CONTENTS

FORTHCOMING ISSUES

March 2006

Implant Procedures
Michael Block, DMD, *Guest Editor*

September 2006

Mandibular Reconstruction
Tirbod Fattahi, DDS, MD and
Rui Fernandes, DMD, MD, *Guest Editors*

PREVIOUS ISSUES

March 2005

Multidimensional Diagnosis, Treatment Planning, and Maxillofacial Surgery
Maria J. Troulis, DDS, MSc, *Guest Editor*

September 2004

Maxillofacial Cosmetic Surgery, Part II
John E. Griffin, Jr, DMD, *Guest Editor*

March 2004

Maxillofacial Cosmetic Surgery, Part I
John E. Griffin, Jr, DMD, *Guest Editor*

Atlas of the Oral and Maxillofacial Surgery Clinics

Atlas Oral Maxillofacial Surg Clin N Am 13 (2005) vii–viii

Preface

Autogenous Bone Grafting

George M. Kushner, DMD, MD
Guest Editor

Reconstructive surgery, or the ability to make a patient ‘‘whole’’ again, is a basic principle of any surgical specialty. This certainly holds true for the specialty of oral and maxillofacial surgery. Oral and maxillofacial surgeons have had a long history of providing hard and soft tissue reconstruction procedures in the maxillofacial regions to improve patients’ lives. I believe the contemporary practice of reconstructive oral and maxillofacial surgery gained strength and momentum when our predecessors were called upon to treat devastating injuries to the maxillofacial region that occurred during wartime, specifically the Vietnam conflict. We became quite adept at hard and soft tissue grafting and were able to perform these procedures safely and predictably for our patients’ benefit.

The modern-day oral and maxillofacial surgeon needs hard tissue grafting procedures to meet patient needs in reconstructive surgery involving trauma, pathology, cleft and craniofacial deformities, orthognathic surgery, aesthetic surgery, and dental implants. The acceptance and popularity of dental implants has created a huge need and demand for bony reconstruction in preparation for dental implants in our patient population. The gold standard for bony reconstruction in the maxillofacial region is currently the use of autogenous bone. There are certainly other biomaterials available for use in the maxillofacial region, including banked bone, ceramics and bioactive glass, and bovine bone, to give some examples. Tissue engineering such as the use of bone morphogenetic protein has promise but is currently not used on a widespread basis; furthermore, it is costly. All the adjunctive procedures have a place in maxillofacial bony reconstruction and are constantly judged against the benchmark of using the patient’s own bone for reconstruction. It is the widespread use of autogenous grafting in the maxillofacial region that sets the oral and maxillofacial field apart from other medical and dental specialties that also treat the maxillofacial region and jaws.

The intent of this issue of the *Atlas of the Oral and Maxillofacial Surgery Clinics of North America* is to provide the reader with a comprehensive review of autogenous bone grafting procedures used in the maxillofacial region. Each of the authors has extensive experience in his grafting technique and has provided a ‘‘hands-on’’ or ‘‘how-to’’ approach to that specific bone harvest technique. The goal is to expand or refine your bone harvest techniques to benefit your patient population. The field of reconstructive oral and maxillofacial surgery is constantly moving forward to provide improved techniques and options for our patients, and we as surgeons must constantly strive to deliver the best possible treatment for our patients.

I would like to acknowledge my mentors—Drs. Brian Alpert, Leon Fiedler, Harold Boyer, Martin Steiner, and Jeff Carter—for their professional support that has allowed me to grow as a surgeon. There have also been 12 years of residents at the University of Louisville who have constantly pushed me to stay energized and current. Lastly, I would like to thank my parents,

doi:10.1016/j.cxom.2005.07.001

George and Norma Kushner, for their support (both emotional and financial) through many years of education. Most importantly, I would like to thank my wife, Diane Kushner, and my children, George, Tommy, and Katie Kushner, for the time I am permitted away from home to pursue my ''other love'': oral and maxillofacial surgery.

George M. Kushner, DMD, MD
Department of Surgical and Hospital Dentistry
University of Louisville School of Dentistry
501 South Preston, #337
Louisville, KY 40202, USA

E-mail address: gmkush01@louisville.edu

ELSEVIER
SAUNDERS

Atlas Oral Maxillofacial Surg Clin N Am 13 (2005) 91–107

Atlas of the Oral and Maxillofacial Surgery Clinics

Mandibular Block Autografts for Alveolar Ridge Augmentation

Michael A. Pikos, DDS[a,b,c,d,e]

[a] *Coastal Jaw Surgery, 2711 Tampa Road, Palm Harbor, FL 34684, USA*
[b] *Division of Oral and Maxillofacial Surgery, Department of Surgery, The University of Miami, 1611 N.W. 12th Avenue, Miami, FL 33136, USA*
[c] *Ohio State University, 305 West 12th Avenue, Columbus, OH 43218-2357, USA*
[d] *College of Dental Medicine, Nova Southeastern University, 3200 South University Drive, Fort Lauderdale, FL 33328, USA*
[e] *College of Dentistry, University of Florida, PO Box 100434, Gainesville, FL 32610-0434, USA*

Reconstruction of alveolar ridge deficiencies requires bone augmentation before implant placement. Osseous defects occur as a result of trauma, prolonged edentulism, congenital anomalies, periodontal disease, and infection, and they often require hard and soft tissue reconstruction. Autogenous bone grafts have been used for many years for ridge augmentation and are still considered the gold standard for jaw reconstruction. The use of autogenous bone grafts with osseointegrated implants originally was discussed by Brånemark and colleagues, who often used the iliac crest as the donor site. Other external donor sites include calvarium, rib, and tibia. For repair of most localized alveolar defects, however, block bone grafts from the symphysis and ramus buccal shelf offer advantages over iliac crest grafts, including close proximity of donor and recipient sites, convenient surgical access, decreased donor site morbidity, and decreased cost.

This article reviews indications, limitations, presurgical evaluation, surgical protocol, and complications associated with mandibular block autografts harvested from the symphysis and ramus buccal shelf for alveolar ridge augmentation. The author draws from 14 years of experience with more than 500 mandibular block autografts.

Indications

Block bone grafts harvested from the symphysis can be used for predictable bone augmentation up to 6 mm in horizontal and vertical dimensions. The range of this cortical cancellous graft thickness is 3 to 11 mm, with most sites providing 5 to 8 mm (Figs. 1 and 2). The density of the grafts is D-1 or D-2, and up to a three-tooth edentulous site can be grafted (Box 1; Table 1).

In contrast, the ramus buccal shelf provides only cortical bone with a range of 2 to 4.5 mm (with most sites providing 3–4 mm) (Figs. 1 and 2). This site is used for horizontal or vertical augmentation of 3 to 4 mm. One ramus buccal shelf can provide adequate bone volume for up to a three- and even four-tooth segment. Bone density is D-1 with minimal, if any, marrow available. Some sites require extensive bone graft volume, which necessitates simultaneous bilateral ramus buccal shelf and symphysis graft harvest. For graft volume of more than 6 to 7 mm thickness, a secondary block graft can be used after appropriate healing of the initial graft (Box 2; Table 1).

MAP Implant Institute, 2711 Tampa Road, Palm Harbor, FL 34684.
E-mail address: Learn@MapImplantInstitute.com

1061-3315/05/$ - see front matter
doi:10.1016/j.cxom.2005.05.003

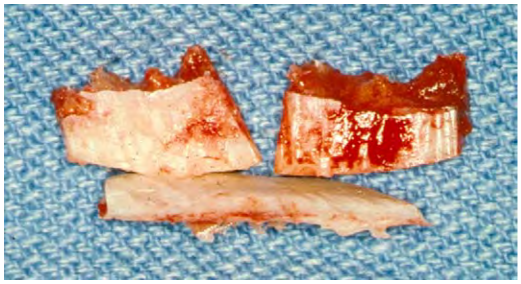

Fig. 1. Symphysis and ramus buccal shelf block grafts harvested from same mandible. Note relative greater cortical thickness of the symphysis grafts.

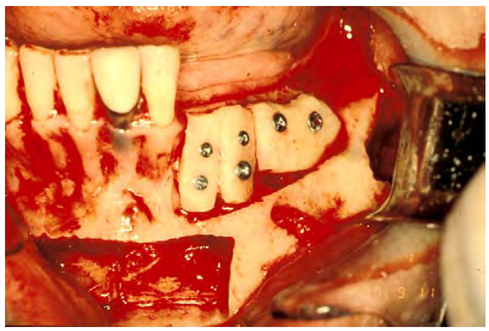

Fig. 2. Fixation of symphysis and ramus block grafts. The two anterior vertical blocks are from the symphysis; the posterior block is from the ramus buccal shelf. Note donor sites.

Presurgical considerations

The recipient site must be evaluated for hard and soft tissue deficiencies, aesthetic concerns, and overall health of the adjacent teeth. Some cases require soft tissue procedures to be performed before or simultaneously with block grafting and in conjunction with implant placement or stage II surgery. These cases include use of connective tissue grafts, palatal epithelial grafts, and human dermis. Conventional radiographs are obtained and include periapical, occlusal, panoramic, and lateral cephalometric views. CT is also used for many cases. Mounted models are used to evaluate interocclusal relationships and ridge shape, and they provide valuable information for implant placement. A diagnostic wax model of the simulated reconstructed ridge and dentition is a useful guide in obtaining presurgical information concerning graft size and shape along with evaluating the occlusion. It also provides a base for template fabrication.

Principles for predictable block bone grafting

Recipient site: soft and hard tissue considerations

Incision design at the recipient site for block grafting varies depending on location within the arches. Maxillary anterior sites require a midcrestal incision that continues in the sulcus for a full tooth on either side of the defect. Bilateral oblique release incisions are made approximately one tooth removed, and a full-thickness mucoperiosteal flap is reflected (Fig. 3).

Box 1. Symphysis block graft: indications

- Horizontal augmentation 4–7 mm (up to three-tooth defect)
- Vertical augmentation 4–6 mm (up to three-tooth defect)

Table 1

	Range block graft thickness	Average block graft thickness obtained	Graft type	Bone density
Symphysis	3–11 mm	4–8 mm	Cortical—dense marrow	D-1, D-2
Ramus buccal shelf	2–4.5 mm	3–4 mm	Cortical only	D-1

I do not recommend papilla-sparing release incisions because they overlie the interface of recipient and donor bone and can result in wound dehiscence. The mandibular anterior site is handled in the same manner with care to avoid injury to the mental neurovascular bundle.

Maxillary posterior sites also require a midcrestal incision that continues in the sulcus one tooth anterior to the defect with an oblique release incision. A posterior oblique release incision is made at the base of the tuberosity and it extends apically to the zygomatic buttress, which allows for complete mucoperiosteal flap reflection and relaxation in an anterior and crestal direction (Figs. 4–8).

Mandibular posterior edentulous sites require a midcrestal and sulcular incision continued to the first bicuspid or canine tooth with an anterior oblique release incision to allow for complete visualization of the mental neurovascular bundle. The incision continues posteriorly up the ascending ramus and can be released obliquely into the buccinator muscle (Fig. 9). If the defect is between teeth, the incision continues in the sulcus of the posterior tooth and then distally. In both cases, the incision is made in the lingual sulcus for three to four teeth anteriorly, which allows for lingual flap reflection via mylohyoid muscle stripping (Figs. 10 and 11).

Recipient site preparation is critical for predictable incorporation of block grafts and includes decortication and perforation into underlying marrow. This preparation provides access for trabecular bone blood vessels to the graft and accelerates revascularization. Surgical trauma created also allows for the regional acceleratory phenomenon to occur, which results in tissue healing two to ten times faster than normal physiologic healing. There is also massive platelet release along with associated growth factors and osteogenic cells. Finally, graft union to the underlying host bone is accomplished more readily, which allows for intimate contact to facilitate graft incorporation.

The addition of platelet-rich plasma to the recipient site after decortication and perforation allows for growth factors to accelerate wound healing by stimulating angiogenesis and mitogenesis (see Fig. 7; Fig. 12). Platelet-rich plasma studies have revealed at least three important growth factors in the alpha granules of platelets: platelet-derived growth factor, transforming growth factor-β_1, and transforming growth factor-β_2. These growth factors have been shown to act on receptor sites of cancellous bone. Platelet-derived growth factor is considered one of the primary healing hormones in any wound and is found in great abundance within platelets. These growth factors enhance bone formation by increasing the rate of stem cell proliferation and inhibiting osteoclast formation, which decreases bone resorption. Bone and platelets contain approximately 100 times more transforming growth factor-β than do any other tissues. Although addition of platelet-rich plasma to the block bone graft protocol has resulted in greater bone incorporation, the stage I surgery time table has not changed. The soft tissue effects of accelerated wound healing are especially advantageous because patients typically exhibit less pain, swelling, and ecchymosis.

For horizontal defects, decortication creates an outline for close graft approximation. Bone burnishing with a large round fissure bur (Brasseler, H71052) from crest of ridge to approximately 4 to 5 mm apically is done initially. Decortication continues apically with a 702L straight fissure bur in a more aggressive fashion to create extra walls to the defect in the form of a rectangular inlay preparation (Figs. 13–15). The site is perforated with a 0.8-mm bur

Box 2. Ramus buccal shelf block graft: indications

- Horizontal augmentation 3–4 mm (up to four-tooth defect)
- Vertical augmentation 3–4 mm (up to four-tooth defect)

Fig. 3. Anterior maxillary recipient site incision design. Note distal oblique release incisions.

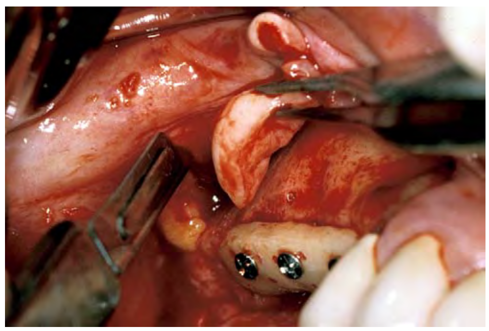

Fig. 4. Posterior oblique release incision made at base of tuberosity. Forceps is grasping anterior aspect of the flap.

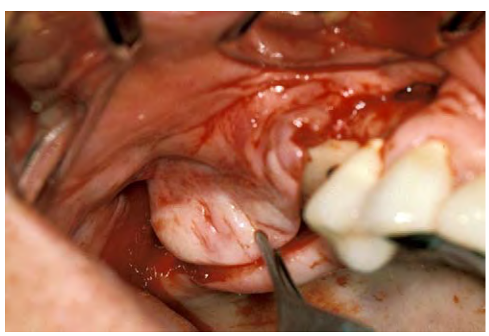

Fig. 5. Note complete relaxation of the buccal flap secondary to periosteal release and oblique release incisions. This flap will be repositioned anteriorly and inferiorly for tension-free closure.

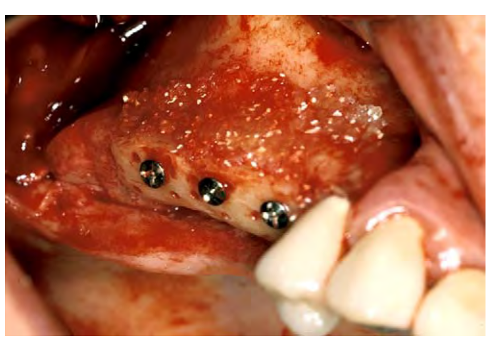

Fig. 6. Fixation of block graft with particulate graft overlay.

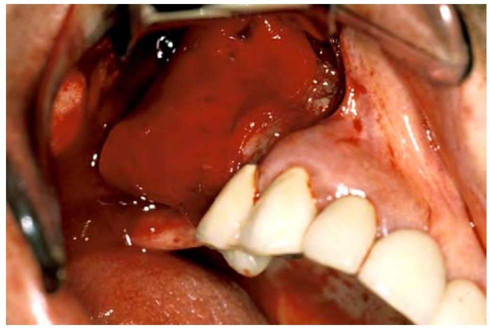

Fig. 7. Collagen membrane impregnated with platelet-rich plasma. This fast resorbing membrane acts as a carrier for the platelet-rich plasma.

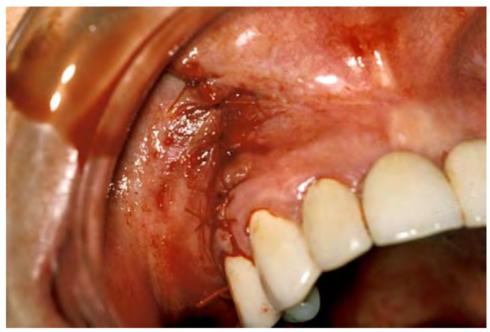

Fig. 8. Tension-free wound closure.

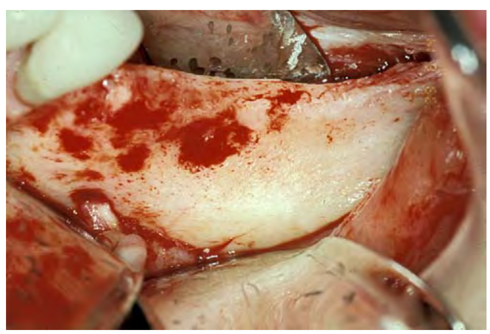

Fig. 9. Incision design for posterior mandibular recipient site. Anterior oblique release incision is made anterior to the mental neurovascular bundle. Distal aspect of the incision continues to the ascending ramus with oblique release incision into the buccinator muscle.

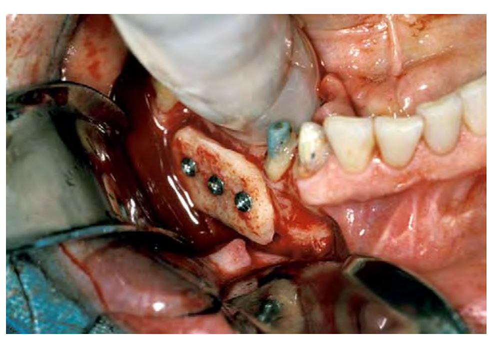

Fig. 10. Stripping of the mylohyoid muscle via finger dissection for lingual flap release. Note that lingual incision continues in the sulcus for three to four teeth to prevent flap tearing.

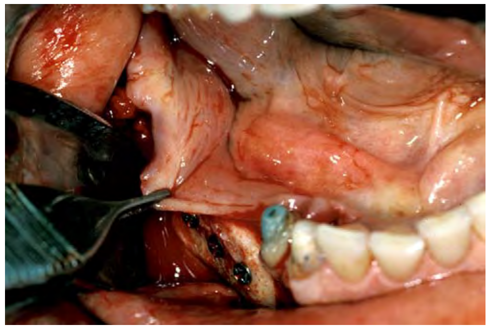

Fig. 11. Complete relaxation of the lingual flap allows for approximately 6 to 8 mm of lingual flap coverage over the block graft.

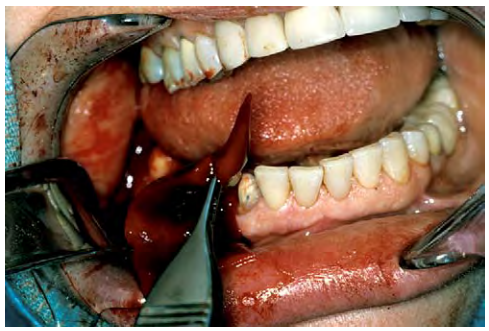

Fig. 12. Collagen membrane impregnated with platelet-rich plasma placed over the graft site.

to penetrate underlying marrow (Fig. 16). Next, platelet-rich plasma is applied to the recipient site and the block is morticed into position and fixated with two 1.6-mm diameter, low-profile head, self-tapping titanium screws (Fig. 17). Two screws are placed to prevent microrotation of the graft, which can result in compromised healing, including resorption and even graft nonunion. Site preparation for vertical augmentation requires only crestal bone burnishing to create bone bleeders followed by perforations into marrow (Fig. 18). A small vertical step is made approximately 2 mm adjacent to the tooth next to the site to allow for a butt joint to form with the end of the block graft. The block can be stored in normal saline or D_5W before contouring. The H71052 round fissure bur is used to smooth any sharp edges before fixation (Figs. 19–21). Horizontal augmentation in the maxilla using either donor site requires 4 months of healing time before implant placement. An additional month is required for horizontal augmentation in the mandible and for vertical augmentation in the maxilla and mandible (Box 3).

After graft fixation, autogenous marrow or particulate allograft can be morticed into any crevices between block graft and recipient bone. If a large amount of particulate graft is used, a collagen membrane is then placed and secured with titanium tacks. Otherwise, no membrane is necessary for predictable block grafting. Before particulate grafting, however, the overlying flap

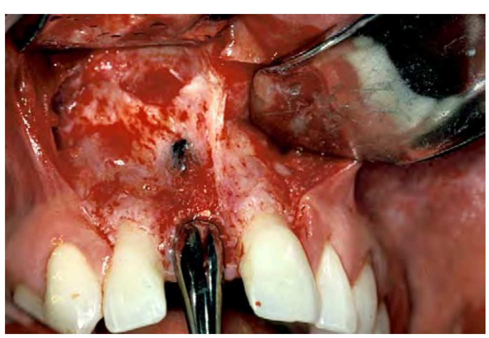

Fig. 13. Anterior maxillary recipient site exposed to reveal horizontal alveolar ridge defect.

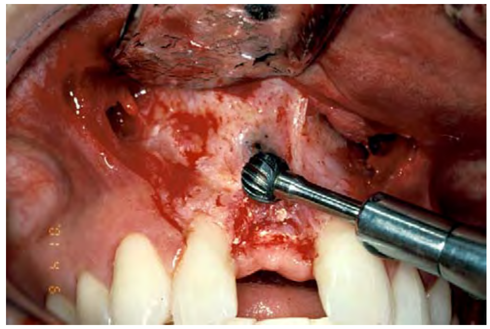

Fig. 14. Decortication begins with large round fissure bur.

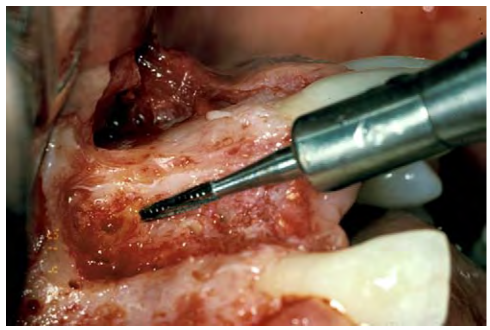

Fig. 15. Decortication continues with use of 702L straight fissure bur in a more aggressive mode at the apical half of the recipient site. Note rectangulation of the defect.

must be made passive to allow for tension-free closure. This procedure is accomplished in all areas by scoring periosteum and using blunt dissection into muscle for complete flap relaxation (Figs. 22–24). In the posterior mandible, it is highly recommended that lingual flap release be obtained by detaching the mylohyoid muscle with sharp and blunt dissection (see Fig. 10), which results in up to a 6– to 8-mm gain of flap relaxation (see Fig. 11). Along with buccal flap manipulation, lingual flap release creates posterior mandibular soft tissue closure in a predictable manner and virtually eliminates incision line opening. Before flap approximation for closure, the entire graft site is immersed in platelet-rich plasma (see Fig. 12). Closure is accomplished using 4-0 Vicryl for the crestal incision and 4-0 and 5-0 chromic for the release incision.

Donor site

Symphysis harvest

Two primary incision designs can be used for harvesting block bone from the symphysis. I prefer a sulcular incision as opposed to the more conventional vestibular approach. This

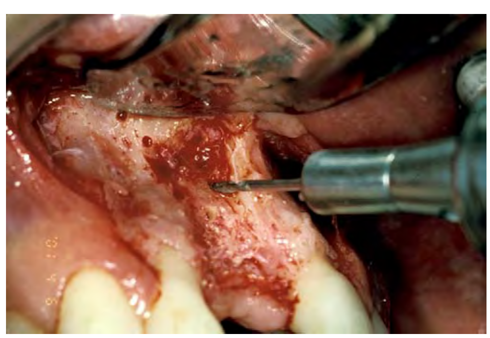

Fig. 16. Perforation of the recipient bed with 0.8-mm diameter bur.

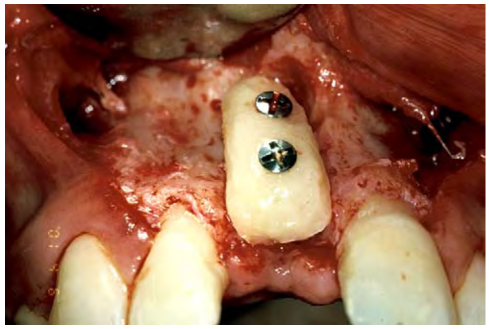

Fig. 17. Note two-point block graft fixation to prevent microrotation.

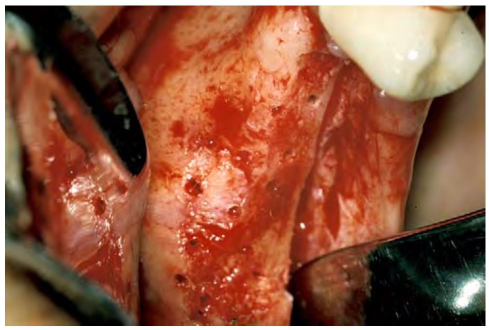

Fig. 18. Posterior maxillary recipient site preparation for vertical augmentation. Crestal burnishing and perforation is completed.

incision can be used safely if the periodontium is healthy and no crowns are present in the anterior dentition that could present aesthetic problems with associated gingival recession. A highly scalloped thin gingival biotype also is contraindicated. The incision begins in the sulcus from second bicuspid to second bicuspid. An oblique releasing incision is made at the distal buccal line angle of these teeth and continues into the depth of the buccal vestibule. A full-thickness mucoperiosteal flap is reflected to the inferior border, which results in a degloving of the anterior mandible and allows for good visualization of the entire symphysis, including both mental neurovascular bundles (Figs. 25 and 26). Additional bone blocks, including cores and scrapings, can be obtained easily. It also provides for easy retraction at the inferior border and results in a relatively dry field. Contrast this with the vestibular approach, which results in more limited access, incomplete visualization of the mental neurovascular bundles, and more difficulty in superior and inferior retraction of the flap margins. Typically, bleeding is secondary to the mentalis muscle incision and results in the need for hemostasis. No wound dehiscence has been noted with the sulcular approach. The vestibular incision can result in wound dehiscence and scar band formation up to 11%. Finally, postoperative pain is less and no associated ptosis has been noted with the intrasulcular approach (Box 4).

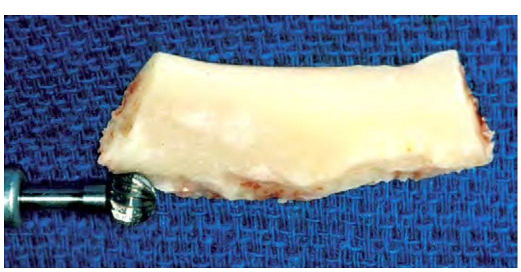

Fig. 19. Ramus buccal shelf block graft harvest. Block is contoured with H71050 round fissure bur.

Fig. 20. Surgical template for stage I surgery is also used for graft contouring.

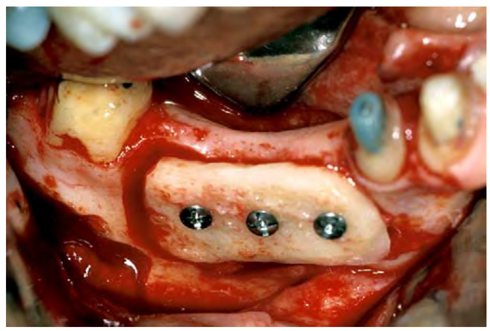

Fig. 21. Block graft fixation completed. Note intimate fit into the recipient site with almost vertical positioning of the block.

The graft size should be approximately 2 mm larger than the recipient site in horizontal and vertical dimensions to allow for contouring. A 702L tapered fissure bur in a straight handpiece is used to penetrate the symphysis cortex via a series of holes that outline the graft. It is important not to encroach within 5 mm of the apices of the incisor and canine teeth and the mental neurovascular foramina. The inferior osteotomy is made no closer than 4 mm from the inferior border. All holes are connected to a depth of at least the full extent of the bur flutes (7 mm), and the graft is harvested using bone spreaders and straight and curved osteotomes. The graft is placed in normal saline before contouring and fixation. The donor site is then packed with gauze soaked in saline, platelet-poor plasma, or platelet-rich plasma. Closure of the site is performed with 4-0 Vicryl horizontal mattress sutures after recipient site closure and includes a particulate graft (Figs. 27–29). Although this graft does not play a role in terms of soft tissue profile, its placement is recommended to allow for a secondary block harvest that can be obtained no sooner than 10 months from initial harvest.

Box 3. Time required for graft incorporation before stage I surgery

Symphysis
- Maxilla: horizontal, 4 months
- Maxilla: vertical, 5 months
- Mandible: horizontal and vertical, 5 months

Ramus buccal shelf
- Maxilla: horizontal, 4 months
- Maxilla: vertical, 5 months
- Mandible: horizontal and vertical, 5 months

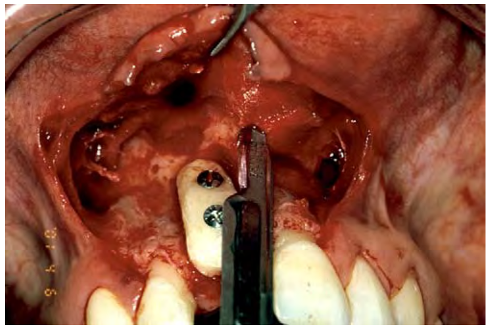

Fig. 22. Flap release via periosteal incisions.

Fig. 23. Curved hemostat is used to spread muscle layers.

Ramus buccal shelf block graft harvest

A full-thickness mucoperiosteal incision is made distal to the most posterior tooth in the mandible and continues to the retromolar pad and ascending ramus. An oblique release incision can be made into the buccinator muscle at the posterior extent of this incision should more flap release be needed. The incision continues in the buccal sulcus opposite the first bicuspid, where an oblique release incision is made to the depth of the vestibule. A full-thickness mucoperiosteal flap is then reflected to the inferior border to allow for visualization of the external oblique ridge, buccal shelf, lateral ramus and body, and mental neurovascular bundle. The flap is further elevated superiorly from the ascending ramus and includes stripping of the temporalis muscle attachment.

Three complete osteotomies and one bone groove must be prepared before graft harvest (Figs. 30 and 31). A superior osteotomy is created approximately 4 to 5 mm medial to the external oblique ridge with a 702L fissure bur in a straight handpiece. It begins opposite the distal half of the mandibular first molar or opposite the second molar and continues posteriorly in the ascending ramus. The length of this osteotomy depends on the graft size. The anterior extent of

Fig. 24. Complete relaxation of the labial flap is accomplished. Note approximation of wound margins at rest.

