# CONTENTS

## FORTHCOMING ISSUES

March 2007

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

September 2007

**Techniques to Treat Snoring and Sleep Apnea**
Mansoor Madani, DMD, *Guest Editor*

## PREVIOUS ISSUES

March 2006

**Implant Procedures**
Michael S. Block, DMD, *Guest Editor*

September 2005

**Autogenous Bone Grafting**
George M. Kushner, DMD, MD, *Guest Editor*

March 2005

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

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Atlas Oral Maxillofacial Surg Clin N Am 14 (2006) vii

Atlas of the Oral and Maxillofacial Surgery Clinics

# Preface


Tirbod Fattahi, DDS, MD Rui Fernandes, DMD, MD
*Guest Editors*

Reconstructive surgery for large ablative defects of the maxillofacial region is an integral part of contemporary oral and maxillofacial surgery. Over the last decade, there have been numerous advances and modifications in techniques and methods used in maxillofacial reconstruction. One of the main breakthrough techniques has been the versatility of microvascular free flap reconstruction. Although there are clear indications for local and regional flaps, as well as free bone grafts, the advent of free flaps has had a tremendous impact on maxillofacial reconstruction.

The intent of this two-volume edition of the *Atlas of the Oral and Maxillofacial Surgery Clinics of North America* is to introduce some of the more common methods for reconstruction of the mandible (volume one) and maxillary reconstruction (volume two) following traumatic avulsion or ablative surgery. Each volume begins with a surgical anatomy of the specific region and is followed by specific methods of reconstruction. Emphasis is placed on all aspects of reconstructive modalities, including local and regional flaps, free bone grafting, microvascular free tissue transfer, and prosthetic rehabilitation.

These two volumes could not have been completed without the hard work and dedication of multiple people, including the various authors who have made invaluable contributions to each chapter. We would also like to acknowledge support from Dr. Richard Haug, Consulting Editor of the *Atlas of the Oral and Maxillofacial Surgery Clinics of North America*, and Elsevier/Saunders. Last, we would like to thank our families, Julia Fattahi, Candace Fernandes, Layla Fattahi, and Gabriela Fernandes, for their endless support, love, and everyday sacrifices that allow us to pursue and complete this endeavor.

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Atlas of the Oral and Maxillofacial Surgery Clinics

# Surgical Anatomy of the Mandibular Region for Reconstructive Purposes

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## Surgical anatomy of the mandibular region for reconstructive purposes

In the current era of contemporary reconstruction of the mandible, microvascular free tissue transfer is the method of choice for large bony and soft tissue defects. As outlined in various articles in this *Atlas*, there are other reconstructive modalities, such as pectoralis major myocutaneous flap and costochondral free grafts. Regardless of the method of reconstruction, the surgical anatomy of the perimandibular region remains unchanged. It is imperative that the reconstructive surgeon be familiar with this anatomy and particular areas of interest as they relate to the microvascular anastomosis. This article reviews the clinically relevant anatomy of the upper neck and the submandibular triangle, with emphasis on surgical pearls of each region.

## Fascia of the perimandibular region

There are two basic fascias of the upper neck and the perimandibular space: superficial and deep (Fig. 1). The superficial fascia is the fibrofatty layer just deep to the dermal plexus of skin. This superficial fascia (superficial cervical fascia) overlies the platysma muscle and is continuous with the superficial fascia of the face between the inferior border of the mandible and the zygomatic arch known as the superficial musculo-aponeurotic system. The function of this fascia is to prevent propagation of superficial infections to the deeper structures.

Just deep to the platysma muscle is the most superficial layer of the deep fascia of the neck. There are many names for this fascia, which only adds to the confusion for the reader. The most commonly used and appropriate names for this fascia include superficial layer of the deep cervical fascia (SDCF) and the investing fascia of the neck. This fascia is of clinical significance when performing mandibular reconstruction. This fascia completely encircles the neck and, in doing so, envelopes the sternocleidomastoid and trapezius muscles on both sides. The SDCF also forms the capsule of the submandibular gland; as it travels onto the face, the name changes to the parotido-masseteric fascia, the deep fascia of the face that comprises the fascia (capsule) of the parotid gland. The SDCF contains the marginal mandibular and cervical branches of the facial nerve and the facial artery and vein. There is a specific anatomic relationship between these structures that is discussed later.

Just deep to the SDCF exists the middle layer of the deep cervical fascia (MDCF). This fascia is also known as the pretracheal (a misnomer, because it actually encircles the trachea completely) or visceral fascia and contains the buccopharyngeal fascia as one its more cephalad components. The middle layer of the deep cervical fascia encircles the trachea, esophagus, thyroid, and parathyroid glands of the neck. This fascia is encountered during a tracheostomy as the last layer before entering the trachea.

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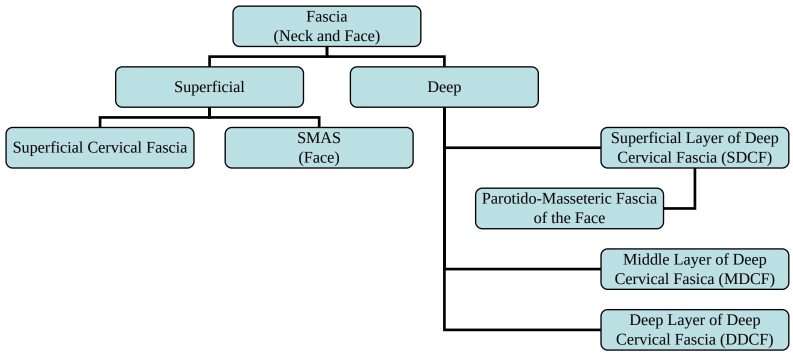


Fig. 1. Fascia of the neck and lower face.

Deep to the middle layer of the deep cervical fascia is the deep layer of the deep cervical fascia. This fascia includes the alar and prevertebral fascia, which run between the carotid sheaths and the prevertebral space, respectively. This fascia is rarely encountered during mandibular reconstruction.

## Submandibular triangle

Perhaps the most important of all cervical triangles when performing mandibular reconstruction, the submandibular triangle is bounded by the inferior border of the mandible superiorly, the anterior belly of the digastric muscle anteriorly, and the posterior belly of the digastric muscle posteriorly. The common tendinous ring of these two muscles forms the inferior border, and the floor (deep) aspect of the triangle is formed by the mylohyoid muscle. The roof or the most anterior surface of this surgical space is the SDCF, just deep to the platysma.

## Structures within the submandibular triangle

The submandibular gland is the largest structure within the submandibular triangle (Figs. 2, 3). Comprised of the superficial and deep parts, it is located between the anterior and posterior

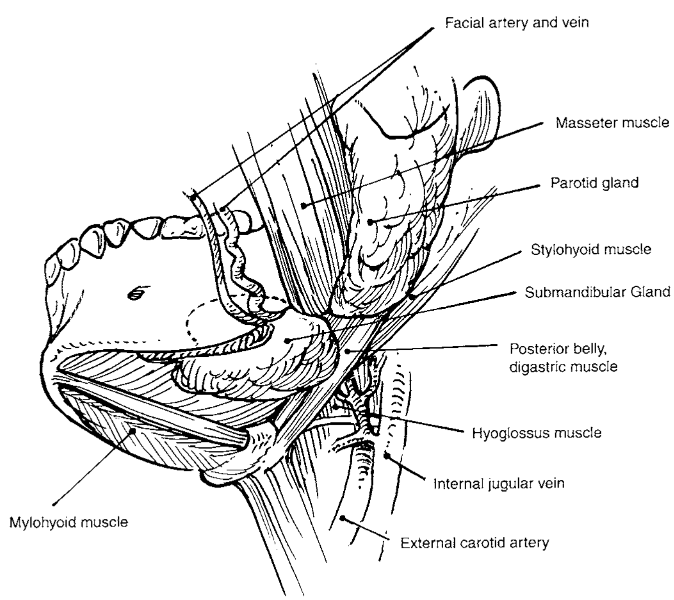


Fig. 2. Lateral view of the submandibular triangle. *From* Miloro M. The surgical management of submandibular gland disease. Atlas Oral Maxillofac Surg Clin North Am 1998;6(1):29–50; with permission.

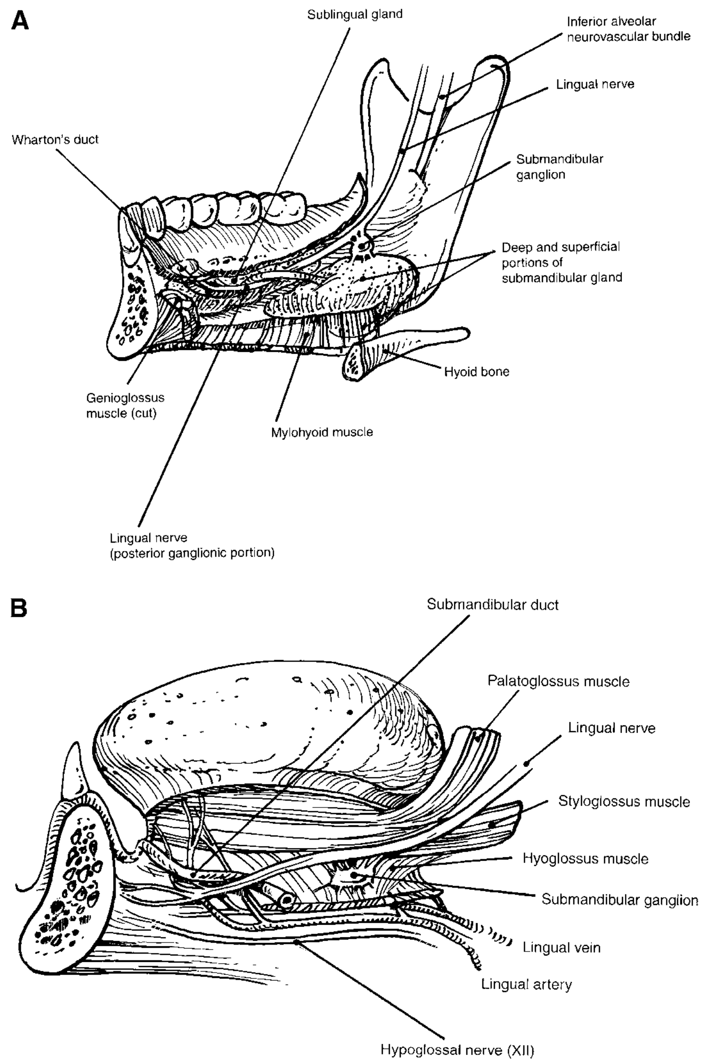


Fig. 3. (A, B) Medial views of the submandibular triangle. *From* Miloro M. The surgical management of submandibular gland disease. Atlas Oral Maxillofac Surg Clin North Am 1998;6(1):32; From Karas ND. Surgery of the salivary ducts. Atlas Oral Maxillofac Surg Clin North Am 1998;6(1):101.

bellies of the digastric muscle, lateral and medial to the mylohyoid (superficial and deep lobes) muscle. It is just deep to the platysma and is covered by the SDCF, which forms the capsule of this gland. The submandibular duct (Wharton's duct) is a 5-cm extension of the posterosuperior portion of the gland, which runs along the posterior and superior aspect of the mylohyoid muscle to enter the sublingual space. The Wharton's duct passes over (superior) to the lingual nerve in the sublingual space. The twelfth cranial nerve, the hypoglossal nerve, is located at the base of the submandibular triangle and runs superficial to the hyoglossus muscle, approximately 2 cm cephalad to the bifurcation of the common carotid system. This nerve is seen easily after a submandibular sialoadenectomy by retracting the anterior belly of the digastric muscle inferiorly and the mylohyoid muscle medially. It is often necessary to remove the submandibular gland during mandibular reconstruction to facilitate inset of the free tissue transfer (Figs. 4, 5). It is ideal to preserve the facial vessels if possible during this procedure for microvascular anastomosis.

The facial artery may come off the external carotid system as an independent artery or off a common trunk along with the lingual artery before dividing. The artery runs deep to the posterior belly of the digastric muscle and runs through the deep portion of the submandibular gland before exiting and coursing over the inferior border of the mandible in a superior and anterior direction. (In fact, no vessel of clinical significance is found superficial to the posterior belly of the digastric muscle.) On the other hand, the facial vein runs superficial to the

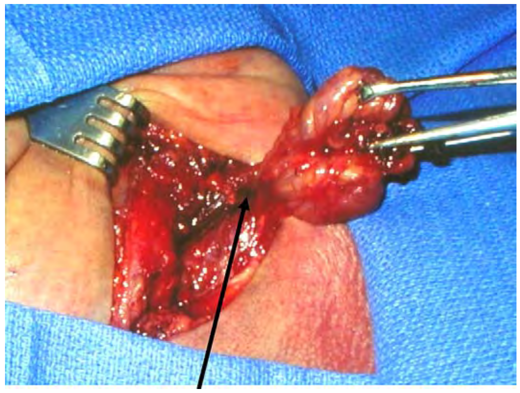

Fig. 4. Removal of the submandibular gland. Arrow points to the Wharton's duct.

submandibular gland and joins the posterior facial vein to form the common facial vein before emptying into the internal jugular vein deep to the sternocleidomastoid muscle.

The marginal mandibular branch of the facial nerve courses in a particular pattern in the perimandibular space. Once it divides from the cervicofacial trunk, the marginal mandibular nerve runs deep to the SDCF, just deep to the platysma. In most instances, this nerve is found cephalad to the inferior border of the mandible, although when it is inferior to the inferior border, it is usually within 1 to 2 cm of the mandible. The marginal mandibular branch is most often located posterior to the facial vessels running in an arc-like fashion superficial (lateral) to the facial vein on its way to innervate the lower lip depressor muscles. Motor nerves found anterior to the facial vessels typically innervate the platysma rather than the lower lip depressors.

During surgical exposure of the submandibular triangle, the facial nerve can be identified easily and protected. An alternative method of protecting the nerve without actually locating and identifying it performing a Martin-Hayes maneuver. The facial vein is identified proximally as it enters the common facial vein (Fig. 6). The vein is ligated just above this level and the suture tie is left long so that it can be retracted superiorly. Because the marginal mandibular branch runs superficial (lateral) to the facial vein, as the surgeon retracts the suture tie superiorly, the nerve is retracted safely from the surgical field.

## Structures outside of the submandibular triangle

Although most of the pertinent anatomy for mandibular reconstruction pertains to the submandibular space, other surgically important landmarks are relative to reconstructive purposes. Just deep to the submandibular triangle and at the posterior aspect of the mylohyoid

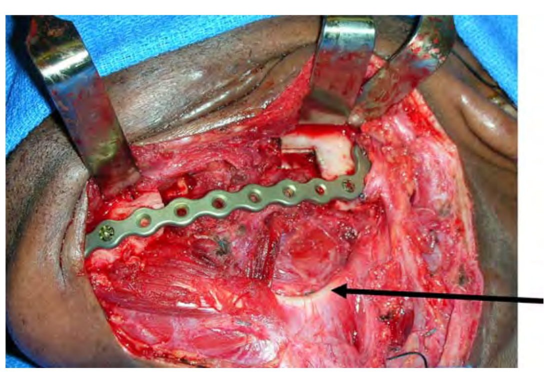

Fig. 5. Surgical site after mandibular resection, application of reconstruction bar, and removal of submandibular gland to facilitate inset of a microvascular free flap. Arrow points to the intermediate tendon of the digastric muscle.

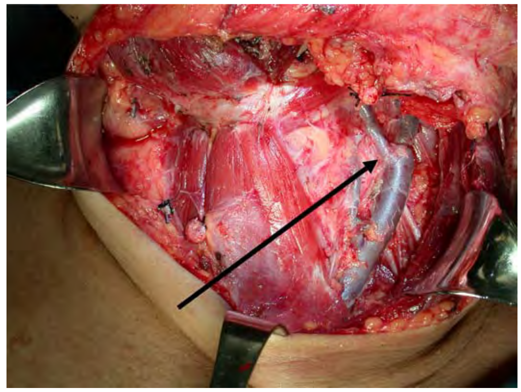

Fig. 6. Origin of the common facial vein (*arrow*). Ligation of the vein at this level and retraction in a superior direction protects the marginal mandibular branch of the facial nerve (Martin Hayes maneuver).

muscle, the hyoglossus muscle runs from the superior aspects of the hyoid bone to insert on the lateral aspect of the tongue. On the superficial (lateral) aspect of this muscle is the hypoglossal nerve. Deep to the muscle is the lingual artery that courses from the external carotid artery in a superior and medial direction toward the tongue. The confluence of three structures on the superficial aspect of the hyoglossus muscle comprises the Lesser's triangle: the twelfth cranial nerve, the anterior belly of the digastric and the posterior belly of the digastric muscle, and their intermediate tendon (Fig. 7). Access to the lingual artery through this triangular space can be obtained with blunt dissection. Although microvascular anastomosis to the lingual artery for mandibular reconstruction is possible, because of the lack of adequate access, this artery may not be the artery of choice. The lingual artery also can be ligated through this triangle in cases of severe bleeding from the tongue or sublingual space.

Inferior and posterior to the hyoid bone, one finds the superior thyroid artery (Fig. 8), which is typically the first or second branch off the external carotid artery. This artery travels in an inferior and anterior direction and loops deep to the omohyoid muscles before piercing the middle layer of the deep cervical fascia and entering the superior pole of the thyroid gland. The significance of this artery is its common use for arterial anastomosis during microvascular free tissue transfer, when the facial artery has been sacrificed. There are two branches of this artery before entering the thyroid gland: the superior laryngeal branch, which passes between the hyoid bone, the thyroid cartilage, which supplies the larynx, and the sternocleidomastoid branch, which supplies the muscle.

