4. 舌・口腔・咽頭再建

4.1 はじめに

近年における再建手技の進歩により、身体さまざまな領域の組織修復が可能になってきた。そして、その再建目的も徐々に変わりつつある。従来の再建目的は、生じた組織欠損を自家組織などで充填または被覆することであった。しかしながら、最近ではより術後の機能・形態を重視した再建に焦点が移ってきている。その最たる領域が、摂食・会話機能に関与してくる頭頸部領域の再建である。そこには、単に組織を移植するのみならず、いかに良い術後機能を維持するかが求められ、同時にそれは切除範囲に応じた再建方法の改良・開発の必要性に関連してくる。本稿では、口腔咽頭領域における切除範囲に応じた適切な再建方法について述べるが、領域が複雑なため舌および中咽頭上側壁欠損の再建について記述する。なお、再建材料に関しては手術時間の短縮を目指し、遊離皮弁で腫瘍切除と同時に皮弁の採取が可能な部位のみを選択した。

4.2 舌再建

舌悪性腫瘍切除後の再建目的は、喉頭の温存のみならず、いかに良い摂食会話機能を維持するかである[1]。そして、その再建方法は舌の切除範囲で異なってくる。まず、舌の切除範囲は大きく6型に分類される(図3.4.1)。すなわち、可動部舌部切、可動部舌半切、舌半切(可動部舌半切ならびに舌根半切)、可動部舌亜全摘(舌根は温存され可動部舌が半分以上切除)、舌亜全摘(舌根ならびに可動部舌が半分以上切除)、舌全摘(舌根ならびに可動部舌が両側舌下神経を含めて全て切除)である。どの切除範囲でも同様であるが、頸部郭清と腫瘍が一塊として切除されることが多く、再建の目的は口腔と頸部の遮断と残存舌の可動域の維持である。

可動部舌部切では、一次縫縮が可能であり再建を要することはまずない。可動部舌半切の再建は、患側の舌骨上筋群が温存されていれば口腔内の再建の必要性はなく、舌はそのまま縫縮する。そして顎下部の死腔には顎二腹筋や胸鎖乳突筋などの充填を要する(図3.4.2)[2]。患側舌骨上筋群が合併切除された場合は、頸部との交通が大きくなり、口腔内に皮弁の移植と顎下部の死腔充填が必要となる。これは舌半切除と同様の術式となる。

舌半切と前述した再建を要する可動部舌半切の場合の再建方法であるが、残存舌尖に皮弁を逢着する方法と残存舌尖を縫縮して新しい舌尖を作成する方法がある。われわれは、どんなに軽い皮弁でもそれを残存舌に縫い付けると舌尖の動きが悪くなることを経験している。移植組織が動かない限りは残存舌を縫縮して舌

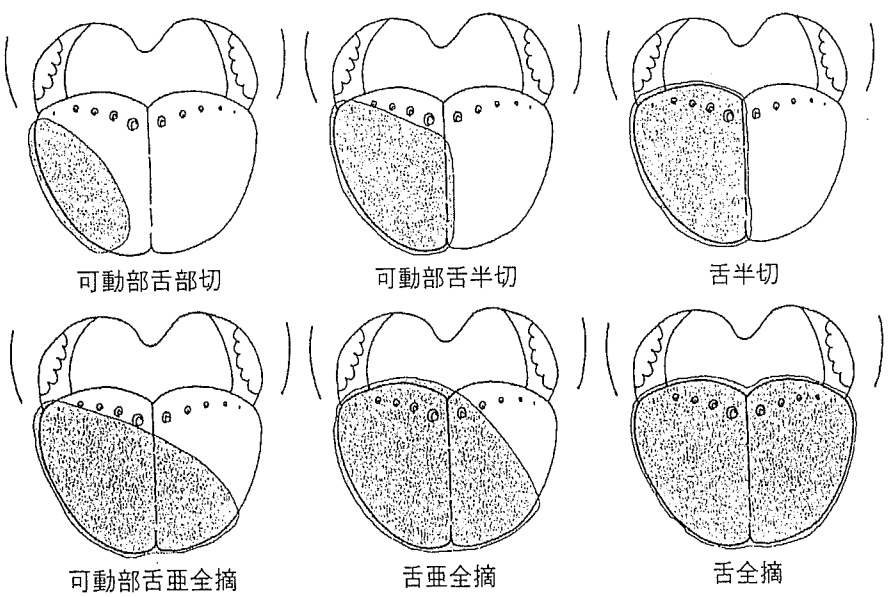

図3.4.1　舌切除範囲の分類

尖を作成し、その裏面から健側口腔底にかけて皮弁を挿入することで瘢痕拘縮を予防し、残存舌の動きが維持できるようにしている（図3.4.3）。さて、皮弁の選択であるが、薄い皮弁が望ましく前腕皮弁、前外側大腿皮弁[3]、そして薄い腹直筋皮弁（厚さ1cm程度）が考えられる[4]。その際、顎下部の死腔充填に脱上皮した皮膚成分、脂肪、そして皮弁に筋肉を母指大ほどつけて移植する方法がある。先の2者では瘻孔を形成したときの治癒期間が長くなる。われわれは皮弁採取部の多少の犠牲はあっても筋肉による顎下部充填が最も安全と考えている。

舌根を含まない可動部舌亜全摘には、外側広筋を付着させた前外側大腿皮弁や腹直筋皮弁が第一選択となる。この場合、移植した皮弁の容量が少ないと再建舌が陥凹して食塊の貯留が起きる。また舌尖音が出にくくなり、スピーチエイドなどの補助装具が必要となる。従って、移植皮弁の幅を十分にとり、隆起型の再建舌になるように心掛ける。舌尖形成に関しては、残存した舌組織の末梢が細長い形状であれば可能であるが、ほとんどの症例では不可能なため、そのまま皮弁を逢着することが多い。舌根が残っているために、後述する術後の喉頭の下垂を防止する必要性はない。