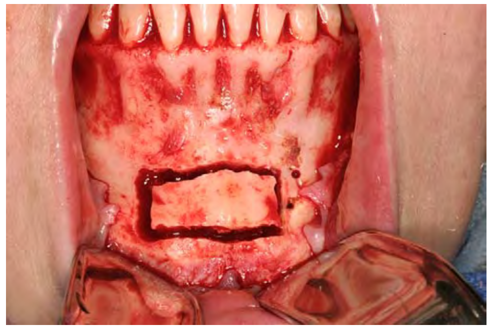

Fig. 25. Outline of symphysis block graft. Sulcular incision design is used with distal oblique release incisions at the second bicuspid bilaterally.

Fig. 26. Symphysis donor site. Bone bleeders are taken care of with electrocautery and collagen plugs.

this bone cut can approach the distal aspect of the first molar depending on the anterior location of the buccal shelf. A modified channel retractor is used for ideal access to the lateral ramus body area to allow for the two vertical bone cuts (Figs. 30 and 31). The vertical osteotomies begin at each end of the superior bone cut and continue inferiorly approximately 10 to 12 mm. All osteotomies just penetrate through buccal cortex into marrow. Finally, a #8 round bur is used to create a groove that connects the inferior aspect of each vertical osteotomy. The graft is then harvested using bone spreaders that are malletted along the superior osteotomy. The graft fractures along the inferior groove and should be harvested carefully so as to avoid injury to the inferior alveolar neurovascular bundle, which is visible 10% to 12% of the time. A sharp ledge is created at the superior extent of the ascending ramus and can be smoothed with a large round fissure bur before closure. Gauze moistened with saline, platelet-poor plasma, or platelet-rich

Box 4. Symphysis harvest

Sulcular incision: advantages over vestibular incision

- Excellent exposure
- Easy retraction
- Minimal bleeding
- Minimal nerve morbidity
- Soft tissue healing without scar band
- No ptosis
- Decreased postoperative pain

Contraindications

- Unhealthy periodontium
- Thin, highly scalloped gingival biotype
- Crowns associated with anterior mandibular teeth

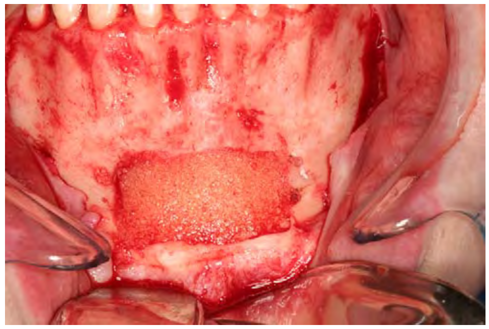

Fig. 27. Particulate demineralized bone putty used for donor site grafting.

plasma is then packed into the wound site. Closure of the donor site can be conducted after graft fixation. No bone grafting of this site is needed because form follows function (functional matrix theory), which allows for complete remodeling of the buccal shelf within 9 to 10 months. A second ramus buccal shelf block graft then can be harvested if needed.

Implant placement

After graft incorporation (Box 3), implants can be placed either submerged (Figs. 32–34) or nonsubmerged (Figs. 35–40), depending on relative density of the overall recipient site. Staging of the mandibular block graft allows increased bone volume and quality to be created before implant placement to ensure better initial implant stability. Ideal implant alignment is also facilitated, with increased bone maturation at the bone-implant interface, which is possible

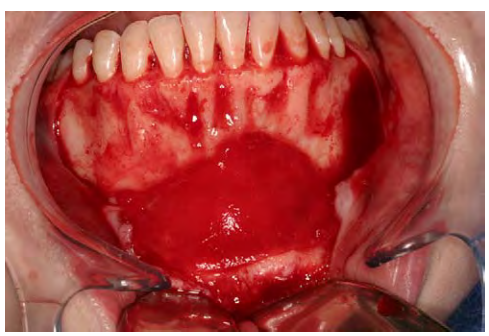

Fig. 28. Collagen membrane impregnated with platelet-rich plasma used over the grafted donor site.

Fig. 29. Primary closure of the symphysis donor site using 4-0 Vicryl horizontal mattress sutures.

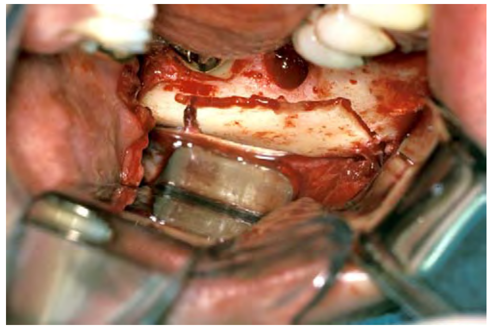

Fig. 30. Ramus buccal shelf block graft osteotomies. Note superior, anterior, and posterior vertical osteotomies and inferior groove.

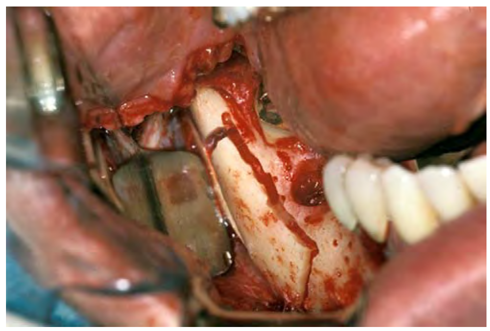

Fig. 31. Ramus buccal shelf harvest site. Note modified channel retractor for excellent soft tissue retraction.

Fig. 32. Four-month re-entry. Note papilla-sparing incision design and excellent graft incorporation.

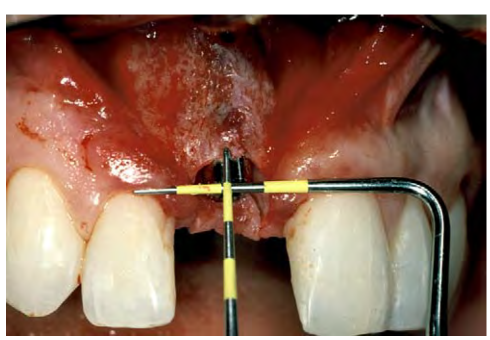

Fig. 33. Stage I surgery complete with 3-mm height, parallel wall healing abutment. Implant rim is 3 mm apical to the free gingival margin of the adjacent central incisor.

Fig. 34. Completed crown fabrication.

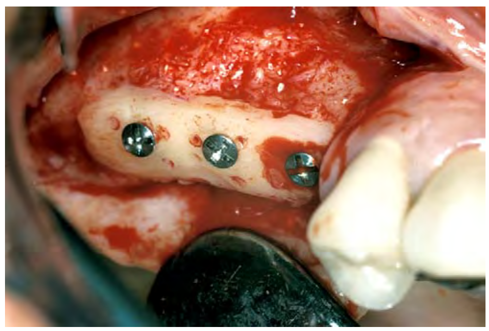

Fig. 35. Five-month re-entry with excellent graft incorporation. Note partial fill of block perforations.

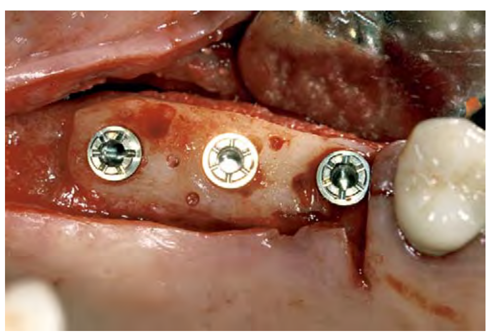

Fig. 36. Stage I implant surgery.

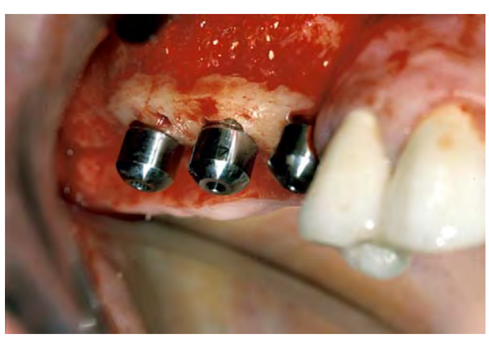

Fig. 37. Healing abutments in place for nonsubmerged protocol into D2 quality bone.

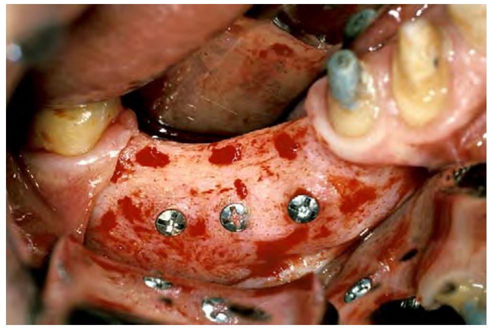

Fig. 38. Five-month re-entry. Note excellent graft incorporation with minimal resorption.

because the grafts exhibit minimal resorption (0–20%). Increased bone density also is obtained using symphyseal bone (type II or I) and ramus buccal shelf bone (type I). Because the greatest stresses of a loaded implant are located around the neck and ridge crest, the crestal bone with increased density can withstand implant loading in a more favorable biomechanical manner. This is a distinct advantage over other regenerative techniques, including guided bone regeneration. Finally, block autografts allow for maximum diameter implants to be used, which results in optimal force distribution to bone.

Complications

Despite the many advantages block grafts offer for alveolar ridge augmentation, complications can occur when mandibular block autografts are used for horizontal and vertical augmentation. Morbidity with this grafting protocol is associated with donor and recipient sites. This information includes the author's experience with 434 block grafts harvested between August 1991 and December 2002: 208 symphysis grafts and 226 ramus buccal shelf grafts.

Symphysis donor site morbidity includes intraoperative complications, such as bleeding, mental nerve injury, soft tissue injury of cheeks, lips, and tongue, block graft fracture, infection, and potential bicortical harvest. Bleeding episodes are intrabony and can be taken care of with cautery, local anesthesia, and collagen plugs. Injury to the mental neurovascular bundle is avoidable with proper surgical technique, especially the use of the sulcular approach for bone harvest. Block fracture and bicortical block harvest also can be prevented by following good surgical technique. Pain, swelling, and bruising occur as normal postoperative sequelae and are not excessive in nature. Use of platelet-rich plasma has decreased overall soft tissue morbidity. Infection rate is minimal (<1%). Neurosensory deficits include altered sensation of the lower lip, chin (<1% permanent), and dysesthesia of the anterior mandibular dentition (transient, 53%; permanent, <1%). No evidence of dehiscence or chin ptosis was seen using the sulcular approach.

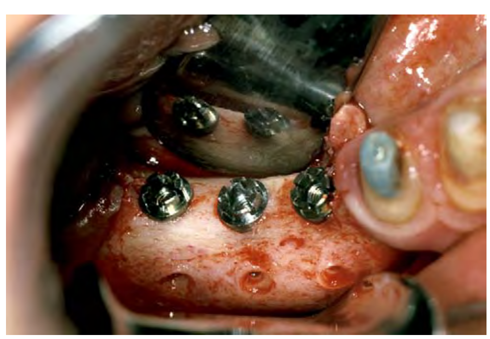

Fig. 39. Stage I surgery completed using threaded root form implants.

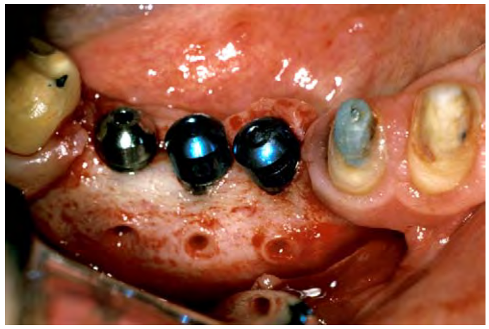

Fig. 40. Healing abutments placed as per nonsubmerged implant protocol.

The ramus buccal shelf harvest also can result in intraoperative complications, including bleeding, nerve injury, soft tissue injury, block fracture, infection, and mandible fracture. Intrabony and soft tissue bleeding can be handled with cautery. Injury to the inferior alveolar and lingual neurovascular bundle can be avoided with proper soft tissue manipulation and meticulous osteotomy preparation. Block fracture is also an avoidable problem with proper surgical technique. Postoperative morbidity includes trismus (approximately 60%), which is transient and can take up to 3 to 4 weeks to resolve. Pain, swelling, and bruising are typically mild to moderate and are minimized with use of platelet-rich plasma. Infection rate is less than 1%. Altered sensation of the lower lip or chin occurs approximately 8% of the time with less than 1% of cases ($n = 1$) being permanent. Altered sensation of the lingual nerve also has been reported but has been transient only. No instances of permanent altered sensation of mandibular dentition have been found.

Complications associated with the recipient site include trismus, bleeding, pain, swelling, infection, neurosensory deficits, bone resorption, dehiscence, and graft failure. Trismus is expected if the recipient site is the posterior mandible, which affects the muscles of mastication. Incidence is 60% and is transient. Bone bleeding is expected secondary to site preparation (decortication and perforation), but excessive bleeding can occur secondary to intrabony and soft tissue vessel transection. Pain, swelling, and bruising are mild to moderate and are minimized with platelet-rich plasma. The infection rate is less than 1% and is usually secondary to graft exposure. Neurosensory deficits can occur secondary to site preparation and block fixation because normal anatomy is violated. Graft dehiscence is the primary complication seen with mandibular block autografts and is primarily caused by soft tissue closure without tension (Fig. 41), thin mucosal tissue (Fig. 42), or excessive prosthesis contact with the graft site. This complication can be prevented in virtually all cases by ensuring primary closure without tension and ensuring adequate mucosal thickness before bone grafting, which often requires soft tissue grafting to be done before block grafting. Block graft resorption is minimal (0–20%) but can be excessive if graft dehiscence occurs. Primary closure without tension along with adequate mucosal thickness prevents virtually all bone graft dehiscence. Unfortunately, wound site dehiscence results in

Fig. 41. Note dehiscence of lingual mucosal tissues with screw exposure.

Fig. 42. Significant block graft dehiscence at 3-week postoperative examination.

partial and more often complete graft loss. In summary, overall morbidity of mandibular block autografts for alveolar ridge augmentation is minimal. Most complications are preventable, and those that occur can be handled predictably with minimal adverse effects to patients.

Further readings

Collins TA. Onlay bone grafting in combination with Brånemark implants. Oral Maxillofac Surg Clin North Am 1991;3: 893–902.

Collins TA, Nunn W. Autogenous veneer grafting for improved esthetics with dental implants. Compend Contin Educ Dent 1994;15:370–6.

Frost H. The biology of fracture healing: an overview for clinicians. Part I. Clin Orthop Relat Res 1989;248:283–92.

Frost H. The regional acceleratory phenomenon: a review. Henry Ford Hosp Med J 1983;31:3–9.

Jensen OT, Pikos MA, Simion M, et al. Bone grafting strategies for vertical alveolar augmentation. In: Peterson's principles of oral and maxillofacial surgery, 2nd edition. Ontario: BC Decker; 2004. p. 223–32.

Jensen J, Sindet-Pedersen S. Autogenous mandibular bone grafts and osseointegrated implants for reconstruction of the severely atrophied maxilla: a preliminary report. J Oral Maxillofac Surg 1991;49:1277–87.

Marx RE. Biology of bone grafts. In: Kelly JPW, editor. OMS knowledge update. Rosemont (IL): American Association of Oral and Maxillofacial Surgeons; 1994. p. RCN3–RCN17.

Misch CE. Contemporary implant dentistry. 2nd edition. St. Louis (MO): Mosby; 1999. p. 443–4.

Misch CM, Misch CE. The repair of localized severe ridge defects for implant placement using mandibular bone grafts. Implant Dent 1995;4:261–7.

Perry T. Ascending ramus offered as alternate harvest site for onlay bone grafting. Dent Implantol Update 1997;3:21–4.

Pikos MA. Alveolar ridge augmentation using mandibular block grafts: clinical update. Alpha Omegan 2000;93(3): 14–21.

Pikos MA. Alveolar ridge augmentation with ramus buccal shelf autografts and impacted third molar removal. Dent Implantol Update 1999;4(10):27–31.

Pikos MA. Block autografts for localized ridge augmentation: Part II. The posterior mandible. Implant Dentistry 2000; 9(1):67–75.

Pikos MA. Block autografts for localized ridge augmentation: Part I. The posterior maxilla. Implant Dentistry 1999;8(3): 279–84.

Pikos MA. Buccolingual expansion of the maxillary ridge. Dent Implantol Update 1992;3(11):85–7.

Pikos MA. Facilitating implant placement with chin grafts as donor sites for maxillary bone augmentation: Part II. Dent Implantol Update 1996;7(1):1–4.

Pikos MA. Facilitating implant placement with chin grafts as donor sites for maxillary bone augmentation: Part I. Dent Implantol Update 1995;6(12):89–92.

Pikos MA. Posterior maxillary bone reconstruction: importance of staging. Implant News and Views 1999;1(3):1, 6–8.

ELSEVIER
SAUNDERS

Atlas Oral Maxillofacial Surg Clin N Am 13 (2005) 109–118

Atlas of the
Oral and
Maxillofacial
Surgery Clinics

Bone Harvest from the Posterior Ilium

Robert E. Marx, DDS

Division of Oral and Maxillofacial Surgery, University of Miami Miller School of Medicine, Deering Medical Plaza, 9380 SW 150th Street, Suite 190, Miami, FL 33157, USA

Bone harvesting from the posterior ilium is indicated when autogenous corticocancellous blocks or cancellous cellular marrow grafts of 50 mL or more of uncompressed bone volume are required at the recipient site. This harvest approach is used commonly in the reconstruction of mandibular continuity defects of 5 cm or larger, hemimaxillectomy reconstructions, larger vertical and horizontal ridge augmentations, and the soft tissue matrix expansion graft (tent pole procedure) for severely resorbed mandibles.

The choice of the posterior ilium for larger reconstructive needs is based on the fact that this anatomic area has the greatest reservoir of bone and a forgiving anatomy in which major blood vessels and nerves are at a distance from the harvest site. Studies have shown that whereas the tibial plateau yields a maximum of 40 mL of uncompressed bone graft volume and the anterior ilium yields 50 mL, the posterior ilium yields up to 120 mL. As a comparison, a surgeon can harvest 2.25 to 2.5 times the amount of bone from the posterior ilium as can be harvested from the anterior ilium, because the cancellous bone in the anterior ilium is limited to the 2 cm of the crest, whereas the cancellous bone in the posterior ilium continues for its full length to the sciatic notch. This is illustrated best by comparing cross-sections at each site. In the anterior region, the medial and lateral cortices converge 2 cm inferior to the crest to limit the cancellous bone volume, whereas in the posterior region the medial and lateral cortices are parallel and are separated by 1.5 to 2 cm of cancellous bone throughout (Fig. 1).

Anatomic considerations

The ilium articulates with the sacrum to form the sacroiliac joint posteriorly and fuses to the pubic bone at its anterior and inferior end to form the acetabulum, to which the femur articulates. The area for bone harvesting is the area of greatest width, which is beneath the insertion of the gluteus maximus muscle. This triangular tubercle of bone measures approximately 3 cm anterior posterior and 4 cm superior inferior. The triangular shape of this tubercle forms a ridge that extends inferiorly 10 to 12 cm to form the sciatic notch. Just medial to this tubercle is the sacroiliac joint, and the ilium itself ends 2 to 2.5 cm posterior to this ridge (Fig. 2).

The lateral surface anterior and inferior to this tubercle forms a large concave surface to which the gluteus medius muscle attaches superiorly and the gluteus minimus muscle attaches anteriorly (Fig. 3). Only the posterior one tenth of the gluteus medius muscle is reflected in the surgical approach to the posterior ilium, and the gluteus minimus is not involved. The fascia of the gluteal muscles extends over the crest of the posterior ilium and becomes confluent with the thoracodorsal fascia (some anatomy texts may call this the lumbodorsal fascia), which is the extension and the caudal insertion of the latissimus dorsi muscle.

E-mail address: rmarx@med.miami.edu

doi:10.1016/j.cxom.2005.06.001

Fig. 1. Cross-sections of the posterior ilium (*left*) and the anterior ilium (*right*) illustrate the greater quantity of cancellous marrow within the posterior ilium.

The medial cortex of the ilium provides the attachment for the iliacus muscle. The blood supply to the entire ilium is via perforating vessels, which enter the medial cortex from the deep circumflex iliac artery that courses through the iliacus muscle just under the periosteum. The vessel continues within the iliacus muscle from anterior to posterior and terminates as the subgluteal artery after it courses through the sciatic notch and ramifies on the lateral surface of the ilium in the area of the posterior tubercle (Fig. 4). The lateral approach to the posterior ilium is away from the main blood supply, which is on the medial surface, and the bone harvesting occurs in the area in which these vessels terminate. The posterior ilium harvest only requires reflection of the gluteus maximus insertion and an insignificantly small portion of the gluteus medius. Because the gluteus maximus muscle is not involved in normal gait, patients experience little or no initial or long-term gait disturbance. Instead, the gluteus maximus muscle is activated when one arises from a sitting position. Patients are cautioned to use the opposite leg for this maneuver for the first 6 weeks.

The pertinent nerve innervations about the posterior ilium harvest site are sensory nerves only. The motor nerves are given off deep to and at a distance from the harvest site. The motor nerves to the leg course through the sciatic notch, which is 5 to 8 cm inferior to the inferior most extent of the harvest site. The pertinent sensory nerves are the superior and middle cluneal nerves. The superior cluneal nerves innervate the skin of the gluteal region from a superior direction as they pierce the thoracodorsal fascia and ramify in the dermis over the harvest site. The superior cluneal nerves represent dorsal sensory rami of L1, L2, and L3. The middle cluneal nerves innervate the skin of the gluteal region from the medial direction and ramify in the dermis about the sacroiliac joint and the harvest site. The incisional approach to the posterior ilium is placed between the two main trunks of these nerves and avoids a broad area of paresthesia/anesthesia postoperatively and avoids the formation of any neuroma (Fig. 5).

Fig. 2. The triangular shaped tubercle of the posterior ilium is the most important landmark for bone harvesting. The sciatic notch is 10 cm to 12 cm inferior to this landmark.

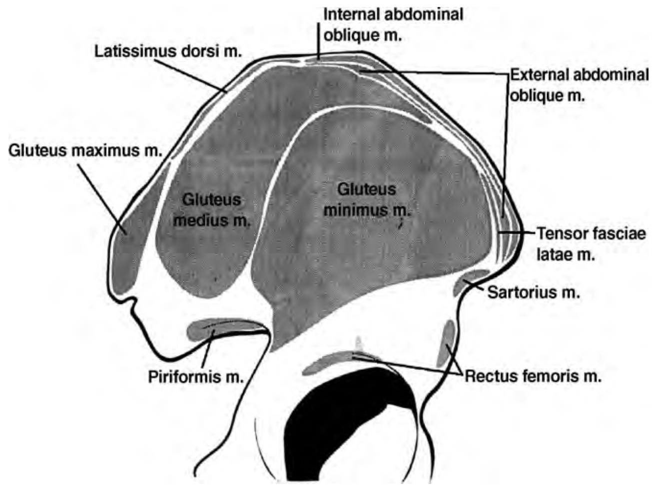

Fig. 3. The gluteus maximus muscle attaches to the tubercle of the posterior ilium. The gluteus medius muscle attaches inferiorly to the tubercle in a concavity.

Surgical approach

Bone harvesting from the posterior ilium is known for a reduced blood loss as compared with the anterior ilium not only by virtue of its location at the distal end of the bone's blood supply but also by virtue of patient positioning. The patient is placed in a prone position with the table reverse flexed at an angle of 210°. Auxiliary supports are provided bilaterally, and a large support roll is placed under the anterior thigh caudal to the pubic symphysis. This positioning results in an elevation of the buttocks and the harvest site, which reduces the venous pressure locally and the blood loss as cancellous marrow is harvested (Fig. 6).

The incision should be curvilinear and follow the palpable curvature of the posterior iliac crest. The incision is usually 10 cm long, with its midpoint positioned over the triangular insertion of the gluteus maximus at the tubercle. The surgeon should draw this incision and regional anatomy with a surgical pen before the incision so as to maintain proper orientation and perspective (Fig. 7). The incision goes through the full skin thickness and the subcutaneous layer to identify the thoracodorsal fascia through which the bony crest can be palpated. The thoracodorsal fascia and periosteum are then incised the full length of the incision. The gluteus maximus muscle is sharply reflected from its triangular insertion because of its tenacious insertions via Sharpe's fibers. Once this sharp reflection passes the gluteal line (approximately 3 cm beneath the crest), the gluteus medius is encountered. This muscle inserts via a periosteum

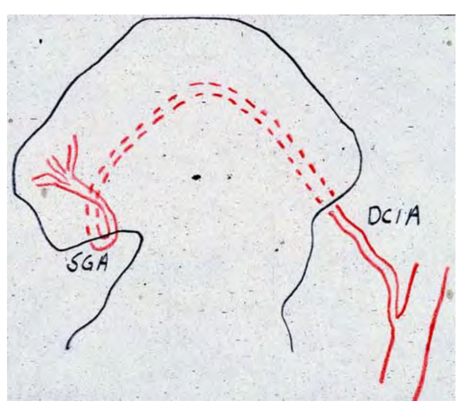

Fig. 4. The blood supply to the entire ilium is via the deep circumflex iliac artery, which courses within the iliacus muscle medial to the ilium and then turns laterally through the sciatic notch to terminate as the subgluteal artery. DCIA, deep circumflex iliac artery; SGA, subgluteal artery.

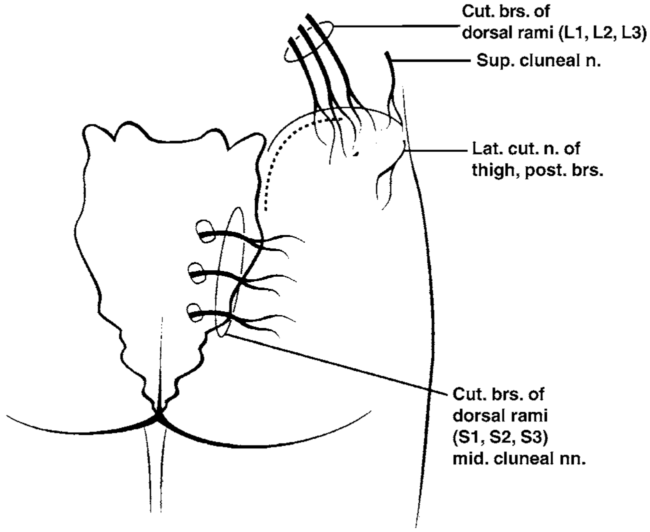

Fig. 5. The 10-cm curvilinear incision used to approach a posterior ilium harvest is placed between the sensory superior and middle clinical nerves.

and can be reflected with a Keyes periosteal elevator. A posterior ilium retractor is inserted for the appropriate side, which should expose a broad surface of the lateral posterior ilium (Fig. 8). At that point, the surgeon may notice several bleeding vessels that emerge from the lateral cortex. The surgeon is advised to cauterize each one to prevent accumulated blood loss during the remainder of the harvest.

The bone removal usually begins with a 5 cm $\times$ 5 cm cortical ostectomy achieved with a reciprocating saw. The posterior edge of the square should be at the height of the ridge of the posterior tubercle. The saw should be passed only through the lateral cortex. Next the saw should accomplish an osteotomy 5 cm anterior along the external edge of the crest and then 5 cm inferiorly at the anterior extent of the square before connecting these vertical limbs at the inferior edge. The 5 cm $\times$ 5 cm cortical cancellous block is removed using a 1-in (2.5 cm) curved osteotome and mallet (Fig. 9A, B). The resultant cortical cancellous block can be used as an autogenous block graft or can be particulated into a cortical cancellous marrow graft with the use of a bone mill. In either case, this block results in 20 to 25 mL of uncompressed bone graft volume (Fig. 10A, B).

At this time, the large reservoir of cancellous marrow in the posterior ilium is directly exposed for harvesting. The surgeon should begin with a bone gouge, which is "walked through" the cancellous marrow with a wrist rotation movement (Fig. 11). This approach dislodges a large curl of cancellous marrow with each entry and maneuver. Once all the

Fig. 6. Positioning for a posterior ilium harvest is prone, with the table in a 210° reverse flex position, an anterior thigh support, and supports in each axilla.

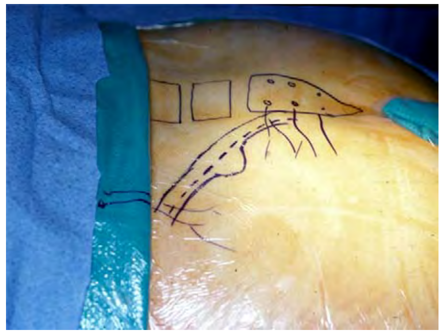

Fig. 7. Curvilinear incision and regional anatomy drawn on the posterior ilium are recommended to keep perspective and orientation throughout surgery.

cancellous marrow obtainable by the bone gouge is harvested, bone curettes can be used to harvest the remainder. The surgeon always should be sure to scrape the marrow side of the medial cortex for additional graft volume because a high concentration of stem cells is located there. The total amount of bone to be harvested is an estimate of the needs at the recipient site. A useful guideline is that 8 to 10 mL of uncompressed harvested bone graft material is required for each 1 cm of length as measured on a panoramic radiograph.

Once all the desired bone is harvested, the bony edges of the harvest site should be smoothed with a rasp and hemostasis achieved. Any bleeding points from the medial cortex lend themselves to control by cautery. Areas of constant oozing are best controlled with a small amount of bone wax compressed into the bleeding point area. As an additional hemostatic measure, 1 g of microfibrillar bovine collage (Fig. 12) or a collagen sponge soaked in 5000 U of bovine thrombin may be placed into the harvest site.

A 7- or 10-mm suction drain is recommended and should be placed into the bony cavity and exited anterior to the incision so that the patient does not lie on it in the postoperative period (Fig. 13). The drain should be activated with only compressed bulb suction, however. One never should use a wall suction drain because the high negative pressure of a wall suction risks promoting continuous marrow space bleeding by capillary and small vessel rupture. The closure is straightforward but crucial. It is important to suspend and close the reflected gluteus maximus to the firm thoracodorsal fascia. Failure to do so causes the gluteus maximus to contract and prolapse into the bony defect, thereby obliterating the space so as to reduce bone regeneration in the donor site. The contracted muscle also fails to reattach at the crest, which reduces the strength of the muscle and results in a visible concavity. The first layer of closure is best accomplished with a 2-0 resorbable suture. The subcutaneous layers and dermis are closed with a 3-0 resorbable suture and the skin surface is closed with small skin staples or a 4-0 nonresorbable suture. A pressure dressing that consists of ‘‘fluffed gauze’’ and an elastic or microfoam tape is then applied (Fig. 14).

