Introducing the Tibial–Dorsalis Pedis Osteocutaneous Shin Flap: A New Option for Oromandibular Reconstruction

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Background: The authors investigated the possibility of incorporating a well-vascularized, partial corticotomy of the anterolateral aspect of the tibia "in-series" with a dorsalis pedis fasciocutaneous free flap for oromandibular reconstruction.

Methods: A cadaveric injection study was performed to characterize the vascular territory of the anterior tibial artery with regard to the surrounding osseous and soft tissue. The two-point breaking strength of the tibia (twist) was examined with fracture strain gauge analysis to determine the threshold of tibia corticotomy that would lead to a pathologic fracture. Finally, the authors performed an in vivo prospective clinical examination of the tibial–dorsalis pedis osteocutaneous shin flap.

Results: The perfusion study revealed that the anterior tibial artery provided a rich matrix of musculofascial periosteal blood supply to the anterolateral cortex of the tibia that could potentially support free osseous tibial transfer. Two-point osteotomy fracture strain gauge analysis demonstrated that the threshold of tibia corticotomy that would lead to pathologic fracture of the remaining tibia was greater than 30 percent. The osteocutaneous shin flap was performed in eight patients. The mean follow-up was 61 months. There were no cases of flap loss, salivary fistula, nonunion, or tibia pathologic fracture. All patients achieved ambulation.

Conclusions: The authors introduce the osteocutaneous tibial–dorsalis pedis free vascularized flap as a viable option for oromandibular reconstruction. Its most notable advantage is the independent mobility of the skin paddle, in combination with bone stock that replicates mandibular bone dimensions, facilitating primary osseointegration or denture rehabilitation. (*Plast. Reconstr. Surg.* 132: 611e, 2013.)

CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, IV.

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THERAPEUTIC

The reconstruction of composite oral cavity defects remains a significant challenge. Reconstructive options for these functional and aesthetic defects have evolved from bone grafts and regional flaps to free tissue transfers. The latter include the iliac crest,[1,2] radial forearm,[3] scapula,[4] and fibula[5] osteocutaneous free flaps. Other options for oromandibular reconstruction include alloplastic reconstruction plates covered by regional musculocutaneous[6] or fasciocutaneous free flaps.[7]

The donor-site requirements for this reconstructive region are demanding, particularly when radiotherapy has been used. The functional aspects of mastication warrant good bone stock and usually a thin, pliable, well-vascularized skin paddle. In addition, the aesthetic outcome of mandibular arch reconstruction remains essential in the social rehabilitation of the oral cancer patient. To complicate the problem, the patients often have a compromised lifespan and a need for a rapid return to acceptable functional performance to maximize their remaining quality of life.[8]

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Some of the limitations of existing osteocutaneous free flap reconstructions include immobile soft-tissue paddles that are thick, insensate, and limited in their capacity for use in reconstructing the three-dimensional soft-tissue needs of the oral cavity. In addition, the bony component often lacks both width and height, limiting its ability to provide a solid foundation for dentures, osseointegrated implants, or dental rehabilitation. It was with these limitations in mind that the authors set out to investigate the possibility of incorporating a well-vascularized partial corticotomy of the anterolateral aspect of the tibia "in-series" with a dorsalis pedis fasciocutaneous free flap.

The theoretical advantages of this type of free tissue transfer are numerous. First, the harvested bone from tibial corticotomy could be designed to match the height and width of the mandibular bone stock, allowing for dental rehabilitation. Second, with an attached dorsalis pedis fasciocutaneous component, such a flap would possess a large, thin, pliable, potentially sensate soft-tissue paddle on a long vascular pedicle with 360 degrees' freedom of motion and nearly total independence from the tibial graft. This would emancipate the soft-tissue mucosal reconstruction from the tethering limitations seen in virtually all other osteocutaneous flaps, and facilitate complex three-dimensional restitution of difficult mucosal defects. Finally, the skin paddle could easily be reinnervated (by means of the superficial peroneal nerve) while remaining only loosely tethered to the bone by a long extension of the flap's vascular pedicle: the anterior tibial artery and vein.

PATIENTS AND METHODS

The study consisted of three components. The first two portions were in vitro studies examining the feasibility of an osteocutaneous flap based on the anterior tibial artery. The third and final component was a prospective clinical examination of the flap in patients with oromandibular defects.

