The Distal Stump of the Intramuscular Motor Branch of the Obturator Nerve Is Useful for the Reconstruction of Long-Standing Facial Paralysis Using a Double-Powered Free Gracilis Muscle Flap Transfer

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Background: Double innervation of the transferred muscle with the contralateral facial nerve and the ipsilateral masseteric nerve has recently been reported by some authors. The aim of this study was to assess the utility of our procedure of double innervation of free gracilis muscle for reconstruction of long-standing facial palsy.
Patients and Methods: In our department, 6 cases of long-standing facial paralysis (4 cases of complete palsy and 2 of incomplete palsy) were reconstructed using a free gracilis muscle double innervated with the masseteric and contralateral facial nerves. The patient age ranged from 37 to 79 years (average 56.7 ± 15.7). In our procedure, the intramuscular motor branch of the transferred muscle was identified and sutured to the ipsilateral masseteric nerve in an end-to-end fashion, and the obturator nerve of the transferred muscle was sutured to the cross-facial nerve graft, which was coapted with the contralateral facial nerve by end-to-end suturing.
Results: All patients were followed up for >18 months and recovered their smiling function. The voluntary movement of the transferred muscle with teeth clenching was observed at approximately 4.7 months, and this movement combined with contralateral mouth angle elevation was observed at approximately 9.5 months after the surgery.
Conclusions: Our experience suggests that the distal stump of the intramuscular motor branch of the obturator nerve may be useful for facial reanimation via double-powered free gracilis muscle flap transfer.

Key Words: Double innervation, facial palsy, free gracilis muscle flap

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For long-standing facial paralysis, neural input to the mimetic muscle is not beneficial because of irreversible fibrosis and its degeneration. Reanimation is instead achieved by free muscle flap transfer, a common procedure for treating chronic paralysis lasting >12 months with either a congenital or developmental cause.[1–8] In facial reanimation using free gracilis muscle transfer with a cross-facial nerve graft (CFNG), 2-stage reconstruction is a popular procedure at present.[1–8] This procedure can achieve a coordinated and spontaneous smile after reconstruction.

However, we occasionally encounter some functional problems through this procedure. First, patients may not be able to smile on each side despite a synchronous bilateral smile being possible because reinnervation of the transferred muscle is dependent only on the healthy contralateral facial nerve. Second, contraction of the muscle may be insufficient, likely due to muscle atrophy caused by a lengthy denervation period and insufficiency of axonal ingrowth into the transferred muscle through the CFNG.[9]

To resolve these issues, a double-powered free latissimus dorsi muscle flap was first described by Watanabe et al in 2009.[9] Subsequently, the use of a double-powered free muscle transfer for facial reanimation in long-standing facial paralysis patients has been reported by several authors.[9–12]

At our department, a double-powered free gracilis muscle flap transfer was performed in 6 patients with long-standing facial paralysis. In our procedure, the proximal stump of the obturator nerve of the free gracilis flap and the distal stump of the intramuscular motor branches of the flap were used as the entrance of motor axons. Each nerve was coapted in an end-to-end fashion to the contralateral facial nerve through the CFNG and ipsilateral masseteric nerve. The purpose of this study was to assess the utility of our procedure.

MATERIALS AND METHODS

Patients

Between 2012 and 2014, 6 patients (3 males and 3 females) ranging from 37 to 79 years of age with long-standing unilateral facial paralysis received a free gracilis muscle transfer innervated by the masseteric nerve and contralateral facial nerve through a sural nerve graft (Table 1). Four patients had complete facial palsy, and 2 had incomplete palsy. The duration of palsy ranged from 12 months to 38 years.