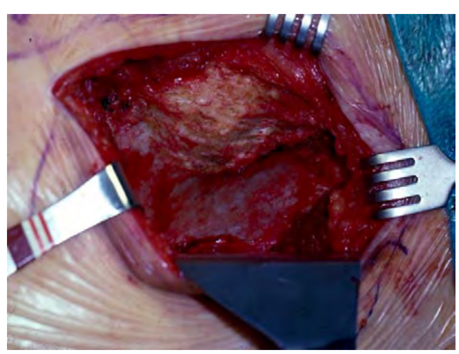

Fig. 8. The tubercle of the right posterior ilium and lateral cortex after reflexion of the gluteus maximus and a small portion of the gluteus medius.

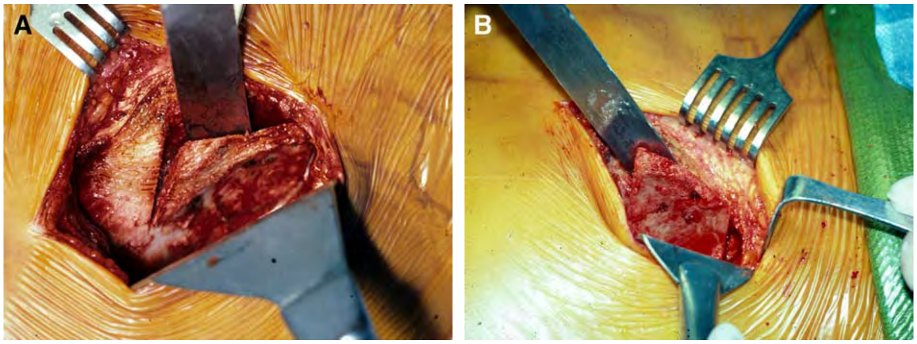

Fig. 9. (*A*) A 1-in curved osteotomy begins the separation of the lateral cortical cancellous block using a vertical malleting. (*B*) Using a cross or oblique angle of the osteotome from posterior superior to contain anterior inferior completes the removal of the 5 cm × 5 cm cortical cancellous block.

Results of posterior ilium harvest

Blood loss ranges from as little as 100 mL to as much as 500 mL (mean, 225 mL). The average 80-kg man yields 100 to 120 mL of uncompressed cancellous bone (Fig. 15), and a 45-kg osteoporotic woman yields approximately 70 mL. A short-term gait disturbance (limp) can be expected for up to 1 week because of muscle pain and soreness. A gait disturbance that lasts more than 1 week is rare, however, and should be evaluated for an unexpected complication.

Postoperative care and instructions

The first postoperative day is recommended to consist of bed rest, although most patients can ambulate. On the second postoperative day, in-room ambulation is encouraged, and by the third postoperative day, walking short distances is recommended. Canes and walkers are unnecessary and are discouraged. The drain is usually left in place until the 24-hour total is 50 mL or less, which requires approximately 2 to 4 days. Instructions upon discharge include reduced activities and no sports activities for 6 weeks. In particular, we instruct patients to avoid bicycling, walking up more than one flight of stairs, and walking more than one city block during the first 6 weeks.

Potential complications and their management

Complications from a posterior ilium harvest are uncommon and usually can be resolved quickly. The following section discusses known complications, their causes, and the recommended management.

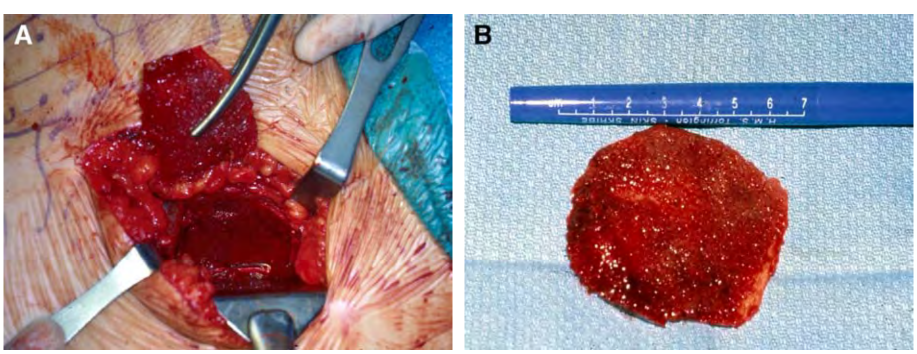

Fig 10. (*A*) Once the cortical cancellous block of bone is removed, the large reservoir of cancellous marrow is directly accessible. (*B*) The 5 cm × 5 cm cortical cancellous block can be used as a direct block graft or milled in a bone mill to yield 20 to 25 mL of particulated cancellous marrow cortex.

Fig. 11. Using a bone gauge is best when beginning the cancellous marrow harvest. It is ‘‘walked through’’ the cancellous marrow with a wrist rotational action to yield a large curl of cancellous marrow.

Seroma

Seromas are statistically the most common complication. Most are caused by overactivity early in the postoperative course, such as extended ambulation, stair climbing, exercise machines, or bicycling. Some cases in which a drain was not used also have resulted in a seroma. Small seromas reabsorb without intervention. Persistent seromas or large seromas should be aspirated, however, and a pressure dressing should be reapplied up to three times. If the seroma persists beyond this point, reinsertion of a drain and a pressure dressing or re-exploration and débridement of the wound are recommended.

Hematoma

Most hematomas are the result of persistent marrow ooze. Every oral and maxillofacial surgeon who has been on trauma call knows that subtle bleeding in the pelvic area can be significant before it becomes clinically apparent, however. Signs of a hematoma or ecchymosis in the groin, thigh, or flank should prompt the surgeon to obtain a complete blood count and assessment of heart rate, blood pressure, drain output, and urine output. If no signs of hypovolemic shock are present, then treatment consists of a pressure dressing and continued monitoring of the complete blood count, urine output, drain output, and vital signs. If evidence exists of impending shock, fluid resuscitation with Ringer’s lactate or even transfusion of O-negative blood may be required, as may be a type and cross-match for transfusion of type-specific blood. If the complete blood count, urine output, and vital signs continue to deteriorate or if the operating surgeon concludes that active bleeding is continuing in the wound, then a return to the operating room to reopen the harvest site and directly control the bleeding or pack the wound may be necessary. Other causes of a hematoma or hypovolemic shock may be arterial bleeder ‘‘pumpers’’ from the medial cortex via the deep circumflex iliac artery or muscle bleeders in the gluteal muscles, which would represent branches of the subgluteal artery.

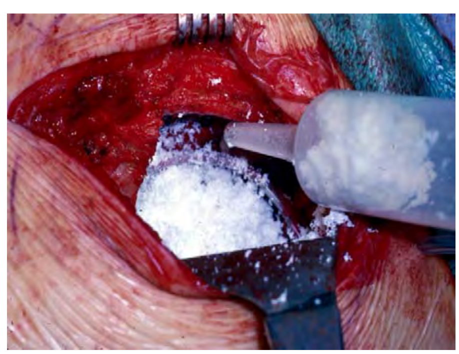

Fig. 12. Microfibrillar bovine collagen is used commonly as a general wound space hemostatic agent.

Fig. 13. A 7- or 10-mm suction drain should be placed into the bone cavity and exited anteriorly so that the patient does not lay on it.

Fracture

A rare complication of bone harvesting from the posterior hip is fracture, which may result from placing the posterior ostectomy posterior to the ridge of the posterior tubercle. This placement undermines the posterior spine of the ilium and may weaken it so that a fracture develops between the ostectomy and the sciatic notch. It also may occur if the osteotomy for the initial corticocancellous block removal is larger than 5 cm × 5 cm. A larger ostectomy reduces the support of the ilium superior to the sciatic notch and may result in a fracture through the sciatic notch. It should be noted that an increased risk for fracture exists in patients with osteoporosis, smokers, or persons with previous surgery of the posterior ilium. A fracture produces pain and a gait disturbance, but its diagnosis must be confirmed radiographically. Such rare fractures are best treated closed with extended bed rest for up to 2 months and serial radiographs to monitor bone remodeling to complement serial clinical evaluations. Open reduction of the fracture is not usually warranted and should be accomplished only by a trained orthopedic surgeon. Once the fracture has initially healed and the patient is comfortable, physical therapy is recommended.

Paresthesias and neuroma

Noticeable paresthesias and neuromas are rare, mostly because of the placement of the incision between the superior and middle clinical nerves. In rare cases of paresthesias, physical

Fig. 14. A pressure dressing of fluffed gauze and foam tape assists hemostasis with constant pressure.

Fig. 15. The posterior ilium can yield a large amount of cancellous marrow for grafting. Two 45-mL caps are filled and a cortical cancellous block of 25 mL identifies 115 mL of bone harvest, which may reconstruct up to a 12-cm mandibular continuity defect.

therapy and time minimize its impact on the patient. Reoperation of the area is not indicated. Neuromas have not been seen with this approach to the posterior ilium. If a neuroma is diagnosed by a painful palpable mass or a painful mass apparent upon imaging of the area, however, then exploration and excision are the only recourse.

Advantages of the posterior ilium harvest

Despite the preceding discussion of potentially concerning complications, the posterior ilium harvest has fewer complications than the anterior ilium harvest. In a review of 839 posterior ilium harvests recorded by the author over 25 years, there have been only 2 fractures (0.2%), 31 seromas (3.6%), 6 hematomas that did not require a return to the operating room (0.7%), 1 postoperative bleed that required a return to the operating room (0.1%), 4 permanent gait disturbances (0.5%) (two of which were the result of the fractures already noted), and no neuromas or patient complaints of an annoying paresthesia. The results are summarized in Box 1.

Compared with the anterior ilium and the proximal tibia for bone graft needs larger than 50 mL, the posterior ilium harvest yields more bone for grafting procedures with less harvesting trauma because of its direct access. There is also less blood loss because of anatomy and patient positioning and earlier patient ambulation because of the avoidance of muscles involved in walking motions. It is an indispensable procedure for continuity defects and larger bone grafting needs, and it has a track record of predictably good outcomes at the recipient site and minimal complications at the donor site.

Disadvantages of the posterior ilium harvest

The main disadvantage of the posterior ilium harvest involves time. Because patients must be placed in a prone position, two teams of surgeons (one at the donor site and one at the recipient site) cannot work simultaneously, as is done with anterior ilium or tibial bone graft harvests. This procedure adds 1 to 2 hours to the overall operating room time. Patients also must be

Box 1. Morbidity of posterior ilium harvest

Seroma: 31 (3.6%)
Hematoma: 6 (0.7%)
Postoperative bleed: 1 (0.1%)
Gait disturbance: 4 (0.5%)
Neuromas: 0 (0%)
Symptomatic paresthesias: 0 (0%)

turned on the operating room table, which poses the risk of displacing the endotracheal tube or tracheostomy. Although this displacement has not occurred in the 839 cases accomplished by this author, it remains a potential complication. Its avoidance must be confirmed by bilateral breath sounds on auscultation and an appropriate end-tidal CO_2 recording.

Further readings

Alhmann E, Patzakis M, Roidis N, et al. Comparison of anterior and posterior iliac crest bone grafts in terms of harvest site morbidity and functional outcomes. J Bone Joint Surg Am 2002;84A(5):716–20.

Marx RE, Morales MJ. Morbidity from bone harvest in major jaw reconstruction: a randomized trial comparing the lateral anterior and posterior approaches to the ilium. J Oral Maxillofac Surg 1988;458:196–203.

Mazock JB, Schaw SR, Triplett RG. Posterior iliac crest bone harvest: review of technique, complication, and use of an epidural catheter for postoperative pain control. J Oral Maxillofac Surg 2003;61(12):1497–503.

Mkenke F, Weisbach V, Winichler E, et al. Morbidity of harvesting bone graft from the iliac crest for preprosthetic augmentation procedures: a prospective study. Int J Oral Maxillofac Surg 2004;33(2):157–63.

ELSEVIER
SAUNDERS

Atlas Oral Maxillofacial Surg Clin N Am 13 (2005) 119–126

Atlas of the
Oral and
Maxillofacial
Surgery Clinics

Tibia Bone Graft Harvest Technique

George M. Kushner, DMD, MD

Department of Surgical and Hospital Dentistry, University of Louisville School of Dentistry, 501 South Preston, # 337, Louisville, KY 40202, USA

Contemporary oral and maxillofacial surgeons need bone grafting techniques to satisfy patient needs in trauma, pathology, reconstructive surgery, and dental implantology. The ''gold standard'' for bony reconstruction of the jaws is the use of autogenous bone grafts. Autogenous grafts are believed to be advantageous in many ways. First, viable osteocytes can be carried to the graft site, and active bone regeneration or osteogenesis can occur [1]. Second, autogenous bone grafts act by osteoinduction when bone morphogenetic proteins stimulate bone formation [1]. Finally, autogenous bone grafts act as a scaffold for vascular ingrowth, which is known as osteoconduction [1]. Many patients simply request that their surgeon ''use my own body to reconstruct me'' rather than deal with potential problems associated with banked bone, allografts, xenografts, or alloplastic graft material. Fortunately, as surgeons, we have a wide choice of autogenous bone donor sites, including jaws, iliac crest, calvarium, and tibia. By expanding the donor sites to the free flap arena, surgeons can expand the donor sites to include the scapula, radius, and fibula.

At the University of Louisville, we have favored the tibia graft harvest as our preferred donor site whenever possible. The tibia graft harvest is a technically easy procedure to perform, yields an excellent quantity of cancellous bone, and has a low complication rate [1–4]. The tibia graft is performed on skeletally mature patients who want the benefit of autogenous bone grafting without the risk and pain associated with other favorite donor sites, such as the iliac crest or calvarium. The surgeon easily can obtain 25 cc of cancellous bone, which is more than adequate for procedures such as bilateral sinus lifts and grafting fracture nonunions [4,5]. The tibia graft harvest can be performed in the office or in an outpatient setting, which can be a critical factor when patients are paying for procedures ''out of pocket,'' as is commonly seen with patients who receive dental implants [4]. Dental implants have become an area of keen interest to oral and maxillofacial surgeons. Being able to offer cost-effective autogenous bone grafting techniques that can fulfill various clinical applications clearly is an excellent service to patients.

The tibia as a donor graft site in maxillofacial reconstruction first appeared in 1992, when Catone and colleagues [2] published their experience with 20 cases. Since then, numerous reports have been published and renewed interest has appeared in using the tibia for maxillofacial reconstruction [4–6]. The University of Louisville oral and maxillofacial surgery residents began using the tibia as a donor site in the mid 1990s while rotating on the orthopedic surgery service. The University of Louisville Hospital is a level-one trauma center that has an active orthopedic surgery service that routinely performs bone grafting in the primary and secondary stages of treatment. The oral and maxillofacial surgery residents were impressed with the versatility and excellent quantity of bone obtained from the tibia. The procedure was performed easily and had a low complication rate in their hands. The oral and maxillofacial surgery residents essentially brought the tibia graft harvest technique back to the oral and maxillofacial surgery service, and we have used the tibia graft harvest effectively for various clinical applications.

E-mail address: gmkush01@louisville.edu

1061-3315/05/$ - see front matter
doi:10.1016/j.cxom.2005.05.001

Review of anatomy

I favor the lateral approach to the tibia metaphysis. The primary bony landmark in the proximal tibia is Gerdy's tubercle. Gerdy's tubercle is a bony protuberance between the patellar ligament (midline) and the head of the fibula, which is palpable 90° laterally. There is thin skin over this area and no vital anatomic structures located over Gerdy's tubercle.

In reviewing the anatomy of the peripheral nervous system, there are only cutaneous branches of the lateral sural nerve in the area of Gerdy's tubercle. The fibular nerve is well protected beneath the head of the fibula and does not enter the surgical field. No major nerve structures are located over Gerdy's tubercle. The vascular anatomy consists of branches of the inferior genicular artery and recurrent anterior tibial artery. These small, terminal branches are easily controlled with electrocautery or clamping and ligating the vessels. Bleeding has not presented as a clinical problem in our series of tibial graft harvests.

The pertinent muscular anatomy near Gerdy's tubercle is the tibialis anterior muscle, which occupies the anterior lateral portion of the proximal tibia and sits inferior to Gerdy's tubercle. The area over Gerdy's tubercle is devoid of any major anatomic structure, which is a key feature in the simplicity of the surgery and the low complication rate. The only anatomic structure one encounters during the dissection is the iliotibial tract, a dense fascial band that runs from the anterior iliac crest to the lateral surface of the tibia.

Surgical technique

The patient is generally in a supine position in the operating room or a recumbent position in the dental chair if the procedure is performed in the dental office. A broad-spectrum antibiotic is given as prophylaxis (generally cephalosporin) for the surgical procedure, and I favor the use of steroids, such as dexamethasone, given preoperatively as long as there are no contraindications to the medications. In the operating room, a tourniquet is used to facilitate hemostasis. If a tourniquet is not available for office use, we routinely place a thigh-sized blood pressure cuff on the patient's thigh to act as a tourniquet. We have performed several tibia graft harvests without any tourniquet/thigh cuff with no adverse sequelae, such as bleeding.

Gerdy's tubercle is palpated and diagrammed with a surgical marking pen (Fig. 1). The area over Gerdy's tubercle is liberally injected with local anesthesia, such as bupivicaine with epinephrine, to provide a vasoconstrictive effect and postoperative pain management. The local anesthesia is placed in the skin, subcutaneous tissues, and down to periosteum and the level of the bone. A sterile surgical preparation is done circumferentially 8 to 12 inches above and below the planned incision site. A 3- to 4-cm incision is made directly over Gerdy's tubercle (Fig. 2). The incision is carried sharply through the skin, subcutaneous tissues (including the iliotibial tract), and periosteum. The periosteum is elevated in preparation for making a cortical window through the cortical bony plate at Gerdy's tubercle. A cortical window can be made with either

Fig. 1. Pertinent anatomy diagrammed on the right tibia. Fibular head is lateral and the patella is midline. Gerdy's tubercle is easily palpable between the two structures, and the incision line is cross-marked.

Fig. 2. Exposing Gerdy's tubercle and proximal metaphysis of the left tibia. Note thin amount of soft tissue that required incision before reaching bone.

a surgical drill or osteotomes and mallet (Fig. 3). I prefer the use of a surgical drill to make an oval bony window to harvest the graft.

The use of an oval hole as opposed to a square or rectangular hole has the theoretical advantage of less stress in the cortical bone at the angles of a square or rectangular hole. I feel that stress lines can be created in the cortical bone with the osteotome and mallet technique, which potentially can weaken the donor site. The cortical bony window is removed and can be discarded or ground up and added to the bone graft. The cancellous bone is harvested with orthopedic curettes by going across the tibial plateau and down the shaft of the tibia (Figs. 4, 5). Great care must be taken in harvesting bone in a superior direction because the surgeon risks entering the joint space of the knee. Once the bone harvest is completed, hemostasis is checked with the tourniquet released. The wound is closed in layers, with the iliotibial tract being reapproximated with 2-0 or 3-0 vicryl sutures (Figs. 6, 7). I favor a subcutaneous suture with 4-0 vicryl and either a running subcuticular stitch and steri-strips or nylon suture skin closure.

Postoperative care

A sterile dressing is placed at the time of surgery. I generally favor an ace wrap placed over the harvest site. The incision site is kept dry for 48 hours, which is common for most surgical incisions. Sutures are generally removed in 10 to 14 days. The patient begins a weight-bearing-as-tolerated protocol immediately after surgery [1,4]. Office-based patients walk out of the facility under their own power. Canes or crutches are generally not given to patients postoperatively. Patients are instructed not to participate in contact sports or vigorous physical activity for 6 weeks. Antibiotic protocols are based on the primary surgical procedure. Analgesics generally are provided for the primary surgical procedure because there is usually minimal pain from the tibia harvest site. Generally, hydrocodone or a pharmacologically equivalent medication is sufficient to manage the postoperative discomfort from the maxillofacial procedure and tibia graft harvest.

Fig. 3. Oval window is made with Hall drill in the cortical bone of Gerdy's tubercle.

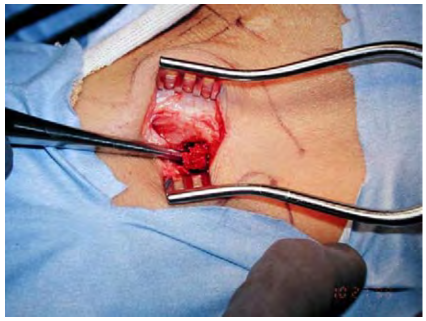

Fig. 4. The cancellous bone is removed with the orthopedic curettes. The direction of bone removal is across and down the shaft of the tibia.

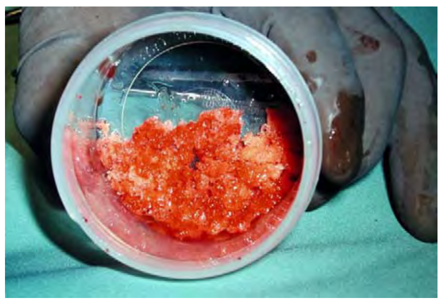

Fig. 5. Cancellous bone harvested from the tibia.

Fig. 6. Evaluation of osteotomy site before closure.

Fig. 7. Closure of incision.

Complications

Surgeons must be aware of any potential complications from the bone graft harvest so that they can assess the risk adequately for the patient. Infection is a known risk for any surgical procedure, which is certainly true for a tibia bone graft harvest. A major complication can be a fracture of the tibia plateau, just as fracture of the pelvis is a known complication after iliac crest harvest. Surgical misadventure into the joint space can require orthopedic surgery consultation and additional treatment. Overall, complication rates from the tibia graft harvest are low. Alt and colleagues [1] reported a 1.9% complication rate with no major complications.

Clinical data

From July 1, 1995 to December 31, 2004 at the Department of Oral and Maxillofacial Surgery, University of Louisville, a total of 141 patients underwent tibia graft harvest procedures. The breakdown is as follows:

1995: 5 patients
2000: 20 patients
2001: 18 patients
2002: 23 patients
2003: 27 patients
2004: 20 patients

No major complications were reported. Two minor complications consisted of wound dehiscence and superficial infection, which required no additional surgery, only dressing changes and oral antibiotic therapy. No complications were reported in patients who underwent office-based surgery. Overall, the complication rate was 1.4% (2/141 patients).

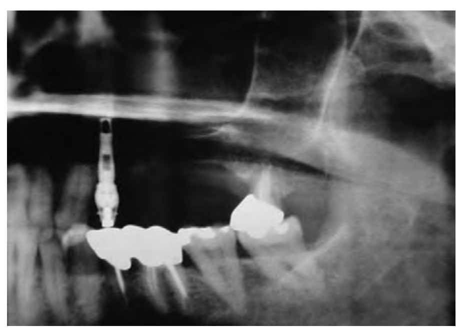

Fig. 8. Example of clinical uses of tibia bone graft. Preoperative radiograph of area planned for a sinus lift and dental implant placement.

Fig. 9. Clinical photo of sinus lift performed with a lateral approach and implants placed.

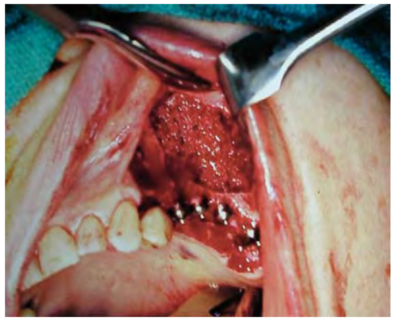

Fig. 10. Autogenous tibia graft placed in sinus lift/implant site.

Fig. 11. Final postoperative radiography of sinus lift and implants.

Fig. 12. Clinical photo of completed prosthesis.

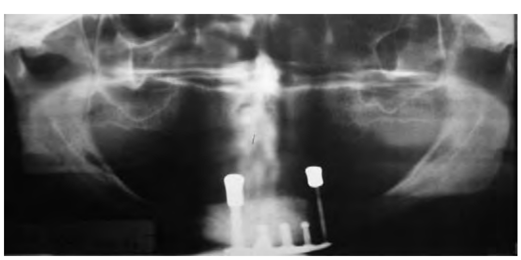

Fig. 13. Example of clinical uses of tibia bone graft. Preoperative radiograph of mandibular staple that is clinically failing and requires removal.

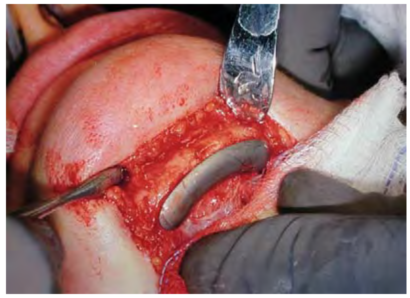

Fig. 14. Submental approach to remove staple and baseplate.

Fig. 15. Sectioned staple removed and posts cored out.

Fig. 16. Remaining defect left in atrophic mandible after staple removal.

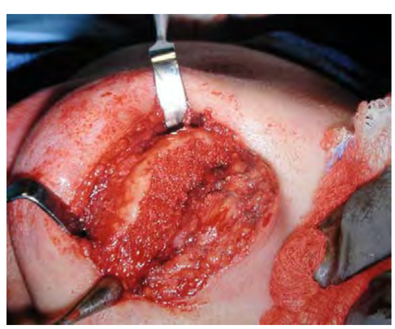

Fig. 17. Mandibular defect grafted with autogenous tibia bone to aid in bony healing and prepare for future implant reconstruction.

Summary

The tibia is an excellent source of autogenous bone that should be considered for any maxillofacial reconstructive procedure. An adequate quantity of cancellous bone can be harvested in the office or the operating room with relative ease to the surgeon and the patient. The tibia graft harvest (in our experience) has a low complication rate of 1.4% with no major complications. Grafting from the proximal tibia has proved to be a valuable addition in fulfilling patient needs in trauma, pathology, reconstruction, and implantology (Figs. 8–17).

Acknowledgments

Dr. Kushner would like to acknowledge the contributions of the entire Department of Oral and Maxillofacial surgery at the University of Louisville for the material used in this article. Attending surgeons: Dr. Brian Alpert, Dr. Martin Steiner, Dr. Harold Boyer, Dr. Kim Goldman, Dr. Paul Tiwana.

Special recognition should be given to the 12 years of OMFS residents during my tenure who have constantly inspired the faculty and energized us to push the envelope to provide improved patient care.

References

[1] Alt V, Nawab A, Seligson D. Bone grafting from the proximal tibia. J Trauma 1999;47:555–7.

[2] Catone GA, Reimer BL, McNeir D, et al. Tibial autogenous cancellous as an alternative donor site in maxillofacial surgery: a preliminary report. J Oral Maxillofacial Surg 1992;50:1258–63.

[3] O'Keefe RM, Reimer BL, Butterfield SL. Harvesting of autogenous cancellous bone graft from the proximal tibial metaphysis: a review of 230 cases. J Orthopedic Trauma 1991;5:469.

[4] Lee C. An in-office technique for harvesting tibial bone: outcomes in 8 patients. J Oral Implantol 2003;29(4):181–4.

[5] Lung G. Quantitative analysis of proximal tibial cancellous bone available for augmentation of maxillofacial defects. J Oral Maxillofacial Surg 1995;53:93–4.

[6] Garg AK. Lateral proximal tibia bone harvest for use in augmentation procedures. Dent Implantol Update 2001;11: 33–7.

Atlas of the Oral and Maxillofacial Surgery Clinics

Atlas Oral Maxillofacial Surg Clin N Am 13 (2005) 127–137

Cranial Bone Grafts: Craniomaxillofacial Applications and Harvesting Techniques

Ramon L. Ruiz, DMD, MD[a,b,*], Timothy A. Turvey, DDS[c], Bernard J. Costello, DMD, MD[d,e], Tinerfe J. Tejera, DMD, MD[a,f]

[a]Department of Oral/Maxillofacial Surgery, Southwest Florida Oral and Facial Surgery, 5285 Summerlin Road, Suite 101 Fort Myers, FL 33919, USA

[b]Children's Hospital of Southwest Florida, 9981 South HealthPark Drive, Fort Myers, FL 33908, USA

[c]Department of Oral and Maxillofacial Surgery, University of North Carolina at Chapel Hill, Manning Drive & Columbia Street, CB #7450, Chapel Hill, NC 27599-7450, USA

[d]Division of Craniofacial and Cleft Surgery, Department of Oral and Maxillofacial Surgery, University of Pittsburgh School of Dental Medicine, 3471 Fifth Avenue, Suite 1112, Pittsburgh, PA 15213, USA

[e]Department of Pediatric Oral and Maxillofacial Surgery, Children's Hospital of Pittsburgh, Salk Hall, Suite G-32, 3501 Terrace Street, Pittsburgh, PA 15261, USA

[f]Lee Memorial Health System, 2776 Cleveland Avenue, Fort Myers, FL 33901, USA

The use of bone grafts taken from the cranial vault provides the most predictable results in maxillofacial and craniofacial reconstructive surgery. Ilium and rib were formerly the most frequently used donor sites, and the site was chosen according to the desired bone consistency. The cranium has now become a favored bone harvest site with numerous applications, including cranial vault and orbital defects, the filling of osteotomy gaps, onlay and interpositional bone grafts during orthognathic procedures, and the skeletal reconstruction of facial cleft deformities. The proximity to the surgical site, ease of harvesting, and quantities of bone available make the calvaria an attractive alternative. Additionally, the consistency of the bone in the cranium (dense cortical) and its rich haversian network allow it to revascularize quickly and resorb minimally. Consequently, cranial bone grafts are excellent for use in repairing and recontouring the craniomaxillofacial skeleton. Allogeneic bone, lyophilized cartilage, and alloplastic materials have all been used in oral and maxillofacial surgery. Although success has been achieved with the use of these materials in certain instances, none has the same success rate or predictability of fresh autogenous bone harvested from the cranial vault. The purpose of this article is to provide an overview of the use of cranial bone grafts in oral and maxillofacial surgery. The review will be limited to autogenous cranial bone grafts with particular attention given to the clinical applications and specific intraoperative, technical considerations during harvesting procedures.

Clinical applications of cranial bone grafts

Craniofacial and orthognathic surgery

When craniofacial reconstructive surgery, such as craniosynostosis repair, is performed during infancy, complete healing of relatively large (1.5-cm) bony defects occurs without the need for additional bone grafting (Fig. 1). This healing occurs because of the combined bone healing capacity of the pericranium and the dura, which is highly osteogenic during infancy. Most residual cranial vault defects heal completely when surgery is performed during the first

* Corresponding author.
E-mail address: pedmaxillofacial@aol.com (R.L. Ruiz).