Part I: Perfusion Study

A perfusion study was performed on fresh cadaveric legs in which the anterior tibial artery was injected with a radiopaque dye. The tissues were imaged with radiographic techniques. Images were then reviewed to characterize the vascular territory of the anterior tibial artery with regard to the surrounding osseous and soft tissue.

Part II: Point Breaking Strength

With the anterolateral tibial musculoperiosteal perfusion established, two-point breaking strength of the tibia was examined. A standard two-point osteotomy fracture strain gauge analysis was used to determine the forces required to fracture intact cadaveric tibias and tibias with corticotomy. In the latter case, the procedure was performed with and without the presence of intramedullary nails.

Part III: Clinical Study

Following the perfusion and two-point osteotomy studies, clinical implementation of this free flap was carried out. Patients requiring oromandibular reconstruction were evaluated prospectively. Inclusion criteria included the following:

1. A digital subtraction angiogram demonstrating three-vessel inflow into the leg.
2. The absence of atherosclerotic or diabetic vascular disease.
3. The absence of ankle or knee osteoarthritis and chondritis.
4. Mandibulectomy defects with significant soft-tissue defect (i.e., mucosal loss, partial glossectomy, floor-of-mouth resection) necessitating sensate soft-tissue reconstruction.

Preoperatively, for each patient, age, sex, cause of disease, and radiation history were recorded. Intraoperatively, the soft-tissue and osseous defects were quantified. Details characterizing each flap's vascular anastomosis and sensory coaptation were noted. The follow-up visit was in the office for all patients. Postoperatively, complications were recorded.

Flap Harvest

Flap harvest was the same in all patients of this study. The tibial bone and dorsalis pedis soft-tissue skin paddle are marked on the patient's lower extremity according to the oromandibular defect (Fig. 1). The anterior tibial artery is approached through an anterolateral longitudinal pretibial incision (Fig. 2). Dissection proceeds in the plane between the tibialis anterior and the extensor digitorum longus in the proximal third of the leg and between the tibialis anterior and the flexor hallucis longus in the middle third. This is the natural course of the anterior tibial artery, which, as it descends, comes to lie closer and closer to the anterolateral surface of the tibia, until, in the lower

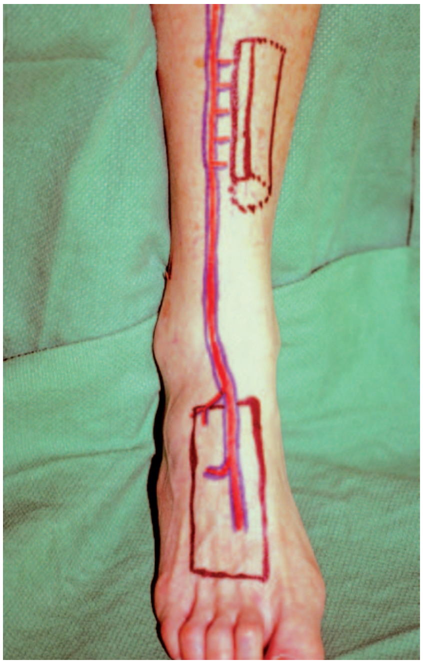

Fig. 1. The "shin" flap marked out on the patient's leg showing the anterior tibial vascular pedicle, the tibial bone, and the in-series dorsalis pedis skin flap.

third it actually lies on the bone. It then crosses the ankle joint under the tendon of the extensor hallucis longus to become the dorsalis pedis in the foot. The periosteal blood supply of the tibia, from the anterior tibial artery, is carefully preserved as the anterolateral tibia is exposed (Fig. 2). In the proximal two-thirds of the leg, these branches pass through the tibialis anterior. It is important to preserve innervation of the tibialis anterior by safeguarding some of the branches from the deep peroneal nerve, particularly in the proximal third of the leg. However, some lower branches may be sacrificed if necessary. A one-third corticotomy of the anther tibia is made with the reciprocating saw corresponding to the exact length of the mandibulectomy defect (Fig. 3). Bone harvest is centered on the middle third of the bone.

