The dorsal soft tissues over the contracted PIP joint are commonly attenuated and ulcerated. This devitalized soft tissue is carefully delineated and excised in a transverse elliptical fashion. For thorough joint exposure, opposing dorsal bipedicle flaps are designed in an H-shaped configuration with the central transverse limb directly over the joint and bilateral vertical limbs extending axially along the radial and ulnar aspects of the joint from the proximal phalanx to the middle phalanx. This design creates two pedicles, each with a 2:0.5–1 width to length ratio that facilitates wide exposure with minimal flap undermining, ease of flap advancement, tension-free closure, and preservation of the proximal and distal dorsal cutaneous arterial vasculature (▶ Fig. 58.3). In contrast to the other types of incisions, this DCAB based bipedicle flap has been designed specifically for exposure and coverage of the reconstructed PIP joints in scleroderma. The symmetrical vascularity of the dual pedicles has proved consistently sufficient to offset the characteristic digital ischemia and promote uncomplicated soft tissue healing. For patients afflicted with the inherent vascular deficiency of scleroderma, the dorsal bipedicle flap has provided a reliable method of exposing and resurfacing the devitalized arthrodesis site.

Elevation of the dorsal flaps invariably reveals severe soft tissue fibrosis with an atrophied extensor mechanism firmly adherent to the underlying bone. The joint is characterized by deformation and subluxation of contiguous articular surfaces. The phalangeal head at the proximal aspect of the joint demonstrates resorption and displacement into a prominent dorsal position whereas the adjacent base of the middle phalanx is abnormally flat, wide, and displaced volarly and proximally into a position of hyperflexion (▶ Fig. 58.4). This continuous joint flexion contracture contributes to progressive bony deformity, resorption, and loss of subchondral cancellous bone. Notably, and in contrast to other arthropathies (i.e., rheumatoid arthritis), these cases of advanced joint destruction do not have synovitis as a prominent finding.

Correction of the deformity requires excision of the phalangeal head as well as adjacent and severely contracted collateral ligaments. Judicious skeletal shortening preserves the critical subchondral cancellous bone and permits precise coaptation of the cancellous surfaces at the fusion site, while alleviating tension on the dorsal skin (▶ Fig. 58.5). Position of the fusion is determined by assessing the functional requirements of individual digits, the pre-existing deformity, and the extent of critical cancellous bone.

In order to prevent excessive volar tension and serious vascular compromise overcorrection of the flexion deformity is avoided by joint positioning in functionally and cosmetically improved flexion postures of 40 to 50 degrees.

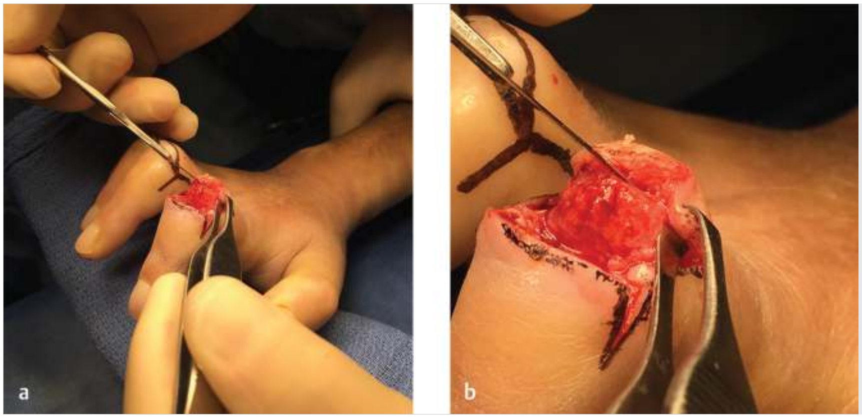

Fig. 58.4 (a, b) Elevation of advancement flaps for access to proximal interphalangeal (PIP) joint, bony shortening, correction of deformity, and preparation of cancellous fusion site.

Fig. 58.5 Proximal interphalangeal (PIP) arthrodeses secured with minimally invasive K-wire fixation demonstrating improved joint position with tension-free flap closures.

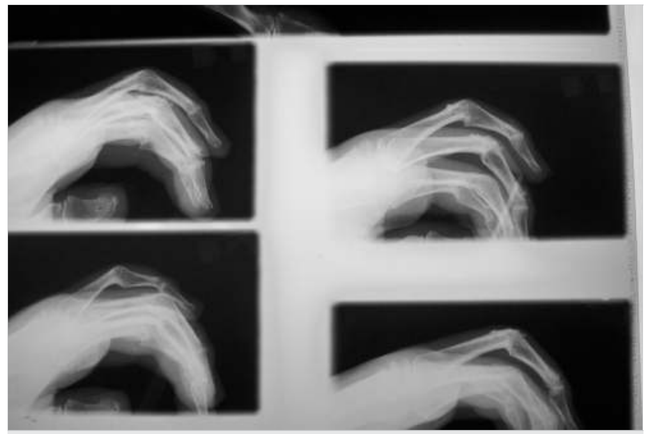

Fig. 58.6 Radiographic evidence of solid proximal interphalangeal (PIP) joint arthrodesis 8 weeks postoperatively.

In the early phase of the senior author's practice, arthrodeses were secured by a combination of intraosseous and K-wires. However, with increasing experience, the use of percutaneous K-wires alone proved a consistently reliable method of secure fixation. This allows for rapid and accurate insertion with minimal trauma, firm stabilization, and easy removal. Fine crossed K-wires are now the preferred method of fixation.[2] Postoperative wound care with continuous splinting is utilized until radiographic documentation of solid fusion is evident (▶ Fig. 58.6).

58.3.2 PIP Joint Arthrodesis Outcomes

In a review of over 100 PIP arthrodesis for scleroderma, our follow-up evaluation typically revealed uncomplicated primary wound healing and consistent radiographic union of the arthrodesis within 8 weeks of surgery. Patients also demonstrated complete eradication of painful ulcers, substantial functional and aesthetic improvement, and high levels of satisfaction.

58.3.3 MCP Implant Arthroplasty

For those hands requiring both PIP and MCP reconstruction, the PIP joints are fused in positions of improved function as a first stage, and MCP joints are reconstructed by silicone arthroplasties as a second stage. The destroyed MCP joints are characterized by excessive extension or fixed flexion with narrowed joint spaces and flattened as well as eburnated cartilaginous surfaces. Similar to the PIP joints and in contrast to other arthropathies, erosive changes are minimal and proliferative synovitis is not encountered.[2,11,12,13,14]

In each case of MCP arthroplasty a transverse incision just proximal to the metacarpal heads is used with minimal soft tissue reflection and preservation of the critical dorsal vasculature (▶ Fig. 58.7). The transverse incision is well vascularized by the DMA network and provides exposure of all four joints simultaneously. In contrast to MCP arthroplasty for other conditions, no attempt is made to preserve or reconstruct the collateral ligaments; rather, a wide resection of the metacarpal head and condyles, including the collateral ligaments, corrects the deformity and achieves relative lengthening of the chronically contracted extensor and flexor tendons. This wide resection achieves sufficient bony shortening to reconstruct a sizeable joint space for implant insertion for restoration of functional tendon excursion and joint mobility. This skeletal resection also facilitates a tension-free primary wound closure.

Arthroplasties are managed by early and intensive therapy initiated on postoperative day 3 to 4 (▶ Fig. 58.8). The program begins with active motion and dynamic extension splinting followed by passive flexion cuffs until implant encapsulation is complete and maximum mobility achieved, a period usually encompassing 4 to 6 months.

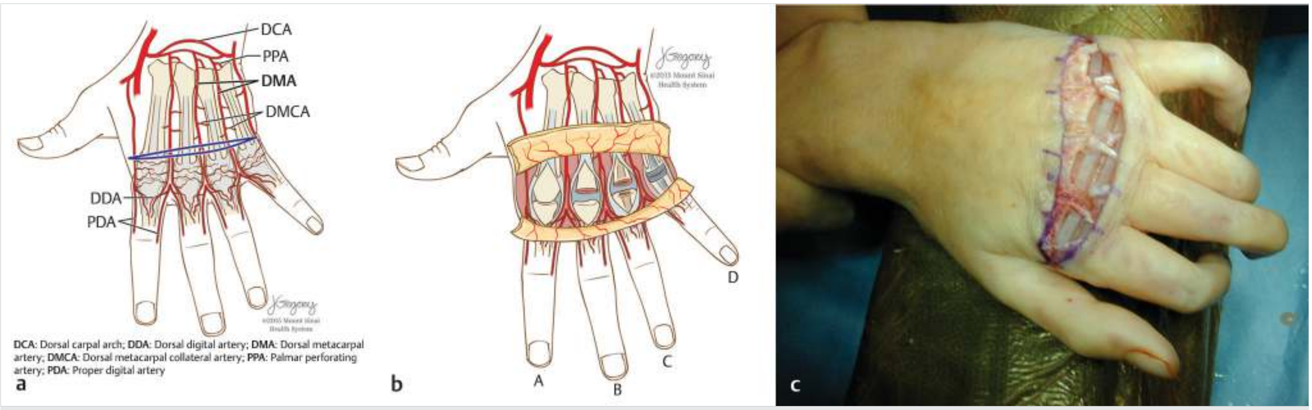

Fig. 58.7 (a, b) The transverse dorsal incision, well perfused by the dorsal metacarpal arterial system, affords wide exposure for implant arthroplasty of all four metacarpophalangeal (MCP) joints simultaneously. Printed with permission from ©Mount Sinai Health System. **(c)** Correction of joint deformity and restoration of functional MCP joints with silicone implant arthroplasties. The extensor tendons are preserved and relatively lengthened for repair.

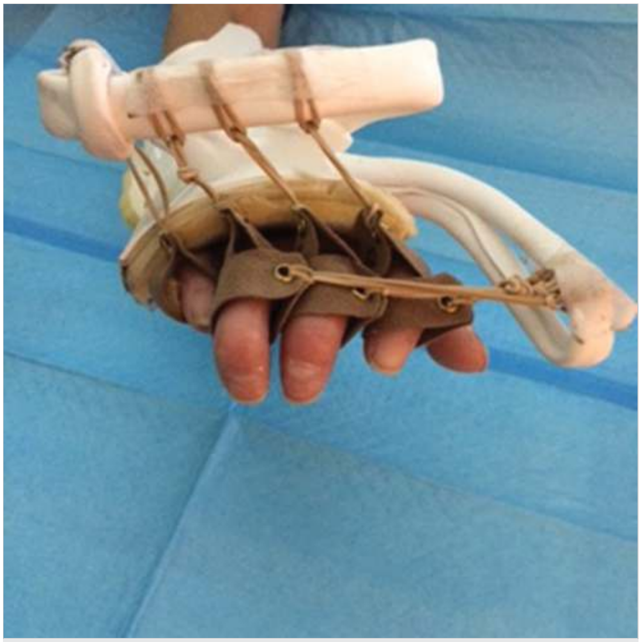

Fig. 58.8 Postoperative dynamic extension splint facilitates recovery of metacarpophalangeal (MCP) joint mobility.

58.3.4 MCP Implant Arthroplasty Outcomes

The silicone implant arthroplasties have proved highly functional, having maintained MCP joint stability and restored substantial joint mobility usually in the range of a 50-degree flexion extension arc. Moreover the implants have demonstrated durability with preservation of pain-free function and with no evidence of implant failure for as long as 10 years after insertion (▶ Fig. 58.9).

Fig. 58.9 Maintenance of well-aligned and functional metacarpophalangeal (MCP) joints with silicone implants 10 years postoperatively.

58.4 Conclusion

Scleroderma is a debilitating systemic disease that entails the classic hand deformity, including progressively severe PIP joint and MCP joint contractures. This chapter described our experience with specific techniques designed to preserve wound vascularity, promote uncomplicated wound healing, and enhance outcomes for PIP and MCP articular reconstruction.

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59 Treatment of Degenerative Arthritis of the Wrist: Arthrodesis and Arthroplasty

Steven Michael Koehler and Charles P. Melone Jr.

Abstract
Degenerative arthritis of the wrist comprises a predictable spectrum of joint disease consisting of four stages of increasing severity that typically results in the characteristic scapholunate advancement collapse (SLAC) pattern of wrist deformity. This chapter discusses distinctive features of this noninflammatory articular disorder and describes, in detail, treatment employing four-corner arthrodesis (4C), proximal row carpectomy (PRC), total wrist arthrodesis, and total wrist arthroplasty. Contingent on the stage of disease and the specific patient profile, both arthrodesis and arthroplasty have proved beneficial in surgical reconstruction of this frequent wrist derangement.

Keywords: arthrodesis, arthroplasty, four-corner, proximal row carpectomy, SLAC, SNAC, wrist arthrodesis, wrist arthroplasty, wrist arthritis, wrist fusion

59.1 Introduction

Degenerative arthritis of the wrist, as described by Watson and colleagues, demonstrates consistent patterns of articular deterioration, most frequently involving the radioscaphoid, scapholunate, and midcarpal joints.[1,2] After reviewing 4,000 radiographs of the wrist and 210 cases of degenerative arthritis of the wrist, the authors concluded that scapholunate advanced collapse clearly is the most common form of noninflammatory wrist arthritis and results from scapholunate ligament disruption with rotatory subluxation of the scaphoid, or, less commonly, from chronic scaphoid nonunion. In either case, a similar and predictable sequence of progressive articular deterioration ensues that has been categorized into the following four stages of increasing severity: Stage I demonstrates distal radioscaphoid joint arthritis; Stage II additionally involves the proximal radiocarpal joint; Stage III progresses to the proximal capitate and the midcarpal joint, but typically spares the critical radiolunate joint from cartilage damage; in contrast, Stage IV or pancarpal arthritis progresses to the radiolunate joint, thereby compromising the entire radiocarpal articulation and severely limiting the options for functional wrist reconstruction.

Effective treatment for degenerative arthritis of the wrist must be formulated with recognition of the specific stages of scapholunate advancement collapse (SLAC) wrist deformity and its predilection for progressive deterioration.

59.2 Indications

Initially, all patients are treated nonoperatively, employing various modalities for pain control including, splint immobilization, anti-inflammatory medication, and steroid injections.[3,4] However, for patients who fail nonoperative treatment, surgical options can then be considered. Different surgical options exist for the various SLAC/scaphoid nonunion advanced collapse (SNAC) stages. In stage I, wrist denervation can be considered alone for pain relief, or coupled with a partial radial styloidectomy in cases of symptomatic radioscaphoid impingement. For stage II, both proximal row carpectomy (PRC) and four-corner arthrodesis (4CA) are frequently employed and reported long-term (17 years) outcomes are similar.[5] Patients should be thoroughly counseled on each procedure's outcomes to permit appropriate informed consent. For stage III, the standard of care is a 4CA, although, as discussed below, some authors would prefer a modified PRC. Lastly, stage IV requires total wrist arthrodesis, or in carefully selected cases, total wrist arthroplasty.

59.3 Operative Technique

59.3.1 Four-Corner Arthrodesis

Introduction

4CA is a well-established and frequently employed motion-preserving procedure for scaphoid nonunion and scapholunate advanced collapse deformity of the wrist (SNAC and SLAC).[1,6,7,8] The objective of the arthrodesis is to achieve a stable and pain-free wrist while maintaining carpal alignment and preserving maximum wrist motion and grip strength.[6,9]

Indications

Classically, indications consist of functionally demanding patients with stage II SLAC/SNAC or stage III collapse deformities (▶ Fig. 59.1a).

Contraindications

Contraindications are evidence of ulnar translocation, radiolunate (RL) incongruity, or pre-existing pancarpal arthritis.

Methodology

Basic requisites for successful arthrodesis comprise precise correction of carpal malalignment, meticulous midcarpal arthrodesis site preparation, adjunctive bone grafting, and stable fixation. Bone graft, usually harvested from the iliac crest or distal radius and, less frequently, from the excised scaphoid, is essential to promote a solid arthrodesis, and a variety of reportedly secure fixation methods, including Kirschner wires (K-wires), staples, compression screws, and locking or nonlocking dorsal circular plates, have been advocated to enhance outcome.[6,9] Our technique of 4CA preferentially employs the en bloc excised native scaphoid as the principal source of bone graft coupled with minimally invasive percutaneous K-wire fixation.

Imaging

We recommend obtaining comprehensive radiographic evaluation for all patients, including high-quality frontal, lateral, and

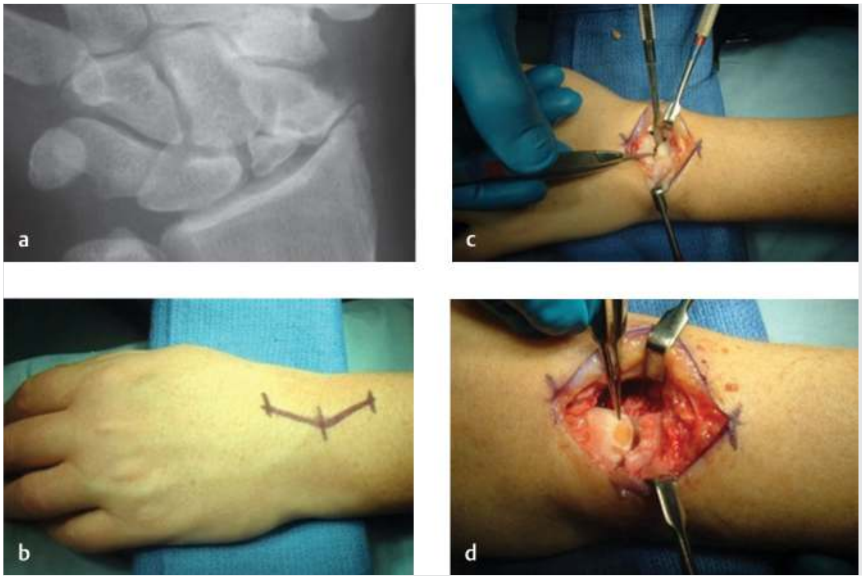

Fig. 59.1 **(a)** Posteroanterior (PA) view of the wrist demonstrating stage II scaphoid nonunion advanced collapse (SNAC). **(b)** A 4 to 5 cm dorsal incision with the apex at the scapholunate interval to approach the wrist between the third and fourth extensor compartments. **(c)** Exposure of the carpus using a Berger capsular flap. **(d)** Deformed scaphoid and eburnation of the head of the capitate, consistent with a stage III SNAC.

oblique projections supplemented with radial-ulnar deviation views.

Pearls

- En bloc excision with thorough debridement to pure cancellous bone of the scaphoid.
- Meticulous preparation of a broad open wedge midcarpal arthrodesis site.
- Coaxial realignment of the capitate and lunate with complete correction of the dorsal intercalated segmental instability (DISI) deformity.
- Insertion of a solid cancellous scaphoid strut graft with supplementary scaphoid, and, when necessary, radius cancellous chip grafts.
- Secure fixation with multiple percutaneous K-wires.

Authors' Technique

- Step 1:
  - A pneumatic tourniquet is used for all patients and balanced regional anesthesia for most.
  - A 4 to 5 cm dorsal incision with its apex at the scapholunate interval, sparing the critical dorsal radiocarpal ligament (DRCL) and the volar extrinsic ligaments, provides wide access to the radiocarpal capsule in the interval between the third and fourth extensor compartments (▶ Fig. 59.1b).
  - A capsulotomy is incised along the radial margin of the DRCL, as advocated by Berger et al and an ulnar based capsule flap, extending to the radial styloid, is reflected exposing the carpal derangement and the radioscaphoid impingement[10] (▶ Fig. 59.1c).
  - Invariably the scaphoid is grossly deformed, displaced volarly and radially, abutted against the radial styloid, and dissociated from the lunate. By blunt and sharp dissection the scaphoid is excised en bloc and a partial radial styloidectomy is performed with a rongeur (▶ Fig. 59.1d and ▶ Fig. 59.2a).
- Step 2:
  - The midcarpal fusion site is thoroughly debrided initially with a power burr and then with a rongeur to cancellous bone of the apposing four carpals. A broad cancellous trough is created spanning the entire midcarpal articulation (▶ Fig. 59.2b). To maximize carpal height, the trough is shaped in a dorsal, open wedge configuration with the proximal capitate and hamate firmly coapted to the volar surfaces of the lunate and triquetrum.
- Step 3:
  - The lunate and capitate are then aligned in a coaxial position by volar displacement of the capitate and correction of the DISI deformity of the lunate and triquetrum.
  - To lessen the prospect of postoperative impingement, prominent dorsal rims of both the radius and the lunate are judiciously tapered to smooth surfaces.
  - With the radial borders of the capitate and lunate in direct alignment and firmly adjoined at their volar margins, a collinear carpus is restored.
  - The reduction is secured with a 0.062 inch K-wire passed percutaneously from the distal radius to the base of the capitate coupled with a distal wire passed proximally across the base of the fusion bed.
  - Two or three additional wires are preset at the distal margin of the trough for insertion and secure fixation once the graft is inserted.
- Step 4:
  - The scaphoid is thoroughly debrided of degenerative cartilage and sclerotic subchondral bone, procuring a purely cancellous, solid wedge that is sculpted to fit the semilunar contours of the fusion bed (▶ Fig. 59.2c).
  - The scaphoid graft, usually measuring 2 cm in length and 1.5 cm in width is then impacted into the fusion bed, providing a substantial block of cancellous bone to promote fusion as well as a strut to maintain the wedge-shaped arthrodesis (▶ Fig. 59.2d).

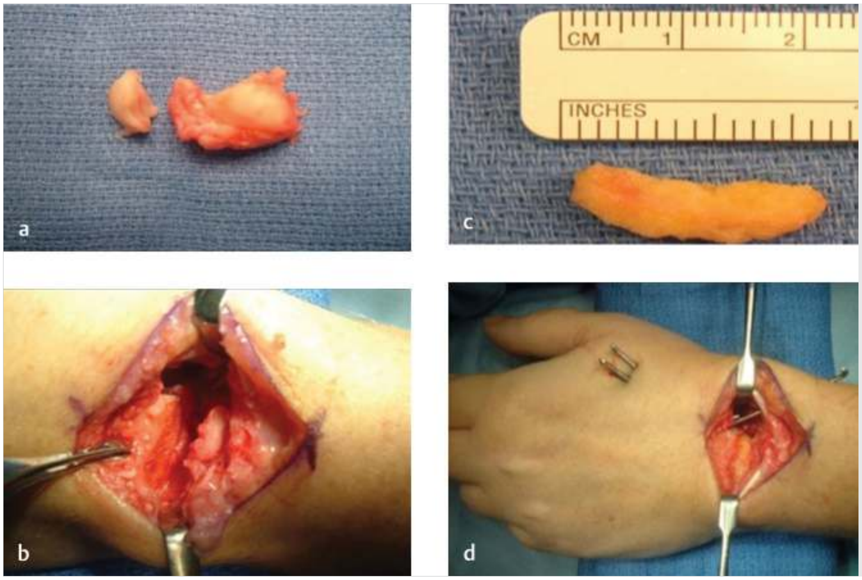

Fig. 59.2 **(a)** En bloc excision of the scaphoid demonstrating deformation. **(b)** The midcarpal fusion site is thoroughly debrided and a broad cancellous trough is created spanning the entire midcarpal articulation. **(c)** The scaphoid is thoroughly debrided, procuring a purely cancellous, solid wedge that fits the semilunar contours of the fusion bed. **(d)** The scaphoid graft is impacted into the fusion bed, providing a substantial block of cancellous bone to promote fusion and a strut to maintain the wedge-shaped arthrodesis.

- Additional cancellous graft from the scaphoid, and, if necessary, cancellous bone harvested from the adjacent radius afford a copious source of healthy bone graft.
- Step 5:
  - Insertion of the preset wires securely transfixes the arthrodesis, and fluoroscopy confirms a thoroughly grafted, well-aligned fusion with accurate K-wire fixation (▶ Fig. 59.3a).
  - The capsular flap, used to enhance carpal stability, is secured to the radial border of the radioscaphocapitate (RSC) ligament, and the remaining capsular tissues are repaired.
  - The tourniquet is deflated, hemostasis achieved, and the skin incision is closed.

Postoperative Care

The surgical repairs are protected with a long-arm thumb spica cast until radiographic union is clearly evident. Solid bony union invariably occurs within 6 to 8 weeks, at which time the wires are removed in the office and rehabilitation is begun (▶ Fig. 59.3b). Although we do not routinely use computed tomography (CT) to assess the fusion site, in uncertain cases it may prove necessary.

