Facial Reanimation by One-Stage Microneurovascular Free Abductor Hallucis Muscle Transplantation: Personal Experience and Long-Term Outcomes

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Background: In 1990, Jiang Hua introduced a new method using one-stage reconstruction with free abductor hallucis muscle transfer for dynamic reanimation of established unilateral facial paralysis. The authors present their experience with this procedure and analyze the postoperative complications and long-term functional and aesthetic outcomes.

Methods: From March of 1990 to March of 2010, 45 patients underwent the free abductor hallucis muscle transfer procedure in the authors' department. Forty-one were followed up for 54.6 months (range, 28 months to 17 years). The Toronto Facial Grading System and Facial Nerve Function Index were used to evaluate facial nerve function at 2 years after surgery and last follow-up. Complications and function of the donor foot were analyzed.

Results: No postoperative mortality was found. Complications occurred in four of 41 patients, including muscle loss, infection, hematoma, and hypertrophic scar. The others obtained satisfactory symmetric faces in the static state and in voluntary contraction of the transferred muscles. Mean values for the Toronto Facial Grading System (50.6 ± 7.8) and the Facial Nerve Function Index (65.7 ± 11.4 percent) were significantly higher at 2 years postoperatively in comparison with preoperative status (21.2 ± 5.3 and 19.5 ± 3.6 percent, respectively) ($p < 0.05$). Long-term outcomes (Toronto Facial Grading System, 54.8 ± 6.9; Facial Nerve Function Index, 79.4 ± 9.6 percent) were awarded higher values than early outcomes shown at 2 years postoperatively ($p < 0.05$).

Conclusions: Free abductor hallucis muscle transfer is safe and effective in dynamic reanimation of longstanding unilateral facial paralysis. Favorable long-term results demonstrate that the authors' technique is an alternative method for facial reanimation. (*Plast. Reconstr. Surg.* 130: 325, 2012.)

CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, IV.

Correction of the deformities caused by longstanding complete and irreversible unilateral facial paralysis is a complex problem. Reanimation of facial paralysis requires restoration of highly complex functions, including normal appearance at rest; symmetry of voluntary motion; symmetry of involuntary motion and controlled balance in expressing emotion; and oral, nasal, and ocular sphincter control, all without loss of other significant functions.[1] When nerve grafting alone is no longer sufficient, dynamic reconstructive procedures such as muscle transposition or cross-facial nerve grafting combined with functional muscle transfer is required.[2] The cross-facial nerve graft/functional muscle transfer strategy for facial reanimation is superior to static reconstruction or regional muscle transposition.[3–6]

Cross-facial nerve grafting and functional muscle transfer can be performed either at the

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same time (one-stage procedure) or with a 10- to 12-month delay between stages (two-stage procedure).[3] The two-stage procedure has some drawbacks, such as long interval between operations and the risk of traumatization of the donor nerve at the time of facial dissection in the second-stage operation.[2] However, most surgeons prefer the latter because the delay between stages permits axon regeneration across the length of the nerve graft and minimizes the denervation interval of transferred muscle. One-stage cross-facial nerve grafting with functional muscle transfer offers potential advantages over staged procedures, including patient preference, safety (with avoidance of additional operative risk), shorter total recovery time, and health care resource implications.[3]

In the past four decades, many muscles have been reported as donor muscles for facial paralysis. In 1995, we reported our microneurovascular free abductor hallucis muscle transplantation for restoration and reanimation of the cheek with longstanding paralysis in one stage.[1,4] In that article, the six-case series showed an 83 percent success rate (five of six patients achieved excellent results).Various studies have been conducted on the long-term results of one- or two-stage cross-facial nerve grafting with functional muscle transfer for facial reanimation. To date, there have been no long-term outcomes using this method. Therefore, in the current study, we presented our long-term outcomes of one-stage microneurovascular free abductor hallucis muscle transplantation for reanimation of unilateral facial paralysis in 41 patients.