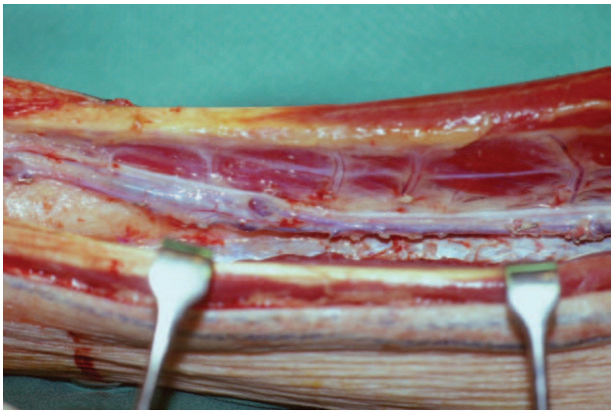

Fig. 2. Closeup of the anterior tibial artery and venae comitantes. Part of the body of the tibialis anterior muscle is being retracted, and a cuff of this muscle is left attached to the lateral cortical surface of the tibia with its robust muscle perforators shown. The tibial bone flap is nourished by this musculoperiosteal blood supply.

The anterior tibial artery is then dissected from the distal aspect of the tibial bone corticotomy, across the ankle, and onto the dorsum of the foot. A soft-tissue dorsalis pedis flap is elevated in the subfascial plane. This is well described elsewhere.[9] The superficial peroneal nerve of the foot is identified and dissected proximally until adequate length is achieved for sensory nerve coaptation in the neck. At the completion of flap elevation, the anterolateral corticotomy of the tibia is completely free of its tibial bed with the dorsalis pedis skin paddle perfusing on its lengthy pedicle (Fig. 4). The flap is left to perfuse at the side of the leg until ready to be harvested.

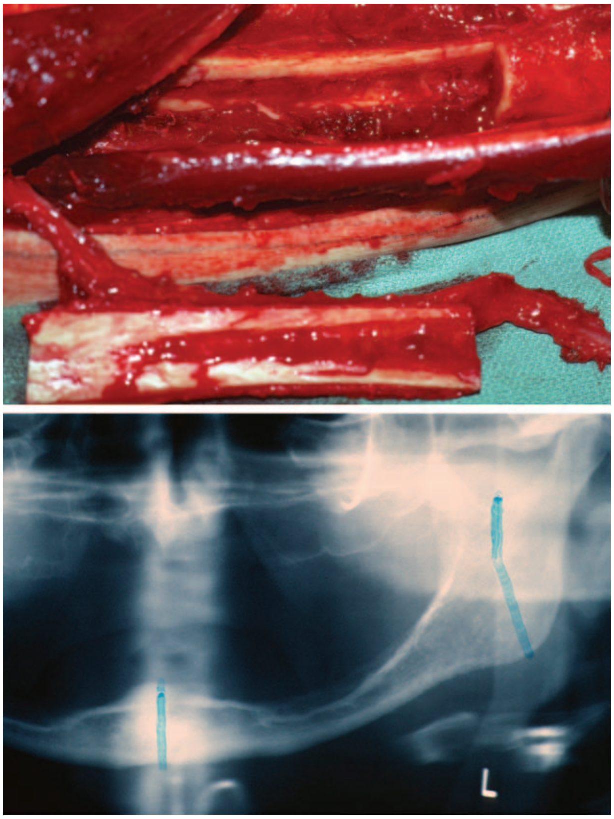

Fig. 3. (*Above*) A lateral corticotomy of the tibia, removing 30 percent of its circumference, has been performed. A cuff of tibialis anterior muscle separates the artery from the bone graft, which is perfused by means of musculoperiosteal perforators. (*Below*) Proposed hemimandibular defect, from symphysis to angle for a radioresistant and chemoresistant T4 squamous cell carcinoma of the floor of the mouth.

Before the mandibular resection, a mandibular reconstruction plate is bent to the shape of the native mandible. Wedge-shaped closing osteotomies are performed to adapt the tibial bone to the reconstruction plate. The reconstruction plate is applied to the medullary aspect of the tibial bone graft using screws. This may be performed while the flap is being perfused at the donor leg. With the tibial bone fixed to the reconstruction plate, the composite osteocutaneous tibial dorsalis pedis flap is ready for division (Fig. 5).

An orthopedic surgeon places an intramedullary nail within the tibia with locking screws, both proximally and distally (Fig. 6). The anterior tibial artery and vein are divided proximally and the free flap is transferred to the recipient site. A full-thickness skin graft from the ipsilateral groin is harvested and sutured to the dorsal pedis donor site with a tie-over bolster dressing. The pretibial incision is simply closed in layers (Fig. 7).

