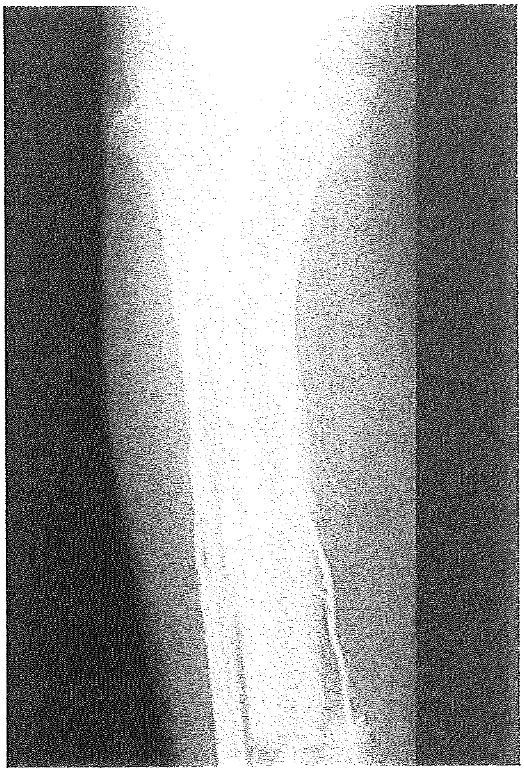


Figure 1 Preoperative angiography of the recipient leg revealed no vascular anomalies.

patency of the three normal vessels(Fig. 1). The perforators in the distal third of the leg were marked with a Doppler rheometer. The size of the flap was 15 × 6 cm (Fig. 2).

After applying a tourniquet at the femoral region (up to 300 mmHg), the posterior and anterior parts of the flap were elevated along with the deep fascia. One main perforator was seen instead of the septocutaneous or musculocutaneous branches, and it directly joined the posterior tibial artery (Fig. 3). Although dissection of the interosseous septum along the fibula was performed to identify the peroneal artery and veins, we could not find the vessels. At last, we decided to divide the fibula at the distal end to identify these vessels. The peroneal artery and veins were found behind the fibula, and further dissection was continued to the proximal portion of the fibula. Finally, the peroneal artery joined the anterior tibial artery (Fig. 4).

We harvested two independent flaps; one was a peroneal flap and the other was a fibula flap. The dorsalis pedis artery and comitant veins were harvested for the recipient vessels. After fixing the bone graft at the recipient site, one comitant vein of the peroneal artery was anastomosed to one of the dorsalis pedis arteries; then the peroneal artery of the fibula was anastomosed to the dorsalis pedis artery. The perforator of the peroneal flap was anastomosed to the dorsalis pedis artery in an end-to-side manner, and the comitant vein of the peroneal artery was anastomosed to another comitant vein of the dorsalis pedis artery (Fig. 5).

Immediately after the operation, the peroneal flap showed good circulation (Fig. 6). The patient's postoperative course was uneventful. Eleven months after the operation, the patient began walking without support (Fig. 7), and x-ray of the right lower leg showed good union between the grafted bone and the recipient bone (Fig. 8).

DISCUSSION

The use of vascularized free osteocutaneous fibula flaps has become established as a reliable and useful method for reconstruction of the mandible or lower leg. Usually, these osteocutaneous flaps have a single pedicle

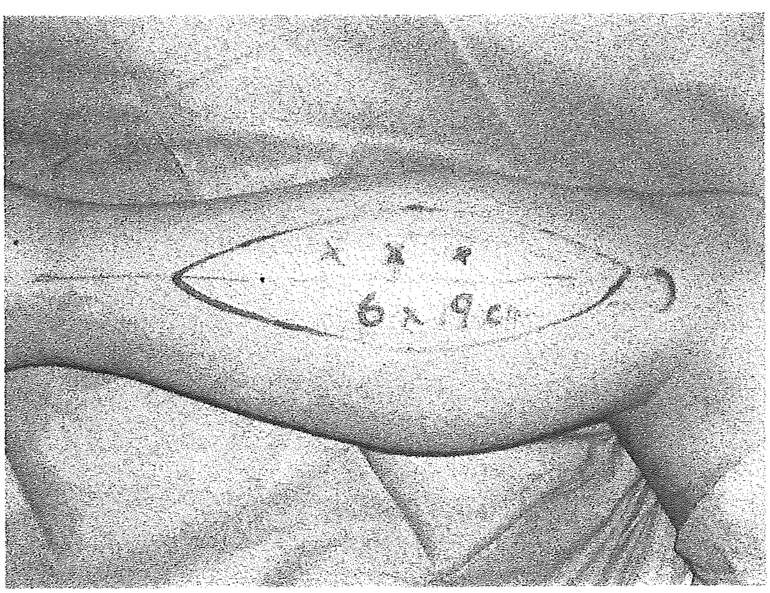


Figure 2 Perforators in the distal third the leg were marked with a Doppler rheometer. The size of the flap was 15 × 6 cm.

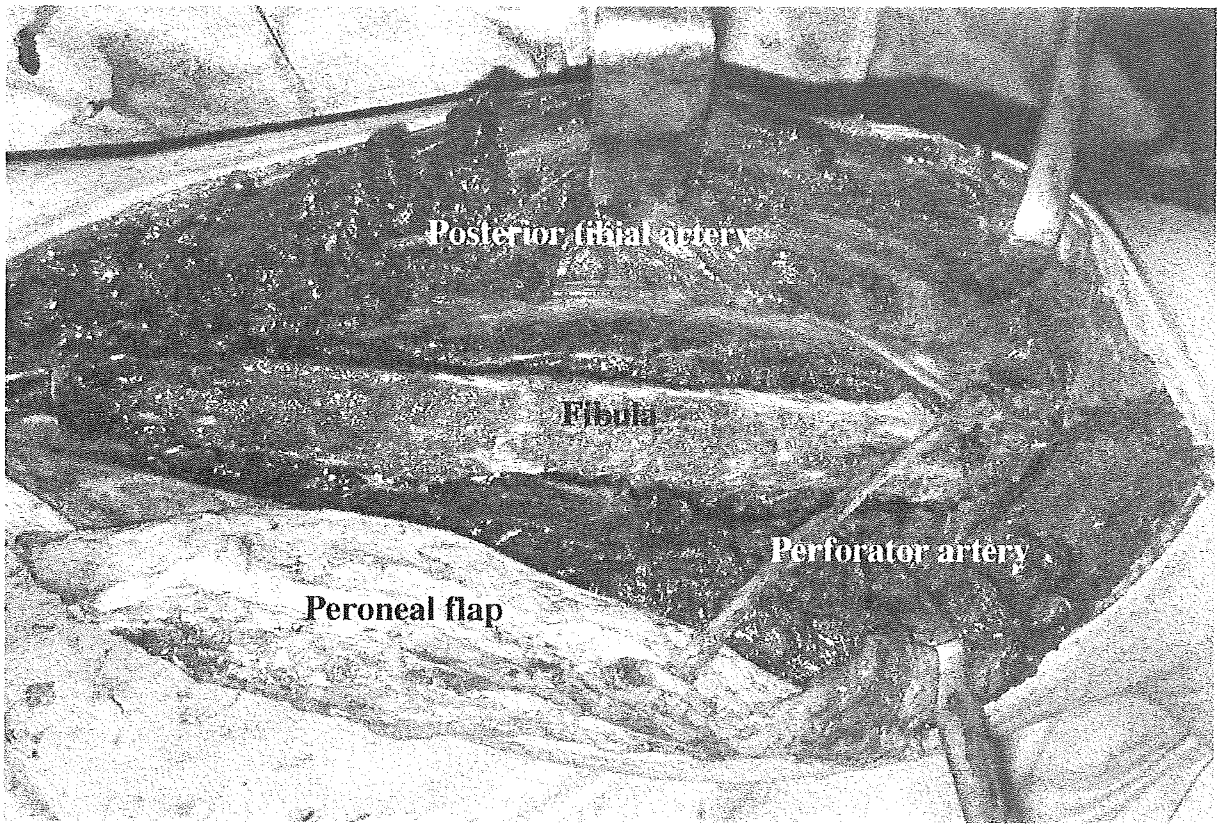


Figure 3 One main perforator was seen instead of the septocutaneous or musculocutaneous branches, and it directly joined the posterior tibial artery.