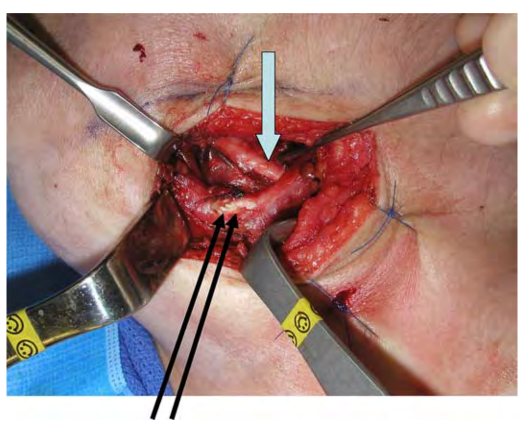

Fig. 7. Lesser's triangle. Double arrow points to the intermediate tendon of the digastric muscle. Wide arrow points to the hypoglossal nerve coursing over the hyoglossus muscle.

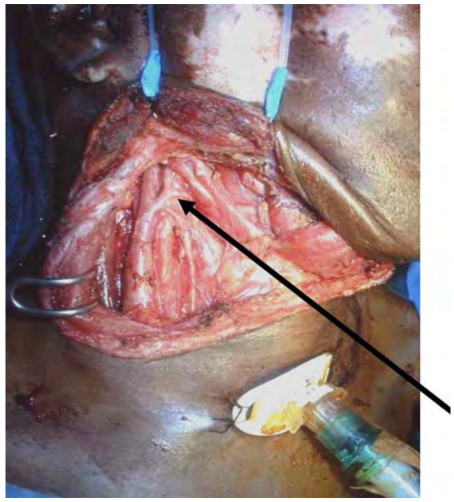

Fig. 8. Origin of the superior thyroid artery off the external carotid system. Arrow points to the origin of the vessel.

## Summary

Regardless of the reconstructive modality, one must be familiar with the pertinent anatomy of the perimandibular space. The contents of the submandibular triangle, the neurovascular relationship, and the fascial lay out of this region are unique. Familiarity with these anatomic structures should facilitate reconstruction of the mandible.

## Further readings

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# Fibula Free Flap in Mandibular Reconstruction

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Mandibular reconstruction continues to be one of the most common surgical challenges faced by oral and maxillofacial surgeons. Coupled with the complex demands of mandibular reconstruction are the public expectations of an expeditious reconstruction, which often translates into a single stage resection and reconstruction. Gone are the days when patients tolerated resections without reconstruction and, to a degree, multiple stage reconstructions.

The advent of microvascular surgery has catapulted the reconstruction of complex head and neck defects to a single stage reconstruction. This technique allows for larger resections and reconstruction, which allows patients to return to normal function in a much shorter period when compared with multistage local, regional pedicled flaps and nonvascularized free bone grafts. Multiple studies have shown the clear superiority of microvascular reconstruction of the mandible when compared with "traditional" methods.

Although the use of microvascular techniques has been around for nearly 20 years, it still has struggled to gain acceptance by American oral and maxillofacial surgeons. This lack of acceptance may be caused primarily by a lack of training in microvascular surgery.

The options for bony free-tissue transfer for mandibular reconstruction primary rest on the fibula, iliac, scapula, and to a much lesser degree, the radius bone. The radial osseocutaneous free flap is seldom used currently because of the lack of bone height and width of the radius and the accompanying morbidity of high rate of fracture of the forearm. The scapula flap is not commonly used for mandibular reconstruction because of the thin bone stock and the inability to tolerate multiple osteotomies. Another significant disadvantage of the scapula flap is the inability to have a two-team approach because of the proximity to the head and neck and the need to turn the patient.

A significant advantage of the scapular flap is that it may be harvested as separate bone and skin/muscle paddles, which allows for its use in complex reconstructions. The iliac crest can provide a large bone stock and muscle and skin for tissue coverage. The main disadvantage of this flap is its short vascular pedicle, which often necessitates a vein graft to increase the pedicle length to carry out the anastomosis.

The fibula free flap continues to be the gold standard and the workhorse flap in the reconstruction of mandibular defects. The advantages of the fibula free flap over other microvascular free tissue flaps include its consistency and uniformity in width and length, its pedicle length and vessel diameter, and the ability to incorporate a skin or muscle component with the flap. The location of the fibula away from the head and neck also allows for a simultaneous two-team approach, which shortens the operative time.

The goals of mandibular reconstruction are not only to re-establish the continuity of the mandible but also to restore function. The return of function entails speech, swallowing, and chewing. To that end, the fibula provides the bony platform for eventual prosthetic rehabilitation of the patient, whether that involves the placement of intraosseous dental implants or conventional dentures.

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## Preoperative assessment

The clinical assessment of the potential fibula free flap candidate involves a thorough assessment of the patient. The suitability of the fibula is based on the perfusion status of the lower extremity and the foot. The clinician should look for signs of previous surgery or trauma and assess the skin temperature, hair growth, and thickening of the nail beds for any evidence of peripheral vascular disease. The evaluation of the lower extremity vasculature has evolved from the use of angiography to less invasive studies, such as color Doppler examination, CT angiography, and magnetic resonance angiography. Although some clinicians advocate only clinical examination of the lower extremity before flap harvesting, magnetic resonance angiography is the author's preferred method of assessment. This examination is important not only to confirm adequate perfusion of the lower extremity but also to confirm the presence of the peroneal artery and rule out the presence of peroneal arterial magna, in which the peroneal artery is the main blood supply to the foot. This variation has been reported to range from 0.2% to 7%.

An evaluation of the anticipated mandibular defect should be undertaken. This study is commonly done with the aid of a panoramic radiograph and CT of the mandible. In oncologic cases a detailed discussion with the ablative surgeon is of utmost importance so that the reconstructive surgeon can have an appreciation of the anticipated defect size and tissues to be replaced. The author uses a critical size defect in the range of 4 to 5 cm as a minimum cutoff for use of the fibula free tissue flap.

Equally as important is the evaluation of the recipient vessels in the head and neck. The recipient vessels most commonly used when reconstructing the mandible are the facial artery and vein. Alternatively, the superior thyroid artery, the external jugular vein, and the internal jugular vein may be used as the recipient vessels. The decision as to which vessel to use depends on the most ideal geometry and the best match of the vessel diameter.

The determination of available recipient vessels is of critical importance in patients who have had previous neck surgeries, especially in patients who have undergone neck dissection. In these cases the operative dictations must be obtained to ascertain the extent of resection and the vessels resected or ligated.

## Raising a bone-only flap

After the patient is transferred to the operating table, the hip and knee are flexed and internally rotated so that the fibula is approximately at a 140° angle to the table. A 1-L saline bag wrapped in a towel is placed under the feet and taped to the bed, and a small bump is placed under the ipsilateral hip so that this desired position is maintained in a passive fashion. The lower extremity is prepared and draped in the usual standard fashion. The head of the fibula is palpated and marked, as is the lateral malleolus inferiorly. The peroneal nerve is palpated and marked. A vertical line connecting the two points is then marked (Fig. 1). The vertical mark

Fig. 1. Fibula markings before harvesting. Note the proximal and distal bone left to ensure knee and ankle stability.

Fig. 2. Incision carried down to fascia. Note the peroneus longus muscle (*arrow*).

represents the intermuscular septum. A sheet of web roll is wrapped around the thigh and a tourniquet is placed over it. Before inflating the tourniquet, the leg is exsanguinated using an eshmark bandage. The tourniquet is inflated to 350 mm Hg.

A skin incision is made that extends from approximately 6 cm inferior to the head of the fibula to the lateral maleolus region. The incision is carried down to the fascia and exposes the peroneous longus muscle (Fig. 2). Dissection is continued under the fascia of the lateral compartment in a posterior direction toward the septum. At this point the muscle is retracted and raised off the fibula from a posterior to anterior direction until the anterior edge is reached (Fig. 3). The anterior crural septum is then incised and the tissue reflected to give access to the anterior compartment. The anterior tibial artery and vein and the nerve are identified and preserved with gentle retraction (Fig. 4). Dissection is continued toward the interosseous septum. Once the septum is reached, it is incised and the posterior tibialis muscle is identified. This muscle is noted for the chevron appearance of its fibers. Dissection is then directed posteriorly and the soleus and flexor hallucis longus muscle are reflected off the fibula. With the aid of curved periosteal elevators, the periosteum is dissected approximately 8 cm above the inferior head of the fibula. This dissection is done carefully so as not to injure the peroneal vessels that run intimately close to the fibula on its medial aspect. Once the retractors are placed and visualized circumferentially, an osteotomy is made and repeated approximately 1 cm above. The intervening free bone segment is removed and the peroneal pedicle identified directly under the posterior tibialis muscle. The pedicle is ligated and divided. A single osteotomy is made superiorly approximately 8 cm below the head of the fibula. Once this osteotomy is completed the fibula is able to be rotated laterally, which allows for a better dissection of the pedicle. The dissection is extended from inferior to superior while taking care to identify and ligate branches from the pedicle. Once the takeoff of the peroneal artery is reached at the junction of the posterior tibial artery, the artery and the committals veins are isolated and the tourniquet is deflated (Fig. 5).

Hemostasis is achieved while the flap is allowed to reperfuse for approximately 30 minutes before harvesting and transferring to the head and neck.

## Raising an osteoseptocutaneous flap

The raising of the fibula osteoseptocutaneous flap is slightly different from the bone-only flap because the dissection must incorporate the skin island flap. The initial marking of the flap

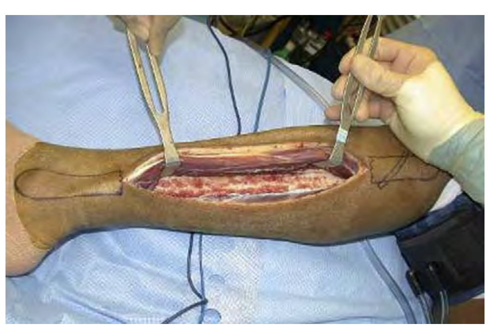

Fig. 3. The peroneus longus muscle has been reflected off the fibula.

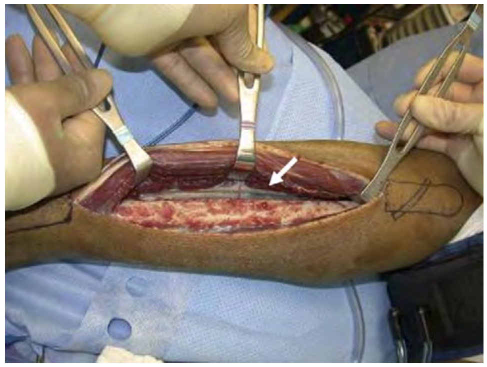

Fig. 4. The anterior compartment has been entered, and the anterior tibial artery, vein, and deep peroneal nerve are visualized (*arrow*). Gentle retraction is used to reflect the contents away.

Fig. 5. Reflected and mobilized fibula. Note the pedicle running superiorly (*inset* and *arrow*).

incorporates the necessary island of skin to be harvested. The skin island is placed at the junction of the middle and lower third of the fibula, because skin perforators are of greater caliber in this region, particularly the septocutaneous perforators. The placement of the skin island can be facilitated with a Doppler image of the skin perforator before designing the skin paddle.

Once the incision is made and carried to the fascia, a subfascial dissection is directed out toward the intermuscular septum. At this point, attention is directed at identifying perforators to be incorporated on the skin flap. If the skin island is not centered over the perforators, the skin paddle can be readjusted to incorporate the perforators in a more ideal fashion. The elevation is the same until the posterior dissection is reached. The posterior aspect of the skin island is incised with careful attention to incorporate the perforators. In cases in which the perforators are tenuous, a cuff of the soleus and flexor hallucis longus muscle is incorporated to capture the musculocutaneous perforators to the skin paddle. The remainder of the flap elevation is the same as previously described (Fig. 6).

Closure of the fibula donor site is done by loose reapproximation of the muscles. Some clinicians advocate that the flexor hallucis longus muscle be sutured to the tibialis posterior muscle and the remaining interosseous membrane to preserve great toe flexion. The muscle closure is over a drain. The skin defect is grafted by harvesting a split-thickness skin graft from the thigh and transferring to the donor site (Fig. 7). A bolster dressing may be placed followed

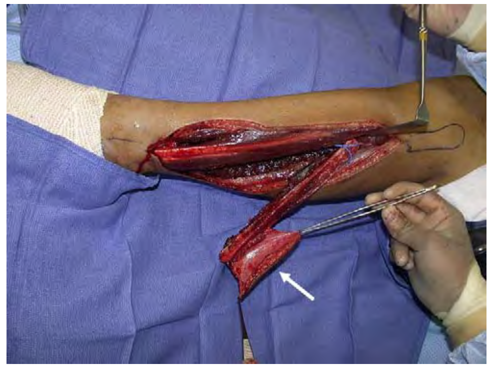

Fig. 6. Raising of a fibula osseocutaneous flap. Note the skin paddle component of the flap (*arrow*).

by posterior splint. The leg is then elevated to decrease edema. The cast and bolster dressing are removed approximately 6 days later. The patient is then allowed to return to function with the aid of physical therapy.

## Osteotomy of the fibula

Once the fibula is harvested, the flap is transferred to the head and neck, where the recipient site had been prepared (Fig. 8A, B). In cases in which only a straight segment is needed, the preparation is straightforward (Fig. 8C–F). When the bony segment to be replaced necessitates that either a single or multiple osteotomies of the fibula be made, the author uses a flexible plastic ruler to aid in measuring and planning the closing osteotomies. Once the segment is measured, a triangular segment is removed so as to give the necessary closing of the fibula bone to recapitulate the native curves of the mandible. Before performing the osteotomy, the periosteum is incised and elevated, and the pedicle is protected with periosteal elevators.

The insetting of the fibula is usually performed by placing a single screw from the reconstruction bar into each fibula segment. Optimization of the height differential between the native mandible and the fibula in selected patients may be achieved by placing the fibula approximately 1 cm superior to the inferior border of the mandible. This technique may take away from the ideal facial contour. An alternative method to increase the bony height of the fibula to improve the placement of dental implants is to perform a double-barrel fibula placement, which improves the height at the cost of decreasing the pedicle length.

The remaining steps of the inset are done by arranging the most appropriate geometry of the pedicle, and then the anastomosis of the vessels is performed under the microscope using 9-0 nylon sutures (Fig. 9A–H).

## Complications

The use of microvascular free tissue transfer carries with it the possibility of flap loss caused by vessel thrombosis. The incidence of total flap loss, however, is less than 5% when the

Fig. 7. Closure of the donor site with placement of a split-thickness skin graft.

procedure is performed by experience practitioners. Regarding the fibula flap, it is important to be cognizant of the skin perforators when performing an osteoseptocutaneous flap. The incorporation of adequate perforators and the addition of a cuff of the flexor hallucis longus lessen the occurrence of the loss of the skin paddle. Importantly, when closing the donor site primarily, one must be cognizant of the potential for the development of a compartment syndrome postoperative and monitor the patient accordingly. Other complications associated with the fibula flap are ankle stiffness, mild ankle instability, personal motor weakness, sensory

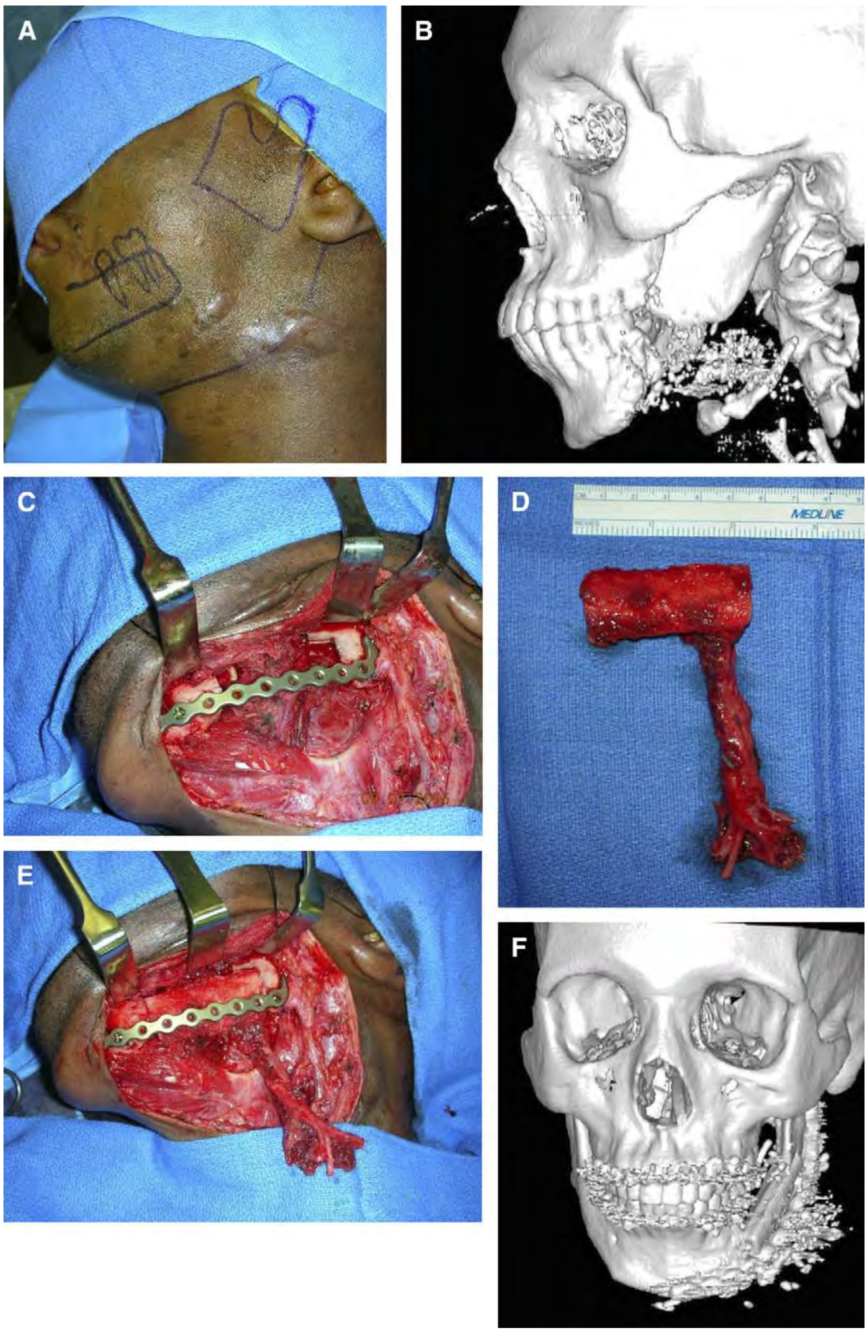


Fig. 8. (*A*) Skin markings with planned incisions. (*B*) A three-dimensional CT scan shows a segmental mandibular defect of the mandible. (*C*) Mandibular defect with reconstruction bar in place. (*D*) Prepared fibula bone flap before inset. (*E*) Inset of fibula bone segment into the mandibular defect before securing the graft and anastomosis. (*F*) Postoperative three-dimensional CT scan. Note the inset fibula and the adequacy of the width of the fibula for osseous implant placement.