The flap is harvested when the recipient site is ready for transfer (Fig. 8). The defect is reconstructed by securing the predrilled holes for the reconstruction plate to the new construct, ensuring close fixation and coaptation of the tibia to the edges of the remaining native mandible (Fig. 9). Once the plate is secured to the native mandible, attention is paid to insetting the dorsalis pedis flap. This independently mobile skin paddle has 360 degrees of motion, allowing it to be inset into complex, asymmetrical, three-dimensional, soft-tissue oral cavity defects (Fig. 10). This may include alveolar mucosa, floor-of-mouth, oropharyngeal, or glossectomy defects. Using microsurgical techniques, the anterior tibial artery and vein in the long 8- to 10-cm donor pedicle are anastomosed to the usual recipient vessels in the neck.[10] Epineural repair is performed between the deep peroneal nerve and a sensory recipient nerve, preferably the lingual nerve.[11] Perfusion to the flap is confirmed and then the neck is closed over drains.

RESULTS

Part I: Perfusion Study

In evaluating a potential skin paddle associated with the anterior tibial artery, radiographic images obtained after the anterior tibial artery was injected with a radiopaque dye were examined. The angiosome from the anterior tibial artery encompasses the area overlying the anterior compartment. The fibula is the lateral border, and the anterior tibia is the medial border. There were very few perforators over the anterior tibial skin emanating from the tibialis anterior muscle. In any case, such a skin paddle would have been somewhat tethered to the tibial bone, giving the flap few advantages over the alternatives. The images, however, did consistently demonstrate that the anterior tibial muscle provided a rich matrix of myofascial periosteal blood supply to the anterolateral cortex of the tibia. These results suggested that an anterior tibial artery could support free osseous tibial transfer.

Part II: Point Breaking Strength

With two-point osteotomy fracture strain gauge analysis, the threshold of tibia corticotomy

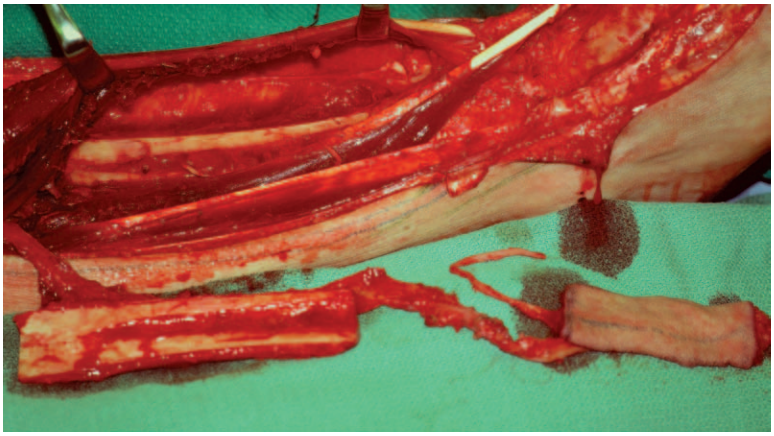

Fig. 4. The anterior tibial pedicle has been dissected distally (beyond the bone graft), and the dorsalis pedis skin flap has been elevated in-series along with the superficial peroneal nerve. The long, independent skin flap pedicle allows 360 degrees of rotation to facilitate insetting, and the donor nerve can easily access the lingual or mental nerves, which are favored recipient nerves in the head and neck.

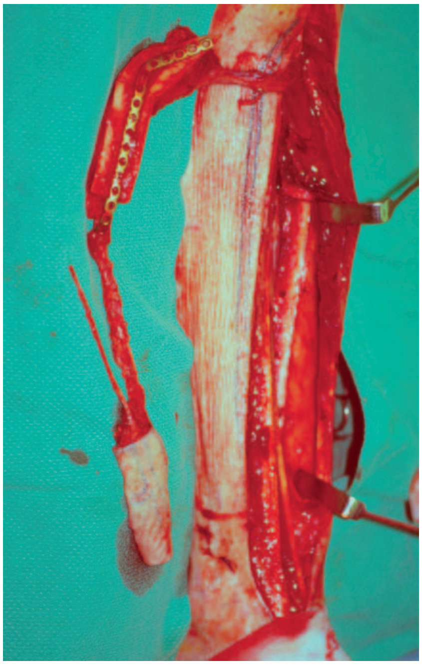

Fig. 5. Entire shin flap perfusing on the anterior tibial vessels after a prebent reconstruction plate (fashioned before the resection) has been used to fix the osteotomized tibia.

that would lead to fracture of the remaining tibia was determined. It was found that greater than 30 percent corticotomy of the tibia weakened the tibia to the inevitable stress risers that could potentially lead to postharvest fractures. Although weakening the overall integrity and structure of the tibia, the lateral 30 percent corticotomy provided a stable foundation for the placement of an immediate intramedullary nail to stabilize the weight-bearing aspects of the tibia-fibula axis. In the cadaveric studies, when intramedullary nails were inserted into the corticotimized tibia, the two-point breaking strength increased to above normal strain gauge levels and well above those measured in unosteotomized cadaveric tibias.