Surgical Procedure

The affected cheek was widely undermined using the superficial musculoaponeurotic system through a preauricular incision, an upper lip incision on the affected side, and a small lower lip incision in the middle of the face. Through these 3 incisions, a subcutaneous pocket was made to insert the transferred muscle. The preauricular incision was extended from the preauricular region to 1 to 2 cm below the mandibular angle. Via this approach, the facial artery and vein were exposed and used as recipient vessels. The masseteric motor nerve was identified at the point of its surgical landmark. The landmark was identified

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TABLE 1. Patient Summary

No.	Age (y)	Sex	Affected Side	Palsy	Duration of Palsy
1	59	M	Right	Incomplete	38 y
2	79	M	Right	Complete	12 mo
3	48	F	Right	Complete	13 mo
4	47	F	Left	Complete	14 mo
5	70	M	Left	Complete	12 mo
6	37	F	Right	Incomplete	6 y

F, female; M, male.

within the area 2 cm below the zygomatic arch and 3 cm anterior from the tragus. The masseteric motor nerve commonly lies approximately 2 cm deep from the muscle surface at the landmark.[13] With gentle dissecting through the masseteric muscle along its vertical axis, its nerve was quickly identified.

On the healthy side of the face, the incision began before the tragus and extended to the mandibular angle. The skin flap was elevated to identify the buccal and zygomatic branch of the facial nerve. The nerve involved in smiling was identified with an electro-nerve stimulator. The subcutaneous tunnel was created with blunt dissection to make space for the CFNG insert. Before flap elevation, the distance from the anterior border of the zygomatic arch to the top of the cupid bow on the affected side was measured, and this became the long axis length of the muscle flap on the medial side. The distance from the posterior border of the zygomatic arch to the mouth angle was then measured, and this became the long axis length of the muscle flap on the lateral side. Each measurement was performed in the subcutaneous pocket.

The gracilis muscle flap was harvested from the medial thigh on the contralateral side and was designed to center the pedicle of the flap. The size of the flap was determined based on the subcutaneous measurement. The long axis length was set to be 1 to 2 cm longer than the length of the subcutaneous pocket in the recipient site, as previously described. The width of the proximal and distal ends was set to be equal to the distance from the mouth angle to the top of the ipsilateral cupid bow on the affected side and the length of the zygomatic arch, respectively. Based on our measurements, the flap was 3 to 4 cm in width and 8 to10 cm in length. During muscle separation at the distal end of the muscle flap, careful dissection was performed to locate the intramuscular motor branch of the flap. With gentle muscle fiber separation, this branch was easily identified, and approximately 3 cm of the length was dissected. This length allowed us to reach the masseteric nerve for nerve suture without any tension. The flap harvest was completed by cutting its pedicle and the obturator nerve, approximately 6 cm of which was included in the flap (Fig. 1A).

Approximately 10 cm of the sural nerve was harvested and then grafted across the face in a reverse manner. Thus, end-to-end epineural suturing was carried out between the obturator nerve and the CFNG, which was sutured to the contralateral facial nerve. In addition, another end-to-end epineural suture was made between the motor nerves inside the gracilis muscle body and masseter nerve on the affected side (Fig. 1B–C). In this procedure, we presumed that the gracilis muscle flap was innervated by the contralateral facial nerve through an interpositional sural nerve graft and the masseteric nerve. The distal end of the muscle flap was fixed to the zygomatic arch by suturing to the periosteum, and the proximal end of the flap was sutured to the orbicularis oris muscle at the upper lip. An additional muscle portion (1×3 cm) was inserted into the subcutaneous tunnel and sutured to the orbicularis oris muscle at the middle face of the lower lip.