1061-3315/05/$ - see front matter
doi:10.1016/j.cxom.2005.07.002

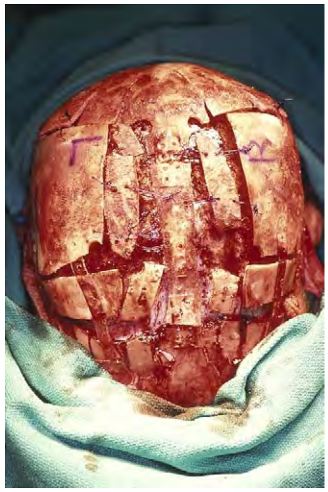

Fig. 1. Reconstruction of the posterior two thirds of the cranial vault in a 6-month-old patient with a diagnosis of sagittal suture craniosynostosis. During infancy, primary healing of relatively large skull defects is possible because of the combined osteogenic potential of the overlying pericranium and underlying dura.

2 years of life. When cranial vault surgery is undertaken between 2 and 4 years of life, complete healing of residual full-thickness defects is less predictable, and either immediate grafting or a secondary procedure for repair may be indicated.

Cranial vault defects result from a number of different etiologies, including trauma, pathology, and unfavorable healing post-synostectomy. After age 4, it is unlikely that even small full-thickness cranial vault defects will resolve without deliberate reconstruction or grafting at the time of the initial surgery. The use of autogenous cranial bone grafts for repair of cranial defects is preferable whenever possible. As a general rule, all bony defects within the craniofacial region are grafted to assure adequate regeneration and continuity. This re-establishes normal cranial vault morphology while restoring protection of important visceral components (ie, brain).

The use of interpositional and onlay bone grafts during orthognathic surgery is also well documented in oral and maxillofacial surgery. Most commonly, autogenous bone grafts are placed during midfacial procedures (Le Fort I level osteotomy) in which there is substantial advancement and lengthening of the maxilla. In these cases, corticocancellous bone grafts accomplish several functions. Interpositional bone grafts can be wedged within the osteotomy sites and help to maintain the new position of the maxilla as well as encourage bone healing and reduce the risk of fibrous union. When higher level facial osteotomies (extra-cranial Le Fort III or monobloc) are undertaken, grafts are of critical importance in restoring anatomic contours and contributing to the stability of the advanced segments. Bone grafts should be placed into all osteotomy gaps and at the zygomatic arch, along the posterior margin of the advanced frontal bones, and to reconstruct orbital floors after the advancement (Fig. 2).

Bone grafts can also be used to recontour the facial skeleton. Cortical bone struts can be shaped and applied in onlay fashion to augment the malar, infraorbital, and paranasal regions at the time of the osteotomy procedure. This allows correction of dysmorphic skeletal structures.

Trauma surgery

Fresh, autogenous bone harvested from the cranial vault has several applications in the management of both primary and secondary traumatic deformities. Split-thickness cranial bone grafts are frequently used for the repair of large orbital floor blow-out fractures with excellent success rates. More recently, high success rates have also been achieved with the use of alloplastic materials and titanium mesh implants. Despite the increased use of artificial materials, cranial bone remains an excellent choice for the reconstruction of defects within the medial orbital wall and floor following trauma. This is especially true for repair of orbital

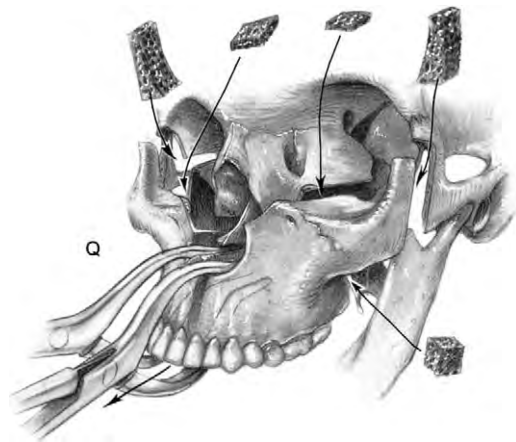

Fig. 2. Diagram of a subcranial Le Fort III level osteotomy frequently used to address the total midfacial deficiency seen in patients with craniofacial dysostosis syndromes (eg, Crouzon syndrome). Simultaneous interpositional and onlay bone grafts improve stability, encourage healing across osteotomy sites, and allow correction of skeletal morphology.

fractures in pediatric patients where ongoing growth is an important consideration. Most of the clinical instances in which cranial bone grafting is applied after trauma involve midfacial injuries. Additional clinical indications include repair of avulsive frontal sinus fractures, primary and secondary treatment of nasal fractures, and grafting to repair missing bone along the facial buttresses (eg, piriform, zygomaticomaxillary) in complex Le Fort level fractures.

Bony reconstruction of the cleft maxilla

Approximately 75% of all orofacial clefts involve the maxilla. Despite successful lip repair and closure of the hard and soft palate during infancy, a residual nasolabial fistula and bony cleft defect that involves the alveolar ridge, maxilla, and piriform rim will remain. These residual deformities are addressed secondarily by bone grafting performed during middle childhood (6 to 9 years of age). The objectives of bone graft reconstruction of the cleft maxilla are to establish adequate bony matrix for eruption of the permanent cuspid tooth, close any residual alveolar fistula, establish bony continuity of the maxillary ridge, and improve the underlying bony support to the nasal base. In the case of bilateral cleft lip and palate, an added benefit of bone graft reconstruction is the stabilization of the previously mobile premaxilla.

Although the ilium remains the favored donor source for grafting of clefts, previous reports have documented similar success rates using cranial diploe. Adequate quantities of cancellous bone may also be harvested from the cranium when necessary with equally good results.

Surgical techniques

General principles

The presurgical assessment of a patient undergoing cranial bone harvest must include radiographs. For patients undergoing extracranial procedures (eg, split-thickness bone harvest, particulate bone harvest), this evaluation consists (at a minimum) of posterior anterior and lateral skull views. A craniofacial CT scan that includes a complete series of axial images will offer the surgeon much greater detail with respect to skull thickness and specific morphologic details as well as identify any anatomic irregularities that could affect the operative plan.

Specific timing of reconstructive procedures involving the need for cranial bone grafts is based on the developmental status of the cranial vault. Cranial development leads to the formation of three distinct layers (outer cortex, medullary space, inner cortex) roughly by age 5. Under normal circumstances, cranial bone may be harvested in children once adequate skull maturation has occurred, but the amount of bone available for split-thickness harvesting may be limited in young children. As development progresses, the three distinct layers become better differentiated and the amount of bone available for split-thickness harvest increases. In cases that require large quantities of split-thickness bone, it may be necessary to postpone the reconstruction until additional skull growth and maturation occur.

The parietal region of the skull is the most useful harvest site for all types (split-thickness, full-thickness, particulate) of cranial bone grafts. This region of the skull affords the greatest thickness and is positioned away from major venous sinuses located within the dural folds surrounding the brain. The parietal region may be approached through an incision within the hair-bearing scalp, which remains well concealed. Although the frontal region of the skull also has adequate bony thickness, it is considered a suboptimal site by comparison. This is because deformities related to the surgical approach/incision or residual bony irregularities at the harvest site would become esthetic problems for the patient.

Basic surgical principles of performing cranial bone harvest include adequate exposure of the surgical site, completion of bony cuts under direct visualization, and the use of irrigation while cutting with power instrumentation. The coronal scalp incision is a versatile and cosmetically acceptable approach for access to the forehead, nose, upper middle face, and orbitozygomatic regions and it simultaneously provides access for the harvesting of cranial bone. Despite the advantages of a coronal approach, large quantities of cranial bone are often harvested with more limited incisions. Adequate exposure is achieved with well-placed vertical or horizontal scalp incisions and generous subperiosteal dissection. Meticulous dissection and retraction of soft tissue structures is important for thorough instrumentation and completion of the osteotomies under direct visualization. Another important technical consideration is the prevention of overheating of bone during the use of power rotary instrumentation. Thermal bone injury contributes to osteocyte death, diminished osteogenic potential of the graft, poor hardware retention, and increased resorption.

Split-thickness cranial bone harvest

Split-thickness corticocancellous bone struts are harvested from the outer table of the cranial vault. The procedure is performed in an extracranial fashion (Fig. 3).

A vertical incision is created approximately 1 to 2 cm posterior and superior to the helix of the ear directly over the parietal prominence of the skull. An incision length of 4 cm is usually adequate for access to the cranial vault. Monopolar electrocautery (Bovie) may be used if a micro-tip (Colorado) needle is employed with a low-energy setting. Alternatively, the incision can be created using a #15 blade, and bipolar electrocautery can be used for hemostasis. A Molt #9 periosteal elevator is used to elevate scalp flaps in the subperiosteal plane exposing the cranial vault. Thrombin-soaked Gel Foam (Pharmacia & Upjohn Company, Kalamazoo, Michigan) (collagen sponge) and sterile bone wax are used to eliminate bleeding from perforating vessels and venous lakes within the outer table of the cranium. The use of a self-retaining retractor is helpful for soft tissue retraction. In cases where the surgeon is already working through a coronal scalp flap, subperiosteal dissection is carried posteriorly to expose the parietal region of the skull.

A fissure bur is used to prepare the proposed harvest site. Corticotomy through the outer table of the cranial vault is performed and several 1.5×4 cm struts of bone are outlined for removal. Next, a medium-sized oval bur is used to perform additional ostectomy along one border of the harvest site and undermine the cortical segments of outer table bone. A spatula osteotome is then used to completely separate each strip of corticocancellous bone. This is done by starting with the osteotome at the undermined edge of the harvest site and advancing along the diploic (cancellous) space in between the inner and outer cortical plates. The leading edge of the osteotome is maintained under constant, direct visualization as it is advanced along the initial strip of bone. Once the first bone strut has been removed, additional undermining along the length of the adjacent strips may be performed using a steiger bur. Following removal of the outer cortical plates, a curette is used to remove cancellous bone (ie, cranial diploe) that remains attached to the inner table of the calvarium. All harvested bone is stored in cool, sterile saline until graft placement. Meticulous care is taken to preserve the integrity of the inner table, thus avoiding any dural exposure or injury to the underlying meninges.

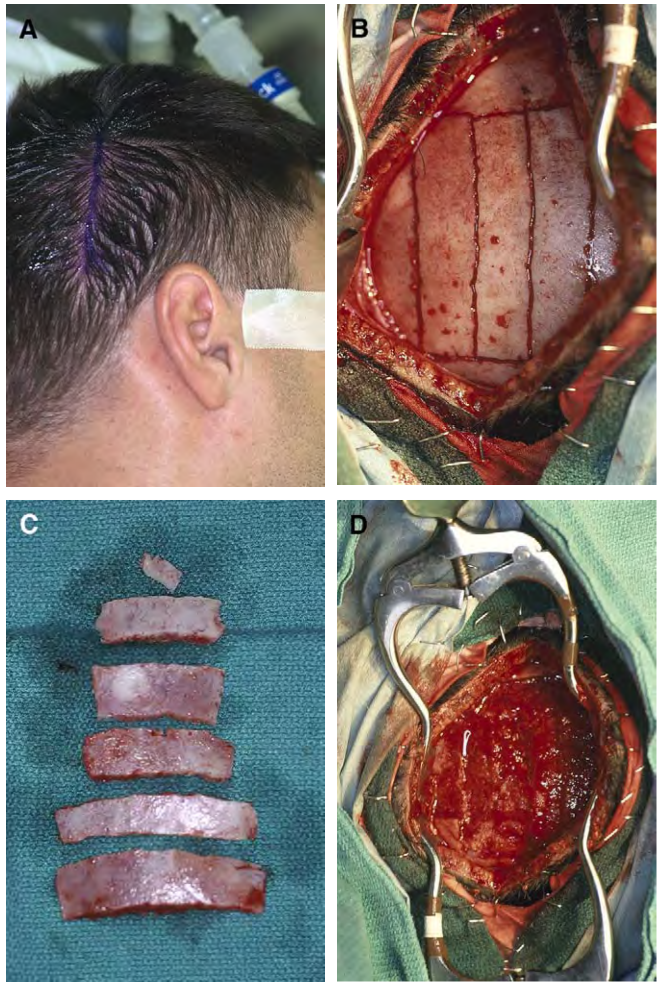

Fig. 3. (*A*) Skin marking for split-thickness cranial bone harvest. A 4-cm vertical incision is placed along the parietal prominence of the skull. (*B*) Scalp dissection with self-retained retractors in place. Retractors are placed underneath the pericranium. The outer table of the cranial vault is then scored using a fissure bur to mark out several struts of bone. The superior edges are then reduced using a medium size round bur to undermine the struts of bone before harvesting is completed using a spatula osteotome. (*C*) Multiple struts of corticocancellous bone removed from the outer table of the skull. (*D*) Intraoperative view of the cranial vault following removal of several split-thickness grafts. Note the cancellous bone within the diploic space. The inner table of the cranium remains intact.

A layered closure of the incision is required for elimination of dead space and an optimal esthetic result. This begins with the placement of deep interrupted sutures for reapproximation of the pericranium and galea and is followed by surgical staples or sutures for cutaneous closure. The use of chromic gut on the skin in children is effective and may obviate the need for postoperative suture removal.

Full-thickness cranial bone harvest

In many patients, full-thickness calvarial bone is harvested via a formal craniotomy procedure (Fig. 4). The authors' experience has been that this approach is most beneficial for younger patients (5–10 years of age) where relatively large amounts of cranial bone are required. In those instances, harvesting adequate split-thickness bone grafts using an ''extracranial'' approach may not be possible without increased risk of dural exposure. Full-thickness harvesting via craniotomy is also useful in adult patients when large amounts of bone are required.

Because full-thickness grafts involve completion of a formal craniotomy, a coronal scalp flap or separate larger incision is generally required. Burr holes are made with a cranial perforator to

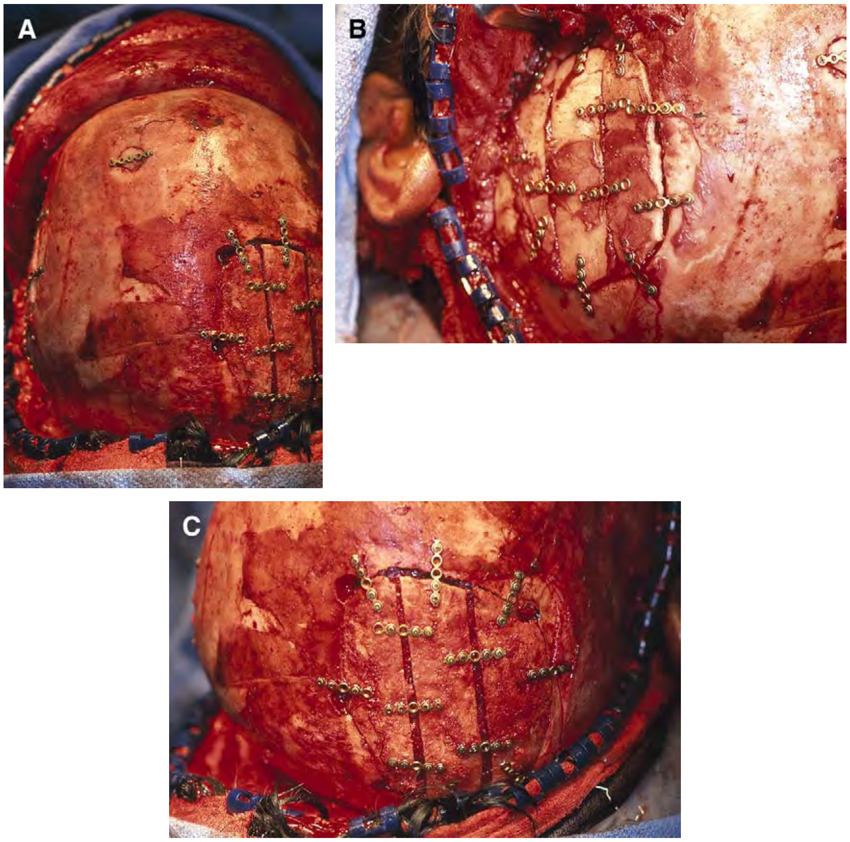

Fig. 4. A 14-year-old female patient after prior craniotomy (for unrelated reasons). The craniotomy bone flap underwent necrosis and loss with a resultant large, full-thickness skull defect involving the left temporo-parietal region. Reconstruction of the left temporo-parietal defect was undertaken by harvesting full-thickness cranium by way of right-sided parietal craniotomy. The bone flap from the right-sided parietal craniotomy was then split into inner and outer cortical plates (tables) and used to reconstruct the original (left temporo-parietal) defect and harvest site (right parietal) defect. Intraoperative views include: (*A*) bird's eye view of cranial vault following the reconstruction; (*B*) repaired left temporo-parietal defect; and (*C*) repair of the right parietal craniotomy harvest site.

provide access for stripping of the dura from the overlying inner table of the cranium. A high-speed, high-torque pneumatic craniotome is then used by the neurosurgeon to complete the craniotomy, and the full-thickness cranial bone flap is removed. The flap is then taken to a separate, sterile back table where portions of full-thickness and split-thickness bone can be taken from the bone flap.

At a separate sterile work table, small sagittal and oscillating saws are used within the diploic space to undermine the inner and outer table cortical plates of the skull flap. Copious irrigation is used throughout the procedure. This is followed by the use of osteotomes to complete the separation of inner and outer tables. Our preference is to start with a spatula and small sharp osteotomes, then advance in size until the separation is complete.

Successful splitting of an adequately sized cranial bone flap into inner and outer cortical plates as described above gives the surgeon ‘‘new’’ autogenous material for reconstruction of cranio-maxillofacial skeletal components (eg, cranium, orbits, nasal complex, maxilla). After the needed graft material has been obtained, the remaining bone (typically the inner table) remains available for repair of the harvest (craniotomy) site defect.

In essence, the harvest procedure involves the removal of a full-thickness cranial bone flap, splitting of the entire bone flap, or portions of the bone flap into inner and outer table components, and reconstruction of both sites (ie, original defect and harvest site defect) with split-thickness bone. In patients undergoing a craniotomy for various reasons (eg, trauma, pathology, and so forth), the above approach may be modified so that the surgeon is harvesting bone from the craniotomy (bone) flap elevated by the neurosurgeon (Fig. 5). In those cases,

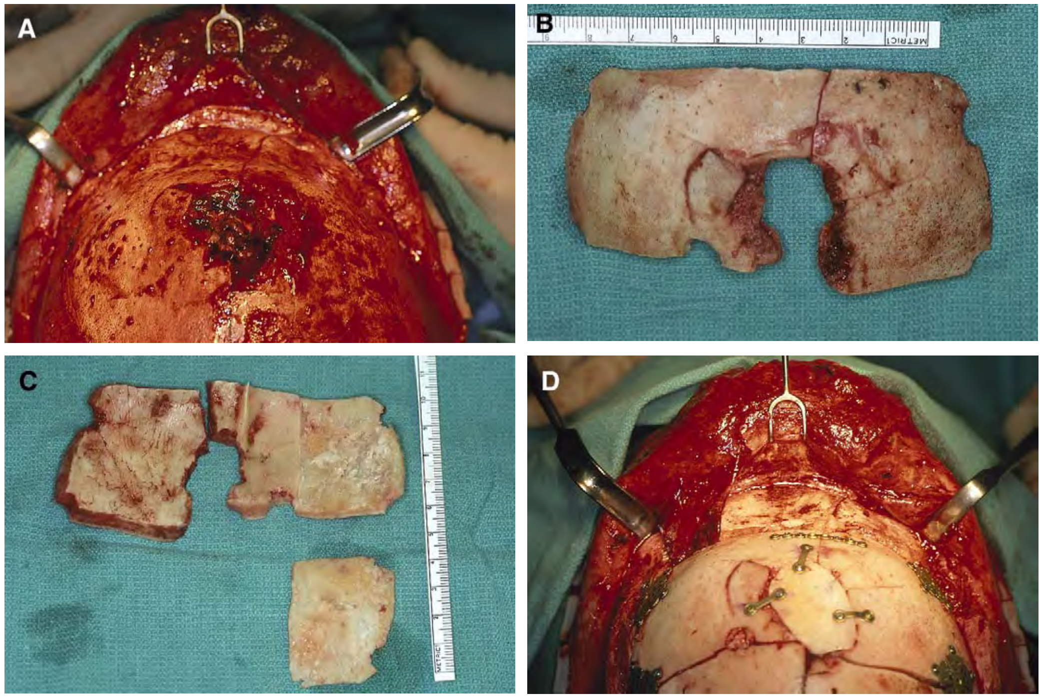

Fig. 5. A 35-year-old male patient sustained a gunshot wound to the upper face with extensive disruption of the anterior skull base and frontal bone. The patient required bifrontal craniotomy secondary to intracranial injuries and active leakage of cerebrospinal fluid. (*A*) Intraoperative view following elevation of a coronal scalp flap reveals the exit-wound defect in the frontal bone. (*B*) Bifrontal craniotomy bone flap removed by the neurosurgeon clearly demonstrates full-thickness defect with avulsive loss of frontal bone segment. (*C*) A split-thickness cranial graft is harvested from the inner table of the bifrontal craniotomy bone flap. This provides adequate bone for repair of the defect, but does not adversely affect craniotomy repair or change the external morphology of the frontal bone. (*D*) Final reconstruction with the bifrontal bone flap intact and repair of the gunshot wound defect with the split-thickness material.

adequate bone may be harvested from the inner table of the bone flap without the need for a separate (second) craniotomy.

Particulate bone grafts

There are several methods for the harvesting of particulate bone grafts from the cranial vault. Most initial descriptions involved the elevation and removal of several strips of outer table in a fashion identical to what is described above for split-thickness cranial bone harvest. Once the outer table segments are removed, a curette is used to scrape cancellous bone and marrow from the diploic space and intact inner table. Although this approach is effective, the amount of cancellous bone available per cm^2 of skull surface harvested is limited when compared with, for example, the anterior ilium. Having to remove several separate bone struts to reach the cancellous layer may also be surgically cumbersome. In the past, surgeons using this approach would expand the total volume of harvested bone by grinding portions of the removed outer table struts with a bone mill and adding it to the particulate mixture. Although this is a reasonable option, the ultimate decision to harvest only cancellous bone from the diploe or add milled cortical bone is based on the consistency of the graft material required by the surgeon.

Another harvesting technique involves the removal of bone directly from the outer surface of the cranial vault (Fig. 6). A scalp incision similar to what is used for split-thickness harvesting is created and a 5×5 cm area of the cranial vault is exposed. A medium-sized, oval bur is then used to perform a superficial "recontouring-type" ostectomy along the outer table of the cranial vault, and a bone-trap device is used to collect the particulate bone. Copious normal saline irrigation is required to ensure that the amount of osteocyte damage from overheating is minimized during this procedure. Ostectomy with bone collection may be continued until the diploic space is exposed. Relatively large amounts of bone are available per cm^2 of skull surface

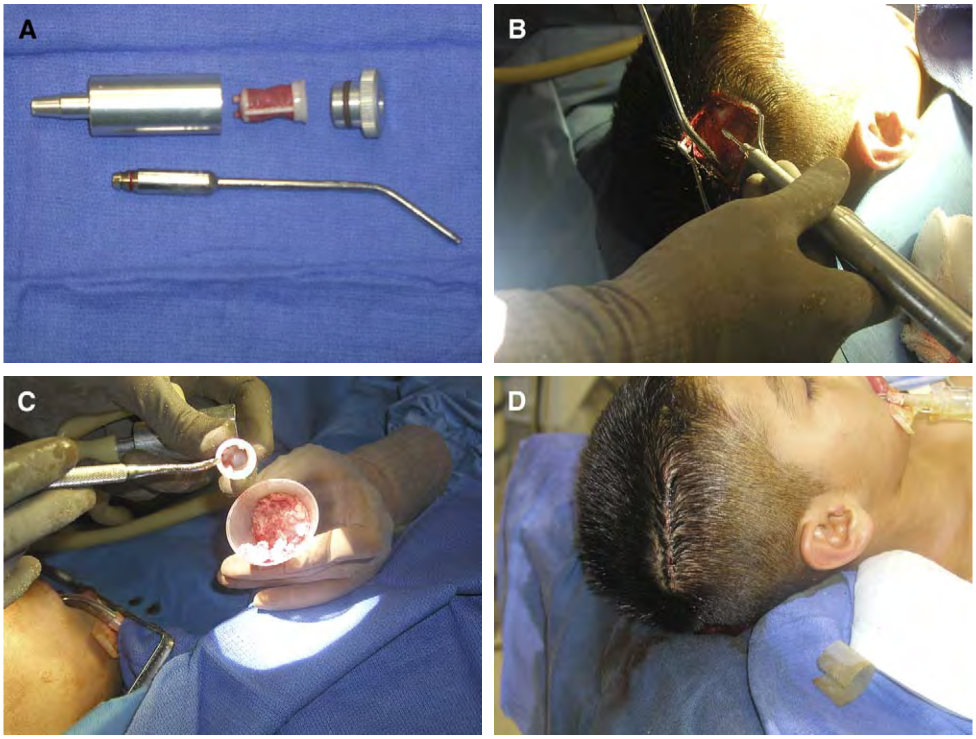

Fig. 6. Surgical technique for harvesting particulate bone from the outer table of the cranial vault. (*A*) Suction assembly used includes a modified suction tip canister that includes a filter or bone trap. (*B*) Use of a medium-sized oval bur on surgical handpiece to perform ostectomy. Copious normal saline irrigation is used to avoid thermal injury. Particulate bone is suctioned using a bone trap device. (*C*) Substantial quantities of particulate cortical bone are collected in the bone trap. The filter device is emptied or changed frequently. (*D*) Closure of the harvest site with layered deep sutures and surgical staples for cutaneous approximation. In this particular patient's case, a limited horizontal incision was used to camouflage the surgical scar within his hair. (Courtesy of Dr. Timothy D. Hogan, Fort Myers, Florida.)

harvested, and the procedure is technically straightforward with decreased chance of perforating through the inner table of the calvarium. Once the outer table bone has been ground away with the rotary instrument, a curette may be employed to harvest cancellous bone from the diploic space. Occasionally, once the outer table of the skull is reduced, one of the diploic veins may cause brisk venous bleeding. The posterior temporal diploic vein and its emissaries are most frequently encountered and are easily managed with thrombin-soaked Gel Foam or sterile bone wax used for hemostasis. Rapid, deliberate, and meticulous attention to bleeding from diploic veins and venous lakes is mandatory to eliminate the risk of significant blood loss and air embolus during harvesting procedures.

Temporalis myo-osseous flap

The use of a temporalis muscle flap to recruit soft tissue as part of oral and maxillofacial reconstructive procedures is a well-established surgical maneuver. In cases where large hard tissue defects require simultaneous attention, the use of composite myo-osseous flaps may be of significant value. The temporalis myo-osseous flap is composed of a segment of full-thickness cranial bone attached to an elevated temporalis muscle flap. This allows for transfer of a vascularized segment of bone for skeletal reconstruction.

The temporalis muscle receives its arterial blood supply from three arteries: the anterior deep temporal artery, posterior deep temporal artery, and middle temporal artery. The anterior and posterior deep temporal arteries are branches of the internal maxillary artery. These arteries run vertically along the extent of the muscle itself. The middle temporal artery arises from the superficial temporal artery just below the level of the zygomatic arch. Above the arch, the middle temporal artery enters the posterior aspect of the temporalis muscle and runs obliquely to the direction of muscle fibers. Because the middle temporal artery runs obliquely, it is more susceptible to injury during the harvesting procedure.

Although the use of temporalis/cranial bone flaps is less common than free cranial grafts, there is still a role for the use of this composite flap in complex midfacial defects. Specifically, this reconstructive option may provide excellent patients undergoing reconstruction of large maxillectomy defects are often candidates for this approach (Fig. 7).

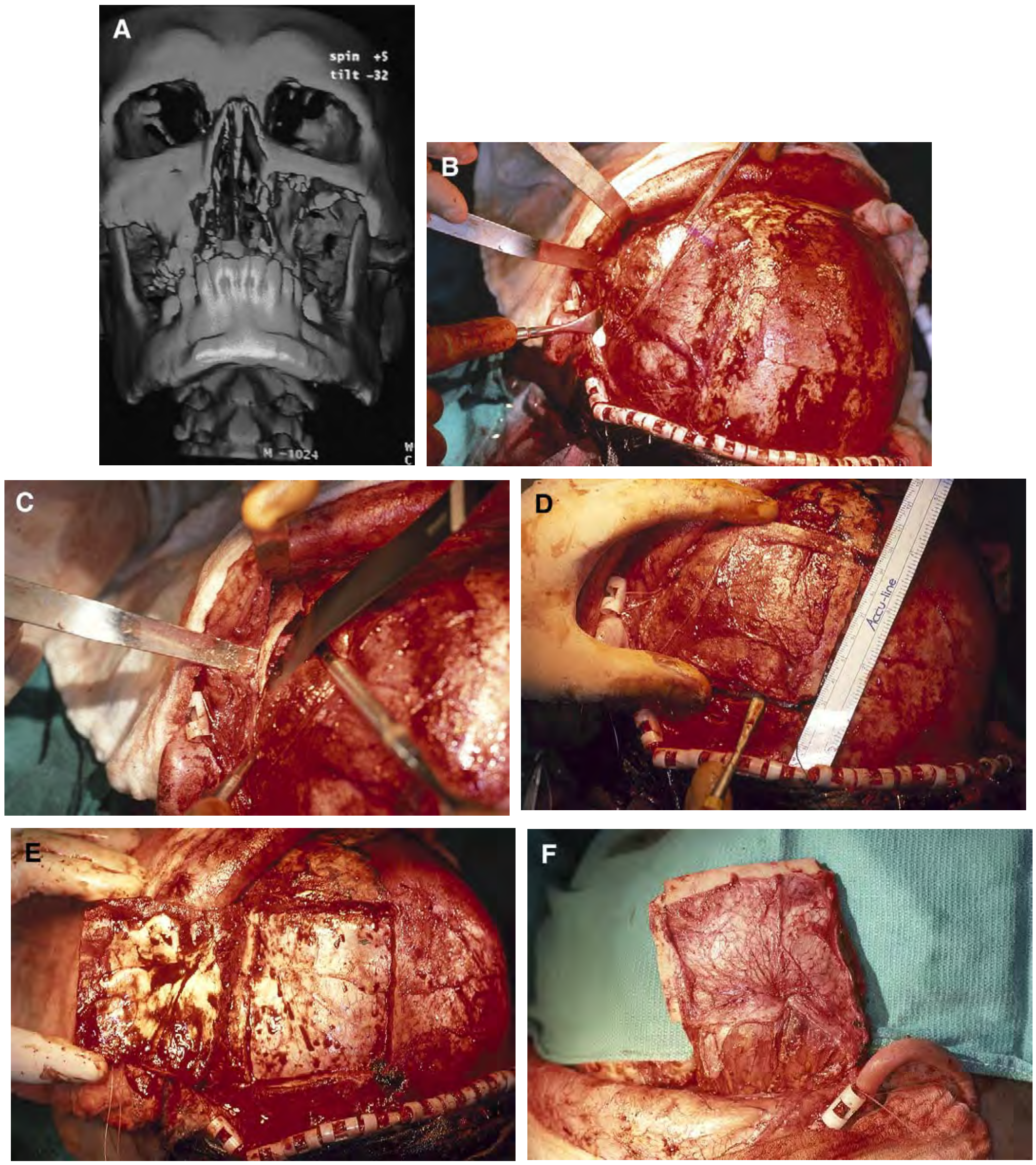

Fig. 7. Reconstructive approach for a 28-year-old male patient after resection of large maxillary ameloblastoma. (*A*) Three-dimensional CT scan views of large, left-sided, subtotal maxillectomy defect. (*B,C*) Surgical approach through coronal scalp flap with broad exposure. Dissection is carried inferiorly to expose the zygomatic arch. Some tunneling under the temporalis muscle is performed in the squamosal region, but the muscle attachments to the temporoparietal segment of bone to be harvested are meticulously preserved. (*D*) Intraoperative view following bur hole placement, dural stripping, and completion of vertical and superior craniotomy bone cuts. (*E*) Inferior portion of craniotomy is completed via manual elevation and out-fracture. (*F*) Composite myo-osseous flap elevated. (*G*) Transoral view of the inset flap with excellent soft tissue coverage of defect and recruited cranial bone. The zygomatic arch is removed and the composite flap has been rotated inferiorly into the oral cavity. Successful transfer often requires that the surgeon section the bone flap to fold it in half. (*H*) Split-thickness cranial bone grafts are harvested from the adjacent cranial vault for repair of the craniotomy defect. (*I*) Intraoperative view of reconstructed craniotomy defect and adjacent split-thickness cranial bone harvest site. (*J*) Following flap inset, the osteotomized zygomatic arch is replaced and fixated with lag screw.