PATIENTS AND METHODS

From March of 1990 to November of 2009, 45 patients received free abductor hallucis muscle transplantation for facial reanimation performed by the senior author (J.H.) at our department. Patients' ages ranged from 17 to 61 years (32.6 ± 18.5) and comprised 24 male patients and 21 female patients. Denervation time ranged from 17 months to 48 years. The cause of the paralysis was varied (Table 1). The frontal facial photographs were analyzed before and after surgery. The Toronto Facial Grading System and the Facial Nerve Function Index were used to evaluate facial nerve function before and after surgery. Meanwhile, the survival of the graft, the width of the face, the scar, and the function of the donor site were analyzed.

Table 1. Causes of Facial Palsy in 45 Patients Undergoing Abductor Hallucis Transfer

Cause	No. of Patients
Birth, congenital	3
Idiopathic, Bell palsy	15
Neoplasm	
Parotid gland tumor	6
Cholesteatoma	3
Acoustic neuroma	7
Trauma, fracture	9
Iatrogenic	2
Total	45

Preoperative Preparations

The dorsalis pedis and posterior tibial artery pulses were palpable and detected by using an ultrasonic vascular scope. Lower extremity angiograms were not necessary. Other preoperative preparations included oral care using compound tinidazole gargle 3 days before the operation and designing incisions on the donor-site and paralyzed face.

Operative Procedures

Sufficiently deep general anesthesia was induced by means of nasotracheal intubation. The facial recipient area preparation and the donor muscle elevation were both performed simultaneously and undertaken in the charge of the senior author (J.H.).

For the group of the donor site, the following steps were performed, in order (Figs. 1 and 2): the muscular insertion was separated from the proximal phalanx of the great toe, the medial plantar nerve was transected nearly 1 cm from the bifurcation of the muscular nerve branch (Fig. 1, *above left, large yellow arrow*), the proximal stump of the medial plantar nerve was buried in the muscle after being separated into several bundles, the muscular origin was separated from the medial tubercle of the calcaneum, and then the tarsal tunnel was dissected to split the tibial nerve from where the nerve divided into the medial and lateral plantar nerve up to gain enough nerve pedicle length. Thus, the abductor hallucis muscle flap based on the posterior tibial vessels (artery and veins) and the fasciculi of the partial tibial nerve (including the medial plantar nerve) were elevated. The connective tissue adhesion between the vessels and the nerve was preserved to provide blood supply for the nerve pedicle. Electrical stimulation to the nerve pedicle led to an evident contraction of the abductor hallucis.

For recipient-site preparation, there are two types of nerves that can serve as the recipient: the