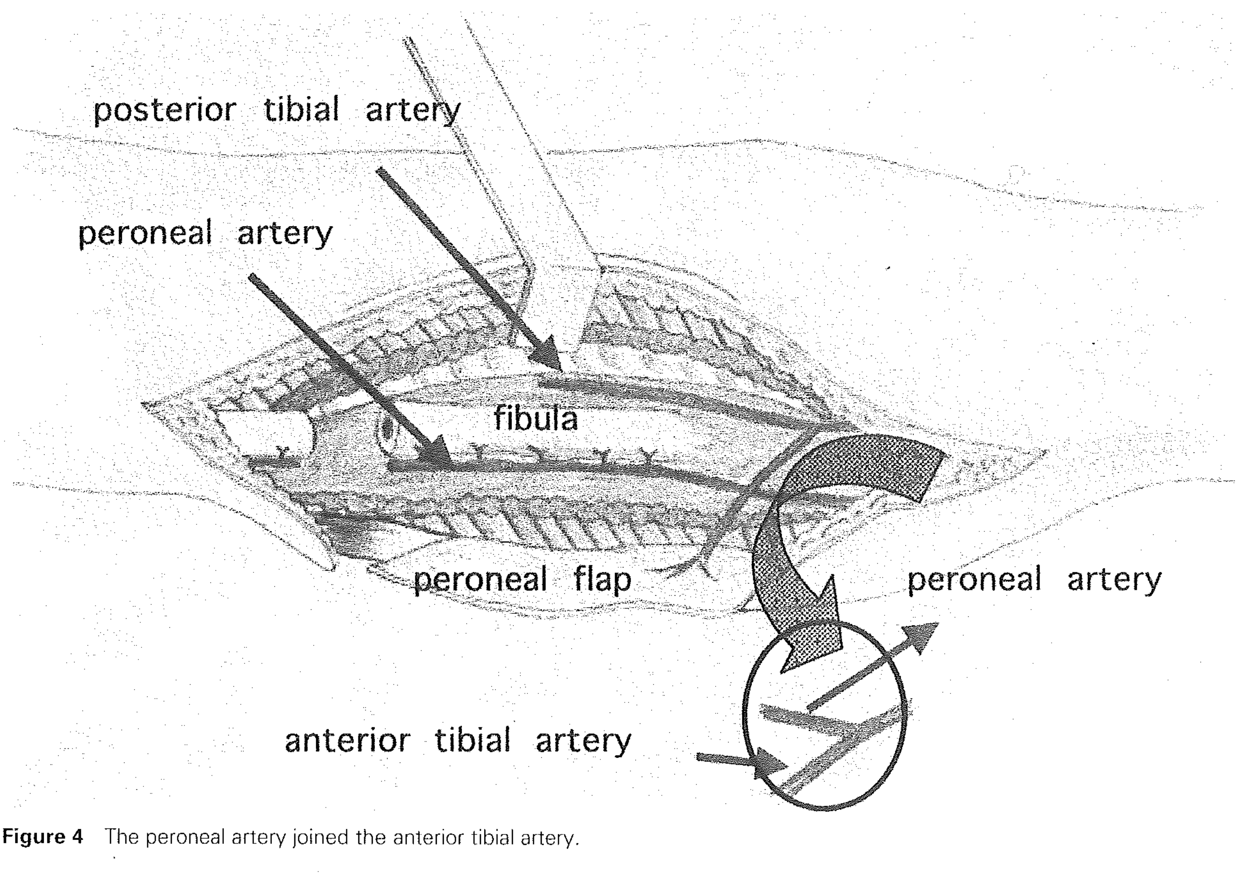
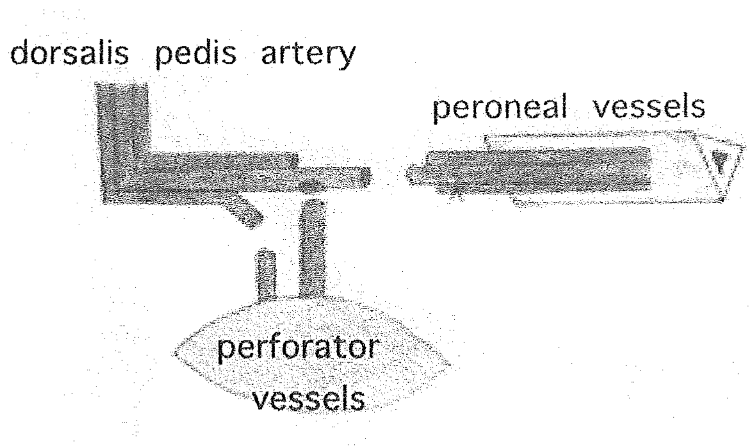
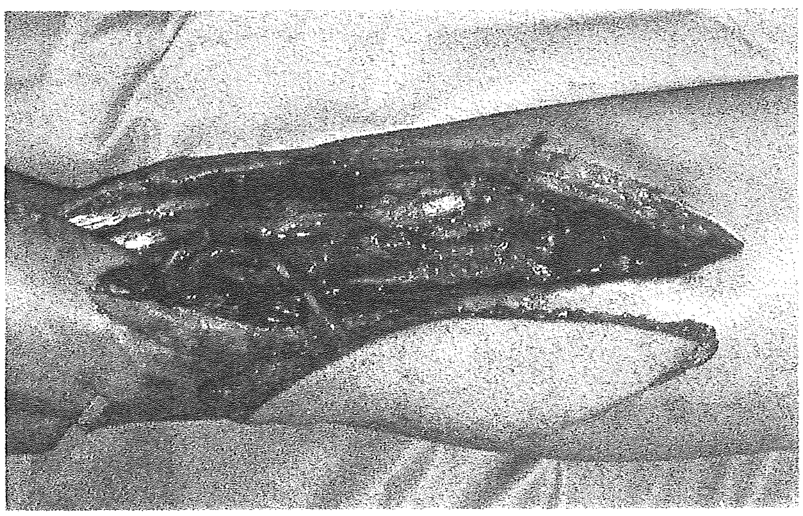


Figure 4 The peroneal artery joined the anterior tibial artery.



A



B

Figure 5 (A, B) Vascular anastomoses were performed as follows: one comitant vein of the peroneal artery was anastomosed to one of the dorsalis pedis arteries; then the peroneal artery of the fibula was anastomosed to the dorsalis pedis artery. The perforator of the peroneal flap was anastomosed to the dorsalis pedis artery in an end-to-side manner, and the comitant vein of the peroneal artery was anastomosed to another comitant vein of the dorsalis pedis artery.

composed of attachment of the peroneal artery to the fibula and septocutaneous or musculocutaneous branches to the lateral skin of the leg.[9] Based on a review of 495 lower extremity arteriograms, Kim et al.[10] reported that the popliteal artery usually divides into the anterior tibial artery and the tibioperoneal trunk posteriorly to the inferior border of the popliteal muscle, while the peroneal artery arises from the tibioperoneal trunk.[7]

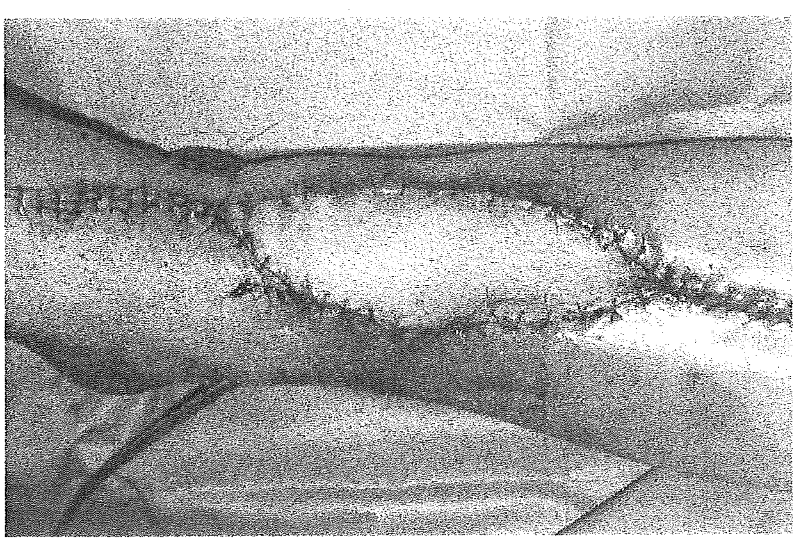


Figure 6 Immediately after the operation, the peroneal flap showed good circulation.

Figure 7 Eleven months postoperative, the patient could walk without any device, and resumed his work.

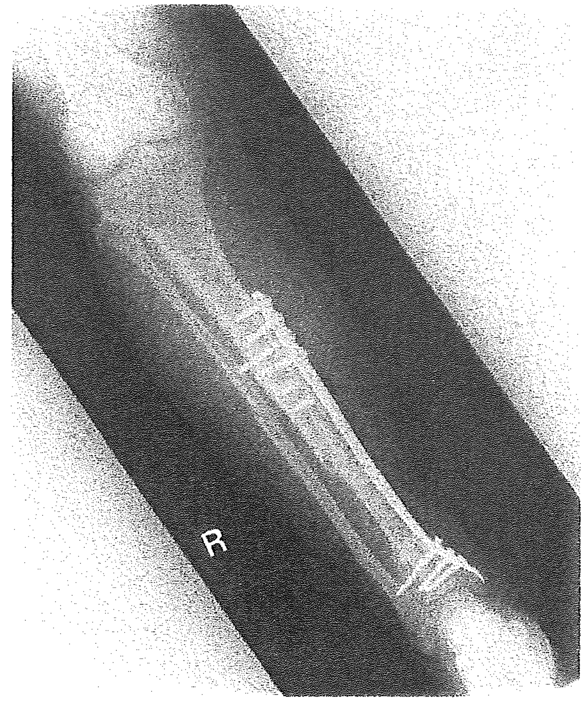


Figure 8 Eleven months postoperative, x-ray of the right lower leg showed good union between the grafted bone and the recipient bone.

With regard to preoperative angiography of the donor or recipient extremity, Lutz et al.[11] concluded that routine recipient-site angiography before microsurgical reconstruction was unjustified, and Disa and Cordeiro[12] concluded that routine donor-site angiography was unnecessary. On the other hand, Kessler et al.[3] and Seres and colleagues[4] reported that donor-site angiography before reconstruction with a free vascularized fibula was important to prevent ischemia in the foot after harvesting this flap, but they did not mention a variant peroneal artery, such as in our case.