Fig. 9. (*A*) Patient s/p gun shot wound to face. Note the extensive soft tissue and bony defect. (*B*) Harvesting of osseomyocutaneous fibula flap to reconstruct defect using the principle of replacing "like with like" tissue. (*C*) Harvested osseomyocutaneous fibula free flap before contouring. (*D*) Inset of flap into the defect site after two closing osteotomies. Note the position of the skin and muscle flap to reconstruct the missing tissues in the submental region. (*E, F*) Closure of skin flaps. Note the recapitulation of the normal lower facial contour and projection. (*G*) Three-dimensional CT scan of the reconstructed mandible shows the inset of the fibula with the closing midline osteotomy. Note excellent bone width and height for the eventual placement of dental implants. (*H*) Facial appearance of patient at 1 week after reconstruction.

loss, and inability to run. Patients should expect to return to normal function with significant decrease in pain at approximately 5 to 6 weeks postoperatively.

## Further readings


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Atlas of the Oral and Maxillofacial Surgery Clinics

Atlas Oral Maxillofacial Surg Clin N Am 14 (2006) 151–159

# Deep Circumflex Iliac Artery Free Flap in Mandible Reconstruction

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Comprehensive reconstructive strategies require the restoration of facial dimensions, including width, height, and projection. To achieve optimal functional and aesthetic results, reconstructive surgeons must be able to replace the skeletal buttresses, restore the external/internal soft tissue envelope, eliminate fistulas, and provide a foundation for dental rehabilitation. Restoration of mandibular architecture is essential to the balance and symmetry of the face. The geometric design of the inferior border of the mandible defines the aesthetic contour of the lower third of the face. This horizontal buttress or mandibular plane defines a soft tissue cephalometric parameter formed by a line that connects menton to gonion. Preservation of the normal physical appearance requires osseous reconstruction and restoration of the soft tissue mandibular plane contour. Functional restoration of the mandibular construct is essential for proper deglutition and speech. Replacement of the dentoalveolar segment allows for ideal placement of endosteal implants and eventual rehabilitation with an implant-borne prosthesis at the level of the occlusal plane.

Historically, mandibular defects have been managed in a multistaged fashion with local and pedicled flaps combined with nonvascularized autologous bone grafts (rib, cranium, and ilium). This approach is practical for osseous defects that measure less than 6 cm but it is still overwhelmed with a predictable amount of resorption. The introduction of free tissue transfer techniques revolutionized the field of reconstructive surgery and established the gold standard in mandibular reconstruction by allowing restoration of composite defects in a single stage. Vascularized bone grafts address the problems associated with bone graft resorption by transferring viable osteocytes and osteoblasts and allowing primary bone healing rather than healing by creeping substitution. Vascularized bone grafts also provide a reliable medium for osseointegrated implants and allow surgeons to tackle previously overwhelming defects with much greater success.

The four major sources of vascularized bone routinely used for craniofacial reconstruction include the fibula, ilium, radius, and scapula. Each source of bone has its own set of inherent advantages and limitations. With respect to dental implants, the fibula and iliac crest reliably provide adequate bone width and height when compared with the scapula and radius. The fibula has proved reliable in managing composite mandibular defects in one stage. Advantages of the fibula flap include a long pedicle length, adequate bone stock, and minimal donor site morbidity. It also allows a two-team approach. The fibula bone flap is limited by its inherent height discrepancy compared with the native mandible. This deficiency makes it less than ideal for restoring the alveolar height at the level of the occlusal plane and mandibular contour

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simultaneously. Placement of the fibula flap at the inferior border of the native mandible yields excellent skeletal and soft-tissue contour but results in implant overloading, which compromises long-term success.

Vascularized iliac bone flap is ideal for the simultaneous reconstruction of a mandibular contour deformity and the dentoalveolar defect. The iliac bone, as compared with the fibula bone, is dramatically thicker and is composed primarily of cancellous bone and bares a striking resemblance to the mandible with regards to shape and contour of the body and angle. Advantages of the iliac bone flap include a superior bone stock (width, length and height) and minimal donor site morbidity. It also permits a simultaneous two-team approach. One potential disadvantage of the iliac crest flap is its short pedicle of 4 to 5 cm, which requires vein grafts when the recipient vessels are not in proximity.

The most reliable periosteal and endosteal blood supply to the iliac bone is from the deep circumflex iliac artery and vein (DCIA and DCIV). The DCIA originates from the external iliac artery cephalad to the inguinal ligament and courses toward the ilium between the transversalis and iliacus fascia to a point 10 cm posterior to the Anterior Superior Iliac Spine (ASIS). Along this path it gives off the ascending branch and osseous perforators (Fig. 1). This pedicle also supplies the adjacent skin via musculocutaneous perforators that pass through the abdominal musculature (Fig. 2). Although the SCIA and SCIV provide predictable blood flow to the adjacent groin skin, the blood supply to the bone is unreliable. The iliac bone may be harvested well into the pelvis to obtain ample bone height and vascular pedicle length. The ascending branch of the DCIA is the vascular pedicle to the internal oblique muscle, which is a thin broad muscle of the anterior abdominal wall that lies between the external oblique and transversus abdominis muscles (Fig. 3). The inclusion of this branch and its associated muscle make it possible to harvest a composite flap that contains muscle, bone, and skin based on the DCIA and DCIV.

In the Western hemisphere the skin of the iliac flap tends to be bulky because of the thickened adipose layer of a more obese population, which limits its use for intraoral resurfacing. The skin may be excluded in cases that only require replacement of mucosa and bone. The denervated internal oblique muscle relines the oral cavity and allows it to contract and become epithelialized over 2 to 3 weeks, which provides a good interface for an implant-borne prosthesis or traditional dentures and obviates the need for later debulking. In cases in which the mandibular defect exclusively involves skin and bone (not requiring internal oblique muscle

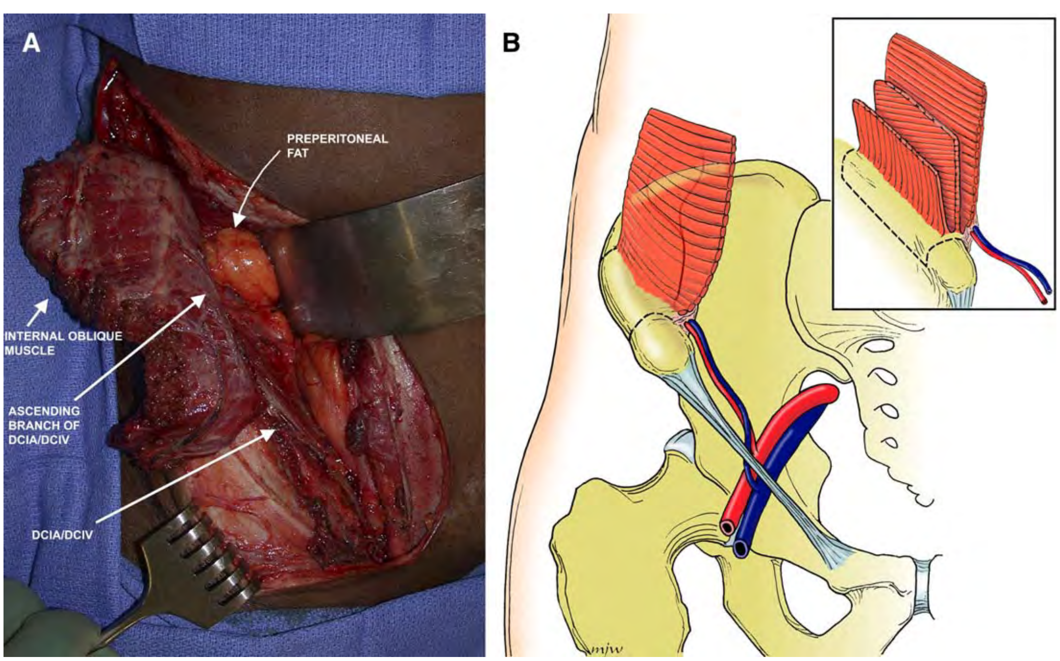


Fig. 1. (*A, B*) Intraoperative photograph and diagram of the deep circumflex iliac vessels and ascending branch to internal oblique muscle.

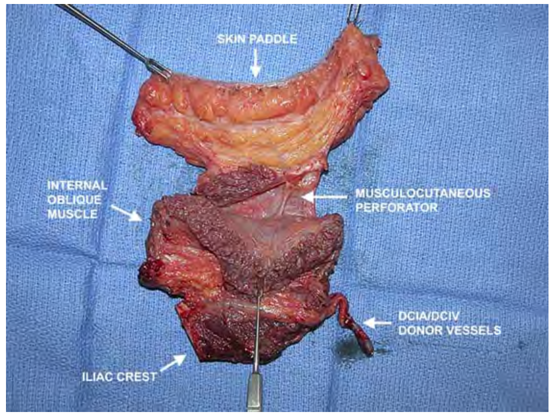


Fig. 2. The harvested flap with a dominant musculocutaneous perforator.

for mucosal replacement), the iliac bone may include a portion of skin as a perforator flap. Retrograde dissection of the skin flap based on a musculocutaneous perforator provides exclusion of the added bulk provided by the external oblique, internal oblique, and transverses abdominis muscles.

## Treatment planning

A precise preoperative evaluation provides information regarding dimensions of the soft and hard tissue defect and deficient alveolar dimensions. Evaluation of the dimensions of the mandibular defect may be analyzed precisely by obtaining clinical photographs, facial moulage, dental impressions, three-dimensional CT, or stereolithographic models. The relationship of the maxilla to the mandible in centric occlusion may be recorded and mounted on an articulator. With improvements in CT software, precise measurements of height and length of the defect may be made preoperatively (Fig. 4). A dental model also facilitates prefabrication of a template, which may be sterilized and used intraoperatively (Fig. 5). The preservation of the occlusal relationship between the maxilla and the neomandible is crucial for future dental rehabilitation.

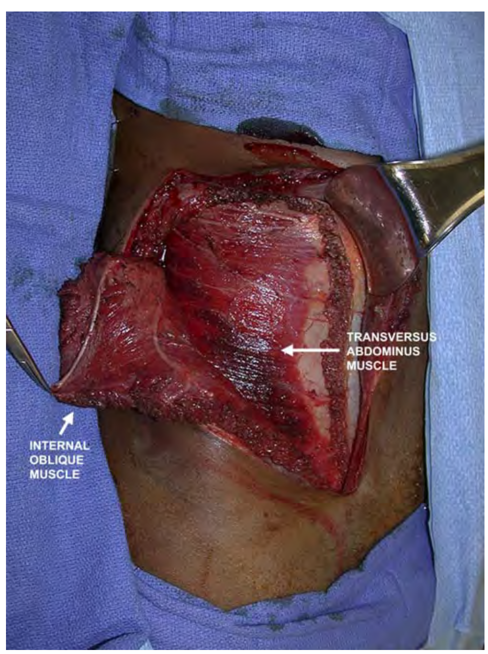


Fig. 3. Elevation of the internal oblique muscle with preservation of the transversus abdominis muscle.

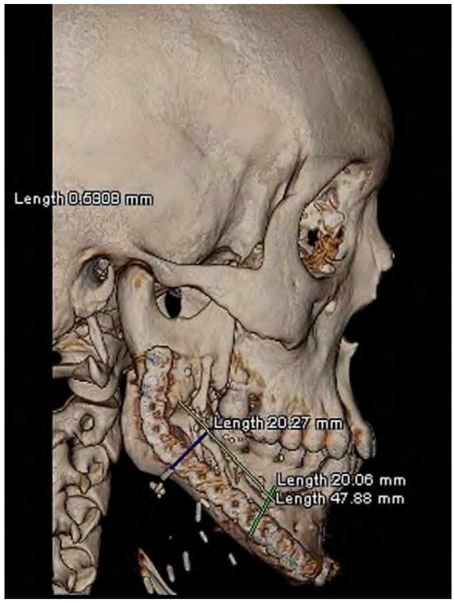


Fig. 4. Three-dimensional CT with measurements of the mandibular defect.

Microsurgical reconstruction of the head and neck region also requires careful preoperative assessment of recipient vessels, including the regions of the superficial temporal, facial, and neck vessels (ie, external carotid branches). This assessment may be performed clinically by observation and palpation, avoiding the potential need for vein grafts because their use increases the incidence of thrombosis. When designing the flap, one must take into account the natural curvature of the ilium and the location of the recipient vessels.

## Flap design

Before surgery, a handheld Doppler is used to document the location of the musculocutaneous perforators commonly located medial and posterior to the ASIS. Although there are various audible signals consistent with multiple perforators, there is usually one dominant signal. The skin flap is outlined around the dominant perforator in an elliptical fashion along the superior border of the anterior ilium, which ensures eventual primary closure of the donor site (Fig. 6).

Fig. 5. A dental model is used to shape the template, which may be sterilized and used intraoperatively.

Fig. 6. Preoperative outline of the iliac bone, internal oblique muscle, skin paddle, and vessels.

The orientation of the bone flap is adjusted based on the contour and shape required and the location of the recipient vessels. Multiple options exist, because the crest can be oriented either to the dentoalveolar segment or inferior border. Based on the width of the native mandible, either a unicortical or bicortical segment of ilium may be used. Classically, we prefer to reconstruct segmental mandibular defects of the body, angle, and ramus with the ipsilateral ilium in an upright position after a 180° rotation, because it restores the premorbid curvature and places the crest at the inferior border and the vascular pedicle at the angle. This maneuver commonly replaces the natural curvature from the canine to the angle region without a need for an osteotomy. When a composite osteocutaneous flap is required, this orientation is particularly useful because it places the internal oblique muscle intraorally and the skin paddle extraorally for external resurfacing (Fig. 7). This soft tissue relationship also may be preserved without the rotation, however, because it follows the same curvature but places the crest at the dentoalveolar segment and the vascular pedicle toward the midline. The contralateral ilium can be used by maintaining the internal oblique muscle intraorally, the skin paddle extraorally, and the crest at the inferior border, but it places the vascular pedicle anteriorly. Although the ASIS clearly resembles the angle of the mandible and may be included in the bone flap, we routinely avoid its removal in an effort to prevent subsequent hernia formation from disinsertion of the inguinal

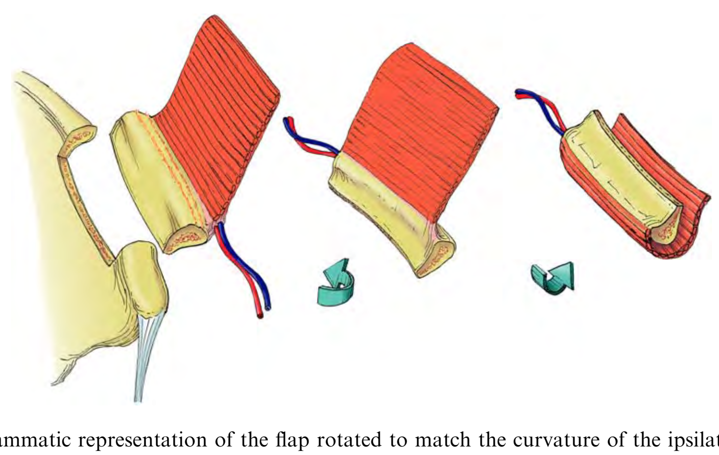

Fig. 7. Diagrammatic representation of the flap rotated to match the curvature of the ipsilateral mandible.

ligament. By preserving the ASIS and positioning the flap more posteriorly, additional pedicle length may be gained.

The iliac bone may be used to reconstruct the anterior mandibular segment, but additional osteotomies are required and close attention must be paid to the location of the recipient vessels. The wedge-shaped osteotomies may be kept open but require packing of cancellous bone chips to ensure bone healing. For reconstruction of oncologic defects that may require adjuvant radiotherapy, we avoid placing nonviable bone, which eventually may become sequestrum and prefer closing wedge osteotomies after careful subperiosteal dissection of the pedicle to avoid kinking.