舌亜全摘・全摘術後の再建方法は、喉頭の温存のみならず摂食・会話機能に大きく関与してくるために、さまざまな工夫を要する。皮弁により再建された舌の形態は隆起型、半隆起型、平坦型、陥凹型に分類され（図3.4.4）、嚥下圧や口蓋音などの術後の機能を考慮すると再建舌が口蓋に接する隆起型の再建が最も望ましい[1,6]。そして、口狭部が狭い隆起型の再建舌を形成するための注意点として、容量のある皮弁（厚さが2cm以上）を選択すること、術後の喉頭下垂を予防することが挙げられる。結果として腹直筋皮弁が第一選択となる。そのデザインは最も皮下脂肪が厚くかつ穿通枝が多い臍周囲を中心とする。経験上、舌根に相当する部分の幅は最低でも8～9cmは必要で、皮下脂肪も2～3cm位は必要である。皮弁のデザインと挙上は、一般的に紡錘型とする場合が多い。舌全摘ならば皮弁は紡錘型で良いが、舌根などの残存組織が多い場合に紡錘型の皮弁をそのまま縫着すると、皮弁が捻れたり大きすぎたりすることがよくある。この場合、舌全摘の紡錘型のテンプレートをイメージし挙上後に、残存舌の表面積だけ皮弁を除去する方が簡便で良い（図3.4.5）。顎下部の死腔の充填目的に使用する腹直筋の筋体は必ずしも全幅必要でなく、1/3～1/2幅で十分である。皮弁の縫着は喉頭蓋谷から縫着を開始し、粘膜並びに皮膚が咽頭腔に内翻するように縫合を行う。そして、口腔内に移り皮弁を歯肉粘膜に縫合する。顎下部には筋体を充填した後に、頸部で血管吻合をする。

最後に、喉頭下垂防止術を付け加える。下顎骨正中から1～2cm程度外側にドリルで2ヵ所ずつ孔を開け、7号ナイロンまたは鋼線で舌骨を吊り上げる。舌骨上縁と下顎下縁との距離は2cm程度とする[5]。気管切開術に関しては、舌半切では必要ないが舌全摘に近いほど必要になることが多い。

隆起型を呈していても、あまり良い術後機能が得ら

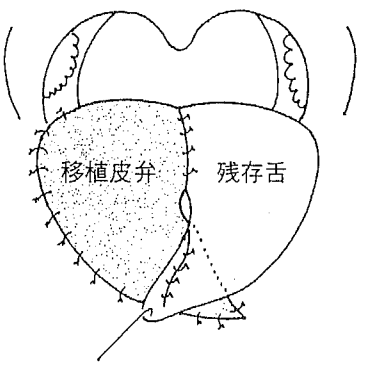

図3.4.3　舌半切、舌尖縫縮

図3.4.2　可動部舌半切症例
A：頸部郭清後の顎下部死腔の状態。顎二腹筋（矢印）。
B：顎二腹筋を広頸筋と縫合し、口腔と頸部を遮断。
C：術後の残存舌の状態。良好な可動域が得られている。

れない症例もある。その理由として術前状態、合併切除範囲、嚥下機能、患者の社会復帰に対する意欲などが関与してくる。術前状態として、アルコール性脳障害や脳梗塞などの神経的疾患がある症例では、喉頭温存は困難である。合併切除範囲では、舌全摘術に加え喉頭蓋までの切除または下顎や中咽頭が半分以上切除された症例では機能の損失が大きく、やはり喉頭の温存を目指した再建は困難である[6]。年齢に伴う嚥下機能の評価は確立された方法がなく、難しい問題であるが、若い人ほど良く、70歳以上になると喉頭温存の可能性がかなり低くなる。

4.3　中咽頭切除後の再建

中咽頭癌切除後の再建でよく遭遇するのは、側壁を中心とした欠損である。そして、この部分の組織欠損に対する再建の目的は、鼻咽腔閉鎖機能と鼻呼吸の維持の大きく二つである。また、移植皮弁と残存した軟口蓋や硬口蓋の断端との縫合部に哆開を生じると、術

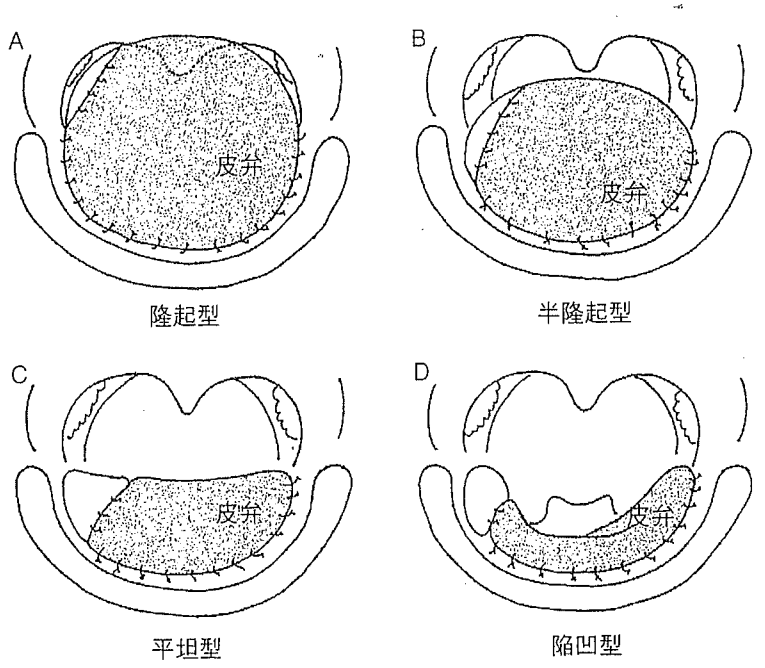

図 3.4.4　再建舌の形態分類
A：隆起型。皮弁は口蓋に接し、開口時に口狭部が見えない。
B：半隆起型。隆起しているが、口狭部が見える。
C：平坦型。移植皮弁が平坦状で、口狭部が広い。
D：陥凹型。移植皮弁は陥凹している。時に喉頭蓋が見える。

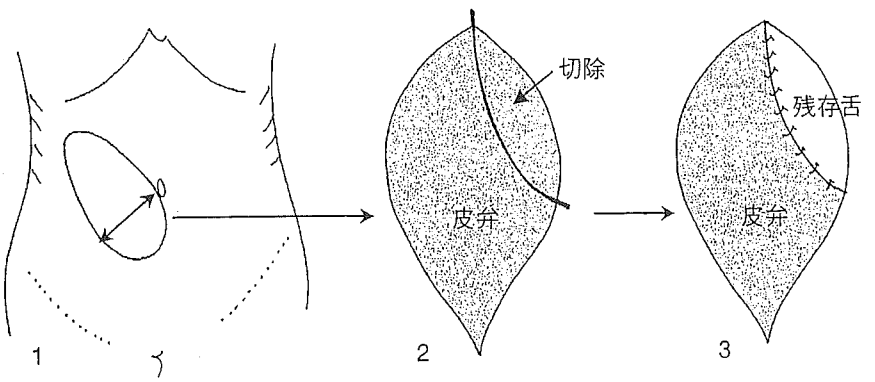

図 3.4.5　腹直筋皮弁の採取部位とテンプレート法
1：皮下脂肪の厚い部分（矢印）で舌根を再建。
2：全摘のデザインで紡錘型に皮弁を採取し、残存舌に相当する部分は切除する。
3：残存舌と移植皮弁を縫合する。