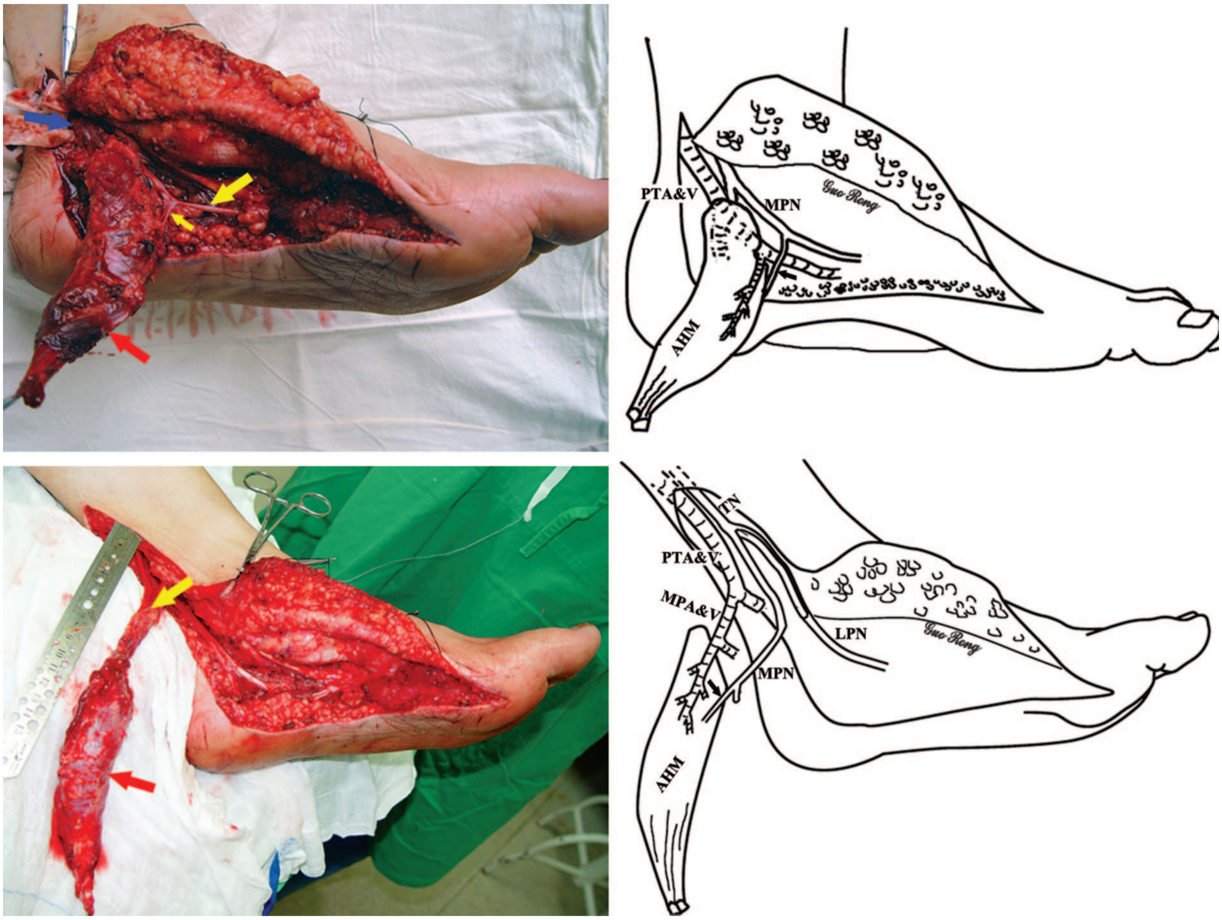

Fig. 1. Dissection of the neurovascular pedicle (*blue arrow*) of the abductor hallucis muscle (*AHM*). (*Above*, *left*) Photograph showing the main motor nerve (*small yellow arrow*) that supplies the abductor hallucis (*red arrow*) and its point of origin from the medial plantar nerve (*large yellow arrow*). (*Below*, *left*) The left abductor hallucis (*red arrow*) was harvested with its neurovascular pedicle (*yellow arrow*). (*Right*) Schematic depictions of photographs on the *left*. *PTA&V*, posterior tibial artery and veins; *MPN*, medial plantar nerve; *MPA&V*, medial plantar artery and veins; *TN*, tibial nerve; *LPN*, lateral plantar nerve.

buccal branches of the facial nerve and the mylohyoid branch of the ipsilateral trigeminal nerve. If the buccal branches of the facial nerve were selected, a preauricular incision was made on the contralateral healthy side to expose the buccal branches of the facial nerve, the facial artery, and veins. If the mylohyoid branch of the ipsilateral trigeminal nerve was selected, another submandibular incision was made on the affected facial side to expose the nerve branch, the facial artery, and veins on the ipsilateral facial side. Then, on the affected side of the face, to hold the transferred muscle, a pocket was dissected between the superficial musculoaponeurotic system and overlying skin and subcutaneous tissue from the temporal incision to the perioral incision.