## Operative technique

The medial or superior incision of the skin paddle is made first, and dissection proceeds toward the crest, superficial to the external oblique muscle, until visualizing the musculocutaneous perforators. Intramuscular dissection proceeds through the external oblique until arriving at the internal oblique muscle. The lateral or inferior incision of the skin paddle is made and dissection proceeds superficial to the tensor fascia lata and external oblique muscle until arriving at the perforators. The remainder of the external oblique muscle and fascia is incised parallel to the crest and dissection proceeds superficial to the internal oblique muscle until a predetermined amount of muscle is exposed. The muscle is incised from the costal margin superiorly, posteriorly, and medially from the linea alba. Submuscular dissection of the internal oblique from the costal margin is less demanding because the loose areolar layer facilitates dissection in a bloodless plane. The internal oblique becomes more adherent as you proceed toward the crest and inguinal ligament. The transversus abdominis muscle must be preserved to maintain the integrity of the abdominal wall.

Dissection of the ascending branch proceeds in a retrograde fashion until arriving at the bifurcation with the DCIA/DCIV and eventually its origin with the external iliac system. The vessels are dissected free from the surrounding tissues adjacent to the ASIS, with careful attention paid to visualizing and protecting the lateral femoral cutaneous nerve (Fig. 8). Attention is directed to the iliac bone, where a small cuff of transversus abdominis and iliacus muscle is preserved adjacent to the crest to ensure preservation of the pedicle along the inner table of

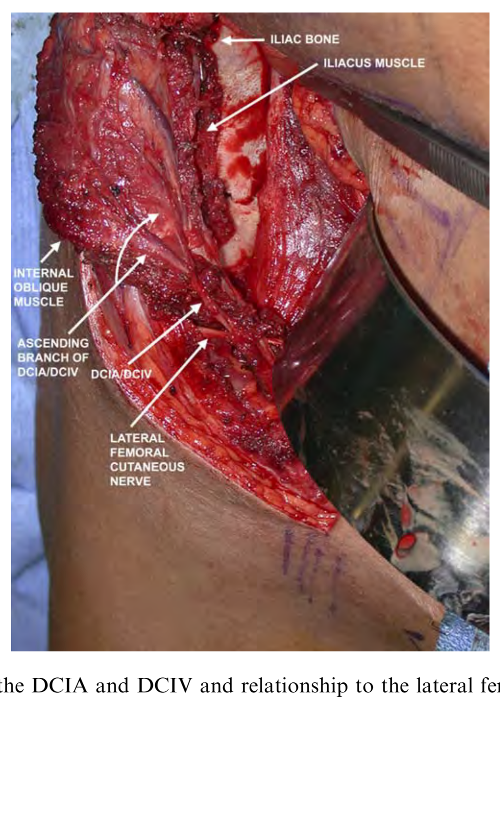


Fig. 8. Bifurcation of the DCIA and DCIV and relationship to the lateral femoral cutaneous nerve.


Fig. 9. Prefabrication of the flap to the template.

the iliac bone. The iliacus muscle is dissected in a subperiosteal fashion to expose the inner table. Electrocautery is used to incise the tensor fascia lata and gluteus medius muscles from the crest. A periosteal elevator is used to strip the lateral muscles and expose the outer table of the iliac bone. A previously molded 2-mm template is sterilized and used intraoperatively to design flap dimensions, facilitate flap inset, and minimize warm ischemia time (Fig. 9). The distal portion of the DCIA/DCIV is ligated and divided, and the osteotomies are made with a reciprocating saw and osteotomes. The flap is inset into the defect (Fig. 10) and the microanastomosis completed.

After completion of the mandibular reconstruction, careful attention is paid to repairing the donor defect. Layered approximation of the transversus abdominis to the iliacus followed by repair of the external oblique to the tensor fascia lata and gluteus medius has proved successful, avoiding the need for synthetic reinforcements. Postoperative CT scan confirms accurate placement of the flap (Fig. 11).

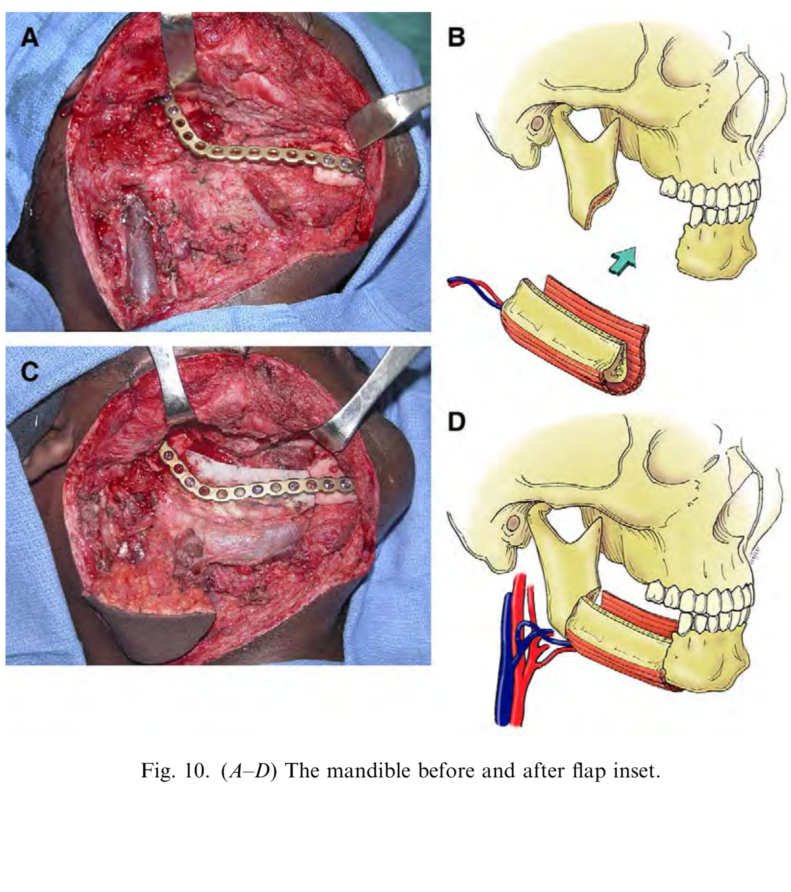


Fig. 10. (*A–D*) The mandible before and after flap inset.

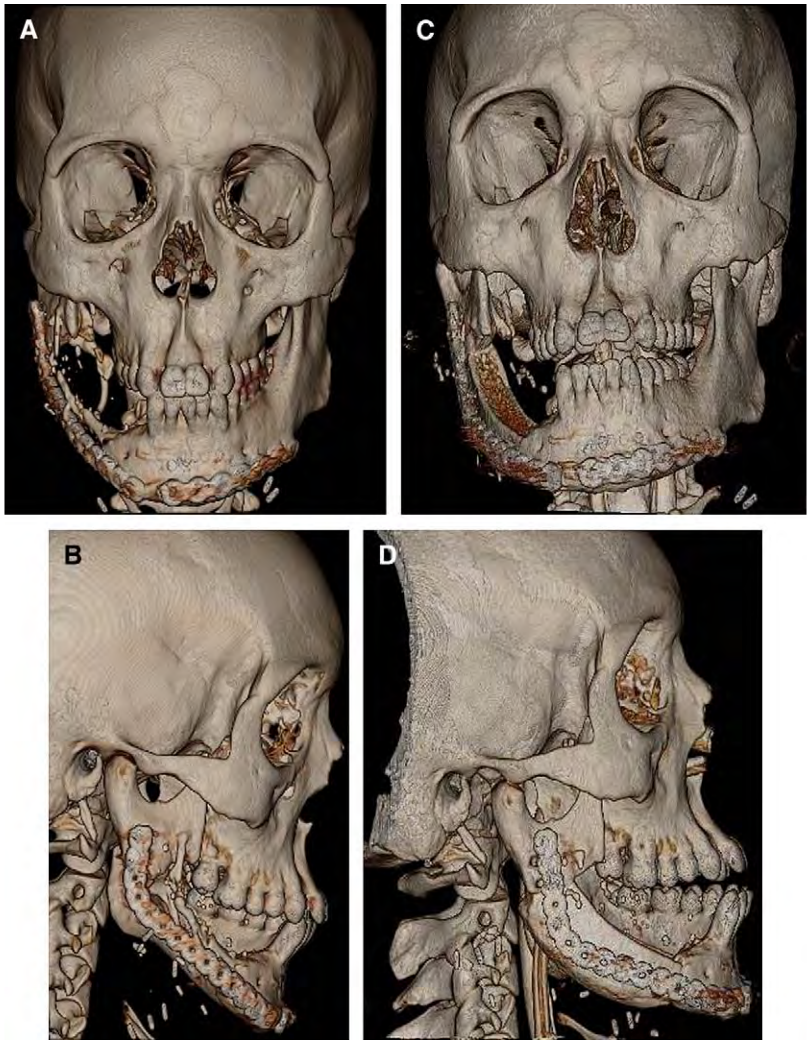


Fig. 11. (*A–D*) CT scan before and after flap inset.

## Summary

Preservation of the lower third of the face through precise restoration of the missing mandibular unit is essential for maintaining form and function. A well-designed composite flap provides the essential vascular template necessary to support the long-term success of this complex anatomic reconstruction. The free iliac bone flap facilitates immediate reconstruction of the mandible with excellent functional and cosmetic results. Achieving a good result after mandibular demolition is invaluable to a patient's quality of life and allows successful rehabilitation, which is otherwise condemned without application of these principles.

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Atlas Oral Maxillofacial Surg Clin N Am 14 (2006) 161–170

Atlas of the Oral and Maxillofacial Surgery Clinics

# Iliac Crest Grafting for Mandibular Reconstruction

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Mandibular reconstruction poses significant challenges to oral and maxillofacial surgeons. The mandible is a complex three-dimensional structure with great functional and aesthetic importance. Precise anatomic restoration allows maintenance of skeletal and dental relationships and preserves aesthetics and physiologic function. The goals of mandibular reconstruction are to establish bone continuity with adequate anteroposterior and transverse relationships to the maxilla and provide a functional oromandibular complex preserving speech, mastication, and deglutition.

Two major types of mandibular defect require reconstruction: marginal and segmental. Marginal defects typically involve the alveolar portion of the bone with an intact inferior or posterior mandibular border, which maintains mandibular continuity, whereas segmental defects are defined by the presence of mandibular discontinuity. When marginal defects are reconstructed, the ultimate goal is to restore the morphology of the alveolar process of the mandible to facilitate placement of osseointegrated dental implants or provide an anatomic foundation for a dental prosthesis. The purpose of reconstruction for segmental defects is to provide mandibular continuity and dentoalveolar reconstruction. Small segmental lateral defects may be well tolerated without reconstruction. When reconstruction is undertaken in a normal host, defects smaller than 5 cm typically can be restored with nonvascularized bone grafting. Defects larger than 5 cm or defects in an irradiated host are typically well suited for microvascular reconstruction. The application of rigid skeletal fixation without bone reconstruction is also appropriate in selected lateral defects in compromised patients with significant comorbidities or a guarded prognosis. Anterior mandibular segmental defects are not well tolerated and often cause significant loss of support for the tongue musculature (glossoptosis), which leads to potential airway compromise if not reconstructed.

Several types of bone grafting are available for mandibular reconstruction, including nonvascular autologous, allogenic and xenogenic bone, and vascularized free tissue transfer. Considering nonvascularized grafting options, autologous bone grafting has the ability to transfer osteocompetent cells to the recipient site (transfer osteogenesis) for osteoid formation. Alloplastic, xenogeneic, and alloplastic bone substrates are incapable of transferring osteocompetent cells and rely on the osteoinductive bone formation from the residual osteocompetent cells at the recipient site (periosteum) for new bone formation.

It is critically important when considering the application of nonvascularized mandibular bone grafting that meticulous surgical technique is used in preparing the recipient site and during bone graft harvesting. The aim is to transfer as many osteocompetent cells to the recipient site as possible. Although grafts may be stored in isotonic saline, it is the author's preference to limit this and transfer the normothermic bone graft directly from the donor to recipient site. This approach requires complete preparation of the donor site before bone graft harvest. It is also important to note that to improve bone graft survival, oral contamination should be avoided; most nonvascularized mandibular bone grafting should be performed transcervically. In situations in which inadvertent perforation of the oral mucosa has occurred,

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the surgical site should be irrigated and closed in a watertight layered fashion before bone graft placement. If large perforations occur before bone graft harvesting, consideration should be given to delaying bone grafting until mucosal healing has occurred.

The greatest volume and quality of osteocompetent cells can be harvested from cancellous bone within the iliac crest. Depending on the volume of the surgical defect, either the anterior or posterior iliac crest may be harvested. It is critically important for oral and maxillofacial surgeons to have an intimate understanding of the surgical anatomy of the iliac crest to facilitate safe graft procurement with the least donor site morbidity.

## Anterior iliac crest

### *Anatomy*

The anterior iliac crest is located between the anterior iliac spine (AIS) and tubercle of the ilium, which is 6 cm posterior to the AIS. Most cancellous bone is located between the AIS and tubercle of the ilium. A maximum of 50 cc of uncompressed cancellous bone can be harvested from the anterior iliac crest. A good rule of thumb is to use 10 cc of uncompressed bone per 1cm of defect; defects up to 5 cm in length can be reconstructed effectively with a single anterior iliac crest donor site. The AIS serves as an attachment for the external abdominal oblique muscle medially and tensor fascia lata laterally. The tensor fascia lata originates from the anterior iliac crest; attaching laterally it fans out inferiorly to attach to the hip and knee joints to insert on the lateral tibia. The tensor fascia lata is the most important structure related to gait disturbance, and surgeons prefer to limit dissection to the medial aspect of the iliac crest to avoid postoperative pain and gait disturbance. Inferior to the anterior iliac crest, the gluteus medius and minimus muscles attach to the lateral cortex. The iliacus muscle attaches to the medial surface of the iliac crest and is reflected during dissection. The inguinal ligament attaches to the anterior superior iliac spine and inserts onto the pubic tubercle. The sartorius muscle attaches to the anterior inferior iliac spine and inserts onto the medial aspect of the tibia (Fig. 1). Both of these structures should not be encountered during dissection.

Several sensory cutaneous nerves in the region of the iliac crest may be encountered, all of which typically transverse the pelvis in a superior-medial to inferior-lateral direction. The most commonly affected nerve is the lateral cutaneous branch of the iliohypogastric nerve (L1, L2), which runs over the tubercle of the ilium. The lateral cutaneous branch of the subcostal nerve (T12, L1) runs over the tip of the anterior superior spine and is slightly inferior to the iliohypogastric nerve. The lateral femoral cutaneous nerve is the most inferior nerve of interest and courses medially between the psoas major and the iliacus muscle, deep to the inguinal ligament to perforate the tensor fascia lata and innervate the skin of the lateral thigh. In 2.5% of the population the lateral femoral cutaneous nerve courses within 1 cm of the anterior superior spine and may be transected accidentally if the dissection plane is extended inferiorly. When this nerve is injured, a condition known as meralgia paresthetica may present, with persistent dysesthesia and anesthesia to the lateral thigh (Fig. 2).

The blood supply to the AIS is based on the perforating branches of the deep circumflex iliac artery and vein, which are located on the medial ilium. The gluteal artery is the most common source of bleeding during harvest of the AIS.