Part III: Clinical Study

Eight patients met inclusion criteria for oromandibular reconstruction with the osteocutaneous shin flap, with equal numbers of men ($n = 4$) and women ($n = 4$) being selected. The average age of the patients was 57 years (range, 48 to 63 years). All patients had recurrent, radiation failure, oral cavity, T4 squamous cell carcinomas.

Intraoperatively, the mean soft-tissue defect size was noted to be 32 cm^2. This was the result of mucosal loss, partial glossectomies, or concomitant floor-of-mouth defects. A full range of osseous defects was noted, including two central

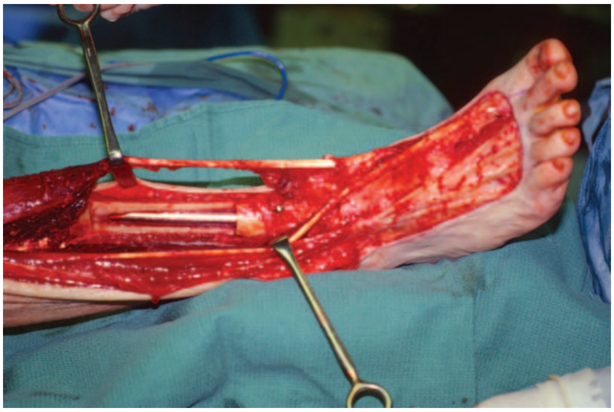

Fig. 6. An immediate intramedullary nail is placed in the donor tibial defect, facilitating early full weight bearing and minimizing the risk of stress fractures of the donor site.

and six lateral mandibulectomies. The mean harvested tibial length was 14 cm, and the soft-tissue paddle of the dorsalis pedis artery averaged 35 cm^2. Table 1 summarizes the preoperative and intraoperative data.

Patients were followed for an average of 61 months, with a median of 40 months (Fig. 11). Gait analysis and donor-site defects were assessed in all patients. All patients were lightly weight bearing with a walker by 10 days postoperatively. They were

Fig. 7. Full-thickness groin skin graft used to resurface the dorsalis pedis donor site. This provides a durable, sebum-secreting, hairy donor coverage over the paratenon of the extensor digitorum tendons.

