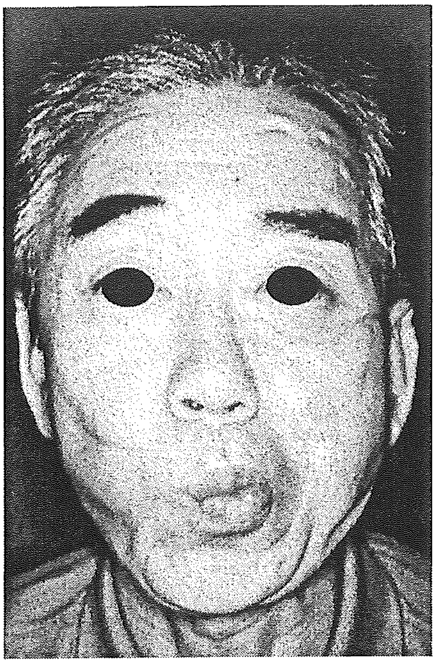

C

FIGURE 8. (continued)

going reconstruction of the lateral wall of the nasal cavity (nasal lining) by the transferred flap did not have discomfort from nasal obstruction. Nine patients who had PMB reconstruction by vascularized bone graft were able to eat a regular diet with a useable dental prosthesis. However, most patients without PMB reconstruction were restricted to a soft/pureed diet because of poor stability of their dental prosthesis. In category II and III maxillary defects (32 patients) in which the orbital floor including the ZMB was removed, the orbital contents were preserved in 12 patients. Nine patients with reconstruction of the orbital floor, including ZMB by vascularized bone or cartilage graft, did not have malposition of eye globe and diplopia. However, two patients with removal of the titanium mesh grafted for ZMB reconstruction and one patient with a fascia lata graft for orbital floor reconstruction had mild to severe vertical diplopia. The remaining 20 patients with category II and III maxillary defects underwent resection of the orbital contents followed by simultaneous reconstruction of the eye socket with the transferred flap. Only seven patients with preservation of upper and lower eyelids were able to wear an ocular prosthesis.

Secondary surgical revisions were required in seven patients to improve their facial appearance. Debulking of the flap, Z-plasty for the flap marginal scar, shaving of the grafted bone, and blepharoplasty on the upper eyelid were performed in six patients. In addition, one patient underwent a free flap surgery for soft tissue augmentation and reanimation of facial palsy (Figure 8).

DISCUSSION

With the development of a vascularized composite autograft using a microsurgical technique, reconstruction of extensive maxillary defects has been achieved to a high level of functional and aesthetic results.[4,5,7–21] However, few published large series describe a surgical approach to maxillary skeletal reconstruction based on the extent of resection of the maxillary bone.[19] In 1998, we introduced the concept of buttress reconstruction for restoration of maxillary skeletal defects.[4] The concept was derived from the principles of anatomic restoration of the vertical and horizontal maxillary buttresses in the surgical management of complex midfacial fractures.[22,23] First, in this retrospective study, the maxillectomy defects were analyzed according to removal of maxillary buttresses because understanding the skeletal defect of maxilla is the first key point in approaching effective maxillary reconstruction.[24,25] Maxillectomy defects of this series were divided into three categories on the basis of anatomic sites of resection. Compared with the classification system for maxillectomies from Memorial Sloan-Kettering Cancer Center, a category I maxillary defect corresponds to type I and II defects, category II to type IV, and category III to type IIIa and IIIb.[19] From the reconstructive surgeon's standpoint, PMB is a main buttress to be reconstructed in a category I maxillary defect. In case of extensive resection of buccal soft tissue including mimetic muscle and skin, the NMB should be reconstructed to prevent the superior and posterior deviation of the alar base. The ZMB is the main buttress to be reconstructed in a category II maxillary defect, especially with extensive resection of the zygomatic process and arch. However, most category II cases do not require skeletal reconstruction. In category III maxillary defects, the ZMB and PMB are the main buttresses to be reconstructed. Reconstruction of the ZMB including the orbital floor is essential for prevention of malposition of the eye globe for preservation of the orbital contents. ZMB reconstruction is also important to provide a good contour for the malar prominence. PMB reconstruction provides sufficient support for fitting a dental prosthesis. In case of extensive resection of buccal soft tissue, the PMB and NMB should be reconstructed to prevent the superior and posterior deviation of the alar base and oral commissure. Accordingly, reconstruction of all three buttresses is considered for the patient with a category III maxillary defect with extensive resection of zygomatic process and arch and buccal soft tissue.

We have demonstrated that a vascularized composite autograft is the most common physiologic material of choice for complex maxillary defects.[4] In skeletal reconstruction with alloplastic materials or nonvascularized bone and cartilage, displacement, infection, absorption, or fistula formation remains a potential problem during the long-term follow-up period. Moreover, in patients who receive preoperative/postoperative radiotherapy, persistent irradiated injury compromises the reconstructed region. Especially in the reconstructed ZMB area, gravity, scar contracture, and tightness of the overlying soft tissue lead to a higher incidence of such complications. With these considerations in mind, several reconstructive techniques using vascularized composite autografts have been mainly used for maxillary reconstruction in our institute. In reconstruction of the ZMB, vascularized eighth and ninth costal cartilage connected to the rectus abdominis myocutaneous flap was used for five (40%) of 15 patients, and the medial border of the scapula connected to the latissimus dorsi myocutaneous or scapular flap was used for six patients (40%). The rectus abdominis myocutaneous flap combined with costal cartilage is a useful tool for restoration of one buttress (ZMB) and a midfacial soft tissue defect. In reconstruction of the PMB, the lateral border of the scapula connected with the latissimus dorsi myocutaneous or scapular flap was used for eight (89%) of nine patients. We consider that the lateral border of the scapula is well tolerated for restoration of the PMB because it has enough volume to provide reliable stability for fitting a dental prosthesis. The latissimus dorsi myocutaneous or scapular flap combined with the V-shaped scapula is good for restoration of two buttresses (medial border for ZMB and lateral border for PMB) and midfacial soft tissue defects. The central space of the V-shaped scapula also allows placement of the bulk of the transferred flap. In reconstruction of all three buttresses, the latissimus dorsi myocutaneous free flap combined with the V-shaped scapular bone and rib is a versatile technique to manage such a complex skeletal defect.

Reconstruction of both skeletal and soft tissues of maxillectomy defects is ideal; however, various factors affect the determination of the reconstructive method. The patient's age, associated diseases, degree of advanced carcinoma, and request for skeletal reconstruction from the surgical oncologist are important issues to be evaluated preoperatively. In this series, buttress reconstruction was performed most frequently for category III (56%) maxillary defects, followed by category I (50%) and category II (20%). The necessity of buttress reconstruction increases according to the extent of

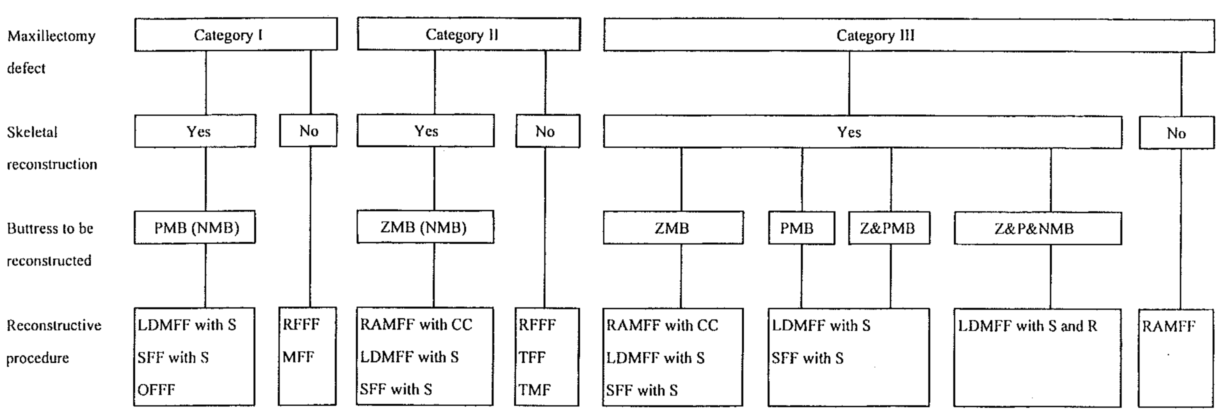

FIGURE 9. A reconstructive algorithm for surgical management of maxillectomy defects. ZMB, zygomaticomaxillary buttress; PMB, pterygomaxillary buttress; NMB, nasomaxillary buttress; RAMFF, rectus abdominis myocutaneous free flap; RFFF, radial forearm free flap; TFF, temporoparietal fascial flap; TMF, temporalis muscle flap; MFF, median forehead flap; RAMFF with CC, rectus abdominis myocutaneous flap combined with costal cartilage; LDMFF with S, latissimus dorsi myocutaneous free flap combined with scapula; SFF with S, scapular free flap combined with scapula; LDMFF with S and R, latissimus dorsi myocutaneous free flap combined with scapula and rib; OFFF, osteocutaneous free flap of fibula; SFF, scapular free flap. V-shaped scapula is applied for reconstruction of two or three buttresses.

maxillary resection. Finally, in a retrospective analysis of this series, we were able to generate a reconstructive algorithm for the surgical management of maxillectomy defects (Figure 9). We advocate that a critical assessment of skeletal defects and associated soft tissue defects after various types of maxillectomies is essential for an adequate approach in solving complex reconstructive problems. On the basis of this assessment, the most effective reconstructive technique should be applied individually. Furthermore, to improve postoperative functional and aesthetic outcomes, one should not hesitate using secondary surgical revisions including free flap transfer in this challenging field of reconstructive head and neck surgery.