### *Surgical technique*

The AIS is approached with an incision that is placed when the skin overlying the AIS is retracted medially, which facilitates the postoperative scar to be lateral to the iliac crest and avoid irritation from clothing. A 4- to 6-cm incision is placed 1 to 2 cm posterior to the tubercle of the ilium and 1 cm inferior to the anterior superior iliac spine, obliquely along the orientation of the anterior iliac crest. This placement avoids the course of the iliohypogasrtic and subcostal nerves superiorly and the lateral femoral cutaneous nerve inferiomedially. The layers of dissection encountered are skin, subcutaneous tissue, and Scarpa's fascia. A dissection plane is

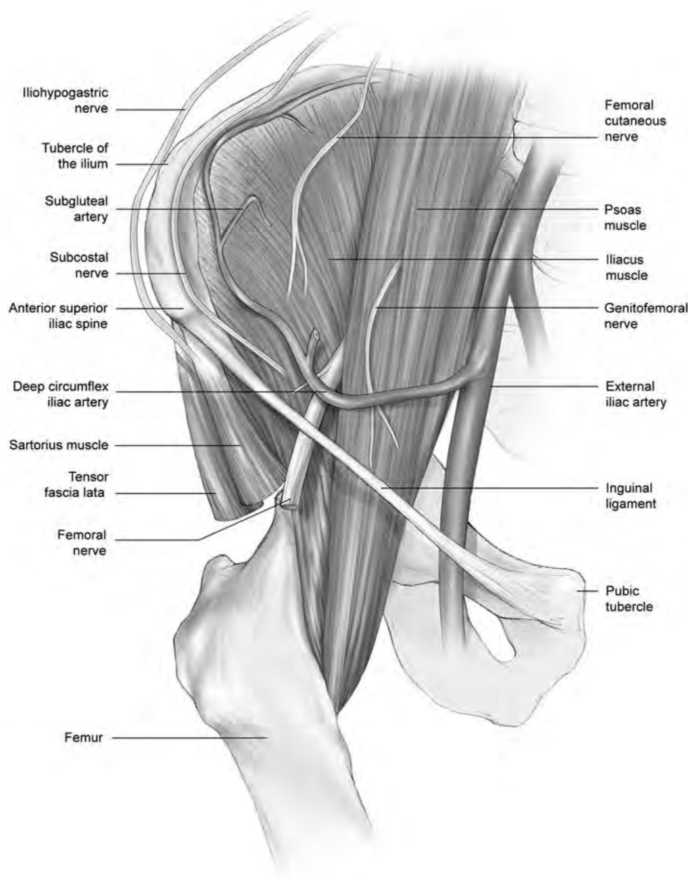


Fig. 1. Anterior view of the anterior iliac crest shows the relationships of the muscular, neural, and vascular structures in relation to the anterior iliac crest. Note that the vascular supply to the anterior iliac crest originates from the deep circumflex iliac artery from the external iliac system. (Copyrighted and used with permission of Mayo Foundation for Medical Education and Research.)

established between the tensor fascia lata laterally and the external and transverse abdominal muscles medially to identity the dense fibrous periosteum of the iliac crest. It is ideal to follow this hypovascular dissection plane without transecting muscle, thereby avoiding posteroperative pain and gait disturbance. Once the iliac crest is identified, the periosteum is sharply transected and with blunt dissection the iliacus muscle is reflected medially to expose the medial iliac crest. This musculoperiosteal layer provides protection to the intra-abdominal contents during bone graft harvesting. Although a lateral approach to iliac crest harvesting can be considered to reduce the risk of inadvertent intra-abdominal injury, it necessitates reflection of the tensor fascia lata and gluteus medius and is associated with significantly higher postoperative pain and gait disturbance. Once the iliac crest is exposed, several techniques may be used for graft harvesting. When purely cancellous bone grafting is required, a clamshell approach using a midcrestal osteotomy is created with the medial and lateral cortices separated to allow access to the underlying cancellous bone. When larger quantities of bone are required, a full-thickness corticocancellous block graft can be harvested (Fig. 3). A total bone length of 4 to 6 cm can be obtained and is limited by the proximity to anterior superior iliac spine and tubercle of the ilium. To limit the risk of AIS and fracture of tubercle of the ilium, 1 to 2 cm of bone posterior to the AIS distance should be maintained. Total depth of harvest can be up to 5 cm, which is typically where the anterior and posterior cortical plates fuse. The underlying cancellous bone is then curretaged as needed. Other approaches are described for harvesting the anterior iliac crest. One is the trap door approach, in which the medial or lateral cortex with attached muscle is pedicled to gain access to the cancellous bone. The other approach, the Tschopp approach,

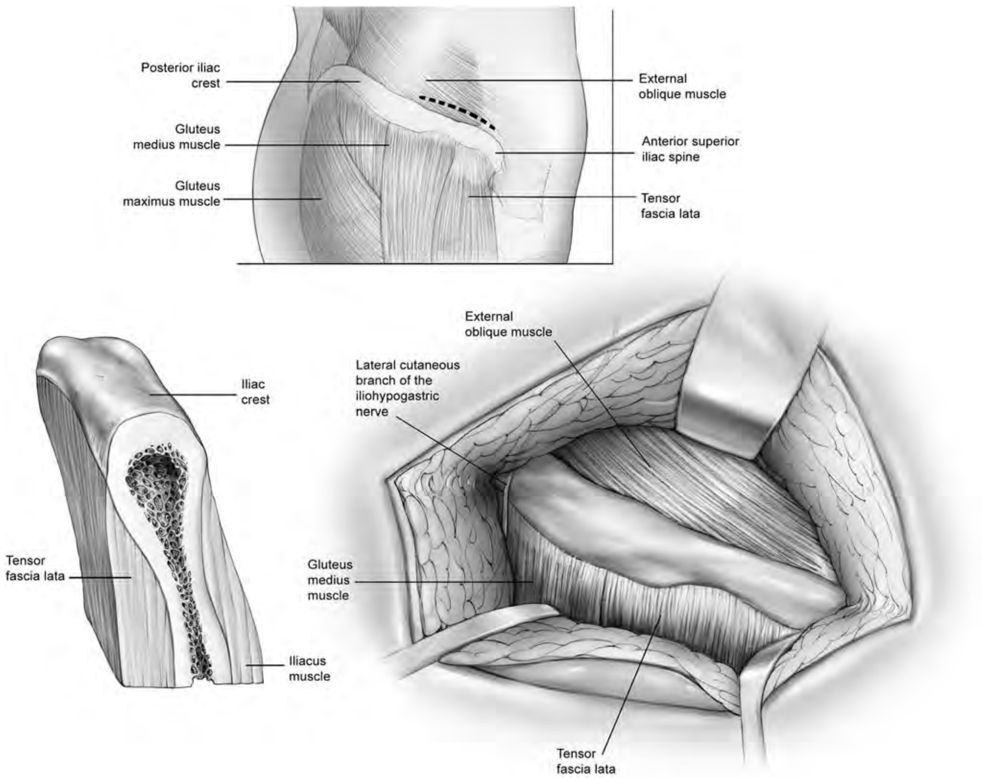


Fig. 2. The anterior iliac crest harvest site with incision placement and the typical medial and lateral muscular attachments. Although not typically visualized during graft harvest, the iliohypogastric nerve may be encountered with superior retraction or extension of the incision. (Copyrighted and used with permission of Mayo Foundation for Medical Education and Research.)

involves obliquely osteotomizing the iliac crest. A third approach, the Tessier approach, involves medial and lateral oblique osteotomies to gain access to the underlying cancellous bone (Fig. 4).

It is imperative for all surgical wounds to be inspected and rendered hemostatic before closure. Hemostatic agents, such as bone wax, microfibrillar collagen, and gelatin sponge, may be used to limit oozing from the cancellous bone. A drain may be used to limit postoperative fluid collection at the discretion of the operating surgeon. Closure should be achieved to reapproximate the periosteal envelope over the iliac crest followed by subcutaneous and skin closure. The patient is allowed to ambulate on postoperative day one but may require assistance with a walking device in the immediate postoperative period.

*Complications and pitfalls*

Major complications rates have been reported to be 0.7% to 25% and include infection, hematoma or seroma fluid collections, gait disturbance, iliac crest fracture, intra-abdominal perforation, ileus, sacroiliac instability, gait disturbance, abdominal hernia, chronic pain, and cosmetic contour deformity. Infection is seen in 1% to 2% of graft sites and should be managed with drainage and antibiotic therapy. Significant hematoma or other fluid collections have been reported in up to 10% of cases and are more common with anterior than posterior iliac crest grafting. Gait disturbance is typically caused by excessive lateral stripping of the tensor fascia lata and gluteus medius muscle. Iliac crest fracture may be caused by excessive cancellous harvesting or undermining of the anterior superior iliac spine or tubercle. Treatment is usually nonsurgical with bed rest followed by assisted ambulation. Ileus may be seen in the postoperative setting. It is usually self-limiting and requires no treatment other than observation until resolution. Intra-abdominal injury occurs because of excessive retraction or failure of appropriate medial protection during harvesting. Hernia formation may occur, although it is

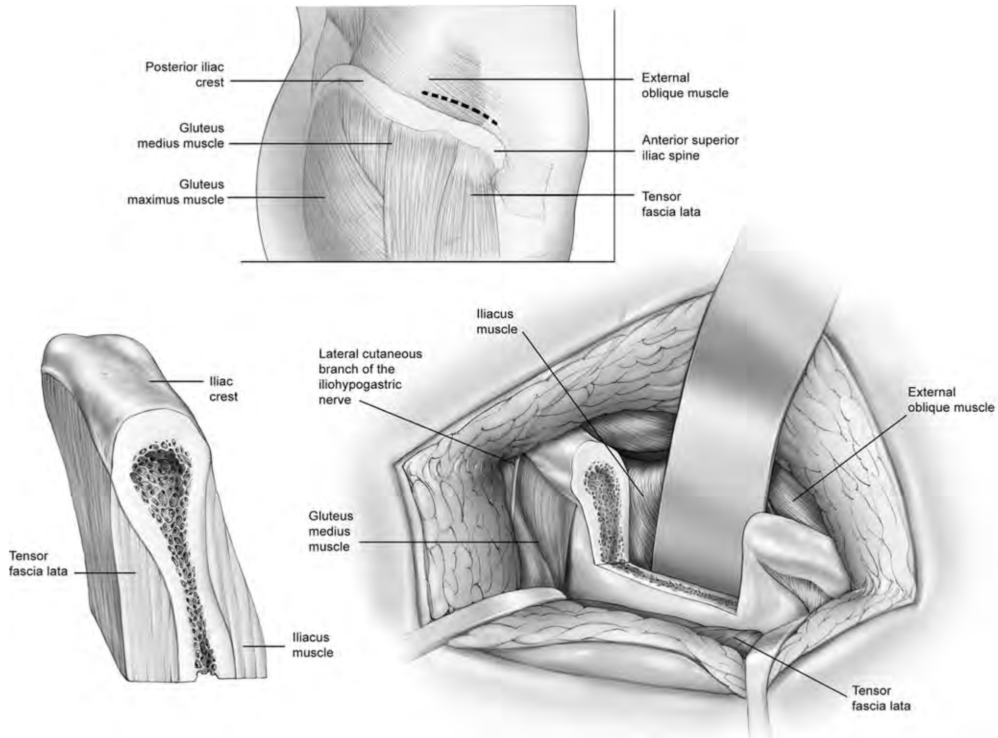


Fig. 3. The typical donor site of the anterior iliac crest after full-thickness cortical bone graft harvest. Note the position of the medial retractor placed in a subperiosteal plane to retract the iliacus muscle and protect the intra-abdominal contents. In situations in which a full-thickness graft is not required, preservation of the lateral cortex limits trauma to the insertion of the tensor fascia lata. (Copyrighted and used with permission of Mayo Foundation for Medical Education and Research.)

rare after routine harvesting. The risk factors for hernia development include full-thickness cortical harvest larger than 4 cm in anterior-posterior length, obesity, and female gender. Sacroiliac instability occurs because of posterior destabilization of the sacroiliac joint. Patients may describe pain of the lower back or pubic rami for several months. Chronic pain and nerve

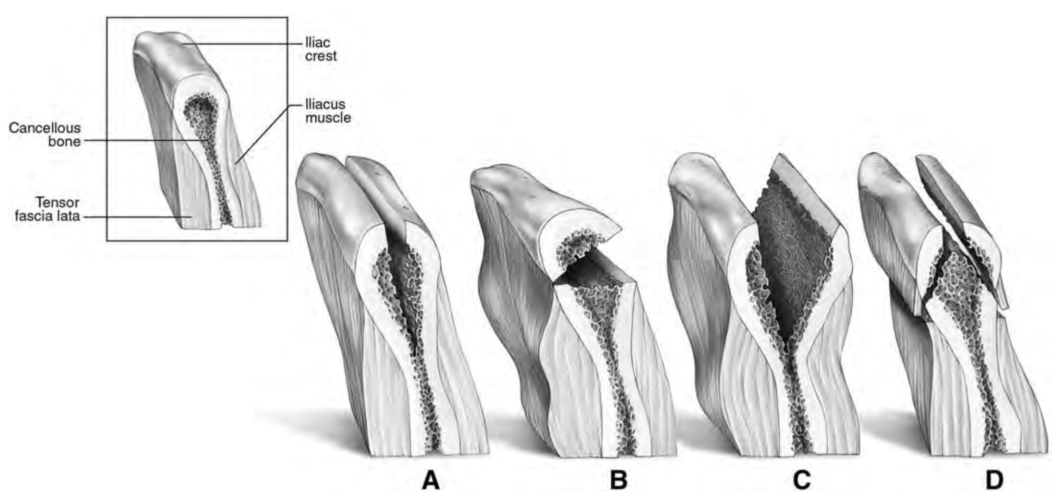


Fig. 4. The various harvesting techniques from the anterior iliac crest. (*A*) Clamshell approach expands the medial and lateral cortices to gain access to the underlying cancellous bone. (*B*) Tschopp approach pedicles the anterior iliac crest osteotomy on the external oblique muscle. (*C*) Trap door approach provides a similar but broader access than the clamshell approach by pedicling the medial and lateral cortices on the external oblique and tensor fascia lata, respectively. (*D*) Tessier approach creates oblique osteotomies to pedicle the medial and lateral walls of the anterior iliac crest to access the cancellous bone. (Copyrighted and used with permission of Mayo Foundation for Medical Education and Research.)

injury typically result from occult nerve injury at the time of harvest, entrapment during closure, or excessive fibrosis of the dissection field leading to neural compression. Cosmetic deformity is accentuated if the rim of the iliac crest is harvested, particularly in slender patients. This occurrence may be avoided by using crestal osteotomy followed by graft harvest and reapproximation of the iliac crest or harvesting only the medial-superior cortex and leaving the superior-lateral rim intact.

## Posterior iliac crest

### *Anatomy*

The posterior iliac crest contains the greatest volume of cancellous bone available for nonvascularized mandibular bone grafting. The posterior iliac crest provides up to 100 cc of uncompressed bone for a 10-cm mandibular defect. Most bone is located beneath the insertion of the gluteus maximus muscle adjacent to the sacroiliac joint. The insertion of the gluteus maximus is defined by the presence of a well-defined and palpable triangular fossa. The gluteus medius attaches to the posterior ilium inferior to the gluteus maximus insertion.

The cutaneous sensory nerves that may be encountered during posterior iliac crest harvest include the superior and middle cluneal nerves. The superior cluneal nerve (L1-3) pierces the lumbodorsal fascia superior to the posterior iliac crest and innervates the skin over the posterior medial buttocks. The middle cluneal nerves (S1-3) emerge from the sacral foramina course laterally and innervate the medial buttocks. The insertion of the gluteus maximus is between the superior and middle cluneal nerves. The sciatic notch and nerve, which supplies the motor innervation to the lower extremity, is 6 to 8 cm inferior to the posterior iliac crest and should not be encountered during routine dissection. The major blood supply to the posterior iliac crest is the subgluteal artery, which is a terminal branch of the deep circumflex system (Fig. 5).

### *Surgical technique*

The patient is placed in prone position with 210° of reverse hip flexion. A hip roll may be used to define further the palpable bony landmarks of the posterior iliac crest. The surgical approach to the posterior iliac crest is bounded superiorly and inferiorly by the position of the superior and middle cluneal nerves, respectively. The incision is centered over the bony prominence of the triangular fossa, which serves as the insertion of the gluteus maximus muscle. A 6- to 8-cm curvilinear incision is placed following the natural curvature of the posterior ilium. This incision should be centered over the palpable insertion of the gluteus maximus to avoid inadverant injury to the superior and middle cluneal nerves. The inferior extension of the incision is typically paramedian and 3 cm lateral to the gluteal crease. The dissection plane is advanced through the skin and subcutaneous tissue to the lateral margin of the posterior iliac crest. The lumbodorsal fascia that separates the abdominal and gluteal muscles is easily visualized as a thick white fascial layer. This layer is sharply transected and elevated along with the fibers from insertion of the gluteus maximus to expose the posterior iliac crest. Inferior to the gluteus maximus is the gluteus medius, which is not as intimately attached to the bone and can be reflected gently to expose the posterior iliac crest further and facilitate appropriate retraction for bone harvest.

Posterior iliac crest harvest may be performed by using a 5 × 5 cm (25 cc) osteotomy of the lateral cortical plate. The posterior osteotomy follows the ridge height of the gluteus maximus insertion, and the remainder of the osteotomy is created anteriorly from this point. The remainder of the cancellous bone may be harvested with a series of bone curettes. The surgical field is rendered hemostatic in a similar fashion to the anterior iliac crest grafts with bone wax, microfibrillar collagen, or gelatin sponge. The periosteal layer along with the lumbodorsal fascia are then reapproximated followed by the subcutaneous tissue and skin closure. The use of a drain is often required for posterior iliac crest grafts and should be placed on low intermittent suction to avoid continued marrow aspiration.

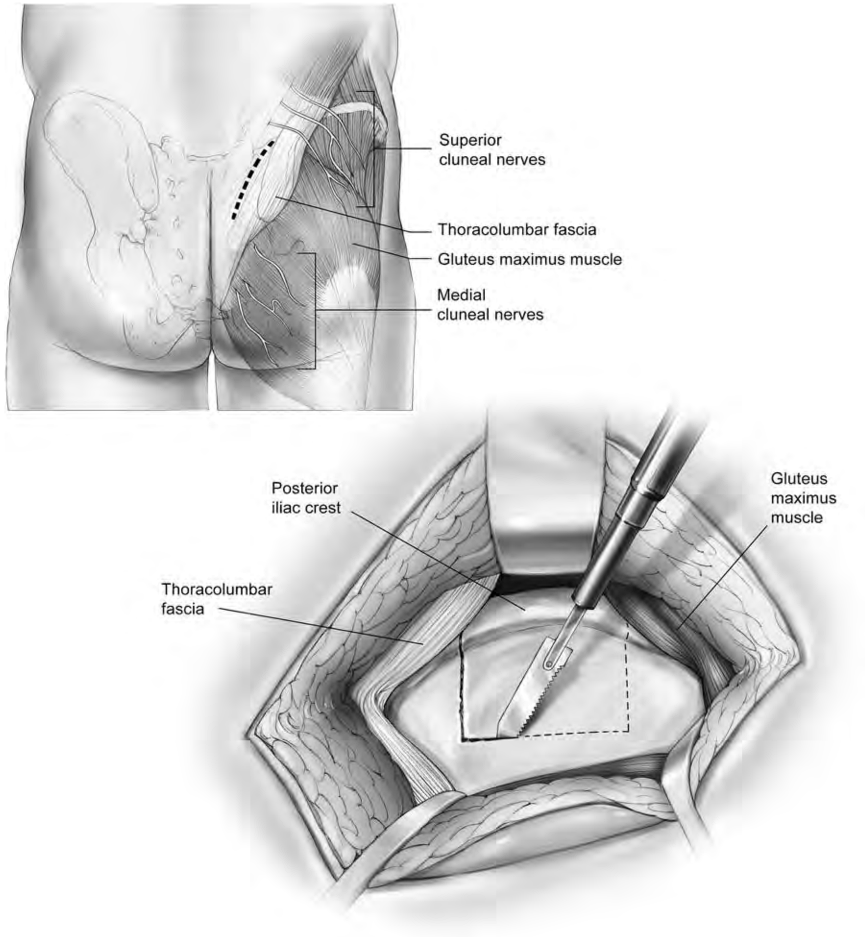


Fig. 5. The posterior iliac crest harvest site shows the orientation of the superior and middle cluneal nerves in relation to the posterior crest. Note the semilunar position of the incision (6–10 cm) following the arc of the posterior iliac crest and being centered over the insertion of the gluteus maximus muscle. (Copyrighted and used with permission of Mayo Foundation for Medical Education and Research.)

