Reconstruction of Mandibular Defects

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ABSTRACT

Defects requiring reconstruction in the mandible are commonly encountered and may result from resection of benign or malignant lesions, trauma, or osteoradionecrosis. Mandibular defects can be classified according to location and extent, as well as involvement of mucosa, skin, and tongue. Vascularized bone flaps, in general, provide the best functional and aesthetic outcome, with the fibula flap remaining the gold standard for mandible reconstruction. In this review, we discuss classification and approach to reconstruction of mandibular defects. We also elaborate upon four commonly used free osteocutaneous flaps, inclusive of fibula, iliac crest, scapula, and radial forearm. Finally, we discuss indications and use of osseointegrated implants as well as recent advances in mandibular reconstruction.

KEYWORDS: Bone flap, condyle, fibular flap, mandible, osseointegrated implant, osteocutaneous flap

Continuing advances in mandibular reconstruction have greatly improved functional and aesthetic outcomes for patients. Outcomes from free vascularized bone flaps have proved markedly superior to those obtained from use of nonvascularized options such as reconstruction plates and bone grafts. The free fibula flap continues to remain the gold standard for mandibular reconstruction against which other modalities are compared.

The mandible serves several important functions in the head and neck, which can be restored to near-normality with the use of vascularized bone flaps. It provides a stable platform for the oral cavity and also a structure to which muscles attach. Most importantly, it allows mastication by providing a stable counterpoint to the maxilla and serving as a base for attachment of dentition. It facilitates speech, swallowing, and breath-

ing by maintaining space within the oral cavity and allowing the tongue to function. It also serves an aesthetic function, defining the projection of the lower third of the face.

ANATOMY OF THE MANDIBLE

The mandible is a U-shaped bone that articulates with the skull base through two unique temporomandibular joints (TMJs), which allow smooth and coordinated mouth opening. The TMJ is a diarthrodial joint, consisting of two bones articulating in a discontinuous fashion allowing freedom of movement dictated by muscles and limited by ligamentous attachments. The TMJ is also lined on its internal aspect by synovium, which secretes synovial fluid, serving both as a lubricant and a nutrition source for joint structures.

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The TMJ is termed a *ginglymoarthrodial joint* as it is functionally divided into two compartments, separated by an articular disk.¹ The superior compartment allows sliding or translational movements and is termed *arthrodial*, and the inferior compartment allows hinge motion or rotation and is therefore termed *ginglymoid*. The TMJ is one of the only synovial joints in the body with an articular disk. The inferior compartment functions in initial mouth opening from an interincisal distance of 0 to 20 mm. Subsequently, the superior compartment allows further translational movement to full mouth opening, to an interincisal distance of 50 mm. In this arthrodial movement, the entire apparatus consisting of the condylar head and articular disk translates in relation to the mandibular fossa of the temporal bone.

On its superior aspect, the mandible bears 16 permanent teeth anchored into the alveolus, consisting of 1 central incisor, 1 lateral incisor, 1 canine, 2 premolars, and 3 molars on each side. These facilitate mastication and can be restored with the use of osseointegrated implants after mandibular reconstruction.

Mandibular movement is provided largely by the four muscles of mastication, which consist of the masseter, temporalis, medial pterygoid, and lateral pterygoid. These muscles are all innervated by the mandibular division of the trigeminal nerve. The lateral pterygoid serves to open the mouth and protrude the mandible, whereas the other three muscles close the mouth and elevate the mandible. Preserving the attachments of these muscles where possible during the resection prevents an imbalance in forces, which can result in pain and altered mouth opening, particularly after radiation therapy.²

TYPE OF DEFECT AND APPROACH TO RECONSTRUCTION

Mandibular defects can generally be considered by their location and extent and can be divided into defects involving the anterior mandible, lateral mandible, and ramus/condyle. The Jewer classification provides an aid in classifying mandibular defects³ and reflects the complexity of the reconstructive problem. Central defects including both canines are designated "C," and lateral segments that exclude the condyle are designated "L." When the condyle is resected together with the lateral mandible, the defect is designated "H," or hemimandibular. Eight permutations of these capital letters—C, L, H, LC, HC, LCL, HCL, and HH—are encountered for mandibular defects. The significance of this is that a lateral defect can be reconstructed with a straight segment of bone, whereas a central defect would require osteotomies. The classification was modified⁴ to include a soft tissue description as well, with "t" representing a significant tongue defect, "m" a mucosal defect, and "s" an external skin defect. As an example, reconstruction of

an LCL-mt defect would be much more complex and require more volume than would a simple L defect.