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REFERENCES

1. Pribaz JJ, Morris DJ, Mulliken, JB. Three-dimensional folded free-flap reconstruction of complex facial defects using intraoperative modeling. Plast Reconstr Surg 1994; 93:285–293.
2. Rollon A, Cia TG, Gonzalez JD, Hernandez JH, Salazar CL, Restoy A. Reconstruction of maxillary and palatal defects with the free radial forearm flap. Eur J Plast Surg 1995;18:220–225.
3. Guler MM, Turegun M, Acikel, C. Three-dimensional reconstruction of types IV and V midfacial defects by free rectus abdominis myocutaneous (RAM) flap. Microsurgery 1998;18:148–151.
4. Yamamoto Y, Minakawa H, Kawashima K, Furukawa H, Sugihara T, Nohira K. Role of buttress reconstruction in zygomaticomaxillary skeletal defects. Plast Reconstr Surg 1998;101:943–950.
5. Yamamoto Y, Minakawa H, Kokubu I, et al. The rectus abdominis myocutaneous flap combined with vascularized costal cartilages in reconstructive craniofacial surgery. Plast Reconstr Surg 1997;100:439–444.
6. Yamamoto Y, Sugihara T, Kawashima K. An anatomic study of the latissimus dosi-rib flap: an extension of the subscapular combined flap. Plast Reconstr Surg 1996;98: 811–816.
7. Serafin D, Riefkohl R, Thomas I, Georgiade NG. Vascularized rib-periosteal and osteocutaneous reconstruction of the maxilla and mandible: An assessment. Plast Reconstr Surg 1980;66:718–727.
8. Swartz WM, Banis JC, Newton ED, Ramasastry SS, Jones NF, Acland R. The osteocutaneous scapular flap for mandibular and maxillary reconstruction. Plast Reconstr Surg 1986;77:530–545.
9. Granick MS, Ramasastry SS, Newton ED, Solomon MP, Hanna DC, Kaltman S. Reconstruction of complex maxillectomy defects with the scapular-free flap. Head Neck 1990;12:377–385.
10. Coleman JJ III, Sultan MR. The bipedicled osteocutaneous scapula flap: a new subscapular system free flap. Plast Reconstr Surg 1991;87:682–692.
11. Nakayama B, Matsuura H, Ishihara O, Hasegawa H, Mataga I, Torii S. Functional reconstruction of a bilateral maxillectomy defect using a fibula osteocutaneous flap with osseointegrated implants. Plast Reconstr Surg 1995; 96:1201–1204.
12. Yamada A, Harii K, Ueda K, Nakatsuka T, Asato H, Kajikawa A. Secondary contour reconstruction of maxillectomy defects with a bone graft vascularized by flow through from radial vascular system. Microsurgery 1996; 17:141–145.
13. Anthony JP, Foster RD, Sharma AB, Kearns GJ, Hoffman WY, Pogrel MA. Reconstruction of a complex midfacial defect with the folded fibular free flap and osseointegrated implants. Ann Plast Surg 1996;37:204–210.
14. Brown JS. Deep circumflex iliac artery free flap with internal oblique muscle as a new method of immediate reconstruction of maxillectomy defect. Head Neck 1996;18: 412–421.
15. Pollice PA, Frodel JL Jr. Secondary reconstruction of upper midface and orbit after total maxillectomy. Arch Otolaryngol Head Neck Surg 1998;124:802–808.
16. Funk GF, Arcuri MR, Frodel JL Jr. Functional dental rehabilitation of massive palatomaxillectomy defects: cases requiring free tissue transfer and osseointegrated implants. Head Neck 1998;20:38–51.
17. Cordeiro PG, Santamaria E, Kraus DH, Strong EW, Shah JP. Reconstruction of total maxillectomy defects with preservation of the orbital contents. Plast Reconstr Surg 1998;102:1874–1884.
18. Kyutoku S, Tsuji H, Inoue T, Kawakami K, Han F, Ogawa Y. Experience with the rectus abdominis myocutaneous flap with vascularized hard tissue for immediate orbitofacial reconstruction. Plast Reconstr Surg 1999;103: 395–402.
19. Cordeiro PG, Santamaria E. A classification system and algorithm for reconstruction of maxillectomy and midfacial defects. Plast Reconstr Surg 2000;105:2331–2346.
20. Triana RJ Jr, Uglesic V, Virag M, et al. Microvascular free flap reconstructive options in patients with partial and total maxillectomy defects. Arch Facial Plast Surg 2000; 2:91–101.
21. Kakibuchi M, Fujikawa M, Hosokawa K, et al. Functional reconstruction of maxilla with free latissimus dorsiscapular osteomusculocutaneous flap. Plast Reconstr Surg 2002;109:1238–1244.
22. Manson PN, Hoopes JE, Su CT. Structural pillars of the facial skeleton: an approach to the management of Le Fort fractures. Plast Reconstr Surg 1980;66:54–61.
23. Gruss JS, Mackinnon SE. Complex maxillary fractures: role of buttress reconstruction and immediate bone grafts. Plast Reconstr Surg 1986;78:9–22.
24. Wells MD, Luce EA. Reconstruction of midfacial defects after surgical resection of malignancies. Clin Plast Surg 1995;22:79–89.
25. Spiro RH, Strong EW, Shah JP. Maxillectomy and its classification. Head Neck 1997;19:309–314.

Sequential Vascularized Iliac Bone Graft and a Superficial Circumflex Iliac Artery Perforator Flap with a Single Source Vessel for Established Mandibular Defects

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The major problems in dealing with established mandibular loss are severe soft-tissue contracture and a limited number of recipient vessels. The skin portion of the iliac osteocutaneous flap often necrotizes in cases without perforators of the deep circumflex iliac vessel. To overcome these problems, eight patients with established mandibular loss and no skin perforators of the deep circumflex iliac vessel were treated with a sequential vascularized iliac bone graft and a superficial circumflex iliac perforator flap with a single recipient vessel. Regarding the recipient vessels, the ipsilateral cervical vessels were used for four patients, and the contralateral facial and ipsilateral superficial temporal vessels were used for two cases each. The superficial circumflex iliac perforator flaps were 7 to 28 cm in length and 3 to 15 cm in width. The iliac bone grafts ranged from 7 to 13 cm in length, and three cases were repaired with the inner cortex of the iliac bone. There were no serious complications, such as flap necrosis or bone infection and resulting absorption. The advantages of this method are that both pedicles are very close to each other and of suitable diameter for anastomosis. Simultaneous flap elevation and preparation for the recipient site is possible. The skin flap and vascularized bone graft can be obtained from the same donor site. A single source vessel can nourish both the large skin area and bone sequentially. Longer dissection of the superficial circumflex iliac system to the proximal femoral division is unnecessary. A large flap can survive with a short segment of the superficial circumflex iliac system. Only the vascularized inner cortex of the iliac bone needs to be used, and the outer iliac cortex can be preserved, which results in less morbidity at the donor site. (*Plast. Reconstr. Surg.* 113: 101, 2004.)

Reconstruction for established mandibular osteocutaneous losses is still difficult because of the requirement for large cutaneous flaps after the release of severely contracted scars. In addition, because the majority of such patients who have undergone multiple previous operations have lost recipient vessels near the mandible, vein grafts are required. The recipient vessels are usually far from the defect and are in the contralateral cervical or ipsilateral temporal region.

The ideal single donor site for mandibular osteocutaneous reconstruction requires no positional change, allows simultaneous flap elevation to the site of the resectioned tumor, and provides a flap with a large skin territory. Many osteocutaneous flaps, however, have a limited skin territory, with the exception of the scapular osteocutaneous flap, which is unpopular because it requires positional changes during the operation. The vascularized fibula can be elevated simultaneously, but a large peroneal skin flap may not be sacrificed because of functional and cosmetic problems. Iliac bone is a good candidate for such established mandibular losses because it can be elevated with a large skin paddle as an osteocutaneous flap. However, the skin flap is often necrotized when skin perforators arising from the deep circumflex iliac artery are missing. To overcome these problems for such difficult mandibular reconstructions, we propose a new method that includes a sequential vascularized iliac bone graft

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and a supercharged superficial circumflex iliac perforator flap with a single recipient vessel.

Patients and Methods

Between March of 1988 and August of 2001, eight patients with established mandibular losses were treated with a sequential vascularized iliac bone graft and a superficial circumflex iliac perforator flap. Regarding the recipient vessels, the ipsilateral cervical vessels were used for four patients and the contralateral facial and ipsilateral superficial temporal vessels were used for two patients each. These latter four patients with distant recipient vessels required saphenous vein grafts. The superficial circumflex iliac perforator flaps ranged from 7 to 28 cm in length and 3 to 15 cm in width. The iliac bone grafts were 7 to 13 cm in length. Three cases were repaired with the inner cortex of the iliac bone. As for postoperative complications during the postoperative follow-up of 17 months to 14 years, although one patient required reanastomosis of an occluded vein (patient 1), there were no serious complications, such as flap necrosis or bone infection and resulting absorption (Table I).

Operative Techniques

The flap design is drawn on the groin region. During groin flap elevation, a perforator from the distal portion of the superficial circumflex iliac artery can be detected near the anterosuperior iliac prominence. The pedicle of the superficial circumflex iliac perforator flap can be a perforator and a short segment of the superficial circumflex iliac vessel. It need not include the proximal portion of the superficial circumflex iliac vessel. The inner cortex of the vascularized iliac bone can be split by an electric saw, and the external cortex can be preserved. The pedicle of the iliac bone, the deep circumflex iliac vessel, is dissected with 5 cm of the ascending branch to join the pedicle of the superficial circumflex iliac perforator flap (Figs. 1 and 2). The deep circumflex iliac vessels are anastomosed to the recipient vessels. In some cases with established mandibular losses, the recipient vessels in the ipsilateral cervical region have been lost because of previous neck dissection. In such cases, the contralateral facial or superior thyroid artery can usually be used. When vessels in the bilateral neck are not available, ipsilateral superficial temporal vessels with the saphenous vein grafts

TABLE I
Summary of Patients with Established Mandibular Loss

Patient	Age (yr) Sex	Disease	Recipient Vessel	Vein Graft	Flap Size (cm)	Bone Size (cm)	Follow-Up	Complications
1*	32 M	Benign tumor	Lingual artery Anterior and external jugular vein	—	15 × 8	9	14 yr	—
2	61 M	Tonsilar carcinoma	Contralateral facial artery and vein	+	13 × 7	7	11 yr	—
3*	58 M	Pharyngeal carcinoma and radiation	Superior thyroid artery and external juglar vein	—	25 × 15	7	10 yr	—
4	59 F	Gingival carcinoma	Contralateral facial artery and external juglar vein	+	28 × 9	13	10 yr	—
5	25 M	Traumatic loss	Submandibular artery and vein	—	10 × 5	7 (inner cortex)	10 yr	—
6	64 F	Gingival carcinoma	Facial artery and external juglar vein	—	7 × 3	10	8 yr	—
7	51 F	Gingival carcinoma	Superficial temporal artery and vein	+	15 × 8	8 (inner cortex)	18 mo	—
8	52 M	Gingival carcinoma	Superficial temporal artery and vein	+	15 × 8	8 (inner cortex)	17 mo	—

*Cases described in this article.

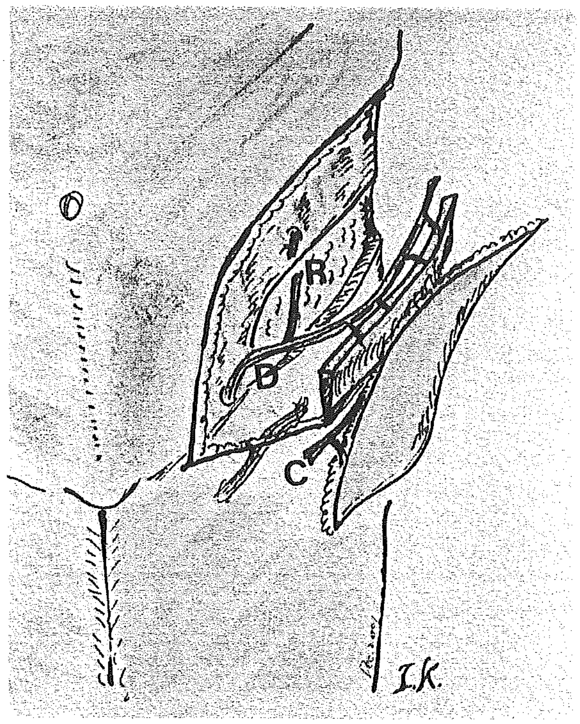

FIG. 1. Operative techniques. Elevation of split iliac bone pedicled with the deep circumflex iliac system (*D*) and a superficial circumflex iliac perforator flap pedicled with the distal perforator of the superficial circumflex iliac system (*C*). *R*, ascending branch of the deep circumflex iliac system.

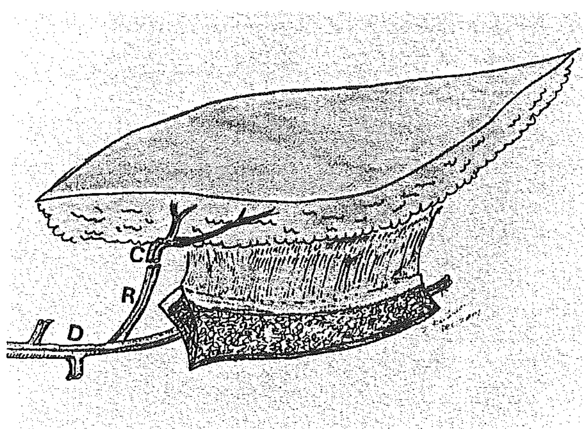

FIG. 2. Operative techniques. The ascending branch (*R*) of the deep circumflex iliac system (*D*) is anastomosed to the distal portion (*C*) of the superficial circumflex iliac system with a perforator.

are preferable. Finally, the donor defect is usually closed directly (Figs. 1 and 2).

In the area of heavily irradiated tissue, these flaps can be transferred to join the mandibular defect after resectioning a sufficient length of irradiated mandible. No intraoral incision is added to prevent postoperative bone infection. In addition, a larger skin flap should be used to close the suture margin without any tension, and a sufficient volume of the flap is transferred to pack the recipient dead cavity. Because there may be no effective recipient vessels in the same irradiated area, recipient vessels are selected as mentioned above.