後の鼻咽腔閉鎖不全、開鼻声につながる。従って、哆開しないような皮弁の縫着方法が必要になる。また、舌再建と同様に欠損範囲を分類し、それに対応した再建方法が必要になる。

中咽頭側壁中心の切除範囲は、大きく3型に分類される。側壁欠損、側壁・上壁欠損、側壁・舌欠損である（図3.4.6）[7,8]。側壁欠損に対する再建は、前腕皮弁や前外側大腿皮弁、そして腹直筋穿通枝皮弁（厚さ1 cm程度）を用いて、単なるパッチ状移植で機能は十分に温存される。その際、顎下部の死腔（母指大ほどの容量）の充填に脂肪組織、できれば筋肉組織で充填できると術後の局所合併症が少ない。

問題なのが、側壁・上壁欠損である。咽頭後壁が半分以上残存している場合には、Gehannoら[9]が報告した後壁の咽頭粘膜弁を翻転して残存軟口蓋断端に縫合する方法を選択する（Gehanno法）（図3.4.7上段）。これにより鼻咽腔を狭小化する。放射線照射後の症例や上壁または後壁の切除範囲が大きい時には、より縫合部に緊張がかかる。この場合には、剥離した咽頭弁の外下方にback-cutを入れると良い[10]。最後に、皮弁をパッチ状に移植する。硬口蓋まで上壁が切除されている場合には、前述した咽頭粘膜弁を翻転して鼻咽腔を完全に塞ぐことができず、硬口蓋側が一部開いた状態になる。このまま皮弁を移植すると、鼻咽腔側に上皮が欠損する部分が生じるが、術後に哆開などの合併症を生じたことはない。

さて、後壁が半分以上切除されている場合には、前述の方法で鼻咽腔を再建するのは不可能である。この場合には、皮弁の一部を折りたたみ残存軟口蓋に相当する部分を脱上皮して、皮弁を縫着するDenude法を

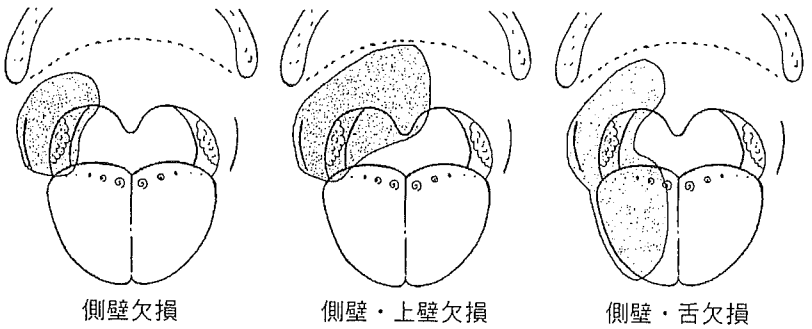

図3.4.6　中咽頭側壁中心欠損の分類

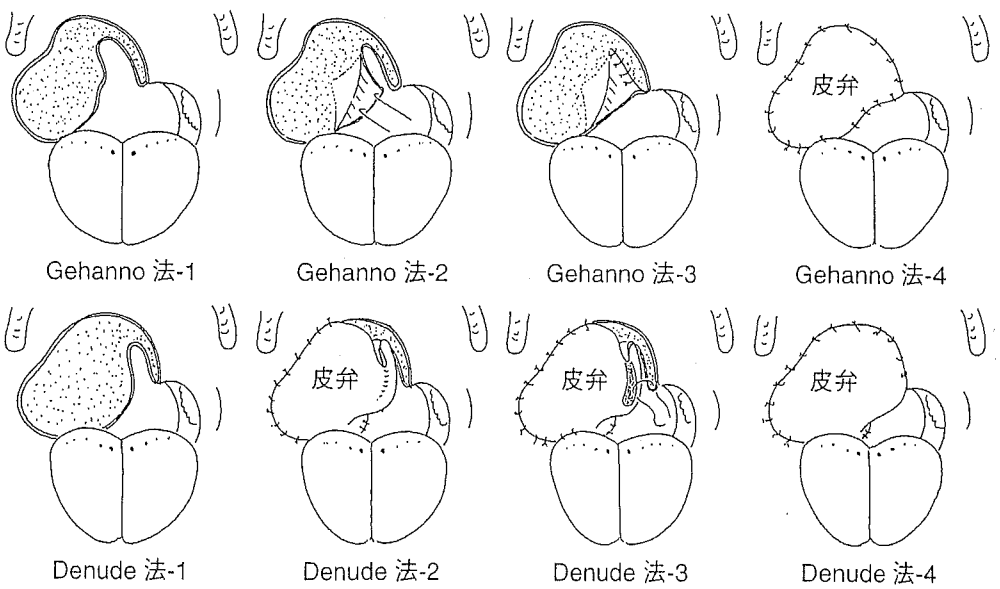

図3.4.7　中咽頭側壁・上壁欠損再建方法
上段：Gehanno法による再建。残存咽頭後壁粘膜を翻転して、残存軟口蓋と縫合する。
下段：Denude法による再建。皮弁を二つ折りにして欠損に縫着し、残存軟口蓋と縫合予定部分を脱上皮する。