When the recipient site was completely prepared, the neurovascular pedicle was transected, and the muscle flap was transferred immediately to the recipient bed. The proximal end of the muscle, close to the pedicle, was split longitudinally into two tails at a length of 3 to 4 cm, with one being inserted into the upper lip and the other into the lower lip and oral commissure with mattress sutures. The distal end of the muscle was fixed to the temporal or zygomatic fascia. The angle of the insertion on the commissure was 30 to 40 degrees above the horizontal, and the amount of tension selected was just sufficient to place the two commissures of the patient's mouth in a balanced position. The neurovascular pedicle was passed subcutaneously through the upper lip to the healthy side if the buccal branch of the facial nerve served as the recipient nerve or through the lower lip to the submandibular area if the mylohyoid branch of the ipsilateral trigeminal nerve served as the recipient nerve. End-to-end anastomosis between donor and recipient arteries, veins,

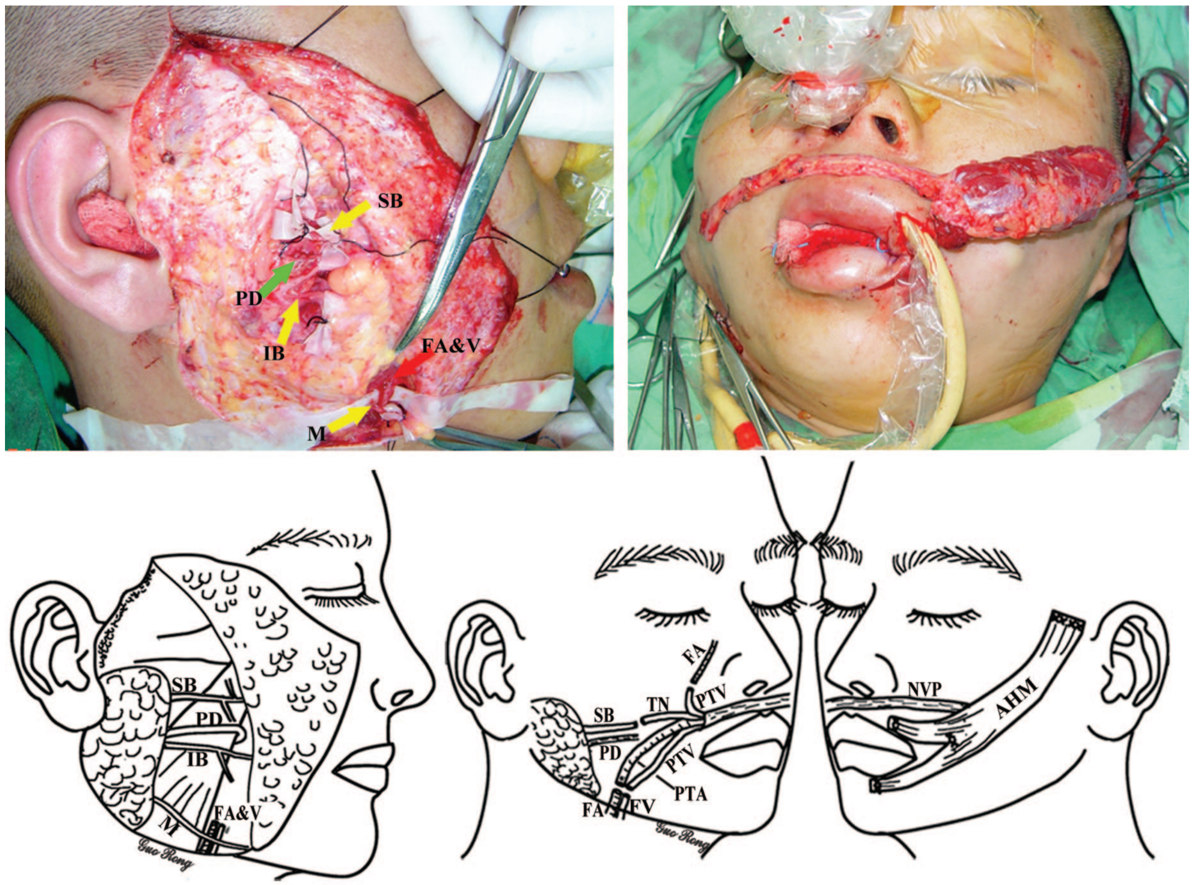

Fig. 2. Dissection of facial nerve branches on the healthy side (*above, left* and *below, left*). (*Above*, *right*, and *below*, *center* and *right*) Fixation of muscle graft and the anastomosis of the nerve and vessels. *SB*, superior branch of the buccal branch of the facial nerve; *PD*, parotid duct; *IB*, inferior branch of the buccal branch of the facial nerve; *M*, marginal mandibular branch of the facial nerve; *FA&V*, facial artery and veins; *PTA*, posterior tibial artery; *PTV*, posterior tibial vein; *TN*, tibial nerve; *AHM*, abductor hallucis muscle; *NVP*, neurovascular pedicle of the abductor hallucis muscle.