Outcomes

4CA is the authors' preferred treatment when SNAC/SLAC has progressed to stage II or III, and has demonstrated functional outcomes comparable to PRC.[5,8] Furthermore, 4CA maintains carpal height and the congruity of the intact radiolunate joint, thereby retaining a functional wrist joint.[6,8]

Since the 4CA technique was introduced by Watson et al in 1981, many methods of fixation have been described: K-wires, staples, compression screws, and locking and nonlocking dorsal circular plates.[7] Unfortunately, many of these implants have resulted in high nonunion rates, screw breakage, radiocarpal impingement, and low patient satisfaction scores, and presently no consensus exists regarding the best fixation technique.

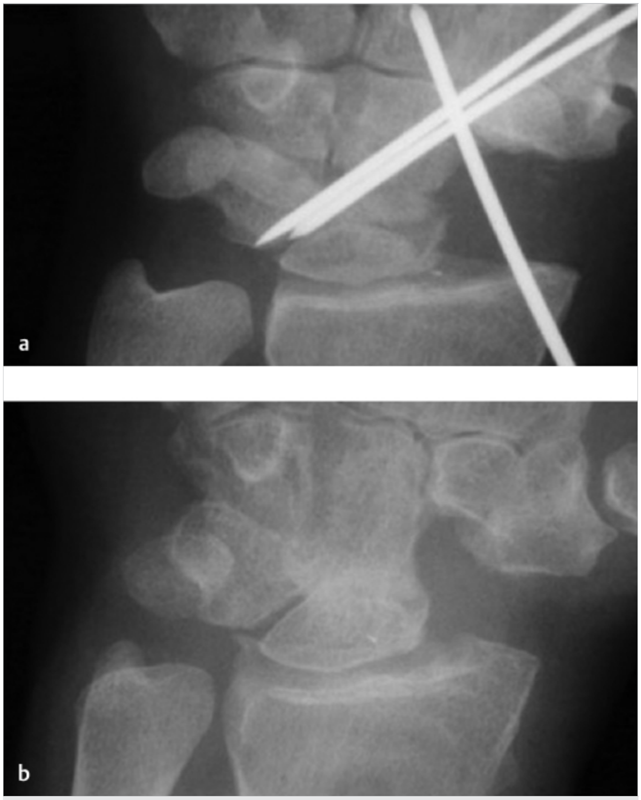

Fig. 59.3 **(a)** Insertion of the preset wires securely transfixes the arthrodesis and fluoroscopy confirms a thoroughly grafted, well-aligned fusion. **(b)** Solid bony fusion at 6 to 8 weeks.

Similar to the experience reported by Ashmead et al and Watson et al, K-wire fixation in our series proved a reliable, minimally invasive, and versatile method of internal fixation that has ensured a solid fusion.[11,12,13]

Critical to success is thorough debridement of the articular surfaces of the midcarpal joint and formation of a purely cancellous fusion bed. Similarly, the excised scaphoid must be thoroughly debrided of degenerative cartilage and sclerotic subchondral bone, thereby procuring healthy cancellous bone to promote fusion. Our experience bears that, with meticulous preparation, the excised scaphoid proved an excellent source of graft that consistently promoted uniform and rapid fusion.

Complications

- Complications can consist of radiocarpal dorsal impingement, superficial or deep pin tract infections, or nonunion.
- Frequently, radiocarpal dorsal impingement can result from residual carpal malalignment due to incomplete correction of the pre-existing and characteristic DISI deformity.
- In all cases of 4CA, the importance of precision carpal reduction with restoration of coaxial radiocarpal alignment cannot be overstated.
- Pin tract infections should be dealt with swiftly and decisively with the initiation of oral antibiotics and pin care. If there is any question regarding deep infection, pins should be removed and the surgical site should be washed out to prevent the onset of osteomyelitis.
- Bone grafting is essential for reliable and consistent union, as well as immobilization. We do not advocate for the use of allograft or bone graft substitutes. Autologous bone graft, providing osteogenesis, osteoconduction, and osteoinduction, is necessary for predictable and reliable fusion outcomes.
- We do not advocate for the usage of BMP-2 in the hand, due to the risks of heterotopic ossification, especially of the vital radiolunate joint.
- Meticulous preparation of the fusion site cannot be overstated.

59.3.2 Proximal Row Carpectomy

Introduction

PRC preserves wrist motion and grip strength while providing pain relief.[14,15,16,17,18,19,20]

PRC is an appealing alternative to 4CA, given its relative technical simplicity, predictable outcome, ease of postoperative rehabilitation, and independence from fusion rates and hardware related complications. Furthermore, PRC permits greater postoperative extremes of wrist range of motion and requires smaller peak tendon forces to achieve identical motion moments within ranges shared between wrists subjected to either 4CA or PRC.[18]

Indications

Strict patient selection is crucial to successful PRC. Because the integrity of the eventual radiocapitate articulation is the strongest predictor of its success, PRC is generally restricted to the stage II/III SLAC/SNAC wrist, in which the articular cartilage of the proximal capitate and the lunate facet are preserved. However, salvage of the proximal articulation of the capitate by either osteochondral resurfacing or interpositional arthroplasty via the modified Eaton approach results in good outcomes of PRC even in the early stage III SLAC/SNAC wrist with mild degenerative changes at the capitolunate articulation preoperatively.[21,22,23] Nevertheless, missed preoperative arthritis of the proximal capitate articular surface remains one of the strongest predictors of eventual PRC failure.[21] Additionally, successful outcomes in PRC require integrity of extrinsic volar ligaments without ulnar translocation of the carpus.[20,22] The authors' preference is to reserve PRC for stage II SLAC/SNAC wrist in functionally less-demanding, relatively older patients (greater than 50 years of age) whose primary goal is pain relief and performing routine activities of daily living.

Imaging

- Preoperative radiographic imaging should include high-quality posteroanterior (PA), lateral, and clenched fist views of the wrist to help delineate cartilage loss at the radioscaphoid articulation (▶ Fig. 59.4).
- It should be noted, however, that standard radiographs have limited predictive value in preoperative planning for PRC due to poor correlation of radiographic demonstrations of degenerative changes at the radiolunate and capitolunate articulations with intraoperative findings.
- Thus, angled PA and lateral radiographs and advanced imaging with either CT or magnetic resonance imaging (MRI) may be useful in patients with questionable cartilage integrity at the midcarpal or radiolunate articulations. (Regardless, intraoperative assessment remains the most reliable determinant of PRC candidacy and patients should always be prepared for possible intraoperative conversion.)

Pearls

- Careful intraoperative assessment of articular surfaces.
- When necessary, interpositional capsular arthroplasty or osteochondral resurfacing.
- En bloc excision of the proximal carpal row.
- Careful maintenance of the RSC ligament.
- Coaxial alignment of the capitate and lunate facet of the radius.
- Assessment of alignment and impingement potential.
- When necessary, radial styloidectomy.

Authors' Technique

- Step 1:
  - A pneumatic tourniquet and regional anesthesia are utilized for most patients. The wrist is flexed to emphasize dorsal capsular ligaments.
  - A 4 to 5 cm dorsal incision with its apex at the scapholunate interval provides ample exposure (▶ Fig. 59.1b). Skin flaps in the plane of the dorsal retinaculum are raised with careful attention to protect the superficial branch of the radial nerve and the dorsal sensory branch of the ulnar nerve.
  - The extensor pollicis longus (EPL) tendon is identified distal to the retinaculum. Its retinaculum is released and the tendon is transposed radially. The fourth compartment is elevated from within the third in an ulnar direction, taking care to preserve the posterior interosseous nerve (PIN) and the critical DRCL and the dorsal intercarpal ligament (DICL).
  - Next, we routinely perform a PIN neurectomy of 1 cm of the terminal division. In the floor of the fourth dorsal compartment the PIN is found at the radial aspect. Care is taken to preserve or ligate the accompanying artery.

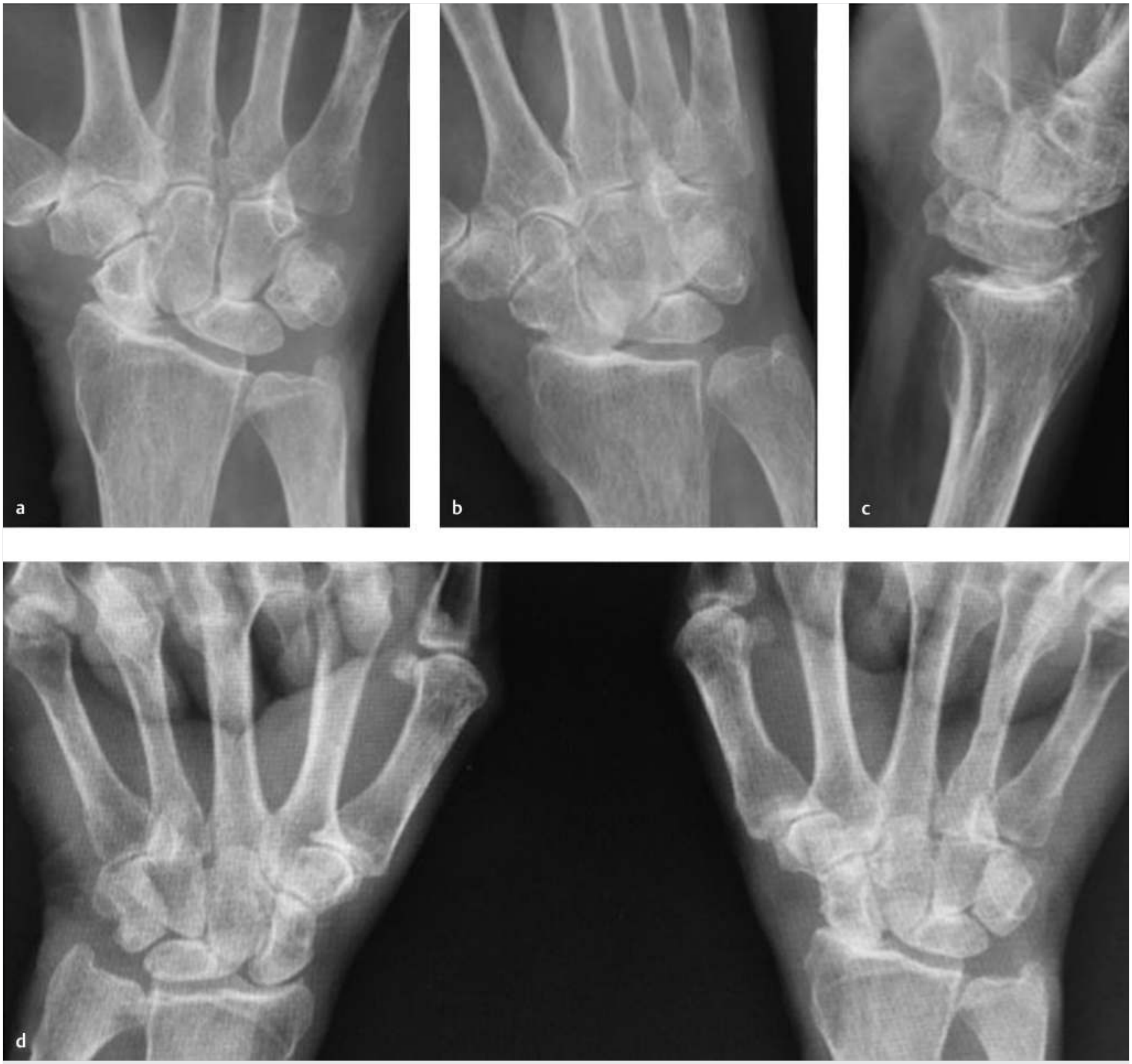

Fig. 59.4 Preoperative radiographic imaging should include high-quality **(a)** posteroanterior (PA), **(b)** oblique, **(c)** lateral, and **(d)** clenched fist views of the wrist to help delineate cartilage loss at the radioscaphoid articulation.

 - Next, a capsulotomy is then incised along the radial margin of the DRCL, as advocated by Berger et al and an ulnar based capsule flap, extending to the radial styloid, is reflected exposing the carpal derangement and the radioscaphoid impingement.[10]
- Step 2:
 - If the integrity of the articular surfaces is in question, then the surgeon has three choices.
 - In the first, a modified Eaton approach, as described previously, is used in which a dorsal transverse capsulotomy is incised, allowing for a distally based capsular flap to be raised, which is eventually interposed in the defective radiocapitate articulation and sutured to the volar capsule.[23] This approach requires pin fixation for 3 weeks.
 - Modifications of the Eaton approach include one documented by Placzek et al, combining interpositional capsular arthroplasty with resection of the head of the capitate resulting in successful symptom relief in 75% of cases.[22,23] We do not advocate for allograft usage.
 - Alternatively, a second option exists if a proximal capitate cartilage defect is present which is less than 10 mm. In this case, osteochondral resurfacing as described by Tang and Imbriglia is used, in which the cartilage defect is excised and replaced with osteochondral graft from the excised carpal row.[24] With this technique, postoperative flexion-extension arcs are 66% of the contralateral side and grip strengths are 71% of the contralateral side, and 75% of patients demonstrate mild to no radiographic evidence

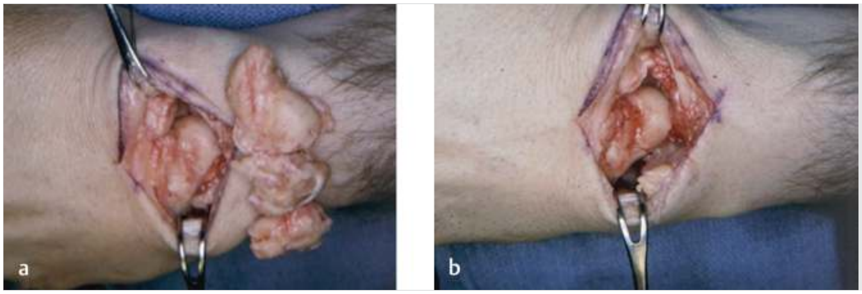

Fig. 59.5 (a) En bloc excision of the proximal carpal row. (b) After removal of the proximal row, the capitate dome is placed precisely into the lunate facet of the radius and the carpus is ensured to be in a collinear relationship with the radius and in slight ulnar deviation and volar tilt.

of degeneration in a series of eight patients followed for 18 months.
  - Lastly, there have been early, anecdotal reports of performing capitate proximal pole resurfacing with commercial products (such as the ArthoSurface Wrist HemiCapitate®). We do not have experience with such products, nor has outcome data been reported in the peer-reviewed literature.
- Step 3:
  - After selection of the appropriate capsulotomy technique, precise en bloc excision of the proximal carpal row is obtained while exquisite care is taken to avoid damaging the articular surfaces of the capitate and lunate facet (▶ Fig. 59.5a).
  - Although multiple techniques for carpal excision exist, it is critical to perform en bloc rather than piecemeal excision in order to protect the underlying volar ligaments. Of utmost importance is the integrity of the RSC ligament at the scaphoid waist as it prevents ulnar subluxation of the remaining carpus postoperatively.
  - Internal fixation may be required in addition to ligamentous repair if the RSC is inadvertently damaged; however, higher rates of failure have been documented in these cases, despite repair.
  - A threaded K-wire (0.062 inch), large threaded Steinmann pin (5/32 inch), or Schanz screw can be inserted into the lunate as a "joystick" for improved maneuverability and visualization.
  - Finger traps with weights may also be used to open the exposure, although we find this rarely necessary.
  - Blunt dissection is preferable to the use of sharp instruments until the ligaments are in full view to prevent iatrogenic ligamentous damage.
  - Each respective carpal bone to be excised is grasped with a penetrating bone reduction clamp and is separated from its underlying ligament utilizing a periosteal, Freer, or Carroll elevator.
  - Some reports indicate superior thumb carpometacarpal (CMC) stability with a retained distal scaphoid pole. However, it should be noted that this increases the risk of radial styloid impingement and may require more extensive radial styloidectomy. We do not retain any distal scaphoid in our approach.
- Step 4:
  - Radiographic congruency between the radius of curvature of the capitate and that of the lunate facet and potential impingement of the trapezium and radial styloid should be verified intraoperatively. If impingement is a concern, radial styloidectomy is indicated but is limited to 5 to 7 mm in order to preserve the origins of the stabilizing radiocarpal ligaments, particularly the RSC.
- Step 5:
  - Next, while not performed by all authors, we stabilize our PRC with K-wires.
  - The capitate dome is placed precisely into the lunate facet of the radius and the carpus is ensured to be in a collinear relationship with the radius and in slight ulnar deviation and volar tilt (▶ Fig. 59.5b).
  - We pass a 0.062 inch smooth K-wire percutaneously from the radial aspect of the radius into the base of the capitate. This is retained postoperatively.
- Step 6:
  - The tourniquet should be released and hemostasis ensured prior to dorsal capsule repair with 2–0 PDS suture and reapproximation of the dorsal retinaculum with 3–0 PDS suture. The EPL should remain transposed.
  - Importantly, we routinely leave a small drain in the wound, as postoperative hematoma is otherwise quite common and can lead to wound complications.

Postoperative Care

Although various authors have reported different postoperative protocols, we immobilize our patients in a long-arm thumb spica splint for 3 weeks postoperatively. After 3 weeks, the K-wire is removed and, under the guidance of a hand therapist, initiation of range of motion in a removable splint for up to 3 additional weeks is performed (▶ Fig. 59.6). We adhere to the adage of "motion before strengthening." Once normal wrist motion has been achieved, then we allow targeted strengthening exercises with return to normal activity as tolerated at 3 months postoperatively. We advise all patients that full recovery should be expected within 12 to 18 months.

Outcomes

Since Stamm published the first series of PRC cases in 1944, it has been known that excision of the proximal carpal row dramatically alters biomechanics at the radiocarpal joint, specifically by decreasing contact area at the radiocarpal joint and thereby introducing a sizeable component of translational motion.[25]

Several recent long-term outcome studies demonstrate good clinical outcomes of PRC for the SLAC/SNAC wrist in the appropriate patient population. Postoperative flexion-extension arcs between 61 and 64% of their respective contralateral sides have been reported for up to 20 years of follow-up. Similarly, postoperative grip strengths between 72 and 91% of that of the contralateral sides have been reported for up to 20 years of postoperative follow-up. Overall, patient satisfaction scores

Fig. 59.6 After 3 weeks, the Kirschner wire is removed and, under the guidance of a hand therapist, initiation of range of motion in a removable splint for up to 3 additional weeks is performed. **(a)** Posteroanterior (PA) view of the wrist 3 weeks after proximal row carpectomy. **(b)** Lateral view of the wrist 3 weeks after proximal row carpectomy.

range between 80 and 94% for up to 20 years of postoperative follow-up.

Complications

- While avoiding the hardware and fusion rate complications seen in 4CA, PRC is not complication-free.
- Among the most commonly noted are synovitis, edema, ulnar carpal subluxation secondary to RSC ligament insufficiency, residual impingement in patients with insufficient radial styloidectomy at index procedure, reflex sympathetic dystrophy in patients without early range of motion, incomplete carpectomy, and persistent radiocarpal arthritis, with eventual progression to radiocarpal arthrodesis.
- Failure rates of PRC for the SLAC/SNAC wrist are between 10 and 35%. It has been suggested that higher failure rates are associated with the presence of preoperative proximal capitate arthritis and younger patient age at the time of surgery, with increased rates of failure in patients undergoing PRC before the age of 40 years.
- Some report that PRC cases that progress to failure demonstrate no alleviation of wrist arthritis pain even transiently postoperatively, indicating that failures may be associated with residual preoperative proximal arthritis.

59.3.3 Salvage Operations

Total Wrist Arthrodesis

Introduction

Total wrist arthrodesis is the fusion of the carpus to the radius, thus eliminating radial carpal motion, but preserving radioulnar articulation and forearm rotation.

Indications

The primary indication for a total wrist arthrodesis is painful, pancarpal degenerative arthritis (▶ Fig. 59.7). Additional indications include: end-stage rheumatoid arthritis, posttraumatic arthritis, radiocarpal or midcarpal joint arthritis, failed limited wrist fusions, failed soft tissue reconstructions, carpal instability patterns, spasticity disorders, brachial plexus injuries, postinfection degeneration, contraindications for joint arthroplasty, and failed arthroplasty.

Contraindications

There are very few contraindications to total wrist arthrodesis: active wrist infection or a lack of an adequate soft tissue envelope are the primary concerns.

Methodology

Traditionally, wrist arthrodesis has been performed in the manner popularized by Mannerfelt and Malmsten, utilizing retrograde Rush pins.[26] Since then, there have been many modifications eventually culminating in the design of compression plating spanning the metacarpal to the distal radius. Typically, plates are applied to the third metacarpal. However, in the event that the third metacarpal is inappropriate (such as in a revision fusion), then many manufacturers making precontoured plates use the second metacarpal (▶ Fig. 59.8). Internal fixation risks hardware complications and the need for hardware removal.[27,28,29] These risks increase with severe osteoporosis. As a result, in osteoporotic rheumatoid wrists we prefer to perform arthrodesis employing temporary K-wire fixation with corticocancellous iliac bone graft, as we will describe (▶ Fig. 59.9). Otherwise, for osteoarthritis or posttraumatic arthritis, we use precontoured compression plating. Additionally, two technical questions have been of much debate in the literature: the joints that must be fused and the ideal wrist position. We include the radioscaphoid, radiolunate, scaphocapitate, lunocapitate, and third CMC joints. The ulnar joints, lunotriquetral and triquetrohamate, do not need to be included. Whether the wrist is fused in neutral or extension has been the topic of multiple manuscripts. Solem et al examined wrist position in 40 wrists at 10.5-year follow-up and reported that wrists fused in extension had significantly better grip strength.[30] Thus, we place the wrist in 10 degrees of extension and slight ulnar deviation.

Fig. 59.7 (a–c) Three radiographic views of the wrist demonstrating pancarpal degenerative arthritis.

Fig. 59.8 (a) Posteroanterior (PA) radiograph of wrist arthrodesis performed with a precontoured plate to the second metacarpal. **(b)** Oblique radiograph. **(c)** Lateral radiograph.

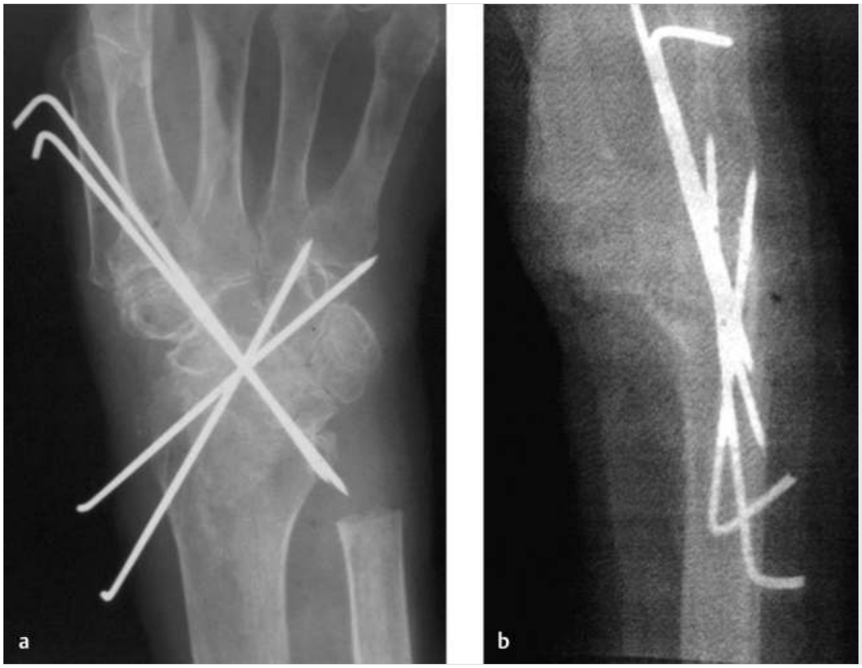

Fig. 59.9 In osteoporotic rheumatoid wrists, arthrodesis is preferred employing temporary Kirschner wire fixation with corticocancellous iliac bone graft. **(a)** Posteroanterior (PA) view of the wrist. **(b)** Lateral view of the wrist.

Imaging

- Preoperative radiographic imaging should include high-quality PA, lateral as well as radial and ulnar deviation views.
- Radiographs should be evaluated for distal radioulnar joint arthritis.