Anterior mandibular (C) defects will typically constitute an absolute indication for reconstruction using vascularized bone. Due to multiple osteotomies required to contour the bone, fibula should be considered the first choice for reconstruction of anterior or large defects.^{5,6} Other modalities of reconstruction have resulted in poor outcomes.

Some centers will reconstruct lateral (L) defects with vascularized bone,^{6,7} whereas others would prefer to use soft tissue flaps with or without plates for reconstruction. In general, reconstruction with vascularized bone has led to better outcomes, with complication rates ranging from 0 to 18%,^{6,7} and an increased number of patients returning to a regular, unrestricted diet (47 to 65%).^{6,7}

Reconstruction with plates has resulted in variable outcomes, with reported complication rates ranging from 7 to 69%.⁸⁻¹² Plate exposure is one of the most common complications^{8,12} and is often the reason for secondary salvage surgery with a vascularized bone flap. Low success rates of plate-only reconstruction have been reported, ranging from 34% at 6 months¹³ to 64% at 1-year follow-up.¹⁴ Plate viability was further reduced by radiation therapy. In our experience, plate reconstruction alone is prone to failure. Not only does the plate become exposed in many instances, leading to complications such as infection and orocutaneous fistulae, but also plate failure is a serious complication that necessitates a second salvage surgery.

Nonvascularized bone grafts (NBGs), such as from iliac crest, are another option for reconstruction of small pure lateral mandibular defects. These are less often used nowadays, however, particularly in centers with microvascular expertise. NBGs are associated with a high rate of complications¹⁵ and are prone to undergoing osteoradionecrosis after radiation therapy. A direct comparison of NBGs and vascularized bone flaps (VBFs) in 75 consecutive reconstructions by Foster et al¹⁶ reported a rate of bony union in 69% of NBGs and 96% of VBFs ($p < 0.001$). Hence, NBG may best be suited for reconstruction of small L defects (<6 cm) in patients who will not tolerate major surgery or in centers without microsurgical expertise. An example is shown in Fig. 1, where a nonvascularized rib segment was used to reconstruct an H defect. Deviation of the mandibular midline to the left has already occurred, and this is a scenario where the patient would be unable to masticate, and where not only has the plate failed but the bone graft would ultimately fail as well.

An argument for using soft tissue flaps alone instead of VBF in reconstruction of posterolateral defects was presented by Mosahebi et al.¹⁷ Often, the skin paddle with a fibula flap is inadequate for reconstruction of large posterosuperior soft tissue and intraoral defects,

Figure 1 Nonvascularized rib was used to bridge a left hemimandibulectomy defect in this patient. Early deviation of the mandibular midline to the left is seen on this Panorex. Ultimately, this form of reconstruction is doomed to failure, with the patient unable to masticate, and potential for failure of the bone graft, particularly after radiation therapy.

as well as through-and-through defects that may require more than one skin paddle for reconstruction. Also, the stiffness of the skin and subcutaneous tissue overlying the fibula does not facilitate molding of the skin paddle into complex three-dimensional defects. The fibula flap does not provide sufficient bulk to fill defects in resections extending superiorly to the glenoid fossa or to the temporal bone.

Soft tissue flaps alone, such as anterolateral thigh (ALT), gracilis, rectus, and latissimus dorsi, have been used successfully in reconstruction of posterolateral defects,^{17,18} with outcomes not statistically different than those obtained with VBF. However, postoperative occlusion was found to be better in one study when vascularized bone was compared with soft tissue flaps for reconstruction of posterior mandibular defects.¹⁸ In the same study, however, 45% of patients were able to tolerate a regular diet despite a suboptimal occlusion. A study by King et al,¹⁹ however, found that VBF had statistically significant superior functional and aesthetic scores for diet, oral competence and speech, public dining, and midline symmetry compared with those of soft tissue flaps alone for reconstruction of posterior mandible defects.