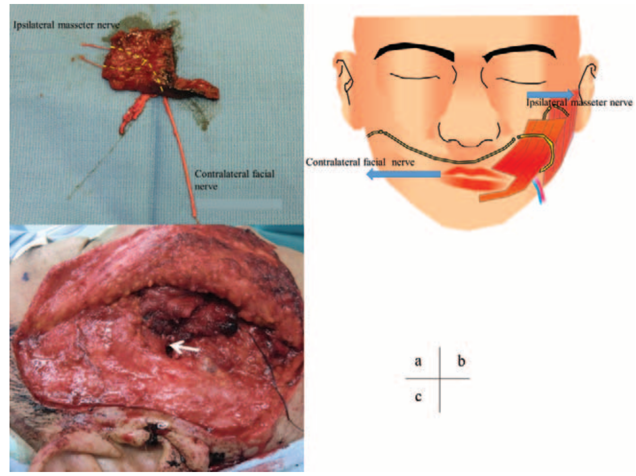

FIGURE 1. A, The gracilis muscle flap was harvested with the obturator nerve and several motor nerves inside the gracilis muscle body itself (white arrow). These nerves were carefully dissected and preserved at lengths of 2 to 3 cm. B, The schematic illustration of our procedure. The obturator nerve was sutured to the contralateral facial nerve through the nerve graft with an end-to-end suture. The motor nerve was sutured to the masseteric nerve with an end-to-end suture. C, During the operation, the motor nerve inside the muscle flap was sutured to the masseteric nerve in an end-to-end fashion (white arrow).

Postoperative Rehabilitation

Rehabilitation was started approximately 2 months after surgery with massaging of the affected cheek to release scar contracture. Biofeedback training using a mirror to provide visual feedback was then performed $\geq$3 times, as frequently as possible, on a daily basis, even if for a short duration. After contractions of the transferred muscle were observed, a greater emphasis was placed on smiling on each side. Smiling on the paralyzed side was initially possible only by voluntary biting; however, the patients continued to practice and eventually became able to smile spontaneously without intention to bite. For smiling on the healthy side, the patients practiced smiling at an intensity at which contraction of the transferred muscle was not noticeable.

Evaluation

Postoperative examinations were performed monthly after surgery. At the clinic, the patients were asked to clench their teeth to confirm voluntary smile movement by the masseter nerve. The patients were then asked to make a symmetric smile with elevation of the mouth angle bilaterally without clenching, to confirm movement of the transferred muscle by the contralateral facial nerve. The patients were further asked to make a symmetrical smile with elevation of the mouth angle bilaterally with teeth clenching to confirm the effect of double-powered movement of the transferred muscle by the ipsilateral masseteric nerve and contralateral facial nerve through the CFNG.

Electromyography of the transplanted muscle was performed to assess the innervation from the contralateral facial nerve through the CFNG after we observed movement of the transferred muscle by the contralateral facial nerve. Electrical stimulation of the contralateral facial nerve was set to the contralateral tragus and the contralateral upper lip, and the amplitude of the transferred muscle was measured on the affected side (Fig. 2 A–C).

The extent of mouth angle movement was measured 18 months after the operation. A photo editing software program (Photoshop; Adobe, USA) was used. The mouth angle at the resting position was indicated in blue, and the mouth angle when smiling or clenching

TABLE 2. Results of Our Cases

No.	Size of the Intramuscular Motor Branch of the Gracilis Muscle Flap (mm)	Size of the Muscle Flap (cm)	Period Until Movement of the Transplanted Muscle With the Masseter Nerve (mo)	Period Until Movement of the Transplanted Muscle With a Cross-Facial Nerve Graft (mo)	CMAP 18 mo After the Operation (Stimulated With the Contralateral Facial Nerve) (uV)	Ratio of Mouth Angle Movement With lenching (18 mo After the Operation) Pre OP→Post OP	Ratio of Mouth Angle Movement Combined With Contralateral Side (18 mo After the Operation) Pre OP→Post OP
1	1.0	4.0 × 8.5	6	10	241	0.52 → 0.95	0.52 → 0.94
2	0.9	3.0 × 8.5	5	9	287	0 → 0.71	0 → 0.61
3	1.0	3.5 × 9.5	5	9	102	0 → 0.92	0 → 0.83
4	1.1	4.0 × 10	5	10	223	0 → 1.05	0 → 0.91
5	1.0	4.0 × 10	6	12	23	0 → 1.01	0 → 0.52
6	1.1	3.5 × 8.0	4	10	235	0.32 → 1.10	0.32 → 1.0

teeth was indicated in yellow. The distance of mouth movement was then defined as that between the blue and yellow points on each side. A was defined as the distance between the blue and yellow points on the healthy side, whereas B was defined as the distance between the blue and yellow points on the affected side. The ratio of these points was the mouth angle movement, defined as B/A (Fig. 2D).