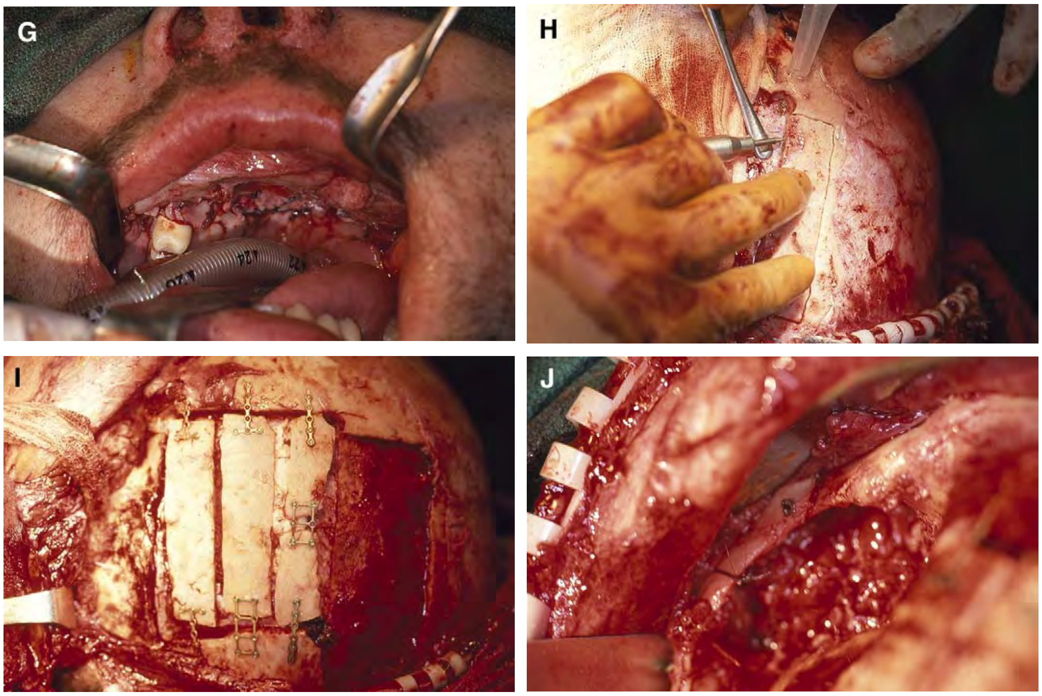

Fig. 7 (*continued*)

The surgical procedure requires broad access through a coronal scalp flap. The temporalis muscle is not elevated during the initial dissection. Dissection is carried inferiorly along the temporal fascia to expose the zygomatic arch. A segment of temporo-parietal bone is measured and marked for harvest, and the overlying muscle and galea attachments are preserved over the segment of bone to be harvested. Next, the temporalis muscle flap, which is attached to the proposed harvest site, is outlined and the vertical arms of the flap are incised using sharp dissection and bipolar electrocautery for hemostasis. Working in conjunction with a neurosurgeon, bur holes are made around the harvest site, and the dura is separated from the bone that is to be removed. The neurosurgeon completes three sides of the craniotomy (superior horizontal, right and left vertical) using a pneumatic craniotome, and hand instruments are used to gently elevate the bone flap. Slowly, the flap is continuously mobilized until the remaining side of the craniotomy (inferior) is completed by way of out-fracture.

Once the flap is completed, it may be turned inferiorly to transfer the bone and muscle tissue into the oral cavity. This frequently requires that the previously exposed zygomatic arch be osteotomized and removed temporarily.

Harvesting this type of composite flap results in a significant defect at the donor site. The harvest site defect is repaired using split-thickness cranial bone grafts. In addition, the posterior half of the temporalis muscle is elevated and advanced forward to cover the soft tissue defect. In some cases, additional tissue may be necessary to avoid postoperative temporal hollowing following temporalis harvest. Free fat grafts may be of use in this purpose.

Summary

The ability to recruit fresh, autogenous bone for the repair of skeletal defects is at the center of reconstructive oral, maxillofacial, and craniofacial surgery. Contemporary surgical principles and technical refinements allow for the effective harvesting of bone from a number of different anatomic sites (eg, cranial vault, mandible, rib, anterior and posterior ilium, tibia). The proximity of the cranial vault to other surgical sites, availability of relatively large quantities of bone, and favorable consistency make cranial bone harvest an extremely viable reconstructive maneuver within the surgeon's armamentarium. Using careful surgical technique, the morbidity associated with the harvesting of cranial bone is low and residual harvest site defects are clinically insignificant.

Acknowlegdments

The authors wish to thank Dr. Timothy D. Hogan for providing a description and clinical photographs of his excellent particulate cranial bone harvesting technique.

Further readings

Harsha BC, Turvey TA, Powers SK. The use of autogenous cranial bone grafts in maxillofacial surgery. A preliminary report. J Oral Maxillofac 1986;44:11–5.

Jackson IT, Helden G, Marx R. Skull bone grafts in maxillofacial and craniofacial surgery. J Oral Maxillofac Surg 1986; 44:949–55.

Korlof B, Nylen B, Rietz K-A. Bone grafting of skull defects. A report of 55 cases. Plast Reconstr Surg 1973;52:378–83.

Luhr HG. A micro-system for cranio-maxillofacial skeletal fixation. Preliminary report. J Craniomaxillofac Surg 1988; 16:312–4.

Posnick JC, Goldstein JA, Armstrong D, et al. Reconstruction of skull defects in children and adolescents by the use of fixed cranial bone grafts: long-term results. Neurosurgery 1993;32:785–91.

Powell NB, Riley RW. Cranial bone grafting in esthetic and reconstructive contouring. Arch Otolaryngol Head Neck Surg 1987;113:713–9.

Ruiz RL, Ritter AM, Turvey TA, et al. Nonsyndromic craniosynostosis: diagnosis and contemporary surgical management. Oral Maxillofac Surg Clin N Am 2004;16:447–63.

Tessier P. Autogenous bone grafts taken from the calvarium for facial and cranial applications. Clin Plast Surg 1982;9: 531–8.

Turvey TA, Ruiz RL. Craniofacial surgery: principles of surgical management. In: Ward-Booth P, Schendel SA, Hausamen JE, editors. Maxillofacial sugery. London: Churchill-Livingston; 1999. p. 841–7.

Atlas of the Oral and Maxillofacial Surgery Clinics

Atlas Oral Maxillofacial Surg Clin N Am 13 (2005) 139–149

Costochondral Rib Grafting

John F. Caccamese, Jr, DMD, MD[a,b],
Ramon L. Ruiz, DMD, MD[c,d],
Bernard J. Costello, DMD, MD[e,f,*]

[a]*Department of Oral and Maxillofacial Surgery, University of Maryland Medical Center, 22 South Green Street, Baltimore, MD 21201, USA*
[b]*R. Adams Cowley Shock Trauma Unit, University of Maryland Hospital for Children, 22 South Green Street, Baltimore, MD 21201, USA*
[c]*Department of Oral/Maxillofacial Surgery, Southwest Florida Oral and Facial Surgery, 5285 Summerlin Road, Suite 101, Fort Myers, FL 33919, USA*
[d]*Children's Hospital of Southwest Florida, 9981 South HealthPark Drive, Fort Myers, FL 33908, USA*
[e]*Division of Craniofacial and Cleft Surgery, Department of Oral and Maxillofacial Surgery, University of Pittsburgh School of Dental Medicine, 3471 Fifth Avenue, Suite 1112, Pittsburgh, PA 15213, USA*
[f]*Department of Pediatric Oral and Maxillofacial Surgery, Children's Hospital of Pittsburgh, Salk Hall, Suite G-32, 3501 Terrace Street, Pittsburgh, PA 15261, USA*

Since the initial report of Gillies in 1920 [1], autologous costochondral grafts have been used to reconstruct the craniomaxillofacial skeleton for various defects. With an improved understanding of graft physiology, the use of other donor sites, and the advent of free tissue transfer, the role of the costochondral graft has diminished. They still serve as an important tool for the reconstruction of microtia, the temporomandibular joint (TMJ), the challenging nose, and other craniomaxillofacial defects. Costochondral grafting is still regarded by many to be the reconstruction of choice for the pediatric TMJ. Likewise, it is regarded as the preferred material for autologous microtia reconstruction. In addition to these indications, the rib has been used for the reconstruction of mandibular body defects, maxillary clefts, cranial vault defects, orbital floor defects, and as onlay grafts to correct deficiencies of the craniofacial skeleton [2,3]. This article considers some of the indications and the technical aspects of rib grafting for the craniomaxillofacial region.

Indications

Temporomandibular joint reconstruction

The TMJ is complex in structure and function. As a result, its reconstruction is particularly challenging. TMJ pathology that requires total reconstruction may be attributable to congenital anomalies, neoplastic processes, trauma, infection, or arthritis. Bony fusion or ankylosis of the TMJ sometimes occurs after trauma, is caused by infection or arthritis, and rarely is the result of congenital causes. The treatment of ankylosis usually results in removal of the fused joint and replacement with an autogenous graft or prosthetic joint. Although distraction osteogenesis has

* Corresponding author. Department of Oral and Maxillofacial Surgery, University of Pittsburgh Medical Center, 3471 Fifth Avenue, Suite 1112, Pittsburgh, PA 15213.
E-mail address: bjc1@pitt.edu (B.J. Costello).

1061-3315/05/$ - see front matter
doi:10.1016/j.cxom.2005.05.004

been advocated as a treatment modality to reconstruct various TMJ defects, outcome data are lacking, and its success is still uncertain. Costochondral grafting continues to be the preferred method for TMJ reconstruction in children.

Treatment of the pathologic condyle must address various issues to maintain function. Rowe [4–6] described his goals in treatment for patients with ankylosis in a series of papers for the Royal College of Surgeons in 1982. These goals include (1) establishing mandibular mobility and function, (2) preventing recurrence of the ankylosis, and (3) restoring the functional growth matrix.

Additional goals include reconstitution of vertical dimension, preservation of the occlusion, and improvement of facial symmetry [7]. Multiple materials have been used to replace the condyle. As with any anatomic structure, finding the best reconstructive material to replace the condyle is difficult. Ideally, materials must be well tolerated by patients, have a low lifetime risk of infection, and provide a long-lasting and dynamic reconstruction to achieve the treatment goals. The costochondral graft replaces not only the vertical bony portion of the ramus but also the cartilage of the condyle and disc articulation (Fig. 1). In the case of pediatric patients, it may be considered advantageous to have a graft that continues to grow with a patient.

Costochondral grafting in a growing child is not without its drawbacks. An otherwise successful graft still may grow at a different rate or not at all. This has been shown by many authors, with most of the data demonstrating overgrowth as being the most common scenario [8–10]. Some researchers have attempted to correlate the degree of graft overgrowth with reconstruction at a younger age or the amount of costal cartilage included with the graft, although the postoperative growth of the graft is still unpredictable [11–14].

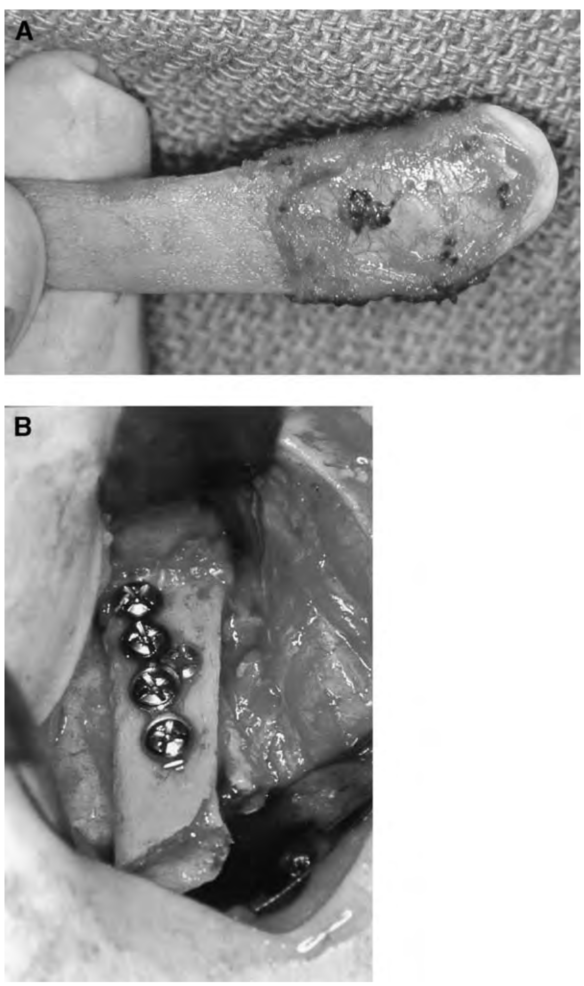

Fig. 1. (*A*) Contoured rib before insertion. (*B*) Rib fixated in situ to lateral ramus with miniplate and position screw. (Courtesy of R.A. Ord, DDS, MD, Baltimore, MD.)

When treating ankylosis, the prevention of reankylosis is always a concern. Ross [15] reviewed the experience over 12 years at Toronto's Hospital for Sick Children and found successful results to be associated with earlier grafting (age 3–9), fewer surgeries, and a diagnosis of hemifacial microsomia, as opposed to Goldenhar syndrome, ankylosis, or pathology. Less than ideal results are associated with the need for bilateral reconstruction, multiple interventions, and congenital etiology. Condyle reconstruction with costochondral grafts generally provides good functional and cosmetic results [3,16]. The timing of the procedure should take into consideration functional and aesthetic issues and the effects of surgery on further mandibular growth.

Nasal reconstruction

Revision rhinoplasty, congenital deformity, and cleft rhinoplasty often require complex nasal reconstruction with the need for considerable support. Rib grafts can be used for cartilage, bone, or a composite of the two skeletal components. The main drawback of contoured cartilage is warping, which commonly occurs to some degree. In contrast, bone grafts are subject to a variable degree of resorption.

Various grafting techniques have been used for nasal reconstruction, of which the L-shaped strut, columellar strut, spreader inlay, shield onlay, and dorsal onlay are the most common [17,18]. Depending on the shape and the type of graft to be used (ie, bone or cartilage versus composite), the ninth, tenth, and eleventh ribs provide good material for osseocartilaginous grafts or pure cartilage (Fig. 2) [17]. Smaller incisions in the inframammary crease are used to harvest cartilage grafts. Some surgeons have suggested the use of Kirschner wires to maintain the structural integrity and prevent postoperative warping of the cartilage grafts when used for columellar strut grafts [19]. This technique can be especially helpful in the posttraumatic crooked or cleft nose.

Ear reconstruction

Malformations of the external ear occur in newborns with a frequency of approximately 1%. Most of these deformities are minor, such as preauricular skin tags; however, microtia may be part of a syndrome (eg, Goldenhar, hemifacial microsomia, and Treacher Collins) that includes other facial and congenital anomalies [20]. Approximately 70% of the cases are unilateral and are often associated with hearing impairment [21]. Cartilage rib grafts may be fabricated into

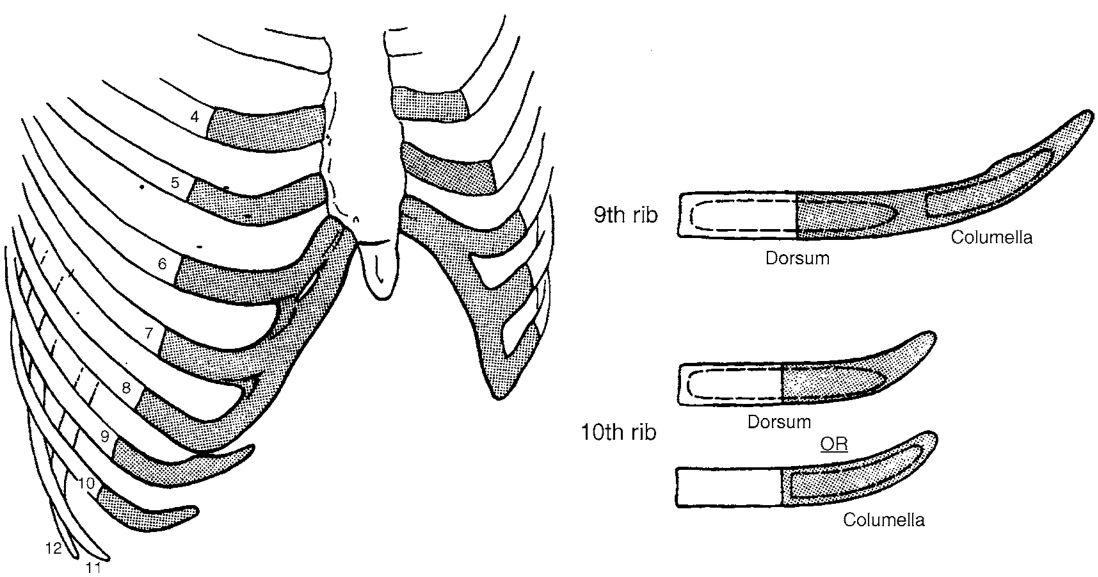

Fig. 2. The ninth and tenth ribs are often used for costochondral nasal reconstruction. (*From* Daniel RK. Rhinoplasty and rib grafts: evolving a flexible operative technique. Plast Reconstr Surg 1994;94:599; with permission.)

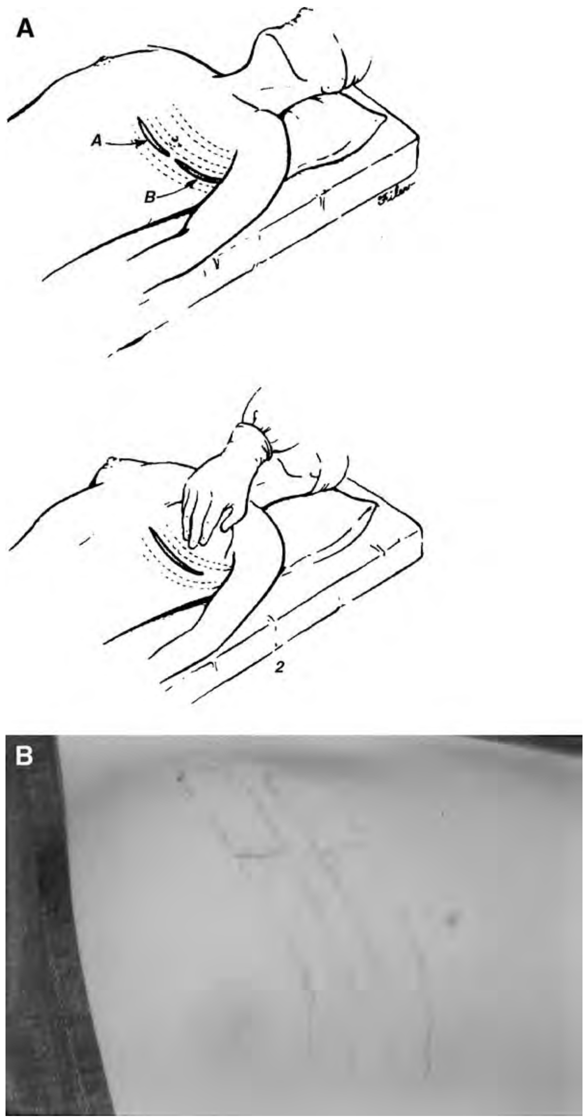

Fig. 3. Incision marking for harvesting of costochondral grafts and osseous grafts in the adult male patient (*A, top illustration*) and the adult female patient (*A, bottom illustration*). (*B*) Fifth and sixth ribs marked on a male patient. (*From* Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:809; with permission; and courtesy of R.A. Ord, DDS, MD, Baltimore, MD.)

custom frameworks for total ear reconstruction. Details of the reconstructive techniques are described elsewhere [22–24].

The current state of ear reconstruction with autogenous rib cartilage is a complex staged process first described by Tanzer and later modified and refined by Brent and colleagues [22–24]. The process is particularly technique sensitive and requires considerable experience. The ideal result is not always realized, and autologous ear reconstruction is not without its shortcomings, even in experienced hands.

Until recently, the results of reconstruction for the dysmorphic or absent ear were disappointing, and the ear often was left unreconstructed. Autologous rib reconstruction and osseointegrated craniofacial implant–supported prostheses have produced acceptable results [25]. Implants support a custom fabricated prosthesis that is usually aesthetically superior but occasionally is associated with tissue irritation at the implant and skin interface. This topic is particularly difficult to address in young children who do not clean the sites regularly. Alloplastic frameworks, such as porous polyethylene, have a higher failure and exposure rate than cartilage grafts. They are a reasonable alternative to grafting or prosthesis in some patients,

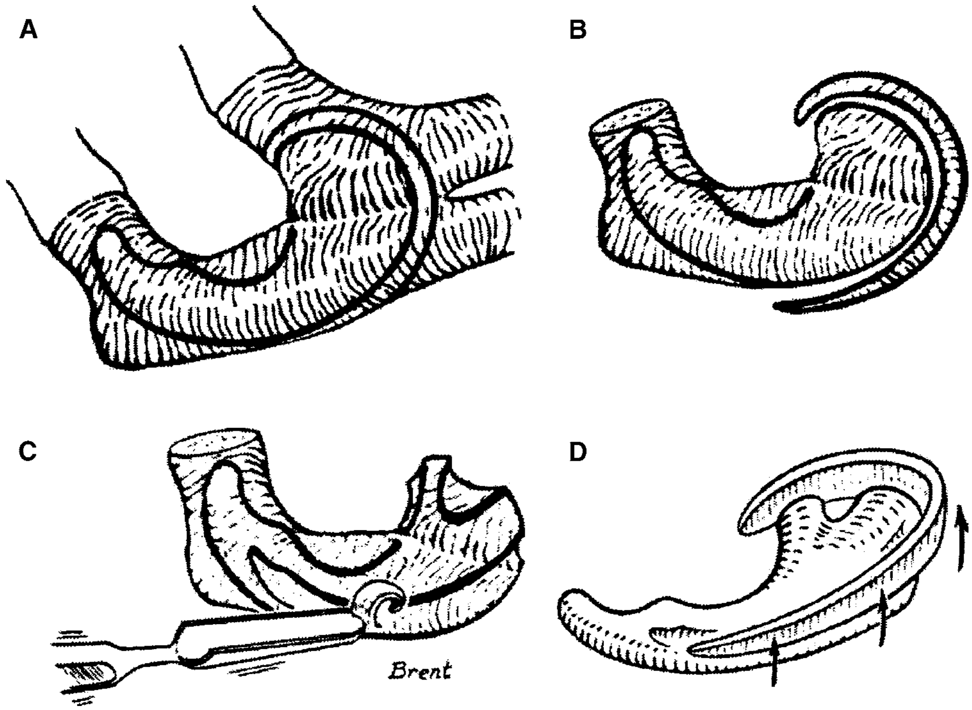

Fig. 4. (*A*) Cartilaginous rib harvest from the synchondrosis for total auricular reconstruction (*B–D*). (*From* Brent B. Microtia repair with rib cartilage grafts: a review of personal experience with 1000 cases. Clin Plast Surg 2002;29:257–71; with permission.)

however. Autologous cartilage experiences fewer complications and is able to withstand trauma fairly well.

Cranioplasty

Multiple materials have been used for cranioplasty, including alloplasts and various types of autogenous bone grafts. Most commonly, split cranium is the preferred material and can be used for defects up to one half of the cranial vault. The goals of reconstruction are to offer protection for the underlying vascular and neural structures of the brain and provide an aesthetic contour to the cranial vault.

For the developing pediatric cranial vault, the use of synthetic materials (eg, polymethylmethacrylate, hydroxyapatite, and custom alloplastic implants) is not ideal because they fail to adapt with the developing neurocranium. Infection, dislodgement, and failure of the material also have been reported [26]. The complication rate using methylmethacrylate has been reported as high as 23% [27]. Autogenous bone is better suited to grafting in pediatric patients because it meets the goals of cranioplasty while potentially allowing for onging growth. Split calvarial grafts are the material of choice; however, they can be somewhat difficult in children younger than 3 to 5 years of age because of decreased calvarial thickness. When extensive grafting is necessary, split rib grafting may provide a reasonable adjunct, but this technique has many drawbacks and is rarely indicated. Some of the drawbacks include extensive resorption and significant contour deformities. Multiple ribs are usually required, and alternating the donor sites can be helpful in maintaining the chest wall integrity.

Procurement procedure

The patient is placed in the supine position, with either the right or the left hemithorax elevated with a soft roll as needed. The operative field is then prepared and draped. If the head and neck are to be included in the field, they should be covered with a sterile drape until the graft

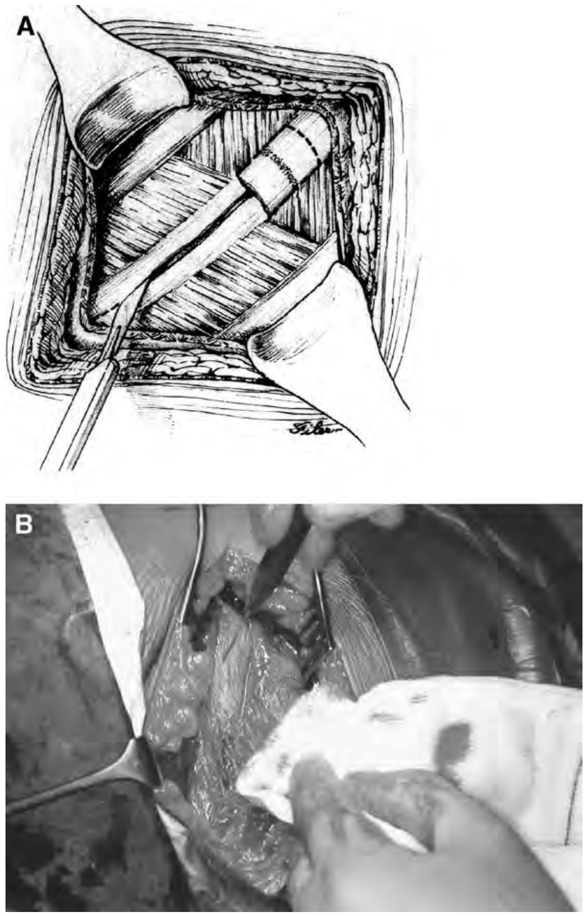

Fig. 5. (*A*) Periosteal incisions for costochondral harvest. Note the cuff of periosteum left at the costochondral junction to prevent fracture of the cartilaginous cap. (*B*) Periosteal incision being performed. (*From* Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:810; with permission; and courtesy of R.A. Ord, DDS, MD, Baltimore, MD.)

is harvested. Detailed preoperative planning should indicate the size of the graft necessary for the reconstruction.

The incision is marked in the inframammary crease and carried from the midaxillary region toward the sternum. It is especially important in young female patients to avoid the developing breast tissue during the initial incision placement and the deeper dissection. The medial length of the incision is based on the amount of cartilage to be harvested (eg, TMJ, ear, nose) (Fig. 3). Local anesthesia with vasoconstrictor is then infiltrated in the superficial tissues. Because of the morphology of the costochondral junction and the synchondrosis, it is preferable to take the graft from the contralateral side of that being reconstructed. For purposes of TMJ or ear reconstruction, the graft may be taken from ribs five to eight (Fig. 4). Rarely, two ribs may be required for certain reconstructions, and in these instances it is best to take the fifth and seventh ribs, which leaves the intervening sixth rib for stability of the thorax. Bilateral rib graft procurement is discouraged because of the tendency for splinting and the development of atelectasis postoperatively. If bilateral TMJ reconstruction is needed, then a staged procedure is preferable. This strategy also avoids the rare complication of bilateral pneumothoraces.

The skin incision is made sharply with a scalpel, followed by the use of electrocautery to gain hemostasis and divide the subcutaneous tissues to the pectoralis and rectus muscles and fascia. The overlying rib periosteum is then incised along the height of contour of the rib in a longitudinal fashion to the length desired. For a costochondral graft to reconstruct the TMJ, it is desirable to leave a cuff of periosteum and perichondrium intact at the costochondral junction to minimize the risk of cartilage separation (Fig. 5).