Though advocates for use of soft tissue flaps alone for reconstruction of posterolateral defects present compelling arguments, some centers routinely reconstruct these defects with multiple free flaps. Wei et al^{20,21} have routinely used combinations such as fibula-ALT, fibula-radial forearm, or iliac crest-tensor fasciae latae flaps with excellent results. Another less technically demanding option is the fibula-pedicled pectoralis major combination.²² An argument against the use of soft tissue flaps alone for reconstruction of L- and H-type defects is that the imbalance of forces on the remaining native mandible results in a deviation to the resected side leading to eventual wear, loss of function, and caries.⁹

In patients who may not be fit for extensive surgery involving free tissue transfer due to comorbidities, regional soft tissue flaps such as pedicled pectoralis

major or cervicodeltopectoral can be used for reconstruction of L and H defects. In practice, it was found in a study by Deleyiannis et al^{23,24} that advanced age (>70 years), moderate or severe comorbidity, and tumor involvement of the base of the tongue were factors that favored use of regional flaps.

In general, it is clear that, if the patient is fit for major surgery, reconstruction of H- and L-type defects with VBF is preferred.^{19,25} However, soft tissue only reconstruction is an acceptable alternative with adequate long-term outcomes. Plate reconstruction and regional flaps should be reserved for patients unfit for major surgery, patients with a poor prognosis, or for salvage surgeries.

CONDYLE RECONSTRUCTION

Reconstruction of the condyle aims to preserve sufficient interincisal opening and also to preserve balance of the mandible articulating against the skull base to stabilize the muscles of mastication and preserve preoperative occlusion. Where possible, the condyle should be preserved during the resection. Otherwise, the condyle can also be affixed as a nonvascularized graft to the end of the reconstruction. Hidalgo^{4,26} showed that nonvascularized condyles transected at the midramus level or higher and subsequently attached to the reconstructed neomandible survived more than a decade. Other options include placing the end of the bone flap into the fossa, interposing periosteum²⁷ or temporalis muscle-fascia.²⁸ The aim in this case is to achieve a painless gap arthroplasty at the TMJ. Surprisingly, many patients do remarkably well, being pain-free and able to chew food.

Costochondral rib grafts have been used for reconstruction of the condyle.^{29,30} In juveniles, the graft will grow with the native mandible. Good results have been reported, with one study reporting an interincisal opening of at least 30 mm in all patients.²⁹ A pure soft tissue reconstruction has also been used successfully, without reconstruction of the mandible.^{18,31} Importantly, adequate soft tissue as a filler in the TMJ both reduces drift of the remaining mandible toward the side of the resection and camouflages the cut edge of the remaining mandible.^{18,32} Criticisms of not reconstructing the condyle are that this relies on the contralateral TMJ to maintain adequate stability and movement of the mandible, leading to inevitable deviation of the mandible to the nonreconstructed side and subsequent malocclusion.⁹

COMMONLY USED FREE FLAPS

Fibula Flap

The fibula provides the best option for mandible reconstruction. It provides a long segment of bone, up to

25 cm in length, that can tolerate multiple osteotomies without compromising its blood supply.³³ It has a sizeable (2 to 3 mm) and lengthy (15 cm) pedicle based on the peroneal artery and its venae comitantes that is

sufficient in most defects. It is usually harvested with an accompanying skin paddle (Fig. 2) and can also be harvested with flexor hallucis longus³⁴ or soleus muscle³⁵ to fill soft tissue defects. The skin paddle is reliably

Figure 2 A large left CL-ms mandibular defect with involvement of floor of mouth and external skin was reconstructed using a free fibula flap. (A) Preoperative CT showing multicystic ameloblastoma involving left mandible, with gross erosion through external bony cortices. (B) Preoperative view showing erosion through skin over the chin. (C) Intraoperative defect. (D) Resected specimen. (E) Fibula flap after harvest. (F) Final result at closure.

vascularized by septocutaneous perforators from the peroneal artery in 90 to 95% of cases. In a small subset of patients, musculocutaneous perforators have been found to originate from the peroneal artery, posterior tibial artery, or tibioperoneal trunk, necessitating a second set of microvascular anastomoses for preservation of the skin paddle.³⁶ Another major advantage of the fibula flap is the ability to use a two-team approach, where the resecting and reconstructive team are able to work simultaneously, as the fibula is far from the head and neck. Reinnervation of free fibula flaps is possible, using the lateral cutaneous sural nerve as the target for neurotization.^{37,38}

The reliability and viability of mandibular defects reconstructed with vascularized fibula has been shown more than a decade out from surgery by Hidalgo et al,⁴ with 70% of patients tolerating a regular diet, maintenance of good aesthetic results, and maintenance of good bone height (92 to 93%).