With regard to variants of the perforators of the lateral skin flap, Weber and Pederson[13] reported two cases in which the skin paddle was supplied by vessels arising from the proximal peroneal artery without intraseptal or intramuscular vessels in the osteocutaneous septum.[14] Yokoo et al.[15] also reported a variant of the intramusculocutaneous perforator in raising a free peroneal osteocutaneous flap, and they performed additional anastomoses to salvage the skin flap.

Strauch and colleagues[6] described four types of variation of the peroneal artery as follows: type A, in which the peroneal artery arises from the posterior tibial artery in 90 percent of cases; type B, in which it arises from the anterior tibial artery in 1 percent of cases; type C, in which it arises from the popliteal artery in 1 percent of cases; and type D, in which it takes the place of the posterior tibial artery in 8 percent of cases.[10] With reference to their classification, our case was suggested to be type B, but to our knowledge, there have been no case reports of this variation of the peroneal artery with the use of vascularized free osteocutaneous fibula flaps.

In our case, although preoperative angiography did not indicate any variations in the three arterial flows of the recipient leg, a longer time was required not only to harvest the fibula flap, but also to perform secondary anastomosis, compared to cases reported previously. The role of preoperative angiography is still controversial, and even if preoperative angiography of the recipient leg reveals normal blood flow in three arteries, these variant vessels must be taken into account when using a free osteocutaneous fibula flap.

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Free Vascularized Nerve Grafting for Immediate Facial Nerve Reconstruction

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Objectives/Hypothesis: **To obtain better functional results after reconstruction to treat facial palsy in the patients with preoperative and intraoperative factors that might inhibit functional recovery, the authors have used free vascularized nerve grafts to immediately reconstruct severed facial nerves.** ***Study Design:*** **The indications for vascularized nerve grafts were 1) scarred recipient bed attributable to previous operations, 2) a history of previous irradiation at the wound, 3) facial skin defects over the nerve graft after tumor ablation, 4) patient age greater than 60 years, and 5) preoperative facial palsy.** ***Methods:*** **Four types of free vascularized nerves were used. Functional recovery after reconstruction could be assessed with two facial nerve grading systems. Ten patients who underwent immediate reconstruction of severed facial nerve after ablative surgery of malignant tumors of the parotid gland were reviewed.** ***Results:*** **Functional recovery after reconstruction could be assessed with the House-Brackmann grading system and a 40-point grading system in 6 of the 10 patients after a mean follow-up period of 29.8 months (range, 10–60 mo). Results with the House-Brackmann system were grade II in 1 patient, grade III in 4 patients, and grade IV in 1 patient; scores on the 40-point grading system were 20 in 1 patient, 22 in 3 patients, 24 in 1 patient, and 28 in 1 patient.** ***Conclusion:*** **The study results indicated that muscle movement recovers satisfactorily after free vascularized nerve grafting. Although a study comparing vascularized nerve grafts and conventional nerve grafts would be necessary to confirm the superiority of vascularized nerve grafts, free vascularized nerve grafts are effective for immediate reconstruction of the severed facial nerve in patients with preoperative and intraoperative factors that might inhibit functional recovery.** ***Key Words:*** **Vascularized nerve graft, facial nerve reconstruction, facial palsy, immediate reconstruction.**

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INTRODUCTION

Facial nerve palsy after ablative surgery of the parotid gland is distressing for patients. To treat early cases of facial paralysis, ipsilateral faciofacial anastomosis achieves the best overall results. When a definite gap is present between the proximal and distal stumps of the severed facial nerve, a conventional interposition autogenous graft of such nerves as the great auricular nerve, branches of cervical nerves, and the sural nerve is the technique of choice for immediate reconstruction.[1] However, the rate and degree of regeneration depend on the length of the graft, the number of scar tissue barriers, the condition of the wound, and the duration of paralysis.[1,2] Functional results seem to be poorer in elderly patients than in younger patients.[2,3]

To treat the patients with preoperative and intraoperative factors that might inhibit functional recovery and to obtain better functional results after reconstruction to treat facial palsy, we have used free vascularized nerve grafts to immediately reconstruct severed facial nerves. In the present report, we describe representative cases and functional results and suggest and discuss the indications for the use of the vascularized nerve graft in cases of facial palsy.

MATERIALS AND METHODS

We have transferred free vascularized nerve grafts for immediate reconstruction of the severed facial nerve in patients with the following preoperative and intraoperative factors that could inhibit functional recovery: 1) scarring of the recipient bed attributable to previous operations, 2) a history of previous irradiation at the wound (not as part of preoperative radiotherapy), 3) facial skin defects over the nerve graft after tumor ablation, 4) age greater than 60 years, and 5) preoperative facial palsy.

Four types of free vascularized nerve were used to repair facial nerve defects. The free vascularized sural nerve graft,[4] which is attached to a small peroneal monitoring flap and nourished by peroneal vessels, is transferred to the nerve defect and used as a cable graft. A free vascularized deep peroneal nerve graft,[5] which is attached to a small dorsalis pedis monitoring flap

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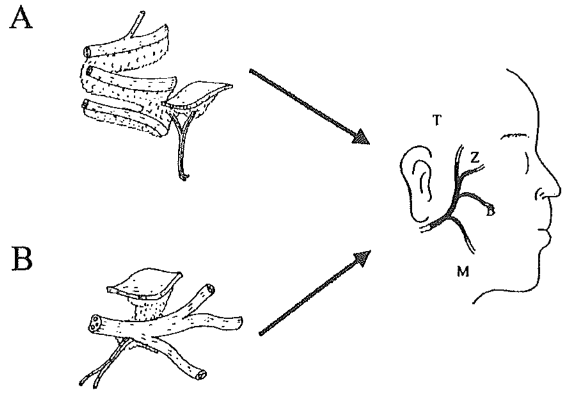

Fig. 1. The method of facial nerve reconstruction with free vascularized nerve graft. (**A**) Cable graft using the vascularized sural nerve graft with monitoring flap. (**B**) Nerve graft using the vascularized deep peroneal nerve, the motor nerve of the vastus lateralis muscle, or the lateral cutaneous nerve of thigh. T = temporal branch; Z = zygomatic branch; B = buccal branch; M = marginal mandibular branch.

and nourished by anterior tibial vessels, is transferred and interposed into the prepared facial nerve defect. A free vascularized motor nerve of the vastus lateralis muscle nourished by descending branches of lateral circumflex femoral vessels is transferred with an anterolateral thigh flap. A free vascularized lateral femoral nerve of the thigh combined with an anterolateral thigh flap was also transferred (Fig. 1).

Since June 1994, 10 cases of vascularized nerve grafts have been transferred for immediate reconstruction of severed facial nerves after ablative surgery around the parotid gland at the National Cancer Center Hospital East (Chiba, Japan) (Table I). The patients were 5 men and 5 women. Five patients had malignant tumors of the parotid gland. Malignant tumors of the parotid gland had recurred after previous surgery in three patients, and facial palsy was present before surgery in one patient. One patient had a squamous cell carcinoma that extended to the facial skin and parotid gland, and one patient had a squamous cell carcinoma at the external acoustic meatus. Seven of the 10 patients were older than 60 years of age. The parotid gland and the facial nerve were resected with the malignant tumor in all 10 patients, and facial skin was resected in 5 patients. No patients underwent preoperative or postoperative radiotherapy.

Free vascularized sural nerves were grafted in four patients, and free vascularized deep peroneal nerves were grafted in three patients. In three of these seven patients, free anterolateral thigh flaps were transferred to reconstruct the facial skin. Free vascularized motor nerves of the vastus lateralis muscle combined with anterolateral thigh flaps were transferred in two patients, and a free vascularized lateral femoral nerve of the thigh combined with an anterolateral thigh flap was transferred in one patient (Table I). Microvascular anastomosis of the transferred flap was performed before reconstruction of each branch of the resected facial nerves. In all patients, fresh bleeding was recognized at both ends of the grafted vascularized nerves.

Functional recovery was assessed with two facial nerve grading systems. As a gross assessment, the House-Brackmann grading system was used (Table II).[6] As a regional assessment, the 40-point grading system was used (Table III).[6,7]

RESULTS

Transferred flaps survived without complications in all patients, except for one patient (patient 8) in whom wound infection developed but healed with conservative treatment. In patients 7 to 10, the functional recovery of the facial nerve could not be assessed because of local tumor recurrence soon after surgery. Therefore, facial nerve function was assessed in 6 of 10 patients (Table IV).

The length of reconstructed (grafted) nerve from the proximal stump of the facial nerve to each peripheral branch of the facial nerve in these six patients ranged from 5 to 7 cm. The mean follow-up period after reconstruction was 29.8 months (range, 10–60 mo). Patient 3 was found to have distant metastases and died less than 1 year after surgery. Results with the House-Brackmann system were grade II in 1 patient, grade III in 4 patients, and grade IV in 1 patient. Results with the 40-point system ranged from 20 to 28 points (mean score, 23 points). The zygomatic and buccal branches of the reconstructed facial nerve recovered partially in all six patients. One young woman (patient 3) who had undergone reconstruc-

TABLE I.
Patient Summary.