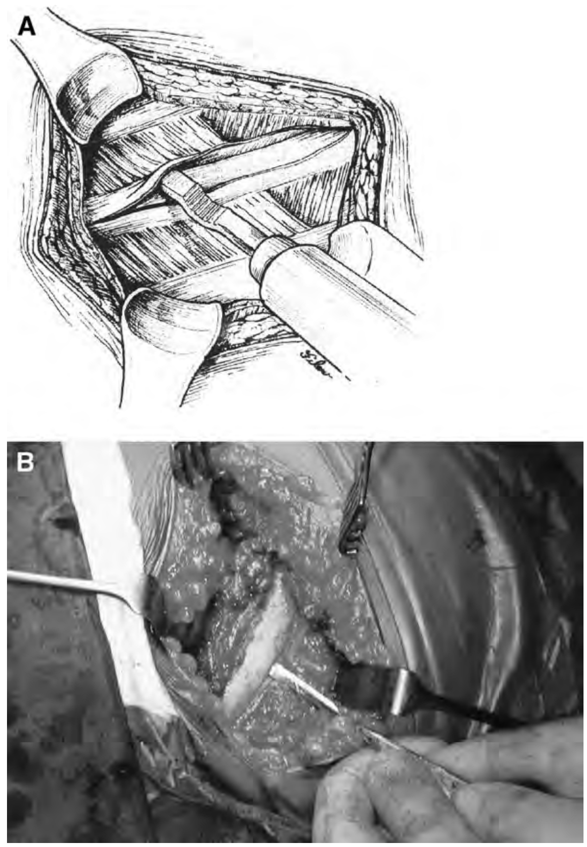

Fig. 6. (*A,B*) Periosteal elevation from the ventral surface of the rib. (*From* Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:809; with permission; and courtesy of R.A. Ord, DDS, MD, Baltimore, MD.)

The periosteum is dissected circumferentially from the remainder of the rib. Any number of periosteal elevators can be used, and their use depends on operator preference (Fig. 6). The surgeon must keep in mind that the neurovascular bundle runs along the inferior border of the rib, and it is essential that the dissection remain subperiosteal (Fig. 7). Small curved periosteal elevators, such as the number one Woodson elevator, are useful for dissecting the neurovascular bundle free from the graft. Once the superior, inferior, and ventral surface periosteum has been elevated and a tunnel created to the dorsal side, the Doyen periosteal elevator is particularly useful (Fig. 8).

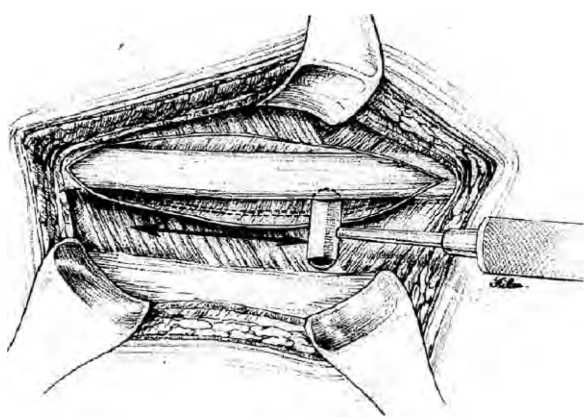

Fig. 7. Periosteal elevation from the cephalic, caudal, and dorsal surfaces of the rib while protecting the neurovascular bundle (*dotted lines*). (*From* Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:809; with permission.)

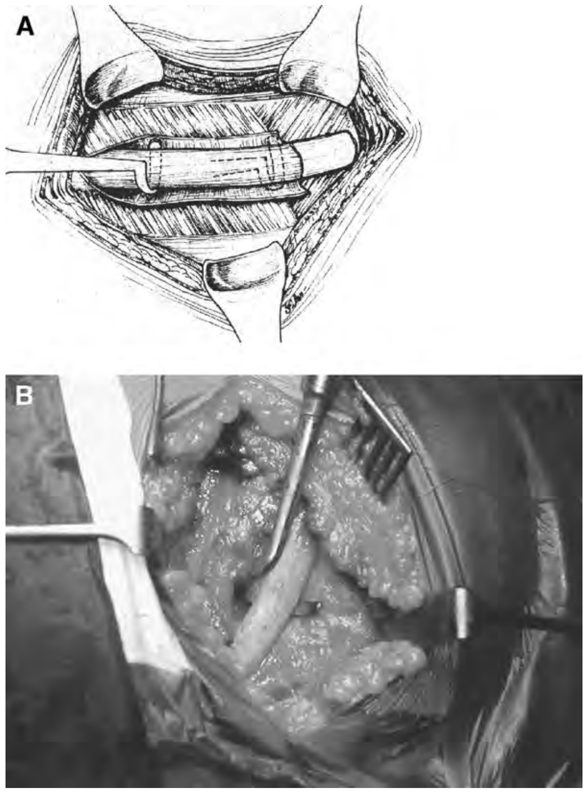

Fig. 8. (*A,B*) Dorsal periosteal elevation using the Doyen elevator. (*From* Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:810; with permission; and courtesy of R.A. Ord, DDS, MD, Baltimore, MD.)

Once the periosteal dissection is complete, the bony portion of the rib can be osteotomized or the cartilage harvested to its desired dimensions. The osteotomy can be accomplished with a saw or rib cutter forceps (Fig. 9). A malleable retractor is placed behind the rib or cartilage to protect the periosteum and prevent an inadvertent pleural injury. Cartilage-only grafts can be procured with a scalpel, but great care is needed to avoid perforating the pleura.

Once the graft is removed, the wound should be irrigated thoroughly and checked for the presence of a pleural injury. This examination can be performed by asking the anesthesiologist to inflate the lung maximally while the wound is irrigated with saline. Bubbles may be seen in the presence of a pleural tear, although false-negative results can be seen with this maneuver. If no tear is visualized, the wound is closed in anatomic layers, beginning with the periosteal sheath. Special care should be taken to avoid pleural perforation and injury to the intercostal nerve during suturing. Well-placed dermal sutures are particularly useful for taking tension off the skin closure to allow for optimal healing.

When a pleural tear does occur, it should be addressed before wound closure. If the injury is small and only involves the parietal pleura, it can be repaired easily without the need for a chest tube in most cases. Several techniques have been described, including simple closure while the lung is maximally inflated. Other surgeons advocate closure of the wound over a 10-Fr red rubber catheter (Fig. 10). The catheter is inserted through the tear into the pleural space. Closure of the wound around the catheter is followed by a watertight closure of the remainder of the wound. The catheter is brought out at a distant location from the tear so that there is no direct conduit into the pleural space when the tube is withdrawn. After skin is closed, the catheter is connected to suction while the anesthesiologist provides a prolonged valsalva. At this time, the tube is removed, and the small skin defect is closed [28,29]. Radiographs are obtained to evaluate for residual pneumothorax. Cardiopulmonary dynamics are usually not affected by the presence of a small pneumothorax, which slowly resolves without intervention. Should the parietal and visceral pleura be violated or instability result from pneumothorax, a chest tube should be placed.

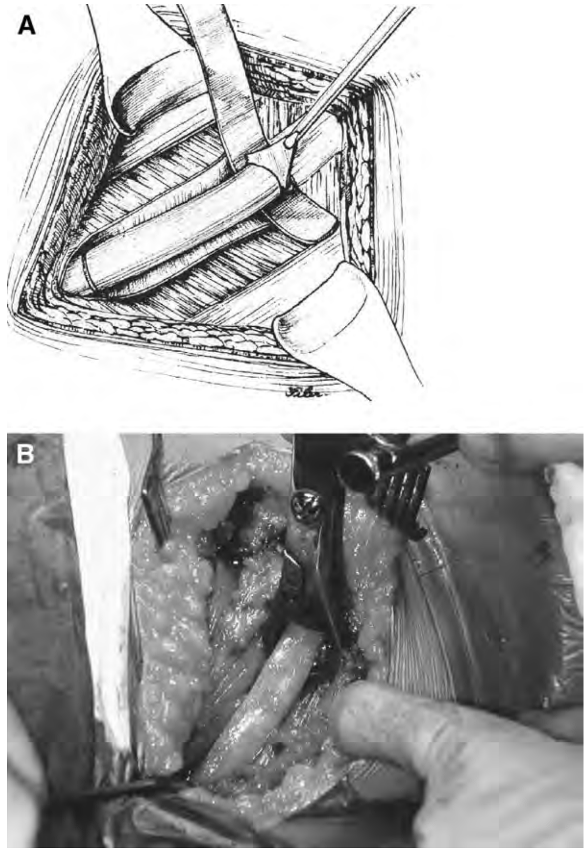

Fig. 9. (*A*) The rib is osteotomized with an oscillating saw. (*B*) Lateral osteotomy performed with rib cutters. (*From* Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:810; with permission; and courtesy of R.A. Ord, DDS, MD, Baltimore, MD.)

Postoperative analgesia in the form of an intercostal block can be administered before emergence from general anesthesia. The long-acting local anesthesia, bupivicaine, may be used for this purpose. The anesthesia greatly improves postoperative pulmonary recovery and compliance with physiotherapy and diminishes the chances for atelectasis, pneumonia, or other postoperative pulmonary complications.

Complications

As with any grafting procedure, complications can be expected in rare instances from the recipient and donor sites. Early complications are seen as in other grafting procedures and include wound infection, loss of fixation, and exposure or fracture of the graft. Late complications at the recipient site may include unpredictable growth of the composite graft, nonunion, ankylosis or limited opening, and malocclusion. Late complications at the donor site include chronic pain, scarring, chest wall instability, and breast deformity.

Laurie and colleagues [30] demonstrated that early morbidity (ie, blood loss, pain, and wound healing problems) is more significant for the iliac donor site than for the chest. Chest donor site morbidity is well described in the literature [29–31]. Of greatest concern in the early morbidity group are pleural laceration and pneumothorax. These complications have been reported as occurring anywhere from 4% to 30% of the time [29,32–34]. Occasionally a delayed pneumothorax occurs when the cut rib lacerates the pleura during respiration.

Superficial and deep wound infections rarely occur. Atelectasis is common and is caused by pain and attenuated respiratory effort. Pulmonary physical therapy and appropriate pain management can help to minimize these problems. Skouteris and colleagues [29] reported no

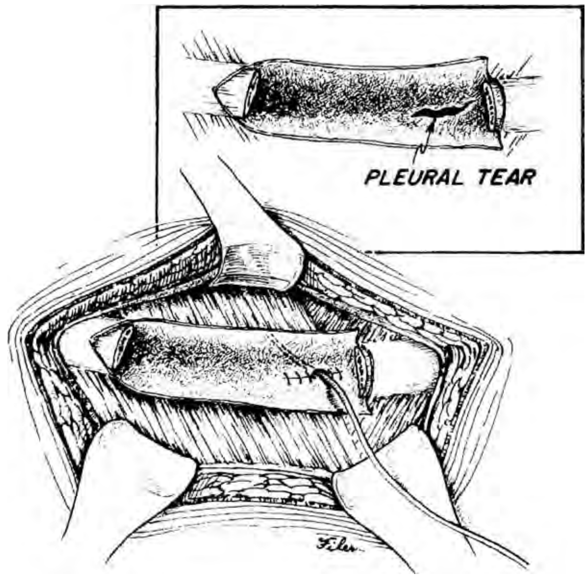

Fig. 10. Repair of pleural injury over a red rubber catheter. (*From* Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:812; with permission.)

postoperative pulmonary complications in their subset of patients for whom bupivicaine subcostal blocks were administered. Lack of complications improved patient compliance with incentive spirometry and deep breathing and coughing exercises.

Laurie and colleagues [30] also reported unaesthetic scarring and long-term pleuritic chest pain as being their most significant—but rare—chronic morbidities associated with costochondral graft harvest. More importantly, they stated that these chronic issues are not easily obviated by changes in surgical technique, as may be possible for iliac harvest.

Despite many reports that harvested ribs regenerate completely in children and partially in adults, Ohara and colleagues [26] reported significant chest wall deformities and thoracic scoliosis in their group of 18 patients who had microtia. The average follow-up was 8 years, and they noted greater frequency of deformities when procurement was accomplished before age 10. The incidence of thoracic scoliosis in their study was 25%, which is higher than the overall incidence in the general population [31]. Their recommendations for avoiding such deformities include allowing for further rib maturation before harvest when possible and avoiding the germinative zone of the costochondral junction.

To avoid deforming the thorax, Brent [22] recommended certain modifications to the cartilage procurement procedure to obtain the ideal sculpting material. He emphasized harvesting only what is needed to create the framework, thus preserving maximum integrity of the chest wall. Chest deformities can be decreased considerably by preserving even a minimal rim of the upper margin of the sixth rib cartilage to obtain the basic ear shape of the framework [22,31,35]. This precautionary measure retains a tether to the sternum so that the rib does not flare outward and potentially distort the chest as a child grows.

Summary

Although indications for rib grafting have decreased in recent years because of the development of other reconstructive options, the rib graft can be used for pediatric and adult craniomaxillofacial reconstruction. Detailed surgical planning, understanding of appropriate treatment options, and execution of precise technique provide for a predictable and successful reconstruction. Although the results are predictable in most situations, long-term follow-up of pediatric patients who receive costochondral grafts to the TMJ is compulsory for evaluating growth.

References

[1] Gillies HD. In: Plastic surgery of the face. London: Oxford University Press; 1920. p. 177–89, 228–35, 383.
[2] Johnson PE, Raftopoulos I. In situ splitting of a rib graft for reconstruction of the orbital floor. Plast Reconstr Surg 1999;103:1709–11.
[3] James DR, Irvine GH. Autogenous rib grafts in maxillofacial surgery. J Craniomaxillofac Surg 1983;11:201–3.
[4] Rowe NL. Ankylosis of the temporomandibular joint. J R Coll Surg Edinb 1982;27:67–79.
[5] Rowe NL. Ankylosis of the temporomandibular joint. J R Coll Surg Edinb 1982;27:167–73.
[6] Rowe NL. Ankylosis of the temporomandibular joint. J R Coll Surg Edinb 1982;27:209–18.
[7] Politis C, Fossion E, Bossuyt M. The use of costochondral grafts in the arthroplasty of the temporomandibular joint. J Craniomaxillofac Surg 1987;15:345–54.
[8] Guyuron B, Lasa C. Unpredictable growth pattern of costochondral graft. Plast Reconstr Surg 1992;90:880–6.
[9] Ware WH. Growth center transplantation in temporomandibular joint surgery. In: Walker RV, editor. Oral surgery: transactions of the third international conference in oral surgery. Edinburgh: E & S Livingstone; 1970. p. 148.
[10] Ware WH, Brown SL. Growth center transplantation to replace mandibular condyles. J Maxillofac Surg 1981; 9:50–8.
[11] Peltomaki T, Vahatalo K, Ronning O. The effect of unilateral costochondral graft on the growth of the marmoset mandible. J Oral Maxillofac Surg 2002;60:1307–14.
[12] Perrot DH, Umeda H, Kaban LB. Costochondral graft reconstruction/reconstruction of the ramus/condyle unit: long term follow-up. Int J Oral Maxillofac Surg 1994;23:321.
[13] Svensson B, Adell R. Costochondral grafts to replace mandibular condyles in juvenile chronic arthritis patients: long term effects on facial growth. J Craniomaxillofac Surg 1998;26:275–85.
[14] Ko EW, Huang CS, Chen YR. Temporomandibular joint reconstruction in children using costochondral grafts. J Oral Maxillofac Surg 1999;57:789–98.
[15] Ross RB. Costochondral grafts replacing the mandibular condyle. Cleft Palate Craniofac J 1999;36:332–9.
[16] MacIntosh RB, Henny FA. A spectrum of application of autogenous costochondral grafts. J Maxillofac Surg 1977; 5:257–67.
[17] Daniel RK. Rhinoplasty and rib grafts: evolving a flexible operative technique. Plast Reconstr Surg 1994;94: 597–609.
[18] Meyer R. In: Secondary functional rhinoplasty: the difficult nose. Orlando (FL): Grune & Stratton; 1988. p. 129–57.
[19] Gunter JP, Clark CP, Friedman RM. Internal stabilization of autogenous rib cartilage grafts in rhinoplasty: a barrier to cartilage warping. Plast Reconstr Surg 1997;100:161–9.
[20] Rollnick BR, Kaye CI. Hemifacial microsomia and variants: pedigree data. Am J Genet 1983;15:233–5.
[21] Harris J, Kallen B, Robert E. The epidemiology of anotia and microtia. J Med Genet 1996;33:809–13.
[22] Brent B. Technical advances in ear reconstruction with autogenous rib cartilage grafts: personal experience with 1200 cases. Plast Reconstr Surg 1999;104:319–34.
[23] Tanzer RC. Total reconstruction of the auricle: the evolution of a plan of treatment. Plast Reconstr Surg 1971;47: 523–33.
[24] Zim SA. Microtia reconstruction: an update. Curr Opin Otolaryngol Head Neck Surg 2003;11:275–81.
[25] Botma M, Aymat A, Gault D, et al. Rib graft reconstruction versus osseointegrated prosthesis for microtia: a significant change in patient preference. Clin Otolaryngol Allied Sci 2001;26:274–7.
[26] Taggard DA, Menezes AH. Successful use of rib grafts for cranioplasty in children. Pediatr Neurosurg 2001;34: 149–55.
[27] Blum KS, Schneider SJ, Rosenthal AD. Methylmethacrylate cranioplasty in children: long term results. Pediatr Neurosurg 1997;26:33–5.
[28] Abubaker AO, Oghalai MA. Bone graft harvesting. Selected Readings in Oral and Maxillofacial Surgery 2001;9:8, 18–22, 34–35.
[29] Skouteris CA, Sotereanos GC. Donor site morbidity following harvesting of autogenous rib grafts. J Oral Maxillofac Surg 1989;47:808–12.
[30] Laurie SWS, Kaban LB, Mulliken JB, et al. Donor-site morbidity after harvesting rib and iliac bone. Plast Reconstr Surg 1984;73:933–8.
[31] Ohara K, Nakamura K, Ohta E. Chest wall deformities and thoracic scoliosis after costal cartilage harvesting. Plast Reconstr Surg 1997;99:1030–6.
[32] Whitaker LA, Munro IR, Jackson IT, et al. Problems in craniofacial surgery. J Maxillofac Surg 1976;4:131–6.
[33] Whitaker LA, Zins J, Reichman J. Bone graft donor site considerations on craniofacial reconstruction. In: Abstracts of the Fourth Congress of the European Association of Maxillofacial Surgery. Stuttgart (Germany): Georg Thieme Verlag 1978. p. 66.
[34] Whitaker LA, Munro IR, Salyer KE, et al. Combined report of problems and complications in 793 craniofacial operations. Plast Reconstr Surg 1979;64:198–203.
[35] Thomson HG, Kim TY, Ein SH. Residual problems in chest donor sites after microtia reconstruction: a long-term study. Plast Reconstr Surg 1995;95:961–8.

Atlas Oral Maxillofacial Surg Clin N Am 13 (2005) 151–171

Atlas of the Oral and Maxillofacial Surgery Clinics

Microvascular Free Bone Flaps

Remy H. Blanchaert, Jr, MD, DDS[a,*],
Christopher M. Harris, MD, DMD[b]

[a]Oral and Maxillofacial Surgery Associates, 1919 N. Webb Road, Wichita, KS 67206, USA
[b]Department of Oral and Maxillofacial Surgery,
University of Missouri-Kansas City School of Dentistry, University of
Missouri-Kansas City School of Medicine, 2301 Holmes Street, Kansas City, MO 64108, USA

In the not-so-distant past, composite bone-containing defects of the maxillofacial region were reconstructed in a series of staged operations over a long period of time. The development and refinement of microvascular free bone flaps has revolutionized the management of such cases by allowing immediate one-stage reconstruction. The advantages of such an approach are obvious. Restoration of facial form, before the development of the scarring process, provides a more natural facial appearance. Economic advantages include decreased direct costs because hospital stay is markedly reduced and total surgical time is decreased. Patients benefit by avoiding a series of operations that require time away from work and family. Complication rates of microvascular free bone flaps parallel—or are better than—those published for bone grafting procedures. Perhaps most importantly, with proper planning, microvascular free bone flap reconstruction allows for definitive dental implant-based mandibular reconstruction (Fig. 1A–D). Reconstruction is important because the ability to eat and speak normally correlates strongly with patient quality of life after maxillofacial reconstruction, as demonstrated in many clinical studies.

Why do some surgeons within the field of oral and maxillofacial surgery condemn the use of free bone flaps for mandibular reconstruction? Perhaps their experience is limited to cases in which appropriate planning and proper attention to detail were not exercised and the outcome was suboptimal. Microvascular free bone flaps are challenging. This article was designed to address the challenges associated with microvascular free bone flaps. The intent is to guide readers through the process of applying microvascular free bone flaps in their practice by outlining the lessons learned through 8 years of extensive involvement in maxillofacial reconstruction. General principles are discussed first, followed by a discussion of the various flaps applicable to maxillofacial reconstruction. Several site-specific case examples also are provided to emphasize the challenges faced in mandibular reconstruction.

Basic principles

Reconstructive surgeons must understand fully the anticipated defect before preoperative planning can begin. It is important that surgeons carefully evaluate the operative site, review appropriate imaging, and discuss the planned operation with other surgeons involved in the case to comprehend the anticipated defect in three dimensions. Microvascular surgeons must select the most appropriate donor site, consider the vessel geometry, and devise a plan for shaping, contouring, and insetting the flap in an expedient manner to minimize the ischemia time and facilitate the microvascular anastomosis.

* Corresponding author.
E-mail address: remy.blanchaert@tmcmed.org (R.H. Blanchaert, Jr).

doi:10.1016/j.cxom.2005.05.002

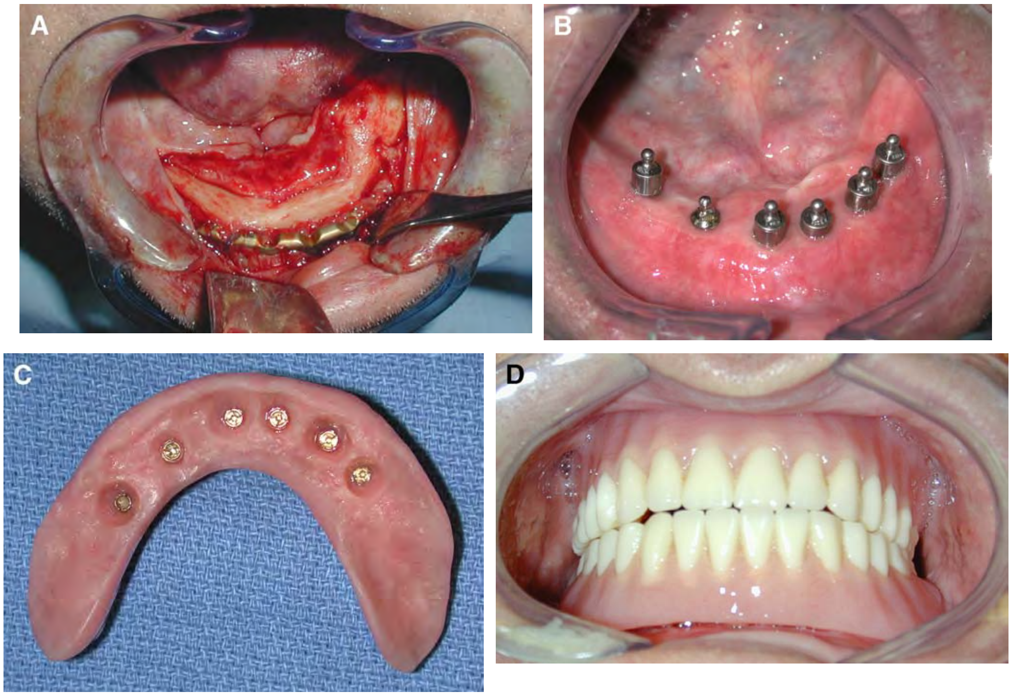

Fig. 1. (*A–D*) This series of images illustrates anterior mandibular reconstruction with a free fibula flap. Note the character of the healing at the sites of osteotomy of the fibula. Dental implant-based rehabilitation completed the reconstruction.

In most cases of composite bone-containing defects of the maxillofacial region, fibula flaps and deep circumflex iliac artery (DCIA) flaps are the most suitable choices. In rare instances, the scapula flap and the free radial forearm osteocutaneous flap may prove useful. The fibula flap is generally favored over the DCIA flap because of ease of harvest, minimal donor site complications, and length of the vascular pedicle. The major advantage of the DCIA flap is that the donor site is completely hidden.

The donor site should be examined carefully to determine suitability. The vascular supply to the flap and the remaining tissues must be assured. Prior surgery can compromise the blood supply (ie, axillary dissection, scapula flap), and vascular anomalies can put the foot or hand at risk after flap harvest (fibula, free radial forearm flap). The site selected for flap harvest affects the orientation of the vascular pedicle and must be considered in designing the flap to ensure appropriate vessel geometry. In general, the vessels of free flaps do not tolerate tension, redundancy, or sharp angles, which can kink the vein obstruction outflow. In the case of mandibular reconstruction, the vessels should be oriented in a manner that protects them from compression by orienting the flap to place the vascular pedicle along the medial aspect of the inferior border of the neomandible. The flap should be designed so that the vessels extend from the flap as near the recipient vessels as possible. For example, if the flap pedicle is to exit the flap at the angle of the right mandible and the skin paddle is to cross over the lateral surface of the neomandible, then the right fibula should be used. Likewise, if the flap is to be similarly oriented but the pedicle must leave the flap at its anterior aspect (ie, angle and ramus reconstruction), then the left leg should be used.

The recipient site must be prepared appropriately before the flap is harvested. Often, the flap can be elevated and allowed to reperfuse while the recipient site is prepared. If surgery involves a patient who underwent irradiation or is a reoperation on a neck that underwent previous neck dissection, however, it may be better to delay flap elevation until after ensuring the presence of acceptable recipient vessels. In either setting, it is best to restore the continuity of the mandible with a reconstruction bar before flap harvest. This approach ensures that the shape of the mandible and drape of the facial tissues are acceptable. The flap can be adapted to this shape at the time of flap inset. In many instances, the reconstruction plate can be adapted before resection, removed for resection, and replaced. When there is lateral expansion or full-thickness tumor involvement, alternate means of plate adaptation must be considered. Stereolithographic models or CAD-CAM polymer models can be created from CT scans, and the reconstruction plate can be adapted to these models after recontouring to a more normal mandibular anatomy (Fig. 2). The need for such a model must be appreciated at the time of initial patient evaluation before imaging is ordered, because special imaging protocols may be required. In some instances it may be helpful to use an external fixation device applied away from the area of the mandible involved in the resection. The device holds the remaining segments of the mandible in place to allow for plate contouring, adaptation, and stabilization (Fig. 3A, B). In other instances, the mandibular contour must be established by placing the teeth in occlusion and repositioning segments that are non–tooth bearing in appropriate position by reference to lateral and posteroanterior cephalometric radiographs. Sometimes a surgeon must adapt the bone plate using only the opposing dental arch as a guide, based on knowledge of normal jaw anatomy. In such cases it is necessary to view the plate adaptation from multiple angles to ensure appropriate positioning (Fig. 4A, B).

The authors favor the use of locking reconstruction plates for stabilization of microvascular free bone flaps in mandibular reconstruction. Larger plates were used initially; however, these newer plates have advantages in many applications, particularly for segmental resection. The larger plates are still used when reconstructing massive resections and for condylar reconstruction. The small 2-mm plates are lower in profile but possess more than enough rigidity to stabilize the bone segments until bone healing is complete. Because of the excellent blood supply, bony union is achieved rapidly (4–6 weeks). This union depends on excellent adaptation of the bone, however. The osteotomies should be created to ensure intimate contact between segments of the flap and between the flap segments and the native mandible. Failure to do so may result in nonunion and subsequent hardware failure (Fig. 5). Standard screws (nonlocking) are used to secure the bone segments to the reconstruction bar. The use of the miniplate technique provides adequate stability if applied properly, using paired plates at each osteotomy or flap-native mandible interface. A single miniplate provides insufficient stability (Fig. 6). The authors do not use miniplate technique because the use of a previously adapted and applied reconstruction plate provides such a useful guide for bone flap recontouring.

Revascularization of the flap is completed after recontouring, stabilization and skin paddle inset, and suturing. Manipulation of the flap while it is ischemic simplifies this process. The flap inset is completed before revascularization to ensure that the vessel geometry is appropriate. Microvascular anastomosis is completed with the use of the operating microscope. The microscope has significant advantages over the use of loupe magnification. The scope offers excellent illumination, variable magnification, and equal visualization of the field by the operator and assistant. The practice of heparinization of the patient at the time of microvascular anastomosis has been shown to be unnecessary and associated with increased local wound complications (hematoma). Irrigation of the vessels is accomplished with a solution of 500 U heparin per 100 mL of saline. An anterior chamber irrigating needle on 5-mL syringes provides

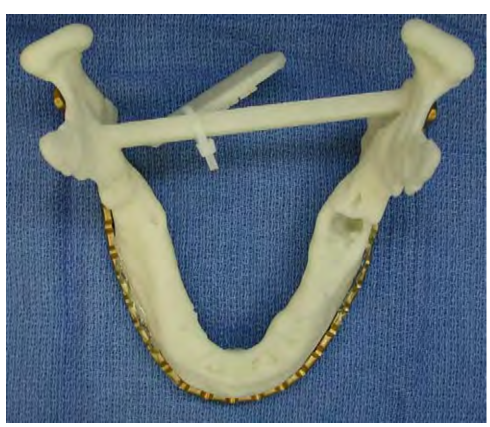

Fig. 2. Preoperative adaptation of a mandibular reconstruction plate to a CAD-CAM model is accomplished after recontouring the site of tumor expansion to approximate a more normal mandibular anatomy.

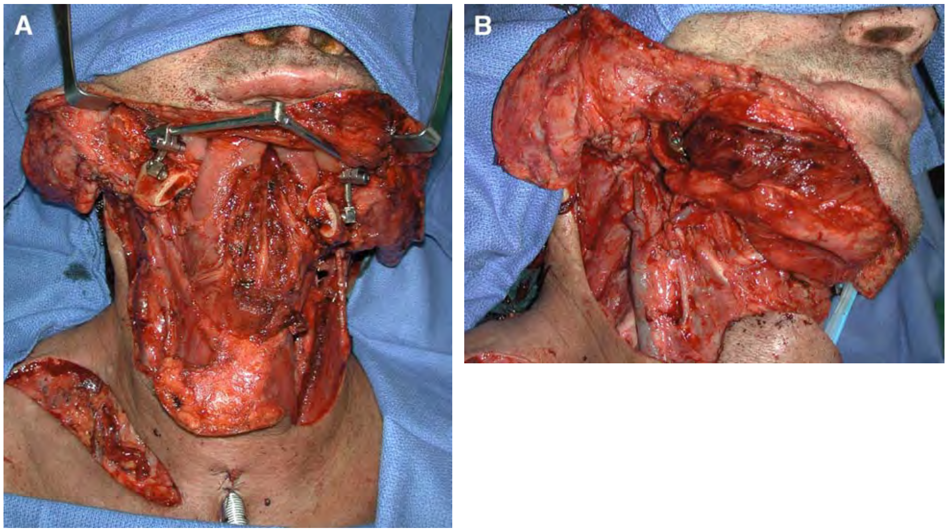

Fig. 3. (*A,B*) This case series demonstrates the use of a mandibular bridge (temporary external fixator device) to maintain the position of the proximal mandibular segments after mandibulectomy. The second image illustrates the appearance after inset of a fibula free flap. Note the position of the vascular pedicle along the medial surface of the neomandible and the lateral position of the vascular perforators to the skin paddle after inset in the mouth.

a suitable irrigation stream. The authors use standard interrupted technique with 9-0 nylon for vessel anastomosis. Disposable approximation clamps are used because they provide reliable clamping forces. End-to-end technique is used most commonly for microvascular anastomosis. The artery is typically approximated first because it is generally deeper than the vein. The facial artery, superior thyroid artery, and external carotid artery are the most commonly used recipient arteries. The common facial vein and external jugular vein are the typically used recipient veins.