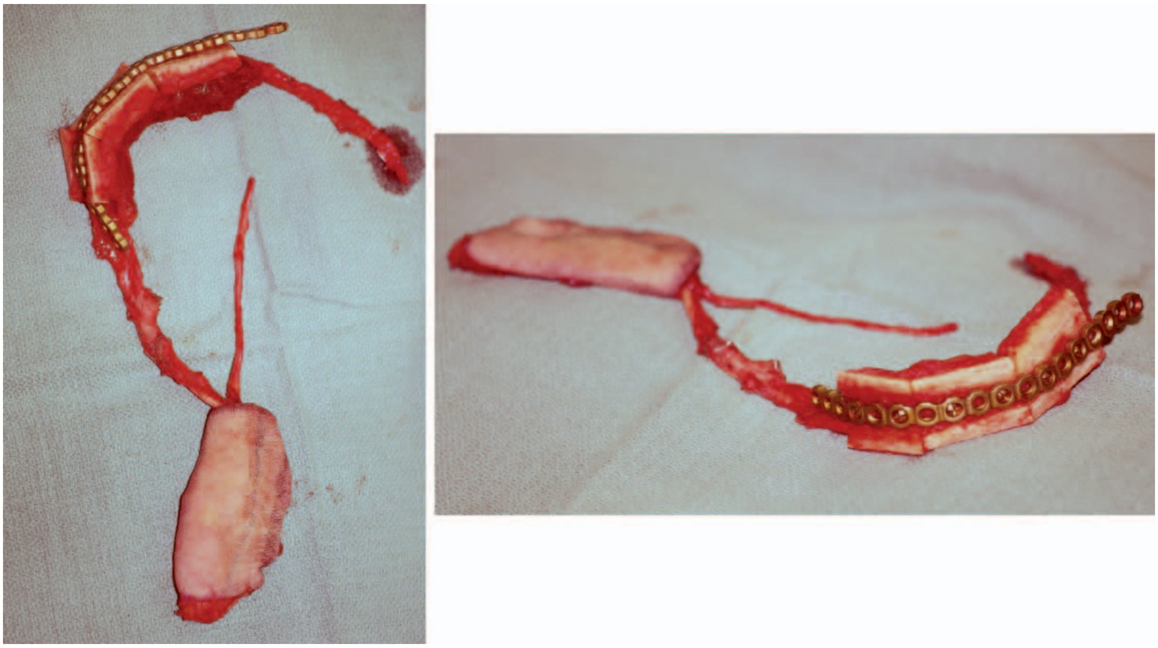

Fig. 8. Shin flap pedicle divided before transfer, showing the osteotomy sites in the tibia, the musculoperiosteal cuff preserved between artery and bone, the innervated dorsalis pedis skin flap, and the long vascular pedicles of both the bone graft and the cutaneous skin paddle. These factors facilitate recipient vessel access and bone and soft-tissue inset. The 30 percent corticotomy produces a good match for the height of the native mandible, and the dense cortical bone will easily accept primary or secondary osseointegrated implants for full dental restoration.

all full weight bearing by 28 days postoperatively. There were two cases (25 percent) of partial skin graft "nonadherence" at the dorsal foot recipient site. There were no cases of complete skin graft nonadherence or pretibial wound dehiscence. All patients were followed by the orthopedic surgery service. There were no pathologic fractures or tibia bone abnormalities at the 5-year follow-up (Fig. 12).

Fig. 9. Bone fixation completed at the recipient site. The long anterior tibial pedicle can access several vessels in the neck dissection field for end-to-end or end-to-side arterial and venous anastomosis.

There were no cases of salivary fistula, flap loss (partial or complete), hematoma, infection, nonunion, malunion, hardware failure, or plate exposure. Three of the eight patients underwent osteointegrated implant reconstruction. Sensory innervation of the dorsalis pedis component of the flap was examined in all patients at 24 months postoperatively. Two-point sensation of 10 mm was achieved in six of the eight patients (75 percent). Light proprioception and hot/cold sensation was achieved in all eight patients (100 percent).

DISCUSSION

Reconstruction of complex oromandibular defects remains challenging, and the innovative new osteocutaneous free shin flap has proven itself to be versatile in many regards. To the authors' knowledge, the use of an osteocutaneous "shin" flap for mandibular reconstruction has never been reported in the literature. Its unique anatomy yields the advantage of an independent skin island, which offers freedom in soft-tissue reconstruction, without sacrificing osseous

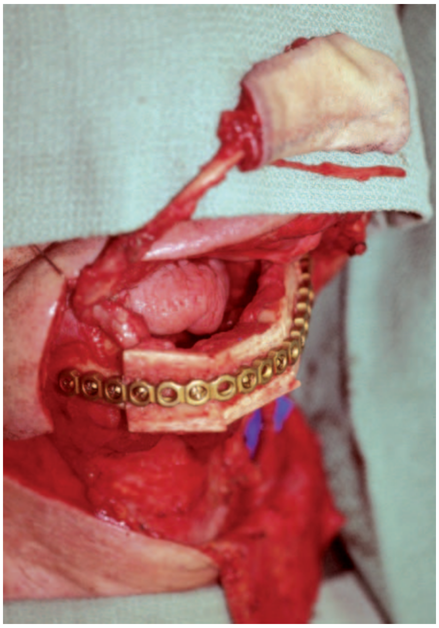

Fig. 10. The vertical height and cortical thickness of the tibia are optimal for mandibular replacement. The medullary surface is externalized at the recipient site to avoid trauma to the perforators in the tibialis anterior muscle. The in-series pedicle of the dorsalis pedis skin flap is long, allowing complete independent positioning of the skin flap in relation to the osseous reconstruction. Complex three-dimensional oropharyngeal reconstruction is thereby facilitated. Finally, the long sensory nerve (superficial peroneal nerve) can be connected end-to-end or end-to-side to the lingual, mental, or glossopharyngeal nerve to restore sensation.