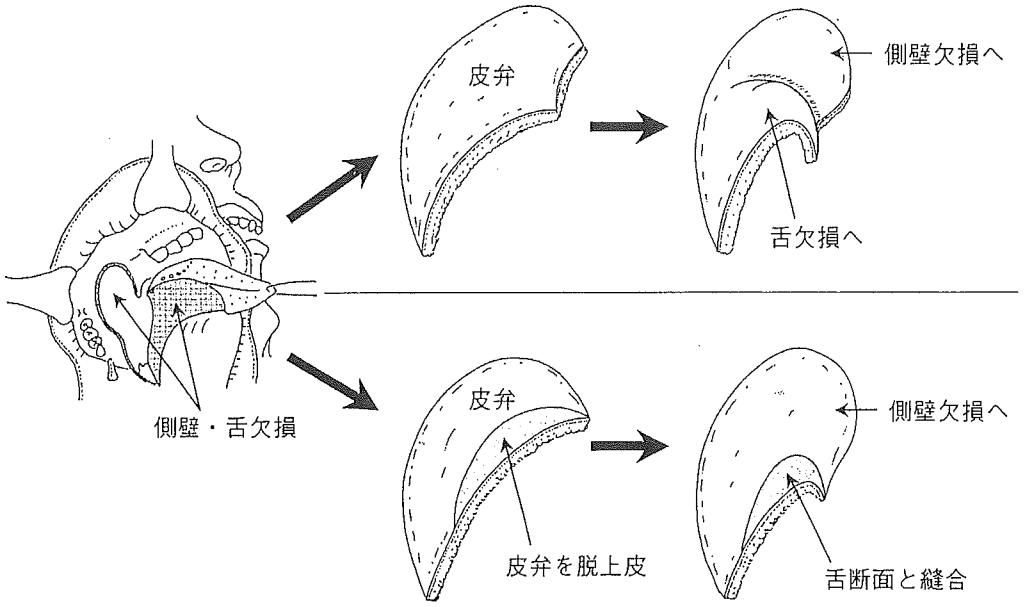

図 3.4.8　中咽頭側壁・舌欠損再建方法
上段：皮弁を二つ折りにして、側壁と舌欠損を再建。
下段：皮弁の一部を脱上皮して、舌断面と縫合。

選択する（図 3.4.7 下段）[8]。これは、皮弁の容量自体で鼻咽腔を狭小化する方法であるが、皮弁の脱上皮した部分と残存軟口蓋断端との縫合部を哆開しやすい。従って、3 層に密に縫合する。以上の縫着方法に伴い皮弁を選択し、移植することになる。鼻呼吸が可能な最小の鼻咽腔の広さは小指頭大の太さ、または 14 Fr 位までとの報告がある[11]。従って、Gehanno 法ならば上壁が 1/3 以上かつ後壁が 1/2 以上残存している症例、Denude 法ならば上壁後壁ともに 1/3 以上残存している症例に対し再建可能である。逆に、それ以上の欠損で鼻咽腔と鼻呼吸機能の両方を温存することは不可能で、現段階では再建の限界と考えている。皮弁の選択であるが、Gehanno 法であれば、前腕皮弁、前外側大腿皮弁、腹直筋皮弁（厚さ 1 cm 程度）が適応に、Denude 法であれば、厚みのある腹直筋皮弁が適応と考えている。

舌癌の中咽頭側壁進展、または中咽頭側壁癌の舌根、可動部舌進展の際には、側壁・舌欠損の形態となる。中咽頭側の欠損は広範囲になることは少ないため、Gehanno 法で対応できることが多い。しかし、中咽頭側壁から上壁の面と舌の面とは空間的に異なるため、工夫を要する。ここで重要なのは残存舌の動きを維持すること、食塊が健側を通過するようにして（知覚のある側から）誤嚥を失くすことである。現在、二通りの皮弁の縫着方法を試みている。一つは皮弁をすり鉢の 1/3 周状に移植し、中咽頭と舌を再建する方法（図 3.4.8 上段）がある。この方法はイメージがつきやすく簡便であるが、再建した中咽頭上壁と再建舌の間で皮弁が折れることにより溝ができ、食塊が患側を通りやすくなるという欠点がある。もう一つの方法は、口腔内の中央に衝立を立てるように皮弁を移植し、残存舌断面に相当する部分の皮弁を脱上皮し移植する（図 3.4.8 下段）。この方法は、食塊がほとんど健側を流れるために誤嚥を生じにくいが、脱上皮する部分が大きいと残存舌の動きが悪くなる。従って、どちらの方法にも利点と欠点がある。現在は、可動部舌を大きく切除された場合には前者を、舌根部分切除程度の合併切除では後者を選択しているが、今後の検討を要する領域である。

4.4　最後に

今回記述した再建方法は、外科治療が主体の組織欠損である。従って、放射線、化学療法が先行している場合、また術後に放射線治療をした場合には、良好な機能が維持できなくなる可能性もある。癌を制御するのは勿論のこと、術後機能にも十分に考慮して、治療方針を選択すべきである。一方、口腔咽頭領域には、舌根、頬粘膜、口腔底、歯肉などまだまだ記述すべき部分があるが、今回は舌・中咽頭側壁を中心に述べさせていただいた。

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Int J Clin Oncol (2005) 10:215–217
DOI 10.1007/s10147-005-0499-4

INTRODUCTION TO REVIEW ARTICLES

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Technical advances of plastic and reconstructive surgery in cancer surgery

Received: April 25, 2005

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

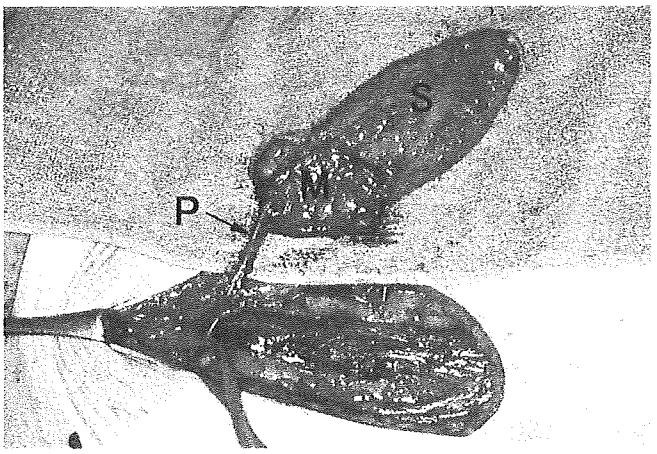

Fig. 1. Elevated rectus abdominis musculocutaneous flap. *S*, skin flap portion; *M*, a small part of the rectus abdominis muscle used to maintain blood supply to the skin flap; *P*, vascular pedicle of the inferior epigastric vessels

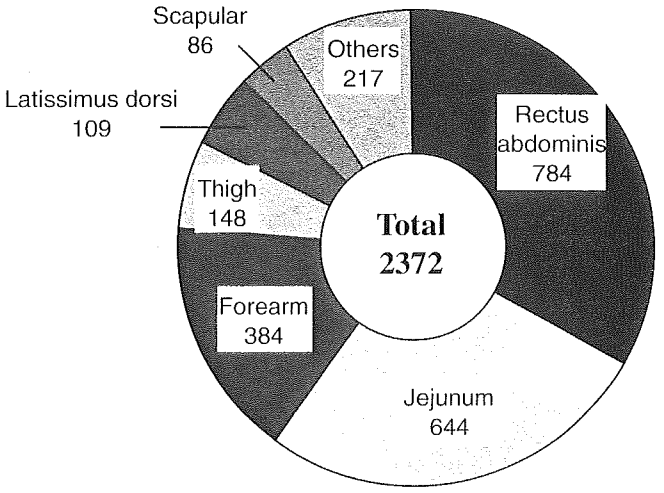

Fig. 2. Free flaps employed for reconstruction at the University of Tokyo Hospital, National Cancer Center Hospital, and other affiliated hospitals (November 1977–December 2000)

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]