Fibula flap

Background

The fibula flap has gained a well-deserved reputation for reliability, ease of harvest, and suitability for definitive implant-supported dental rehabilitation. A few oral and maxillofacial

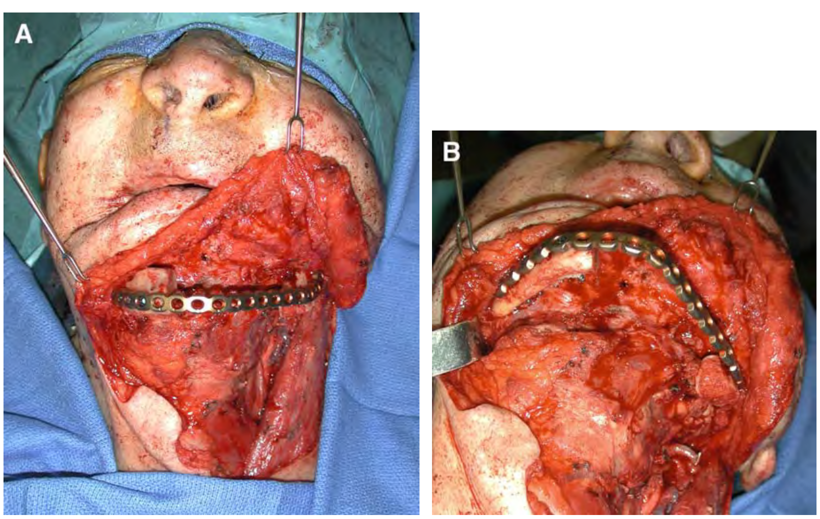

Fig. 4. (*A,B*) This series of images demonstrates the challenges faced in secondary reconstruction. This case involved multiple operations and bone grafts after shotgun injury. The two images show how viewing the reconstruction from multiple angles facilitates anatomic mandibular reconstruction.

Fig. 5. This image displays hardware failure caused by nonunion of the DCIA flap to the native mandible. The source of this problem seems to be inadequate flap inset.

surgeons proclaim this flap unsuitable for mandibular reconstruction. The fibula mandibular reconstruction is different in appearance and height in comparison to the native mandible in some cases. The literature that describes success with the flap for this purpose and the senior author's extensive experience dispute those who downplay the use of this flap. The flap height and shape of the flap resemble closely the structure of an atrophic edentulous mandible. Throughout the world, the fibula flap has become the most common means of primary mandibular reconstruction. The distance of the donor site from the head and neck field is an advantage because it allows for simultaneous surgery. Likewise, the lack of significant morbidity of the flap harvest with proper attention to detail is also a significant advantage of the flap.

Early reports of poor reliability of the skin paddle have proved to be related to a poor understanding of the flap anatomy, which has led to errors in flap harvest rather than a true problem with the flap itself. These errors occurred because the vascular perforators to the skin do not always pass to the skin within the lateral intramuscular septum and can be musculocutaneous perforators (Fig. 7). The presence of musculocutaneous perforators complicates the harvest and limits the mobility of the skin paddle slightly, but it is managed easily by an experienced surgeon.

The fibula flap is based on the peroneal artery and vein. These vessels are of good diameter and quality. Preoperative evaluation of the perfusion of the lower extremity should be performed before planning surgery. The authors perform a clinical assessment and determine the necessity for additional studies based on the findings of that examination. The examination should consider color and character of the skin, hair distribution, temperature, nail thickness, and the character and quality of the pulses within the foot. Identification of any abnormality should trigger a vascular imaging study. The authors prefer magnetic resonance angiography (Fig. 8) over arteriography because of the radiation and the dye load required for the

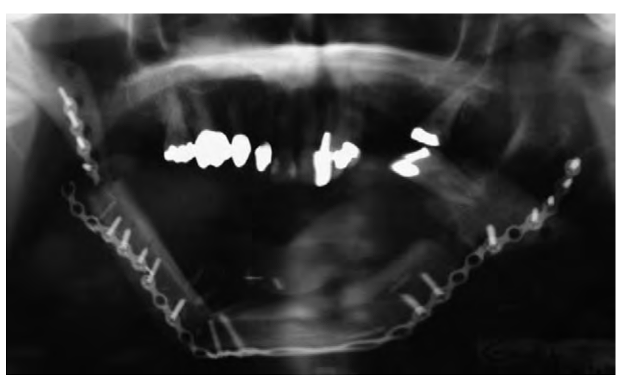

Fig. 6. This image demonstrates the inadequate stability provided by a single miniplate. The free fibula flap did not heal to the native mandible. The cause of this nonunion could be either inadequate stability or poor inset. Miniplates should be applied in two planes as a paired plate construct.

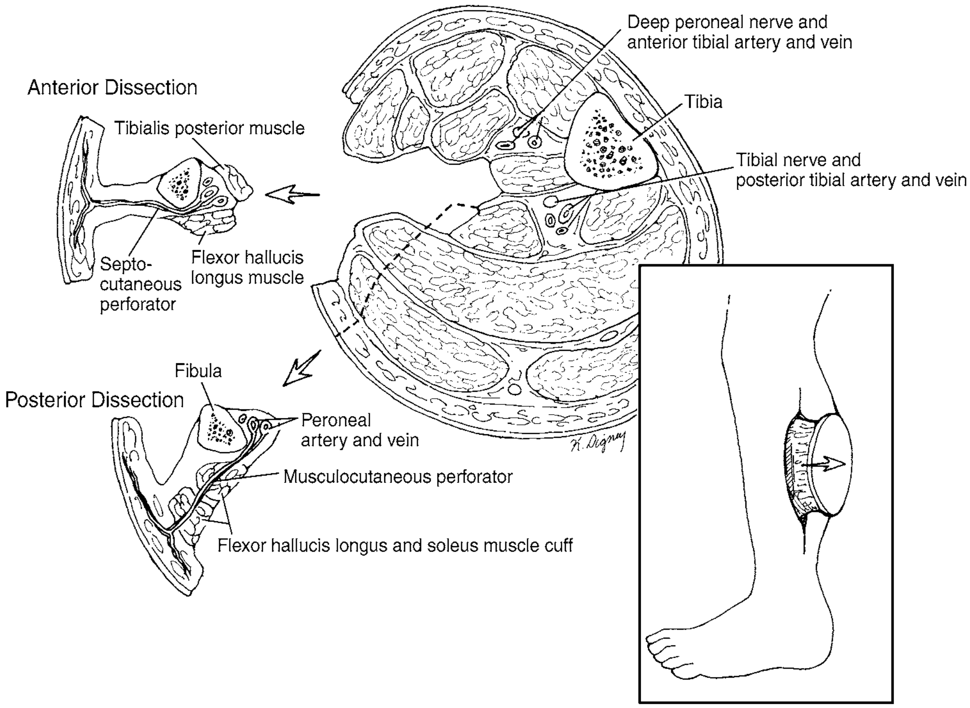

Fig. 7. This artist sketch is an excellent depiction of the flap harvest, character of the perforators, and proximity to adjacent structures.

arteriography. Based on studies, it is estimated that 10% to 20% of lower extremities display abnormal characteristics, which causes the harvest of the peroneal artery to potentially compromise the vascularity of the foot. The rationale for not studying all legs is that with an excellent clinical examination the likelihood of a significant abnormality is low and all three major vessels will be seen in the course of flap elevation, which makes it possible to identify any abnormality before flap harvest.

Fig. 8. This is an AP MRA image of the right leg. The detail seen with this imaging technique is remarkable.

The fibula flap offers flexibility in flap design and placement that provides reconstructive surgeons with important options in the selection of appropriate recipient vessels. Surgeons should select the donor leg and design the flap to simplify inset and maximize vascular pedicle length. The length of the available fibula allows for nearly total mandibular reconstruction. The character and quality of the bone, along with the excellent segmental vascular supply, allow surgeons to custom contour the flap to the ideal dimensions of the mandible. Closing osteotomies allow precision inset of the flap to ensure excellent, direct bone contact. When properly recontoured and inset, the flap heals rapidly and restores mandibular continuity despite the administration of postoperative adjuvant radiation therapy. The bone supports the placement of dental implants immediately at the time of flap reconstruction, after bone healing, or after resolution of the acute effects of the radiation therapy. Mandibular hardware should be removed at the time of implant placement to ensure load transfer to the bone element of the flap.

Technique

A patient's donor leg should be shaved with clippers and the surgical anatomic landmarks outlined in detail. It is often possible to identify the location of the perforators to the skin with a Doppler probe. Typically they are located near the junction of the middle and distal third of the fibula. If they can be identified, they should be marked clearly, as in the clinical example provided. Protection of the articulations of the fibula and peroneal nerve is enhanced by appropriately marking the skin (Fig. 9A–C). Stabilization of the leg can be facilitated with the placement of a bump at an appropriate location to serve as a foot rest. A sandbag or liter bag of intravenous fluid secured with tape across the bed is appropriate for this purpose (Fig. 10). The site is prepared simultaneously with the head and neck site. The two fields are kept isolated throughout the procedure. Surgical skin prepping solution is excellent for site preparation, and an extremity drape is used to isolate the field. A sterile tourniquet is placed above the knee. The tourniquet is inflated to 100 mm Hg above systolic blood pressure after exsanguination of the leg by elevation for 3 to 5 minutes.

Simultaneous flap harvest and head and neck surgical site preparation can be performed in a two-team manner. The surgical time required for fibula flap elevation is approximately 70 minutes. Although the flap can be elevated and modified in situ while pedicled to decrease ischemia time, the authors prefer not to do this. Instead, the authors design the flap backward, beginning from the site of the vascular reanastomosis first to ensure acceptable vessel geometry. The time required to osteotomize, recontour the flap, and complete the inset and reanastomosis is well within the allowable time for warm ischemia. There is little advantage to complicating the procedure by trying to perform osteotomies with the flap pedicled. The total ischemia time for a fibula flap is approximately 3 hours 20 minutes, including tourniquet time.

The lateral intramuscular septum is easily palpable in all but the heaviest of patients. The skin paddle is oriented over the perforating vessels and the lateral intramuscular septum (Fig. 11). The anterior skin paddle elevation is completed first with dissection through the skin, subcutaneous tissue, and fascia. Refinement of the location of the skin paddle later can be made after visualizing the perforators. It is helpful to mark them on the skin paddle to assist in creation of the posterior incision to center the perforators within the skin paddle.

The peroneus longus, peroneus brevis, and flexor hallicus longus are reflected from the anterior and medial portion of the fibula to the intramuscular septum (Fig. 12A, B). This procedure is best accomplished with electrocautery while taking care to preserve a small muscle cuff. After incision of the intramuscular septum, the deep peroneal nerve and the anterior tibial vessels are easily visualized at this point within the reflected medial tissue elevation (Fig. 13). Gentle medial reflection is necessary to identify the interosseous membrane. The posterior skin paddle elevation is then accomplished. It is necessary to remain subfascial throughout this dissection and to remain vigilant for possible musculocutaneous perforators.

Proximal and distal osteotomies are made through the fibula at least 6 cm away from the terminations of the fibula to maintain adequate stability of the knee and ankle joints. The fibula is then rotated and the intraosseous membrane is incised along its length with a scissors to expose the tibialis posterior muscle. Typically the most distal aspect of the peroneal vessels can be seen easily at this point. Ligation of the vessels allows increased lateral movement of the flap

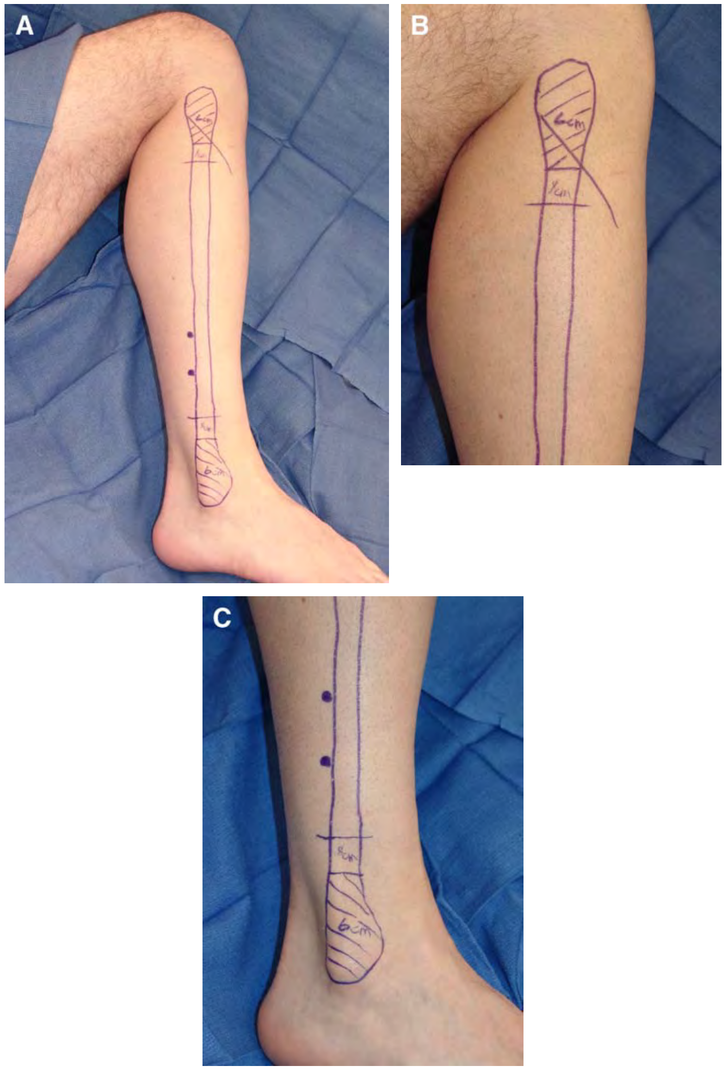

Fig. 9. (*A–C*) This series of images demonstrates the depiction of the relevant anatomy for the fibula harvest. Maintenance of 6 to 8 cm of the fibula near the joints and the common peroneal nerve is depicted.

and eases visualization of the remainder of the dissection. The vascular pedicle is then dissected free by dividing the overlying chevron-shaped tibialis posterior muscle. Many large branches from the peroneal vessels to the soleus and gastrocnemius muscles require ligation to facilitate retraction. As the dissection proceeds proximally, the posterior dissection also must be completed. This procedure is slightly more difficult if the perforators are of the intramuscular type. To facilitate this, it helps to put a finger along the medial aspect of the vascular pedicle and directly visualize the perforators while cutting down with electrocautery to join the medial dissection. A small muscle cuff also is usually harvested, which helps to fill the voids present along the medial aspect of the mandibular reconstruction.

Throughout this portion of the dissection the posterior tibial vessels are visualized within the medially retracted tissues. Extreme care should be given to avoid undue pressure on the posterior tibial nerve. The operating surgeon must examine frequently the position of the retractors used to ensure safe positioning because the retracting surgeon, who is frequently on the opposite side of the table, has no direct view. The vascular pedicle should be skeletonized before flap harvest (Fig. 14), which greatly facilitates subsequent microvascular anastomosis. There is routinely a large soleus branch approximately 4 cm from the bifurcation that is often difficult to visualize. Care should be taken to identify and ligate this branch because of the consequences of bleeding obscuring visualization at this critical location. There is often what seems to be a cutaneous perforator along the upper one third of the fibula length. The surgeon must take care not to rely

Fig. 10. This image demonstrates the value of a support placed on the operating table to allow hands-free support of the leg to facilitate fibula harvest.

on this vessel unless he or she is certain that it arises from the peroneal vessels. This perforator is often from a circumflex branch.

After complete isolation of the flap pedicle, the tourniquet should be released to visualize flap perfusion and ensure hemostasis. Appropriate preparation of the recipient bed should include thorough mobilization of recipient vessels and assurance of excellent flow at the site of planned anastomosis. The field should be prepared to facilitate the flap modification and inset. If possible, accommodation should be made for a contouring bur and a sagittal saw to be available for use simultaneously, which avoids wasting time switching appliances. Division of the flap and transfer to the head and neck field is accomplished when the site is appropriately prepared. The donor site leg may be packed with lap sponges and wrapped in gauze for later management, or a member from the operative team may close the leg over a drain while the flap inset is occurring. Closure should be accomplished by loose approximation of the muscles, buried

Fig. 11. This image shows the positioning of the skin paddle of the fibula flap over the lateral intramuscular septum. The location of the perforators to the skin paddle have been identified and depicted on the leg. The flap is oriented directly over these vessels.

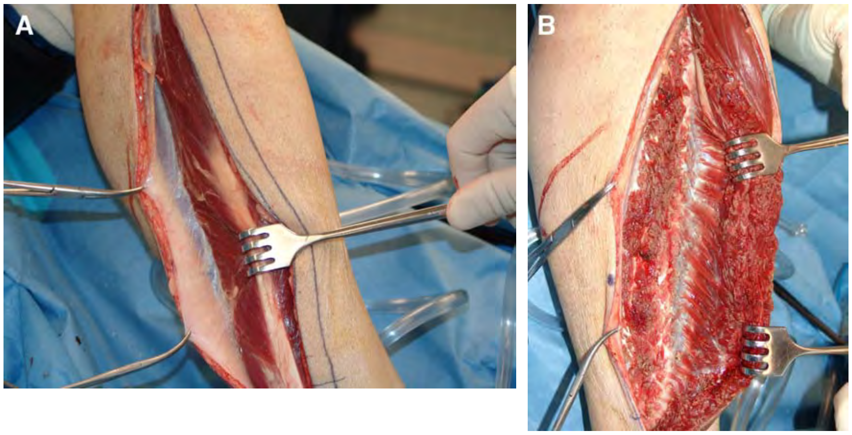

Fig. 12. (*A*) The anterior incision and posterior dissection of the skin paddle of the fibula flap. The vascular perforator is seen directly opposite the retractor. (*B*) The appearance of the donor site during the anterior-medial dissection.

closure of the dermis, and stabilization of the skin at the skin paddle donor site. The skin paddle donor site is then grafted with split-thickness skin from the thigh. The graft should be secured with resorbable suture and a tie-over bolster dressing. The foot and ankle should be stabilized in a lower leg posterior splint that is well padded. If no skin paddle is harvested, the skin may be approximated directly and the lower leg dressed with light elastic compression.

The osteotomies of the fibula are made precisely to allow maximum bone contact at the interface of the fibula segments and the fibula-to-native-mandible interface. When the surgery is properly performed, the bone flap literally snaps into place. Stabilization is limited to one or two screws per segment. This portion of the reconstruction is critical to the outcome. Failure to achieve proper bone inset can result in nonunion and subsequent hardware failure, which are common reasons why the senior author sees other surgeons' patients for revisions. The skin paddle inset often requires customization of the skin paddle by excision of skin and dermis where excess exists and maintenance of the underlying dermal plexus, fat, and fascia to ensure adequate perfusion. The flap should be sutured into position without tension using horizontal mattress sutures. A general principle that should be followed is that more tissue is better than not enough; some degree of redundancy is shared across wounds to err on the side of excess tissue maintenance.

Postoperative mobilization can begin immediately if there is no skin graft or at the time of removal of the bolster dressing (5 days) if a skin graft is used. Donor site elevation is required

Fig. 13. The contents of the anterior compartment are visualized in this image. The interosseous septum is seen anterior to the fibula. Beneath the septum the peroneal vessels are identified.

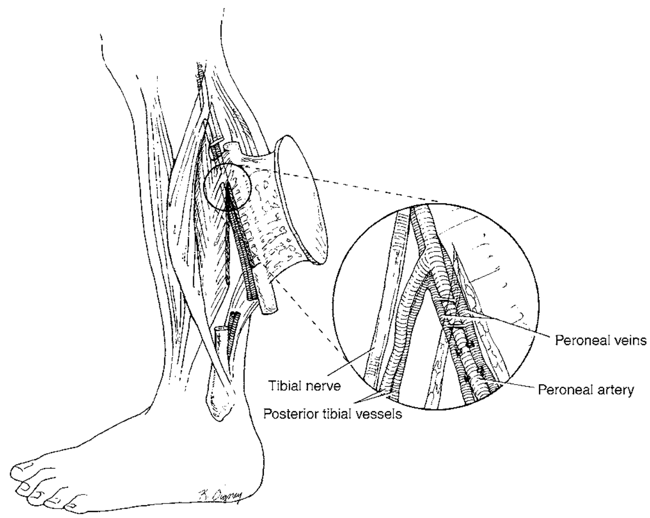

Fig. 14. Flap elevation and dissection of the proximal vascular pedicle.

throughout the first few weeks to prevent lymphedema in the leg. Return to normal activities can be ensured as soon as 4 to 6 weeks after surgery.

Deep circumflex iliac artery flap

Background

The DCIA flap was developed from early experience with the groin flap. The proper vascular pedicle for the osteomusculocutaneous flap was determined to be the DCIA and vein. These vessels arise from the external iliac artery and vein just above the inguinal ligament. They have average diameters of 2 to 3 mm. The ascending branch of the DCIA provides the blood supply to the internal oblique muscle, which has become the favored soft tissue for harvest with the flap. Harvesting a well-vascularized muscle and allowing secondary epithelialization within the oral cavity provides a character and quality of tissue that are well suited to reconstruction of the dentoalveolar apparatus. The muscle undergoes a process of atrophy and mucosalization that results in a fixed mucosal lining that adheres densely to the iliac bone over which it has been draped. This process provides an ideal site for dental implant-based oral rehabilitation.

The flap initially was described to include the overlying skin and fat and the internal oblique muscle. The skin is supplied by muscular perforators and is well vascularized. The only problem with the skin element of the flap is that it is often too thick and immobile. The flap is commonly used with only the internal oblique muscle.

The donor site provides some interesting challenges in the course of its reconstruction. Potential exists for hernia formation through the bone harvest site and the weakened abdominal wall. To avoid hernia, the iliac harvest defect is typically spanned with either titanium mesh or polypropylene mesh, and the abdominal wall likewise is supported with polypropylene mesh. It is not uncommon to spend twice as much time on the closure of the defect site as in the harvesting of the flap. Proper patient selection is important. The authors prefer not to perform the DCIA flap in active men or laborers. Instead, the DCIA flap has been used typically in thin women and retired thin men. One surprising challenge encountered with the use of the DCIA flap in mandibular reconstruction has been too much bone height, which interferes with the interarch space required for implant-based dental rehabilitation. The DCIA flap is the clear second choice for mandibular reconstruction after the fibula.

A significant advantage of the flap is that the distance from the head and neck field allows simultaneous two-team surgery, which helps considerably to offset the challenges imposed by the difficulty of the flap harvest and the donor site reconstruction.

Technique

The patient is positioned supine with the table flat. It may be helpful to place a small bolster under the hip opposite the harvest site to facilitate visualization of the vascular pedicle. Assistance is mandatory and is best provided by a retractor holder opposite the surgeon and an assistant on the same side as the surgeon. The site should be shaved, prepared, draped, and covered with an occlusive barrier to isolate the field. The surgical anatomic landmarks should be marked clearly (Fig. 15A). If a skin paddle is to be used, it should be oriented directly over the iliac crest, should be elliptical shaped, and should be of sufficient width to ensure capture of the musculocutaneous perforators. In the more typical flap harvest without skin paddle, the access incision is placed in a natural skin crease within the groin that extends laterally superior to the iliac crest. The skin is incised and the external oblique muscle is identified and incised approximately 2 cm from the iliac crest (Fig. 15B). The external oblique muscle is then retracted and the internal oblique muscle is dissected along its entire length to the linea semilunaris

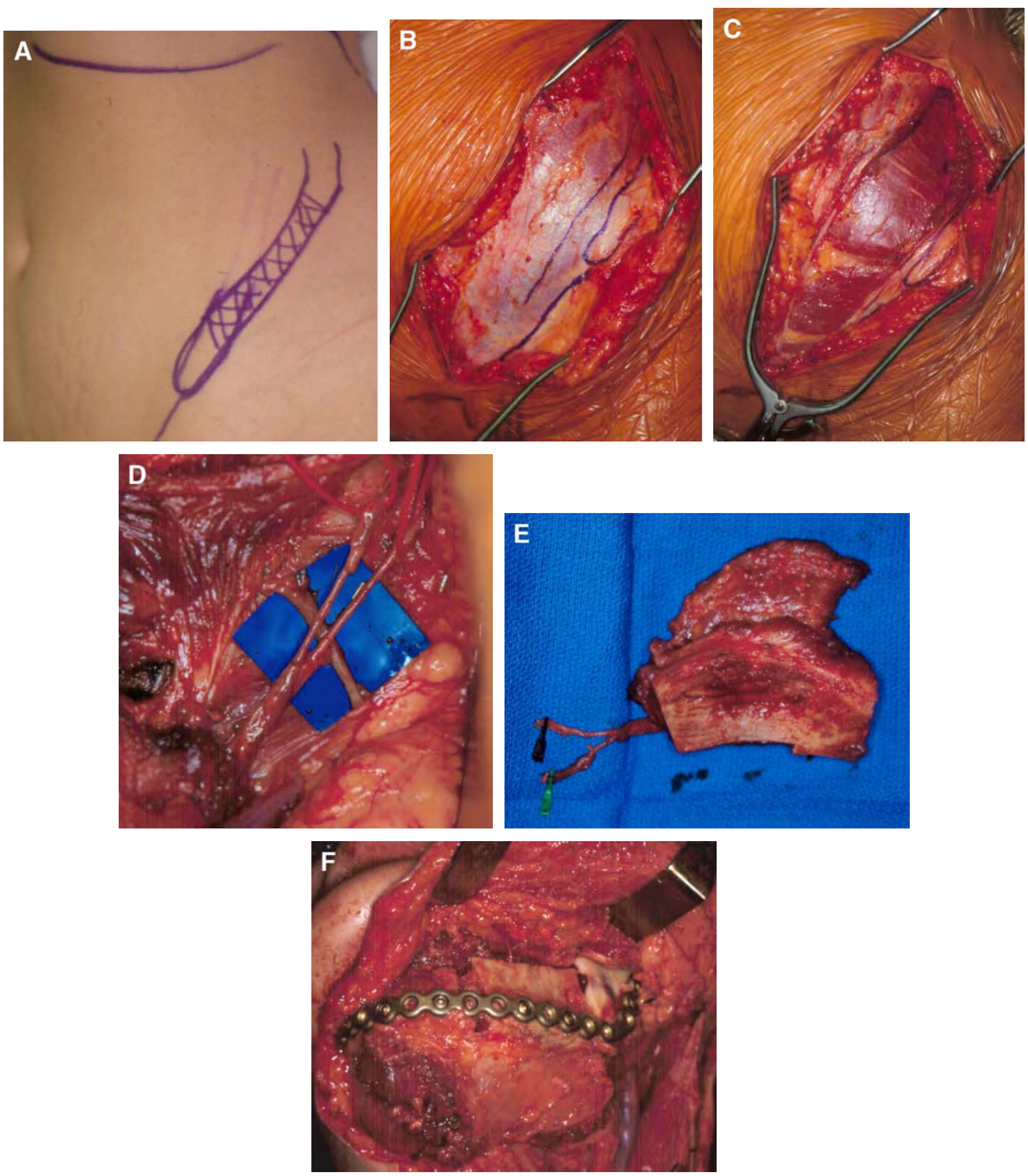

Fig. 15. (*A–F*) This series of images illustrates the harvest of a DCIA flap. The text supports these drawings well.

medially and superior to the inferior margin of the rib cage (Fig. 15C). The required amount of internal oblique muscle is then incised and the muscle is elevated from the transversalis muscle. The ascending branch of the DCIA is traced along the deep surface of the internal oblique muscle to the major DCIA pedicle.

Upon identification of the major pedicle, it is wise to extend the dissection medially to the external iliac vessels. There is substantial variability in the arrangement of the deep circumflex vessels and the lateral femoral cutaneous nerve (Fig. 15D). The DCIV can provide surgeons with some challenges because it may exist as two distinct vessels. The authors' experience is that these vessels always come together before draining into the external iliac vein. It is possible, however, that they can remain separate, as described in the literature. If the veins remain separate, it is possible to evaluate flow and reanastomose only the vein with the greatest flow.

After isolation of the flap pedicle, it is appropriate to begin the osteotomies required to harvest the bone element of the flap. The transversalis muscle must be transected approximately 2 cm from the iliac crest or preferably with direct visualization of the vascular pedicle to avoid its injury (Fig. 16A). The preperitoneal fat must be retracted medially and the iliacus muscle must be transected to expose the iliac bone. The muscles are released laterally from the iliac crest to the level of the planned osteotomy. Osteotomies are then completed to free the flap, which

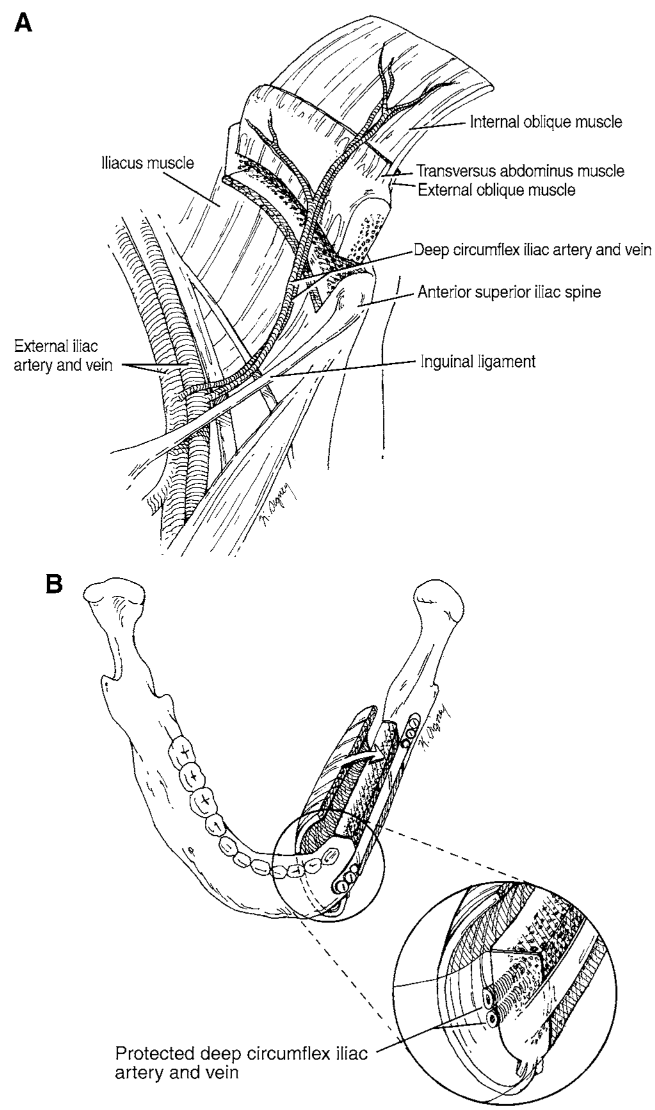

Fig. 16. (*A,B*) The flap harvest and flap inset. Note the position of the vascular pedicle along the medial surface of the neomandible.

remains pedicled to the DCIA and DCIV at the external iliac vessels. The authors prefer to maintain approximately 2 to 3 cm of iliac bone intact at the anterior superior iliac spine, which facilitates reconstruction of the continuity of the iliac crest to avoid hernia formation. The vascular pedicle is divided and the flap transferred to the recipient site after proper preparation of the recipient site (Fig. 15E).