Patient No.	Sex	Age (y)	Diagnosis	Indication for VN-G	VN-G	Combined Flap	Outcome
1	F	51	Recurrence of PGT	Scar	Deep peroneal nerve	Dorsalis pedis flap	Local recurrence
2	M	60	Recurrence of PGT	Scar, age	Deep peroneal nerve	None	Alive without PGT
3	F	30	Recurrence of PGT	Scar, FP	Sural nerve	Peroneal flap	Alive without PGT
4	F	70	PGT	Age	Sural nerve	Peroneal flap	Died of PGT
5	M	78	PGT	Age, skin defect	Motor nerve of VL	ALT	Alive without PGT
6	M	80	SCC of skin	Age, skin defect	Deep peroneal nerve	ALT	Alive without PGT
7	M	61	PGT	Age, skin defect	Sural nerve	ALT	Died of PGT
8	F	48	Recurrence of SCC of EAM	Scar	Sural nerve	ALT	Died of SCC
9	M	71	PGT	Age, skin defect	Lateral femoral nerve of thigh	ALT	Local recurrence
10	F	60	PGT	Age	Motor nerve of VL	ALT	Local recurrence

N = nerve; VN-G = vascularized nerve graft; FP = facial palsy; PGT = parotid gland tumor; SCC = squamous cell carcinoma; EAM = external acoustic meatus; VL = vastus lateralis muscle; ALT = anterolateral thigh flap.

TABLE II. House-Brackmann Grading System.	
Grade	Definition
I. Normal	Normal facial function in all areas.
II. Mild dysfunction	Slight weakness noticeable only on close inspection. At rest: normal symmetry and tone. Motion: some to normal movement of forehead; ability to close eye with minimal effort and slight asymmetry; ability to move corners of mouth with maximum effort and slight asymmetry. No synkinesis, contracture or hemifacial spasm.
III. Moderate dysfunction	Obvious but not disfiguring difference between two sides; no functional impairment; noticeable but not severe synkinesis, contracture and/or hemifacial spasm. At rest: normal symmetry and tone. Motion: slight to no movement of forehead; ability to close eye with maximal effort and obvious asymmetry; ability to move corners of mouth with maximal effort and obvious asymmetry. Patients with obvious but not disfiguring synkinesis, contracture, and/or hemifacial spasm are Grade III regardless of degree of motor activity.
IV. Moderately severe dysfunction	Obvious weakness and/or disfiguring asymmetry. At rest: normal symmetry and tone. Motion: no movement of forehead; inability to close eye completely with maximal effort; asymmetry movement of corners of mouth with maximal effort. Patients with synkinesis, mass action, and/or hemifacial spasm severe enough to interface with function are Grade IV regardless of degree of motor activity.
V. Severe dysfunction	Only barely perceptible motion. At rest: possible asymmetry with droop of corner of mouth and decreased or absent nasal labial fold. Motion: no movement of forehead; incomplete closure of eye and only slight movement of lid with maximal effort; slight movement of corner of mouth. Synkinesis, contracture, and hemifacial spasm usually absent.
VI. Total paralysis	Loss of tone; asymmetry; no motion; no synkinesis; contracture, or hemifacial spasm.

tion of the temporal branch of the facial nerve could move her forehead slightly. The marginal mandibular branch of the facial nerve recovered in one of three patients who underwent reconstruction of the marginal mandibular branch.

CASE REPORTS

Case 1

A 30-year-old woman (patient 3) underwent ablative surgery for parotid gland cancer at another hospital 3 months before she visited our hospital. Preoperative magnetic resonance imaging (MRI) examination revealed complete right-side facial palsy and residual tumor. The residual tumor was resected, and a free vascularized sural nerve graft and a monitoring flap supplied by peroneal vessels were transferred. The temporal, zygomatic, buccal, and marginal mandibular branches of the severed facial nerve were reconstructed with a cabled vascularized sural nerve. The lengths of grafted vascularized nerves were 7, 6, 6, and 7 cm, respectively. Sixty months after surgery, symmetry and tone were nearly normal (House-Brackmann system, grade II; 40-point system, score of 28). The reconstructed temporal branch recovered, but the reconstructed marginal mandibular branch did not (Fig. 2).

TABLE III. Forty-Point Grading System.			
Motion	Scale-of-Three Rating		
At rest	0	2	4
Wrinkle forehead	0	2	4
Brink	0	2	4
Closure of eye lightly	0	2	4
Closure of eye tightly	0	2	4
Closure of eye on involved side only	0	2	4
Wrinkle nose	0	2	4
Whistle	0	2	4
Grin	0	2	4
Depress lower lip	0	2	4

Case 2

An 80-year-old man (patient 6) had squamous cell carcinoma that extended to the facial skin and parotid gland. The tumor was excised with facial skin and the right-side facial nerve. A 17×9-cm free anterolateral thigh flap and a free deep peroneal nerve graft were transferred. The zygomatic, buccal, and marginal mandibular branches of the severed facial nerve were reconstructed with branches of the deep peroneal nerve. The lengths of grafted vascularized nerves were, 7, 8, and 8 cm, respectively. Strong movements of the corners of the mouth were recognized 10 months after surgery. Thirty-three months after surgery, obvious but not disfiguring differences between the two sides of the face had developed. No movements of the forehead were recognized (House-Brackmann system, grade III; 40-point system, score of 24) (Fig. 3).

DISCUSSION

Many clinical and experimental studies have confirmed the superiority of nerve regeneration with vascularized nerve grafts over that with conventional free grafts.[4,5] Experiments by Koshima and Harii[8] have demonstrated the increased density and diameter of regenerating axons and accelerated axonal sprouting of vascularized nerve grafts in poor vascular beds. A histological and functional study by Mackinnon et al.[9] in a patient with a forearm injury has shown that the regeneration of vascularized nerve grafts is superior to that of conventional nerve grafts. Doi et al.[10] have compared vascularized and conventional sural nerve grafts in the reconstruction of the extremities and have suggested that a vascularized nerve graft is indicated when the nerve gap is greater than 6 cm and is associated with a massive skin defect. Although vascularized nerves show superior regeneration, most reported cases have involved reconstruction of nerve defects of the extremities or treatment of brachial plexus

TABLE IV.
Length of Grafted Vascularized Nerves and Functional Results.

Patient No.	Follow-Up (Mo)	Reconstruction/Recovery (Length*)				H-B System (Grade)	40-Point System (Points)
		Temporal Br	Zygomatic Br	Buccal Br	Marginal Br		
1	34	−/−	+/+ (6)	+/+ (6)	−/−	III	22
2	24	−/−	+/+ (9)	+/+ (8)	−/−	III	22
3	60	+/+ (7)	+/+ (6)	+/+ (6)	+/− (7)	II	28
4	10	−/−	+/+ (5)	+/+ (6)	+/− (7)	IV	20
5	18	−/−	+/+ (7)	+/+ (7)	−/−	III	22
6	33	−/−	+/+ (7)	+/+ (8)	+/+ (8)	III	24

*Length of vascularized nerve graft in centimeters.
Br = Branch; H-B = House-Brackmann.

palsies. Therefore, we used free vascularized nerve grafts for immediate reconstruction of the facial nerve in patients with preoperative and intraoperative factors that could inhibit functional recovery.

Extratemporal facial nerve reconstruction with nerve grafts was developed for routine clinical use by Conley and Miehlke[11] in 1973. However, the degree of functional recovery is influenced by many factors, such as the extent of damage and tissue loss, the vascularity of the bed where repair is carried out, previous or postoperative radiotherapy, and the patient's age, general health, and nutritional status. Conley and Miehlke[11] reported that patients with excessively large defects which included the cheek skin, a large potion of the mimetic muscles, and a portion of a temporal bone had less favorable outcomes. Pillsbury and Fisch[12] have reported poorer results in patients receiving radiotherapy, which they concluded was a contraindication to conventional nerve grafts. However, McGuirt and McCabe[13] have indicated that postoperative radiotherapy has no effect on the outcome of facial nerve autografts. Although none of the patients receiving vascularized nerve graft in our series had undergone radiotherapy, we think a history of previous irradiation at the wound (not as part of preoperative radiotherapy) encourages wound scarring and damages the vascular bed. Therefore, we suggest that vascularized nerve grafts are indicated for patients with previous irradiation at the wound. In four of our six patients who could be evaluated, functional results after surgery were satisfactory despite wound scars from previous surgeries or large facial skin defects. This result suggests that regeneration with free vascularized nerve grafts is normal or accelerated even in poor vascular beds.

Studies have shown that nerve-fiber regeneration is less efficient in older animals.[14] However, outcomes of neural reconstruction with vascularized nerve grafts have been poorly studied in elderly patients because in such instances, most grafts are performed in cases of extremity injury, which are less common in elderly patients. Okamura and Yanagihara[3] have reported that none of their 17 elderly patients had scores of 20 or higher on the 40-point system after conventional facial nerve repair. Sakihama et al.[15] have reported that among the 281 patients with Bell's palsy or Hunt syndrome, patients older than 60 years of age showed poor recovery. Therefore, we investigated functional results of vascularized nerve grafting in such older patients. Four of our 6 patients in whom postoperative function could be evaluated were older than 60 years of age; these patients had scores on the 40-point system of 20, 22, 22, and 24. These results suggest that accelerated axonal regeneration in the vascularized nerve graft might prevent rapid muscle atrophy resulting from denervative in elderly patients and help achieve satisfactory functional results. This positive influence might also have contributed to the good outcome in patient 3, a 30-year-old woman who had had preoperative facial palsy.