RESULTS

During flap elevation, 3 or more intramuscular motor branches of the muscle flap suitable in size for microsurgical coaptation were identified in all cases. The size of the motor branch was 0.9 to 1.1 mm. In all cases, the flap successfully survived (Table 2).

All patients were followed up for >1 year and recovered their smiling function. All patients were able to smile voluntarily and involuntarily and could also control their smile. The first voluntary movement of the mouth angle on the paralyzed side with teeth clenching was achieved at a mean of 4.7 months (range: 4–5 mo)

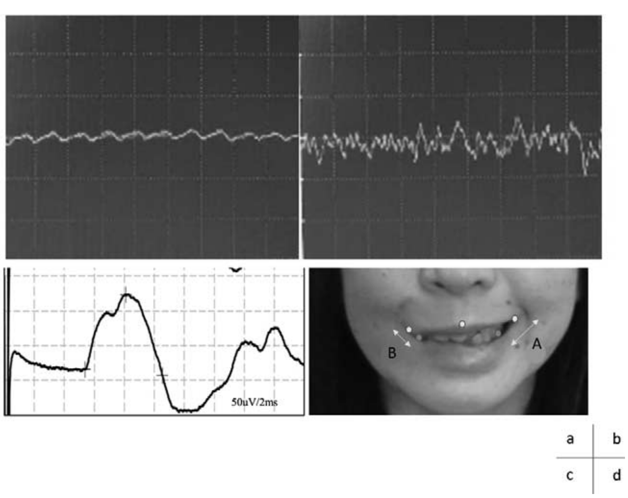

FIGURE 2. Electromyography 18 months after surgery in case 1. A high spike on electromyography could be seen with clenching in all patients. A, At the resting position. B, With clenching. C, Electromyography showed motor potentials during electrical stimulation of the contralateral facial nerve through a cross-facial nerve graft. D, The extent of mouth angle movement was measured 18 months after the operation. A photo editing software program (Photoshop; Adobe, USA) was used. The mouth angle at the resting position was indicated in blue, and the mouth angle when smiling or clenching teeth was indicated in yellow. The distance of mouth movement was then defined as that between the blue and yellow points on each side. A was defined as the distance between the blue and yellow points on the healthy side, whereas B was defined as the distance between the blue and yellow points on the affected side. The ratio of these points was the mouth angle movement, defined as B/A.

after surgery, and synchronous movement of the mouth angle on the healthy side was achieved within a mean of 9.5 months (range: 9–10 mo) after surgery (Table 2).

Electromyography showed the motor potentials during electrical stimulation of the contralateral facial nerve through the CFNG (Table 2). Furthermore, a high spike on electromyography was observed with clenching in all patients (Fig. 2 A–C). All patients were able to control the strength of their smile with or without clenching their teeth and were able to move their mouth angle only on the affected side with clenching. The ratio of the mouth angle movement with clenching was 0.96 ± 0.14, and the ratio of the mouth angle movement through the CFNG was 0.80 ± 1.93.

Representative Patients

Patient 1

A 59-year-old male presented with incomplete facial palsy on the right side of his face in 2011 (Fig. 3A–B). The time of onset of palsy was unknown; however, he had suffered from facial palsy for 38 years. In the resting position, his face looked symmetric, but he could not make a symmetric smile due to incomplete palsy. The patient underwent surgery in 2011. The free gracilis muscle was obtained from his left thigh and transferred to the right side of his face. The artery of the flap was anastomosed with the facial artery in an end-to-end fashion, and the vein of the flap was anastomosed to the facial vein in an end-to-end fashion. The obturator nerve was sutured to the nerve graft, which opposed the side sutured to the buccal branch of the left facial nerve. Furthermore, the motor nerve inside the muscle flap was sutured to the masseteric nerve in an end-to-end fashion (Fig. 1C). All procedures were performed in 1 stage. The flap completely survived. Six months after the operation, the muscle flap began to move when he clinched his teeth. At 10 months after the operation, the flap started to move synchronously with contralateral face movement (Fig. 4 A–D). At 18 months after the