Pearls

- If distal radioulnar joint arthritis requires a concurrent procedure, then we perform a matched distal ulnar resection.
- Bone graft from the iliac crest is used.
- If plate fixation is going to be used and finger extensor tendons are directly overlying the plate at the end of the surgery, we recommend using the extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) tendons to supplement soft tissue coverage and protect the finger extensors (▶ Fig. 59.10).
- A high-speed burr is used during the surgery, but care must be taken to avoid thermal damage to the bone as this will increase the possibility for nonunion.
- Radiographic interpretation of the status of the wrist arthrodesis can be challenging if internal fixation is used. This is because of the plate and because the fusion only occurs across the dorsal aspect of the joints. The deep, anterior cortex, bones, and often cartilage are still preserved. This can frequently lead to radiologists underestimating fusion and a CT scan may be necessary. The technique with temporary K-wire fixation obviates this problem.

Authors' Technique of Plate Fixation

- Step 1:
  - A dorsal midline incision is made, centered at the radiocarpal joint and extending distally along the middle finger metacarpal and proximally, about 5 cm proximal to Lister's tubercle.
  - Flaps are elevated and the third dorsal compartment is incised and the EPL is dislocated radially.
  - The fourth dorsal compartment is opened from within the third and the fourth compartment is elevated. A PIN neurectomy is performed.
  - Next, a capsulotomy is then incised midline and ulnar and radial flaps are created. There is no need to preserve the DICL or DRCL.
  - Subperiosteal dissection is used to expose the dorsal radius, the carpus, and the middle finger metacarpal.
- Step 2:
  - Lister's tubercle is removed with an osteotome. The dorsal aspect of the radius, carpus, and third CMC joints are decorticated using a high-speed burr. The dorsal radius must be contoured by decortication in order to seat the fusion plate on the dorsal radius.
  - All of the joints to be fused must be first denuded of articular cartilage using a rongeur and then the subchondral bone

Fig. 59.10 After plate fixation for wrist arthrodesis, the extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) tendons are used to supplement soft tissue coverage and protect the finger extensors.

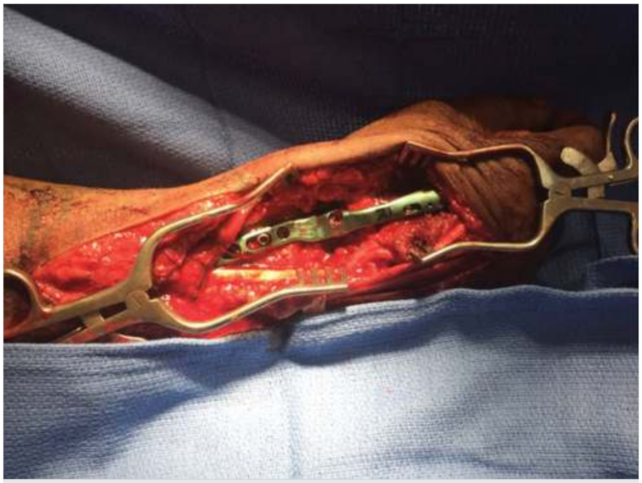

Fig. 59.11 To accept the arthrodesis plate, a groove in the distal radius articular surface needs to be created to accept the curved portion of the plate. Locking screw fixation is used in patients with poor bone stock.

can be removed with a high-speed burr. These must include the radioscaphoid, radiolunate, scaphocapitate, lunocapitate, and third CMC joints.
   - The ulnar joints, lunotriquetral and triquetrohamate, do not need to be included.
- Step 3:
   - The plate location must be determined. In most cases, a groove in the distal radial articular surface needs to be created to accept the curved portion of the plate (▶ Fig. 59.11).
   - Desired arthrodesis position is 10 degrees extension and slight ulnar deviation.
   - We then harvest copious bone graft from the iliac crest to augment the fusion site.
- Step 4:
   - The prepared articular surfaces are filled with bone graft harvested from the iliac crest.
   - The plate is applied to the dorsum of the radius, carpus, and middle finger metacarpal (or index finger metacarpal) and first affixed to the middle finger metacarpal in neutral rotation.
   - Next, the plate is affixed to the radius in compression mode, taking care to avoid malrotation. Locking screw fixation can be used in patients with poor bone stock (▶ Fig. 59.11).
   - We routinely supplement fixation with an oblique carpal screw (▶ Fig. 59.8).
- Step 5:
   - Once the plate is fixed, additional bone graft should be packed around it and the prepared joints.
   - We then close the capsular flap over the plate.
   - The ECRL and ECRB tendons are frequently released from the metacarpals and incorporated into the capsular closure, supplementing it.
   - The extensor retinaculum is allowed to fall back radially, leaving the EPL transposed (▶ Fig. 59.10).
   - The skin is then closed and a bulking dressing is applied with a volar splint. Care is taken not to splint the metacarpophalangeal joints in extension which can result in intrinsic tightness and loss of finger range of motion.

Authors' Technique of K-Wire Fixation

- Step 1:
   - A dorsal midline incision is made, centered at the radiocarpal joint and extending distally along the middle finger metacarpal and proximally, about 5 cm proximal to Lister's tubercle.
   - The interval between the fifth and sixth dorsal compartments is incised and a radially based retinacular flap is created.
   - The extensor tendons are retracted and the floor of the fourth dorsal compartment is exposed, exposing the PIN. A PIN neurectomy is performed.
   - Next, a capsulotomy is then incised along the radial margin of the DRCL, as advocated by Berger et al and an ulnar based capsule flap, extending to the radial styloid, is reflected exposing the carpal derangement and the radioscaphoid impingement.[10]
   - Subperiosteal dissection is used to expose the dorsal radius, the carpus, and the middle finger metacarpal.
- Step 2:
   - Next, all of the joints to be fused must be first denuded of articular cartilage using a rongeur and then the subchondral bone can be removed with a high-speed burr. These include the radioscaphoid, radiolunate, scaphocapitate, lunocapitate, and third CMC joints.
   - The ulnar joints, lunotriquetral and triquetrohamate, do not need to be included.
   - The carpus reduction is then contoured onto the distal radius so that there will be precise coaptation of the exposed cancellous surfaces.
- Step 3:
   - Desired arthrodesis position is 10 degrees extension and slight ulnar deviation.
   - We then harvest a triangular or trapezoidal corticocancellous bone graft from the iliac crest as well as copious cancellous graft.
- Step 4:
   - Next, a matching triangular or trapezoidal fusion bed is created across the radiocarpal and midcarpal joints with a rongeur and burr. The fusion bed should extend proximally into the medullary canal of the radius, but we do not routinely extend distally across the CMC joints.
   - Next, the radiocarpal and midcarpal joints are fixed with two percutaneously placed 0.062 inch K-wires: one from the radius into the scaphoid and capitate and one from the trapezoid into the capitate and distal radius (▶ Fig. 59.12a).
   - The prepared articular surfaces are filled with bone graft.
   - The corticocancellous slot graft is then fixed under compression into the fusion bed with an additional two percutaneous 0.062 inch K-wires: one from the radius into the lunate and hamate and one from the trapezoid into the capitate, lunate, and distal radius (▶ Fig. 59.12b).
   - The proximal end of the graft is slotted within the medullary canal of the radius, while the distal end is firmly impacted against the distal border of the fusion bed (▶ Fig. 59.9).
   - The wires are bent and cut outside the skin.
- Step 5:
   - We then close the capsular flap over the plate.

- The ECRL and ECRB tendons are frequently released from the metacarpals and incorporated into the capsular closure, supplementing it, if necessary.
- The extensor retinaculum is allowed to fall back radially. The EPL is transposed subcutaneously.
- The skin is then closed and a bulking dressing is applied with a long-arm splint in neutral pronation/supination. Care is taken not to splint the metacarpophalangeal joints in extension; this can result in intrinsic tightness and loss of finger range of motion.

Postoperative Care

In the event of plate fixation, at 2 weeks we routinely move the patient to a removable splint that is to be worn at all times, except for bathing. Immediate finger range of motion and edema control are emphasized during this time. The removable splint is worn until 3 months after surgery. Once radiographs demonstrate consolidation of the prepared articular surfaces, with no hardware loosening or lucency, then strengthening exercises may begin, typically at 3 months. For K-wire fixation, the patient is moved to a long-arm cast at 2 weeks when the sutures are removed. The cast is removed at 6 weeks to examine the pin sites and to perform orthogonal radiographs. Fusion is considered to have occurred when bony trabeculae bridge all fusion sites (▶ Fig. 59.13). A cast is reapplied if fusion has not been achieved, with out of cast radiographs being repeated as needed every 2 weeks. Once radiographic fusion has occurred, the K-wires are removed in the office and patients are then placed into a short-arm removable splint for comfort for a period of 1 to 2 weeks. While in a removable splint, patients are referred to hand therapy to start range of motion exercises.

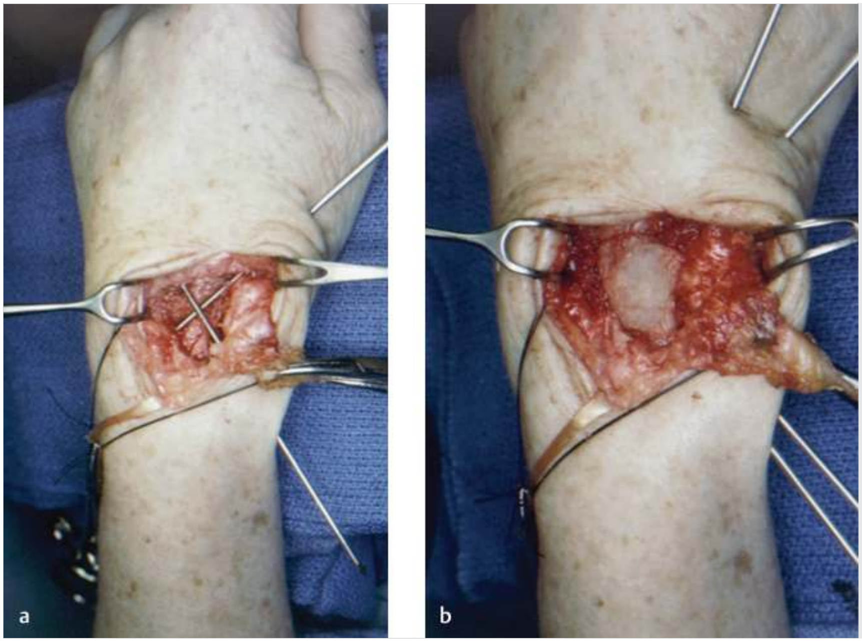

Fig. 59.12 (a) An alternative to plate fixation is Kirschner wire (K-wire) fixation. The radiocarpal and midcarpal joints are fixed with two percutaneously placed 0.065 inch K-wires: one from the radius into the scaphoid and one from the trapezoid into the capitate and distal radius. **(b)** The corticocancellous slot graft is fixed under compression into the fusion bed with an additional two percutaneous 0.062 inch K-wires: one from the radius into the lunate and hamate and one from the trapezoid into the capitate, lunate, and distal radius.

Fig. 59.13 (a, b) Once radiographs demonstrate consolidation of the prepared articular surfaces, with no hardware loosening or lucency, then strengthening exercises may begin, typically at 3 months. For Kirschner wire fixation, the patient is moved to a long-arm cast at 2 weeks when the sutures are removed. The cast is removed at 6 weeks to examine the pin sites and to perform orthogonal radiographs. Fusion is considered to have occurred when bony trabeculae bridge all fusion sites.

Outcomes

Successful fusion results in high patient satisfaction. They can expect excellent pain relief and the ability of the patient to complete most activities of daily living. Patients can expect about 80% of grip strength. However, perineal care and using the hand in tight spaces can be quite limited. Based on the work of Solem and colleagues, long-term follow-up (average of 10.5 years) of plate-based wrist arthrodesis results in an average visual Analog Scale (VAS) and disabilities of the arm, shoulder and hand (DASH) score of 26 (for those placed in dorsal extension), and grip strength about 80% of the unoperated side.[30] Our unpublished results on 90 wrists in 78 patients with an average follow-up of 3.8 years are as follows: all patients went on to radiographic fusion with an average time of 6.5 weeks, and grip and pinch strength increased from their preoperative values by 66 and 103%, respectively. Wrist pain was completely eliminated in 98% of patients. Our complications consisted of five patients with superficial pin site infections successfully treated with oral antibiotics and pin care.

Complications

- Failure to contour the dorsal radius will result in poor fixation and a prominent plate.
- Plate prominence may lead to extensor tenosynovitis or rupture.
- Poor technique or patient attributes may lead to nonunion and hardware loosening, which can have disastrous consequences and require revision.
- Ulnocarpal impaction.
- Carpal tunnel syndrome.
- Infection.

Total Wrist Arthroplasty

Introduction

Designed as an alternative to total wrist arthrodesis, arthroplasty was designed to provide pain relief and retain motion and function in patients with end-stage wrist arthritis (▶ Fig. 59.7). First experimented with in the 1890s, and now in the fourth generation of prosthesis design, total wrist arthroplasty has been plagued by high complication rates. Additionally, as the medical management of rheumatoid arthritis has improved, the rates of arthroplasty have decreased. In our practice, we do not perform arthroplasty, as we believe the results of arthrodesis are superior with fewer complication rates.

Indications

Indications are pancarpal arthritis in a low-demand patient who desires wrist motion with the ability to adhere to the strict activity limitations (▶ Fig. 59.7). Typically, this is in a patient with inflammatory arthritis. The active patient with osteoarthritis is a very controversial indication.

Contraindications

Contraindications include a history of bone infection, ligamentous laxity or nonfunctional radial wrist extensors, resorption of the distal carpal row, the need to bear weight (such as in the use of walking aides), and the inability to adhere to strict activity limitations. Sports such as golf, tennis, and bowling are restricted. Use of the wrist requiring lifting over 20 pounds is discouraged. In patients with advanced synovitis of the wrist resulting in carpal subluxation, ulnar translation, and destruction of both carpal rows, wrist arthrodesis is always preferred.

Methodology

The current fourth generation of arthroplasty implants are similarly designed: screw fixation to the carpus and porous ingrowth surface to increase osseointegration. This allows for implantation without cement, ameliorating many of the complications associated with cement in prior generations.

Imaging

Preoperative imaging consisting of true AP and lateral radiographs of the wrist are vital. The degree of carpal collapse and subluxation/dislocation of the radiocarpal joint must be assessed. In patients with excessive carpal bone resorption, the distal component fixation my need to cross the CMC joints. Additionally, based on radiographs, supplementary bone grafting may be necessary to improve distal component fixation. In patients with volar subluxation of the wrist, arthroplasty may be contraindicated, as over-resection of the distal radius may be necessary. Additionally, the soft tissue capsule may be compromised.

Generalized Technique

The authors do not currently perform this procedure, preferring arthrodesis, instead. However, the general technique principles are outlined below.

- Step 1:
  - Exposure is performed as with arthrodesis. However, it is recommended that extensor retinaculum be reflected from radial to ulnar, so that it can be used to reinforce the dorsal joint capsule, if necessary, at the conclusion of the procedure.
  - During exposure, a synovectomy of the extensor tendons should be performed.
- Step 2:
  - Carpal cutting guides are generally used to assist in resection of the lunate, triquetrum, proximal scaphoid, head of capitate, and head of the hamate. It is imperative to adhere to manufacturer guidelines and to use imaging during every step to ensure proper alignment.
- Step 3:
  - Generally, radial resurfacing guides are used to contour the radius and control the amount of resection. Furthermore, templates generally permit control of volar and dorsal resection to achieve optimal alignment.
- Step 4:
  - Trialing of components generally takes place. Assessing stability through radioulnar deviation and flexion-extension of the wrist. If range of motion is satisfactory and there is good stability, the surgeon can proceed to implantation (▶ Fig. 59.14).

Fig. 59.14 (a–c) Three radiographic views after total wrist arthroplasty.

Outcomes

A recent systematic review of fourth-generation implants compiled 5-year outcomes in 405 arthroplasties.[31] Average postoperative DASH scores ranged from 20 to 45 (scale 0–100). Average postoperative patient-rated wrist evaluation (PRWE) scores ranged from 24 to 36 (scale 0–100). Average postoperative VAS scores ranged from 0 to 2.7 (scale 0–10). Survival rates ranged between 57 and 100% at 5 years.

Complications

Complication rates range from 11 to 69% in the literature, with the most frequent complications being dislocations (22%), impingement (17%), wound problems (3–17%), infection (3–14%), and nonunion (10%).[31] Other catastrophic complications include tendon rupture (3–5%) and periprosthetic fracture (5%).

59.4 Conclusion

Degenerative wrist arthritis results from specific patterns of radiocarpal and intercarpal articular degeneration, the foremost pattern being SLAC/SNAC as described and staged by Watson and colleagues.[1,2] For patients who fail nonoperative treatment, surgical options can be rewarding. For stage II, both PRC and 4CA have been employed with success. In stage III, 4CA is presently the standard method of reconstruction. Lastly, symptomatic stage IV requires a total wrist reconstruction, either arthroplasty or arthrodesis, with arthrodesis preferred by most surgeons.

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60 Thumb Reconstruction: Toe-to-Thumb Transfer

Kriya Gishen, Morad Askari, and Harris Gellman

Abstract

The thumb is the single most important digit in the hand. Thumb amputation has a devastating impact on a patient's life and is an indication for reconstructive surgery. Toe-to-thumb transfer can provide significant functional and aesthetic outcomes for the patient. Effort must be made to preserve bone length, joint structures, tendons, vessels, and nerves. Reconstruction may be performed acutely, subacutely, or at a later time. The overall success of toe-to-thumb transfer is currently in excess of 95%. Success of surgery is generally defined in terms of improved motor function, sensation, and perception of the toe as a thumb.

This chapter aims to provide a brief overview of the indications of toe-to-thumb transfer for thumb reconstruction. The chapter then details the operative steps of the toe-to-thumb transfers as performed by senior authors. Finally, the chapter concludes with a summary of recommended postoperative care.

A review of current literature was performed primarily using articles available through PubMed. Search terms included "thumb amputation," "toe-to-thumb transfer," and "thumb reconstruction." All articles were reviewed for indications of procedure, intraoperative details, and postoperative care

Common indications for toe-to-thumb transplantation include amputation secondary to trauma or neoplastic disease. Additionally, certain congenital deformities, such as constriction ring syndrome, congenital thumb absence, or symbrachydactyly are indications for operation. The goal of the surgery is to restore motor function, sensation and perception of toe as thumb. Operative steps are detailed in the chapter.

Keywords: thumb amputation, thumb reconstruction, toe-to-thumb transfer

60.1 Introduction

The thumb, which gives the hand most of its functionality, is the single most important digit in the hand. Thus, thumb amputation can have devastating impact on a patient's life and is an indication for reconstructive surgery. Among reconstructive techniques for the thumb, toe-to-thumb transfer has specific indications and poses a challenging procedure with potentially great functional and aesthetic outcomes for the patient. The toe is a sturdy structure with a thick but sensate soft tissue component, which closely replicates that of the thumb.[1] Effort must be made to preserve bone length, joint structures, tendons, vessels and nerves. Reconstruction may be performed acutely, subacutely, or at a later time.

60.2 Indications

Thumb amputation secondary to trauma or neoplastic disease commonly necessitates toe-to-thumb transfer. Additionally, certain congenital deformities, such as constriction ring syndrome, congenital thumb absence, or symbrachydactyly, in which the joints, muscles, and tendons proximal to the amputation site are well preserved, may improve with toe-to-thumb transfer.[2,3]

60.3 Operative Technique

The first step in planning thumb reconstruction with toe transfer is selection of the donor toe. Multiple studies have shown that gait and balance remain sufficient without all toes.[2,4] The most commonly used donor toes are the great toe and the second toe. Generally, when the level of tissue loss is distal to metacarpophalangeal joint the patient is best served with the great toe transfer. Tissue loss just proximal to this joint is better managed with the second toe transfer. The great toe is considered preferable because it can be shaped to resemble the thumb. This donor site defect leads to an obvious aesthetic deformity of the foot and may slightly diminish foot push-off strength. Therefore, if the great toe is selected for transfer, it is recommended to use the nondominant side. Additionally, in order to maintain function of the first metatarsophalangeal joint, the great toe should not be harvested proximal to the base of the proximal phalanx.[5] On the other hand, the second toe harvest may include the metatarsophalangeal joint, which can ultimately provide a reconstruction of more adequate length.

- At the time of surgery, the patient is taken to the operating room, placed under general anesthesia, and prepped and draped in standard surgical manner.
- Preparation of the recipient site begins with a cruciate incision of the skin overlying the amputation site for best exposure of the recipient vessels, nerves, tendons, and bone.
- Next, the recipient artery is exposed. The common digital artery, the princeps pollicis artery, or the radial arteries are explored and prepared.
- Further preparation of the recipient site involves exposure of a vein of adequate size on the dorsum of the hand or the stump. The nerve stumps of the amputated digit are exposed and any neuroma should be resected at this time.
- The end of metacarpal or phalangeal bone is leveled and slightly shortened while preserving adequate length for fixation. At minimum, 5 mm of bone is required for interosseous wire fixation in the phalangeal bone.[6]
- Following assurance that suitable neurovascular tissue is present at the recipient site, the toe flap is harvested. Incisions are designed in the dorsal first webspace for the great toe as well as second toe transfer where the dorsal and plantar metatarsal arteries merge, proximal to the intermetatarsal ligament.[7] In 70% of patients,[8] the dorsal metatarsal artery is the larger of the two. It should be traced retrograde to the dorsalis pedis.
- A dorsal vein is identified and taken with the flap.
- Next the extensor and flexor tendons are divided proximally allowing adequate length for tendon repair.
- Osteotomy is performed on the head of first or second metatarsal bone while neurovascular bundles are carefully protected.

- Toe perfusion should be assessed prior to division of vessels.
- Following separation of the great toe, it is trimmed to better resemble a thumb. Depending on the size of the toe, a wedge of skin, fat, and nail bed/plate are removed from one side of the toe.[9] At times, a limited "wrap-around" flap can be elevated to further trim the phalangeal bone. To trim the interphalangeal joint, periosteum and medial collateral ligament are elevated together. Subperiosteal dissection continues to the midvolar line of the proximal and distal phalanges. The saw is used to remove the adequate amount of bone longitudinally. The flap is then wrapped back around the trimmed bone and reapproximated. The adequate trimming should allow for the circumference of the toe at the level of the eponychium, interphalangeal joint, and midproximal phalanx to be within 2 to 3 mm of comparable levels in the contralateral thumb.
- If the second toe rather than the great toe is the selected donor site, the skin is marked with dorsal and plantar V-shaped flaps. The apex of each "V" should be 5 to 10 mm proximal to the planned osteotomy site. Vessels and nerves of the first webspace are exposed. The transmetatarsal ligament is transected. The extensor retinaculum is opened to transect the extensor digitorum longus and brevis tendons at a more proximal position. At the level of intended osteotomy, the flexor sheath should be opened and tendons transected. The bone is divided.[10]
- To inset the toe flap at the recipient stump, the sequence of repair and fixation is as follows: bone, extensor tendon, flexor tendon, nerves, artery, vein, and skin.
- Bone fixation is frequently completed by interosseous wiring to avoid extensive manipulation of the surrounding tissue. Two 26- or 28-guage wires are passed through 1-mm drill holes at bone edges. These holes should be placed 2 mm from the edge.
- Extensor tendon should be repaired under mild tension, and the joint pinned in extension after flexor tendon repair to prevent contracture in flexed position or extensive extension at the joint.
- Standard microscopic techniques are used for the nerves, artery, and vein anastomoses.
- The skin is then loosely closed.

60.4 Conclusion

The overall success of toe-to-thumb transfer exceeds 95%.[5] Success of surgery is generally defined in terms of motor function, sensation, and perception of toe as thumb. Approximately, 10% of patients undergo additional procedures, mostly for further debulking of the tip.[10] Most patient ultimately achieve a two-point discrimination of less than 10 mm,[11,12] and perceive the donor toe to be a thumb within 6 months of surgery.[13] To optimize surgical outcome, patients must participate in early rehabilitation with mobilization as soon as 3 days postoperatively and strengthening exercises beginning at 2 months.

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61 Treatment of Tumors of the Hand: Sarcoma

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Abstract

The treatment of tumors of the hand is unique in hand surgery. Successful management of benign tumors can increase quality of life, but the successful management of malignant hand tumors can mean patient survival. The surgical management of malignant tumors should be part of a multidisciplinary approach. Only once diagnosis and staging have been determined, should a surgical plan be made. Adjuvant therapy, radiation or chemotherapy, may be indicated depending on diagnosis. Determining optimal surgical management includes careful consideration of involved anatomy, postresection hand function, local soft tissue coverage, and the possible need for sentinel lymph node biopsy or other concomitant procedure.