In the present series, we used four kinds of free vascularized nerve graft. Active bleeding occurred at the cut end of the transferred nerve after microsurgical anastomosis in all cases. However, because harvesting the sural nerve is somewhat difficult to perform with the patient in the supine position, we prefer to use the deep peroneal nerve, which is easier to elevate. If a facial skin defect is present, we choose the lateral cutaneous nerve of the thigh or the motor nerve of the vastus lateralis muscle combined with an anterolateral thigh flap.

The House-Brackmann system is widely used in both Europe and the United States, especially in facial nerve reconstruction after ablative surgery of cerebellopontine angle tumors, because the evaluation criteria are clearly defined at each grade and include sequelae, such as synkinesis, contracture, and spasm. However, a disadvantage of the House-Brackmann system is the difficulty of evaluating patients who have different grades of facial palsy in different areas of the face. Indeed, it was extremely difficult to achieve grade II results in reconstruction of the peripheral part of the facial nerve because the temporal branch is less likely to recover. In contrast, the 40-point system is useful for evaluating the degree of recovery in different areas of the face.

Although a study comparing functional results would be necessary to confirm the superiority of vascularized nerve grafts over conventional grafts, such a study would be extremely difficult to perform owing to the great variation in preoperative condition among individual patients. As an alternative, the superiority of vascularized nerve grafts might be confirmed with bilateral reconstruction of severed facial nerves in a single patient, with a vascularized nerve graft for one side and a conventional nerve

Fig. 2. Case 3. (A) Vascularized sural nerve graft with monitoring flap. (B) Temporal, zygomatic, buccal, and marginal mandibular branches of the facial nerve were reconstructed with cabled vascularized sural nerve graft. (C) Frontal view, 60 months after reconstruction. Almost-normal symmetry at rest. (D) Light closure of eyes. (E) Grin. (F) Whistle.

Fig. 3. Case 6. (A) Vascularized deep peroneal nerve graft. Proximal cut end of the nerve (arrowhead) and distal cut end of the nerve (arrows). (B) Free anterolateral thigh flap. (C) Zygomatic, buccal, and marginal mandibular branches of the facial nerve were reconstructed with a vascularized deep peroneal nerve graft (arrowheads), and facial skin was reconstructed with an anterolateral thigh flap. (D) Frontal view, 33 months after reconstruction. Obvious but not disfiguring difference between two sides at rest is evident. (E) Grin. (F) Whistle.

graft for the other side; however, such cases are extremely rare. In the 6 of our 10 patients in whom functional investigation was possible, vascularized nerve grafts achieved good functional recovery even in the poor conditions previously reported by many authors.[3,11,12,15] Therefore, we think that vascularized nerve grafts are effective for reconstruction of the severed facial nerve in patients with preoperative and intraoperative factors that could inhibit functional recovery, such as facial skin defects over the nerve graft, hypovascular scars, preoperative facial palsy, and age greater than 60 years.

CONCLUSION

Although a study comparing functional results would be necessary to confirm the superiority of vascularized nerve grafts over conventional grafts, we think free vascularized nerve grafts are effective for immediate reconstruction of the severed facial nerve in patients with preoperative and intraoperative factors that might inhibit functional recovery.

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REVIEW ARTICLE

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Functional reconstruction with free flaps following ablation of oropharyngeal cancer

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Abstract With the development of various reconstructive procedures, most patients who have undergone ablative surgery for oropharyngeal cancer have obtained satisfactory functional results and good quality of life. However, many questions remain concerning methods of obtaining optimal postoperative oral and pharyngeal functions, especially after glossectomy. This review focuses on reconstructive methods after partial glossectomy, hemiglossectomy, and subtotal or total glossectomy and discusses current problems and the possibility of sensory and dynamic reconstruction.

Key words Reconstruction after glossectomy · Postoperative functions · Microsurgical reconstruction

Introduction

The ultimate purpose of reconstruction is to duplicate the form and function of normal anatomic structures. The goals of oropharyngeal reconstruction from the 1970s to the early 1980s were to close the oral cavity and to avoid local postoperative complications. Several reconstructive methods employing microsurgical techniques were introduced to achieve these goals. However, the goals of reconstruction have now changed to maintaining postoperative function and improving quality of life.

In this field, functional reconstruction after glossectomy is the most challenging area; however, postoperative functional results are often unstable, and additional laryngectomy may be required because of intractable aspiration and pneumonia. In this review, we discuss reconstructive methods after partial glossectomy, hemiglossectomy, and subtotal or total glossectomy; we also discuss the possibility of dynamic and sensory reconstruction and current problems.

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History of reconstructive methods after glossectomy

Resection of the intrinsic and extrinsic musculature of the tongue prevents active intraoral food transposition and inhibits articulation. Loss of the mylohyoid sling removes the support of the floor of the mouth and prevents elevation of the base of the tongue, affecting speech and swallowing functions. Reconstruction immediately after glossectomy involves three aspects: restoration of the mucosal surface to preserve the movement of the residual tongue, restoration of coordinated motor activity, and restoration of sensation. Early attempts at reconstruction after glossectomy aimed only to resurface the defect with skin grafts, local mucosal flaps, and, later skin flaps, such as the deltopectoral skin flap.[1–3] Because these flaps were of insufficient bulk, reconstruction with them resulted in dead space, pooling of secretions, and high rates of local complications. Because of these poor results, radiotherapy was often selected as an alternative treatment until the 1970s.[4] After the pectoralis major myocutaneous flap was introduced to head and neck reconstruction by Ariyan[5] and Baek et al.[6] in 1979, both wider surgical resection and satisfactory postoperative functions became possible. The bulk of the pectoralis major myocutaneous flap decreases the size of the oral cavity and fills the dead space. However, this flap has several disadvantages, including poor reliability of its cutaneous portion, limited pedicle length, and compromised tongue elevation due to the muscle's downward traction. To address these problems, the free flap with microsurgical anastomosis was introduced to head and neck reconstruction in the early 1980s. Flaps often used for reconstruction include the free radial forearm flap,[7] the rectus abdominis musculocutane-

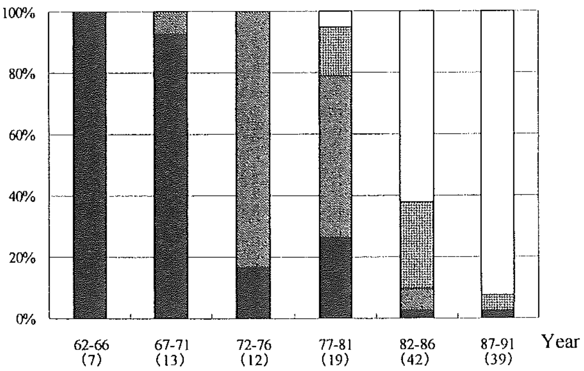

Fig. 1. Changes in the reconstructive methods used for massive oropharyngeal defects at the National Cancer Center Hospital, Japan, from 1962 to 1991. The numbers of patients with massive oropharyngeal defects are shown in *parentheses*. *Pale gray bars*, free flap; *stippled bars*, pedicled myocutaneous flap; *striped bars*, pedicled cutaneous flap; *black bars*, without reconstruction

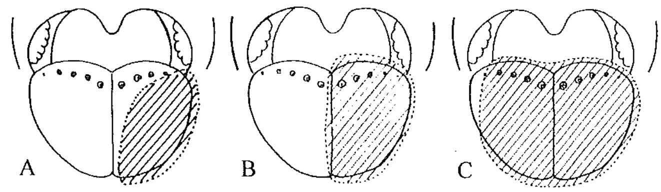

Fig. 2A–C. Classification of glossectomy defects. **A** shows partial glossectomy, in which the defect involves less than half of the mobile tongue and resection of the tongue base is minimal. **B** shows hemiglossectomy, which involves resection of half of the mobile tongue and tongue base. **C** shows subtotal or total glossectomy, in which more than two-thirds of the mobile tongue and the tongue base are removed

ous flap,[8] the latissimus dorsi musculocutaneous flap,[9] the scapular flap,[10] and the jejunal flap,[11] all of which are easily elevated and have long vascular pedicles. In the early 1990s, the use of microsurgical techniques and free flaps for head and neck reconstruction became widespread (Fig. 1). For the reconstruction of large, complex defects of the head and neck, the anterolateral thigh flap has been suggested by several authors.[12–14] The main advantage of this flap is the possibility of combined transfer with other flaps, allowing a variety of large defects of the head and neck to be repaired.

Morbidity at the flap donor site remains a concern. To minimize donor-site morbidity, perforator flaps, which are skin flaps without harvested muscle, were developed to reconstruct head and neck defects. The deep inferior epigastric artery perforator flap is the most commonly used flap of this type.[15] The classic free groin flap has also been used to minimize donor-site morbidity in head and neck reconstruction.[16]

Although several reconstructive methods and flaps have been developed since the 1970s, several important points should be kept in mind, such as minimizing early postoperative complications that may prolong hospitalization and become life-threatening, maintaining postoperative functions, and decreasing the degrees of surgical invasiveness and donor-site morbidity. To shorten operative time, the preferred flap is one that can be elevated simultaneously with tumor resection while the patient remains in the supine position.

Classification of defects after glossectomy

We have classified defects after glossectomy into three types: those after partial glossectomy, hemiglossectomy, and subtotal or total glossectomy (Fig. 2). In partial glossectomy the defect involves less than half of the mobile tongue, and resection of the tongue base is minimal. Hemiglossectomy resects half the tongue base and half the mobile tongue. In subtotal or total glossectomy more than two-thirds of the mobile tongue and the tongue base are removed.