Donor site morbidity from fibula flap harvest is slight, with main issues being pain on ambulation and ankle instability. A majority of patients (ranging from 72 to 76%) were pain-free on ambulation.^{39,40} As a caveat, whereas function was preserved with fibula harvest, Bodde et al found that restoration of gait was not complete while walking at high velocity or while performing complicated actions.⁴¹ Early complications that can be prevented through meticulous technique include skin graft loss, wound dehiscence, and compartment syndrome from excessively tight primary closure of the donor site. Late complications such as weakness of great toe flexion can also be prevented by preservation of the neurovascular supply to the flexor hallucis longus.^{41,42} By ensuring that a sufficient segment of distal fibula is preserved, problems with ankle instability and pain can be prevented.

Several technical refinements help in maximizing the reconstruction. A drawback of fibula for mandibular reconstruction is its limited height,⁴³ which does not allow both contouring of the inferior mandibular margin and restoring sufficient alveolar height for dental implants. One solution is to inset the fibula construct in a double-barreled fashion,^{44,45} greatly increasing the height of the neomandible. This is particularly useful for reconstruction of anterior (C) defects. The fibula can also be placed more superiorly, around 10 to 15 mm inferior to the occlusal plane, to provide sufficient bone height for placement of implants.⁴⁵ The inferior border may be reconstructed with a supplementary 2.4-mm reconstruction plate to restore lower facial projection. Vertical distraction osteogenesis can also be applied secondarily to gain adequate alveolar height for osseointegrated implants, using a horizontal osteotomy.⁴⁵⁻⁴⁷

The role of preoperative angiography remains controversial. It has a definite use in patients with known peripheral vascular disease, previous leg trauma, or pre-

vious surgery.⁴⁸ Noninvasive modalities such as magnetic resonance angiography⁴⁹ and computed tomography (CT) angiography⁵⁰ have reduced the invasiveness of angiography but are disadvantaged by the cost of routine studies. Some would advocate preoperative angiograms for all patients⁵¹ due to its high positive predictive value and sensitivity in detecting vascular aberrations; however, others believe that this is unnecessary.⁵² The decision for routine preoperative angiography would ultimately depend on one's preference and practice.

Iliac Crest Osteocutaneous Flap

The iliac crest provides a large piece of curved corticocancellous bone, measuring 6 to 16 cm in length. It has a natural curvature that complements the curve of the lateral, and sometimes anterior, mandible and can be placed accordingly to fill defects. The flap is based off the deep circumflex iliac artery (DCIA), which arises from the lateral aspect of the external iliac artery, and can be harvested with its overlying skin, supplied through cutaneous perforators. When an osteocutaneous flap is harvested, a cuff of oblique and transversalis muscles must be included to protect the deep circumflex iliac vessels and musculocutaneous perforators, with the muscle cuff harvested in continuity with the overlying skin island. The diameter of the DCIA is in the range 2 to 3 mm, and the length of the pedicle from the anterosuperior iliac spine to its junction at the external iliac artery is around 5 to 7 cm.⁵³

Advantages with use of the DCIA flap include a bone height that is often greater than that achieved with the fibula flap, as well as arguably the best donor site cosmesis of all commonly used free flaps in mandible reconstruction, being hidden under clothing. A large amount of bone that tolerates placement of osseointegrated implants can be harvested. In a defect extending across the midline, an osteotomy can be performed to recreate the contour of the anterior mandible.^{3,54} In this instance, it is important that the periosteum and iliacus muscle on the medial surface are kept intact to maintain the blood supply to the distal portion of the iliac crest. The muscle cuff bridging the two segments along the superior margin of the iliac crest must also be kept in continuity. Due to laxity of skin in the area, primary closure of the donor site is often possible.