CASE REPORTS

Case 1

A 32-year-old man had lost a 10-cm-long section of his left mandible because of an adamantinoma. It had been repaired with a free iliac bone graft and hydroxyapatite; however, because those reconstructions failed, the patient had been transferred to our department. Because the right iliac bone had been sacrificed during the previous operation, a sequential vascularized iliac bone graft and a superficial circumflex iliac perforator flap (15 × 8 cm) from the left side were transferred. After the bone graft was fixed to the mandibular defect, a perforator flap was implanted into the external submandibular skin defect. The deep circumflex iliac vessels were anastomosed to the lingual artery and the external jugular vein of the left side. The short pedicles of the perforator flap were anastomosed to the ascending artery of the deep circumflex iliac artery and the anterior jugular vein.

The postoperative course was smooth. There was excellent bone union and no tumor recurrence, complications at the donor site, or functional disturbance of the donor leg (Fig. 3).

Case 3

A 58-year-old man with left pharyngeal carcinoma had been treated with radiation therapy. However, he had an incurable fistula originating from an irradiated necrotic mandible that was surrounded by wide irradiated skin. In addition, the necrotic mandible was exposed intraorally through a mucosal defect of the alveolus.

After wide resection of the irradiated mandible and irradiated skin, the intraoral mucosal defect was closed directly. A resulting mandibular defect with a wide external skin defect was repaired with a sequential vascularized iliac bone graft and a superficial circumflex iliac perforator flap (25 × 15 cm) from the left groin region. After the bone graft was fixed to the mandibular defect, a perforator flap was implanted into the external skin defect. The deep circumflex iliac vessels were anastomosed to the superior thyroid artery and the external jugular vein of the left side. The short pedicles of the perforator flap were anastomosed to the ascending artery of the deep circumflex iliac artery and the anterior jugular vein. The donor defect for the flap was closed directly. Postoperatively, there was good bone union and no tumor recurrence, flap necrosis, fistula, or infection of the bone (Figs. 4 and 5).

DISCUSSION

Reconstruction of large mandibular bone defects with large skin defects can be a difficult surgical challenge. Especially in cases with established mandibular losses, there are serious problems with the absence of recipient vessels

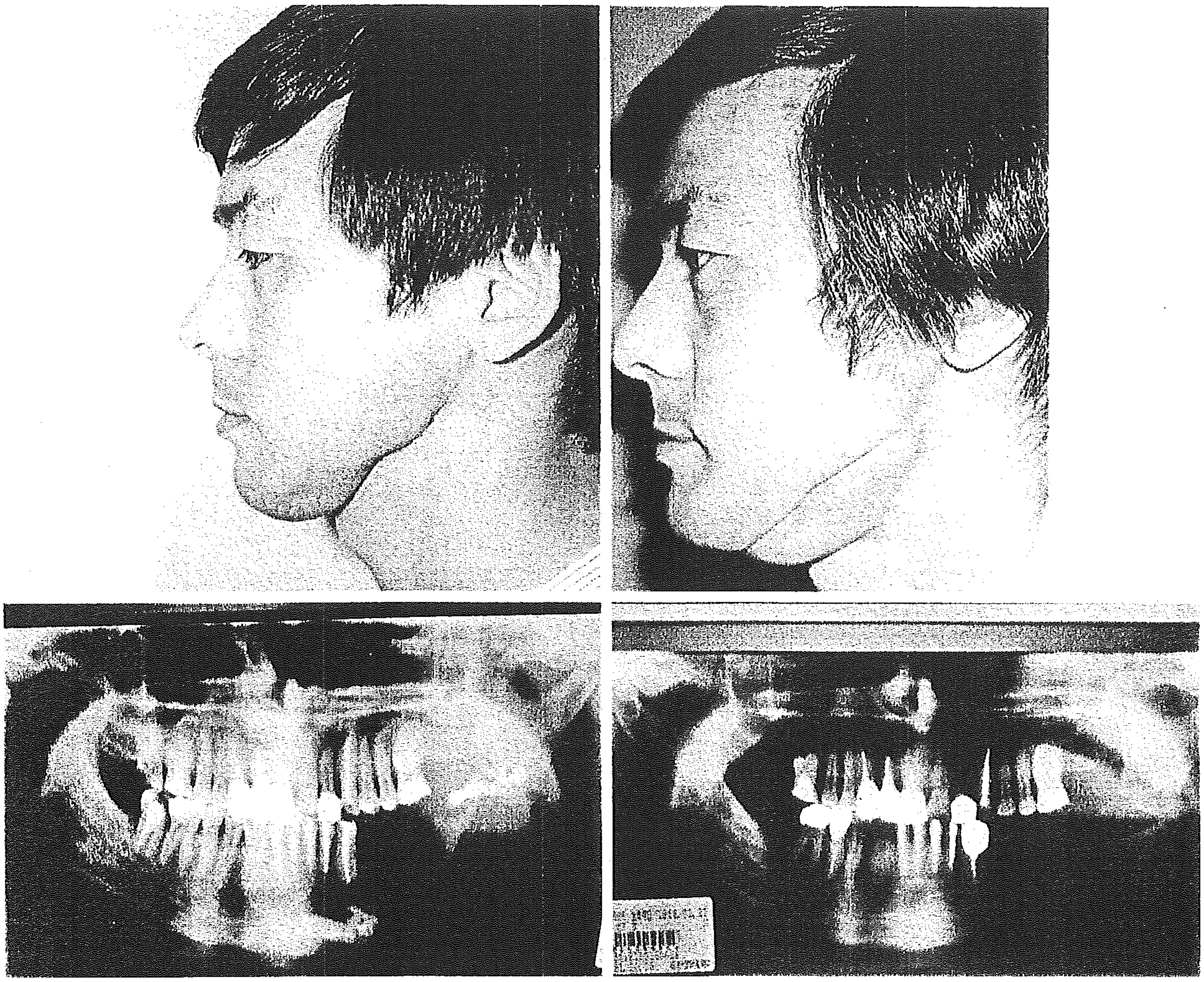

FIG. 3. Case 1. (*Above, left*) Despite a previous bone graft and apatite implantation, this 32-year-old man had scar contracture with hemimandibular loss. (*Below, left*) Preoperative radiograph shows mandibular loss. (*Above, right*) Superficial circumflex iliac perforator flap at 7 months after the operation, which was resected later. (*Below, right*) Radiograph shows the vascularized iliac bone graft at 4 years after the operation.

in the cervical region because of previous bilateral neck dissection and with severe intraoral and extraoral scar contracture caused by previous radiation therapy. In addition, the resulting defects after release of these contractures require large skin flaps.

As potential donor sites for large vascularized bone, the scapula,[1] radius,[2] rib,[3] fibula,[4,5] and iliac bone[6] have been introduced. Although the scapular osteocutaneous flap has a wide skin territory, it cannot be obtained simultaneously with tumor removal or resectioning. We believe the ideal donor sites must be far from the recipient site for simultaneous flap elevation.

Although an iliac osteocutaneous flap and a fibular osteocutaneous flap can be obtained from distant areas far from the recipient site, the dimension of the latter skin flap should be limited because of postoperative functional and cosmetic problems. Iliac osteocutaneous flaps often have partial necrosis of the cutaneous flap because of loss of skin perforators arising from the deep circumflex iliac artery.

To overcome the problem with iliac osteocutaneous flaps, we developed the concept of chimera flaps,[7] which seem to be important in creating customized large flaps (i.e., flaps, cutaneous and osseous) that can be combined with additional vascular anastomoses. Using this concept, very large thin or thick flaps to cover osteocutaneous defects can be combined easily with well-vascularized bone. However, this method is complicated in that the bone

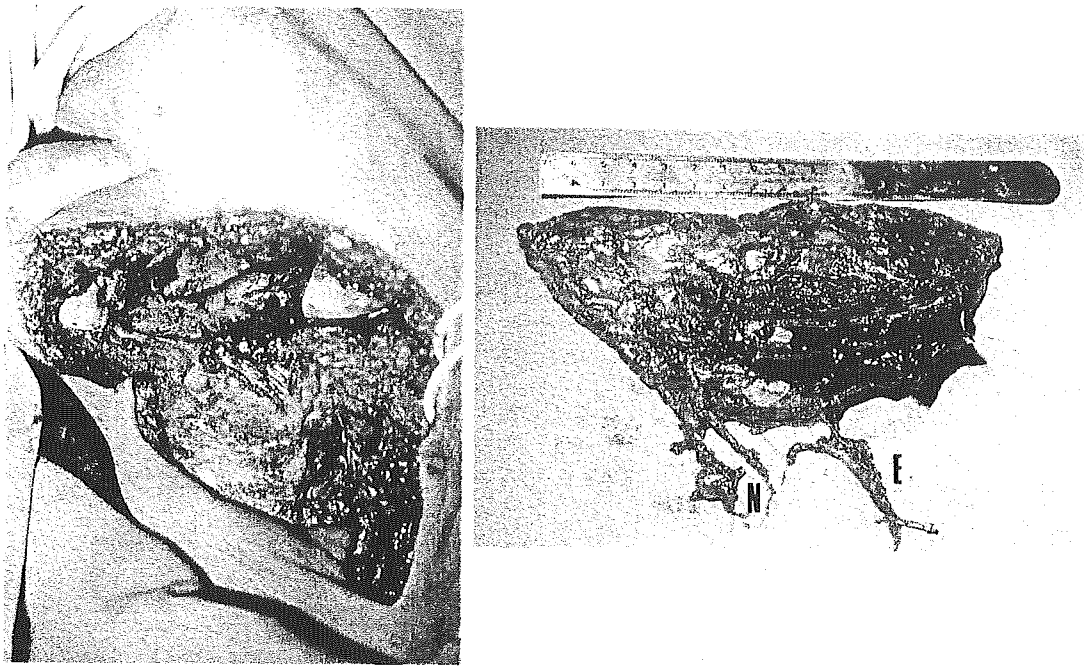

FIG. 4. Case 3. (*Left*) The irradiated mandible and cervical skin of this 58-year-old man were resected widely. (*Right*) The osteocutaneous defect was repaired with sequential vascularized iliac bone pedicled with the deep circumflex iliac system (*E*) and a superficial circumflex iliac perforator flap pedicled with the short superficial circumflex iliac system (*N*).

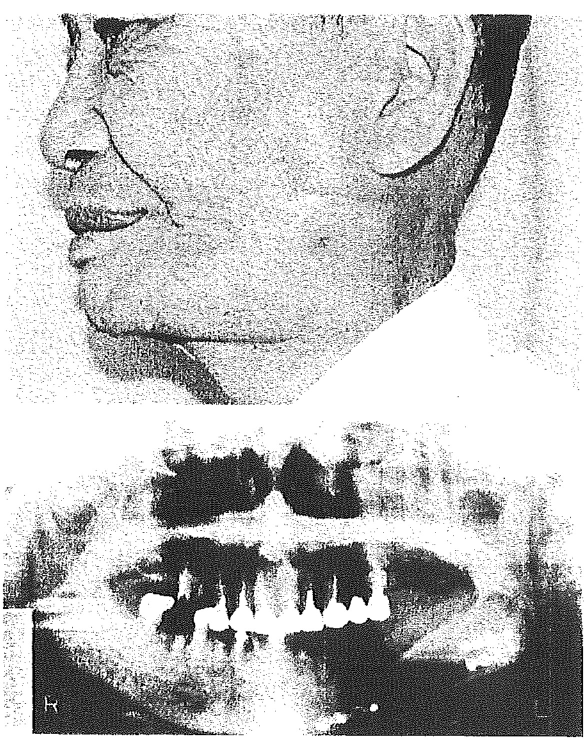

FIG. 5. Case 3. (*Above*) Postoperative appearance at 10 years after the operation. (*Below*) Postoperative radiograph shows no bone absorption at 10 years after the operation.

and skin flap are collected from different regions. The combination of an anterolateral thigh flap with a vascularized iliac bone or fibula,[8,9] reported originally by us, is an example. On the basis of our cases, the major disadvantage is the necessity for different donor sites for bone and the skin flaps even in cases with defects that are not so wide. In this regard, the scapular osteocutaneous flap seems to be ideal, because the bone and skin flaps can be obtained as a composite flap and not from different sites. However, many authors believe that simultaneous elevation of the scapular osteocutaneous flap is impossible during tumor resectioning and that the unavoidable positional change before flap elevation is time consuming.