Partial glossectomy defects

In most patients with partial glossectomy, primary closure is possible with minimal disturbance of speech and swallowing functions. When a wide defect of the mucosa of the floor of the mouth remains after primary closure from the tip of the residual tongue, transfer of a split-thickness skin graft is the most adaptable and simple procedure. The degree of redundancy can best be gauged by distracting the tongue and tailoring the graft to the defect that has been stretched to its maximum dimensions.[17] Local mucosal flaps, such as the buccal mucosal flap and the facial artery musculomucosal flap,[18] are also effective for preventing local contracture. For filling submandibular dead space, local flaps, such as the digastric muscle flap[19] and the sternocleidomastoid flap, are useful.

Hemiglossectomy defects

Resection of half of the mobile tongue and tongue base produces significant swallowing and speech dysfunction. Important points in the reconstruction of this type of defect are to preserve the mobility of the mobile tongue and to fill the dead space just below the mandible after tumor resection with the pull-through method. Because the total volume of dead space is moderate, a moderately sized flap should be selected and transferred. Possible choices include a radial forearm flap, an anterolateral thigh flap, an anteromedial thigh flap, a deep epigastric inferior artery perforator flap, and a groin flap. However, when the flap is sutured to the cut edges of the residual mobile tongue, the reconstructed tongue's movements are often inhibited by the weight of the flap and by contracture in the oral space. To resolve this problem, a bilobular radial forearm flap[20] has been suggested to preserve tongue mobility, by separating the reconstruction of the mobile tongue from the reconstruction of the floor of the mouth. Multilobular anterolateral thigh flaps[21] have also been developed for this purpose, although speech function with these flaps has not been accurately evaluated. Our experiences of the past 25 years suggest that the mobile residual tongue should be closed primarily 3 to 4cm from its tip to allow maximal movement and that the flap should be grafted to the defect of the floor of the mouth.

The pectoralis major myocutaneous flap is also another good choice for reconstruction after hemiglossectomy;[5,6] however, the flap cannot be elevated while the tumor is being resected, and the bulkiness of subcutaneous tissues in female patients can be a problem. With adequate reconstructive procedures after hemiglossectomy, functional results are satisfactory in most patients.

Subtotal or total glossectomy defects

The development of the microsurgical free-flap technique has greatly improved the quality of life of patients after subtotal or total glossectomy. We have achieved satisfactory results in reconstruction after subtotal and total glossectomy, with laryngeal preservation in 95.3% and 70% of patients, respectively.[22,23] However, some patients have poor speech and swallowing functions after surgery, despite laryngeal preservation. Considerable effort must be made to preserve the larynx;[24–27] however, functional results are often unstable, and the effectiveness of total glossectomy without laryngactomy remains questionable.[28]

To obtain satisfactory results in reconstruction after subtotal or total glossectomy, several important points must be considered, including: (1) the patient's preoperative condition, (2) structures resected in addition to the tongue, (3) the patient's age, (4) the bulk of the transferred flap, and (5) laryngeal suspension.

In a previous study, we found that patients with preoperative cerebral dysfunction or poor cardiovascular or pulmonary function were poor candidates for laryngeal preservation. Furthermore, we believe that laryngeal preservation will be of limited benefit if more than half of the oral and cervical tissues or the entire tongue and epiglottis have been resected. The postoperative function of unresected tissues is difficult to predict preoperatively, but it is negatively correlated with patient age. Postoperative function is generally poorer in patients older than 70 years.[23]

A transferred flap of sufficient bulk works together with the buccal, palatal, and neighboring pharyngeal muscles to produce positive oropharyngeal propulsion-pump forces. However, few studies[17,29,30] have examined the importance of the height of the reconstructed tongue for swallowing and articulation. In our recent study,[31] we classified the shape of the reconstructed tongue into four types – protuberant, semiprotuberant, flat, and depressed – and found that postoperative speech and swallowing functions were significantly worse in patients with flat or depressed tongues than in patients with semiprotuberant or protuberant tongues.

To help ensure that reconstructed tongues are protuberant, wider flaps, at least 1.5-cm-thick, should be used. Therefore, we prefer rectus abdominis musculocutaneous

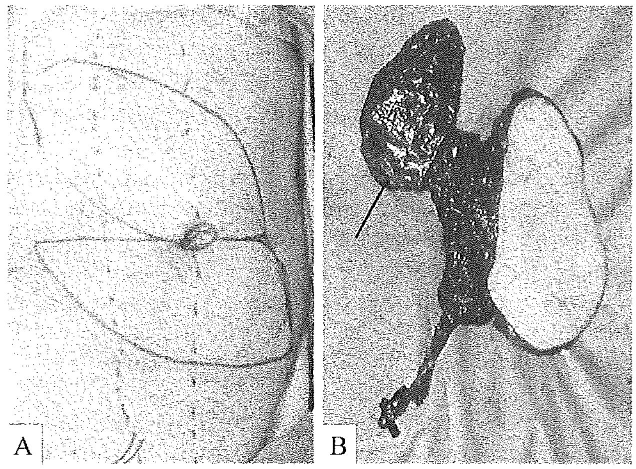

Fig. 3A,B. Rectus abdominis musculocutaneous flap in an extremely thin patient. **A** shows the design of the cutaneous portion of the flap. **B** shows the elevated flap; the cutaneous portion is de-epithelialized (*arrow*) and grafted under another cutaneous portion of the flap at the neck to reconstruct a tongue of sufficient volume

flaps, which can be elevated while the tumor is being resected with the patient in the supine position. Some authors[32] have suggested that, to ensure a reconstructed tongue of sufficient height, cutaneous flaps should be designed approximately 20% wider and longer than the defect. We now intend to design flaps 30% wider than the defect (i.e., 9 to 10cm wide in Asian patients). However, problems still arise in patients who have lost a great deal of weight. For such patients, it may be necessary for several cutaneous flaps to be transferred to increase tissue volume (Fig. 3). Several authors have reported the use of pedicled pectoralis major myocutaneous flaps for reconstruction after total glossectomy.[33–35] However, in Asian patients, the reliable cutaneous portion of this flap does not fill the oral cavity, and neck contracture often develops postoperatively.

The effectiveness of laryngeal suspension has been discussed in several articles.[24,33,35] However, a cineradiographic study by Myers[36] has shown that neither the hyoid bone nor laryngeal elevation are essential for effective swallowing. Indeed, most of our patients could swallow without additional laryngeal suspension; however, in two of our patients, severe laryngeal prolapse occurred and caused the reconstructed tongue to be depressed. Therefore, to prevent prolapse of the transferred flap, we now use thick nylon sutures to suspend the larynx from the mandible (with approximately 2cm between the superior border of the hyoid bone and the inferior border of the mandible).

To achieve a more functional reconstructed tongue

A fully functional tongue cannot be reconstructed with current methods, and the possibility of postoperative function is dependent on the extent of resection. However, to obtain better functional results, some ambitious reconstructive procedures have been attempted. Mucosal sensation plays an important role in oral function and the patient's quality of life. The ability to sense ingested material in different parts of the mouth facilitates its presentation either to the teeth for chewing or to the tongue for swallowing. Intact intraoral sensation prevents the pooling of saliva and drooling that are frequently seen after extensive head and neck reconstruction. To restore sensation to the reconstructed tongue, David,[37] in 1977, first reported the use of the innervated deltopectoral cutaneous flap for intraoral reconstruction; he obtained good results in two of four patients. The free sensate dorsalis pedis flap and lateral arm flaps have also been used to restore intraoral sensation.[38,39] More recently, innervated radial forearm flaps have been the most commonly used for reconstruction after partial glossectomy.[40] In particular, Boyd et al.[41] have shown, with sophisticated sensory testing, that the innervated flap is superior to the noninnervated flap. We also examined the benefit of the sensory flap in patients in whom more than half of the tongue had been resected;[42] we found that postoperative sensory recovery was significantly better with innervated sensate anterolateral thigh or rectus abdominis muscle flaps than with noninnervated flaps. However, results of Semmes-Weinstein testing showed that recovery did not reach the level of protective sensation. Although additional objective and functional testing is required and the need for sensory reeducation should be considered, this simple operative procedure, using sensate flaps, can improve postoperative intraoral function and should be attempted after glossectomy when possible.

Reconstruction of a mobile tongue after glossectomy is the goal for the patient and for many reconstructive surgeons. However, tongue musculature is now most often reconstructed with nonfunctional, noncontractile tissues. Some attempts have been made to reconstruct the mobile tongue with a latissimus dorsi musculocutaneous flap or a rectus abdominis musculocutaneous flap in which the included motor nerves are coapted to the remaining hypoglossal nerve.[43,44] Although the effectiveness of these dynamic reconstructive methods after glossectomy has been reported, equally satisfactory results can be obtained with the methods we have described for use after subtotal or total glossectomy defects. Because the hypoglossal nerve includes many types of motor nerve fibers for intrinsic tongue muscles, whether a single transferred muscle can help to restore complicated swallowing functions is questionable. Ideally, three or more muscle-transfer procedures should be performed to reconstruct the mobile tongue. Reinnervating the transferred muscle by coapting its motor nerves to the hypoglossal nerve will help to decrease the degree of muscle atrophy and maintain the volume of the reconstructed tongue. Infrahyoid muscle flap transfer[45] and temporal muscle suspension[46] are other methods to increase the movement of the reconstructed tongue by exploiting the contractile force of neighboring muscles. Reconstructing a fully mobile tongue is extremely difficult with current methods; however, we remain motivated to develop surgical procedures to optimize the patient's quality of life.