However, the DCIA flap also has several significant disadvantages, which has prevented it from becoming the gold standard in mandibular reconstruction. Groin skin provides a poor color match in the head and neck. The natural curvature of the iliac crest makes shaping the bone in anterior defects difficult. The obligatory muscle cuff is bulky and difficult to inset, and it results in a poor aesthetic outcome. The bulky soft tissue part of the flap is not easily inset in relation to the bone, as the musculocutaneous perforators to the skin do

not tolerate shearing and torsion well. This makes resurfacing of intraoral defects difficult as the skin paddle is located on the external aspect of the iliac crest bone. Accessory flaps such as pedicled pectoralis major to reconstruct one surface or a second free flap are options in reconstruction of extensive through-and-through mandibular defects.

As harvest of the DCIA flap involves extensive dissection and division of the oblique and transversalis muscles, there is the risk of postoperative hernia. This can be prevented through meticulous closure of the

abdominal wall as detailed by Taylor.⁵⁵ Another complication is injury due to the lateral cutaneous nerve of the thigh and subsequent numbness in that region due to the excessive dissection required. Patients typically have pain at the donor site that limits gait and prevents early mobilization. This may limit the use of the DCIA flap in elderly patients. In general, however, gait disturbance resolves after the initial postoperative period.³

In our practice, the DCIA flap is used as a second-line free flap, when the fibula is not available. An example is illustrated in Fig. 3, where the patient had a

Figure 3 A deep circumflex iliac artery (DCIA) flap was used to reconstruct a large right LC-s mandibular defect, where the fibula and radial forearm were not available due to previous reconstruction. (A) Intraoperative photograph showing the flap inset and held in place with a 2.4-mm reconstruction plate. (B) Harvested iliac crest osteocutaneous flap. (C) Complete dental restoration with osseointegrated implants, 14 months after surgery. (D) Panorex shows union of DCIA flap with native mandible on both sides. Part of the reconstruction plate has been removed to facilitate placement of osseointegrated implants. (E) Frontal view of patient, 14 months after surgery.

successful reconstruction and ultimately full dental rehabilitation using osseointegrated implants.

Scapular Free Osteocutaneous Flap

The scapular osteocutaneous free flap is based off the circumflex scapular arterial (CSA) system. It provides an unparalleled quantity of skin and soft tissue and also allows chimeric flaps to be harvested, with multiple skin paddles for reconstruction of complex mandibular defects. When a very large quantity of soft tissue is required, the scapular flap can be harvested together with the latissimus dorsi for additional fill.⁵⁶ Skin paddles can be based off the transverse branch (scapular flap) or vertical branch (parascapular flap) of the circumflex scapular system. Bone is supplied either by perforating vessels from the CSA or the angular branch of the thoracodorsal artery. The lateral border of the scapula provides up to 14 cm of corticocancellous bone.⁵⁷ The diameter of the vessels is 2 to 3 mm, and pedicle length is 6 to 9 cm.

Unfortunately, bone harvested with the scapular osteocutaneous flap lacks a segmental blood supply and hence does not tolerate osteotomies. A single osteotomy can be made, with two bone segments based off the CSA and angular branch of the thoracodorsal artery. The angular branch can supply as much as 8 cm of inferior border scapular bone,⁵⁷ and originates 6 to 9 cm from the bony branch of the CSA.⁵⁸ The quality of scapular bone is, in general, inferior to that obtained with fibula and DCIA flaps; however, a majority of specimens tolerate placement of osseointegrated implants.⁵⁹

Advantages of the scapular flap include a concealed donor site and large quantity of skin and soft tissue. Disadvantages include inability to use a two-team approach as harvest of the flap necessitates turning from the supine to lateral position, as well as decreased range of motion of the shoulder and difficulty lifting objects after surgery.^{57,60} However, in a study by Coleman et al,⁶¹ symptoms of pain, mobility, and strength were judged as "mild" for most patients, with little to no limitation of activities of daily living.

Radial Forearm Osteocutaneous Flap

The radial forearm flap provides a large quantity of soft, supple tissue that finds many applications in reconstruction of the head and neck. As an osteocutaneous flap, however, it is limited in that only a short segment of thin monocortical bone measuring up to 14 cm can be harvested and does not tolerate osteotomies well. Bone harvest should be limited to 30% of the circumference to prevent subsequent fracture of the radius.⁶² Success of single and double osteotomies using radial bone, however, has been reported for mandible reconstruction.⁶³ To preserve viability of the bone, it must be harvested in continuity with a cuff of flexor pollicis longus to preserve

perfusion from branches through the lateral intermuscular septum from the radial artery. Because of its limited thickness, radial bone supports osseointegrated implant placement poorly.⁶⁴

The main criticism of the radial forearm osteocutaneous flap is the incidence of fracture of the radius after flap harvest, which, in the literature, has ranged from 0 to 67%.⁶²⁻⁶⁵ Methods to prevent this include use of a keel-shaped osteotomy,⁶² prophylactic plating⁶⁶ of the radius, bone grafting of the donor, and preventing overzealous bone harvest. Other limitations include an unsightly donor site as well as requirement for a volar splint or cast if a split-thickness skin graft is used to aid in closure of the donor site.