If adequate fixation is obtained without oral contamination, it is the author's preference not to use intermaxillary fixation in the immediate postoperative period and to maintain patients on a soft mechanical diet until evidence of healing has occurred.

*Complications and pitfalls*

The posterior iliac crest has 2 to 2.5 times the bone available for harvest as compared with the anterior iliac crest. There is typically less postoperative morbidity, pain, and gait disturbance with a posterior iliac graft. The major disadvantages include additional intraoperative time (up to 2 hours) for patient positioning, increased risk for endotracheal tube displacement, and lack of simultaneous mandibular surgery and graft procurement, as with an anterior iliac crest graft. Injuries to the subgluteal artery have been reported, although they are infrequent and may be the source of compartment syndrome of the buttock in the postoperative setting. If this does occur, direct exposure with further release of the gluteal muscles and ligation of the transected artery is recommended. If bleeding continues, laparotomy via retroperitoneal approach or selective embolization may be required. Ureteral injury should be considered in patients with postoperative hematuria, abdominal distention, and ileus. Hernia also may occur in the posterior graft site and is associated with similar risk factors as for the anterior iliac crest. Cluneal nerve injury is seen with posterior pelvic pain that radiates to the buttocks and is exacerbated with sitting. The indications for posterior iliac crest graft are similar to anterior crest harvest; however, posterior ilium is indicated in situations in which more than 50 cc of bone or a 5-cm defect is to be reconstructed or when patient intolerance to donor site morbidity from the anterior iliac crest is present.

## Summary

The key advantage of autologous bone grafts in comparison to other nonvascularized grafts is the ability of the graft material to remodel with physiologic function of the mandible. There are several options for nonvascularized bone grafting; however, the anterior or posterior iliac crest allows the greatest volume of corticocancellous bone to be harvested with the least donor site morbidity. The objectives of reconstruction are to establish bone continuity or augment the existing bone contours to facilitate prosthetic rehabilitation and optimize facial aesthetics and oropharyngeal function. The critical basic principles of reconstruction are to avoid oral contamination and maintain bone graft stability during the initial healing phase to avoid increase failure rates caused by infection, fibrous nonunion, and bone graft resorption.

Several successful carrier methods have been described for mandibular reconstruction, including, titanium mesh crib, cadaveric bone trays, resorbable plates, and metal reconstruction plates (Fig. 6). For marginal defect reconstruction, bone grafts may be supported with positional fixation. To ensure healing, adequate soft tissue coverage is required to maintain vascularity to the graft and prevent extrusion. In irradiated patients with small defects or patients unwilling or unable to tolerate microvascular reconstruction, nonvascularized bone grafts may be placed in a staged fashion with local or regional flaps for soft tissue closure followed by bone grafting. Iliac crest grafting can be performed using corticocancellous blocks, particulate cancellous marrow, or a combination of both (Fig. 7). Regardless of the specific techniques,

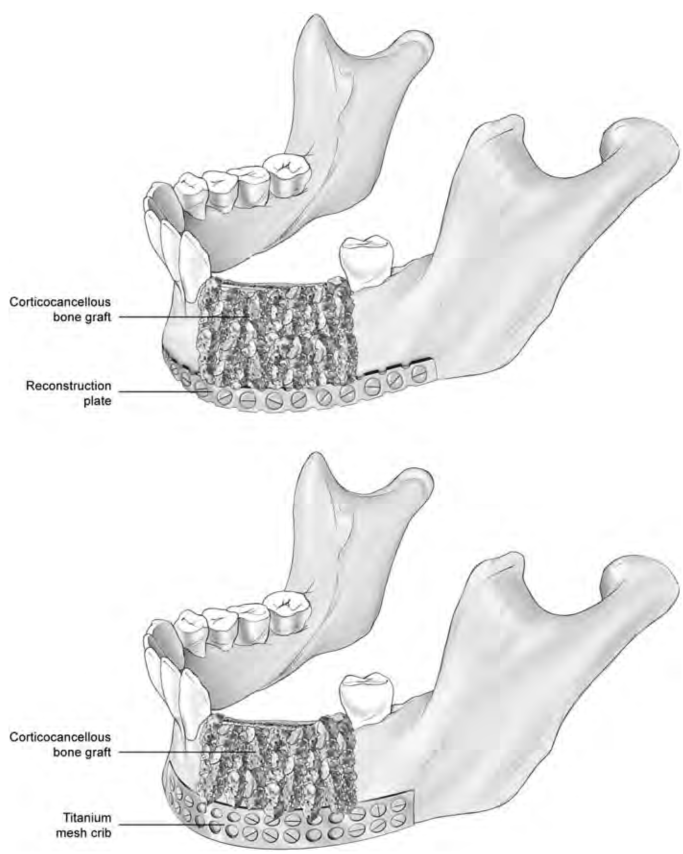


Fig. 6. A 5-cm lateral mandibular defect reconstructed with corticocancellous block with rigid fixation with a reconstruction plate or titanium mesh crib. It is critical during graft placement that perforation of oral mucosa is avoided. The grafts should be fixated rigidly if immediate postoperative function is planned for the patient. (Copyrighted and used with permission of Mayo Foundation for Medical Education and Research.)

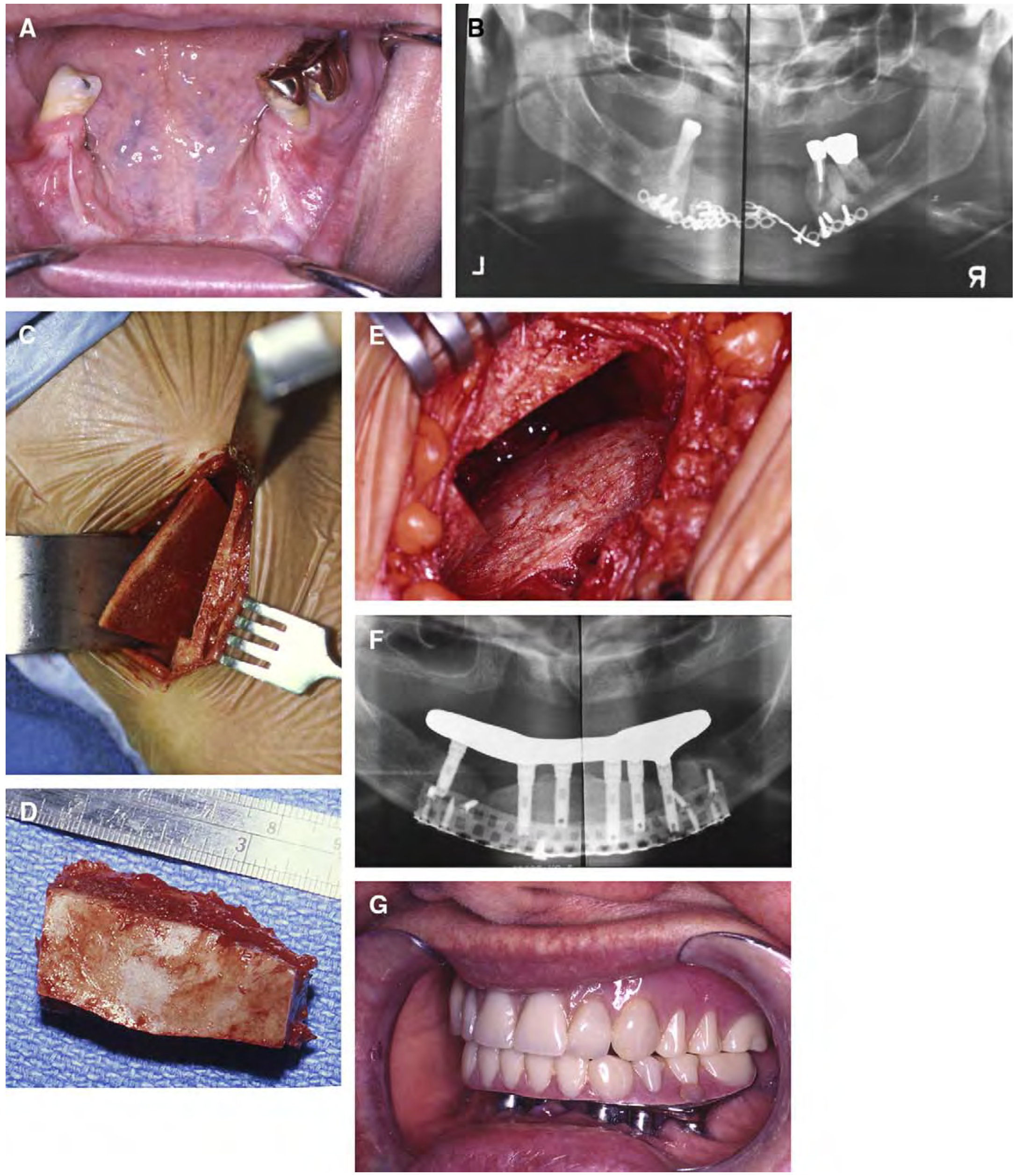


Fig. 7. (*A*) Preoperative clinical appearance of a patient with a 5-cm anterior segmental defect secondary to tumor resection. (*B*) Preoperative panoramic radiograph shows failure of attempted internal fixation without bone graft. (*C*) Anterior Iliac crest harvest site shows corticocancellous block graft osteotomized and pedicled to the external oblique muscle. (*D*) 5 × 5 cm corticocancellous block graft harvested. (*E*) Donor site defect created after corticocancellous block harvest. (*F*) Postoperative panoramic radiograph shows corticocancellous bone graft with titanium mesh crib reconstructed with endosseous dental implants after a 6-month period of graft consolidation. (*G*) Postoperative view of a patient after final prosthetic reconstruction is completed.

it is critical for reconstructive surgeons to be familiar with the techniques of iliac crest bone grafting from either the anterior or posterior iliac crest to provide safe graft procurement and optimize grafting success for mandibular reconstruction.

**Acknowledgments**

The authors wish to acknowledge Robert F. Morreale, MST, CMI, Director of Medical Illustration and Animation, Mayo Clinic, Rochester, Minnesota, for his expertise and meticulous preparation of the illustrations used in this article.

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# Pectoralis Major Myocutaneous Flap Reconstruction of the Mandible

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## Brief history

The pectoralis major myocutaneous (PM) flap was first described for head and neck reconstruction in 1979. It quickly became the cornerstone technique for reconstruction of large defects of the lower third of the face and neck. Despite the increased contemporary use of versatile microvascular free flaps, the PM flap continues to play a useful role in the reconstruction of traumatic and ablative head and neck defects.

Since its original description, many have proposed variations of the PM flap. Examples of modification have included the incorporation of an osseous component by harvesting a portion of rib with the flap to replace resected or avulsed mandible or the incorporation of two epithelial surfaces for through-and-through defects. Others surgeons have used the bulk of the muscle without transferring the skin paddle. Numerous alterations have been proposed to customize and increase the applications of the flap for each individual situation. This article describes in detail the use of the PM flap in mandibular reconstruction, including preoperative considerations, anatomy, and surgical technique.

## Indications and preoperative considerations

When considering a PM flap for reconstruction, one must conceptualize and anticipate the planned surgical defect, specifically its location and three-dimensional size and shape. Consideration also must be given to the unique anatomy of the pectoralis donor site and the overall medical condition of the patient. Preoperative analysis of all of these factors is essential for successful predictable reconstruction.

The dimensions of the anticipated defect from pathologic resection or traumatic avulsion are important to understand. The cutaneous or mucosal portion of the defect must correspond to the cutaneous portion of the flap. The skin paddles of PM flaps are most often square, ovoid, or round in nature to avoid sharp or acute angles. The cutaneous paddle on the pectoralis muscle also must be located and oriented to maximize the reach of the flap and prevent compression or torsion of the vascular pedicle. The ideal use of the PM flap is for the mandible, floor of mouth, upper neck, and lower one third of the face.

When defects are primarily mucosal or cutaneous, the bulk of the PM muscle and subcutaneous tissues can be problematic. A thinner or more delicate free flap should be considered in these instances. The bulk of muscle and subcutaneous tissue may be advantageous

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for large vessel coverage when a neck dissection or large resection is to be performed. If an osseous continuity defect is to be restored, a reconstruction bar is placed to maintain the native anatomy and prevent contracture. Definitive osseous reconstruction may be performed at a later date.

The donor site should be evaluated for tissue quality, thickness, and history of prior surgery or radiation. Although few true contraindications to the PM flap exist, a prior history of radical axillary node dissection has been suggested as a true contraindication. History of breast surgery, augmentation, or reconstruction can limit the quality and quantity of musculocutaneous perforators to the skin paddle or interrupt the dermal plexus. Prior flap reconstruction of the breast can severely limit the arc of rotation and reach of the flap. Morbidly obese or large-breasted individuals with excessive adipose or mammary tissue also may have compromised predictable survival of the cutaneous paddle.

Finally, the overall health of the individual contributes greatly to surgical success when relying on predictable microvasculature performance for large tissue transfers. Smoking, diabetes, peripheral vascular disease, poor nutritional status, hypertension, prior radiation, and scar tissue have been suspected in reduced success of cutaneous tissue survival. Patients who smoke should be warned that they should quit at least 2 weeks before surgery for improved chances of flap survival. These same factors are considered for free tissue transfers, thus, patients with increased risk factors for PM flap failure also may be less likely to qualify for a free tissue flap.

## Anatomy

The pectoralis major muscle is a large fan-shaped muscle that originates medially from the sternum, superiorly from the medial half of the clavicle, and inferomedially from the aponeurosis of the rectus abdominis muscle along the cartilaginous portion of the sixth rib. This interdigitation of the pectoralis major and the rectus abdominus is noteworthy during dissection to ensure separation the PM from this confluence while maintaining the attachment of the rectus abdominus to the sixth rib. The pectoralis muscle narrows and increases in thickness as it reaches superolaterally toward the intraturbercular groove of the proximal humerus (Fig. 1). The lateral edge of the muscle forms the anterior wall of the axilla and axillary fold. The action of the muscle causes medial rotation and adduction of the humerus.

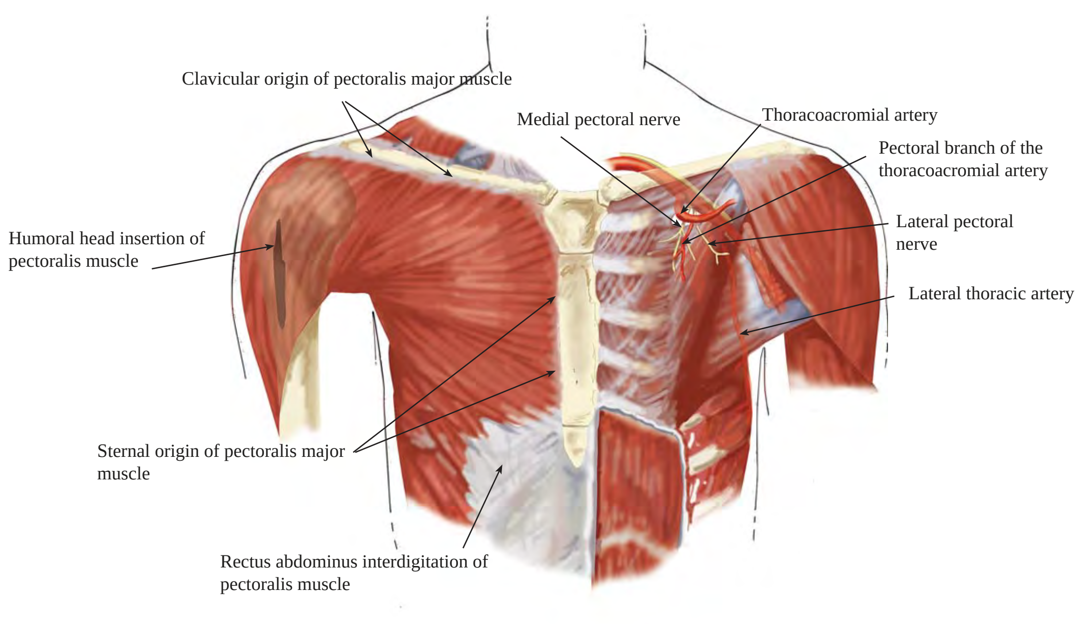


Fig. 1. Anatomy of the pectoralis major muscle with the muscle intact and removed.

The pectoralis major muscle is a type V muscle flap based on the Mathes Nahai flap classification with a dominant vascular pedicle and multiple secondary pedicles. The dominant pedicle is the pectoral branch of the thoracoacromial artery. The thoracoacromial artery is the first branch of the axillary artery after it has passed deep to the clavicle. The thoracoacromial trunk has four branches: the deltoid, acromial, clavicular, and pectoral. The pectoral branch courses inferiorly and enters the pectoralis major muscle from the deep surface.