and nerves was accomplished using the operating microscope. Applied anatomy of the abductor hallucis muscle with its morphology and blood and nerve supply is available in our previous article.[1]

Postoperative Treatments and Methods of Evaluation

Intravenous administration of antibiotics was not withdrawn until 5 to 7 days after surgery to prevent muscle graft infection. The semitube drain in the healthy facial side and the vacuum drain in the muscular tunnel were removed 48 to 72 hours and 5 to 7 days after the procedure, respectively. Then, an elastic facial mask was introduced to maintain a proper tension of the muscle all day long for 2 to 3 months. Two months after the operation, patients were started on massage therapy to assist in preventing adhesions between the muscle flap and the overlying skin envelope. All patients were encouraged to repeat a series of training exercises in front of the mirror several times per day after they felt the first contractions of the transplanted muscle.

Postoperatively, all patients were required to attend further consultation in our clinic at 3, 6, and 12 months and were thereafter reviewed yearly. The Toronto Facial Grading System[7–10] and the Facial Nerve Function Index[11] were used to evaluate facial nerve function before and after surgery. Each patient was scored by three different plastic surgeons, and the averaged scores at each selected time point were presented as mean ± SD. None of the observers had any knowledge of patient identification. Electromyography of the transplanted abductor hallucis muscles was performed at two time points: 6 months after the operation and in November of 2009. All were performed by the same physician and using the same electromyography device. For the purpose of this study, the photographs, videotapes, and electromyographic reports relating to the preoperative consultation and last follow-up were analyzed. The facial function (Toronto Facial Grading System and Facial Nerve Function Index), scar in the facial operative regions and foot donor sites, and function of the donor feet were evaluated in all cases.

Statistical Analysis

All data collected were coded so that no patient identification was possible. Descriptive statistics such as mean, standard deviation, and percentage were used to present the data. Comparisons between preoperative and postoperative measurements were performed by using paired t tests. The significance level was set at $p < 0.05$.

Fig. 3. A 41-year old woman suffered from complete right facial paralysis for 2 years following excision of right acoustic neuroma. (*Above*, *left*) Appearance of the face at rest before the operation. (*Above*, *right*) Appearance during smiling before the operation. Seven months postoperatively, normal appearance was observed at rest (*below*, *left*), whereas slightly synchronous movement of the oral commissure and the nasolabial fold (*below*, *right*) was observed when the patient smiled.

RESULTS

Forty-one of the 45 patients who underwent facial reconstruction using one-stage free abductor hallucis muscle transplantation were followed up. The mean follow-up period for this series was 54.6 months (range, 28 months to 17 years) (6 months to 2 years, $n = 18$; 2 to 5 years, $n = 11$; >5 years, $n = 12$). The mean operating time and mean blood loss were 345 minutes (range, 295 to 410 minutes) and 225 ml (range, 100 to 600 ml), respectively. The mean hospital stay was 12.5 days (range, 8 to 16 days) after the operation. The mean length of the muscle pedicle was 14.2 cm (range, 12 to 19 cm).