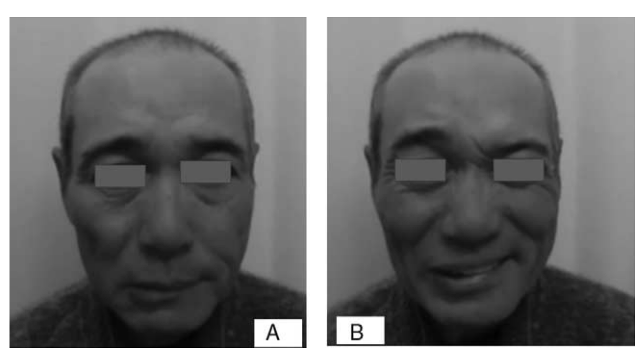

FIGURE 3. A, Preoperative view at rest. B, Preoperative view with smiling.

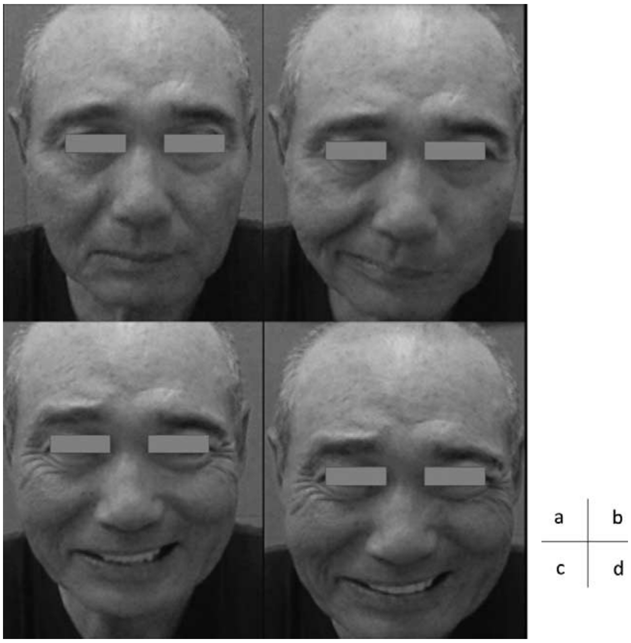

FIGURE 4. A, Postoperative view at rest. B, Postoperative view with clenching alone. The patient can move only the affected side with clenching. C, Postoperative view with smiling alone. D, Postoperative view with smiling combined with clenching.

operation, electromyography was performed, which revealed that the muscle flap was innervated with the contralateral facial nerve and ipsilateral masseteric nerve (Fig. 2 A–C). The patient was satisfied with the result.

Patient 2

A 47-year-old female presented with complete facial palsy on the left side of her face in 2014 (Fig. 5A–B) after undergoing brain tumor resection. The operation procedure was similar to that performed for the other cases. Voluntary mouth movement on the paralyzed side was observed with clenching 5 months after the operation, and synchronous mouth movement with the healthy side was seen 10 months after the operation (Fig. 6A–D). Electromyography of the muscle flap showed that it was stimulated by the masseter and evoked the potential of the CFNG, indicating that the facial nerve of the unaffected side remained functional.

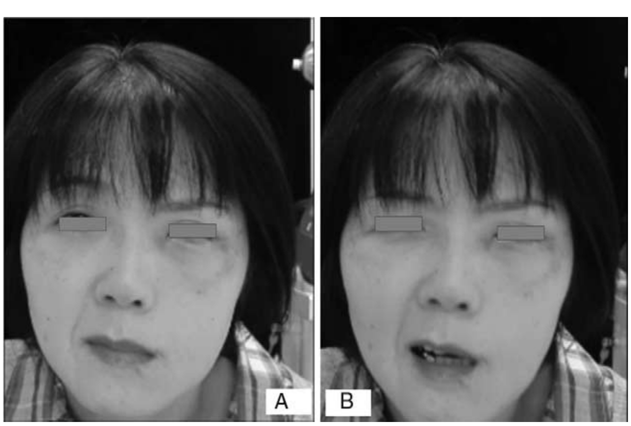

FIGURE 5. A, Preoperative view at rest. B, Preoperative view with smiling.