Conclusion

In this review, we have described several reconstructive methods for obtaining good functional results after glossectomy. However, surgeons should always consider prognosis when selecting reconstructive methods for patients who have undergone glossectomy, because the survival rate of these patients is generally low. Important points that enable the selection of appropriate reconstructive methods are: minimizing early postoperative complications, maintaining postoperative functions, and decreasing surgical invasiveness and flap donor-site morbidity.

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Pelvic Ring Reconstruction with the Double-Barreled Vascularized Fibular Free Flap

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Background: Although hemipelvectomy has been the standard treatment for malignant tumors of the pelvis, limb salvage surgery is now the treatment of choice, even for patients with advanced tumors. For these patients, pelvic reconstruction is needed to maintain the stability of the pelvis and the spinal column and to allow ambulation. In this report, the authors' experiences with pelvic ring reconstruction are described.

Methods: Pelvic ring reconstruction with free double-barreled vascularized fibular grafts was performed after resection of malignant pelvic tumors in five patients. The graft was fixed with a fixation plate and screws in three patients and with the Cotrel-Dubousset rod system in two patients. After surgery, perioperative and postoperative findings were evaluated.

Results: In one patient, a pedicled rectus abdominis musculocutaneous flap was transferred to repair defects of the skin and underlying soft tissue. The free fibular graft was transferred successfully in four of five patients; however, the graft was removed in one patient because of infection with methicillin-resistant *Staphylococcus aureus*. After surgery, three of the four patients with successful grafts could walk with full weight bearing and without a cane; the fourth patient died as a result of multiple metastases to the lung before walking was attempted.

Conclusions: The double-barreled fibular graft is well vascularized and can achieve satisfactory bone union. It is a safe and effective method for reconstructing the pelvic ring. Furthermore, the Cotrel-Dubousset rod system can provide rigid fixation soon after surgery and is useful for early rehabilitation of walking. (*Plast. Reconstr. Surg.* 116: 1340, 2005.)

Hemipelvectomy was the standard treatment for malignant tumors of the pelvis, but limb salvage surgery is now preferred even for patients with advanced tumors. It is appropriate to salvage the limb when the procedure provides a satisfactory surgical margin or when an amputation cannot provide a better margin. For these patients, pelvic reconstruction is essential to maintain the stability of the pelvis and the spinal column. Also, it is important to reestablish a continuity of the ilium, the sacrum, and the pubis. Historically, a free bone graft was the only choice for restoring bony defects, but now the free vascularized bone graft can provide excellent results for pelvic ring reconstruction. However, pelvic ring reconstruction still has several unresolved problems, such as the optimal methods of bone transplantation and fixation and the poor

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TABLE I
Patient Data

Patient	Age (yr)	Sex	Diagnosis	Location	Resection Type	Reconstruction Method	Fixation	Vascular Anastomosis
1	32	M	Chondrosarcoma	Right ilium	I	DBF and p-RAMC	C-D rod	Superior gluteal
2	52	F	Chondrosarcoma	Left ilium	I	DBF	C-D rod	Superior gluteal
3	18	F	Metastatic osteosarcoma	Left ilium	I	DBF	Screw and plate	Lumbar
4	14	M	Ewing's sarcoma	Right ilium	I and II	DBF	Screw and plate	Deep inferior epigastric
5	4	M	Osteosarcoma	Left ilium	I and II	DBF	Screw and plate	Deep inferior epigastric

M, male; F, female; DBF, double-barreled fibular graft; p-RAMC, pedicled rectus abdominis musculocutaneous flap; C-D rod, Cotrel-Dubousset rod system.

prognosis of malignant pelvic tumors. The most important issues are the safety of pelvic ring reconstruction and the degree of functional recovery. In this article, we report on five cases of pelvic ring reconstruction after resection of malignant pelvic tumors.

Patients and Methods

From 1998 through 2003, we performed pelvic ring reconstruction after resection of malignant pelvic tumors in five patients, including three male patients and two female patients, aged 14 to 52 years. The pathologic diagnosis was chondrosarcoma in two patients, osteosarcoma in two patients, and Ewing's sarcoma in one patient. Areas of resection were classified according to Enneking's system.[1] Enneking's type I resection was performed in three patients, and type I and type II resection was performed in two patients. The pelvic ring was reconstructed with free double-barreled vascularized fibular grafts in all patients. In one patient, a pedicled rectus abdominis musculocutaneous flap was transferred simultaneously. The graft was fixed with a fixation plate and screws in three patients and with the Cotrel-Dubousset rod system in two patients. The vascular pedicle was anastomosed with the superior gluteal artery and vein in two patients, with the lumbar artery and vein in one patient, and with the deep inferior epigastric artery and vein in two patients (Table I).

Results

The free fibular graft was transferred successfully in four of five patients. However, the graft was removed in one patient because of infection with methicillin-resistant *Staphylococcus aureus.* Walking rehabilitation was started in four patients, but one patient died as a result of multiple metastases to the lung before walking could be attempted. Walking rehabilitation started within 25 days after surgery in the two patients treated most recently with the Cotrel-Dubousset rod system. However, the two patients treated earlier began walking after only 55 days and 104 days, respectively. Finally, of the four patients in whom the fibular graft transfer was successful, three could walk with full weight-bearing and without a cane. Analysis with Enneking's scoring system[2] in the two most recent patients showed satisfactory lower extremity function (Table II).

Case 1

Patient 1 was a 32-year-old man with chondrosarcoma of the left ilium (Fig. 1). The large tumor was resected along with the ilium and the invaded skin (Fig. 2). A free fibular graft was obtained from the left leg (Fig. 3), double-barreled with single osteotomy, and placed between the stump of the iliac bone and the sacral bone. The graft was rigidly fixed with the Cotrel-Dubousset rod system (Figs. 4 and 5). A pedicled rectus abdominis musculocutaneous flap was transferred to repair the defects of the skin and underlying soft tissue (Fig. 6). Twenty-five days after surgery, the patient started walking with one-third weight bearing. By 7 months after surgery, full weight bearing was possible, and the patient could walk with-

TABLE II
Postoperative Course

Patient	Complications	Start Walking (POD)	Walking Ability	Lower Limb Function (%)	Outcome	Follow-Up (mo)
1	None	25	Walk without cane	63.3	Disease-free	7
2	None	14	Walk without cane	86.7	Disease-free	12
3	MRSA	104	Wheelchair	NA	Disease-free	14
4	None	None	Died before attempted	NA	Died as a result of disease	3
5	None	55	Walk without cane	NA	Died as a result of disease	23

POD, postoperative day; MRSA, infection with methicillin-resistant *Staphylococcus aureus*; NA, not assessed.

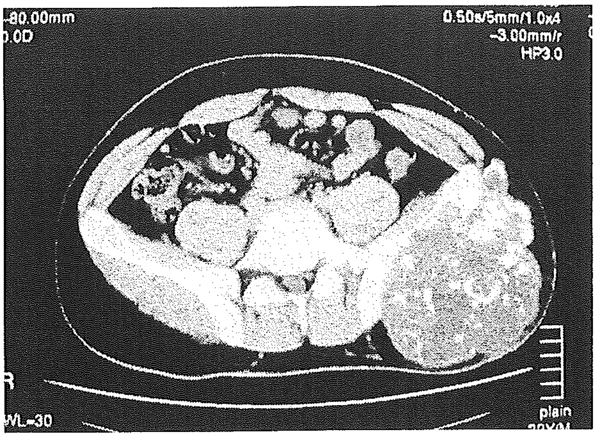

FIG. 1. Computed tomographic scan indicates a large chondrosarcoma at the left iliac bone.

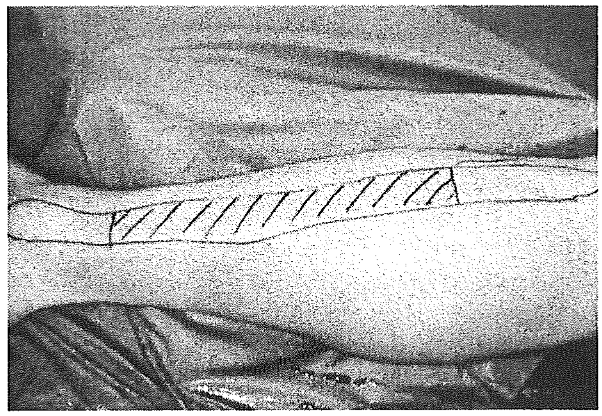

FIG. 3. A free vascularized fibular graft was harvested from the left leg.

out a cane. Radiographs obtained 7 months after surgery showed satisfactory bone union and alignment (Fig. 7).