Table 1. Preoperative and Intraoperative Characteristics of Eight Patients Undergoing Oromandibular Reconstruction with Osteocutaneous Shin Flaps

Characteristic	Value
No. of patients	8
No. of men	4
No. of women	4
Diagnosis of recurrent, radiation failure, oral cavity, T4 squamous cell carcinomas, no.	8
Age, yr	
Mean	57
Range	48–63
Mean soft-tissue defect, cm^2	32
Osseous defect, no.	
Lateral mandibulectomy from angle to parasymphysis	4
Lateral mandibulectomy body/angle to midline	2
Central mandibulectomy body to body	2
Mean harvested tibial length, cm	14
Mean dorsalis pedis skin paddle dimension, cm^2	35
Arterial anastomosis, no.	
End-to-end facial artery	4
End-to-end superior thyroid artery	4
Venous anastomosis, no.	
End-to-side internal jugular vein	6
End-to-end facial vein	2
Sensory coaptation (end-to-side to lingual), no.	8

reconstruction. The long distance between the distal end of the tibial corticotomy and the dorsalis pedis allows for a great degree of freedom of rotation. This enables optimal insetting of the soft-tissue reconstruction in these difficult and closed spaces of the oral cavity. Furthermore, the soft-tissue component is thin, pliable, and usually hairless. Just as noteworthy, however, is the sensate nature of this dorsalis pedis flap. The proximal vascular pedicle is long, allowing for ease in microvascular anastomoses, and the neural pedicle of the dorsalis pedis is equally conducive to recipient access.

The tibial bone provides ideal bone stock for the reconstruction of mandibular height and thickness. Lack of vertical height is a major disadvantage of the free fibula flap, the criterion standard for oromandibular reconstruction. The dense, thick, tibial outer cortex provides ideal fixation for reconstruction plates, thereby promoting stable fixation and primary bony union. In the prospective clinical arm of this study, there were no cases of nonunion. This is despite the hostile nature of the irradiated recipient beds. The bone stock of the tibia facilitates primary dental osseointegration in those patients having a prognosis good enough to warrant it.

The perfusion and breaking strength studies helped the authors determine the technical details surrounding harvest of the flap. Intraoperatively, a corticotomy of the anterior tibia is made to correspond with the exact mandibulectomy defect. Based on the breaking strength data, the full width of the flat anterolateral surface of the tibia could be harvested.

The ideal place to harvest the tibia is along the middle third of the bone. As the perfusion study demonstrates, there is a rich myoperiosteal blood supply from the tibialis anterior. The osteotomized segment of tibia needs to include the anterior tibial artery and a cuff of attached tibialis anterior muscle. Harvesting the proximal third of the tibia is problematic, as the motor innervation of the tibialis anterior is present there in addition to the vascular bifurcation. Also, there is great difficulty in dissecting between the fibula and tibia in this location.

Concerns over the tibia donor site proved to be overcome by primary intramedullary rod fixation of the tibia. In this series, there were no stress-rise fractures or limitations in ambulation. Nonetheless, the authors acknowledge that wound dehiscence or infection of the tibial donor