Goals of plastic and reconstructive surgery

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

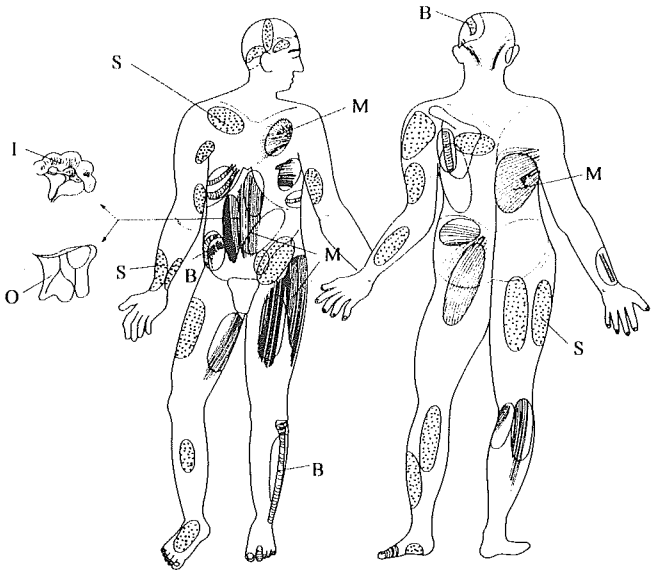

Fig. 3. Donor tissues and organs available for microvascular free flap transfers. *S*, skin flap; *M*, muscle and musculocutaneous flap; *B*, vascularized bone graft and osteocutaneous flap; *I*, intestine; *O*, omentum. Reproducted from Harii et al.,[21] with permission

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%

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

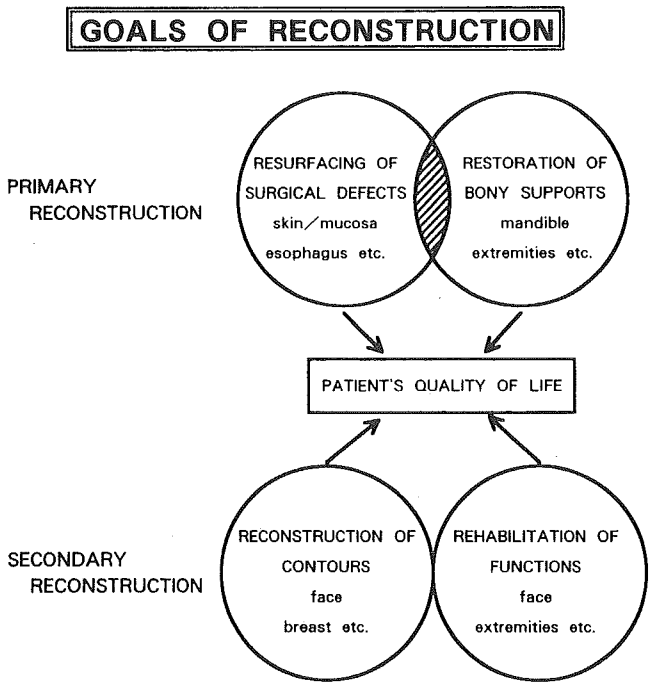

Fig. 4. Goals of plastic surgical reconstruction. Reproducted from Harii et al.,[21] with permission

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.

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Int J Clin Oncol (2005) 10:234–242
DOI 10.1007/s10147-005-0504-y

REVIEW ARTICLE

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Choice of osseous and osteocutaneous flaps for mandibular reconstruction

Received: May 13, 2005

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

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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.

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 long-standing 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-

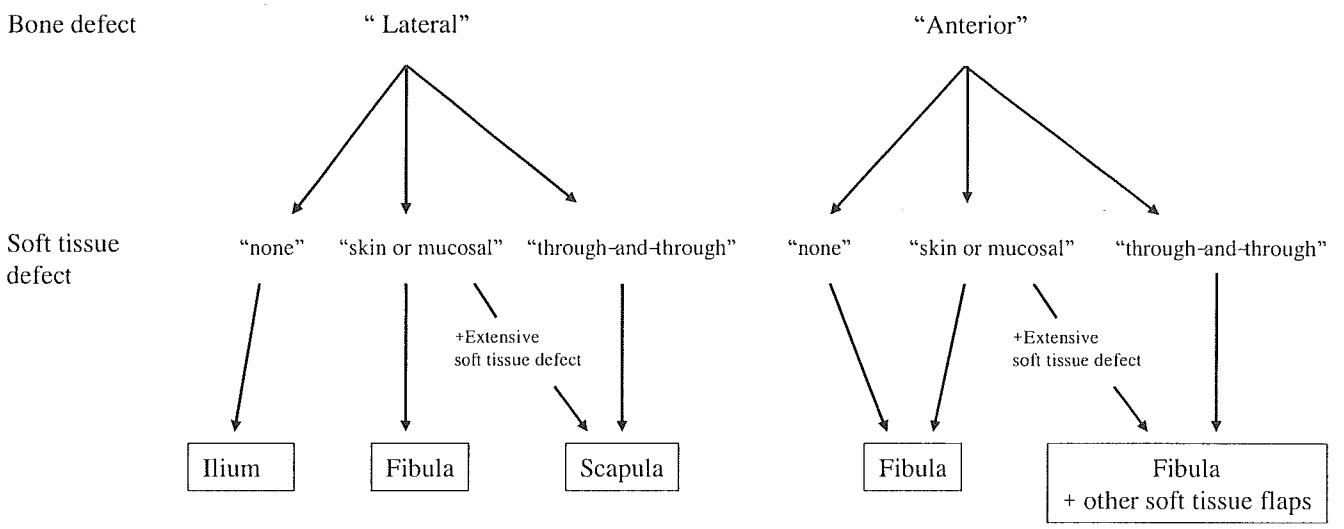

Fig. 1. Algorithm for mandibular reconstruction with osseous free flaps

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.

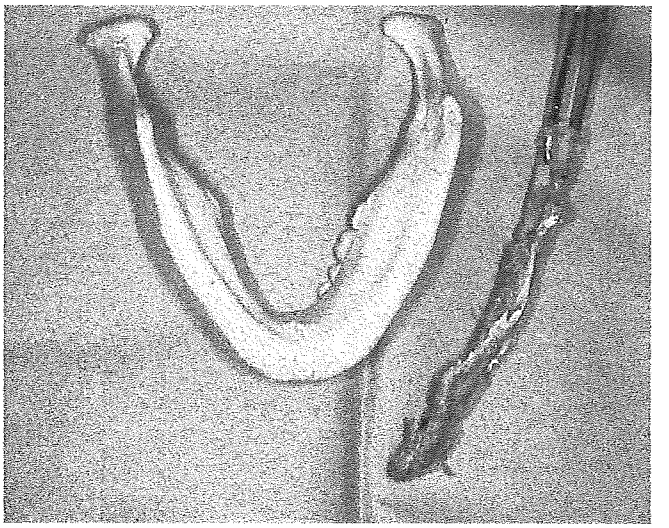

Fig. 2. Slight curve of the scapula resembles that of the lateral mandible and leads to superiority in lateral reconstruction

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.