CONCLUSIONS

In this article, we have described the development of a sequential vascularized iliac bone graft with a supercharged superficial circumflex iliac perforator flap. Among candidates with established osteocutaneous losses, this flap is suitable for the following reasons. Their pedicles, the ascending branch of the deep iliac system and the distal portion of the superficial iliac system, are very close to each other and their diameters are suitable for anastomosis. Simultaneous flap elevation is possible because the donor sites are far from the recipient area. The skin flap and vascularized bone graft can be obtained from the same donor site. Sequential combination of double tissue transplants with a single source vessel and a single recipient vessel provides enough nourishment for both a large skin territory and bone. This concept has been summarized in our previous articles (connected anterolateral thigh flap-groin flap,[10] classification of combined or connected flaps[11,12]). There is no need for longer dissection of the superficial circumflex iliac system to the proximal femoral division. The large superficial circumflex iliac perforator flap can survive with a perforator and a short segment of the superficial circumflex iliac system. Only the vascularized inner cortex of the iliac bone needs to be used. The outer cortex is preserved, resulting in no deformity of the iliac crest. This flap seems to result in less morbidity at the donor site.

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REFERENCES

1. Swartz, W. M., Banis, J. C., Newton, E. D., Ramasastry, S. S., Jones, N. F., and Acland, R. The osteocutaneous scapular flap for mandibular and maxillary reconstruction. *Plast. Reconstr. Surg.* 77: 530, 1986.
2. Soutar, D. S., and McGregor, I. A. The radial forearm flap in intraoral reconstruction: The experience of 60 consecutive cases. *Plast. Reconstr. Surg.* 78: 1, 1986.
3. Serafin, D., Reifkhol, R., Thomas, I., and Georgiade, N. G. Vascularized rib-periosteal and osteocutaneous reconstruction of the maxilla and mandible: An assessment. *Plast. Reconstr. Surg.* 66: 718, 1980.
4. Watanabe, H., Yamano, Y., Hosoda, M., and Fukuda, M. Reconstruction of a mandibular defect with a vascularized fibular bone graft. Presented at the 14th Annual Meeting of the Japanese Society of Reconstructive Microsurgery, Tsukuba City, Japan, December 5, 1987.
5. Hidalgo, D. A. Fibula free flap: A new method of mandible reconstruction. *Plast. Reconstr. Surg.* 84: 71, 1989.
6. Taylor, G. I., Townsend, P., and Corlett, R. Superiority of the deep circumflex iliac vessels as the supply for free groin flaps: Clinical work. *Plast. Reconstr. Surg.* 64: 745, 1979.
7. Koshima, I., Yamamoto, H., Hosoda, M., Moriguchi, T., Orita, Y., and Nagayama, H. Free combined composite flaps using lateral circumflex femoral system for repair of massive defects of the head and neck regions: An introduction to the chimeric flap principle. *Plast. Reconstr. Surg.* 92: 411, 1993.
8. Koshima, I., Hosoda, S., Inagawa, K., Urushibara, K., and Moriguchi, T. Free combined anterolateral thigh flap and vascularized fibula for wide, through-and-through oromandibular defects. *Reconstr. Microsurg.* 14: 529, 1998.
9. Wei, F. C., Celik, N., Chen, F. C., Cheng, M. H., and Huang, W. C. Combined anterolateral thigh flap and vascularized fibula osteocutaneous flap in reconstruction of extensive composite mandibular defects. *Plast. Reconstr. Surg.* 109: 45, 2002.
10. Koshima, I., Yamamoto, H., Moriguchi, T., and Orita, Y. Extended anterior thigh flaps for repair of massive cervical defects involving pharyngoesophagus and skin: An introduction to the "mosaic" flap principle. *Ann. Plast. Surg.* 32: 321, 1994.
11. Koshima, I. Classification of free combined or connected tissue (flap) transfers. *Ann. Plast. Surg.* 33: 462, 1994.
12. Koshima, I. A new classification of free combined or connected tissue transfers: Introduction to the concept of bridge. Siamese, chimeric, mosaic, and chain-circle flaps. *Acta Med. Okayama* 55: 329, 2001.

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INTRODUCTION TO REVIEW ARTICLES

Kiyonori Harii

Technical advances of plastic and reconstructive surgery in cancer surgery

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Key words Reconstruction · Free flap · Microsurgery · Musculocutaneous flap

Historical background

The history of plastic surgery in cancer treatment can be traced back in the literature to the early nineteenth century. Graefe and Dieffenbach in Germany repaired a nose and cheek defect following cancer resection, using local tissue transposition,[1] while, at the beginning of the twentieth century, Iginio Tansini in Italy first employed the latissimus dorsi muscle-skin flap for closing a skin defect following mastectomy.[2] Owens,[3] in 1955, also developed a compound muscle-skin flap, using the sternocleidomastoid muscle for closure of a face and cheek defect. Although these reports are sporadic, plastic and reconstructive surgeons have long recognized the importance of plastic surgery for the closure of a defect following cancer resection.

In modern cancer reconstructive surgery, McGregor,[4] in 1963, first developed the temporal flap for repairing post-excisional defects following surgery for intraoral cancer. McGregor and Reid[5] later extended the use of this flap to include primary closure of full-thickness cheek defects following the ablation of squamous cell carcinomas in the buccal region. Bakamjian and Littlewood[6] on the other hand, employed a cervical skin flap for intraoral and pharyngeal repair following cancer ablation. However, the use of such local tissues as neck skin for reconstruction in cancer surgery is open to debate and is limited because the local tissue surrounding cancers may be pathologically unsound. Radiation also greatly influences the vascularity of local skin and tissue and may lead to flap necrosis.

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To overcome this problem, Bakamjian,[7] in 1965, developed a versatile skin flap taken from the pectoral region (the so-called deltopectoral flap), using tissue distant from the original cancer lesion, for reconstruction following the resection of pharyngo-esophageal carcinoma, although Aymard,[8] in 1917, had first reported a similar flap for nasal reconstruction. McGregor and Jackson,[9] and Bakamjian et al.[10] further extended the role of the deltopectoral flap to a wide range of defects following the ablation of head and neck cancers. The deltopectoral flap was then championed as the most versatile flap in head and neck cancer surgery until the development of the microvascular free flap and the musculocutaneous flap.

Advances in plastic surgical procedures

Two remarkable advances in flap surgery, developed in the mid-1970s, established the important role of plastic surgery in cancer treatment. These are detailed below.

Muscle and musculocutaneous flaps

The development of muscle and musculocutaneous flaps in the mid-1970s was associated with great potential for a wide range of cancer reconstructions, because of the reliable vascularity of the flaps and the technical simplicity of the procedures.[11] A large island skin paddle, based on superficial skeletal muscle, could be safely transposed or rotated to close a deep and extensive defect. The large-caliber nutrient vessels of muscles, or those with a long vascular pedicle facilitated the microvascular free transfer of the musculocutaneous flap (the free musculocutaneous flap; Fig. 1).

The pectoralis major musculocutaneous flap[12] in the head and neck, the latissimus dorsi[13] or rectus abdominis flap[14] in the breast and chest, and the gracilis[15] or the posterior gluteal thigh flap[16] in the buttock and perineal regions were favored. However, the arc of rotation of the musculocutaneous flap is essentially limited by the maximum length

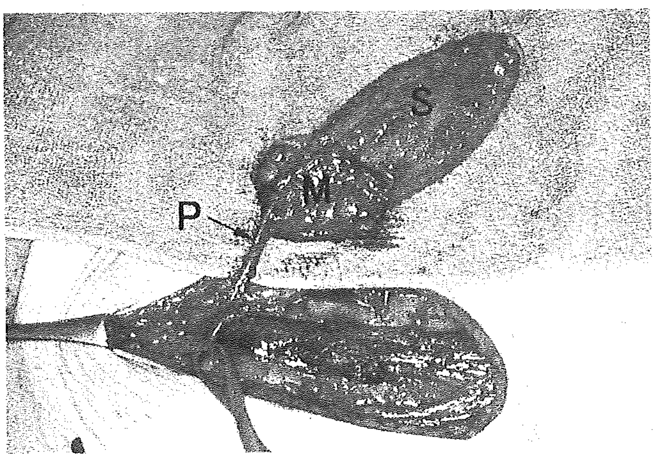

Fig. 1. Elevated rectus abdominis musculocutaneous flap. *S*, skin flap portion; *M*, a small part of the rectus abdominis muscle used to maintain blood supply to the skin flap; *P*, vascular pedicle of the inferior epigastric vessels

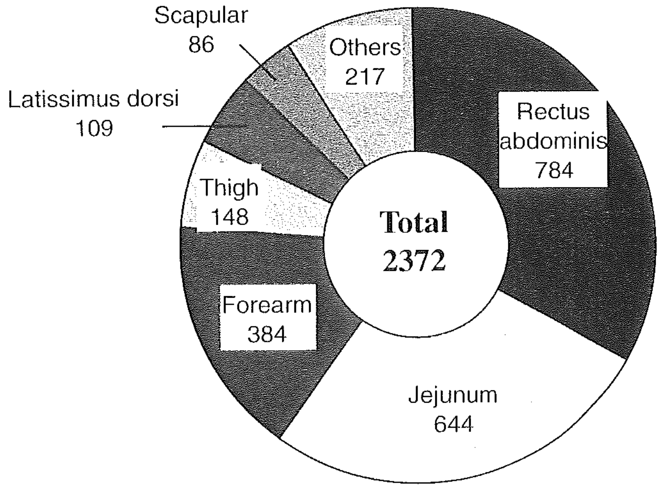

Fig. 2. Free flaps employed for reconstruction at the University of Tokyo Hospital, National Cancer Center Hospital, and other affiliated hospitals (November 1977–December 2000)

of its vascular pedicle, and this limitation is generally disadvantageous in reconstruction of the head and neck.

Microvascular free tissue transfer (free flap)

In contrast to the muscle and musculocutaneous flaps, microvascular free tissue and organ transfer (the so-called free flap) enabled various types of autogenous tissue flaps to be freely transferred to a distant recipient bed.[17,18] Adequate tissue and organs of a required size could be employed in the recipient defect. However, because of the technical difficulty, requiring special microsurgical skills, the free flap was not able to develop to its full potential in cancer surgery until the development of the musculocutaneous and fascio- (or septo-) cutaneous flaps, which provide many new donor flaps with large-caliber nutrient vessels. Using microsurgery, the incidence of thrombus formation in the anastomosed vessels in these flaps decreased in comparison with the incidence in skin flaps nourished by small nutrient vessels. Taking great advantage of the development of free flaps, which facilitate one-stage transfer of required tissue flaps from a distant site, we, since 1980, have developed a free flap for head and neck reconstruction following cancer resection at the National Cancer Center Hospital.[19] Over 2300 flaps have been transferred, with high success rates, in our series at the National Cancer Center and the University of Tokyo Hospital (Fig. 2; Tables 1, 2).[20] In addition, more than 40 tissue and organ flaps, including cutaneous and septocutaneous flaps, muscle and musculocutaneous flaps, osseous and osteocutaneous flaps, and intestinal and omental flaps, are now clinically available (Fig. 3).[21]

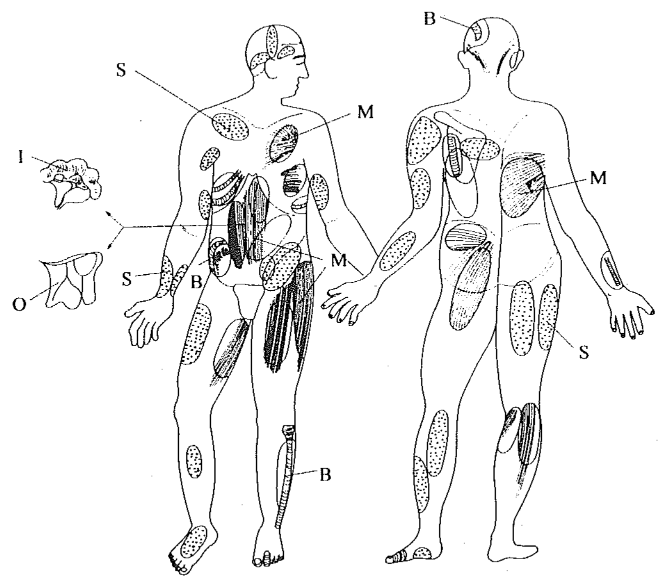

Fig. 3. Donor tissues and organs available for microvascular free flap transfers. *S*, skin flap; *M*, muscle and musculocutaneous flap; *B*, vascularized bone graft and osteocutaneous flap; *I*, intestine; *O*, omentum. Reproduced from Harii et al.,[21] with permission