Keywords: amputation, benign, hand tumors, lesion, limb salvage, malignant, sarcoma

61.1 Introduction

Tumors of the hand can result from any abnormal growth of hand tissue. Skin cancers are most common, followed by benign tumors and tumor-like lesions.[1,2] The most common benign soft tissue tumors of the hand are ganglions, giant cell tumors, and epidermal inclusion cysts. The most common benign tumors of the bones of the hand are enchondromas, periosteal chondromas, and osteochondromas.[3] Malignant soft tissue and bone tumors of the hand are very rare.[4] The most common deep tissue malignant tumors of the hand, in descending order, are epithelioid sarcoma, synovial sarcoma, malignant fibrous histiocytoma, and chondrosarcoma.[5] Numerous other benign and malignant hand tumors exist, and each tumor of the hand requires carefully planned, diagnosis-specific management.

61.2 Indications

Surgical management of benign tumors of the hand is indicated for both definitive diagnosis and symptomatic relief. Marginal surgical excision with protection of adjacent structures can often provide relief of symptoms and ensure good hand function. Malignant tumors of the hand are treated with surgical resection, and possibly with adjuvant radiation or chemotherapy, depending on the diagnosis and stage. Surgery should only be used after tumor diagnosis and staging have been completed.[6,7] Wide resection or amputation is indicated for local control of malignant tumors of the hand.[8,9] In addition to the surgery, adjuvant chemotherapy or radiation therapy must be considered based on the type of malignancy. Metastases to lymph nodes are more common in rhabdomyosarcoma, epithelioid sarcoma, clear cell sarcoma, and angiosarcoma; and sentinel lymph biopsy may be indicated.[10] Soft tissue coverage following tumor resection should be performed locally and primarily if possible.[11]

61.3 Operative Technique

The goal of surgical management of malignant tumors of the hand is elimination of the tumor and any local or distant spread, with a secondary goal of restoring function to the upper extremity.[12] With careful image-based planning, the surgical treatment of hand malignancies can be accomplished successfully. It is important to extirpate the entire tumor, meaning that a healthy margin of tissue must be taken with the tumor. In other parts of the body, a radical resection of a malignant tumor is usually carried out, in which the entire compartment is removed. In the hand this is difficult because tumors that involve extrinsic musculature theoretically contaminate the entire muscle compartment to the origin in the forearm or elbow.[10] In most cases a wide resection can accomplish complete extirpation of the tumor, and leave greater function of the remaining hand.[13] In these cases, a healthy margin on pathological examination is imperative, and even then, there is no guarantee of oncologic cure.[7,14,15,16] If a healthy tissue margin cannot be taken with the tumor then amputation should be considered. Although function of the postsurgical hand is important, complete extirpation of the tumor is the greatest priority as it may impact survival.

The surgery begins with a plan. Magnetic resonance imaging (MRI), radiographs, computed tomography (CT) scan, angiograms, bone scans, and positron emission tomography (PET) scans are all potential modalities to help with this step. MRI is very helpful in determining the anatomic extension of the mass, and can help guide the surgeon in determining the anatomic structures that must be resected with the mass. A CT angiogram may be helpful in determining the extent to which the vascular system is affected by the tumor and what structures will have vascular flow after resection. The involved anatomy of the tumor can be determined with the help of this imaging, and a resection plan can be made. Next, a reconstruction and closure plan can be determined utilizing the remaining tendons, fascia, and skin. Reconstruction is best performed primarily, at the time of the definitive resection of the tumor.[17] An Allen's test must be performed to determine if the hand will be adequately perfused after resection of the ulnar or radial artery, and vascular reconstruction may be indicated.

There are important key principles to surgical resection of a malignant hand tumor. The goal of the resection is to have a cuff of normal tissue in all directions on the resected specimen. The major nerves and vessels of the area must be free of any tumor and if they are not, they must be part of the resection or amputation. The biopsy site and any contaminated area from previous surgery must be excised. A pneumatic tourniquet should be used for visualization as well as local control of tumor dispersion. Esmarch exsanguination is contraindicated to reduce risk of tumor cell seeding. Functional motor reconstruction must be accomplished with local muscle or tendon transfers. Similarly, soft tissue coverage should be performed with local flaps as distant donor sites can be contaminated during the resection surgery. Dead space should be minimized with the use of one or more drains to prevent hematoma. Prophylactic perioperative antibiotics should be given as tumor resection wounds have increased risk of infection.[18]

In the operating room, have the patient's imaging viewable for reference. Begin the surgery by outlining the planned incisions with a marking pen. Inflate the tourniquet without exsanguination. Make the planned incisions. Cauterize bleeding vessels and ligate large vessels throughout, as bleeding can carry tumor cells and contaminate adjacent tissues. Identify each deeper structure as it is encountered during dissection. Sever involved tendons, and tag proximally with suture for possible use in the reconstruction and closure. Sever nerves on tension. Once the specimen is removed, tag the removed specimen with suture to orient the pathologist unless the orientation is obvious. Attempt to reduce the dead space left in the defect as much as possible with the deep closure, and place a drain to reduce hematoma formation. Elevate local flaps for coverage of the defect and close the wound definitively, or use a negative-pressure wound dressing for temporary closure, and await pathology determination of healthy margins.[19,20] Postoperatively, keep the hand elevated. Remove the drain on postoperative day 1 or 2 depending on drain output. Initiate therapy on the remaining fingers as early as 1 week postoperatively.

Every malignant tumor of the hand is different, making each surgery unique. To illustrate one version of this procedure, consider the example of a 67-year-old man with a left hand first webspace epithelioid sarcoma (▶ Fig. 61.1a, b and ▶ Video 61.1). MRI shows a tumor involving the thenar eminence, the radial artery, the median nerve, and the flexor tendons to the thumb and index finger (▶ Fig. 61.1c, d). A partial hand amputation was performed including the thumb and index finger (▶ Fig. 61.1e). The specimen measured 11.7 × 6.7 × 6.5 cm (▶ Fig. 61.1f). The defect (▶ Fig. 61.1g) was covered immediately with the use of a fillet flap of the middle finger (▶ Fig. 61.1h). Pathology confirmed epithelioid sarcoma and clear margins (▶ Fig. 61.1i).

61.4 Conclusion

Meticulous planning and surgical decision-making are paramount for the treatment of hand tumors. It is of vital importance to treat any hand mass with the appropriate care to reduce morbidity and mortality. The treatment of a malignant hand mass carries even more gravity, as an unsuccessful resection may not only limit function but also impact a patient's final outcome and life span.

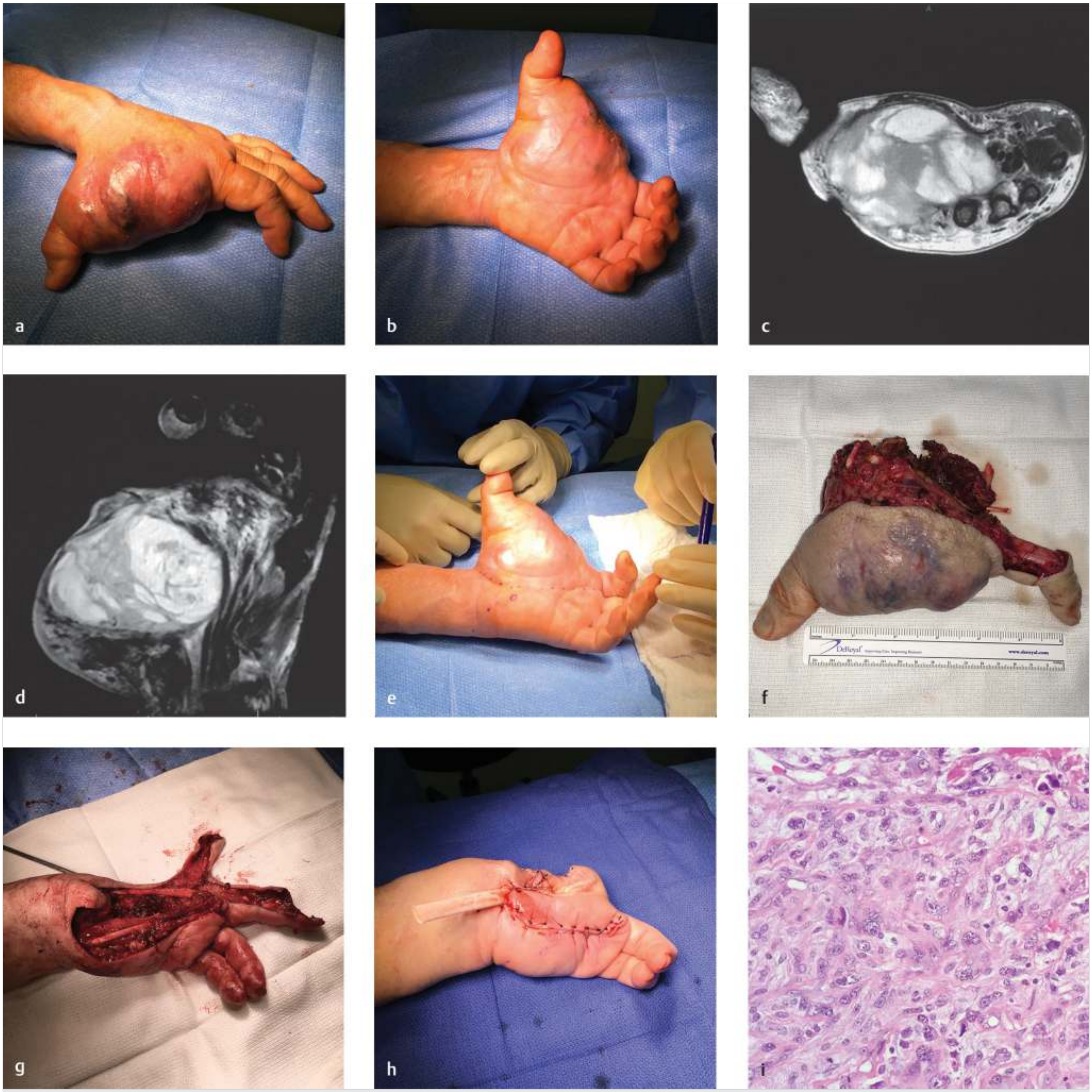
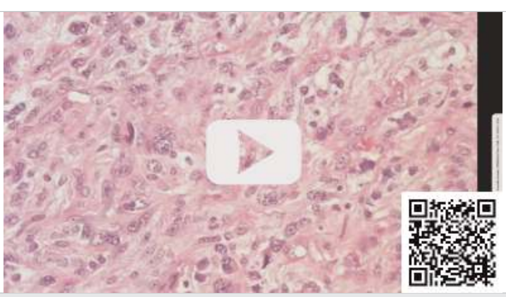


Fig. 61.1 **(a, b)** Left hand of a 67-year-old man with biopsy-proven epithelioid sarcoma. **(c, d)** Magnetic resonance imaging shows the tumor in the first webspace of the left hand with extension to the index and middle fingers. **(e)** Planned incision for partial hand amputation. **(f)** Tumor specimen. **(g)** The hand status post partial amputation. **(h)** Hand closure utilizing middle finger fillet flap. **(i)** Histological appearance of epithelioid sarcoma.



Video 61.1 Resection and coverage of epithelioid sarcoma of the hand

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62 Congenital Hand Reconstruction

Joshua Michael Adkinson

Abstract
Congenital hand differences are frequently encountered by the pediatric plastic surgeon and affect approximately 2 in every 1,000 live births. Syndactyly, thumb duplication, and thumb hypoplasia are some of the more common anomalies referred for evaluation. These conditions may have a substantial physical and psychological impact on the children and their parents. Successful treatment requires a thorough understanding of normal anatomy and anatomic variants, hand development, reconstructive strategies, and short- and long-term outcomes.

Keywords: congenital hand, pediatric hand, pollicization, polydactyly, syndactyly, thumb duplication, thumb hypoplasia

62.1 Introduction

62.1.1 Syndactyly

Syndactyly is defined by the level of fusion and the elements involved. Complete syndactyly involves the entire finger from the web to the tip (▶ Fig. 62.1), whereas incomplete syndactyly does not involve the entire finger (▶ Fig. 62.2). Simple syndactyly describes fusion of the skin only, whereas complex syndactyly describes a variable amount of bony fusion. Complicated syndactyly refers to fusion of multiple digits and multiple elements. This subtype may include additional bony abnormalities, such as extra, missing, or duplicated phalanges.[1]

62.1.2 Thumb Duplication

- Classification of the duplicated thumb is based on the level of duplication (▶ Table 62.1). The most common variant is Type IV (40–50%), which represents a complete duplication of the proximal and distal phalanges (▶ Fig. 62.3).

Fig. 62.1 Complete syndactyly of third webspace.

- Importantly, the thumb is not simply duplicated; the structures are abnormal in size and shape.[2] Generally, the duplicated radial digit is smaller in length and width.[3] The flexor and extensor tendons diverge and insert eccentrically into the base of the distal phalanges. The intrinsic musculature is aberrant and, in proximal duplications, the abductor pollicis brevis (APB) muscle inserts on the radial duplicate, whereas the remaining intrinsic muscles insert on the ulnar duplicate. The ulnar collateral ligament (UCL) of the metacarpophalangeal (MCP) joint is typically preserved because of the presence of the ulnar duplicate.[4]

62.1.3 Thumb Hypoplasia (Pollicization)

- Thumb hypoplasia is most commonly described using the Blauth classification system, which directly correlates with surgical treatment (▶ Table 62.2). The new anatomic functions of the pollicized digit are detailed in ▶ Table 62.3.
- Although Type IV (▶ Fig. 62.4) and V thumbs are easy to identify clinically, it can be difficult to distinguish Type IIIA (stable carpometacarpal [CMC] joint) from Type IIIB (unstable CMC joint) thumbs. This differentiation is based on serial examination of hand use.[5] If the thumb is integrated in object manipulation,

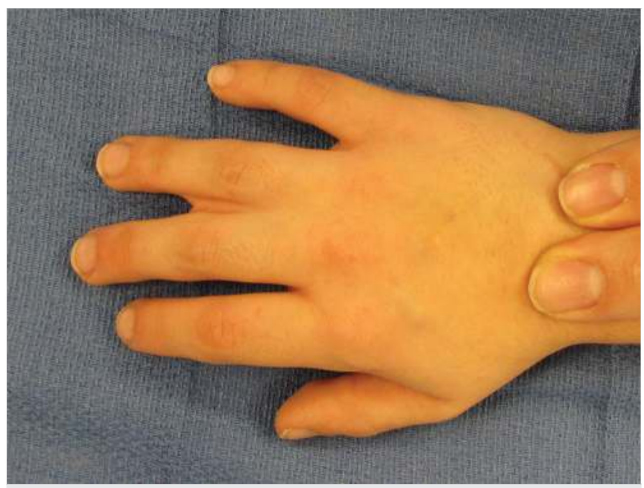

Fig. 62.2 Incomplete syndactyly of third webspace.

Table 62.1 Duplicated thumb classification system

Wassel type	Anatomic description
I	Bifid distal phalanx
II	Duplicated distal phalanx
III	Bifid proximal phalanx
IV	Duplicated proximal phalanx
V	Bifid metacarpal
VI	Duplicated metacarpal
VII	Triphalangeal thumb

Fig. 62.3 Type IV thumb duplication.

Table 62.2 Types of thumb hypoplasia and treatment options

Type	Appearance	Treatment
I	Minor generalized hypoplasia	Augmentation or no treatment
II	Absence of thenar intrinsic muscles Narrowed first webspace Insufficiency of thumb metacarpophalangeal ulnar collateral ligament	Opponensplasty (abductor digiti minimi, flexor digitorum superficialis) First webspace deepening Ulnar collateral ligament reconstruction
III	Type II plus extrinsic muscle and tendon abnormalities A. Stable CMC joint B. Unstable CMC joint	A. Reconstruction as with Type II B. Pollicization
IV	Pouce flottant (floating thumb)	Pollicization
V	Thumb absence	Pollicization

Abbreviation: CMC, carpometacarpal.

the CMC joint is likely stable and the thumb may be reconstructed. If the child uses scissor grasp between the index and long fingers, the index finger will begin to pronate and function more like a thumb. This finding suggests an unstable CMC joint (Type IIIB thumb).
- Many other anomalies are associated with thumb hypoplasia. Thumb hypoplasia is associated with VACTERL (i.e., vertebral abnormalities, anal atresia, cardiac abnormalities, tracheoesophageal fistula and/or esophageal atresia, renal agenesis and dysplasia, and limb defects), Fanconi anemia, Holt-Oram syndrome, and radial longitudinal deficiency.

62.2 Indications

62.2.1 Syndactyly

- Syndactyly release is indicated to improve appearance and function, as well as to prevent progressive finger deformity with growth.
- Surgery is performed between 12 and 18 months of age when the structures are larger and anesthesia is safer as compared to younger ages. For syndactyly involving the first and fourth webspaces (i.e., border digits), earlier release at approximately 6 months of age is recommended to prevent angulatory deformities resulting from differences in digital length.
- If adjacent webspaces are involved, it is safer to release them at separate stages at least 3 months apart in an effort to avoid digital ischemia of the central digit.
- For cases of incomplete syndactyly without a functional deficit and complicated cases that may result in worse postoperative function, surgery may not be indicated.

Table 62.3 Functional anatomy after pollicization

Original function	New function
Skeletal Units	
Distal interphalangeal joint	Interphalangeal joint
Proximal interphalangeal joint	Metacarpophalangeal joint
Metacarpophalangeal joint	Carpometacarpal joint
Musculotendinous Units	
Extensor indicis proprius	Extensor pollicis longus
Extensor digitorum communis (index)	Abductor pollicis longus
First palmar interosseous	Adductor pollicis
First dorsal interosseous	Abductor pollicis brevis

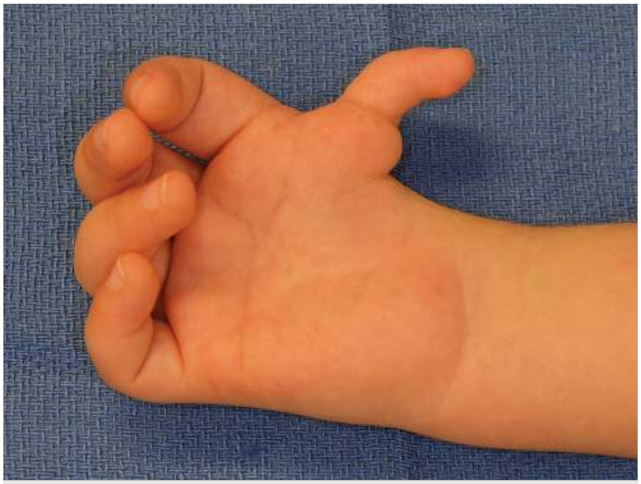

Fig. 62.4 Type IV thumb hypoplasia.

62.2.2 Thumb Duplication

- The goal of reconstruction is to improve the size and shape of the thumb without compromising function. Some children with a duplicated thumb may function reasonably well. However, the stigma of an uncorrected deformity may not be acceptable for the children or their parents.[6]
- Timing of surgery varies, but is typically considered around 12 months of age. This allows correction of the deformity before the development of substantial deviation of the duplicated elements and integrated thumb–index finger pinch. Further, anesthesia is safer at this age compared with younger ages and structures are larger, which facilitates dissection.

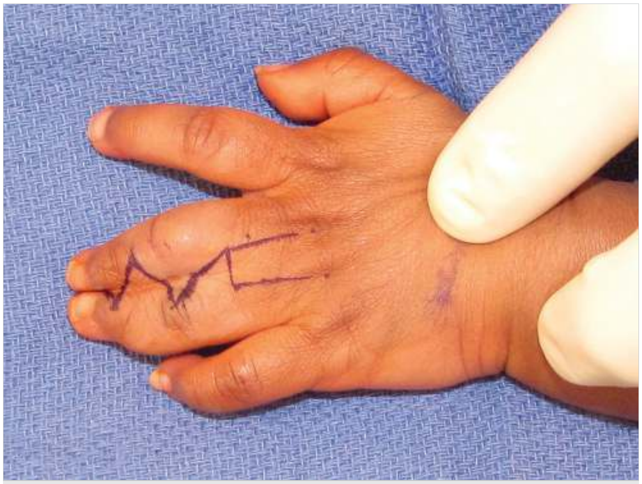

Fig. 62.5 Dorsal skin markings for syndactyly release.

Fig. 62.7 Long-arm cast.

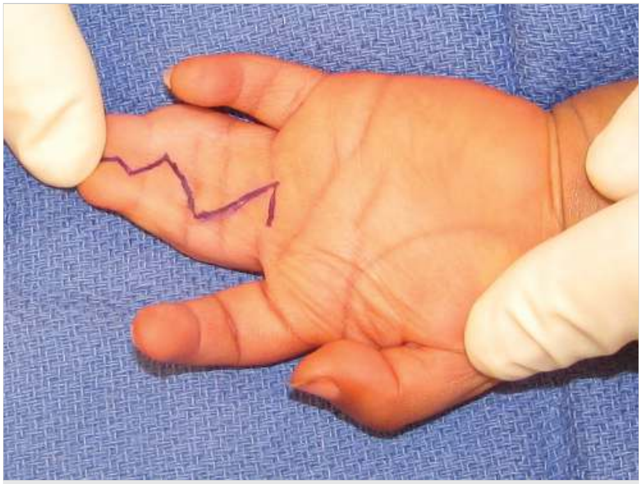

Fig. 62.6 Volar skin markings for syndactyly release.

62.2.3 Thumb Hypoplasia (Pollicization)

- Blauth Types I, II, and IIIB may be reconstructed using first webspace deepening, tendon transfers, and joint stabilization procedures, as needed.
- Hypoplastic thumbs with an inadequate CMC joint (Blauth Types IIIB, IV, and V) are best reconstructed by pollicization.[7,8]
- Pollicization is generally offered at 12 to 18 months of age as general anesthesia is safer and structures are larger, facilitating dissection. Surgery at this age also allows time for preliminary correction of any associated radial longitudinal deficiency (typically addressed between 3 and 6 months of age).

62.3 Operative Technique

62.3.1 Syndactyly

- The patient is placed supine on the operating table with the entire upper arm prepared in the surgical area. A nonsterile tourniquet is applied on the upper arm. When a full-thickness skin graft is anticipated (most cases), the groin should also be prepared into the field. The antecubital skin may also be used as a donor site for skin graft.
- A proximally based dorsal rectangular flap is created for webspace reconstruction. It is designed by marking the mid-point of metacarpal head and the mid-point of each proximal phalanx. The points are connected by slightly convergent lines that form a proximally based flap with its base at the level of metacarpal heads.
- The distal interdigitating flaps are designed using two Z-shaped lines, one dorsal and the other on the volar aspect of the hand. The dorsal markings are created by connecting the distal corner of the dorsal rectangular flap, the mid-point of the dorsal crease at the proximal interphalangeal (PIP) joint, the mid-point of the middle phalanx, and the mid-point of the dorsal crease at the distal interphalangeal (DIP) joint (▶ Fig. 62.5).
- The Z-shaped line should be at the same level on the dorsal side and the volar side (▶ Fig. 62.6).
- The dorsal rectangular flap is elevated first with a thin layer of fat.
- The interdigitating dorsal and volar flaps are elevated just onto the edge of the fingers to prevent unnecessary tendon exposure.
- If the fusion is complete, the fingertip containing the nail plate may be cut sharply using heavy scissors.
- Tenotomy scissors are used to spread transversely between the fused digits. Transverse fascial bands are identified and sharply divided in a distal to proximal direction. The digits should be completely released, ensuring protection of the neurovascular structures (▶ Fig. 62.7).
- The proximally based dorsal rectangular flap is advanced into the newly created webspace and secured using 5–0 chromic sutures. The flap should easily advance into the new webspace without tension.
- The digital flaps are incompletely inset with plans to minimize the number of small skin grafts needed to cover skin-deficient areas.
- The tourniquet is then deflated and hemostasis is ensured.

Fig. 62.8 Completely separated digits with skin grafts in place. Kirschner wire in place for simultaneous corrected clinodactyly of the ring finger.