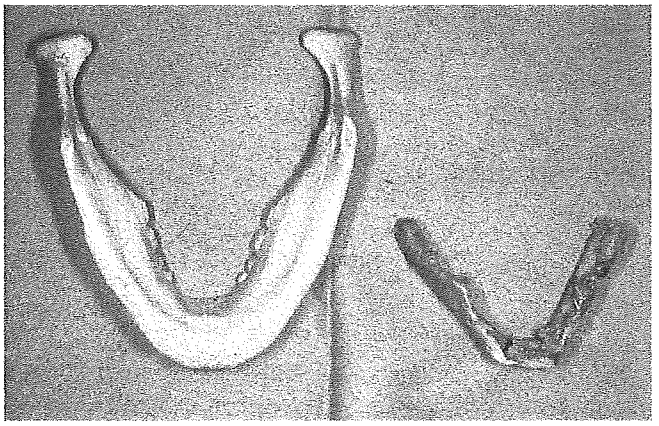

Fig. 3. Quantity of scapula that can be harvested without shoulder morbidity is limited to the contour of the anterior segment

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

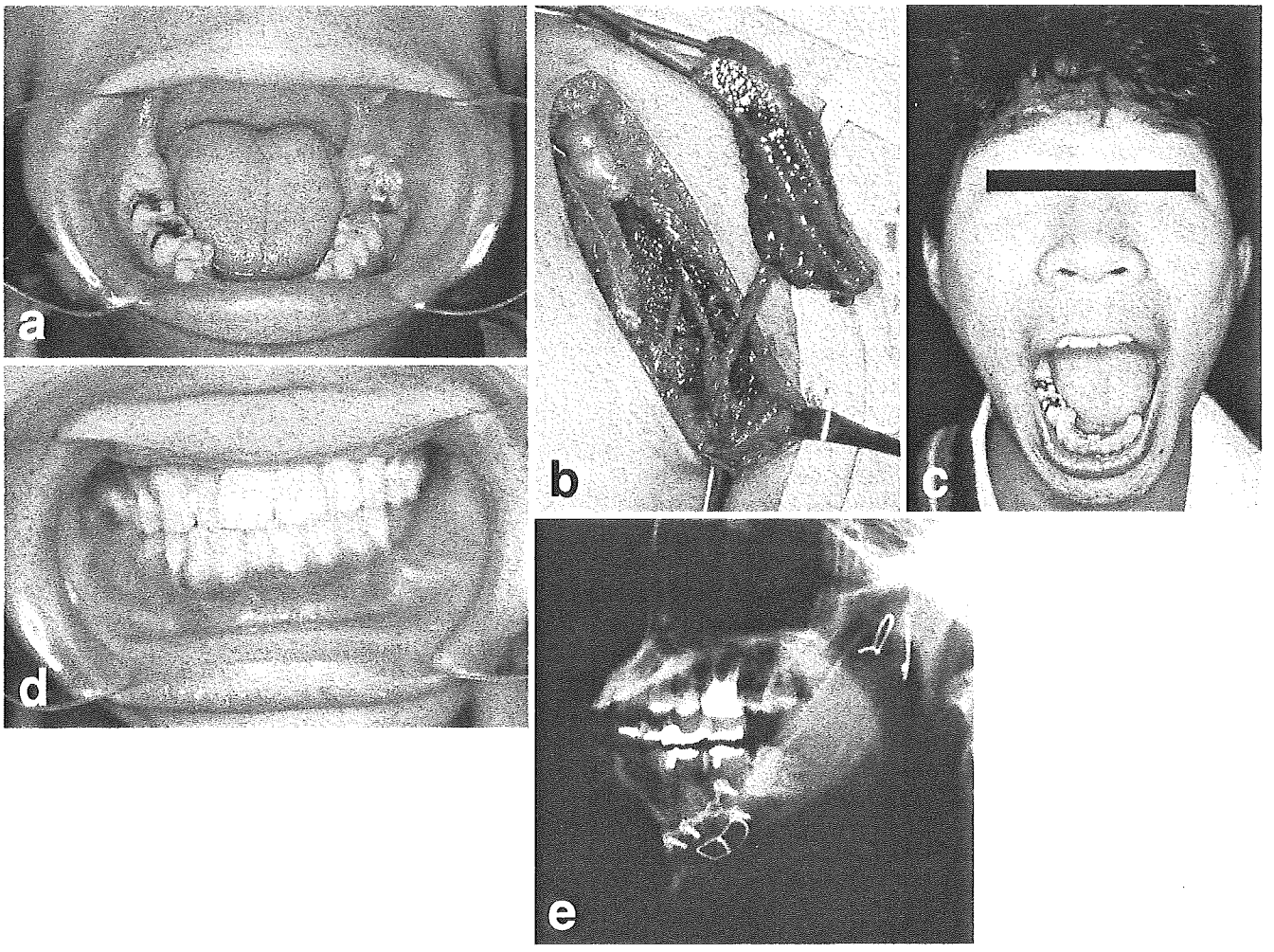

Fig. 4a–e. Findings in a 30-year-old man with left mandibular ameloblastoma (case 1). **a** Preoperative intraoral appearance. **b** Vascularized ilium was elevated. **c** One-year postoperative appearance with mouth open. **d** Stable occlusion was achieved. **e** Radiograph 1 year postoperatively