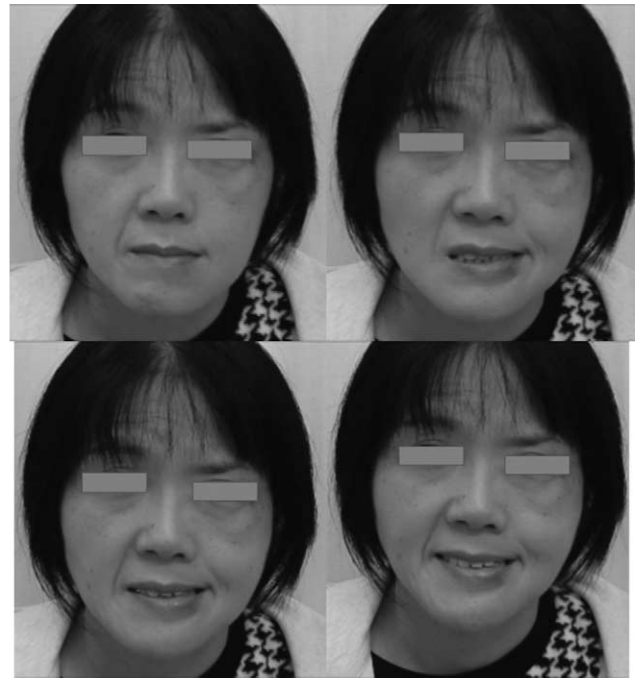

FIGURE 6. A, Postoperative view at rest. B, Postoperative view with clenching alone. The patient can move only the affected side with clenching. C, Postoperative view with smiling alone. D, Postoperative view with smiling combined with clenching.

DISCUSSION

In 1976, Harii et al[15] reported the first case of free gracilis muscle transfer for reconstruction surgery due to facial palsy. In this report, the muscle flap was innervated with the masseter nerve. In 1980 to 1984, O'Brien et al[1] and Vedung et al[2] achieved the correct stimulus by anastomosing the sural nerve on the contralateral facial nerve. In these reports, the muscle flap was innervated by the contralateral facial nerve through the sural nerve graft. Through this procedure, patients were able to achieve a natural and spontaneous smile synchronized with contralateral facial movement. After these reports, the procedure began to enjoy widespread use, and it is currently recognized as an effective method of reconstructing a natural smile.[1–8]

In 1998, Harii et al reported 1-stage reconstruction of facial palsy using a free latissimus dorsi muscle flap transfer.[16] In this procedure, a long thoracodorsal nerve is sutured to the contralateral facial nerve in an end-to-end fashion, and the treatment period is shorter than that of 2-staged procedures.[17] However, we occasionally encounter some functional problems using this procedure. First, patients may not be able to smile on each side, although a synchronous bilateral smile is possible because reinnervation of the transferred muscle is dependent only on the healthy contralateral facial nerve. Second, muscle contraction is occasionally insufficient, likely due to muscle atrophy associated with the denervation period and insufficient axonal ingrowth into the transferred muscle through the CFNG.[13,14] To overcome these issues, double innervation of the gracilis muscle was reported by several groups since 2009.[9–12,18] In the present study, we applied a new technique of double innervation using the free gracilis muscle with the contralateral facial nerve and ipsilateral masseteric nerve.

The double innervation technique using a free muscle flap for facial palsy reconstruction was first reported by Watanabe et al in 2009.[9] The authors reported the advantages of dual innervation, which enabled faster reinnervation of the transferred muscle, both a spontaneous and voluntary smile and emotional facial expression without biting and less synkinesis of the transferred muscle after rehabilitation. In their procedure, the transplanted muscle was innervated with the masseteric nerve through muscular neurotization and the contralateral facial nerve through an end-to-end suture with the thoracodorsal nerve.