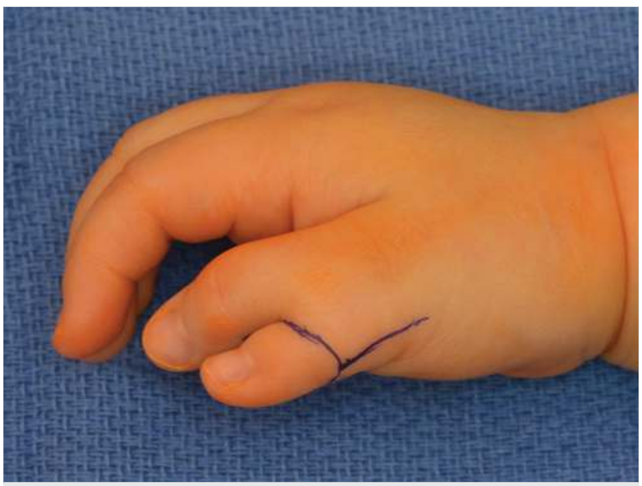

Fig. 62.9 Preoperative markings for Type IV thumb duplication.

- The interdigitating flaps are then completely inset and bare areas are addressed using full-thickness skin grafts.
- The full-thickness skin graft is taken from the lateral groin to minimize future hair growth at the recipient site. The skin and dermis are elevated sharply with a scalpel and any additional subcutaneous fat is removed with scissors.
- The skin graft is then cut to fill defects on the fingers. It is technically easier to cover fewer, larger skin defects than many small skin defects (▶ Fig. 62.8).
- The skin graft donor site dermis is reapproximated using absorbable suture and the skin is reapproximated with a subcuticular 4–0 Monocryl suture.
- Dressings are applied to provide compression to and minimize shear of the skin grafts.
- The wound should be protected using a long-arm cast for 2 to 3 weeks—it is imperative that the elbow be flexed at least 90 degrees to prevent premature cast removal (▶ Fig. 62.7).

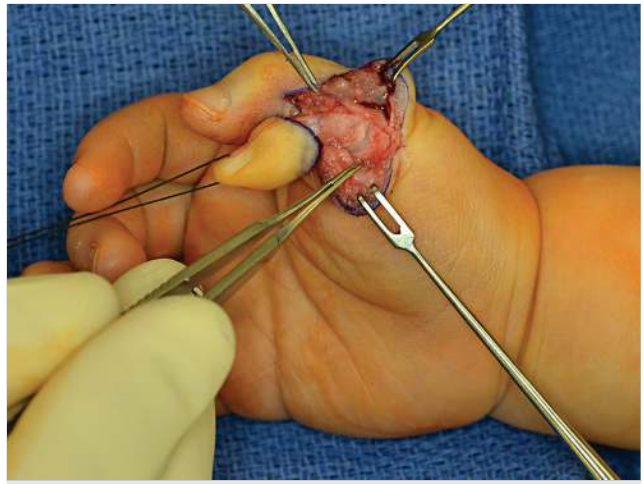

Fig. 62.10 Radial collateral ligament elevated with periosteal flap (held in lower forceps).

62.3.2 Thumb Duplication

- The operation is performed under general anesthesia with the patient in the supine position. A tourniquet is placed on the upper arm and the entire extremity is prepared and draped. Intraoperative fluoroscopy using a mini-C arm is required to confirm anatomy, alignment, or in planning and performing osteotomies.
- The radial duplicate is selected for removal because it is usually smaller and removal does not disturb the important UCL of the retained thumb. A racquet-shaped incision is designed (▶ Fig. 62.9). Full-thickness skin flaps are elevated to expose the radial aspect of the MCP joint and the extensor mechanism.
- The insertion of APB is detached, and the radial collateral ligament (RCL) is elevated with an extended periosteal flap to allow for reinsertion into the retained thumb proximal phalanx (▶ Fig. 62.10).
- The extensor and flexor tendons to the duplicated thumb are transected as distally as possible.
- The soft tissue connections between the duplicated elements are divided sharply. The MCP joint is entered and the radial duplicate is removed.
- Using a scalpel, an oblique osteotomy of the radial aspect of the metacarpal head is performed to reduce its prominence. Extreme care should be used when performing this maneuver to prevent transection of the previously elevated proximally based radial collateral ligament (▶ Fig. 62.11).
- If necessary, metacarpal or phalangeal osteotomies are performed at this time, guided by fluoroscopy. Closing wedge osteotomies allow for direct bone-to-bone healing, but may shorten an already small thumb.
- The thumb is neutrally aligned and secured in place using a longitudinal 0.035-inch Kirschner wire traversing the MCP joint (▶ Fig. 62.12).
- The periosteal flap carrying the RCL and the APB insertion is sutured to the radial base of the ulnar thumb proximal phalanx using multiple 4–0 nonabsorbable suture (▶ Fig. 62.13).

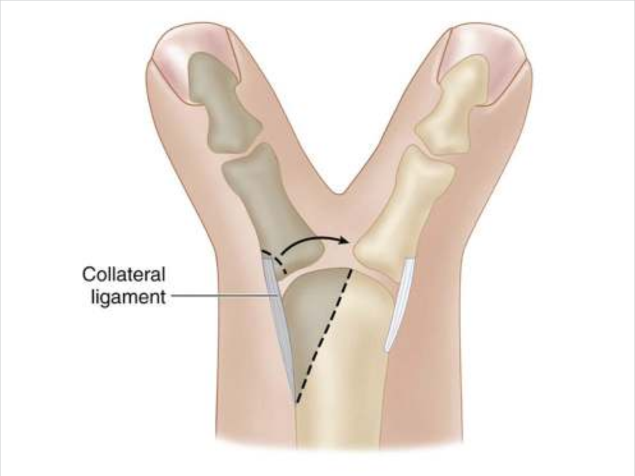

Fig. 62.11 Metacarpal head osteotomy.

Fig. 62.13 Reinsertion of the radial collateral ligament into the proximal phalanx.

Fig. 62.12 Kirschner wire fixation of the thumb in neutral alignment.

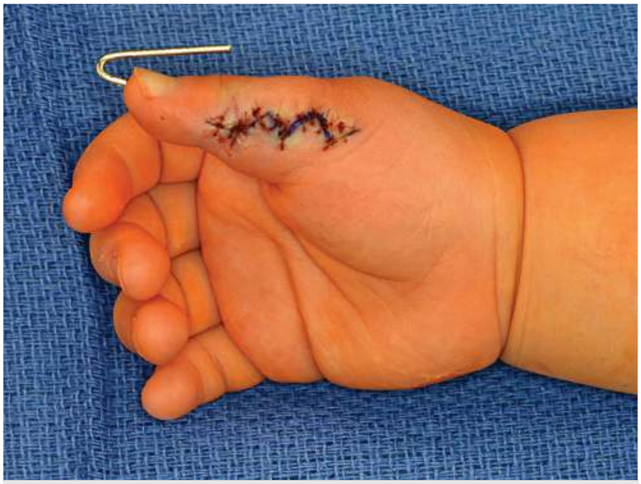

Fig. 62.14 Skin closure.

- The duplicated extensor tendon of the resected thumb is sutured to the ulnar aspect of the retained thumb distal phalanx to balance the deforming forces acting across the thumb interphalangeal (IP) joint. This may be performed through the radial incision or passed subcutaneously to an additional incision over the ulnar aspect of the distal phalanx (▶ Fig. 62.13).
- The tourniquet is released and hemostasis ensured. The skin flaps are contoured and closed with multiple interdigitating Z-plasties to prevent future scar contracture (▶ Fig. 62.14).
- A well-padded long-arm thumb spica cast is applied to the arm, with the elbow in at least 90 degrees of flexion.
- The K-wire is removed between 4 and 6 weeks postoperatively.

62.3.3 Thumb Hypoplasia (Pollicization)

- The procedure is performed under general anesthesia with the patient placed supine on the operating room table. A well-padded tourniquet is placed on the upper arm and the limb is prepared and draped in the usual fashion.
- A longitudinal curvilinear incision is marked over the palmar aspect of the index finger metacarpal. An inverted U-shaped incision is marked over the proximal volar and dorsal aspects of index finger proximal phalanx. The markings converge at the level of the palmar digital crease (▶ Fig. 62.15).
- The palmar skin incisions are made first, and full-thickness skin flaps are elevated.
- The index finger radial digital neurovascular bundle is identified and isolated. The common digital artery to the second webspace is then identified. The dissection continues distally to isolate the ulnar digital artery to the index finger and the radial digital artery to the long finger (▶ Fig. 62.16).
- The radial digital artery to the long finger is ligated using 6–0 Prolene suture or micro clips distal to the bifurcation. After this structure is divided, the index finger is entirely based on the common digital artery to the second webspace and the index finger radial digital artery, if present. The vessels are mobilized proximally to the level of the superficial arch to prevent tethering of the vessels with proximal transposition of the index finger.

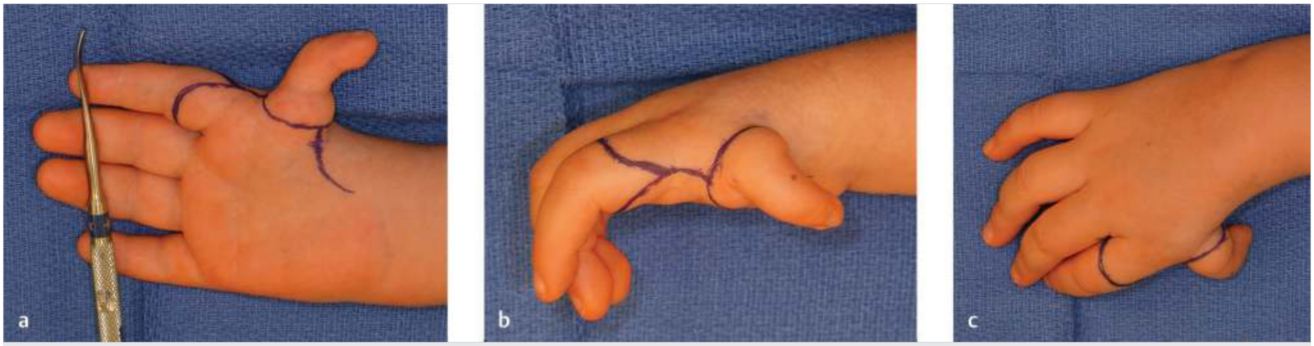

Fig. 62.15 **(a)** Volar skin markings. **(b)** Radial skin markings. **(c)** Dorsal skin markings.

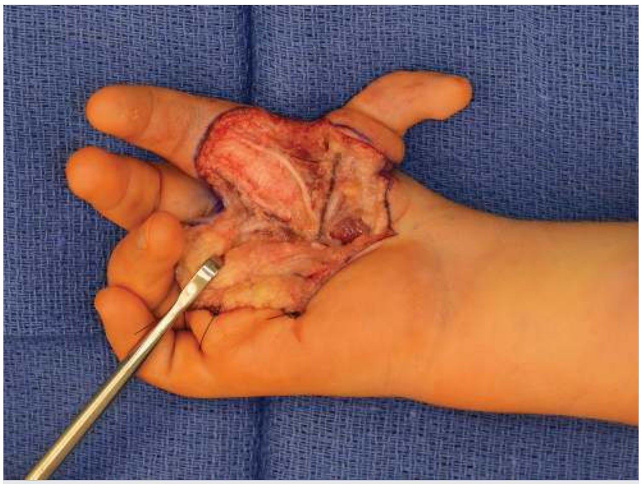

Fig. 62.16 Dissection of neurovascular structures.

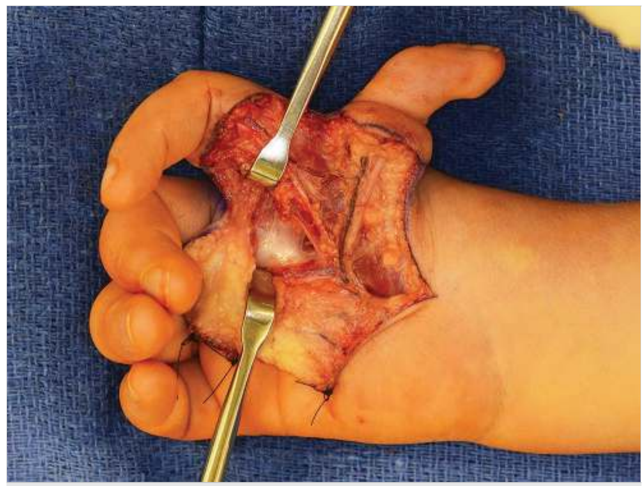

Fig. 62.17 Transverse metacarpal ligament.

- Intraneural dissection of the common digital nerve is done to separate the fibers of the ulnar digital nerve to the index finger from the fibers of the radial digital nerve to the middle finger. This dissection is carried proximally to the level of the superficial arch.
- The A1 pulley of the index finger is divided.
- The ulnar neurovascular bundle of the index finger is retracted radially, and the transverse metacarpal ligament between the index and long fingers is sharply divided at the neck of the metacarpal (▶ Fig. 62.17).
- The dorsal skin incision is made and flaps are raised at the dermal layer. It is imperative to keep the dorsal veins within the subdermal layer to maintain venous outflow from the index finger.
- The juncturae tendineae between the index and long finger extensor tendons are divided.
- The first dorsal and palmar interossei are elevated off the radial and ulnar aspects of the index metacarpal shaft, respectively, leaving only the proximal portion attached to the metacarpal base. The tendinous portion of the interossei is divided distally at the MCP joint level.
- The skin is elevated over the index finger proximal phalanx, and the radial and ulnar lateral bands are identified on either side of midproximal phalanx. The location of these structures can be confirmed by placing them on traction and noting extension of the index finger PIP joint. The lateral bands are tagged with nonabsorbable suture for future identification.
- The index finger metacarpal shaft is shortened by performing two osteotomies; the distal osteotomy is created through the physis, whereas the proximal osteotomy is done at the metacarpal base (▶ Fig. 62.18).
- To prevent hyperextension of the index finger MCP joint (new thumb CMC joint), the dorsal capsule is sutured to the physis with nonabsorbable suture while the joint is in maximal hyperextension.
- The new thumb is placed over the base of the index metacarpal. The MCP joint will now function as the thumb CMC joint. It is positioned in 45 degrees of palmar abduction and 100 to 120 degrees of pronation to recreate the position of the thumb (▶ Fig. 62.19). Sutures are used to stabilize the pollicized digit to the residual index metacarpal base.
- The first dorsal interosseus tendon is attached to the radial lateral band at the midproximal phalanx to provide abduction of the pollicized index finger. The first palmar interosseus tendon is attached to the ulnar lateral band and functions as the thumb adductor.
- The extensor and flexor tendons are left undisturbed and will shorten over time.
- The skin flaps are loosely inset with a few chromic sutures.

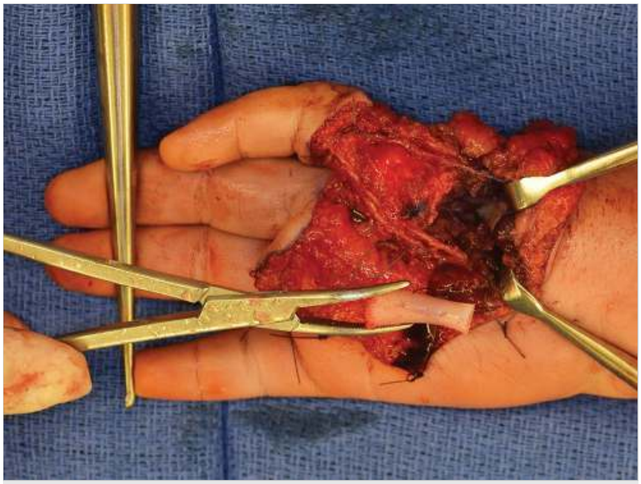

Fig. 62.18 Resection of metacarpal shaft.

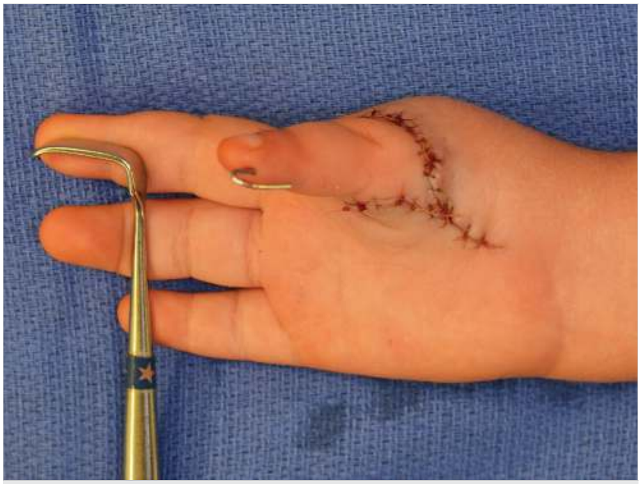

Fig. 62.19 Index finger repositioning and skin flap inset.

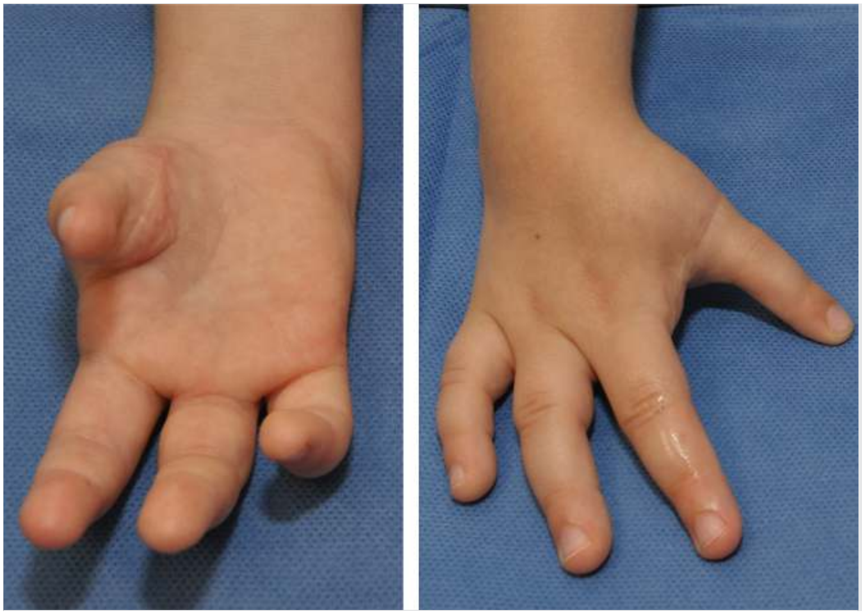

Fig. 62.20 Follow-up at 1 year after pollicization.

- The tourniquet is released, and the pollicized digit is inspected for capillary refill and evidence of vascular compromise. After ensuring meticulous hemostasis, the skin flaps are fully inset.
- A well-padded long-arm thumb spica cast is applied with the elbow in at least 90 degrees of flexion to prevent premature removal.
- The cast is removed at 4 weeks and hand therapy is initiated to address thumb mobility, pinch, and grasp. A short-arm thumb spica splint is worn for an additional 4 to 8 weeks for protection and stability.
- Long-term follow-up is shown in ▶ Fig. 62.20.

62.4 Conclusion

62.4.1 Syndactyly

- A flap should always be used to resurface the webspace.
- Digits should be covered by interdigitating flaps. Full-thickness skin grafts are frequently required to completely cover exposed subcutaneous tissues after digital separation.
- Stage release of adjacent webspaces to avoid vascular compromise.
- Web creep (longitudinal extension of the commissural scar) may occur after reconstruction and can be prevented by avoiding a straight-line scar in the webspace.[9] If present, it may be addressed using local tissue rearrangement.
- With meticulous technique and preoperative planning, children with syndactyly do very well after reconstruction.

62.4.2 Thumb Duplication

- The anatomy of a duplicated thumb is never normal, but examination and radiographs will provide enough information for surgical planning.

- Never sacrifice function to improve the appearance of a duplicated thumb.
- In proximal duplications, the radial duplicate is most commonly selected for removal; this ensures the preservation of the UCL of the MCP joint.
- The reconstructed thumb will be smaller and weaker than the contralateral unaffected thumb.[10]
- The development of an angular deformity is not uncommon during growth. As such, patients should be re-evaluated annually. If a progressive deformity occurs, a corrective osteotomy may be performed to straighten the thumb. This is ideally performed before school age (5 years old).

62.4.3 Thumb Hypoplasia (Pollicization)

- Pollicization is the preferred procedure for Blauth Types IIIB, IV, and V thumbs.
- The procedure requires meticulous attention to detail and a thorough understanding of normal and aberrant anatomy.
- Shortening of the index finger extrinsic tendons is not required because they will shorten over time.
- In general, outcomes following pollicization are directly related to the mobility of the index finger.[11] Pollicization achieves about 30% of grip and pinch strength compared with the contralateral thumb.

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63 Lower Extremity: Soft Tissue Reconstruction

Eric I-Yun Chang

Abstract
Lower extremity reconstruction can be simplified based upon the location of the defect. Reconstruction of wounds along the proximal third of the lower extremity is ideally suited for a pedicled gastrocnemius muscle flap while lower extremity defects along the middle third are most amenable for a pedicled soleus muscle flap for reconstruction. Wounds along the distal third of the lower extremity are more complicated but can be reconstructed with local pedicled or propeller flaps or free tissue transfer.

Keywords: gastrocnemius flap, local pedicle flap, lower extremity reconstruction, medial plantar artery flap, propeller flap, reverse sural flap, skin graft, soleus flap

63.1 Introduction

Reconstruction of the lower extremity is typically due to tumor extirpation or in the setting of traumatic injuries.[1] Lower extremity wounds can be particularly challenging due to the extent of resection for cancer clearance or zone of injury based upon the mechanism of trauma. Another large subset of patients who often need lower extremity reconstruction includes those patients with various comorbid conditions such as peripheral vascular disease (PVD) and diabetes mellitus.[2,3] The primary goal is often limb salvage and avoiding any amputation.

63.2 Indications

Typically, lower extremity reconstruction focuses upon soft tissue coverage of vital structures such as exposed bone, tendon, and neurovascular bundles.[1] However, the etiology of the wound must be taken into account. If the wound is due to resection of malignancy, the presence of neoadjuvant treatments such as chemotherapy and radiation or the need for additional adjuvant treatments must be considered. For traumatic wounds, the Gustilo classification is often employed but may be limited due to the mechanism of injury. The zone of injury may be significantly larger in the setting of blast or crush injuries compared to penetrating wounds. The treatment of patients with diabetic ulcers and nonhealing wounds due to PVD must focus on medical optimization prior to proceeding with extensive reconstructive surgery.[2,3]

The options for reconstruction of the lower extremity are generally based upon the location of the wound. Reconstruction of the superior aspect of the lower extremity above the knee can often be performed with primary complex closure and local tissue rearrangement. Wounds involving the distal aspects of the lower extremity around the knee and distally usually require flap reconstruction. This portion of the lower extremity is divided into thirds to facilitate the decision-making process. Obviously, adequate debridement of nonviable and devitalized tissue and medical optimization should be performed prior to undergoing reconstruction.

63.3 Operative Technique

Wounds along the proximal third of the lower extremity around the knee can typically be reconstructed with a pedicled gastrocnemius muscle flap (▶ Fig. 63.1).[4,5,6] The gastrocnemius muscle is a bilobed muscle that is divided by a central raphe with the medial muscle belly being larger and longer in size (▶ Fig. 63.2). This enables the gastrocnemius muscle to be divided in half, if necessary, depending on the size and location of the defect. The gastrocnemius muscle is elevated off the soleus muscle, and the distal attachments to the Achilles tendon are divided allowing the muscle to rotate superiorly and provide coverage of the wound (▶ Fig. 63.3). A skin graft will be necessary to cover the muscle.

The primary option for reconstruction of the middle third of the lower extremity is a pedicled soleus muscle flap (▶ Fig. 63.4).[7,8] The soleus muscle also has a medial and lateral belly which is separated by an intermuscular septum. This central septum allows the soleus muscle to be split in half similar to the gastrocnemius muscle so that a hemisoleus flap may be elevated. The soleus muscle is dissected from the overlying gastrocnemius muscle. Based upon the extent of the defect, a hemisoleus flap or the entire soleus muscle may be harvested; however, a hemisoleus flap does provide a greater arc of rotation (▶ Fig. 63.5). After the soleus muscle has been completely elevated and rotated into the wound, a skin graft is also required for coverage of the muscle.

Reconstruction of the distal third of the lower extremity is significantly more difficult due to the lack of adequate donor soft tissues in this region. Clearly, if the zone of injury extends

Fig. 63.1 Defect of the upper third of the right lower extremity after neoadjuvant chemoradiation and radical resection of malignant fibrosarcoma.

Fig. 63.2 Elevation of the lateral gastrocnemius muscle flap with scoring of the fascia.

Fig. 63.3 Coverage of the proximal third defect with a pedicled lateral gastrocnemius muscle flap.