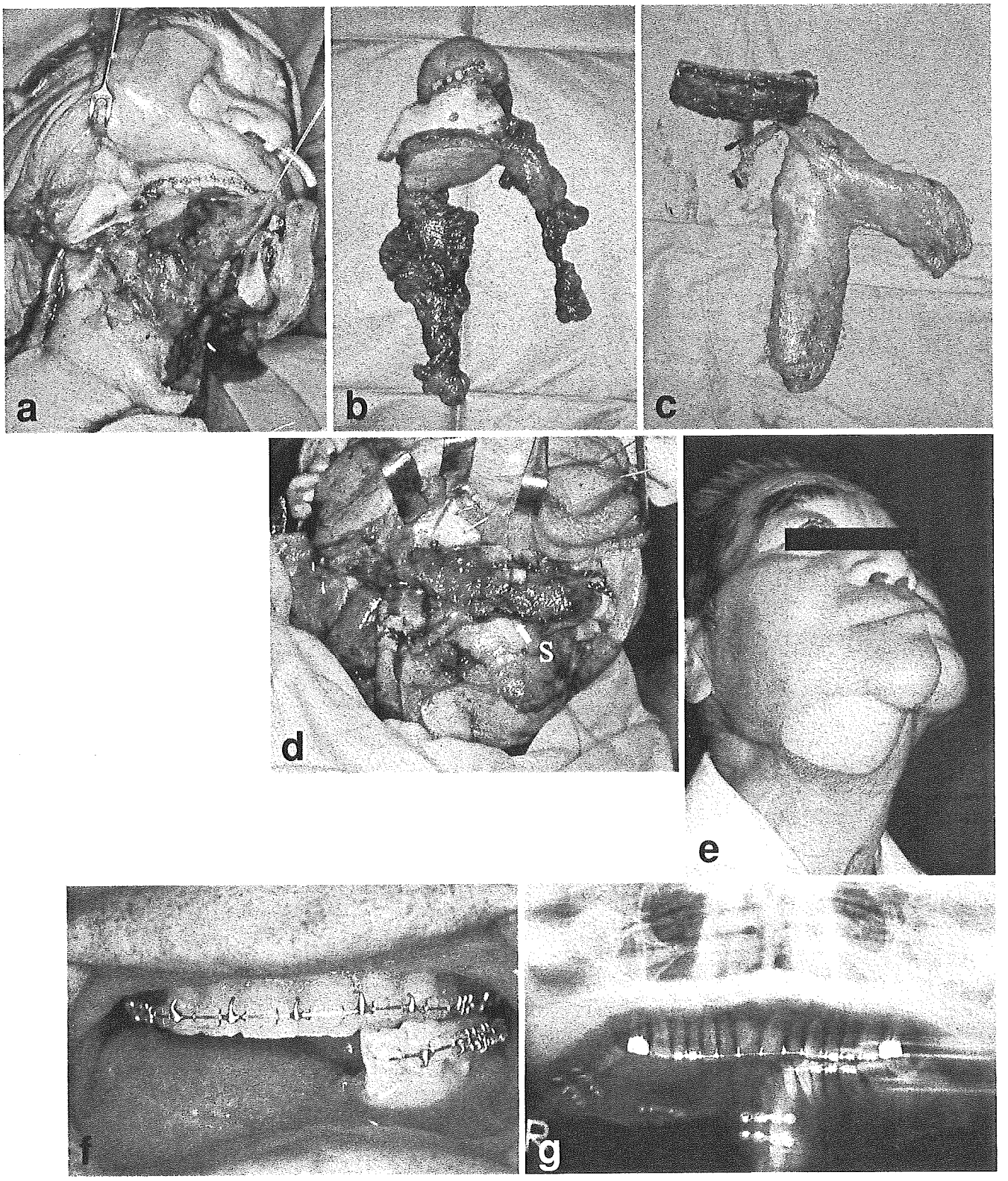

Fig. 5a–g. Findings in a 63-year-old man with cancer of the right side of the tongue (T2N3M0) (case 2) **a,b** Tumor ablation included segmental mandibulectomy and resection of the tongue and facial skin, with neck dissection on both sides. **c** Vascularized scapula with two skin paddles was harvested. **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

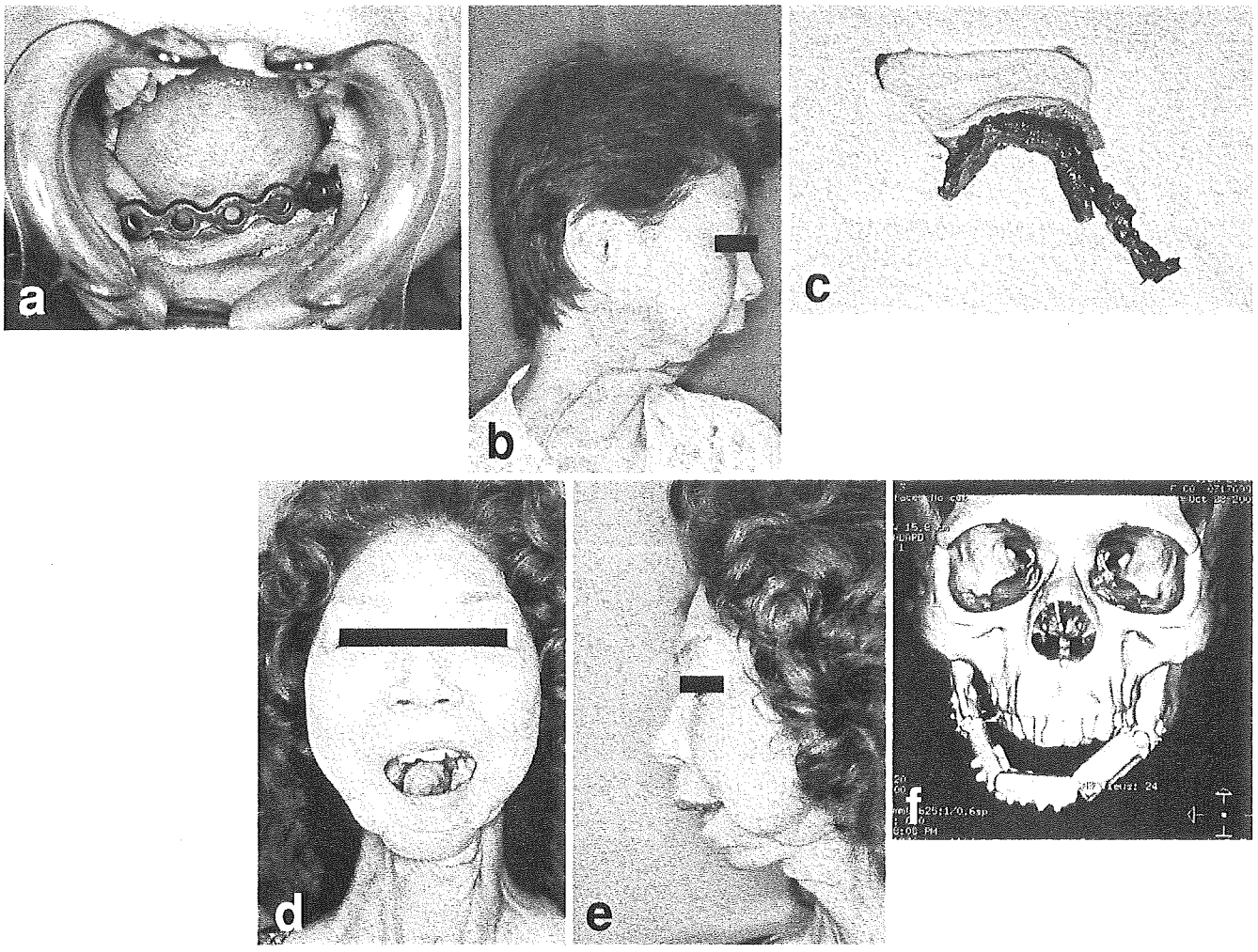

Fig. 6a–f. Findings in a 60-year-old woman with plate exposure in the oral floor (case 3). **a** Reconstruction plate was exposed intraorally. **b** Preoperatve clinical appearance. **c** Vascularized fibula with a skin paddle. **d** Two-years postoperative appearance with mouth open. **e** Postoperative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

Acknowledgment This work was supported in part by a Grant-in-Aid for cancer research from the Ministry of Health, Labour, and Welfare of Japan.