DISCUSSION

Although hemipelvectomy was the standard treatment for malignant tumors of the pelvis, limb salvage surgery is now the treatment of choice, even for patients with advanced tumors.[3,4] For these patients, pelvic reconstruction is essential for maintaining stability of the pelvis and the spinal column and to allow ambulation. Various types of graft materials, in-

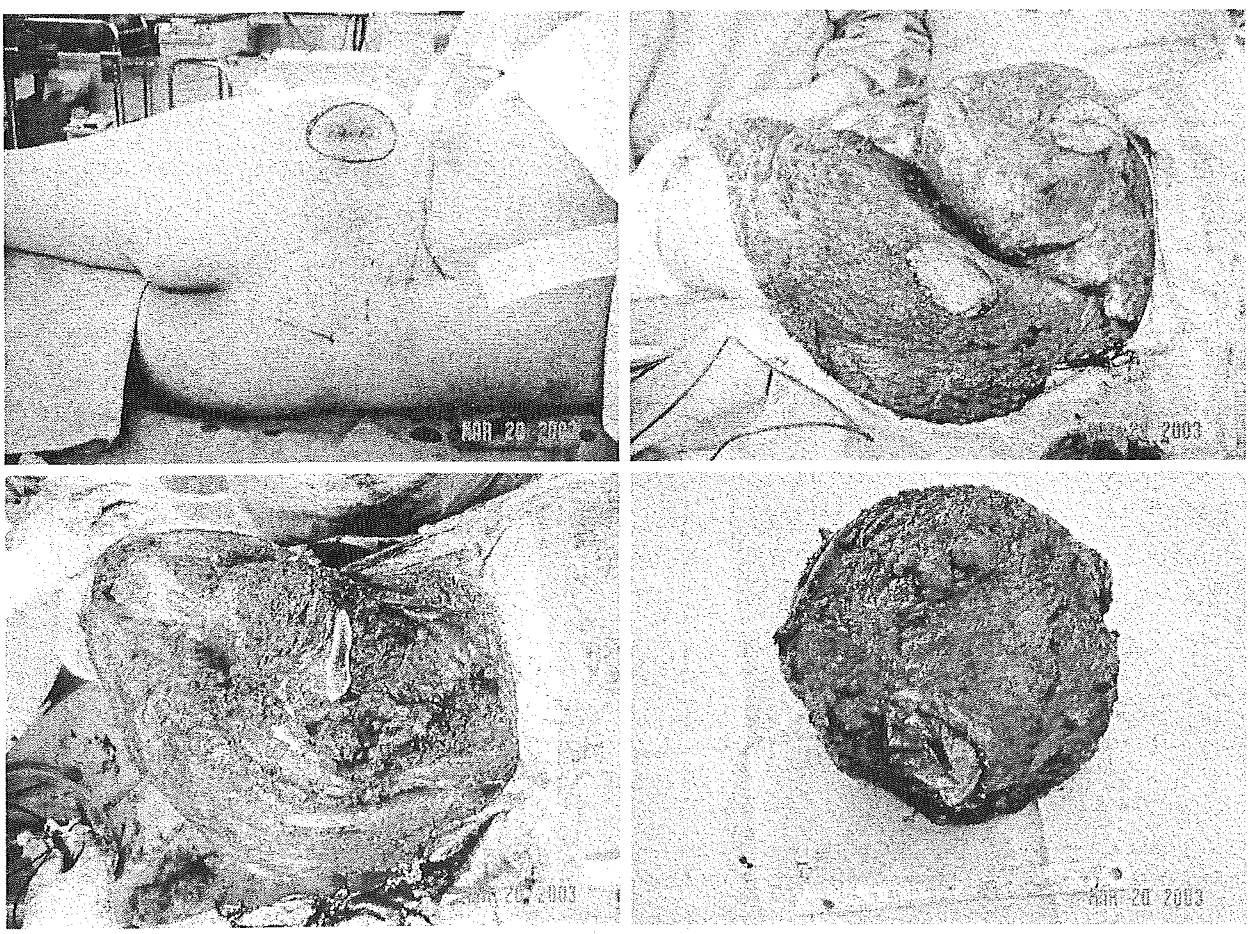

FIG. 2. (*Above, left*) Skin incision design. (*Above, right*) The skin flap was elevated and the invaded skin was removed. (*Below, left*) The resected area shows the stump of iliac bone and sacral bone. (*Below, right*) Resected tumor.

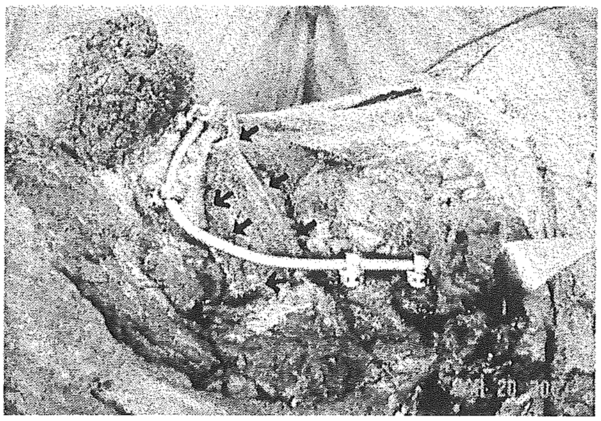

FIG. 4. The graft was double-barreled and fixed with the Cotrel-Dubousset rod system. *Arrow* indicates a fibula graft.

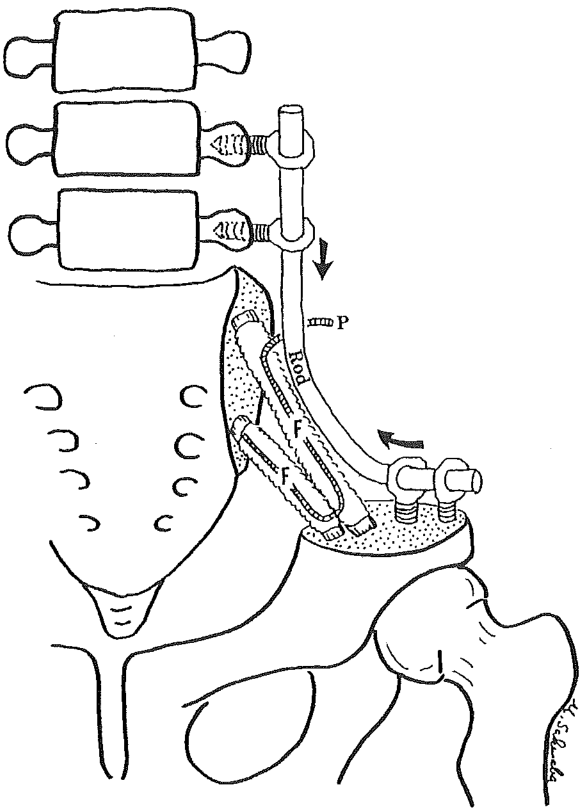

FIG. 5. Schematic image shows inset of the double-barreled vascularized fibular flap (*F*) and the rod system. The fibular flap was fixed between the stump of the sacrum and the ilium by compression pressure (*arrows*) along the rod. The vascular pedicle (*P*) of the flap was anastomosed to the superior gluteal artery and vein.

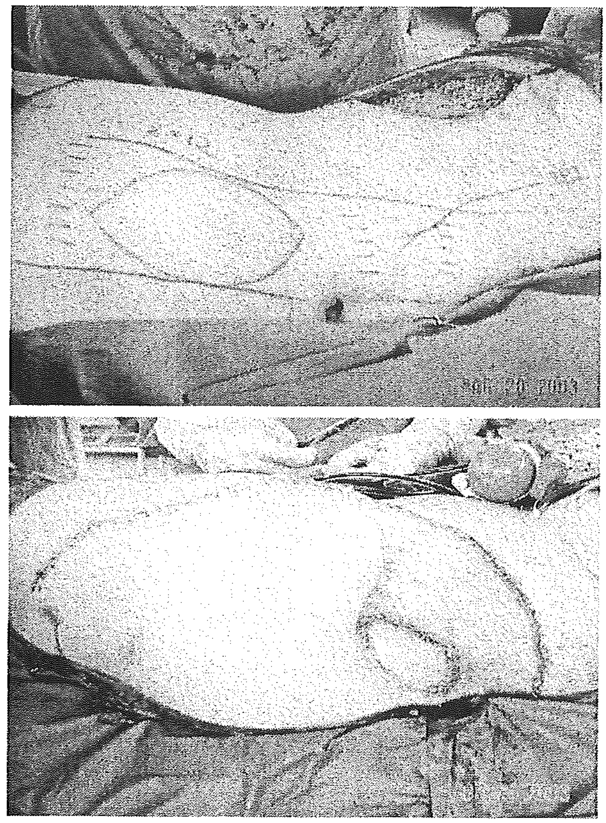

FIG. 6. (*Above*) A pedicled rectus abdominis musculocutaneous flap was harvested and (*below*) the flap was transferred to repair the defects of the skin and underlying soft tissue.

cluding free bone grafts, homogenized bone grafts, the artificial pelvis, and vascularized bone grafts, can be used for pelvic ring reconstruction. However, we do not use free bone grafts, homogenized bone grafts, or the artificial pelvis, because complications, such as bone absorption of the graft and wound infections, are common. Instead, we prefer vascularized iliac bone or fibular bone. Vascularized bone grafts heal as fractures do, with quicker remodeling and minimal resorption, thereby allowing earlier rehabilitation and better functional results.[5,6]

An advantage of the iliac bone graft is that it can be used as a pedicled flap, which does not require microvascular anastomosis. However, because iliac bone grafts are relatively short, they are suitable only for small defects. Furthermore, the rotation arc of pedicled iliac bone grafts is limited by the shortness of the deep circumflex iliac artery and vein. For these reasons, the vascularized iliac bone graft is indicated only for pubic bone reconstruction.

In contrast, the vascularized fibular graft is long enough for reconstruction of large iliac bone defects. Furthermore, the fibular graft can be elevated at the same time the tumor is resected, shortening operating time. Possible disadvantages of the fibular graft are its narrow width and the necessity of microvascular anastomosis. As previously reported, the fibular