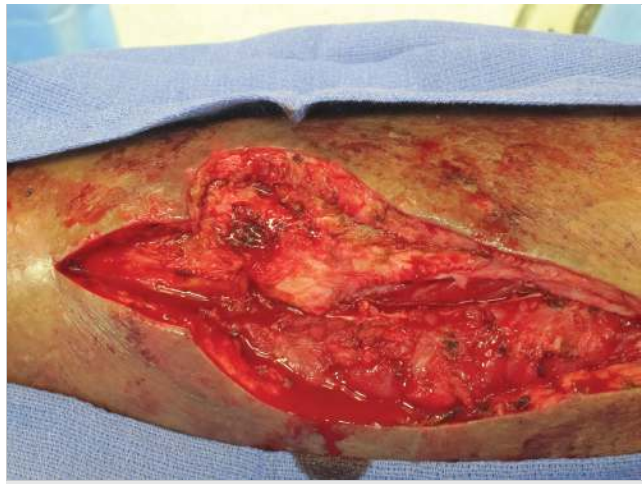

Fig. 63.4 Defect of the middle third of the right lower extremity after debridement of chronic wound and removal of infected hardware for tibia fracture.

Fig. 63.5 Elevation of the medial hemisoleus flap.

beyond the actual wound or the field of radiation encompasses a large area of the surrounding soft tissues, local and regional flaps would not be possible. Based upon the size, location, and mechanism of the defect, reconstruction along the distal third may require free tissue transfer. In these instances, a free muscle flap such as the rectus abdominus, latissimus dorsi, or gracilis would be recommended.[9,10]

For defects along the ankle and heel, a reversed sural fasciomyocutaneous flap is a suitable option.[11,12,13] The most inferior perforator of the peroneal artery is identified in the retromalleolar region approximately 5 to 6 cm superior to the lateral malleolus with a Doppler probe, which will serve as the pivot point of the flap. The dimensions of the flap are marked and may extend proximally to the popliteal fossa if necessary. The flap should be elevated carefully to preserve the mesentery of the medial sural neurovascular bundle. Harvesting a portion of the gastrocnemius muscle may help to preserve the subdermal plexus and provide additional soft tissue for obliteration of any dead space within the heel if needed.[14] The donor site can be closed primarily if the flap width is 7 cm or less.

Defects along the plantar surface of the foot and heel can be reconstructed with a medial plantar flap.[15,16,17] Once again, a Doppler probe is used to identify the location of the medial plantar artery and the flap is centered along the course of the vessel. The flap is elevated approximately 1 cm proximal to the metatarsal head in order to avoid compromising the weight-bearing region of the forefoot (▶ Fig. 63.6). The dissection proceeds to identify the medial plantar artery, which is located between the adductor hallucis and flexor digitorum brevis muscles. The flap is elevated in the subfascial plane from distal to proximal taking care to preserve the main plantar nerve (▶ Fig. 63.7). The vascular pedicle and surrounding fat are elevated until the flap reaches the defect (▶ Fig. 63.8). A skin graft is usually necessary for coverage of the donor site.

The recent development of perforator flaps led to the introduction of propeller flaps as another option for lower extremity reconstruction.[18,19,20] The location of the perforator is identified with a Doppler probe and the design of the two skin paddles are centered over the perforator which serves as the point of

Fig. 63.6 Defect of the distal third of third of the right lower extremity after radical resection of malignant melanoma with exposure of the calcaneus.

Fig. 63.7 Elevation of the medial plantar artery flap.

Fig. 63.8 Coverage of the calcaneal defect with a pedicled medial plantar artery flap.

rotation for the flap. The flap is elevated typically in the subfascial plane to the perforator and rotated 180 degrees along the longitudinal access of the extremity in order to reconstruct the defect.

63.4 Conclusion

Lower extremity reconstruction is crucial as these surgeries often coincide with limb salvage in order to avoid any amputation. The primary options for reconstruction are generally based upon the principle of thirds where the proximal two-thirds of the lower extremity are amenable to pedicled muscle flaps while the distal third often requires free flap coverage. Even if limb salvage is not possible, recent advancements in targeted muscle reinnervation (TMR) and robotic prostheses offer patients new hope in the setting of an amputation.

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64 Lower Extremity Wound Treatment with Free Flap

Hyunsuk Peter Suh and Joon Pio Hong

Abstract
Lower extremity wound can be caused by underlying ischemia, diabetes, osteomyelitis or severe trauma, or tumor ablation surgery. If the local tissue is not sufficient for closure of the wound or the surrounding soft tissues are not well perfused because of the underlying vasculopathy, vessel injury, or scarring, free flap is an option for lower extremity wound treatment. In some cases, free flap can be an easier option and has a better aesthetical result. To successfully reconstruct lower extremity wound, there are five key steps to follow: (1) wound bed preparation, (2) recipient vessel preparation, (3) flap selection/elevation, (4) microanastomosis, and (5) flap insetting. Postoperative management is also crucial for flap success and minimizing the complications.

Keywords: flap monitoring, free flap, Lower extremity reconstruction

64.1 Introduction

- Lower extremity wound caused by severe trauma, ischemia, and chronic infection is difficult to close in many cases.
- If local tissue is not sufficient or skin graft is not possible, free flap can be an option for wound coverage.
- One should have adequate knowledge when to do the free flap and how to adequately perform the procedures.
- Most common and important comorbidities:
  - Peripheral artery obstructive disease.
  - Wound infection.
  - Osteomyelitis.
  - Peripheral vessel injury.
  - Diabetes.

64.2 Indications

- Bone, joint, tendon, or implant exposure.
- Failure of local treatment including primary closure or local flap.[1,2]
- To maintain maximal functional length of foot or leg.
- Defect caused by:
  - Trauma.
  - Cancer ablation surgery.
  - Ischemic wound.
  - Diabetic foot.

64.3 Operative Technique

- Diagnosis and imaging:
  - Vascular status; evaluating perfusion of the lower extremity.[3,4]
  - Occult vascular injury cannot be excluded by physical examination in long bone injury.
  - Vessel examination is crucial especially for flap coverage.
  - Clinically:
    - Pulse; often limited due to peripheral vasoconstriction and tissue edema.
    - Extremity temperature.
    - Capillary refilling.
  - Vascular examination is essential in following circumstances:
    - Loss of one or more peripheral pulse.
    - Neurological deficit secondary to injury.
    - In compound fracture after reduction surgery.
  - Handheld Doppler tracing:
    - Check peripheral vessel flow: dorsalis pedis artery, anterior tibial artery, or posterior tibial artery.
    - Retrograde flow examination is also possible by pressing the posterior tibial artery or dorsalis pedis artery and checking the flow of the other.
  - Conventional angiography (▶ Fig. 64.1 and ▶ Video 64.1):
    - Invasive and more radiation compared to computed tomography (CT) angiography.
    - Can verify the direction of the flow.
    - Can minimize the artifact and signal disturbance even with the foreign body.
  - Check CT angiography (▶ Fig. 64.2):
    - As sensitive as and conventional angiography.[3,4,5]
    - Three-dimensional reconstruction is possible; location of pathologic area and fracture can be assessed.
    - Fast test with less complication.

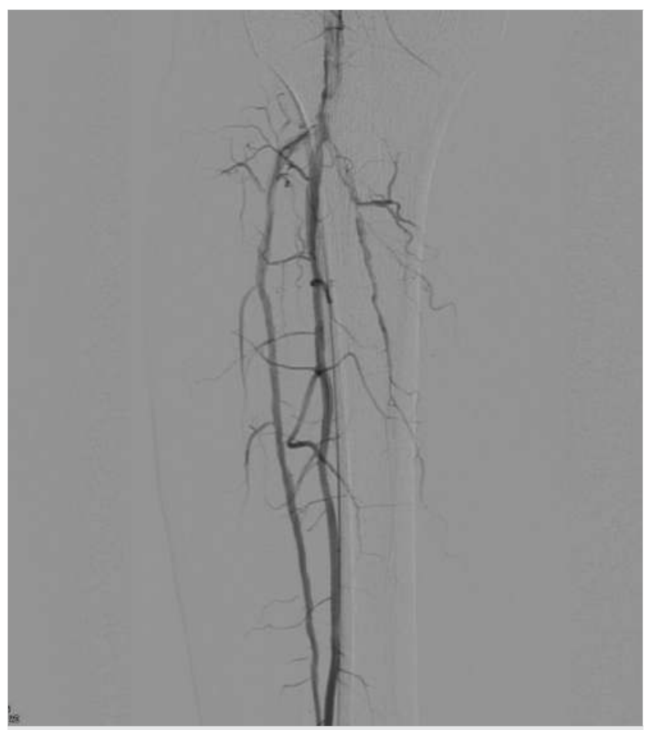


Fig. 64.1 Conventional angiography. By using conventional angiography, signal disturbance or artifact due to external fixator or implant can be minimized.

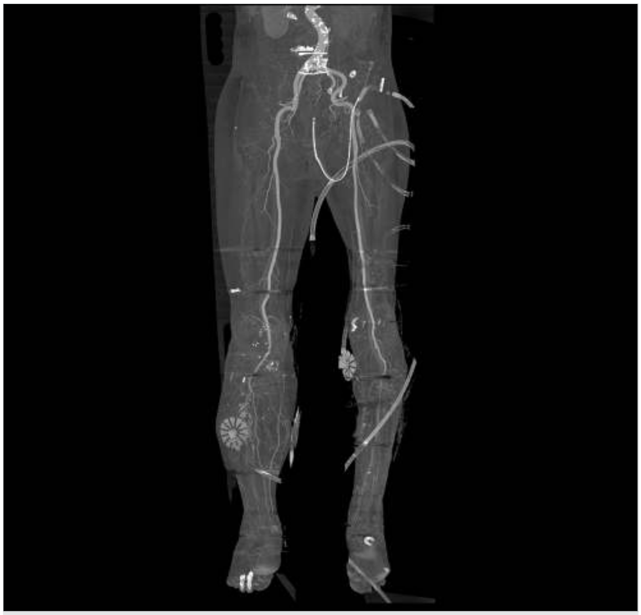


Fig. 64.2 Computed tomography (CT) angiography of lower extremity.

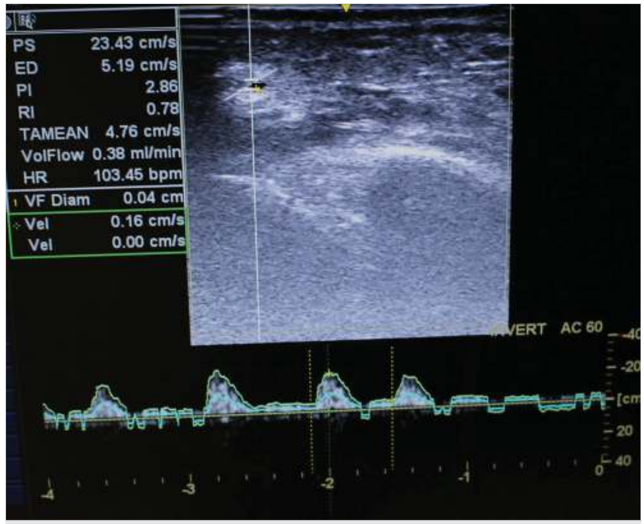


Fig. 64.3 Color Doppler. The size of the vessel and the flow velocity of the vessels can be checked.

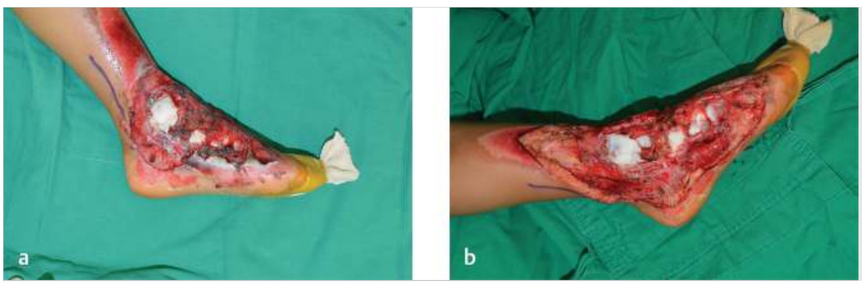


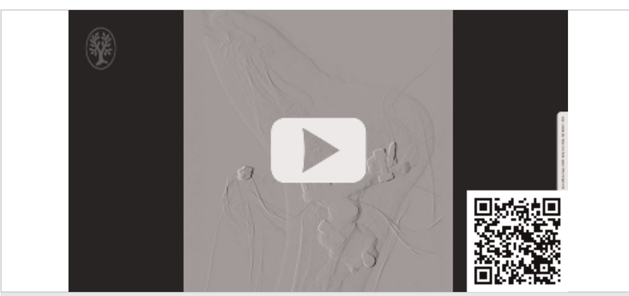
Fig. 64.4 Debridement for acute wound. **(a)** There are nonviable tissue and necrotic tissue before debridement. **(b)** After debridement there is minimal necrotic tissue and pin-point bleeding is checked from the base of the defect.

Fig. 64.5 Debridement for infected diabetic ulcer. **(a)** There is necrotic tissue and infected bone. Pus is draining along the fascial layer. **(b)** After serial surgical debridement and negative pressure wound therapy, there is no necrotic tissue left.

- ◦ Magnetic resonance (MR) angiography.
- ◦ Color flow Doppler (▶ Fig. 64.3).
- Prerequisite for flap coverage:
  - ◦ Wound bed preparation.
  - ◦ Proper debridement; necrotic tissue or nonviable tissue should be debrided.[1,2]
  - ◦ Control of infection; serial debridement with negative pressure wound therapy helps to achieve proper wound bed before flap coverage.
  - ◦ Infection might be aggravated after flap surgery if necrotic tissue and bacterial colonization are not solved.
  - ◦ There is neither definite laboratory data nor certain number of debridement which ensures successful reconstruction.
  - ◦ Decreasing inflammatory markers and improving status of wound infection is one of most important signs to cover the wound.
  - ◦ The procedure can take from days to weeks in infected wound.
  - ◦ Improving perfusion; angioplasty or bypass surgery can improve distal circulation and increase success rate of free flap transfer and limb salvage.
- Debridement and wound bed preparation (▶ Fig. 64.4 and ▶ Fig. 64.5):
  - ◦ Complete debridement of necrotic and nonviable tissues.
  - ◦ Pin-point bleeding from the wound bed is the most important clue of proper debridement.

- Fresh tendon can be saved even if there is no bleeding from it to preserve the joint function after wound coverage.
- Epithelializing edge of the wound should be excised with blade to promote wound healing at the margin of the transferred flap.
- Send culture study before and after debridement for postoperative antibiotics selection.

• Recipient vessel preparation:[2]
  - During the debridement, peripheral vessels or perforator with good flow can be found and should be preserved.
  - Use loupe with × 3.5 to approximately × 5 magnification to dissect the recipient vessel.
  - Even if there is a fibrosis and scarring, vessels with good perfusion can be found after proper dissection under microscope (> × 5.0 magnification).
  - If there is too much scar or no vessel with proper perfusion, look for the vessel around the wound.
  - Veins are more fragile under the scar tissue.
  - In ischemic limb, move to another vascular territory if there is no perforator or any vessel with flow.
  - Vessel pulsation and pulsatile flow from the distal cut end of the vessel can be regarded as reliable indicators for recipient artery.
  - For the recipient vein, it is hard to guarantee the patency because there is no back flow from it because of multiple valves.
  - It is safer to use deep vein system rather than cutaneous vein especially in trauma cases with proximal injury.
  - Dissect few centimeters of the vessel around the area of microanastomosis to promote easy handling and vessel clamp application (▶ Fig. 64.6).
  - Cut the vein at more distal location to gain more length (▶ Fig. 64.6).
  - If there is more vein around the defect, preserve it for additional vein anastomosis or revision surgery.



Video 64.1 With conventional angiography, flow of the vessels can be detected

• Flap selection and flap elevation:
  - Muscle flap, fascia flap, perforator flap, and conjoined flap can be elevated (▶ Fig. 64.7).
  - If the flap is planned to be elevated from the lower limb, elevate the flap from the same limb where there is the wound and preserve another limb from scarring from flap harvest.

• Microanastomosis:
  - Use surgical microscope with more than × 5 magnification.
  - Either artery or vein can be sutured first.
  - If one lies deeper, the microanastomosis would become more difficult or impossible after suturing the other; therefore, suture deeper one first.
  - If the recipient artery is perforator vessel, make sure there is no kinking of artery.
  - Less than 1:3 size mismatch can be overcome just by dilatation of the lumen.
  - When peripheral vessels (anterior tibial artery, posterior tibial artery, or dorsalis pedis artery) are used for anastomosis, used end-to-side method or flow-through method to preserve distal circulation (▶ Fig. 64.8).

• After anastomosis, check perfusion:
  - Check pulsation of pedicle and perforator.
  - Check venous outflow at the anastomosis site by milking test.
  - Check capillary refill of the flap.
  - Confirm free bleeding from the flap margin.
  - Check if there is no rotation of pedicle before anastomosis and prevent kinking of artery and vein before insetting flap.

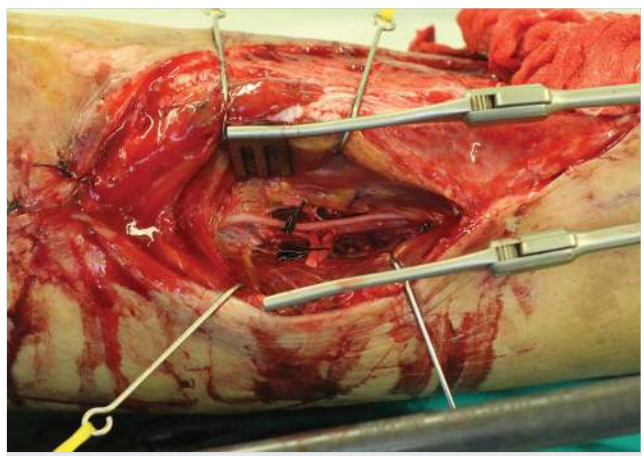


Fig. 64.6 Preparation of recipient vessel. Few centimeters of the vessels should be dissected for easy handling and clamping of branches. Veins are cut from the distal (right side of the picture) to gain more length.

Fig. 64.7 **(a)** Skin flap and **(b)** musculocutaneous flap for soft tissue coverage.

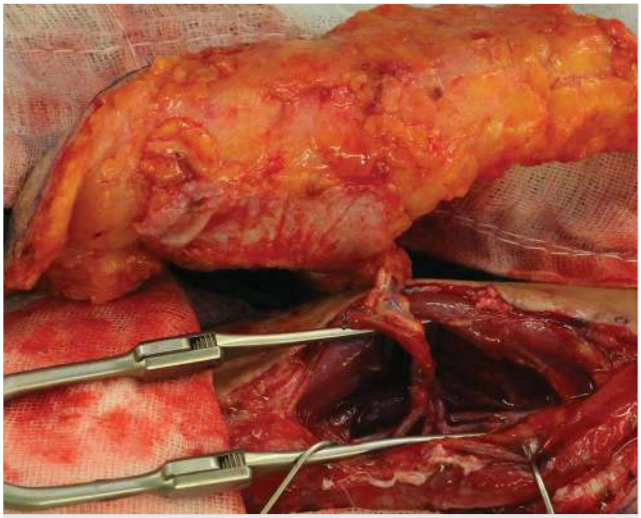


Fig. 64.8 End-to-side microanastomosis of one artery and two end-to-end microanastomosis of veins.

- Flap insetting:
  - Approximate skin edge to promote wound healing.
  - Locate suction drainage or Penrose drain to prevent hematoma or seroma collection.
  - When inserting suction drain, care must be taken not to kink the pedicle.
- Dressing:
  - Keep soft dressing for 5 days and prevent compressing of pedicle.
  - If anterior tibial artery or dorsalis pedis is used as a recipient artery, dorsiflexion is essential.
  - Keep dorsiflexion of ankle if there is immobilization to prevent plantar flexion contracture.
- Aftercare:
  - Wheelchair ambulation after postoperative day 2.
  - Discharge patient after about postoperative day 4 to 5.
  - Weight bearing is possible after around 4 to 5 days depending on bony stability.

Video 64.2 Key procedures of flap surgery on lower pextremity wound

  - Partial weight bearing is possible after 3 weeks when the flap is placed on the plantar surface.

Overall approach is shown in ▶ Video 64.2.

64.4 Conclusion

Free flap is one of the options for lower extremity wound coverage. For successful free flap reconstruction, vessel evaluation, wound bed preparation, and postoperative care are as important as microsurgical procedures.

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Section V

Integument

V

65 Burn Reconstruction

Nelson Piccolo and Sigrid Blome-Eberwein

Abstract
With more and more burn-injured patients becoming burn survivors over the past five decades, burn reconstruction has become a much more common, and often very challenging, request for plastic surgeons all over the world. Almost all burn injuries leave scars, ranging from "just" pigment-related changes (lighter than surrounding skin in fair-skinned people, darker in dark-skinned people), which can nevertheless be very obvious and hard to hide, to massively hypertrophic scars with severe functional impairment. In the medical community the term "burn reconstruction" is often used to describe advanced methods used to close the burn wound, namely, skin substitutes and tissue transfer. We will instead concentrate in this chapter on the most common true "reconstruction" procedures for burn-related scars.

Keywords: burn scar, burn survivor, butterfly plasty, closed platysmotomy, fat injection, fractional CO_2 laser, reconstruction, scar management, scar subcision, scar treatment, tissue expansion, Z-plasty

65.1 Introduction

The first principle of burn reconstruction is to await the end result of the remodeling phase of wound healing. This can mean 3 to 18 months after wound closure. During this phase, scar treatment is indicated, including, but not necessarily limited to, scar massage, moisturizing, compression garments, lymphedema therapy, physical and occupational therapy with stretching and splinting, fractional ablative and nonablative laser treatments (▶ Fig. 65.1), special positioning, and weight gain control. True burn reconstruction begins when no more rapid change in scar appearance or function can be noticed.

All scars have structural changes that distinguish them from normal skin, whether spontaneously healed, mesh-grafted, sheet grafted, or closed by more sophisticated tissue regeneration template or transfer methods. In addition to the already mentioned pigment changes, burn scars have reduced or no oil glands, sweat glands, and hair follicles. They contain less elastin, lack sophisticated nerve endings (hot/cold sensation, vibration, and light touch are always affected in grafted scars, while pressure, pain, and pruritus sensation may be preserved), and often cover large body areas. Simple excision or excision over tissue expanders is most often not an option and carries its own problem of creating a contour deficit and/or a new scar that, due to the created tension, most often widens with time.

Fig. 65.1 Scar post fractional laser treatment.

65.2 Indications

The most common indications for burn reconstruction procedures are functionally limiting scar contractures across joints; symptomatic hypertrophic scars (itching and pain); and openly visible scars on face, scalp, chest, hands, and lower legs. Obviously, all available techniques of local and free tissue transfer, as well as dermal regeneration and expander techniques, have been used in burn scar reconstruction, but these techniques have been described in detail elsewhere.[1,2,3,4]

Although some scar entities like pigment and structure and hypertrophy can be positively influenced by various light-based therapies,[5] certain tension related issues need surgical rearrangement in order to achieve "scar rehabilitation" (a term used by Dr. Matthias B. Donelan, Shriners Hospital in Boston)[6] and full release of contractures.

We will describe (1) a webspace release procedure most often used on hands and toes, (2) an axillary contracture release via Z-plasty, (3) scar subcision and fat injection for symptomatic scars adherent to underlying muscle fascia, (4) percutaneous contracture band release of the neck, and (5) a multiple expander technique for reconstruction.

65.3 Operative Technique

In general, burn scars have no or very limited parallel blood supply and decreased tensile strength and elasticity. The 2:1 rule for width to length in random skin flaps does not necessarily apply. This is particularly true in scars that result from split-thickness skin graft on fat tissue or fascia. Most scar reconstruction techniques rely on surrounding healthy skin, which can be inserted into the line of tension to rearrange the direction of the scar and contracture. In burn scars, the available healthy surrounding tissue is often very limited. In Z-plasty–based releases we therefore recommend NOT to trim any angles or corners, but instead use all tissue available. Initially the suture lines will appear bumpy, but with scar remodeling this tissue will be used for tension release.

65.3.1 Webspace Release: Butterfly Plasty

This technique works well in webspace contractures caused by grafting of the dorsum of the hand/foot and fingers/toes, when

Fig. 65.2 Central incision and limb design.