In 2012, Biglioli et al[10] reported another method for double innervation. Although Watanabe et al[9] reported that additional innervation was dependent on muscular neurotization, Biglioli et al[10] reported that additional innervation was dependent on end-to-side anastomosis between the CFNG and the obturator nerve. Therefore, the proximal end of the obturator nerve was sutured to the masseteric nerve with an end-to-end suture. In 2014, Cardenas et al[11] reported another method. In their procedure, additional innervation was dependent on end-to-side anastomosis between the masseteric nerve and the obturator nerve. The proximal end of the obturator nerve was therefore sutured to the contralateral facial nerve through the nerve graft.

In the aforementioned procedures,[9–11] the second innervation was dependent on an end-to-side suture. From our experience, however, the extent of innervation with this technique is difficult to compare with that achieved with end-to-end anastomosis. Okazaki et al.[12] reported double-innervation techniques in which double innervation was achieved with an end-to-end suture. In our method, we were unable to achieve double innervation with end-to-end anastomosis.

One unique detail of our procedure is that additional innervation from the masseteric nerve was achieved with an end-to-end suture in a retrograde fashion at the distal stump of the intramuscular branches of the obturator nerve. To our knowledge, no previous reports have described innervation of the muscle flap using the distal stump of the motor nerve inside the muscle.

In all of our cases, movement of the transferred muscle could be seen with clenching approximately 4 to 6 months, and synchronous movement on the contralateral side could be seen approximately 10 to 12 months. This difference in timing might correlate with the length from the motor source to the muscle. The distal end of the motor nerve was approximately 3 cm in length, and it was sutured to the masseter nerve. In contrast, the obturator nerve was approximately 6 cm in length and was sutured to the branch of the contralateral facial nerve through the CFNG.

It is difficult to compare cases in which the transplanted muscle was innervated only with the masseter nerve or a contralateral facial nerve graft to those with double innervation due to the low number of such cases of single innervation. However, our results of double innervation showed that the extent of movement with the transplanted muscle was 0.96 ± 0.14, and the ratio of the mouth angle movement through the CFNG was 0.80 ± 1.93, which seemed a similar extent to these cases that was innervated with only 1 nerve. In cases in which the muscle was innervated with the masseter nerve, the extent of movement became large, but it is difficult to do in spontaneously. In contrast, in cases in which the muscle was innervated with the contralateral facial nerve through the CFNG, the extent of movement was occasionally small. In case 3 in Table 2, the movement of the mouth angle was almost half of that on the healthy side (0.52). However, the movement became strong combined with clenching (ratio: 1.01). The lack of movement from the CFNG may be covered with masseter nerve stimulation.

Therefore, the advantages of our procedure are as follows: the movement of the transplanted muscle can be seen within 4 to 6 months; both voluntary and spontaneous movement reconstruction can be achieved; the patient can control the extent of movement of the mouth angle on the affected side; and the patient can move the affected side separately from the healthy side by clenching their teeth. With these advantages, patients can achieve greater variety of facial movement.

We believe that the contralateral facial nerve might help patients move the transferred muscle spontaneously, and the masseter nerve might help patients move the muscle strongly. To enhance these effects, rehabilitation using mirror feedback is important to help patients make a horizontal cortical pathway between the V and VII cranial nerve motor centers.[18]

In our cases, double innervation was confirmed by electromyography analyses. However, the mechanism underlying double innervation of the transplanted muscle remains unclear. In our series, the extent of compound muscle action potential with stimulation of the facial nerve on the healthy side varied widely among the patients. This variation may be due to technical issues of nerve grafting. Therefore, the mechanism underlying double innervation of the transplanted muscle should be further investigated using experimental animal models.

In conclusion, successful double innervation was achieved using our procedure. Our novel technique involves the intramuscular motor branch of a gracilis muscle flap as a second motor source and may help expand the variety of muscle movements achievable with transferred muscles.

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