Table 1. Outcome of transferred major flaps (November 1977–December 2000)

Flaps	Complete survival	Total necrosis	Partial necrosis
Rectus abdominis	93.3%	3.6%	3.1%
Jejunum	96.9%	3.1%	0%
Forearm	95.8%	2.6%	1.6%
Thigh	90.5%	7.4%	2.0%
Latissimus dorsi	85.3%	3.7%	11.0%
Scapular	91.9%	4.7%	3.5%
Iliac	79.5%	15.9%	4.5%
Fibular	81.5%	11.1%	7.4%

Goals of plastic and reconstructive surgery

In many fields of contemporary cancer surgery, function-preserving or nonradical and minimally invasive operations

Table 2. Causes of free-flap failures (November 1977–December 2000)

Causes	Total necrosis	Partial necrosis
Arterial thrombosis	36	7
Venous thrombosis	28	4
Infection	18	11
Anomaly of vascular pedicle	8	4
Problems in flap elevation	6	29
Miscellaneous	4	5
Total	100	60

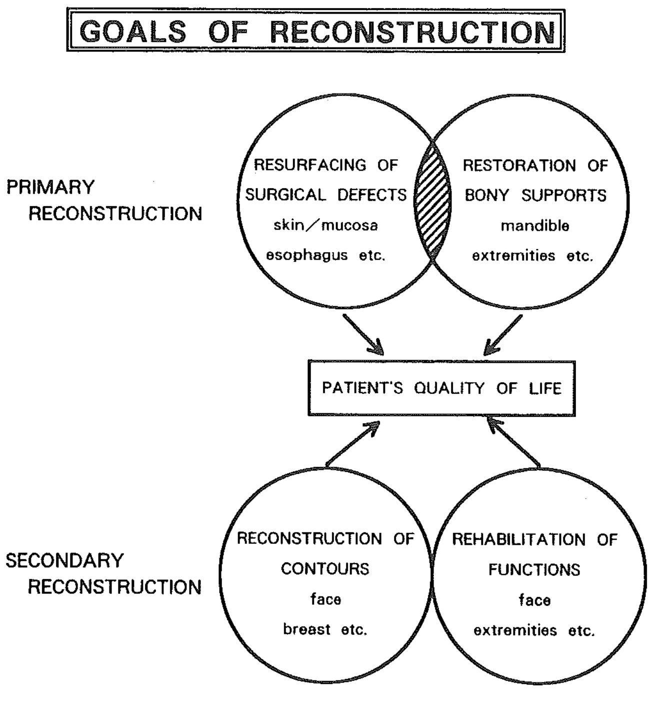

Fig. 4. Goals of plastic surgical reconstruction. Reproducted from Harii et al.,[21] with permission

such as endoscopic surgery are highly recommended to maintain a good quality of life for cancer patients. However, complete resection of carcinoma is mandatory in surgery, and this frequently requires the sacrifice of wide areas of healthy surrounding tissues and organs, resulting in functional disabilities or aesthetic deformities.

The primary goal of plastic and reconstructive surgery is the adequate and immediate closure of surgical defects following cancer ablation. The immediate (or primary) reconstruction achieved with cancer ablation should protect important vital organs, prevent infection, and restore the primary functions necessary for survival. The secondary goal is functional and/or contour reconstruction to maintain patients' quality of life, including social activities, and this is usually achieved secondarily some time after cancer ablation. In both primary and secondary reconstruction, the improvement of quality of life in cancer patients is naturally the final goal of plastic and reconstructive surgery (Fig. 4). At present, plastic surgical procedures are widely applied to such areas as skull and skull-base reconstruction, head and neck reconstruction, breast and thoracic wall reconstruction, perineal and buttock reconstruction, and extremity reconstruction.

I believe the ongoing development of plastic and reconstructive surgery will greatly contribute to cancer treatment, especially from the standpoint of patients' quality of life.

References

1. Goldwyn RM (1977) Johann Friedric Dieffenbach (1794–1847). In: McDowell F (ed) The source book of plastic surgery. Williams & Wilkins, Baltimore, pp 443–452
2. Maxwell GP (1980) Iginio Tansini and the origin of the latissimus dorsi musculocutaneous flap. Plast Reconstr Surg 65:686–692
3. Owens N (1955) A compound neck pedicle designed for the repair of massive facial defects: formation, development and application. Plast Reconstr Surg 15:369–389
4. McGregor IA (1963) The temporal flap in intra-oral cancer: its use in repairing the post-excisional defect. Br J Plast Surg 16:318–335
5. McGregor JA, Reid WH (1966) The use of the temporal flap in the primary repair of full-thickness defects of the cheek. Plast Reconstr Surg 38:1–9
6. Bakamjian VY, Littlewood M (1964) Cervical skin flaps for intraoral and pharyngeal repair following cancer surgery. Br J Plast Surg 17:191–210
7. Bakamjian VY (1965) A two-stage method for pharyngoesophageal reconstruction with a primary pectoral skin flap. Plast Reconstr Surg 36:173–184
8. Aymard JL (1917) Nasal reconstruction. Lancet 2:888–892
9. McGregor IA, Jackson IT (1970) The extended role of the deltopectoral flap. Br J Plast Surg 23:173–185
10. Bakamjian VY, Long M, Rigg B (1971) Experience with medially based deltopectoral flap in reconstructive surgery of the head and neck. Br J Plast Surg 24:174–183
11. McCraw JB, Dibbell DG, Carraway JH (1977) Clinical definition of independent myocutaneous vascular territories. Plast Reconstr Surg 60:341–352
12. Ariyan S (1979) The pectoralis major myocutaneous flap. A versatile flap for reconstruction in the head and neck. Plast Reconstr Surg 63:73–81
13. Bostwick J III, Scheflan M (1980) The latissimus dorsi musculocutaneous flap: a one-stage breast reconstruction. Clin Plast Surg 7:71–78
14. Hartrampf CR, Scheflan M, Black PW (1982) Breast reconstruction with a transverse abdominal island flap. Plast Reconstr Surg 69:216–225
15. McCraw JB, Massey FM, Shanklin KD, et al. (1976) Vaginal reconstruction with gracilis myocutaneous flaps. Plast Reconstr Surg 58:176–183
16. Achauer BM, Braly P, Berman ML, et al. (1984) Immediate vaginal reconstruction following resection for malignancy using the gluteal thigh flap. Gynecol Oncol 19:79–89
17. Daniel RK, Taylor GI (1973) Distant transfer of an island flap by microvascular anastomoses. A clinical technique. Plast Reconstr Surg 52:111–117
18. Harii K, Omori K, Omori S (1974) Successful clinical transfer of ten free flaps by microvascular anastomoses. Plast Reconstr Surg 53:259–270
19. Harii K (1990) The role of plastic surgery in surgical therapy for cancer patients. Jpn J Clin Oncol 20:48–57
20. Nakatsuka T, Harii K, Asato H, et al. (2003) Analytic review of 2372 free flap transfers for head and neck reconstruction following cancer resection. J Reconstr Microsurg 19:363–368; discussion, 369
21. Harii K, Asato H, Nakatsuka T, et al. (1999) Reconstructive plastic surgery in cancer treatment: surgery for quality of life. Int J Clin Oncol 4:193–201

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REVIEW ARTICLE

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Choice of osseous and osteocutaneous flaps for mandibular reconstruction

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Abstract Microvascular free flap transfer currently represents one of the most popular methods for mandibular reconstruction. With the various free flap options now available, there is a general consensus that no single kind of osseous or osteocutaneous flap can resolve the entire spectrum of mandibular defects. A suitable flap, therefore, should be selected according to the specific type of bone and soft tissue defect. We have developed an algorithm for mandibular reconstruction, in which the bony defect is termed as either "lateral" or "anterior" and the soft-tissue defect is classified as "none," "skin or mucosal," or "through-and-through." For proper flap selection, the bony defect condition should be considered first, followed by the soft-tissue defect condition. When the bony defect is "lateral" and the soft tissue is not defective, the ilium is the best choice. When the bony defect is "lateral" and a small "skin or mucosal" soft-tissue defect is present, the fibula represents the optimal choice. When the bony defect is "lateral" and an extensive "skin or mucosal" or "through-and-through" soft-tissue defect exists, the scapula should be selected. When the bony defect is "anterior," the fibula should always be selected. However, when an "anterior" bone defect also displays an "extensive" or "through-and-through" soft-tissue defect, the fibula should be used with other soft-tissue flaps. Flaps such as a forearm flap, anterior thigh flap, or rectus abdominis musculocutaneous flap are suitable, depending on the size of the soft-tissue defect.

Key words Mandible · Reconstruction · Flap · Microsurgery

Introduction

The mandible frames the lower third of the face and represents an integral component of mastication, deglutition, phonation, and oral competence. This structure also represents a major component of the human form, capable of suggesting either strength or weakness of character. The effect of mandibular resection following cancer of the oral cavity can thus prove devastating to the psychological and physical welfare of the patient. In the pursuit of perfect restoration of defective mandibles, reconstructive surgeons have made numerous technical advances over the past several decades.

Free flaps currently represent the preferred method for mandibular reconstruction. With the various free flap options now available, reconstructions of composite mandibular defects have been able to achieve significant improvements in both functional and esthetic results. The unique features of each flap have been well characterized in the literature. The quality of each type of bone is distinct, as is the quality of the accompanying skin portion. As a result, no single kind of osseous or osteocutaneous flap is considered capable of resolving the wide variety of mandibular defects, so a suitable flap should be selected according to the type of bone and soft-tissue defect.[1,2] Moreover, double free flaps should be considered for patients in whom defects are extensive or recipient vessels are not readily available.[3–5]

The present study reviewed mandibular reconstructions, particularly those using microvascular composite free flaps, and compared free osseous and osteocutaneous flaps to identify optimal flap choice for each patient.

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History

Experiences with mandibular reconstruction from around the world and from the earliest times have been described in a collective review by McDowell and Ohlwiler.[6] They state that the first successful mandibular resection appears to have been performed in 1810. After ablative surgeons recognized that patients experienced difficulties in breathing, swallowing, and speaking after mandibular resection, stabilization of residual jaw fragments by bone graft or implants was initiated. According to Kazanjian and Converse,[7] some bone transplants were attempted in the nineteenth century, but they did not gain widespread popularity until World War I, when Delageniere[8] applied tibial osteoperiosteal grafts to the jaw. World War II saw large numbers of patients requiring facial restoration, promoting the extensive use of bone grafts for mandibular surgery.[9] Although various kinds of skeletal sources had been explored, most surgeons preferred autogenous rib[10,11] or ilium,[12,13] particularly for composite resection of the tongue, jaw, and neck.[14] Autogenous bone grafts remained a mainstay of mandibular reconstruction afterwards.[7,15,16] However, survival rates following these free bone grafts varied, ranging from 20% to 90%.[17] High failure rates were attributable to lack of blood supply to the grafted bone, insufficient mucosal cover, scarred bed, infection, fistula, or stress on the graft.[18,19] To overcome such problems, living bone graft with a reliable soft-tissue flap was developed. Although the basic idea of this type of flap had appeared sporadically in the literature,[20] Snyder et al.[21] are credited with re-introducing osteocutaneous flaps. They succeeded in transfers of the clavicle or rib, combined with an overlying skin flap to the mandible by delaying procedures. Various types of pedicled osteocutaneous flaps or osteomyocutaneous flaps, such as sternocleidomastoid muscle with clavicle, pectoralis major muscle with rib or sternum, and trapezius muscle with scapula have subsequently been used to provide vascularization to the transferred bone and soft tissues.[22–25] However, these frequently failed when large segments of bone required osteotomies for contour adjustment and complex soft-tissue replacement. Such failures were primarily related to the need for such bone to be nourished solely by the relatively poor blood supply received through muscle insertions or a limited periosteal vascular supply. Moreover, neck skin contracture is inevitable after transferring pedicled flaps from the anterior chest, and use of the clavicle may cause significant dropping of the shoulder joint.