Fig. 65.3 Mobilized butterfly plasty flaps.

there is healthy skin on the palmar/plantar surface and in between the fingers/toes. Under tourniquet, the central incision is placed along the line of tension and the release cut is placed centrally into the least flexible and most contracted side (▶ Fig. 65.2). The Z-plasty limbs are designed to match the length of the release, essentially using a triangular advancement flap of healthy skin to be centrally inserted into the contracture (▶ Fig. 65.3). All flaps are mobilized on subcutaneous tissue and sutured in place with 5–0 or 4–0 nonabsorbable suture (▶ Fig. 65.4). No postoperative splinting is necessary, but dressings need to function as webspace spacers. A theoretical design blueprint of a butterfly plasty is depicted in ▶ Fig. 65.5. Often, the scar contracture continues into the digits and combinations of butterfly and Z-plasties need to be employed (▶ Fig. 65.6, ▶ Fig. 65.7, ▶ Fig. 65.8, ▶ Fig. 65.9, and ▶ Fig. 65.10).

65.3.2 Axillary Contracture Release: Z-Plasty

On the same principle as in webspace release the line of contracture is the central incision line. This has to be mapped with the patient awake and in maximal abduction. Often there is an anterior and a posterior contracture. Most likely these have to be addressed in two separate procedures at least 6 months apart. Z-plasty limbs are then designed according to available

Fig. 65.4 Fully executed butterfly plasty.

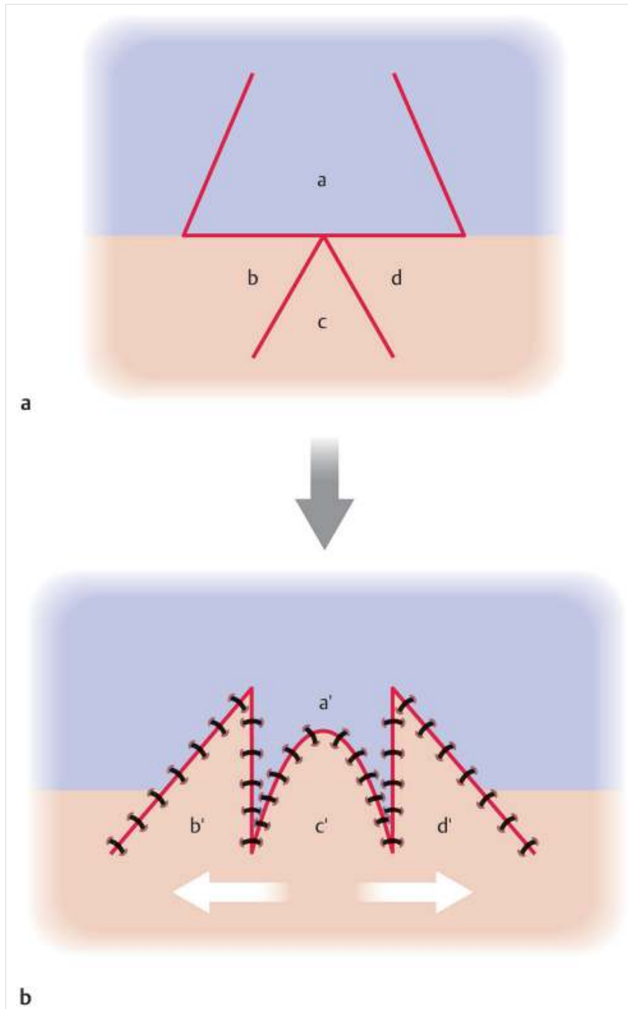

Fig. 65.5 **(a, b)** Butterfly plasty template.

Fig. 65.6 Finger flexion contracture and webspace contracture after palmar burn.

Fig. 65.9 Extension and nail bed contracture.

Fig. 65.7 Post release with butterfly and Z-plasty combination.

Fig. 65.10 After nail bed release (Achauer flap) and butterfly and Z-plasty combination.

Fig. 65.8 Result after release with butterfly and Z-plasty.

healthy or more flexible tissue (▶ Fig. 65.11). Sometimes a full-thickness or split-thickness graft has to be used to bridge a large tissue deficit after contracture release (▶ Fig. 65.12). Flaps are raised on subcutaneous tissue and the surrounding scar may need to be subcised using blunt dissection with scissors. Prior to incision 0.25% bupivacaine with epinephrine may be used to minimize the need for electrocautery during dissection, which can impair wound healing in these marginally perfused tissues. The wounds are flushed with saline and skin is approximated using 5–0 or 4–0 nonabsorbable suture (to minimize inflammatory reaction). Skin approximation should be performed meticulously, keeping tension redistribution in mind (▶ Fig. 65.13, ▶ Fig. 65.14, ▶ Fig. 65.15, ▶ Fig. 65.16, ▶ Fig. 65.17, ▶ Fig. 65.18, ▶ Fig. 65.19, ▶ Fig. 65.20, ▶ Fig. 65.21, and ▶ Fig. 65.22).

65.3.3 Scar Subcision and Fat Injection for Symptomatic Adherent Scars

The fat harvest donor site is determined according to scar distribution. Most commonly the abdomen is used. A 1-cm incision is placed in the inferior umbilical fold and tumescent solution is injected into the donor area. Fat harvest is performed

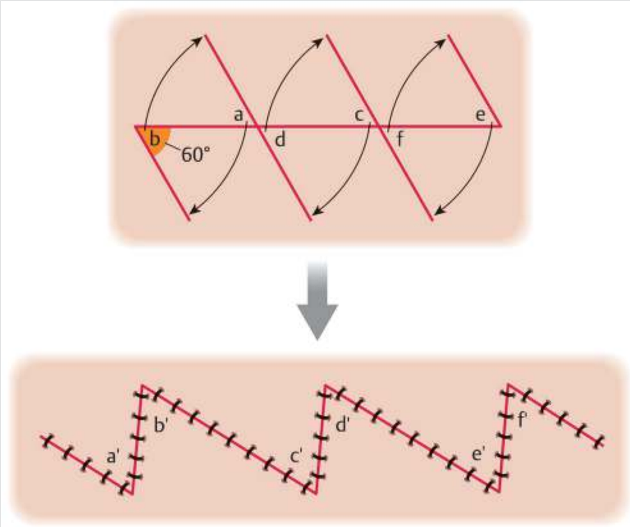

Fig. 65.11 Multiple Z-plasty template.

Fig. 65.12 Dorsal foot contracture release with butterfly plasties and full-thickness skin graft.

Fig. 65.13 Axillary contracture.

Fig. 65.14 Line of tension.

Fig. 65.15 After Z-plasty release.

mechanically by Toomey® syringe (Medline Industries, Inc., Mundelein, IL) to preserve some structural fat elements. This is then mechanically separated from the tumescent solution by either spontaneous separation or centrifugation at low settings. The injectate is then placed in 10-cc syringes and injected into the recipient scar through stab incisions by subcision, and withdrawal technique through a Coleman™ dissecting cannula (Mentor Worldwide LLC, Santa Barbara, CA). The goal is to create a new layer of fat tissue between the scarred skin and the underlying structures. Since the scar tissue is very rigid, there is a tendency of the fat injectate to "escape" into softer, more flexible tissues. This can be somewhat avoided by minimizing the amount of injection sites and by avoiding the edges of the scar when dissecting ▶ Video 65.1. Each incision is closed with 5–0 suture. Steri-Strips will allow fat to exit again. The injected area of scar needs to be protected from pressure for 10 days. We use a customized foam dressing to distribute pressure to the noninjected surrounding skin (▶ Fig. 65.23).

Fig. 65.16 Running axillary Z-plasties.

Fig. 65.17 Axillary contracture release after approximation.

Fig. 65.18 Axillary contracture release with partial flap necrosis.

Fig. 65.19 Improved axillary contracture from 50 degrees abduction to 85 degrees abduction.

Fig. 65.20 Axillary contracture post flame burn.

Fig. 65.21 Axillary contracture post release.

Fig. 65.22 Result post axillary contracture release.

Fig. 65.23 Customized foam dressing.

Video 65.1 Key procedures of flap surgery on lower extremity wound

Fig. 65.24 Subcutaneous contracture bands after multiple reconstructive interventions.

Fig. 65.25 Subcutaneous contracture bands after minimally invasive release and CO_2 laser.

65.3.4 Percutaneous Contracture Band Release

The contracture band release technique was introduced by Dr. Haik.[7] It is based on minimally invasive disruption of subcutaneous scar bands by "sawing" through them with a coarse suture. It brings instant relief to the feeling of "tightness" so often complained about by burn survivors, even after major surgical contracture releases of the neck. It can be easily used in other body areas. The results are permanent in our experience (2 years), although outcome has not been formally studied to date.

For neck location the procedure is performed under sterile conditions and if the patient is under anesthesia, detailed outlining of the subcutaneous contracture bands has to be performed before anesthesia is administered in a sitting position. The strategically best location for each release is chosen based on maximal tenting and underlying structure avoidance (external jugular veins, etc.). Bupivacaine with epinephrine is injected 2 mm next to the contracture band. A No. 2 braided suture, preferably on a straight needle and preferably non-dyed (Ethibond or similar, silk leaves black marks), is passed under the contracture band and returned through the same skin puncture between the skin and (over) the contracture band, exiting through the same first skin puncture. The contracture band is then mechanically divided by friction. The puncture holes are covered with antibiotic ointment. The patient is instructed to stretch as much as possible for 48 hours. Minimal discomfort postoperatively has been reported. There may be some degree of discoloration from small hematomas in the area of scar band division for 3 weeks (▶ Video 65.2, ▶ Fig. 65.24 and ▶ Fig. 65.25).

Video 65.2 Percutaneous contracture band release of the neck

65.3.5 Tissue Expansion

The main advantages of using tissue expansion in burn reconstruction are the gain of normal tissue and a more secure flap as a consequence of the formation of a reactive capsule, which warrants the flap perfusion.[8,9,10] In certain indications, the results can be quite aesthetically and functionally favorable and there is a relatively steep learning curve (10–15 cases).[11]

Complications are well documented[11,12,13,14,15,16] and can be decreased dramatically with rigorous technique. In burn or nevus reconstruction, there may be a need for sequential

Fig. 65.26 Preoperative view of abdominal burn scar.

Fig. 65.27 Operative planning of overlapping expander insertion in abdomen.

Fig. 65.28 Fully expanded expanders.

expansion procedures and the patient and/or his/her family must be prepared for this. When using more than one implant, we always use partially overlapping tissue expanders.

65.3.6 Tissue Expander Placement

The expander pocket is created through a small to moderate incision parallel to and at the border of the scar, undermining suprafascially enough to fit the flattened, empty expander(s). The injection port is placed in a separate cavity, very frequently on the opposite side of the scar. A continuous suction drain, exiting through scar tissue, is placed before the expander is inserted. The expanders are placed in such a manner that they overlap each other at least by a third.

65.3.7 Overlapping Tissue Expanders

To obtain a greater amount of expanded tissue, we followed the idea of the croissant-shaped expander, and developed the concept of superposing rectangular shaped tissue expanders. Although the principle is the same (the superpositioning results in a "C," "L," or "V" shape), the extremities of these so placed rectangular expanders will also "grow," similarly to its entire body and yield exponentially more tissue (unlike regular croissants, where the "ends" or "extremities" expand only a minimum).

This is most advantageous in areas where it would be desirable to advance tissue in more than one plane, such as shoulders, neck, breast, etc. We inject into the expanders once a week and we frequently go beyond the nominal volume (up to 1.8 times).[17] The tissue advanced in this manner can replace scar tissue in certain indications without disrupting the overall body contour, especially on abdomen and chest (▶ Fig. 65.26, ▶ Fig. 65.27, ▶ Fig. 65.28, ▶ Fig. 65.29, ▶ Fig. 65.30, ▶ Fig. 65.31, and ▶ Fig. 65.32).

Of note, the use of integrated port expanders may be preferable in areas like scalp and extremities, where healthy tissue is scarce. Hydrophilic, self-expanding expanders have been used successfully outside of the USA; however, they are not currently approved by the FDA.

Fig. 65.29 Expander removal and periumbilical incision.

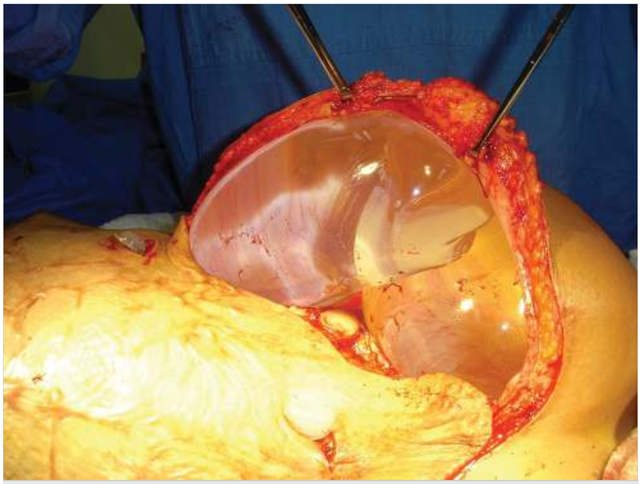

Fig. 65.30 Overlapping expanders in pocket.

Fig. 65.31 Frontal postoperative result.

Fig. 65.32 Postoperative superimposed expander reconstruction in abdomen, lateral view.

65.4 Conclusion

Burn reconstruction aims at the reconstruction of the pre-burn status of the patient, even though a “reconstitutio ad integrum” is not achievable. The burn survivors need to be involved in prioritizing certain aspects of their impairment and realistic expectations need to be discussed at the beginning of the reconstructive process, rather than focusing on individual problems with unrealistic outcome expectations. Most often this means that functional deficits like joint range of motion (ROM) will be addressed first. The reconstructive plan needs to be adjusted to available resources, especially availability of uninjured skin. The surgical techniques encompass the entire spectrum of plastic reconstructive surgery, complicated in many cases by surrounding scar tissue. This chapter only elaborated on the most common techniques. More detailed treatments of specific problems can be found in the references listed.

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66 Lesions of the Integument: Treatment of Cancers of the Integument Including Malignant Melanoma

Graeme Perks

Abstract
The integument, the largest, most complex organ in the body, is the interface between the organism and the environment. It comprises the skin, hair, nails, nerve receptors, and glands, and plays a very important role in the immunological function of the body. Unsurprisingly, lesions are common, and in most cases readily identifiable to the experienced clinician. Surgery where indicated, is, usually, straightforward.

Keywords: melanoma, nonmelanoma, sarcoma, skin

66.1 Introduction

Cancers of the integument are the most common types of cancers in the body. In particular, basal cell carcinoma (BCC) and squamous cell carcinoma (SCC) are the most common forms. Incidence of cancer increases with age as well as other risk factors such as sun exposure and occupational hazards including chemical exposure, immunosuppression, and radiation exposure. We will review the most common types of cancers of the extremities, the surgical techniques indicated for their treatment, and the results that can be obtained through proper, thorough evaluation and treatment.

66.2 Indications

Lesions of the integument are frequently amenable to surgery under local anesthetic, which can be injected almost painlessly by all practitioners.[1] In neglected conditions, the extent of cancers and infections (usually in elderly, mentally compromised, or frightened patients) may mandate a general anesthetic.

Nonmelanoma cancers (of ectodermal origin), BCC, and SCC are the most common skin cancers. Malignant melanoma (of neuroectodermal origin) is the other most prevalent skin cancer. These malignant lesions occur most commonly on sun exposed skin in people of Caucasian descent. The incidence is therefore highest among white Australians, New Zealander, and South Africans, and with increasing age.

66.3 Operative Technique

66.3.1 Basal Cell Carcinoma and Squamous Cell Carcinoma

The most common nonmelanoma skin cancers, BCC, account for about 80% of skin cancers, while SCC accounts for less than 20%.

Excision of skin malignancy is determined by the type of tumor. A preceding punch biopsy may be indicated when in doubt about the diagnosis. A 3-mm margin of normal skin around any well-defined BCC while for those BCCs with morphoeic/sclerosing characteristics complete excision needs 5 mm or more and a cuff of subcutaneous fat, or deeper tissue depending on the infiltrating nature of the tumor, is removed with the lesion.[2]

Mohs micrographic surgery has a valuable role to play in the management of BCC, even though there is no randomized control data.[3]

Excellent cosmetic results can be obtained by harnessing the viscoelastic properties of skin, creep and stress relaxation, to obtain direct closure when initially it looks impossible, and a graft or flap was anticipated (▶ Fig. 66.1, ▶ Fig. 66.2, and ▶ Fig. 66.3).

SCC management is well reviewed in a European consensus report[4] that excision should be "a standardised minimal margin of 5 mm even for low-risk tumors. For tumors, with histological thickness of > 6 mm or in tumors with high risk pathological features, e.g., high histological grade, subcutaneous invasion, perineural invasion, recurrent tumors and/or tumors at high risk locations an extended margin of 10 mm is recommended."

Lymph node metastases are a reflection of high grade and thicker tumor. However, as yet there is no evidence that sentinel node biopsy has a defined role in the management of cutaneous SCC.

Radical surgery is indicated to treat a Marjolin's ulcer (SCC arising from chronic unhealed burn scar) such as seen in ▶ Fig. 66.4.

- Incisional biopsy from the margin to confirm the diagnosis (local anesthetic).
- Preoperative magnetic resonance imaging (MRI) of the primary. Whole-body computed tomography (CT) staging for distant metastases.

Fig. 66.1 (a–c) Blunt dissection in the subgaleal plane with a blunt dilator permits insertion of a tissue expander.

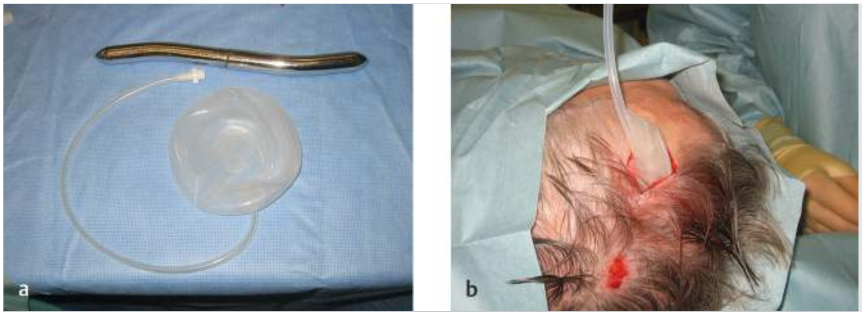

Fig. 66.2 (a, b) Inflate the expander until the skin blanches, wait for 10 minutes, and then release the tension. After 5 minutes repeat the procedure. This is known as "load-cycling," following which it is easier to approximate the skin edges, so-called "creep," and less force is noted to hold the skin apposed, so-called "stress-relaxation."

Fig. 66.3 (a–c) Squamous cell carcinoma management is well reviewed in a European consensus report[4] that excision should be a standardised minimal margin of 5 mm even for low-risk tumors.

- Surgery resecting the deep fascia and muscle where indicated.
- Reconstruction with a meshed skin graft.
- Three good indications for a meshed skin graft:
  - Skin shortage as in major burn surgery.
  - Excessively oozing wound bed.
  - Wound bed with contour irregularities (▶ Fig. 66.5).

66.3.2 Keratoacanthoma

These lesions characteristically exhibit rapid growth, reaching a large size within days or weeks followed by a plateau phase then subsequent involution. Keratoacanthoma (KA) mimics well-differentiated SCC and appear smooth, dome-shaped, symmetrical, and capped with keratin plug and debris. KA is commonly found on sun-exposed skin, often face, forearms, and hands, just like SCC. The hardest decision is from the histopathologist because incision biopsy is hard to distinguish microscopically from an SCC; hence, the pathologist would prefer to receive an excision biopsy. As an involuting KA heals with scarring, but usually less than surgical excision, it presents with management dilemma. It is better to err on the side of caution and perform excision biopsy than leave a growing SCC. Remember that "Good judgment is born of experience, and experience is born of bad judgement" (A.A. Milne, author of *Winnie the Pooh* books) (▶ Fig. 66.6).

66.3.3 Malignant Melanoma

Melanoma is classified into subtypes: superficial spreading melanoma (SSM) 50 to 60 (▶ Fig. 66.7), nodular melanoma (NM) 10 to 15, seen here developed within a pre-existing naevus (▶ Fig. 66.8) lentigo maligna melanoma (LMM) 10 to 15% (▶ Fig. 66.9), acral lentiginous melanoma (ALM) (▶ Fig. 66.10), and desmoplastic melanoma (DM), determined by morphologic and histologic appearance.

Fig. 66.4 Radical surgery is indicated to treat a Marjolin's ulcer (squamous cell carcinoma arising from chronic unhealed burn scar).

Although the ABCD rule might apply to superficial spreading lesions, namely, **A**symmetrical pigmented lesion with irregular **B**orders, **C**olor variation, typically of larger **D**iameter, the nodular melanoma might be better noted as **E**levated, **F**irm, and **G**rowing, the EFG rule. These tumors are more likely to be misdiagnosed as BCC or SCC. Up to 20% of melanomas are

Fig. 66.5 (a, b) Keratoacanthoma. These lesions characteristically exhibit rapid growth, reaching a large size within days or weeks followed by a plateau phase then subsequent involution.

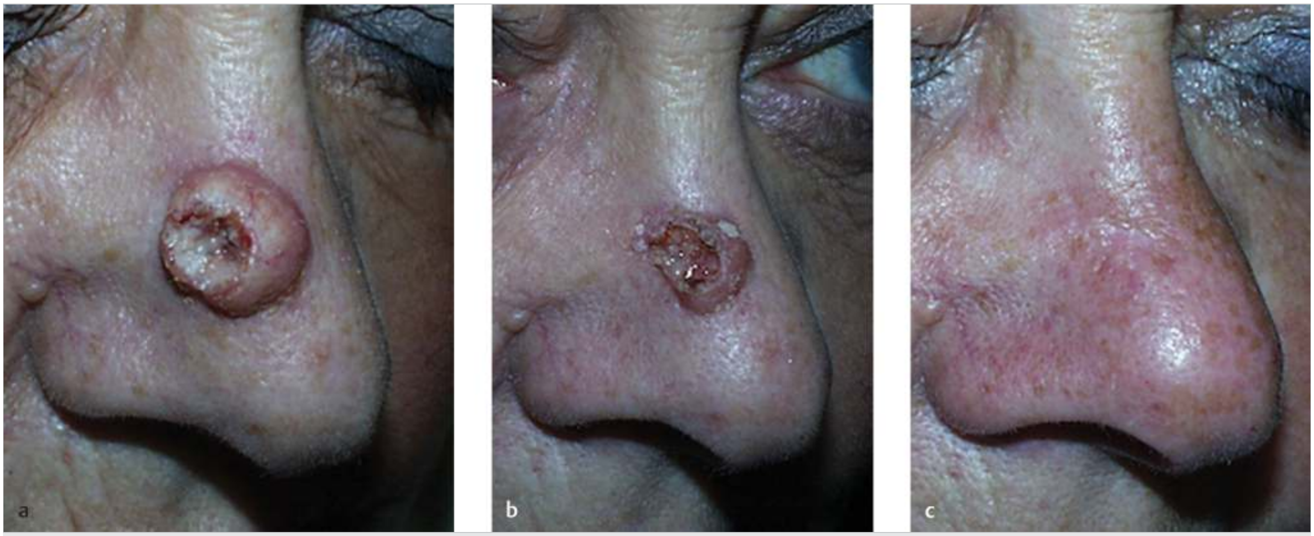

Fig. 66.6 (a) Rapidly growing lesion for 6 weeks—incisional biopsy of margin performed. **(b)** After 2 weeks, histopathology reported either a well-differentiated squamous cell carcinoma (SCC) or keratoacanthoma (KA), and the lesion is reduced in size. **(c)** A barely visible scar 4 months later.

Fig. 66.7 Melanoma is classified into subtypes; superficial spreading melanoma (SSM) is seen here.

Fig. 66.8 Nodular melanoma (NM) seen here developed within a pre-existing naevus.

Fig. 66.9 Lentigo maligna melanoma (LMM).

Fig. 66.10 Acral lentiginous melanoma (ALM) and desmoplastic melanoma (DM), determined by morphologic and histologic appearance.

amelanotic or hypopigmented usually nodular, acral lentiginous, and desmoplastic tumors.

There are many excellent international evidence-based guidelines describing the management of this common skin malignancy.[5,6,7]

The overarching principles are:

- Histological diagnosis of the lesion (a formal excision biopsy with 2 mm cutaneous margin into the subcutaneous fat). Direct closure of lesion. Incisional biopsy appropriate if lesion too large to close directly.
- Definitive surgical excision (vertical margins as measured from the edge of the tumor) width based on the histological tumor thickness, down to but not including the deep fascia (unless a very thick subcutaneous pannus in which case a depth equal to the width of excision).