Overall, there was no postoperative mortality. Postoperative complications occurred in four of 41 patients (9.8 percent). One patient's muscle flap was lost because of vascular crisis. Two patients' muscle flaps failed to function adequately because of postoperative infection and hematoma after 2 years. One patient developed hypertrophic scar on the face. The others had small and well-concealed scars on the face that usually settled nicely with time. All patients could stand stably 1 month postoperatively and climb up the stairs without any difficulty from the first floor to the third floor 2 months postoperatively. Normal daily walking was restored 3 months after the operation and walking with weight-bearing was also restored 6 months after the operation. The abduction function of the big toe was partially lost after removal of the muscle. Some patients complained of numbness on the medial area of the donor foot after the operation that recovered 6 months after surgery without any other intervention, at which point there was no numbness, itching, or pain. All patients obtained satisfactory symmetric faces in the static state and on voluntary contraction of the transferred muscles. Some of our cases are shown in Figures 3 through 7.

Thirty-two patients underwent secondary revision surgery. In detail, 21 patients underwent scar revision surgery, especially in the healthy face, three underwent muscle graft reanchoring surgery and temporal scar revision at the same time, four patients underwent selective myectomy of muscle graft, two patients underwent cheek defatting from the original oral incision, and the other five patients underwent temporal region face lift to correct the sagging skin and subcutaneous tissue 1 to 2 years after surgery because of long-term denervation.

Twenty-two patients (53.7 percent) contacted us when they felt the first twitches of the muscle, and functional onset ranged from 6 to 10 months. Electromyography of the free abductor hallucis showed that all of these muscles except one survived and had contractive function 6 months postoperatively. The mean Toronto Facial Grading System and Facial Nerve Function Index values were significantly higher at 2 years after free-muscle transfer (Toronto Facial Grading System, 50.6 ± 7.8; Facial Nerve Function Index, 65.7 ± 11.4 percent) in comparison with the preoperative status (Toronto Facial Grading System, 21.2 ± 5.3; Facial Nerve Function Index, $19.5 \pm$

Fig. 4. A 38-year old woman suffered from complete left facial paralysis for 13 years after excision of a left parotid gland tumor. (*Left*) Appearance of the face during smiling before the operation. (*Center*) Appearance at 11-month follow-up, displaying a soft symmetric smile. (*Right*) Photograph at 2-year follow-up shows an improved symmetric smile.

Fig. 5. A 23-year-old woman presented to our department with a 22-year history of left Bell palsy. The left adductor hallucis muscle was transferred based on the posterior tibial vessels and tibial nerve. The buccal branch of the facial nerve on the unaffected facial side was selected as the recipient nerve. Nine years postoperatively, a face with symmetry and defatting was obtained at rest, and the corner of the affected side was able to elevate and the nasolabial fold was produced when the transferred muscle was contracted voluntarily. Sensation in the sole was recovered, and walking was not affected.

3.6 percent) ($p < 0.05$). Long-term outcomes (Toronto Facial Grading System, 54.8 ± 6.9; Facial Nerve Function Index, 79.4 ± 9.6 percent) were scored higher than early outcomes shown at 2 years after free-muscle transfer ($p < 0.05$) (Fig. 8).

Among the 41 abductor hallucis muscles, three were innervated by the mylohyoid branch of the ipsilateral trigeminal nerve and 38 were innervated by the buccal branches of the facial nerve (14 from the superior branch and 24 from the

Fig. 6. Preoperative and 17-year postoperative views obtained at rest and during smiling of a 17-year-old female patient who suffered from complete posttraumatic right facial paralysis of 6 years' duration. (*Above*, *left*) Preoperatively, at rest; (*above*, *right*) preoperatively, while smiling; (*below*, *left*) postoperatively, at rest; and (*below*, *right*) postoperatively, while smiling.

inferior branch). Compared with the buccal branch of the facial nerve group, it took less time for the mylohyoid branch of the ipsilateral trigeminal nerve group to gain muscle reinnervation (6 to 8 months versus 8 to 10 months).