After giving off the thoracoacromial artery, the axillary artery continues deep to the insertion of the pectoralis minor muscle. Immediately lateral to the pectoralis minor muscle, the lateral thoracic artery arises and parallels the pectoralis artery. The lateral thoracic artery provides vascularity to the lateral portion of the pectoralis major muscle. Perfusion studies have shown this artery to be a significant source of blood supply to the pectoralis major in up to 27% of individuals. Preservation of this vessel may improve flap viability but limit the arc of rotation.

The pectoralis muscle also is supplied medially by the parasternal perforators from the internal mammary artery. It is important to note the location of the first and second perforators, which supply the deltopectoral flap. By preserving these vessels, the deltopectoral flap is maintained should a salvage flap be required.

The microvascular cutaneous anatomy is less obvious but warrants an understanding of the concept of angiosomes. Briefly, an angiosome is defined as a segment of tissue supplied by a dominant artery and vein. Adjacent angiosomes are connected by ‘‘choke’’ vessels. If a dominant vessel is interrupted, the choke vessels may open to allow perfusion of the compromised angiosome based on the adjacent angiosome’s vascular supply. The skin of the medial pectoral region derives its blood supply from the internal mammary perforators. Because the PM flap is elevated, however, and the internal mammary perforators are divided. The response of the choke vessels allows the adjacent angiosome, supplied by the pectoral branch or lateral thoracic artery, to maintain the viability of the medial pectoral region.

The motor innervation to the pectoralis muscle is supplied by the medial and lateral pectoral nerves. These two nerves are branches of the brachial plexus and exit medial and lateral to the pectoralis minor muscle. Division of these nerves improves the arc of rotation of the flap and results in atrophy of the flap.

## Surgical technique

After sterile preparation, wide draping is performed to expose the chest to the contralateral nipple, inferior to the costal margin, the axilla, and upper arm. Wide exposure is essential to verify position and anatomy throughout the dissection. The contralateral anatomy helps provide reference and comparison throughout the dissection.

Next the sternal notch and first three intercostal spaces are marked with a surgical pen. A mark is then made in the midclavicular region to reference the anticipated exit of the thoracoacromial artery. Next the location of the deltopectoral flap is marked to allow identification and preservation of the vasculature of the first and second intercostal arteries. The deltopectoral flap is preserved in the event a salvage flap is required. No cutaneous incisions are made, which would violate this back-up flap.

The skin paddle is then drawn in the inferomedial quadrant of the pectoralis region (Fig. 2). The paddle should have minimal subcutaneous and mammary tissue. The distance from the midclavicular point to the skin paddle should exceed the distance from the midclavicular point to the head or neck defect. A ribbon or surgical sponge can be used to simulate the planned distance. One should err on the side of extra length to ensure minimal tension on the flap when it is inset into the defect (Fig. 3).

Two incision designs can be used for the exposure to the pectoral muscle: the midpectoral incision and the inframammary incision. Both designs are efficacious, with the inframammary incision being considered more cosmetic. We use the midpectoral incision except in female patients, in whom ‘‘violating’’ the breast may be objectionable to the patient. In our experience the midpectoral incision may be used on most patients without deforming the breast excessively. This approach eases exposure during dissection. The midpectoral incision starts at the inferolateral corner of the deltopectoral flap near the axilla and runs inferomedially across

Fig. 2. Preoperative markings with the skin paddle in the inferomedial quadrant and the intercostal spaces. Note the planned incision for the right modified radical neck dissection.

the chest, medial to the nipple, to connect to the superolateral edge of the skin paddle. This planned incision divides the cutaneous dissection into a superomedial and an inferolateral region (Fig. 4).

The cutaneous incision is made with a #10 blade from the axillary region to the superior lateral edge of the planned skin paddle. Electrocautery can be used to carry this incision to the level of the muscle. After the muscle is identified, the inferolateral dissection is completed to identify the lateral margin of the pectoralis muscle. This exposure also allows the surgeon to note the caudal extent of the muscle and ensure that the cutaneous paddle is appropriately located over the pectoralis major muscle and has not been placed too far caudally.

Next the cutaneous portion of the skin paddle incision is completed circumferentially. The subcutaneous dissection to the pectoralis muscle is completed with a blade, taking care to bevel the dissection away from the skin paddle to create a wider base relative to the cutaneous paddle (Fig. 4). Electrocautery is not used during this portion of the dissection to avoid possible retrograde thrombosis, which may compromise the cutaneous paddle. Bipolar electrocautery may be used to achieve hemostasis. The beveled design is used to maintain the widest supply of musculocutaneous perforators to the subdermal and dermal plexus of vessels. Great care is taken to avoid shearing forces across the skin paddle. Sutures may be placed to anchor the dermis of the paddle down to the pectoralis muscle to prevent shearing of the paddle. Once again, maintaining the perforators is essential for cutaneous survival.

With the midpectoral incision, lateral muscular dissection, and paddle isolation completed, the superiomedial subcutaneous dissection is completed to the level of the clavicle. The origins and insertion of the pectoralis major muscle are exposed (Fig. 5).

Next, the lateral and inferior elevation of the PM flap begins between the pectoralis major muscle and the chest wall. This loose areolar plane is easily identified with blunt dissection. Intercostal perforators must be identified and controlled preferably with hemoclips or bipolar electrocautery. Inferiorly, the depth of dissection is along the intercostals muscles. Meticulous dissection releases the muscle from the external oblique/rectus abdominus confluence. After the

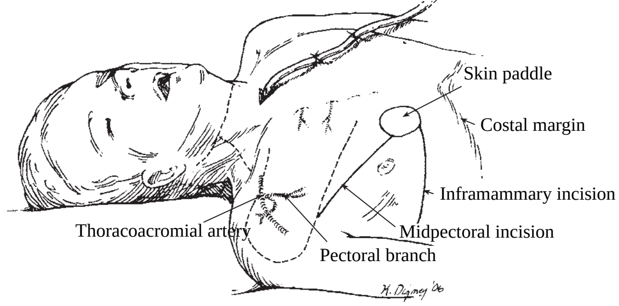


Fig. 3. Illustration of preoperative marking. Note the deltopectoral flap, the clavicle, the vasculature, and the midpectoral incision coursing to the skin paddle.

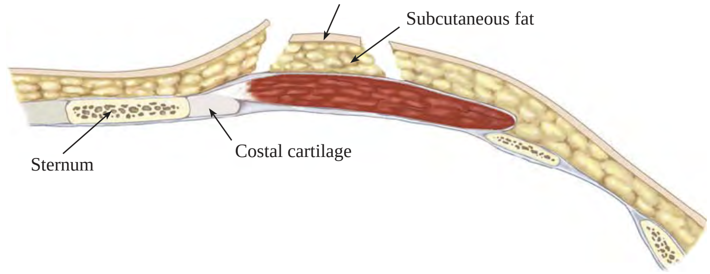


Fig. 4. Cross-section demonstrates the beveled subcutaneous dissection technique to ensure preservation of the musculocutaneous vascular system.

inferior and medial attachments are released, the medial sternal origins are divided, with attention directed toward identifying and controlling the internal mammary perforators. This may be accomplished with Mayo scissors to avoid the use of unipolar electrocautery to prevent retrograde thrombosis. The first and second internal mammary perforators are preserved to ensure the viability of the deltopectoral flap as a back-up salvage option.

The dissection proceeds in an inferior to superior direction in the loose areolar plane between the pectoralis minor and major muscle. The pectoral branch of the thoracoacromial artery is identified on the undersurface of pectoralis major muscle. The pectoralis branch may be identified medial to the superior aspect of the pectoralis minor, whereas the lateral thoracic artery is lateral to this muscle (Fig. 6).

The lateral portion of the pectoralis major muscle is elevated and followed to its insertion on the superior aspect of the humerus. The humeral insertion of the pectoralis major muscle is divided with a combination of blunt dissection and electrocautery with great attention paid to maintaining hemostasis. The location and integrity of the pectoralis branch must be kept under constant visualization. The lateral thoracic artery should be identified and maintained if possible. The cephalic vein, which courses in the deltopectoral groove, is used as a landmark to define the superolateral border of the pectoralis muscle.

After the inferior and medial origins and lateral insertion of the PM flap have been released, attention is turned to identifying and dividing the medial and lateral pectoral nerves. Specific division of the medial and lateral pectoral nerves improves the rotation and reach of the flap. This maneuver also results in muscle atrophy, which improves the aesthetic acceptability to the patient by reducing its bulk. Additional mobilization of the flap may be achieved by further skeletonizing the vascular pedicle. We prefer to leave an adequate cuff of tissue to protect the vessels from compression yet achieve adequate mobilization and allow a tension-free rotation and inset of the flap.

After the flap has been mobilized completely, the tunnel into the head and neck must be created. In cases in which a concomitant neck dissection has been completed, with resection of the sternocleidomastoid muscle, this may be relatively easy. The tunnel is created with a combination of superior and inferior dissection. From the neck, a subplatysmal plane of dissection is created over the clavicle. The external jugular vein must be identified and managed

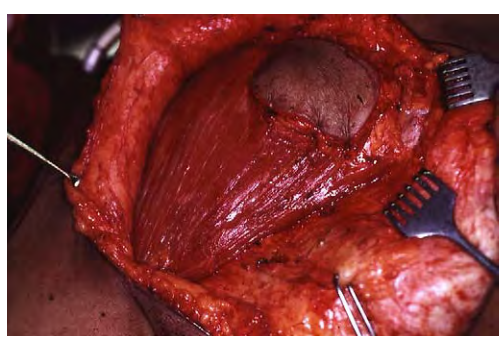

Fig. 5. Pectoral split incision with the beveled skin paddle sutured to the pectoralis major muscle.

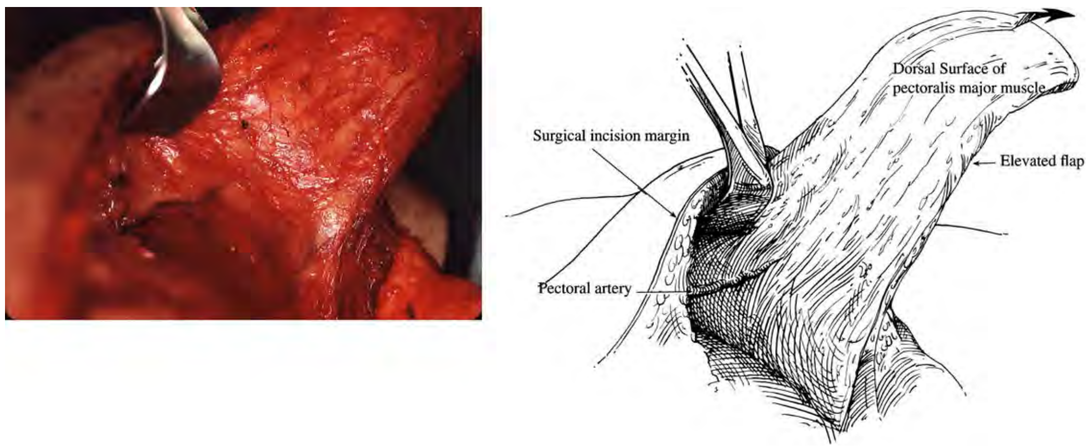


Fig. 6. Illustration demonstrates elevation of the pectoralis major muscle. Note the pectoralis branch of the thoracoacromial artery.

as indicated. If the sternocleidomastoid muscle is present, the plane of dissection is superficial to this muscle. From an inferior approach, a subfascial pocket is created to complete the tunnel. By visualizing this pocket from below, we are able to use direct visualization to complete the tunnel. By using a combination of tactile sense and direct visualization, we ensure adequate tunnel width to prevent compression of the vascular pedicle. Typically, the tunnel should accommodate the width of four fingers easily. In some instances in which a larger skin paddle is present, a larger tunnel may be necessary. Inadequate tunnel width may result in flap failure or distal paddle ischemia and necrosis.

The flap is transferred gently into the neck. Care is taken to limit torsion of the flap, which may compromise the pedicle. The flap is then draped over the exposed neck. If a modified radical neck dissection has been completed, it will allow coverage of the great vessels and offer protection for postoperative radiation. Well-placed sutures around the perimeter of the flap limit redundancy in the neck, which also support the distal portion of the flap and limit tension on the cutaneous paddle. If the PM flap is being used in a posttraumatic case, wide undermining of the cervical skin may be required to allow closure over the flap without further compression. A split-thickness skin graft may even be required to cover any exposed muscle.

After the proximal flap has been draped and inset in the neck, the distal portion of the flap is inset into the defect. If a mandibular continuity defect is present, the distal muscular portion of the flap should be sutured over the previously placed reconstruction bar (Fig. 7), which further supports the cutaneous paddle and provides coverage for the bar if there is distal cutaneous ischemia. This approach may prevent exposure and bacterial colonization of the reconstruction bar, which can result in infection and require removal of the bar.

## Complications

As with any surgery, risks and complications must be considered before surgery. PM flap complications can be subdivided into recipient site complications and donor site complications. The recipient site complications include flap necrosis, poor healing, infections, fistulization, and seroma. Donor site complications include uncontrolled bleeding, hematoma, wound dehiscence, infection, and seroma. Rarely complications also may include rib osteomyelitis, seeding of tumor, and even metastatic spread of tumor to the base of flap.

Mehta and colleagues evaluated 220 consecutive PM flap for oral cavity reconstruction and correlated their complications to several risk factors. Hematoma formation was correlated to advanced tumor stage and subsequently more radical surgeries. Infections were increased in patients with hemoglobin levels $<10$ g/dL, serum albumin $<3$ g/dL, and presence of underlying systemic disease. Infections also significantly increased hospital stay. Dehiscence was more common in female patients, patients with serum albumin $<3$ g/dL, bipedicled flaps, and history

Fig. 7. PM flap inserted into the oral cavity after lip split and mandibular resection. Note the draping of the muscle over the bar and the support of the muscle with sutures for stabilization.

of prior chemotherapy. Fistulas occurred more commonly at the anterior three-point suture between the flap, floor of mouth, and mucoperiosteum at the cut edge of the mandible. Fistula risk also increased with more extensive resection. Extensive resection also significantly increased hospital stay. Flap necrosis also seems to be more common in women than men.

Chepeha and colleagues compared their findings in 179 patients who underwent either a PM flap or a radial artery forearm free flap. They reported minor complications as those that required treatments, including packing, drainage, and medication, but did not require treatment in the operating room (ie, wound infection, partial flap necrosis or dehiscence, minor fistulas, plate exposure, hematoma, wound abscess, seroma, and postoperative hemorrhage). Major complications included fistula, necrosis, dehiscence, required surgical treatment, and death. Their findings revealed that patients who underwent PM flap reconstruction experienced significantly higher rates of minor complications, higher rates of G-tube dependence, and longer hospitalization than patients who underwent a soft tissue microvascular free flap.

Ord's retrospective analysis of 50 reconstruction cases using the PM flap reported three total flap failures, two of which were attributed to technical failure. An additional three flaps underwent partial necrosis and sloughing of more than 40% of the skin paddle.

Surgical technique and planning are essential to minimize complications. The use of skin paddles that extend caudally onto the rectus sheath to facilitate more cephalad coverage of defects has a greater incidence of partial flap necrosis. Compression of the pedicle either by improper tunnel preparation or by improperly placed dressings, bandages, and tapes also should be kept in mind. The bulk and weight of the PM flap also should be considered carefully, not only because of aesthetic and functional matters but also because of problems with healing, tension, and increased risk for dehiscence. Attention to detail during preoperative planning and intraoperatively may minimize preventable causes of surgical complications.

## Postoperative care

Postoperative care begins in the operating room. It is imperative to monitor and have adequate control of bleeding from the flap donor site to avoid seroma and hematoma formation. We advocate the placement of at least two suction drains in the chest. The nursing staff should be made aware that the neck prominence is secondary to the flap and not caused by a hematoma. Equally important is avoidance of placing circumferential dressings around the neck.

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Atlas Oral Maxillofacial Surg Clin N Am 14 (2006) 179–183

Atlas of the Oral and Maxillofacial Surgery Clinics

# Costochondral Rib Grafts in Mandibular Reconstruction

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The main role of costochondral rib grafts in mandibular reconstruction is in temporomandibular joint (TMJ) arthroplasty. Autologous rib grafting in craniofacial surgery dates back to the early twentieth century; however, Poswillo [1] was the first surgeon to truly establish the physiologic compatibility of costochondral grafting for the TMJ [2]. Although other autogenous donor sites, such as the sternoclavicular and metacarpal joints, have been used, the costochondral graft is the autogenous reconstruction material of choice for TMJ arthroplasty in the pediatric population. The costochondral rib graft is adaptable to the TMJ not only because of its native size and dimensions but also because its hyaline cartilaginous cap (as opposed to fibrocartilage) can withstand the biomechanical stresses of the TMJ and act as a new growth center. This article highlights the harvesting technique for costochondral rib grafting in temporomandibular reconstruction.

## Indications

Although used in adult patients who have failed multiple alloplastic TMJ implants, most patients who require a costochondral rib graft for TMJ arthroplasty are growing patients who have ankylosis of the joint (intracapsular) or suffer from a neoplasm of the condylar head that requires a condylectomy and immediate reconstruction (Fig. 1). In either case, the goals of reconstruction are similar: to re-establish the vertical height of the lower face (ramus), re-establish the premorbid occlusion, and allow for a dynamic grow of the new condylar head as the cartilaginous cap of rib continues to grow.