With the advent of microvascular free tissue transfer, many reconstructive surgeons adopted vascularized bone transfer to avoid morbidities of free bone graft or pedicled bone graft. The free osseous flap has become preferable to non-vascularized bone grafts or pedicled osteocutaneous flaps thanks to higher rates of bone survival and lower rates of infection and fistula. Osseous flaps for mandibular reconstruction have been widely developed from the rib,[26–28] metatarsus,[29–31] ilium,[32–34] scapula,[35–37] fibula[38–40] and radius.[41–43]

Along with vascularized bone flaps, free soft-tissue flaps have also played an important role in the progress of mandibular reconstruction by reviving the use of biomaterials. According to Hamaker,[19] Martin was the first to reform the mandibular arch with an external prosthetic appliance, in 1889. Since then, mandibular replacements have utilized a wide variety of foreign substitutes, including ivory, rubber, wire mesh, celluloid, vitallium, steel, acrylic, polyethylene, and silicone.[44–49] With these implants, the mandible can be restored without the need to spare time for harvesting and reshaping autogenous bone. However, subsequent infection and extrusion were not uncommon even when these implants were used in combination with adjacent musculocutaneous and axial cutaneous flaps, resulting in these prostheses falling from favor. Differing from the regional flaps previously used, free flaps with well-vascularized soft tissue provide reliable primary wound healing, reducing the risk of plate exposure.[50,51] Furthermore, new biomaterials such as titanium used in the plate have decreased longstanding problems of implant loosening and fracture.[52,53] The use of reconstruction plates covered with a well-vascularized free soft-tissue flap might therefore be indicated for reducing donor-site morbidity.

Free osseous flaps for mandibular reconstruction

Rib

The first successful bone transfers with microsurgical revascularization were performed in dogs by Ostrup and Fredrickson[54] and McCullough and Fredrickson.[55] The posterior part of the ninth rib, nourished by the posterior intercostal vessels, was used to reconstruct the mandible. At the Microvascular Panel of the Pan Pacific Surgical Association in 1975, McKee reported 11 mandibular reconstructions with revascularized free rib grafts, and this is considered to represent the first report of consecutive cases in a clinical setting. Because the rib was almost the only donor site for use as vascularized bone, several surgeons used the rib for mandibular reconstruction.[27] However, the operative techniques involved in harvesting the rib are very complicated, as a posterior dissection within 3 cm of the costvertebral joint is required to preserve intramedullary blood flow.[26] Although Schlenker et al.[56] developed a latissimus dorsi osteomyocutaneous flap for easier harvest of the rib, significant morbidity is associated with taking a segment of rib along with the adjacent intercostal muscles. Moreover, the rib does not readily lend itself to reshaping, due to poor vascularization. Given these weaknesses and the new development of other osseous flaps, vascularized rib grafts have seen little recent use.

Metatarsus

The use of vascularized metatarsus was originally developed from the free dorsalis pedis flap[57] and was first applied by O'Brien et al.,[29] Bell and Barron,[30] and Salibian et al.[58]

for mandibular reconstruction. The skin overlying the metatarsus is thin and pliable, providing an excellent intraoral lining to fit a denture.[31] Each metatarsus has an average of three foramina for nutrient vessels concentrated in the proximal and distal thirds of the bone, allowing osteotomy to be performed without compromising bone survival. Conversely, the thinness and lack of bulk of the bone result in difficulty evacuating a dead space after ablative surgery. Rosen et al.[59] proposed that the metatarsus was indicated for anterior arch reconstruction with a small soft-tissue defect. However, apparent donor site morbidity[60] led to replacement of the metatarsus by the fibula, which offers similar advantages.

Ilium

Although the superficial circumflex iliac vessels were first used as the vascular pedicle for combining a groin skin flap with iliac bone,[61] Taylor et al.[33] subsequently noted that the deep circumflex system plays a major role in supplying the bone. The deep circumflex iliac vessels are now recommended as nutrient pedicle vessels, particularly for the restoration of large bone defects such as the mandible.[62] The iliac crest displays an intrinsic curvature that is used to advantage in mandibular reconstruction. Hemimandibular defects are easily replaced by incorporating the anterior edge of the ilium.[63] No other site in the body can supply as much bone, and the inconspicuous donor-site scar is also advantageous. Conversely, the soft-tissue attachment is often excessively bulky, and the associated vasculature can occasionally prove unreliable.[37] To overcome this problem, the internal oblique-iliac crest osteomyocutaneous flap with skin graft was developed by Urken et al.[64] However, additional pedicled or free flaps are often required for stable results.[65] Urken et al.[4] also subsequently adopted combined sensate radial forearm and iliac crest free flaps. Nevertheless, the iliac crest is an excellent and reliable complementary flap for mandibular reconstruction, eminently suited to osseointegration, due to the large amount of cortical bone.[66]

Scapula

Gilbert and Teot[67] described the first use of a free scapular flap in 1982, with a detailed anatomical study by dos Santos[68] being done before the first clinical trial. Teot et al.[35] further described the osteocutaneous scapular flap and used this for mandibular reconstruction in one patient. After reports by Swartz et al.[36] and Granick et al.[69] of consecutive patients in whom a free scapular flap was used for mandibular reconstruction, this flap has been used as a versatile flap for mandibular reconstruction.[70] A solid graft is provided that can replace a relatively long bone defect, of up to about 13 cm in length. Soft-tissue bulk is not excessive and donor site morbidity and deformity are acceptable. As the scapular skin island and bone have separate vascular pedicles, three-dimensional maneuverability of the flap relative to the bone significantly facilitates simpler reconstruction of the oral cavity without remnant dead space. In addition, according to Coleman and Sultan,[71] anterior reconstructions that require two osteotomies are possible using the angular branch of the thoracodorsal artery as a vascular pedicle to the inferior pole of the scapula. One disadvantage of the scapular flap is the need to reposition the patient during the operation.

Fibula

Considerable confusion exists regarding the first successful free fibula transfer.[72] Most publications have cited Taylor et al.[73] as performing the first successful clinical free fibula transfer. However, Ueba and Fujikawa[74] had already succeeded in transferring the fibula by this time. Their work remained unpublished until 1983, and has been neglected by all except O'Brien et al.,[75] who have always cited them in their references as the first to perform successful free transfer. The free fibula flap was predominantly used for limb reconstruction, and was rarely used for mandibular reconstruction until consecutive cases were described by Hidalgo[38] and Hidalgo and Rekow.[76] Recently, the free fibula flap has become a preferred graft for mandibular reconstruction, providing sufficient bone to reconstruct any length of mandibular defect, while the straightness and thick cortex of the bone allow easy contouring after osteotomy. The skin flap of the fibula is thin and pliable, and is thus suitable for use as oral lining. Harvest can be undertaken simultaneously with ablative surgery, and donor site morbidity is minimal. However, unreliability of the attached skin, as reported by Hidalgo,[38] has limited the potential for reconstruction of composite mandibular defects.[40] Moreover, the potential exists for leaving dead space when the free fibula flap is used as a single composite flap, readily leading to infection and fistula formation.[5]

Radius

In 1983, Soutar et al.[77] reported ten cases of intraoral reconstruction using a radial forearm flap, including radial bone to replace segments of the mandible. Since then, mandibular reconstruction using the radius has gained in popularity.[78] The long pedicle can reach even to the contralateral side of the neck. The skin paddle is reliable and provides a large area of good-quality, thin, soft-tissue coverage for intraoral defects. A high rate of fracture in the radius after harvesting remains problematic, although keel-shaped modification[79] or prophylactic plating of the radius[80] can be performed to avoid radial fractures. The bone thickness that can be harvested from the radius is too small to endure stress in the mandible.[81]

Choice of osseous and osteocutaneous flaps

We previously reported 178 consecutive cases of mandibular reconstruction using microvascular free flaps, comparing flap success rates, complications, and esthetic and func-

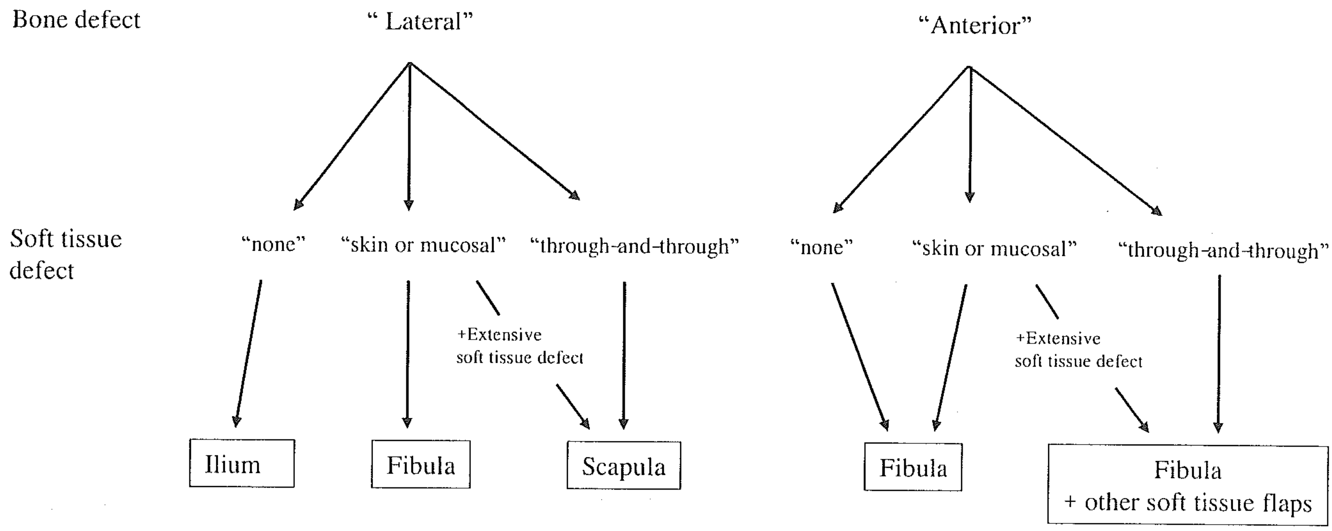

Fig. 1. Algorithm for mandibular reconstruction with osseous free flaps

tional results.[82] Based on these data, we concluded that osseous and osteocutaneous flaps should be selected depending on the condition of the mandibular bone and surrounding soft-tissue defect. We have therefore developed an algorithm to assist flap selection in mandibular reconstruction (Fig. 1).

In our algorithm, the bone defect can be categorized as either "lateral" or "anterior." Soft-tissue defects are classified into three categories: "none" (no or minimal defect on both sides of facial skin and oral mucosa); "skin or mucosal" (only skin or mucosal defect); and "through-and-through" (defect is through-and-through from the oral mucosa to the facial skin). When selecting a suitable flap, the bone-defect condition should be considered first, followed by the soft-tissue defect condition.

In patients displaying a "lateral" mandibular defect whose soft-tissue defect can be categorized as "none," the ilium is the best choice. One of the advantages of the ilium is the large amount of bone with the capacity for ready osseointegration.[83] A segment of ilium is easily applied to lateral segmental defects of the mandible, because the shape already resembles that of the hemimandible.[33] However, given the unreliable vascularity of skin flap segments of the iliac osteocutaneous flap, reconstruction after benign tumor resection and secondary reconstruction without soft-tissue defect represents a preferable indication for the iliac flap. Use of the ilium is particularly recommended for young patients, as the scar of the donor site is typically hidden under clothing. Contour deformity after harvesting can be overcome by single cortex bone harvest[84] or the implantation of hydroxyapatite.

In patients with a "lateral" mandibular defect and a "skin or mucosal" soft-tissue defect, the fibula is the best choice. However, an additional free soft-tissue flap such as a forearm flap is often required for reliable intra-oral lining, if vascular unreliability of the fibular skin flap becomes evident after elevation. Although the fibula is a good material for these types of reconstruction, the donor site scar is conspicuous.