DISCUSSION

Facial reanimation by functional muscle transfer with cross-facial nerve grafting is the criterion standard treatment for chronic unilateral facial palsy. Functional muscle transfer and cross-facial nerve grafting can be performed either at the same time or with a several-month delay between stages. To date, results with the one-stage reconstruction have been contradictory. Harii et al. claimed satisfactory results in 80 percent of patients,[12] whereas Sajjadian et al. concluded that outcomes were admittedly moderate.[13] An experimental model of functional muscle transfer with interposed nerve grafting demonstrated that the

Fig. 7. The scar on donor foot (left foot) was small and well concealed 9 years postoperatively (same patient as in Fig. 5). The patient could stand stably 1 month postoperatively, resume normal daily walking 3 months postoperatively, and resume walking with weight-bearing 6 months postoperatively. There was no numbness, itching, or pain in the donor foot 6 months postoperatively.

outcomes were not significantly different between one- and two-stage surgery groups.[3] Many investigators currently support one-stage methods of reconstruction.[1,12,13] They believe that one-stage methods offer potential advantages over staged procedures, including patient preference, safety (with avoidance of additional operative risk), shorter total recovery time, and fewer health care resource implications.[3] In 1995, an 83 percent success rate (five of six patients achieved excellent results) was achieved when we reported our microneurovascular free abductor hallucis muscle transplantation for restoration and reanimation of the cheek with longstanding paralysis in one stage.[1] Now, in this series of 41 cases, a 93 percent success rate (38 of 41 patients achieved excellent results) was achieved, which adds evidence to the notion that the one-stage method is better than two-stage methods.

For the procedure, we should emphasize two key points besides careful elevation of the muscle flap and successful anastomosis of the nerve branches and vessels. One is the recipient nerve branch and the other is the splitting of the muscle flap. Sihler stain is a whole-mount nerve staining technique that renders muscles and other soft tissue translucent or transparent while staining the nerves in dark blue. It permits mapping of entire

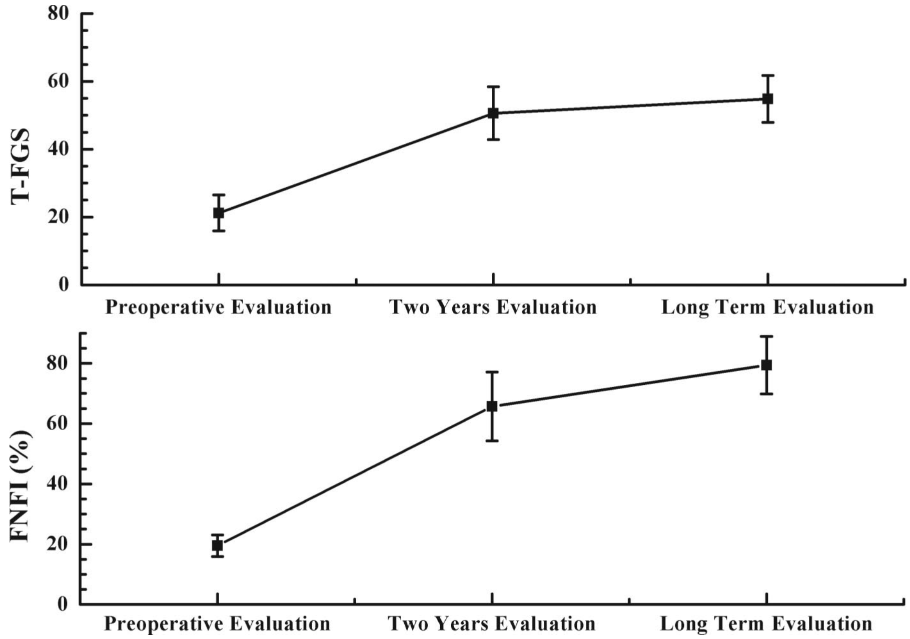

Fig. 8. Average Toronto Facial Grading System scores and Facial Nerve Function Index by length of follow-up. The mean Toronto Facial Grading System and Facial Nerve Function Index values were significantly higher at 2 years after free-muscle transfer (Toronto Facial Grading System, 50.6 ± 7.8; Facial Nerve Function Index, 65.7 ± 11.4 percent) in comparison with the preoperative status (Toronto Facial Grading System, 21.2 ± 5.3; Facial Nerve Function Index, 19.5 ± 3.6 percent) ($p < 0.05$). Long-term outcomes (Toronto Facial Grading System, 54.8 ± 6.9; Facial Nerve Function Index, 79.4 ± 9.6 percent) were scored higher than early outcomes shown at 2 years after free-muscle transfer ($p < 0.05$).