Inset of the bone flap is completed in such a way as to ensure protection of the vascular pedicle on the medial aspect of the flap with the internal oblique muscle on the medial-inferior aspect of the flap (ie, with the iliac crest positioned inferiorly and the cut surface superiorly) (see Fig. 15F; Fig. 16B). Care must be taken in design of the flap because the somewhat limited pedicle length must be allowed for. The maintenance of the ASIS assists in that regard by effectively lengthening the vascular pedicle. Curvature of the bone element of the flap requires creating opening osteotomies of the lateral cortex with greenstick fracture of the inner cortex. The gap is packed with particulate cancellous bone (this is demonstrated in Fig. 15F). The muscle is then draped around the neomandible. The muscle fascia is sutured to the mucosal edges within the oral cavity to provide an effective seal. Rapid granulation of the exposed muscle is common. The color and character of the exposed muscle provide an excellent means of monitoring.

The donor site is reconstructed by stabilizing a double thickness of polypropylene mesh to span the bone defect, which is secured via drill holes in the ilium. The transversalis and external oblique muscles are then sutured to the aponeurosis and supported with another layer of mesh. The skin is approximated in layers (Scarpa's fascia, dermis, skin) over a closed suction drain. An appropriate bowel regimen is recommended for use in the preoperative and postoperative time frame to avoid constipation and straining at stool. Likewise, lifting weights of more than 15 pounds, strenuous exercise, and labor are delayed until at least 4 weeks after surgery to avoid the development of hernia.

Radial forearm osteocutaneous flap

Background

The free radial forearm fasciocutaneous flap has excellent use in head and neck surgery primarily because of the thin, pliable character of the tissue and the reliability of its vasculature. A major advantage of the flap is that the distant location of the flap donor site allows simultaneous flap harvest and cancer resection or recipient site preparation. The use of this flap as a bone-containing flap is, however, somewhat limited because of the minimal volume of bone that can be harvested. The primary uses of the flap are to restore facial form and provide support of adjacent structures, as in reconstruction of the premaxilla to provide nasal and lip support. The senior author believes that the bone stock is insufficient for use in mandibular reconstruction because it does not support endosseous dental implant rehabilitation. Dental rehabilitation should be a primary goal of all mandibular reconstructions. Quality-of-life studies demonstrate that for patients, the most important aspects that affect their quality of life are eating normally and speaking clearly. Without dental rehabilitation, the achievement of these goals would be impossible; the free radial forearm osteocutaneous flap remains a rarely used flap in the surgical armamentarium.

The free radial forearm flap receives its vascular supply from the radial artery. The flap's venous drainage is from either the venae comitantes or the cephalic vein. The authors prefer the cephalic vein because its size more closely approximates that of many potential recipient veins in the neck and facilitates end-to-end anastomosis. These vessels average 2 mm in diameter. Before flap harvest, a surgeon must ensure adequate communication between the superficial and deep palmar arches, which is most easily done using the relatively simple Allen's test. The absence of an appropriate communication has been described in 12% of specimens investigated. Although the nondominant hand is generally selected, a poor Allen's test result has governed the selection of flap donor site in several of the senior author's cases. A positive Allen's test result demonstrates the absence of communication between the palmar arches in the patient being evaluated (Fig. 17). Note that the portion of the hand that appears well perfused with the radial

Fig. 17. An Allen's test that demonstrates the lack of communication between the superficial and deep palmar arches. Note the pale character of the thumb and first finger.

artery occluded is limited to that area primarily supplied by the ulnar artery. In this instance, selection of an alternate donor site is required.

The limitations of the bone stock available in the radial forearm fasciocutaneous flap already have been outlined. The amount of bone that can be harvested is limited to 40% of the diameter of the radius between the insertion of the pronator teres proximally and the brachioradialis distally (Fig. 18). To avoid the creation of internal stress, the osteotomy should be completed without sharp internal line angles. It is best to plate prophylactically across the defect at the radius harvest site because the rate of fracture is approximately 25%. The deformity that results from fracture of the radius is unacceptable. The blood supply to the radius is through segmental periosteal branches within the anterolateral intramuscular septum and the flexor pollicis longus muscle. The nature of this blood supply allows for osteotomies to be performed, provided appropriate care is given to avoiding excessive periosteal elevation.

Technique

An appropriate donor site is selected based on the character of the tissue and the appearance of the vasculature. An Allen's test must confirm adequate ulnar artery perfusion of the thumb with radial artery occlusion. If it is difficult to determine perfusion based on color of the skin (ie,

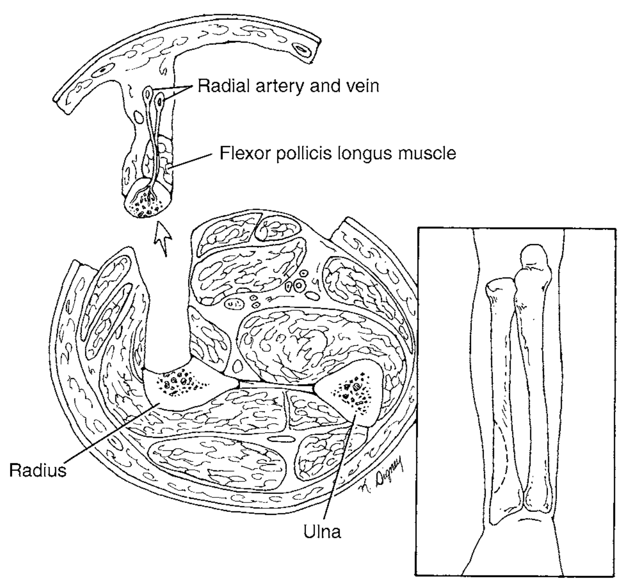

Fig. 18. A cross-section of the radius harvest site and the appropriate shape of the radius osteotomy.

dark-skinned subject), a pulse oximeter probe can be attached to the thumb and the test repeated. The appropriate donor site should be selected well before surgery and the cephalic vein should be protected from venipuncture. On the day of surgery, the authors prefer to mark the radial artery and cephalic vein with a surgical marker in the preoperative holding area. This preparation facilitates design of the flap once the final dimensions of the defect site have been determined.

The donor site arm is prepared simultaneously with the resection/recipient site. The arm is prepared to the axilla and draped with an extremity drape. A sterile tourniquet is applied to the upper arm after the flap has been outlined on the ventral surface of the forearm overlying the radial artery. Inflation of the tourniquet is accomplished after exsanguination of the arm with an elastic bandage. The tourniquet should be inflated to 250 mm Hg or approximately 100 mm Hg above systolic blood pressure. Dissection and flap elevation are aided by stabilizing the hand/wrist with a lap sponge across the palm secured by nonpenetrating towel clamps.

The flap elevation is performed from the distal. The radial artery, its venae comitantes, and the cephalic vein are ligated. A judgment call as to the fate of the dorsal radial nerve must be made based on the degree of its exposure and the possibility of painful altered sensations upon its postoperative stimulation. This nerve may be covered only by the skin graft and may be prone to constant stimulation. It is perhaps best to sacrifice this nerve from the distal of the flap harvest site to beneath the forearm musculature to avoid postoperative dysesthesia. The fascial compartment that contains the vascular supply is dissected free from the underlying muscles from the lateral aspect of the skin paddle. Proximal incision is made in the groove between the flexor carpi radialis and brachioradialis muscle or along or near the cephalic vein. The dissection is then carried down to the level of the brachioradialis muscle. The brachioradialis muscle can be reflected laterally to expose the proximal vascular pedicle. The medial skin paddle elevation and proximal dissection are then completed. The flexor carpi radialis can be retracted medially to expose fully the vascular pedicle and the radius. The appropriate osteotomy site is then identified and isolated. The osteotomy is made carefully to avoid creation of areas of isolated stress and avoid removing more than 40% of the diameter of the radius. The flap then remains pedicled on the proximal vascular pedicle. The proximal vascular pedicle is dissected free from its venae comitantes at the site at which vascular anastamosis is likely to occur.

The authors prefer to allow reperfusion of the flap at this time to ensure adequate perfusion and hemostasis. The flap may be repositioned and wrapped in lap sponges and gauze until the preparation of the recipient site is ensured.

The head and neck field always must remain isolated from the donor site. The morbidity of a local infection in the wrist is significant. Extreme limitation of mobility is the likely outcome. The vascular pedicle of the flap is transected and the flap transferred to the recipient site. The flap inset is completed and the bone stabilized with miniplates or a reconstruction plate before vascular reanastomosis. The surgical team may be split, and a team member or members may be left behind during the flap inset to complete the closure of the proximal portion of the donor site over a drain, stabilization of the skin edges of the flap harvest site to the underlying fascia, and coverage of the defect with a split-thickness skin graft. The arm should be splinted in the position of maximum function (wrist dorsiflexed 45°; fingers neutral) with a simple volar splint.

Scapula flap

Background

The scapula free flap is based on the circumflex scapular artery and vein. These vessels are of large caliber, with common diameters of 4 mm (range 2–6 mm). This flap has perhaps the most versatility and adaptability of any of the bone-containing microvascular free flaps in common usage. The flap is generally reserved for specific indications in head and neck reconstruction because of the challenges imposed by the need to reposition the patient to allow flap harvest and the donor site morbidity related to the flap harvest. Such indications include through-and-through composite defects of the mandible and complex three-dimensional defects of the maxilla. The major advantage of this flap is the availability of two separately mobile cutaneous segments.

Approximately 8 cm of bone can be harvested along the lateral border of the scapula. The bone is well perfused through numerous branches. Care must be taken to identify the origin of the blood supply to the scapular tip via the angular artery if it is to be included. The angular artery commonly arises from the thoracodorsal artery. Proximal dissection of the vascular pedicle and transection of the flap pedicle at the subscapular artery and vein results in the ability to transfer simultaneously the latissimus dorsi muscle and the serratus anterior muscle with the flap. Although this is a common point of discussion, the authors know personally of no surgeon who actually has performed such a flap.

The scapula bone is of acceptable quality and quantity for midface reconstruction in most cases but may fall short of ideal for mandibular reconstruction because of its limitations in size and volume. The bone is commonly insufficient in width to accept endosseous implants in women and often is insufficient in men, which limits the flap's acceptance.

Technique

The patient must be positioned in the lateral decubitus position. For use in head and neck reconstruction, the primary operative site must be packed and covered before repositioning and repreparation of the operative field. Lap sponges should be placed in the operative site, and a large transparent adhesive drape should be used to cover the site of the resection and the neck dissection. The surgeon also should realize that closure of the flap harvest site and repositioning are required again after flap harvest and before flap inset and revascularization. This process requires operative team coordination and planning to ensure a smooth transition with minimal loss of time to limit flap ischemia. To avoid brachial plexus injury, careful support and movement of the arm at the site of the flap harvest and support and protection of the contralateral brachial plexus with an axillary roll are required.

The scapular outline should be marked, and the orientation of the cutaneous branches of the circumflex scapular artery should be drawn to facilitate the orientation of the skin paddles. The transverse cutaneous branch runs horizontally across the scapula midway between the scapular spine and the scapular tip. The descending cutaneous branch is located vertically along a parallel to the lateral border of the scapula. The origination of these two cutaneous branches from the circumflex scapular artery is identified in the triangular space formed by the teres major, teres minor, and the long head of the triceps brachii muscle (Fig. 19). This site typically can be palpated or identified with a simple Doppler probe. The cutaneous elements should be dissected

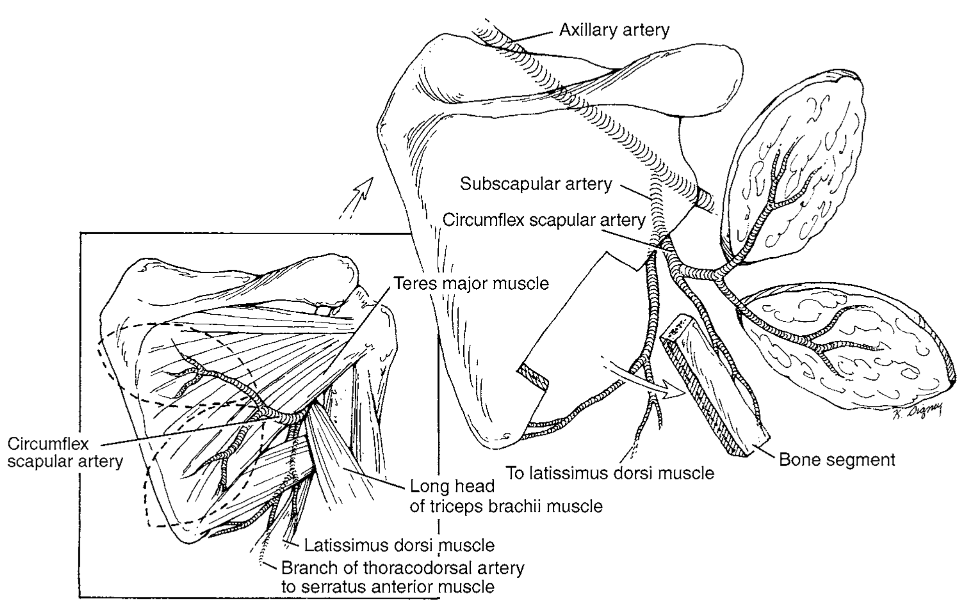

Fig. 19. An excellent depiction of the scapula flap design and harvest.

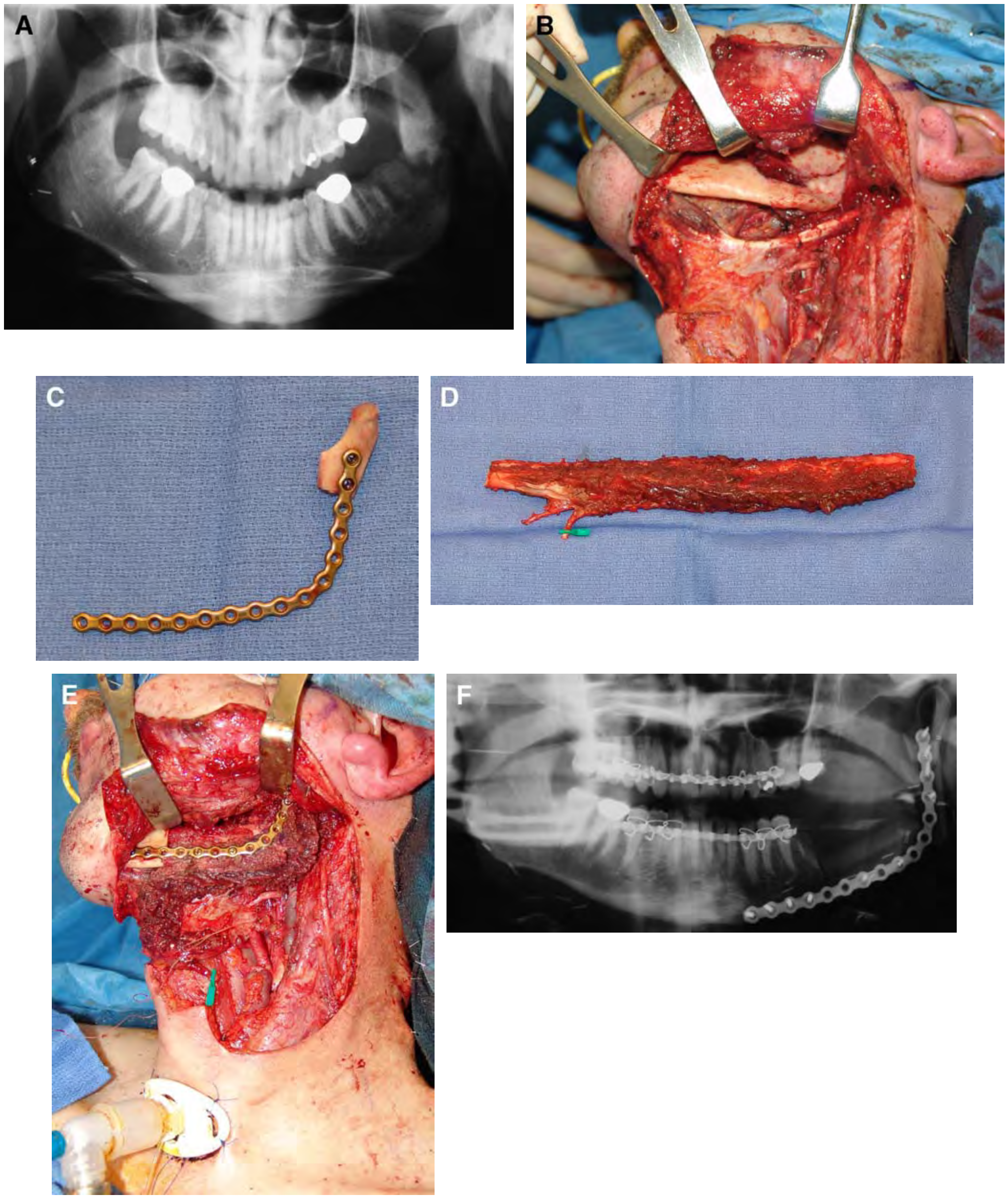

Fig. 20. (*A–F*) The use of a fibula flap in the reconstruction of osteoradionecrosis of the left mandible. The patient was treated with combined modality chemotherapy and radiation for cancer of the base of the tongue. (*A*) Bone destruction on the left posterior body and vertical ramus. (*B*) The character of the tissues and mandible within the radiated field. Note the change in character of the mandible in the mid-body region. (*C*) The extracorporeal adaptation of the healthy native condyle to the reconstruction plate. (*D*) The fibula before osteotomies and flap inset. (*E*) The completed inset of the flap before vascular anastamosis. (*F*) Panorex demonstrates the character of the flap in the early postoperative time frame.

first to allow identification of the vascular pedicle. The inferior margin of the cutaneous flap is incised through skin and subcutaneous tissue down to the level of the fascia overlying the rhomboid and infraspinatus muscles. When the teres major is identified in the course of the dissection, the superior margin of this muscle is followed to the triangular space. The superior margin of the skin paddle is then incised and elevated in a similar manner. Handling of the flap is facilitated by harvesting a small cuff of the fascia overlying the infraspinatus muscle surrounding the cutaneous branches near the vascular pedicle. After elevation of the skin paddles, the bone exposure and osteotomies can be undertaken.

The blood supply to the lateral border of the scapula arises from multiple periosteal branches of the circumflex scapular artery and vein. To preserve these branches, the teres major muscle

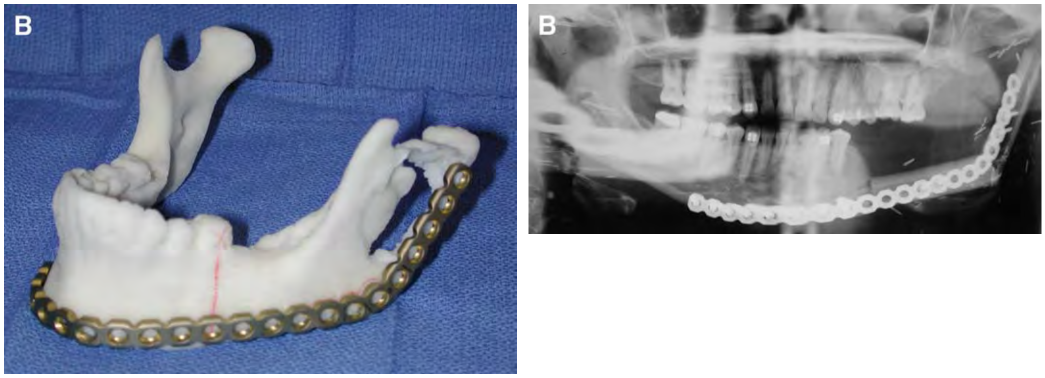

Fig. 21. (*A*) The use of a CAD-CAM model to adapt the reconstruction bar in a case of a hemimandibulectomy, including the articulation of the mandible. (*B*) A panoramic radiograph shows the early postoperative appearance of the flap.

must be transected and a muscle cuff must be included along the lateral surface of the scapula. The latissimus dorsi muscle can be preserved by dissecting it free from the lateral border of the teres major muscle. Once this muscle transection is completed, excellent visualization of the thoracodorsal, angular, and circumflex scapular artery is created. The thoracodorsal artery is ligated and transected (unless the latissimus dorsi muscle is to be included in the flap), as is the angular artery. The proximal dissection of the vascular pedicle is best completed at this time while the structures are stable. The circumflex scapular artery and vein should be isolated to facilitate the later anastomosis of these vessels to acceptable recipient vessels in the neck after flap transfer.

The osteotomies of the lateral border of the scapular are accomplished after dividing the infraspinatus muscled in a longitudinal direction to create a 3-cm muscle cuff along the lateral border. With these muscles retracted, the bone is best cut with an oscillating saw. The tip of the scapula is seldom harvested because of its separate blood supply. The available bone length is approximately 8 cm. After completion of the osteotomies, the bone flap is elevated and the subscapularis muscle is transected with a similar 3-cm muscle cuff to complete the mobilization of the flap. The flap can be harvested with the desired length of vascular pedicle and set aside while the donor site is closed.

The teres major muscle must be repaired via direct suture or sutured to the remaining scapula through drill holes. Either method significantly reduces the function of the muscle. The functions of the teres major muscle include internal rotation, extension, and adduction of the arm. The limitation of these functions remains the primary drawback to the use of this flap. The overlying skin is then advanced and reapproximated over a drain in layers. The operative site is dressed and the patient repositioned for flap inset and vascular reanastomosis.

Clinical examples

Case #1: Lateral mandibular resection for osteoradionecrosis

The patient is a 45-year-old white man who 4 years ago underwent right radical neck dissection and combined modality chemotherapy-radiation therapy for tongue base squamous cell carcinoma. He had undergone extraction of partially impacted third molars 3 weeks before initiation of radiation therapy. The left third molar site never healed, and osteoradionecrosis developed. He received approximately 45 hyperbaric oxygen therapy treatments and numerous courses of antibiotic therapy without resolution before being referred for definitive intervention. Extensive bone destruction was seen on panoramic radiograph. The extent of the diseased mandibular bone can be seen in a preoperative MRI study. The posterior body, angle, and vertical ramus of the mandible clearly are affected. This case illustrates the use of the native

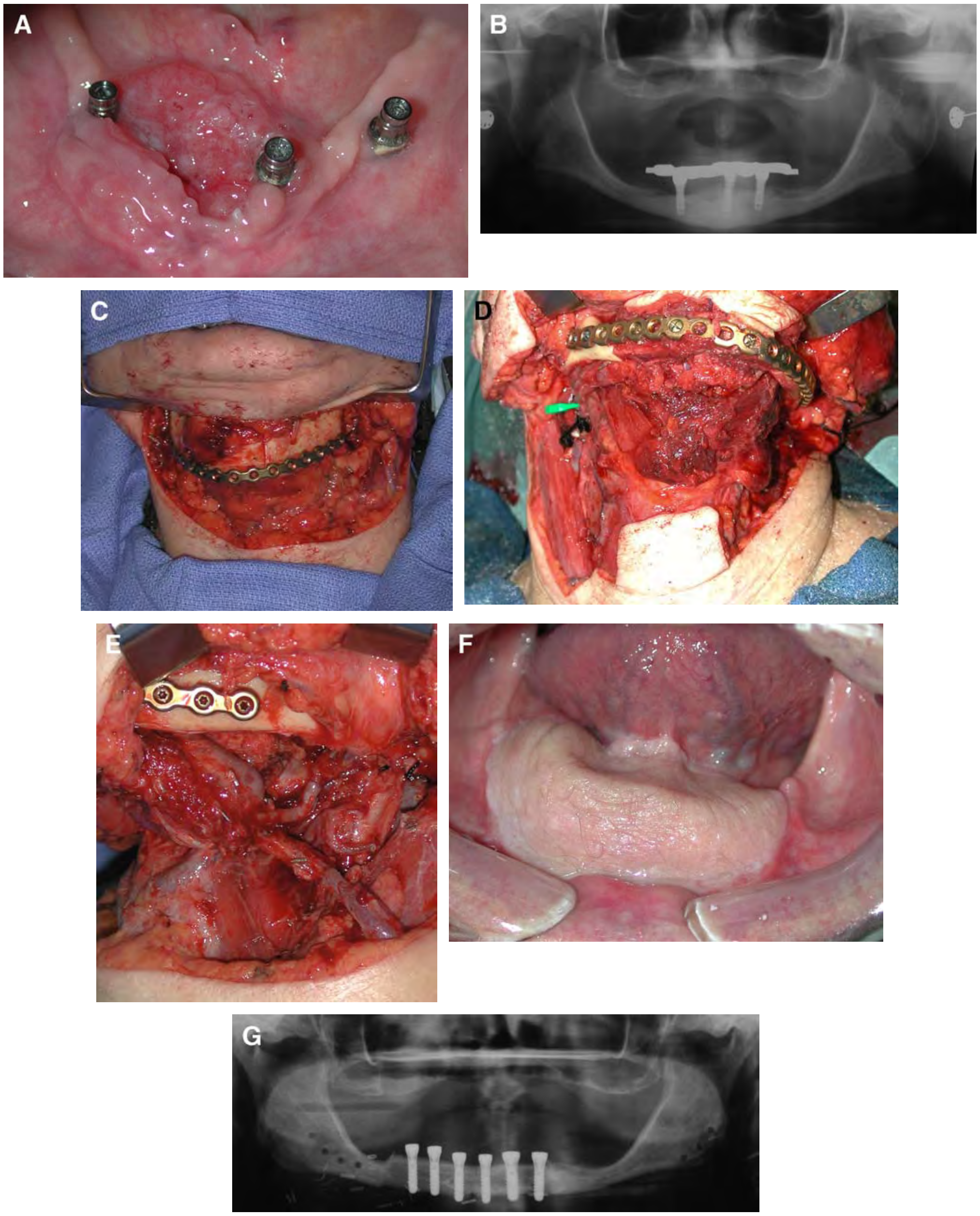

Fig. 22. (*A–G*) The management of an anterior floor of mouth squamous cell carcinoma that infiltrates the mandible. The reconstruction plate was adapted directly to the mandible and removed before resection. Flap inset and reanastomosis are depicted, as is proper vessel geometry (*E*). The skin paddle provides excellent mobility of the tongue, and the fibula is more than adequate to support dental implant-based rehabilitation.

condyle and its articular surface as a graft. The bone plate was placed before resection and removed. The condyle was reattached and the plate replaced (Fig. 20A–F).

Case #2: Vertical ramus and condylar reconstruction: recurrent ameloblastoma

A 25-year-old patient presented with recurrent ameloblastoma that involved the posterior body, angle, vertical ramus, and condyle. This case example demonstrates the use of a microvascular free fibula flap in condylar reconstruction. A computer-generated model was used to prebend the mandibular reconstruction plate. Suspension of the condylar reconstruction is required at the articular fossa. Arch bars and elastic traction help suspend the neocondyle throughout its early healing stages (Fig. 21A, B).

Case #3: Floor-of-mouth squamous cell carcinoma

A 64-year-old woman was referred with a large floor-of-mouth squamous cell carcinoma infiltrating the mandible. This case illustrates adaptation of the 2-mm locking plate before resection, flap inset, appropriate vessel geometry, and the mobility of the skin paddle. Definitive dental rehabilitation was accomplished with endosseous implants. The implants are placed as soon as bone healing is completed or after resolution of the acute effects of radiation therapy (Fig. 22A–G).

Summary

Microvascular free bone flaps are a modern means of restoring bone-containing composite defects of the maxillofacial region. The techniques are simple and reliable. The results are reproducible and offer significant advantages over staged mandibular reconstruction. In particular, these techniques decrease costs and provide a means of rapid definitive reconstruction. Patients avoid multiple surgical procedures with immediate reconstruction that allows them to return to productive lives in society. Proper selection of an appropriate donor site and appropriate preoperative planning facilitate application of these techniques in an expedient manner. Microvascular free bone flap reconstruction should be considered for all patients with composite bone-containing defects of the maxillofacial region.

Further readings

Brown JS. Deep circumflex iliac artery free flap with internal oblique muscle as a new method of immediate reconstruction of maxillectomy defect. Head Neck 1996;18:412–21.

Brown MR, McCulloch TM, Funk GF, et al. Resource utilization and patient morbidity in head and neck reconstruction. Laryngoscope 1997;107:1028–31.

Frodel JL, Funk GF, Capper DT, et al. Osseointegrated implants: a comparative study of bone thickness in four vascularized bone flaps. Plast Reconstr Surg 1993;92:449–55.

Hidalgo DA, Rekow A. A review of 60 consecutive fibula free flap mandibular reconstruction. Plast Reconstr Surg 1995; 96:585–96; discussion 597–602.

Kroll SS, Schusterman MA, Reece GP. Costs and complications in mandibular reconstruction. Ann Plast Surg 1992;29: 341–7.

Sullivan MJ, Baker SR, Crompton R, et al. Free scapula osteocutaneous flap for mandibular reconstruction. Arch Otolaryngol Head Neck Surg 1989;115:1334–40.

Urken ML, Weinberg H, Vickery C, et al. The internal oblique-iliac crest free flap in composite defects of the oral cavity involving bone, skin and mucosa. Laryngoscope 1991;101:257–70.

Vaughan ED. The radial forearm free flap in orofacial reconstruction: personal experience in 120 consecutive cases. J Craniomaxillofac Surg 1990;18:2–7.