Fig. 66.11 Here a 2-cm margin definitive resection is planned around a transverse biopsy scar.

Margins of Excision

- In situ melanoma 5 mm (but up to 10 mm for lentigo maligna).
- (pT1) melanoma of < 1.0 mm, 1 cm.
- (pT2) melanoma of 1.01 to 2.00 mm, 1 to 2 cm.
- (pT3) melanoma of 2.01 to 4.00 mm, 2 cm (consideration for wider margin if histological features indicate).
- (pT4) melanoma of > 4.0 mm, 2 cm.
- Reconstruction as indicated—aesthetic results with local tissue are superior to skin graft.

Here a 2-cm margin definitive resection is planned around a transverse biopsy scar (▶ Fig. 66.11).

A lateral arm flap is raised as a V-Y advancement based on a perforator of the posterior radial collateral artery (▶ Fig. 66.12a) and advanced to close the defect (▶ Fig. 66.12b).

At 6 months, the contour is excellent and the wound is maturing (▶ Fig. 66.12c).

Sentinel node biopsy provides the best prognostic indication of stage of the disease. It is an outcome data collection in evolution and one should expect recommendations to change in time (▶ Table 66.1).

66.3.4 Merkel Cell Carcinoma

Merkel cell carcinoma is a very aggressive carcinoma of neuroendocrine cell origin (Merkel cells in the basal layer of the epidermis) which occurs most commonly on the head and neck, usually in older individuals of Caucasian descent with a strong history of sun exposure (▶ Fig. 66.13).

The management is well described in guidelines[8,9]:

- Clinical examination, full skin and regional lymph node group palpation, ultrasound of the nodal region, and positron emission tomography–computed tomography (PET-CT) are undertaken.
- Incisional biopsy will confirm the diagnosis.
- Definitive excision with a 1- to 2-cm margin depending on the anatomical site, reconstruction, and sentinel node biopsy (if available) are performed.

Fig. 66.12 **(a)** A lateral arm flap is raised as a V-Y advancement based on a perforator of the posterior radial collateral artery and **(b)** advanced to close the defect. **(c)** The contour is excellent and the wound is maturing at 6 months.

Table 66.1 Australian Guideline Summary of Sentinel Node Biopsy evidence base

Evidence summary	Level
The status of the sentinel lymph node is the most significant predictor of melanoma-specific survival for patients with melanoma > 1 mm Breslow thickness	III-3, IV
Overall, for patients with melanoma > 1 mm thick, sentinel lymph node biopsy followed by immediate completion lymph node dissection for a positive node does not prolong melanoma-specific survival or overall survival compared with not performing sentinel node biopsy (nodal observation) and delayed lymph node dissection for clinically detected nodes	II
For patients with intermediate thickness melanoma (1.2–3.5 mm thick) who harbor metastatic disease within the sentinel node, early intervention with sentinel lymph node biopsy may be associated with an increased melanoma-specific survival compared with nodal observation	III-2
Complication rates for sentinel lymph node biopsy are low. The procedure should be performed in a center with appropriate expertise as complication rates are inversely related to procedure volume—this particularly applies to primaries arising in the head and neck	III-3

Fig. 66.13 Merkel cell carcinoma is a very aggressive carcinoma of neuroendocrine cell origin (Merkel cells in the basal layer of the epidermis) which occurs most commonly on the head and neck, usually in older individuals of Caucasian descent with a strong history of sun exposure.

Therapeutic lymph node dissection for any proven nodal disease, as in this case (▶ Fig. 66.14a).

In this case a wide excision of the primary tumor necessitated flap reconstruction, so excision and neck dissection were planned in natural skin lines into which a radial forearm free flap was placed (▶ Fig. 66.14b).

Radiation therapy to the primary site has proven in retrospective studies to reduce local recurrence.

There is no proven survival advantage to lymph node dissection in the presence of sentinel node biopsy detected micrometases, but regional tumor control is facilitated if the patient is fit enough. Radiation therapy would be an alternative therapy.

66.3.5 Dermatofibrosarcoma Protruberans (DFSP)

Dermatofibrosarcoma protruberans (DFSP) is a rare, indolent, intermediate grade tumor, typically truncal rather than extremity or least commonly on the head and neck. Very slow growing over years, these tumors start as small patch of flesh-colored or red/purple plaque-like lesion. The ill-defined skin lesion may then become raised, umbilicated, or lobulated firm mass (▶ Fig. 66.15).[10]

Although margin control is difficult to ensure with surgical excision, metastases will not occur unless transformation to a sarcoma occurs (less than 5% of cases). Mohs micrographic surgery claims to have better control over local recurrence than wide local excision (recommended 3-cm margin). Although

Fig. 66.14 **(a)** Definitive excision with a 1- to 2-cm margin depending on the anatomical site, reconstruction, and sentinel node biopsy (if available) are performed. Therapeutic lymph node dissection for any proven nodal disease, as in this case. **(b)** In this case a wide excision of the primary tumor necessitated flap reconstruction, so excision and neck dissection were planned in natural skin lines into which a radial forearm free flap was placed.

Fig. 66.15 Although margin control is difficult to ensure with surgical excision, metastases will not occur unless transformation to a sarcoma occurs (less than 5% of cases). Mohs micrographic surgery claims to have better control over local recurrence than wide local excision (recommended 3-cm margin).[11]

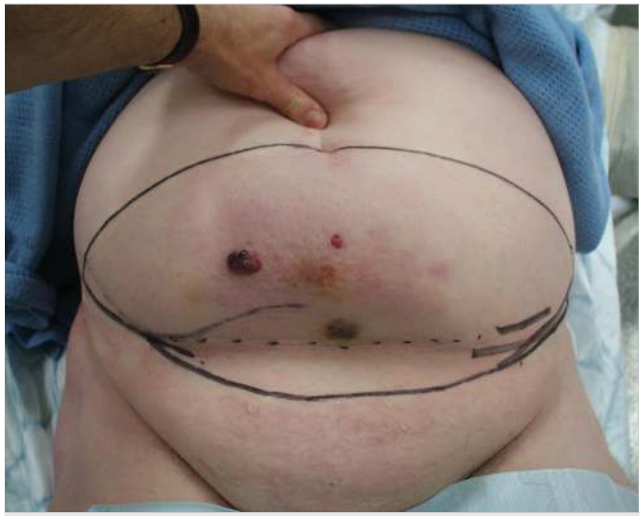

Fig. 66.17 A hemangioma had been the initial diagnosis for what transpired to be a radiation-induced angiosarcoma following external beam radiotherapy for uterine malignancy.

Fig. 66.16 Sarcomas (malignant tumors arising from mesodermal elements in the skin, e.g., blood vessels, nerves) are uncommon lesions of the integument. Angiosarcoma is particularly difficult to identify on occasion such as seen here with similarities to ecchymosis of a resolving cutaneous bruise.

there are no randomized control trial comparative data, efforts are being made to address this.[11]

The principles of management:

- Incision biopsy to confirm diagnosis.
- MRI only for extensive lesions, PET-CT or whole-body CT if malignant transformation.
- Wide local excision with underlying fascia:
  - Or Mohs micrographic surgery reconstruction.

66.3.6 Sarcoma

Sarcomas (malignant tumors arising from mesodermal elements in the skin, e.g., blood vessels, nerves) are uncommon lesions of the integument. Angiosarcoma is particularly difficult to identify on occasion such as seen here with similarities to ecchymosis of a resolving cutaneous bruise (▶ Fig. 66.16).

A prior history of therapeutic irradiation, usually two or more years before presentation, should arouse suspicion when any new lesion arises within the irradiation field (▶ Fig. 66.17).

A hemangioma had been the initial diagnosis for what transpired to be a radiation-induced angiosarcoma following external beam radiotherapy for uterine malignancy (▶ Fig. 66.17).

The principles of management are:

- Tissue diagnosis (incision or excisional biopsy with 2 mm margin if direct closure is feasible).
- Staging MRI of primary lesion, CT of chest, abdomen, and pelvis, or PET-CT scan.
- Definitive resection.
- Reconstruction as determined by the resection.

Here the resection was planned and the defect closed using an apronectomy technique, removing the affected radiation field (▶ Fig. 66.18).

Breast irradiation is the most common field treatment and a Danish study related the risk of second cancer (sarcoma):

"The estimated attributable risk related to radiotherapy for the radiotherapy-associated sites translates into one radiation-induced second cancer in every 200 women treated with radiotherapy."[12]

Fig. 66.18 The resection was planned and the defect closed using an apronectomy technique, removing the affected radiation field.

Definitive reconstruction requires confirmation that the surgical margin is clear of tumor. A temporizing "cheap reconstructive option" such as a split skin graft may be utilized while awaiting the definitive histology report. Here a locally advanced leiomyosarcoma of the scalp (▶ Fig. 66.19a) resected with pericranium at the deep margin has been reconstructed with a split skin graft. Despite grafting onto bare calvarium (▶ Fig. 66.19b), a healthy reconstruction resulted (▶ Fig. 66.19c).

Offers to reconstruct the defect were rebuffed; a hairpiece being deemed preferrable by the patient (▶ Fig. 66.19d).

66.3.7 Lipoma

Subcutaneous soft tissue tumor of unknown etiology though some evidence exists that minor trauma might have a role. Most lipomas are first noted at about 1 cm diameter and grow slowly to attain large size over many years if neglected.

A small number of patients have multiple lipomata and there is a familial genetic tendency. Small (usually < 2 cm) painful subcutaneous lipoma may on histological examination be diagnosed as an angiolipoma (numerous blood vessels among the fat with fibrin thrombi).

Here multiple painful lesions are being removed in one sitting using selected access incisions to reach as many as possible with the least number of incisions (▶ Fig. 66.20). Liposuction has been described but there is a much higher risk of incomplete removal and thus recurrence.

66.3.8 Necrotizing Fasciitis

Necrotizing fasciitis (or the eponymous "Fournier's Gangrene" of the penoscrotal/perineal region) is a potentially

Fig. 66.19 **(a)** Leiomyoma of scalp resected with pericranium at the deep margin has been reconstructed with a split skin graft. **(b)** Despite grafting onto bare calvarium, **(c)** a healthy reconstruction resulted. **(d)** Offers to reconstruct the defect were rebuffed; a hairpiece being deemed preferrable by the patient.

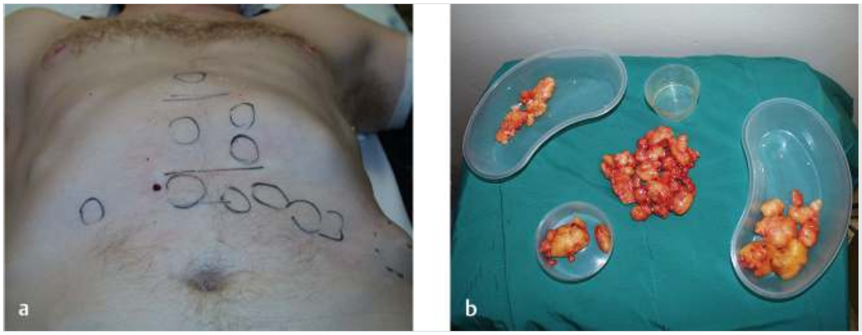

Fig. 66.20 (a, b) Here multiple painful lesions are being removed in one sitting using selected access incisions to reach as many as possible with the least number of incisions.

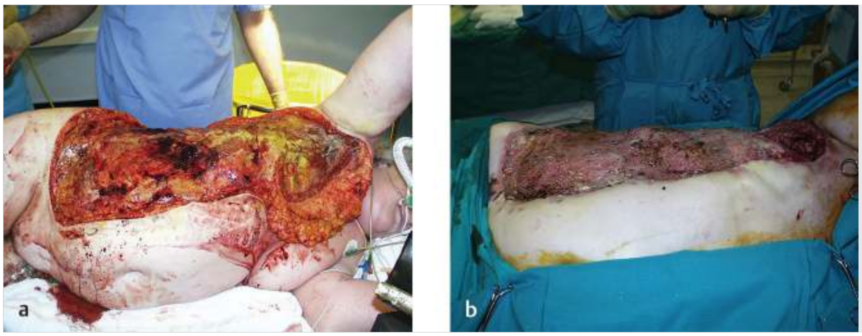

Fig. 66.21 (a) Physiological support of the patient is combined with antibiotic therapy but surgery is the definitive treatment. Resection of all the affected integument and fascia/muscle to reach healthy bleeding tissue is performed under general anesthetic. Temporizing dressing with a vacuum-assisted closure (VAC) device may be useful at this point. **(b)** A second examination and further debridement of any nonviable tissue is commonly performed after 48 hours. Once hemodynamically stable the defect is resurfaced with split skin graft reconstruction.

life-threatening synergistic bacterial soft tissue infection, usually a mixture of aerobic (usually Group A streptococcal) and anaerobic organisms.[13] Treatment usually necessitates extensive skin, subcutaneous, fascial, and sometimes muscle resection of the affected integument, with resultant massive skin loss.

The diagnosis is often difficult with a vague history of skin injury, skin redness/swelling (sometimes minimal), and undefined general malaise and pyrexia. Localized pain, disproportionate to the area of skin redness, and a marked rise in white blood cell count should raise concern. MRI scan might demonstrate gas within tissue planes in the case of gas-producing bacterial infection. A missed diagnosis will soon lead to septic shock.

The "sweep test" is a key procedure to diagnose the condition which is performed as follows:

- Local anesthetic infiltration over the suspicious area.
- Full-thickness skin incision long enough to insert an index finger.
- Look for the presence of "dirty dishwater" fluid oozing from the subcutaneous tissue.
- "Sweep" a finger into the subcutaneous space down to the deep fascia—no resistance to the passage of the finger over the fascia is pathognomonic of necrotizing fasciitis.

Physiological support of the patient is combined with antibiotic therapy but surgery is the definitive treatment.

Resection of all the affected integument and fascia/muscle to reach healthy bleeding tissue is performed under general anesthetic. Temporizing dressing with a vacuum-assisted closure (VAC) device may be useful at this point (▶ Fig. 66.21a).

A second examination and further debridement of any nonviable tissue is commonly performed after 48 hours. Once hemodynamically stable the defect is resurfaced with split skin graft reconstruction (▶ Fig. 66.21b).

Fig. 66.22 At site of intravenous (IV) cannula placement, in a healthcare professional.

66.3.9 Dermatitis Artefacta

This rare but commonly misdiagnosed condition can result in much wasted energy by clinicians. A trivial event which then leads to a skin wound which steadfastly resists all efforts to promote healing should raise suspicions.

Features may include bizarre outlines in a linear or geometric pattern, clearly demarcated from surrounding normal skin. Ulceration, cellulitis, swelling, blisters, or nonhealing surgical wounds can result depending on the mechanism of injury, commonly on a site readily accessible to the patient's fingers. However, many devices may be used to create the wound including (but not exclusively) fingernails, objects (sharp or blunt), chemicals, and cigarettes (▶ Fig. 66.22).

Collaborative care provided with a clinical psychologist is key to a successful nonsurgical outcome. Direct confrontation has no role to play. The underlying cause may never be determined.

66.4 Conclusion

Tumors of the integument are very common. The most common cancers of the integument, BCC and SCC, can often be cured by local excision. Other diseases of the integument require radical debridement, such as necrotizing fasciitis. Tumors with high rates of local invasion require wider excision as well. Some tumors, such as melanoma, have a propensity for regional and distant metastases. In these cases, lymph node biopsy is often indicated for higher grade tumors.

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67 Vascular Anomalies and Congenital Nevi

Arin K. Greene and Jeremy A. Goss

Abstract

Vascular anomalies and congenital nevi often require resection to improve a deformity, reduce the risk of malignant transformation, or to improve pain, bleeding, or ulceration. Most lesions are able to be removed using standard lenticular excision and linear closure. However, round lesions on the face may benefit from circular excision and purse-string closure to limit the length of the scar.

Keywords: congenital, hemangioma, integument, nevus, resection, vascular anomalies

67.1 Introduction

Vascular anomalies and congenital nevi are common pediatric skin lesions. Their primary morbidity is lowered self-esteem because they cause a deformity. Some types of vascular anomalies can also result in bleeding, ulceration, pain, and obstruction/destruction of important anatomical structures. Congenital nevi have a low risk of transformation to melanoma (3% for giant lesions and < 1% for smaller nevi). Many vascular anomalies and most congenital nevi do not require treatment and can be observed. Symptomatic vascular anomalies are managed by pharmacotherapy (e.g., corticosteroid, b-blockers, sirolimus, vincristine), sclerotherapy, embolization, laser, and/or resection. Congenital nevi that are concerning for malignant transformation or are causing a deformity are managed by excision; rarely laser, dermabrasion, or topical pharmacotherapy is used. The standard operative technique to treat vascular anomalies and congenital nevi is lenticular excision and linear closure. Almost all lesions can be removed and closed by approximating adjacent tissue; skin grafts and flaps are rarely required. A technique that the senior author frequently uses to remove vascular anomalies and congenital nevi is circular excision and purse-string closure.

67.2 Indications

Traditional lenticular resection of a circular lesion results in a linear scar two to three times the diameter of the lesion.[1] In contrast, if a round vascular anomaly or nevus is removed as a circle and closed with a purse-string suture, the scar is approximately one-third the area of the original lesion. The cicatrix then can be removed lenticularly in a second stage giving a linear scar the diameter of the original lesion.[1] Circular excision is primarily indicated for round lesions on the face where it is important to limit the length of the scar. Circular vascular anomalies or nevi outside of the face usually are removed using a lenticular resection because the scar typically is favorable in a relaxed skin-tension line, and the procedure is done in one stage. Elliptical vascular anomalies and nevi of the face are also removed in a lenticular manner because the linear scar is not significantly longer than the diameter of the long-axis of the lesion. Compared to lenticular excision, circular removal often requires a second stage and the wound dehiscence rate is slightly higher because one purse-string suture primarily approximates the skin.

67.3 Operative Technique

When removing a round vascular anomaly or nevus of the face, the table is turned 90 degrees to facilitate access to the surgical site (▶ Video 67.1). Intraoperative antibiotics are not administered except when resecting large lymphatic malformations because they are prone to infection. When removing a vascular anomaly, the incision should be directly on the periphery of the lesion; margins are not required because vascular anomalies are benign and excising additional tissue will increase the size of the scar. If a congenital nevus is thought to be at risk for malignancy (e.g., ulcerated, irregular colors or boarders) then 1 to 2 mm margins are added around the periphery of the lesion. If a congenital nevus is being extirpated only to improve the patient's appearance, then ≤ 1 mm margin is added to the area in order to limit the length of the scar.

Local anesthetic with epinephrine is infused underneath the lesion as well as in its periphery where skin undermining will occur. A #67 mini blade is used to make the incision, and the vascular anomaly or nevus is excised using a scissors. Next, wide skin undermining is performed to obtain skin laxity prior to closing the wound. Limiting tension is important to reduce the risk of wound dehiscence and to ensure that the resulting circular scar does not widen. An intradermal Vicryl suture typically is used for the purse-string closure. Depending on the size of the defect, a 5–0, 4–0, or 3–0 suture is chosen. Next, the epidermis is approximated with interrupted 6–0 or 5–0 chromic suture, so that the child does not have to undergo suture removal. Finally, cyanoacrylate glue and tape are applied to reinforce the wound closure and protect the area from the patient. The bunching of skin at the end of the procedure resolves over several weeks as the area flattens. Occasionally, patients with large circular lesions of the face can be treated with multiple circular excisions to obtain as small of a scar as possible before considering conversion of the scar into a line.

The patient is evaluated 6 to 12 months postoperatively to assess the appearance of the circular scar. The smaller the

Video 67.1 Circular excision of an involuted hemangioma with purse-string closure

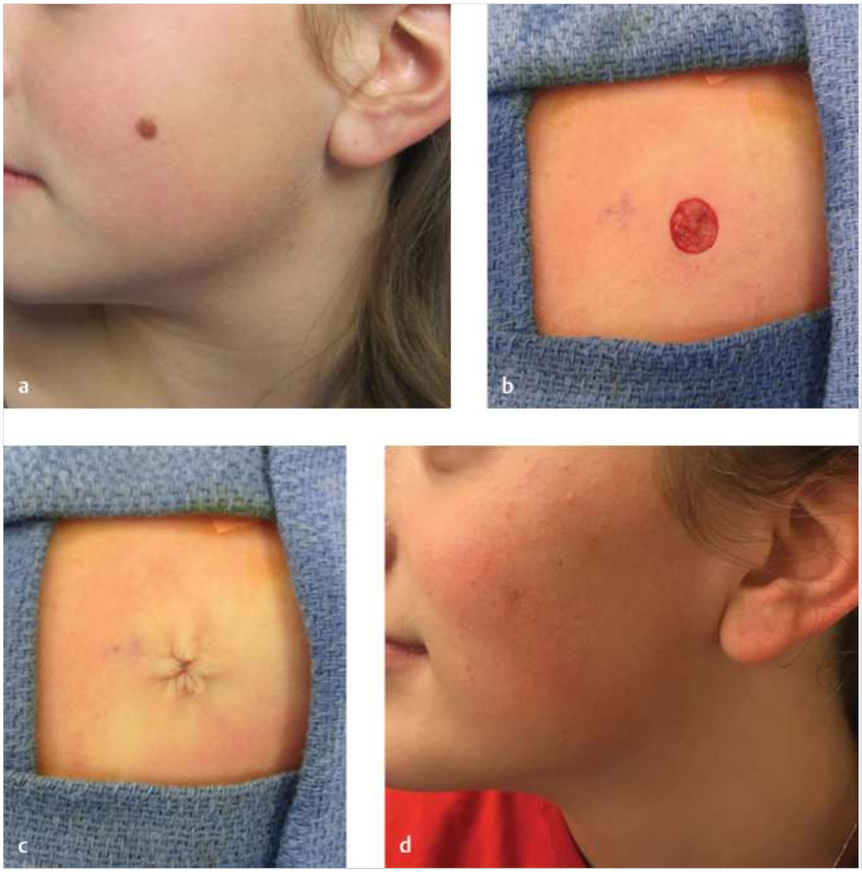

Fig. 67.1 A female child presented with an enlarging nevus of the cheek that was causing psychosocial morbidity. Because the lesion was round and located in an aesthetically sensitive area it was removed using circular excision to limit the length of the scar. **(a)** Preoperative appearance. **(b)** Intraoperative view after circular excision with ≤ 1 mm margin. **(c)** Purse-string closure of the wound. **(d)** The circular scar is difficult to appreciate postoperatively, and a second-stage procedure was not performed.

diameter of the lesion that was removed, the more likely patients/families are pleased with the circular scar after the first stage and are not interested in another procedure to convert the cicatrix into a line.[2] Small round scars can appear like acne or chickenpox scars (▶ Fig. 67.1). If a second-stage procedure is performed, a traditional lenticular excision is marked around the scar without margins (▶ Fig. 67.2). Local anesthetic with epinephrine is infused and the scar is excised. Typically, skin undermining is performed to reduce the tension on the closure. The wound edges are approximated with interrupted Vicryl suture followed by either 7–0 chromic suture or an intradermal Monocryl suture so that the child does not have to undergo suture removal. Cyanoacrylate glue and tape are then applied.

67.4 Conclusion

Lenticular excision of a circular lesion results in a linear scar two to three times longer than its diameter. Round vascular anomalies and nevi located in aesthetically sensitive areas of the face often benefit from circular excision and purse-string closure to limit the length of the scar. Large lesions can undergo multiple circular excisions. Small circular scars may not benefit from a second stage because they can appear favorable like an acne or chickenpox scar. Ultimately, if a circular scar undergoes lenticular resection and linear closure the length of the scar approximates the diameter of the original circular lesion.

Fig. 67.2 A 3-year-old girl with an involuted infantile hemangioma of the nose. Because the area was round and in an unfavorable location, it was removed with circular resection. **(a)** Preoperative view. **(b)** After circular excision and purse-string closure. **(c, d)** Second-stage lenticular excision of the cicatrix to give a linear scar. **(e)** Postoperative result.

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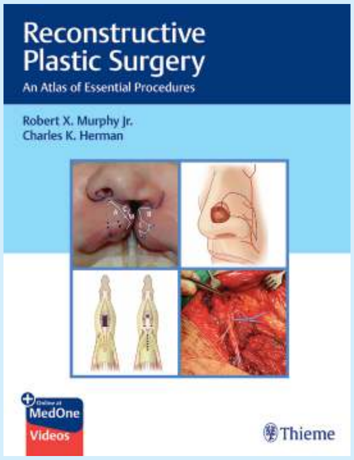

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