nerve supply patterns of skeletal or mimetic muscles after the specimens are fixed in neutralized formalin, macerated in potassium hydroxide, decalcified in acetic acid, stained in Ehrlich hematoxylin, destained in acetic acid, and cleared in glycerin. Using modified Sihler nerve staining technique, we found that the buccal branches divided into many secondary rami and formed a mesh-like plexus by communicating with one another lateral to the zygomaticus major before they entered the target mimetic muscles.[14] The potential benefit of the nerve plexus is that it can enlarge the innervation spectrum and enhance the compensation ability of the buccal branches in the event of injury or cutoff (recipient nerve in facial reanimation operations). Clinical follow-up showed that there was no long-term secondary dysfunction even when one of these branches was injured in facial paralysis reanimation surgery, indicating that the buccal branch of the facial nerve is the most suitable recipient nerve.[14] Mylohyoid branches of the trigeminal nerve were chosen as the recipient nerve in three patients for early exploration. The patients cannot achieve smiling totally independently of a “trigger” such as mastication or clenching, although the dependency will diminish after a long period (at least 2 years) of neuromuscular training. Because of the better results of the buccal branch of facial nerve group, the superior or inferior branch of the buccal branch of the facial nerve was selected as the recipient nerve. Another finding using this technique was that the innervated nerve branch entered the abductor hallucis muscle 5.1 ± 0.5 cm from the origination and then divided into three intramuscular primary branches. One branch went back toward the origin to dominate the proximal one-third, and the other two branches went forward to dominate the distal two-thirds.[15] Thus, it is quite safe for the neurovascular pedicle when the proximal end of the muscle is split longitudinally into two tails at the length of 3 to 4 cm. Most of the muscle function remained intact except for the proximal one-third.

There are many types of facial grading systems. However, none of the facial nerve function grading systems has become the standard to date. Among them, the Toronto Facial Grading System[8–10] and the Facial Nerve Function Index[11] are more popular and objective. In our study, the mean Toronto Facial Grading System and Facial Nerve Function Index values were significantly higher at 2 years after the procedure in comparison with the preoperative status, and long-term outcomes were higher. Undoubtedly, the secondary revision operations would have added to the long-term results compared with that of 2 years. In a series of 27 free-muscle transfers with follow-up ranging from 2 to 15 years (mean, 8.5 years), Ylä-Kotola et al. stated that the longer the follow-up, the poorer the function of the free muscle.[16] However, in the current study, based on 18 years of clinical experience and our experimental studies,[17] we demonstrated that time is not a limitation to muscle function. Denervation and reinnervation of the free transplanted muscle are related to the recovery of muscle function.[17] The outcomes of our procedure were related to the age at which the patient underwent surgery and to massage and exercise of the transplanted muscle, and had no relation to the causes or duration of facial paralysis. Our analysis also showed that there was no difference between those in which superior rami of buccal branches of the facial nerve (n = 14) or inferior rami of buccal branches of the facial nerve (n = 24) were used. According to our anatomical research, there are several advantages to using the abductor hallucis muscle for facial reanimation, including the following[1]: (1) excursion nearly similar to that of the normal side of the face, (2) a reliable vascular and nerve pattern of similar size to that of the recipient, (3) no resulting functional deficit after removal of the muscle, and (4) location sufficiently distant from the face to allow for two operating teams to work simultaneously.

CONCLUSIONS

One-stage free transfer of the abductor hallucis muscle plus anastomosis of blood vessels and nerves is safe and effective for dynamic reanimation of longstanding unilateral facial paralysis. The types and rates of complications encountered are acceptable. The favorable long-term results demonstrate that our technique is an alternative method for facial reanimation.

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PATIENT CONSENT

Patients provided written consent for the use of their images.

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