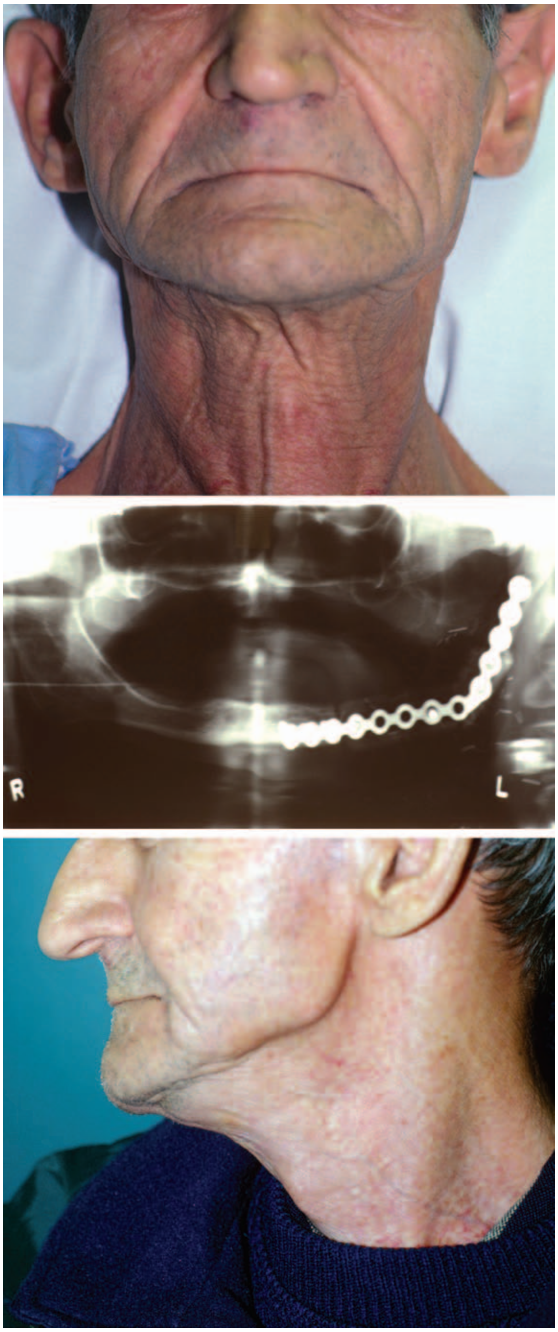

Fig. 11. (*Above*) Preoperative mandibular contour. (*Center*) Panorex image showing mandibular body, angle, and ascending ramus reconstruction. (*Below*) Mandibular reconstruction with excellent contour restoration at 6 months.

site can become problematic. Hardware could be exposed, with difficult locoregional reconstructive options. Full-thickness skin grafting of the dorsalis pedis defect was an essential and stable component of the patient's recovery and rehabilitation. Dorsalis pedis donor sites can be problematic with shoe wear and ambulation.

Fig. 12. Locking intramedullary nail in donor tibial bone.

This report presents another viable option when anatomical and physiologic limitations prevent the use of the free fibula osteocutaneous flap or other less commonly used flaps. The indications for use of the osteocutaneous shin flap exist when the use of the usual free flaps is not feasible in certain patients or when restoration of mandibular height is deemed to be vital in others.

The fibular free flap has been presented in the literature as the first choice in mandibular reconstruction.[12] Fibular flaps have a disadvantage of requiring a distal skin paddle to obtain a reliable microvascular blood supply as documented by the anatomical studies of Jones et al.[13] Free fibular flaps may also not be an option if preoperative angiography demonstrates bilateral peroneal vessel–dominant lower legs.

The radial forearm flap is also a viable option for mandibular reconstruction, especially in large posterior soft-tissue defects with small bone requirements.[14,15] The osteocutaneous radius forearm flap is useful for small bone requirements but, in the early stages of one's learning curve, carries a distinct risk of radial bone fracture.

The scapular free flap has a similar advantage to the shin flap in that it allows for more mobile and somewhat independent skin components, and may even be combined with the latissimus dorsi for more extensive reconstructions.[16,17] Takushima et al. found this flap more advantageous than a combined free fibula and soft-tissue flap for a lateral or hemimandibular defect with a large through-and-through soft-tissue defect.[18] However, it has the disadvantages of requiring the patient to be turned midway through the operation and, like the radial forearm flap, the bone stock is limited. The tibial–dorsalis pedis osteocutaneous shin flap, in contrast, can be harvested in the supine position at a remote location from the ablative surgeons. Other disadvantages of the scapula include the lack of segmental blood supply, which theoretically limits the number of osteotomies. The quality of bone has also been reported as inferior,[19] but some studies have shown that it can tolerate some dental implants.[20]

The iliac crest flap[1,2,21] provides an unprecedented quantity of bone for mandibular reconstruction. Using the classic techniques of Manchester,[22,23] it can be made to reconstruct a hemimandible without the need for osteotomy. It has a natural curvature that mimics the mandible and adequate bony height to accommodate even the largest osseointegrated implants.[24,25] Although the flap's elevation is said to be tricky, a learning curve is established early because of the constancy of the anatomy. The donor site is cosmetically excellent but a major source of postoperative pain. Although the skin component is abundant, it is unsuitable for intraoral use because of tethering and the necessary inclusion of a full-thickness muscle cuff.[19,21] Use of an internal oblique muscle flap[26] can supply this deficiency at the price of weakening the abdominal repair and predisposing to a hernia.

There are a plethora of choices for oromandibular reconstruction. Although the fibula osteocutaneous flap has proven to be the criterion standard, the tibia offers its own set of advantages and may become a viable alternative.

CONCLUSIONS

This free osteocutaneous tibial–dorsalis pedis flap appears to be reliable and safe, provided that the donor site is handled appropriately. Its main advantages are the quality of the bone (straight, with both height and thickness equivalent to that of the mandible) and a completely independent and potentially sensate skin paddle. Its disadvantages are principally a weakening of the tibia (which must be stabilized with intramedullary nails) and a skin graft to the foot that may prolong immobilization. Nevertheless, it is a viable option that greatly expands the number of options for complex oromandibular reconstruction.

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