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Revisional Operations Improve Results of Neurovascular Free Muscle Transfer for Treatment of Facial Paralysis

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Background: Neurovascular free muscle transfer is currently the mainstay for smile reconstruction. However, problems such as excessive muscle bulk and dislocation of the transferred muscle attachment have been described. Furthermore, dynamic movements of the transferred muscle are sometimes too strong or too weak, resulting in facial asymmetry. In these cases, secondary revisional operations for the transferred muscle are required after neurovascular free muscle transfer. This report describes revisional operative procedures in detail and examines the extent of improvement of the smile by comparing preoperative and postoperative results.

Methods: Of 468 patients in whom neurovascular free muscle transfer was performed between 1977 and 2000, a total of 183 received revisional operations for the transferred muscle. Operations included revision of muscle attachment in 129 patients, debulking of the cheek in 114 patients, and fascia graft in 21 patients.

Results: Evaluation with the grading scale was performed in 117 of the 183 patients. Grading improved in 59 patients and worsened in seven patients. The remaining 51 patients displayed no change in grading. Differences between preoperative and postoperative grading were compared statistically, and revisional operations improved the grading score.

Conclusions: Revisional operations are effective and important as secondary operations after neurovascular free muscle transfer. However, care must be taken not to damage the neurovascular pedicles. (*Plast. Reconstr. Surg.* 116: 371, 2005.)

The goal of facial reconstruction in long-standing facial paralysis is to achieve symmetry at rest, during voluntary motion, and during expression of emotion. Although all areas of the face, eyebrows, eyelids, mouth, and cheeks may require attention, one of the most important functions is the ability to smile voluntarily and thus facilitate emotional communication.[1] Numerous reconstructive procedures, including nerve transfer[2] and local muscle transfer,[3] have been developed to achieve a natural-looking smile. Neurovascular free muscle transfer is now the mainstay for smile reconstruction.[4,5] Since the introduction of neurovascular free muscle transfer by Harii et al.,[6] problems such as excessive muscle bulk and dislocation of muscle attachment have been described. To solve the problem of excessive muscle bulk, Manktelow and Zuker[7] refined use of the gracilis muscle by identifying independent neuromuscular units within the graci-

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Presented at the 13th International Congress of the International Confederation for Plastic, Reconstructive and Aesthetic Surgery, in Sydney, Australia, August 10 to 15, 2003.

DOI: 10.1097/01.PRS.0000169687.94376.78

lis. Dellon and Mackinnon[8,9] also used a small, segmentally innervated portion of the latissimus dorsi muscle.

Fixation of transferred muscle on both the nasolabial and malar sides also represents an important factor for acquiring maximum excursion. Asato et al.[10] used a disposable stapler to create a stable muscle end for accurate muscle fixation in the nasolabial fold line. Bartlett[11] reported that superior fixation was achieved using zygomatic arch periosteum and the superficial layer of deep temporal fascia. With such technical refinements, smiles acquired using neurovascular free muscle have improved. However, some cases still show unnatural smiling because of dislocation of muscle attachment (particularly in the nasolabial fold) or excessive bulk of the cheek resulting from the volume of transferred muscle. Furthermore, dynamic movement of transferred muscle is sometimes too strong or too weak, resulting in facial asymmetry.

In these cases, secondary revisional operations are required after neurovascular free muscle transfer. However, no reports have yet described revisional operations in detail, with only brief notions by Terzis and Noah,[4] in which revision and debulking of free muscle were performed in 26 percent of patients, and O'Brien et al.,[12] in which release, debulking, and reinsertion of muscle were performed as secondary procedures. The present report describes revisional operative procedures in detail and analyzes the extent of improvement to the smile by comparing preoperative and postoperative results.

Patients and Methods

Patient Profiles

Between 1977 and 2000, neurovascular free muscle transfer was performed in 468 patients with longstanding facial paralysis. Of these, 183 patients (39.1 percent) have received revisional operations to the transferred muscle, with one revisional operation in 128 patients, two in 39 patients, three in 10 patients, and four in six patients. Operations included revision of attachment, debulking of cheek, and fascia graft (Table I). Revision of muscle attachment was performed from either a nasolabial fold incision (n = 92) or a preauricular incision (n = 37). Debulking of cheek protrusion was performed by debulking transferred muscle with subcutaneous fat tissue from a preauricular or nasolabial incision (n = 100) or by liposuction of buccal subcutaneous fat (n = 14). Fascia graft was performed for muscle elongation or lower lip suspension (n = 21).

TABLE I
Revisional Operations

Type of Operation	No. of Patients
Revision of attachment	
Nasolabial fold incision	92
Preauricular incision	37
Debulking of the cheek	
Muscle debulking	100
Liposuction	14
Fascia transfer	21

Evaluation

The grading scales[5] shown in Table II are used to evaluate the results of neurovascular free muscle transfer. These were applied to revisional operations by comparing results before and after revisional operations in 117 patients. When several revisional operations were performed, results were evaluated after all revisional operations. Grading scores were statistically compared between those obtained preoperatively and postoperatively using the McNemar test.

TABLE II
Evaluation Criteria

Grade	Description
5	Symmetric balance and good facial tone at rest Sufficient muscle power upon voluntary contraction Synchronous and natural expression upon emotional facial movements, especially upon smiling EMG demonstrating relatively high amplitudes with full interference patterns and high evoked potential obtained upon stimulation of the contralateral facial nerve
4	Symmetric balance and good facial tone at rest Active muscle contraction acquired but not sufficiently synchronous (too strong or slightly weak) EMG demonstrating good interference patterns and evoked potentials Results well accepted by the patients
3	Symmetric balance and good facial tone at rest Insufficient contraction of the muscle Low volitional EMG spikes with discrete interference patterns
2	Reduced symmetric balance upon smiling No effective contraction of the muscle EMG with no interference patterns
1	No correction Electrically silent EMG
0	No follow-up