Prefabricated radial forearm flaps have recently been reported for mandibular reconstruction, circumventing the problem of inadequate bone stock. Leonhardt et al⁶⁷ reported implantation of cylinders of cancellous iliac crest, with elevation and transfer of the flap 4 weeks later. Bone consolidation was observed 4 years after surgery.

OSSEOINTEGRATED IMPLANTS

Dental rehabilitation is an important part of mandible reconstruction. The use of osseointegrated implants allows stable anchorage for placement of implant-borne dentures, even in the absence of an alveolar ridge, allowing restoration of speech and mastication and enhancing dental cosmesis. The reported incidence of use of osseointegrated implants ranges from 0 to 40%.^{68,69}

Implants can be placed at the time of the primary reconstruction or secondarily with a delayed procedure. Advantages of primary implant placement include enhanced access to the bone segment and increased surgical exposure, allowing accurate alignment of implants with the opposing maxillary dentition. Primary placement also avoids the need for a second surgery, enhancing the speed of dental rehabilitation and social adjustment.⁷⁰ This is generally reserved for patients with benign lesions or low-grade malignant tumors with excellent prognoses.

Delayed placement of osseointegrated implants is favored by others, who suggest that blood supply of the bone flap at the primary surgery may be compromised because of osteotomies and hardware placement, and also that placement of implants is less precise at the first surgery, as healing of the soft tissues and bone has not yet occurred. Also in patients with an unknown prognosis, it may not be appropriate to place implants primarily.⁶⁸

The placement of implants before and after radiotherapy has been advocated by different authors. As there is typically a delay of ~6 weeks between reconstruction and radiation therapy, and a further delay before onset of the effects of radiation on bone, Urken has argued that primary placement allows osseointegration in the interim period.⁷¹ However, other reports

suggest that postoperative radiation increases the risk of loosening of fixtures and development of secondary osteoradionecrosis.^{72,73} Placement of implants after radiotherapy prevents wasting of implants in patients with a poorer prognosis. Implant survival has been reported to be worse in previously irradiated mandibles compared with that for mandibles not exposed to radiation.^{74,75}

Prerequisites for placement of osseointegrated implants include an adequate vertical bone height, with different authors quoting values ranging from 5 to 10 mm.^{59,68–75} A minimum of 1 mm of healthy bone surrounding the implants is also required.⁷⁶

RECENT ADVANCES

Recent research into mandible reconstruction has focused on the use of tissue engineering approaches to repair bone defects, mostly in large animal models such as swine, goats, and primates. Scaffolds ranging from collagen sponges⁷⁷ to autologous autoclaved bone⁷⁸ have been used together with bone marrow–derived stromal cells and growth factors such as bone morphogenetic protein (BMP)-2^{77,79} to facilitate osteogenic differentiation of implanted cells. BMP-2 has also been used clinically to aid in osseous regeneration of critical-sized mandibular defects with success.⁸⁰ Significantly, a tissue-engineered vascularized bone graft was used successfully to repair an extended mandibular defect in a man.⁸¹ Three-dimensional CT and computer-aided design techniques were used to create a titanium mesh cage filled with bone blocks and infiltrated with BMP-7. The construct was then implanted into the latissimus dorsi muscle and transferred 7 weeks later as a prefabricated free flap. Such translational advances in basic science research certainly promise better options for reconstruction of the mandible.

CONCLUSION

Patients requiring mandible reconstruction today have much better outcomes. Vascularized bone flaps are the best option for a functional and aesthetic reconstruction, with the free fibula flap remaining the gold standard for mandible reconstruction. Reconstruction with alternative flaps such as scapula, iliac crest, and radial forearm flaps results in good outcomes in patients in whom fibula flaps are not available. Advances in translational research promise new modalities of treatment.

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