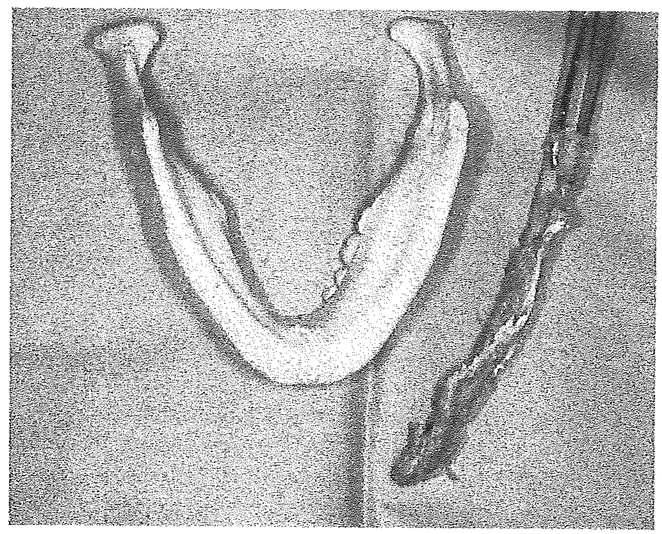

Fig. 2. Slight curve of the scapula resembles that of the lateral mandible and leads to superiority in lateral reconstruction

In patients presenting with a "lateral" mandibular defect and an extensive "skin or mucosal" or "through-and-through" soft tissue defect, the scapula is the best choice. For the scapula, at least one osteotomy is possible without devascularization. Good seals in both the oral mucosa and facial skin can be achieved using separated skin paddles of scapula without leaving a dead space. Moreover, the slight curve of the scapula resembles that of the lateral mandible and leads to superiority in lateral reconstruction (Fig. 2). Some authors report that the quantity and quality of grafts from the scapula are low and osseointegration does not occur.[64] However, our experiences suggest that few cases involving lateral bone defect or through-and-through soft tissue-defect require osseointegration. In most cases where the bone defect is lateral, oral rehabilitation can be achieved with the residual teeth or by using a dental prosthesis. Application of osseointegration is generally not absolutely necessary, because the prognosis for a patient who requires extensive composite mandibular resection is not good. Another disadvantage of the scapula flap is the need to change the position of the patient during operation for flap harvest. However, double free flaps, which are required in this situation as an alternative choice, also need time for harvesting, and morbidities of the soft-tissue flaps associated with the osseous flap must be considered. A composite scapula flap thus appears better than a combination of fibula and soft-tissue flap.

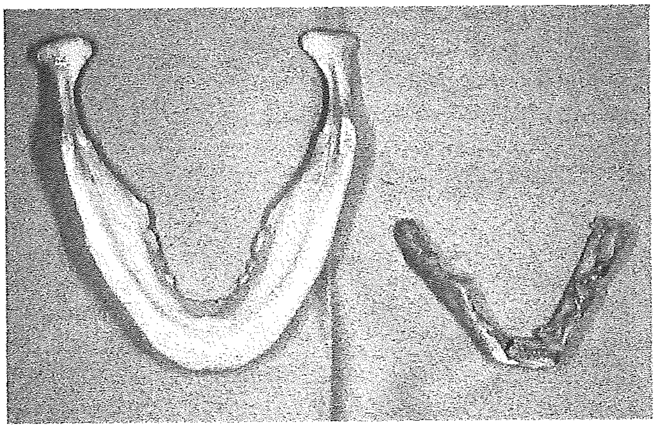

Fig. 3. Quantity of scapula that can be harvested without shoulder morbidity is limited to the contour of the anterior segment

In patients displaying an "anterior" mandibular defect, use of the fibula is always the best choice, as the bone can be osteotomized into three segments to match the contour of the horseshoe-shaped mandible without destroying the vascularity of the segments. A soft-tissue flap combined with the fibula is frequently necessary when the vascularity of the fibular skin flap is unstable, or when the soft-tissue defect is extensive or through-and-through. A forearm flap, anterior thigh flap, or rectus abdominis musculocutaneous flap should be selected as a soft-tissue flap, depending on the size of the soft-tissue defect. Although Coleman and Sultan[71] reported that the scapula can be divided into three

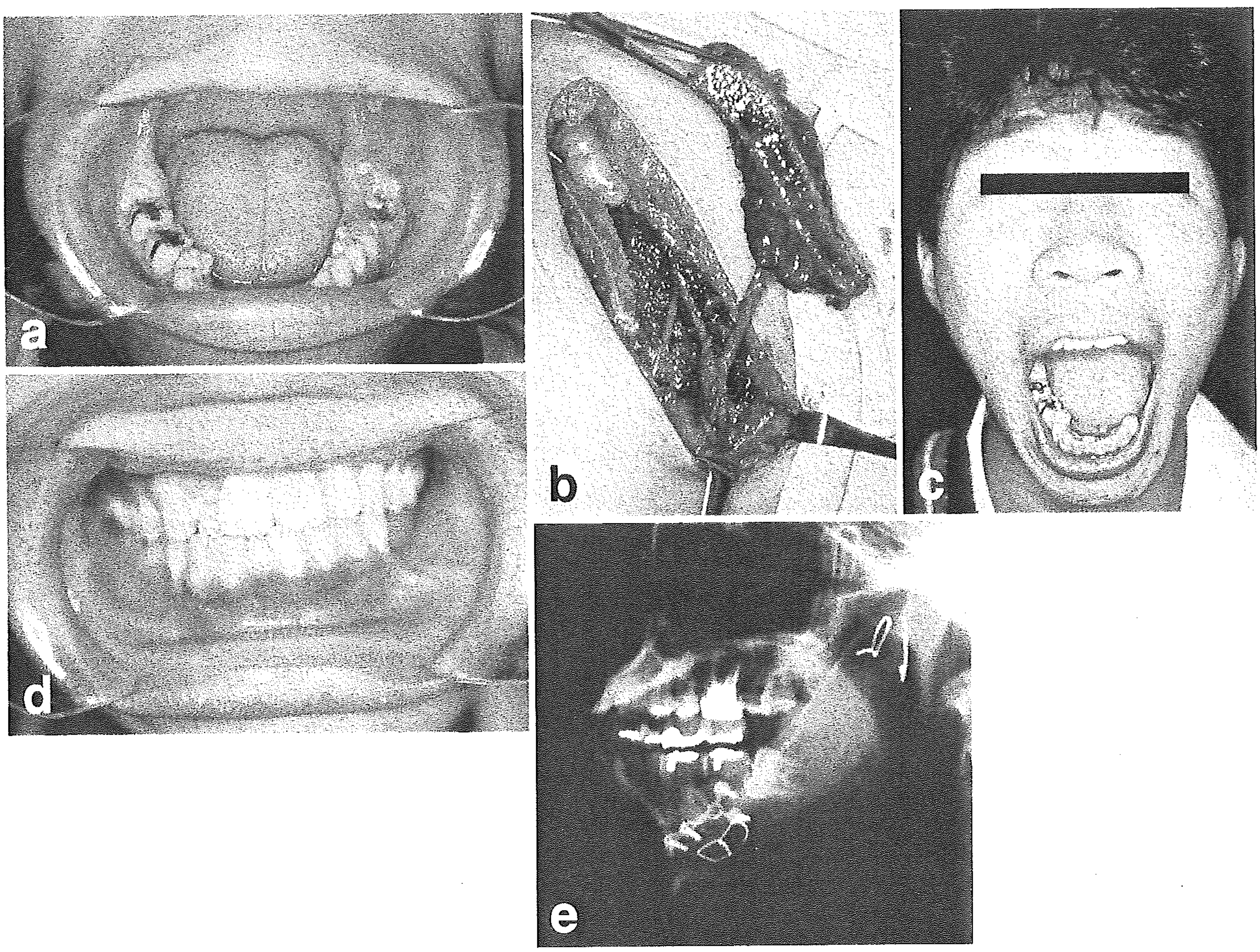

Fig. 4a–e. Findings in a 30-year-old man with left mandibular ameloblastoma (case 1). **a** Preoperative intraoral appearance. **b** Vascularized ilium was. elevated. **c** One-year postoperative appearance with mouth open. **d** Stable occlusion was achieved. **e** Radiograph 1 year postoperatively

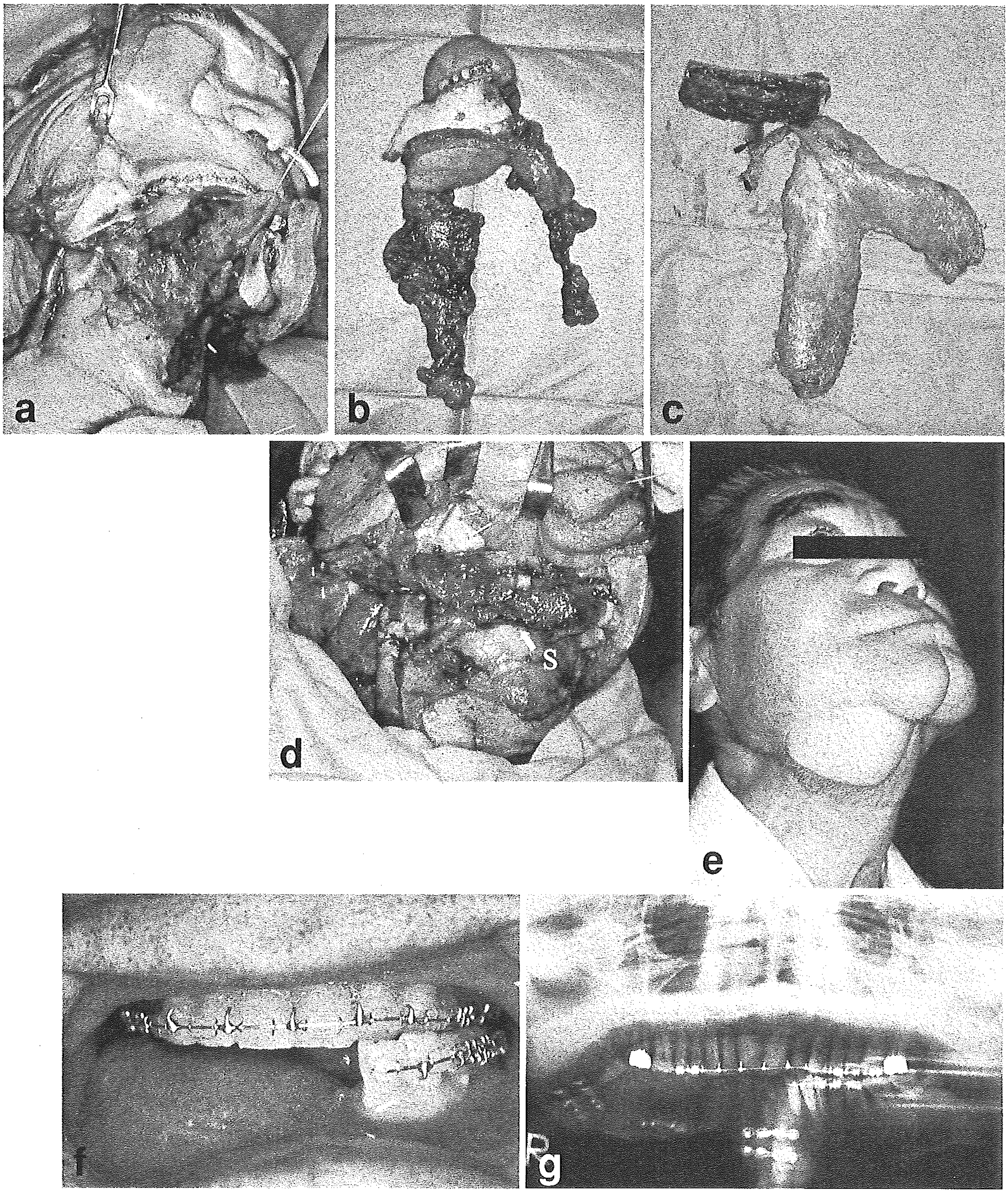

Fig. 5a–g. Findings in a 63-year-old man with cancer of the right side of the tongue (T2N3M0) (case 2) **a,b** Tumor ablation included segmental mandibulectomy and resection of the tongue and facial skin, with neck dissection on both sides. **c** Vascularized scapula with two skin paddles was harvested. **d** The mandible was reconstructed with the scapula (*s*) with one osteotomy. **e** Clinical appearance 1 year postoperatively. **f** Intraoral appearance. **g** Radiograph 1 year postoperatively