A costochondral rib graft with a cartilaginous cap secured to the native mandible can be expected to grow spontaneously in a growing patient. The rate of reankylosis after costochondral rib grafting is most common in adult patients, especially individuals with multiple previous operations, because this patient population is prone to heterotopic bone formation [3]. One of the most unpredictable factors regarding costochondral bone grafting is the degree of growth. Although lack of growth and potential reankylosis are possible, overgrowth of the costochondral rib graft is the most common scenario after TMJ arthroplasty in growing patients [4]. Some authors have postulated a direct correlation between the rate of overgrowth with reconstruction at an earlier age or an excessive amount of cartilaginous cap harvested during the procurement, although other clinicians have not been able to predict such results successfully [5–7].

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Fig. 1. Ankylosis of TMJ with compensatory coronoid hyperplasia.

## Harvesting technique

After a patient is transferred to the operating table and placed under general anesthesia, the endotracheal tube is secured and a rolled towel is placed in a longitudinal fashion under the scapula of the side to be harvested. If the harvesting is to be done in a child, the incision should be thought out carefully to take into account future growth. The placement of the incision is particularly important for female patients. In these patients, one should take into consideration the level of the nipple and the incision site. The incision should be placed so that when the breast mound develops, the incision will not be on the breast proper or cause areolar retraction. This occurrence is best avoided by palpating the level at which the pectoralis muscle ends and placing the incision below this level (approximately 2.5 cm below the nipple) [8]. The specific rib number is not as important as the placement of the incision [9]. By placing the incision at this level, the most commonly harvested rib is either the sixth or seventh rib (Fig. 2).

The incision is made with a #15 blade, and dissection is then continued with electrocautery. The muscles are dissected and the rib is exposed. The periosteum is reflected from lateral toward the medial aspect of the dissection (Fig. 3). Care should be taken so as not to injure the vascular bundle when reflecting the periosteum on the inferior aspect of the rib. The extent of periosteal reflection is based on whether a cartilage cap is going to be harvested. In cases of segmental mandibular resections that do not involve the condyle region in infant patients, a segment of the rib may be used to graft the continuity defect. The ribs are especially suited in this patient population because of the paucity of suitable donor sites in this patient population [10]. In instances in which the cartilage is not needed, the harvest is straightforward. The periosteum is reflected superiorly and inferiorly, and the inner aspect is reflected with the aid of a Doyen (pigtail) retractor. Once the appropriate length is dissected, the medial cut is done followed by the posterior cut with the aid of a guillotine rib cutter.

Fig. 2. Ribs 5 and 6 marked on the left chest wall before harvest.

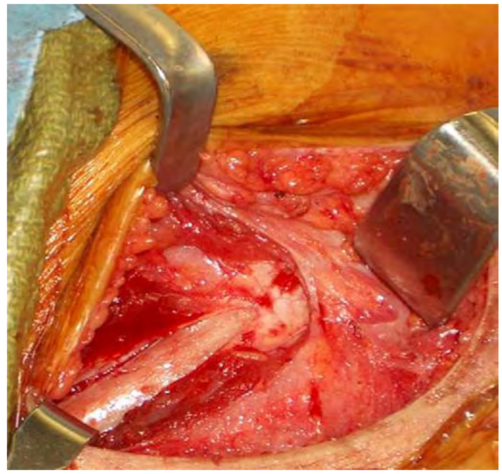

Fig. 3. Exposure of the bony rib before the cartilaginous release.

In instances in which a cartilage cap is needed, the dissection is extended to the costochondral junction, with care taken to leave the overlying periosteum/perichondrium in the area intact. This maneuver aids in the retention of the cartilage cap to the rib. Approximately 2 to 5 mm of cartilage is maintained on the graft, and the medial incision is completed with the use of a blade (Fig. 4). The remainder of the harvesting is the same as previously stated.

Once the harvest is completed, the anesthesiologist is asked to give a positive pressure breath and the presence of air leaks is checked. This maneuver may be aided by placing saline on the field and checking for air bubbles. If one is detected, a small catheter is inserted and a purse string suture is placed around the opening. With the anesthesiologist giving a positive pressure breath, the catheter is removed while the suture is tied. In the event that this maneuver is not successful, it may be repeated or a chest tube inserted.

The incision is closed in layers, taking care to reapproximate the periosteum followed by the muscles. The dermis is closed and a running subcuticular closure is used to close the skin. The incision is covered with steristrips. The harvested costochondral graft is transferred to the head and neck, where the recipient site has been prepared. The distal mandible is well exposed, as is the glenoid fossa. The rib graft is then placed in the most ideal position and secured to native mandible with the aid of titanium plates or wire fixation or both (Fig. 5). Titanium plates can be cut into individual ‘‘washers’’ along with bicortical screws to secure the rib to the native mandible. This technique serves to decrease the likelihood of graft fracture caused by dissipation of stress forces along the graft. Particular care also must be taken at this time not to disrupt the cartilage cap.

Once the graft is secured, the patient is taken out of intermaxillary fixation and the occlusion and rotational and translational movements of the mandible are checked passively. When these movements are found to be satisfactory to the surgeon, the area is irrigated with saline-containing


Fig. 4. Harvest of the rib with preserved cartilage cap.

Fig. 5. Fixation of the costochondral graft to the native mandible with three bicortical screws.

antibiotic and the neck is closed in a standard fashion. The patient may be placed once again in intermaxillary fixation before awakening. The fixation may be maintained for a period of 2 weeks. Upon arrival to the postanesthesia care unit, a chest film is obtained to rule out the presence of a pneumothorax.

## Complications

The most often encountered immediate complications with the rib graft are loss of the cartilage cap and pleural tears. In cases in which the cartilage cap is separated from the rib, the authors prefer to secure the cap to the graft using nonresorbable sutures (Fig. 6). Pleural tears can be managed as stated in the technique section. Delayed complications relate to the cosmetic defects of the chest wall, conspicuous scar near the breast, or areola retraction.

## Discussion

The costochondral graft is used predominantly for condylar reconstruction in children and adolescents. The rib graft also may be used in reconstructing mandibular segmental defects that do not involve the condyles in infants. The advantage of the costochondral graft over other reconstructive modalities is that it has the potential for continued growth. This advantage makes it a better graft than the fibula flap when used in growing patients. This benefit brings with it some uncertainties. The graft has been shown to grow at a different rate than the contralateral natural condyle [11], whereas others have shown no growth, excessive growth, and deficient growth [5]. In cases in which there has been deficient or no growth, evidence exists to the benefit of distraction osteogenesis of the graft [12]. The use of this technique renders it indispensable to oral and maxillofacial surgeons.

Fig. 6. Cartilage cap has been secured to the rib using a nonresorbable suture.

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Atlas Oral Maxillofacial Surg Clin N Am 14 (2006) 185–189

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# The Anterolateral Thigh Flap in Mandibular Reconstruction

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The greatest advancement in head and neck reconstructive surgery in the past two decades has undoubtedly been in the area of microsurgery. The 1970s and 1980s saw a boom in the use of local and regional flaps. The use of pedicled regional flaps experienced an all-time high following Ayrian's publication on the use of the pectoralis major flap for head and neck reconstruction. Although free vascularized flaps had previously been used to reconstruct other areas in the body, their use in the head and neck did not become popular until the 1980s, following Hidalgo's publication of the free fibula flap for the reconstruction of mandibular defects. Equally important was the publication of the use of the radial forearm fasciocutaneous free flap for the reconstruction of head and neck defects. The radial forearm free flap quickly replaced the pectoralis flap as the new "workhorse" for the head and neck. Since then, a variety of free flaps have been described for use in the reconstruction of acquired defects in the head and neck, and in particular the oral cavity.

The concept of perforator flaps has been around for quite a while. However, the first publication of the use of perforator flaps, in particular the anterolateral free flap, did not come until 1984, with the publication of Song's work in plastic reconstructive surgery [1]. Perforator flaps are based on cutaneous, small-diameter vessels that originate from a main pedicle and perforate fascia or muscle to reach the skin [2]. Although controversy exists as to the exact definition of a perforator flap [3], this definition encapsulates the essence of the flap. The most widely known perforator flaps are (1) the deep inferior epigastric flap, (2) the superior gluteal artery flap, (3) the thoracodorsal flap, and (4) the anterolateral thigh flap (ALT) [4].

The ALT flap is a perforator flap that is based on the descending branch of the lateral circumflex femoral artery. It is currently one the most favored flaps for head and neck reconstruction in Asia and has recently gained popularity in the United States. The use of the ALT did not reach its current status as "the radial forearm's big brother" [5] until Chang Gung Memorial Hospital's (Taipei, Taiwan) experience with 672 ALT flaps [6]. The slow adoption of the ALT in the United States has been attributed to the difficulty of dissection, the variations of the vascular anatomy, and the thick thigh commonly found in Westerners [7,8]. Despite these concerns, the ALT has continued to gain popularity as more microvascular surgeons become familiar with the nuances of harvesting this flap.

## Anatomy

The ALT flap is based on the descending branch of the lateral circumflex femoral artery (LCFA). The LCFA is the largest branch from the profunda femoris system. The LCFA has a descending branch that forms the basis for the ALT flap in the majority of cases. It also has an ascending branch and a transverse branch. The main perforator to the ALT may at times

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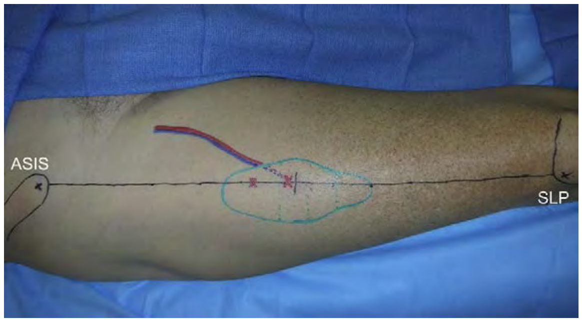


Fig. 1. Skin markings for the harvesting of the ALT flap. A line is drawn from the anterior superior iliac spine (ASIS) to the superior lateral patella (SLP). The halfway point between this line is marked, and Doppler ultrasonography is used to identify the perforators. Once the perforators are marked (*red x's*), the flap to be harvested is marked (*green line*).

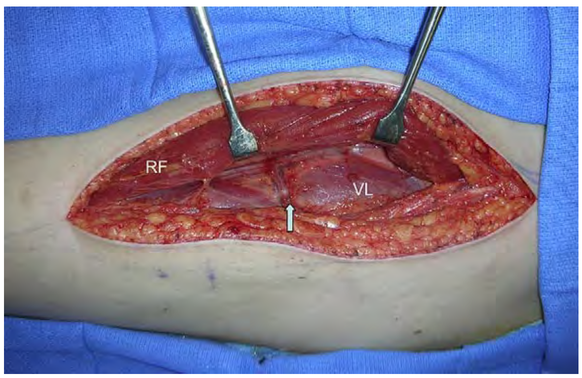


Fig. 2. After medial dissection, the perforators are identified and traced to the descending branch of the LCFA. Note this large perforator is a septocutaneous type (*arrow*). RF, rectus femoris; VL, vastus lateralis.

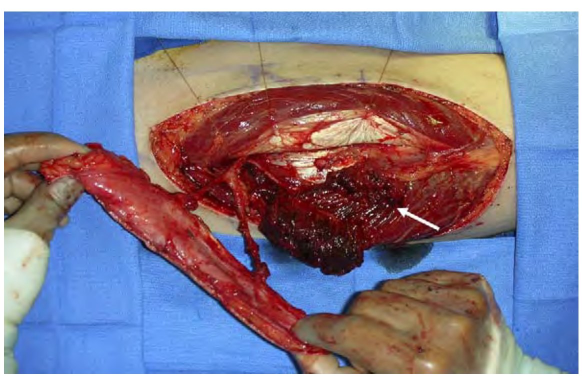

Fig. 3. Dissection of muscular perforator has been completed by intramuscular dissection (*arrow*), the muscle will be reapproximated at the completion of the harvest. Note the thickness of the flap and the incorporation of two perforators.

originate from the transverse branch. The pedicle descends down the leg in the septum formed by the rectus femoris muscle and the vastus lateralis muscle.

The ALT flap can be harvested as a sensate flap by incorporating the anterior branch of the lateral cutaneous nerve of the thigh. The venous drainage of the flap is based on two venae commitans of the LCFA. The pedicle of the flap varies from 8 cm to as long as 16 cm and has a vessel diameter of 2 mm.

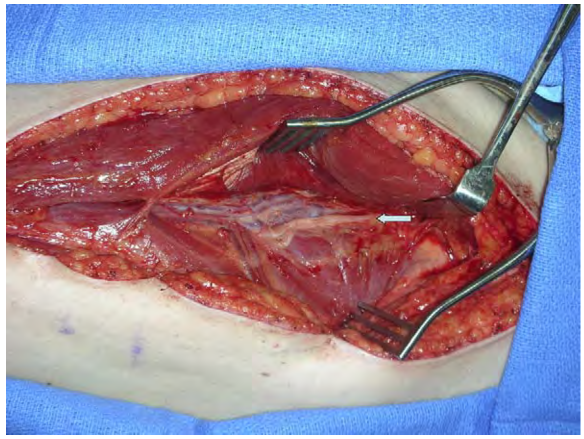

Fig. 4. Dissection has been performed in a cephalad direction and the motor branch to the vastus lateralis muscle is noted traveling in intimate association with the main vascular pedicle (*arrow*).

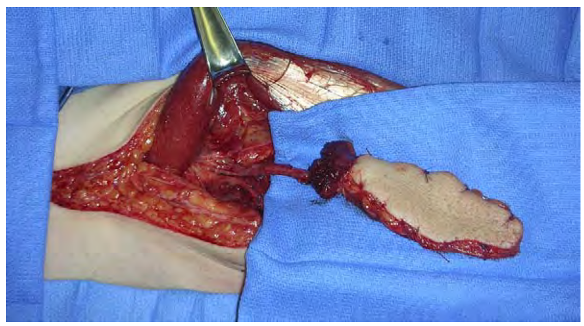

Fig. 5. Once adequate length of the vascular pedicle is dissected, the vessels are then divided and transferred to the head and neck.

Fig. 6. Harvested ALT flap. Note the length of the vascular pedicle and the excellent thickness of the flap.

## Harvesting technique

The flap is raised with the patient in the supine position. A mark is made from the anterior superior iliac spine to the superolateral point in the patella. Midway between these two points a mark is made, and then with the aid of Doppler ultrasonography, the perforators are marked out (Fig. 1). The most common position for the perforators is at the inferior lateral quadrant. An incision is then made on the medial aspect of the thigh, proceeding downward to the fascia. A subfascial dissection is performed laterally until the perforators are identified. The vast majority (88%) of the perforators will be muscular perforators (Fig. 2), while a smaller (12%) percentage will be septocutaneous perforators (Fig. 3). Once the perforators are identified, dissection is continued between the vastus lateralis and the rectus femoris in a cephalad direction. At this time, care should be taken to identify and preserve the motor branch of the nerve

Fig. 7. Example of ALT flap based on two separate perforators, allowing for two separate skin paddles with a single main vascular pedicle.


Fig. 8. (*A*) Extensive defect of the chin, lip, mandible, and floor of the mouth secondary to a self-inflicted gunshot wound. (*B, C*) Frontal view and profile of the patient after initial closure of the defect. Note the significant mandibular deficiency. (*D*) Initial insertion of the ALT flap along the floor of mouth with the pedicle brought to the right neck. (*E*) The ALT flap is de-epithelialized after completion of the vascular anastomosis. The de-epithelialized area allows for separate reconstruction of the floor of the mouth and the chin. (*F*) Early postoperative healing of the ALT flap. (*G, H*) Postoperative facial frontal view and lateral view of the patient after the re-establishing of the facial projection and a more harmonious profile.

to the vastus lateralis (Fig. 4). The pedicle is traced between the two muscles in a cephalad direction. Once the pedicle length is found to be of adequate length for transfer and tension-free anastomosis, the flap is harvested after completion of the lateral skin incisions and dissection to the pedicle (Figs. 5–7). In cases where the perforator is a musculocutaneous type, meticulous muscular dissection must be performed, taking care to identify and clip the muscular branches. The donor site is then closed primarily after undermining the edges of the incision. Suction drains are routinely used.

## Case illustration

A 43-year-old male was brought to the emergency room after a self-inflicted gunshot wound to the lower face. He suffered extensive soft tissue loss to the chin, the floor of the mouth, and the lower lip. He also lost the bone on the anterior mandible. The patient was reconstructed during the initial hospitalization with an osteocutaneous fibula free flap. Due to extreme agitation secondary to narcotic withdrawal, the patient suffered a total flap loss. The flap was debrided and the defect closed primarily until he was stabilized. After discharge and psychiatric care, he was taken back to the operating theater, where his soft tissue defects were reconstructed with an ALT flap. The ALT flap allowed for the restoration of mandibular projection by providing coverage over a mandibular reconstruction bar while reconstructing the floor of the mouth and the lip and chin soft tissue defect (Fig. 8A–H).

## Discussion

The advantages of the ALT flap are numerous. One of the great appeals of this flap is that it has low donor site morbidity and is at a site where it can be easily hidden. A large amount of skin territory can be harvested with ease of harvest, allowing a two-team approach. Another benefit of the ALT is its ability to withstand thinning. That ability allows the ALT to be "custom" fitted to the defect, not only in size but also in depth.

The main drawback of the ALT flap is the difficulty in elevation when the main perforator is a musculocutaneous type.

The boundaries of reconstructive surgery continue to be pushed. A testament to this is the publication by Wei and colleagues on the concept of "free style perforators flaps," where Doppler ultrasonography is used to find a perforator in a suitable area, and a flap is outlined and raised down to the axial vessel [3]. This approach will be rendered even more commonplace with the advent of "super-microsurgery" [9]. These concepts make it a very exciting time to be a surgeon involved in the reconstruction of these most difficult head and neck defects.

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