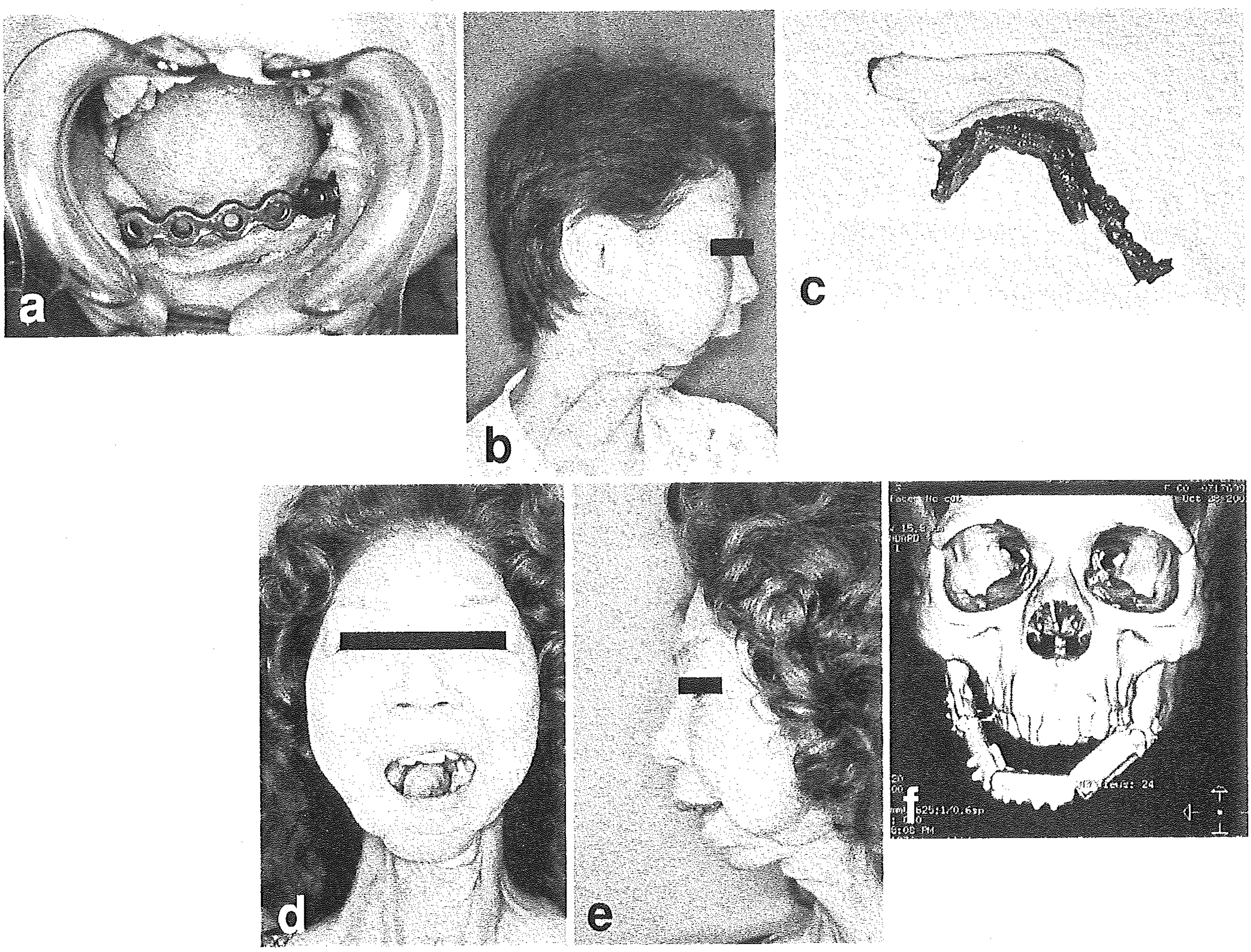

Fig. 6a–f. Findings in a 60-year-old woman with plate exposure in the oral floor (case 3). **a** Reconstruction plate was exposed intraorally. **b** Preoperatve clinical appearance. **c** Vascularized fibula with a skin paddle. **d** Two-years postoperative appearance with mouth open. **e** Postoperative lateral view. **f** Postoperative three-dimensional computed tomography

portions to make an anterior angle using the angular branch, the quantity of scapula that can be harvested without shoulder morbidity is limited to the contour of the anterior segment (Fig. 3).

Besides the choice of osseous and osteocutaneous flaps, mandibular reconstruction using implants combined with a free soft-tissue flap should be considered in certain cases. According to Boyd et al.,[51] anterior defects fail more frequently than defects that do not cross the midline. The use of implants with free soft-tissue flaps is thus preferable in patients with lateral bony defects in whom the prognosis is so poor that osseous flap harvest is contraindicated by donor-site morbidity.

Representative clinical cases

Some representative clinical cases are described below.

Case 1

A 30-year-old man presented with left mandibular ameloblastoma. Segmental mandibulectomy was performed. Because the bony defect was lateral and the oral mucosa was not defective, with a small soft-tissue defect, a vascularized iliac segment was used, according to our algorithm. As of 1 year postoperatively, the patient displayed stable occlusion of the remaining teeth (Fig. 4).

Case 2

A 63-year-old man presented with cancer of the right side of the tongue (T2N3M0). Tumor ablation included segmental mandibulectomy and resection of the tongue and facial skin, with neck dissection on both sides. Because the bone defect was lateral and the soft-tissue defect was the through-and-through type, a vascularized free scapula with two skin paddles was used (Fig. 5). Although the patient could eat an almost normal diet as of 6 months postoperatively, osseointegration to the grafted scapula is planned to achieve further improvement.

Case 3

A 60-year-old woman presented with plate exposure in the oral floor after ablative surgery for squamous cell carcinoma of the mandibular gingiva. Simultaneous reconstruction was achieved using a reconstruction plate for the defect of the bony segment, and a rectus abdominis musculocutaneous flap was used for coverage of soft-tissue defects, resulting in exposure of the reconstruction plate. Because the bony defect was anterior and the soft-tissue defect involved a small area of facial skin, a vascularized fibula segment was used to replace the exposed plate. As of 2 years postoperatively, the patient demonstrated stable occlusion with the aid of her denture, and facial cosmesis was improved (Fig. 6e).

Conclusion

Primary reconstruction materials have been changing ever since mandibular reconstruction using a free osseous flap was developed. Initially, primary reconstruction materials comprised the rib and ilium, then the scapula gained preference. Most recently, the fibula has become the material of choice for mandibular reconstructions. Based on our previous retrospective statistical analysis, we proposed considerations for flap choice. Our algorithm differs from those of other authors,[5,85] particularly with regard to our recommendation to use a composite scapular flap to reconstruct lateral defects, although Wei et al.[5] and Cordeiro et al.[85] employed the fibula. The goals of mandibular reconstruction are the restoration of both oral function and esthetic contours. No available methods are universally suited to application for all of the various possible mandibular defects. Because an appropriate flap should be selected according to the types of bone and soft-tissue defects present, we propose the use of our algorithm for determining suitable methods for reconstruction of the mandible.

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References

1. Cordeiro PG, Hidalgo DA (1995) Conceptual considerations in mandibular reconstruction. Clin Plast Surg 22:61–69
2. Chen YB, Chen HC, Hahn LH (1994) Major mandibular reconstruction with vascularized bone grafts: indications and selection of donor tissue. Microsurgery 15:227–237
3. Nakatsuka T, Harii K, Yamada A, et al. (1992) Dual free flap transfer using forearm flap for mandibular reconstruction. Head Neck 14:452–458
4. Urken ML, Weinberg H, Vickery C, et al. (1992) The combined sensate radical forearm and iliac crest free flaps for reconstruction of significant glossectomy-mandibulectomy defects. Laryngoscope 102:543–558
5. Wei FC, Demirkan F, Chen HC, et al. (1999) Double free flaps in reconstruction of extensive composite mandibular defects in head and neck cancer. Plast Reconstr Surg 103:39–47
6. McDowell F, Ohlwiler D (1962) Mandibular resection and replacement. Collective review. Int Abstr Surg 115:103–114
7. Kazanjian VH, Converse JM (1959) The surgical treatment of facial injuries. Williams & Wilkins, Baltimore
8. Delageniere H (1916) Periosteal grafts placed on the tibia. Bull Mem Soc Chir Paris 42:1048–1051
9. Blocker TG, Stout RA (1949) Mandibular reconstruction in World War II. Plast Reconstr Surg 4:153–156
10. Brown JB, Cannon B (1947) Repair of major defects of the face. Ann Surg 126:624–632
11. Longacre JJ, Destefano GA (1957) Further observations of the behavior of autogenous split-rib grafts in reconstruction of extensive defects of the cranium and face. Plast Reconstr Surg 20:281–296
12. New GB, Erich JB (1944) Bone grafts to the mandible. Am J Surg 63:153–167
13. Marino H, Turco NB, Craviotto M (1949) Immediate reconstruction of the lower jaw following surgical excision of large tumors. Plast Reconstr Surg 4:36–44
14. Ward GE, Robben JO (1951) A composite operation for radical neck dissection and removal of cancer of the mouth. Cancer 4:98–109
15. Converse JM, Campbell RM (1954) Bone grafts in surgery of the face. Surg Clin North Am 34:375–401
16. Millard DR, Dembrow V, Shocket E, et al. (1967) Immediate reconstruction of the resected mandibular arch. Am J Surg 114:605–613
17. Bromberg BE, Walden RH, Rubin LR (1963) Mandibular bone grafts. A technique in fixation. Plast Reconstr Surg 32:589–599
18. Adamo AK, Szal RL (1979) Timing, results, and complications of mandibular reconstructive surgery: report of 32 cases. J Oral Surg 37:755–763
19. Hamaker RC (1981) Irradiation of autogenous mandibular grafts in primary reconstructions. Laryngoscope 91:1031–1051
20. Blair VP (1918) Surgery and diseases of the mouth and jaw. CV Mosby, St. Louis
21. Snyder CC, Bateman JM, Davis CW, et al. (1970) Mandibulo-facial restoration with live osteocutaneous flaps. Plast Reconstr Surg 45:14–19
22. Conley J (1972) Use of composite flaps containing bone for major repairs in the head and neck. Plast Reconstr Surg 49:522–526
23. Ariyan S (1980) Pectoralis major, sternomastoid, and other musculocutaneous flaps for head and neck reconstruction. Clin Plast Surg 7:89–109
24. Panje W, Cutting C (1980) Trapezius osteomyocutaneous island flap for reconstruction of the anterior floor of the mouth and the mandible. Head Neck Surg 3:66–71
25. Mignogna FV, Rankow R, Garay KF (1993) A–O reconstruction plate and sternal osteomyocutaneous flap in primary mandibular reconstruction. Am J Surg 166:416–420
26. Daniel RK (1977) Free rib transfer by microvascular anastomoses. Plast Reconstr Surg 59:737–738
27. Serafin D, Villarreal-Rios A, Georgiade NG (1977) A rib-containing free flap to reconstruct mandibular defects. Br J Plast Surg 30:263–266
28. Harashina T, Nakajima H, Imai T (1978) Reconstruction of mandibular defects with revascularized free rib grafts. Plast Reconstr Surg 62:514–522
29. O'Brien BM, Morrison WA, MacLeod AM, et al. (1979) Microvascular osteocutaneous transfer using the groin flap and iliac crest and the dorsalis pedis flap and second metatarsal. Br J Plast Surg 32:188–206
30. Bell MS, Barron PT (1980) A new method of oral reconstruction using a free composite foot flap. Ann Plast Surg 5:281–287
31. MacLeod AM, Robinson DW (1982) Reconstruction of defects involving the mandible and floor of mouth by free osteo-cutaneous flaps derived from the foot. Br J Plast Surg 35:239–246
32. Daniel RK (1978) Mandibular reconstruction with free tissue transfers. Ann Plast Surg 1:346–371