Masseter-to-Facial Nerve Transfer

A Highly Effective Technique for Facial Reanimation After Acoustic Neuroma Resection

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Background: Masseter-to-facial nerve transfer is a new procedure for patients who acquire a proximal injury to the facial nerve. This article reports that this procedure is effective and associated with minimal morbidities.

Methods: From November 2010 to February 2013, 16 patients underwent a masseter-to-facial nerve transfer. Their denervation periods varied from 2 to 18 months, with an average of 10.1 ± 4.1 months. Their ages varied from 22 to 70 years, with an average of 34.7 ± 15.4 years. The etiology of denervation was tumor resection in the cerebellopontine angle in all cases. All of the patients were followed up several times. The outcomes of the first follow-up at 3 months postoperatively and the last follow-up at a minimum 12 months postoperatively were documented. Using Terzis' and Metha's scales, the smile outcomes and synkinetic movements as visualized using standardized videos were graded preoperatively and postoperatively. The periods between the operation and the onset of mimetic muscle contraction were documented. A questionnaire was administered to evaluate the donor-site morbidity and the ability to smile without biting.

Results: The final outcomes for smile function were as follows: 9 patients (56.3%) had excellent or good function, 5 patients (31.3%) had moderate function, and 2 patients (12.5%) had poor function. There was significant improvement between the preoperative and postoperative time points and between the outcomes at the first and last follow-ups ($P < 0.05$). Additionally, 13 (81.3%) patients had the ability to smile without biting 12 months postoperatively. The onset of muscle motion varied from 56 to 365 days and was positively correlated with age in the group of patients older than 40 years and negatively correlated with the outcome of the first follow-up. Four (25%) patients complained of concavity at the parotideomasseteric region, but none complained of disturbance in food intake. Synkinetic movements were observed in all patients and were rated as mild.

Conclusions: The masseter-facial nerve transfer effectively reanimated the paralytic muscle in patients who acquired an intracranial facial nerve injury with minimal deficits at the donor site. After continued physical therapy, some patients were able to regain a symmetrical and effortless smile with mild synkinetic movements.

Key Words: facial nerve, nerve transfer, masseter nerve, acoustic neuroma

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After the introduction of the operating microscope and intraoperative electrophysiological monitoring, the rates of facial nerve (FN) anatomic preservation have improved quickly and are now greater than 90%.[1–3] However, functional deficits still occur, causing severe psychological and aesthetic problems for the patient.[4,5] Rivas (2011) reported that 12% of 281 patients did not have a good recovery and exhibited postoperative facial palsy.[6]

If a patient does not experience spontaneous recovery, timely facial nerve reconstruction is important for him to ensure positive outcomes.[7] However, such reconstruction is difficult for patients with an acquired injury at the level of the cerebellopontine angle and internal auditory canal because reinnervating the paretic muscle from the normal side using the cross-facial nerve grafting (CFNG) technique takes a long time, and this technique is only suitable for paralyzed patients who experienced denervation within the previous 5 months. Otherwise, another cranial nerve transfer is a viable option.[8] Partial hypoglossal nerve transfer with a nerve graft has become a widely used technique during the past 30 years.[9] However, the consequences include hemiglossal atrophy, which impairs effective communication and food intake,[10,11] and uncertain outcomes resulting from partial motor source input and nerve grafting that reduces the number of axons innervating the paretic muscles.[10] To reduce these morbidities, a new technique using the descending branch of the masseter nerve for neurotization of the distal of facial nerve has recently been reported.[12–14] We present this technique to document its high effectiveness and show not only that the paretic mimetic muscle regains powerful contraction in patients undergoing early repair but also that a symmetrical smile is reestablished in patients denervated longer than 12 months.

PATIENTS AND METHODS

From November 2010 to February 2013, masseter-to-facial nerve transfers were performed and followed up for a minimum of 12 months postoperatively in 16 patients, including 3 males and 13 females. Their ages at the time of the nerve transfer varied from 22 to 70 years, with an average age of 34.7 ± 15.4 years. Their etiology of denervation was tumor resection in the cerebellopontine angle in all cases. The denervation period before the masseter nerve transfers ranged from 2 to 18 months, with an average of 10.1 ± 4.1 months (Table 1). The patient selection criterion was acquisition of a proximal injury to the facial nerve within 2 years after tumor resection. In our series, except for patient 1, whose facial nerve was resected during tumor removal, the patients had a minimum 6-month delay after the facial nerve injury to avoid disturbing spontaneous recovery and were confirmed to have complete facial palsy before the reconstructive surgery.

The same surgeon (W.W.) performed all of the procedures, which involved transfer of the descending branch of the masseter nerve to the distal branch of the facial nerve to innervate the paretic mimetic muscle. All patients started intensive biofeedback physical training in front of a mirror 5 weeks postoperatively. A detailed description of these techniques is presented in previous publications.[15]

TABLE 1. Patient Demographics

Case	Gender	Age, yr	Period of Denervation, mo[a]	Etiology	Side	Grade
1	F	27	2	Acoustic neuroma	Left	Complete
2	M	41	6	Acoustic neuroma	Left	Complete
3	F	22	11	Epithelioma of the fourth ventricle	Right	Complete
4	F	27	15	Acoustic neuroma	Left	Complete
5	F	25	10	Meningioma	Left	Complete
6	F	24	11	Acoustic neuroma	Left	Complete
7	M	70	10	Acoustic neuroma	Left	Complete
8	M	22	7	Acoustic neuroma	Left	Complete
9	F	66	7	Acoustic neuroma	Left	Complete
10	F	23	13	Acoustic neuroma	Left	Complete
11	F	33	8	Acoustic neuroma	Left	Complete
12	F	48	6	Acoustic neuroma	Right	Complete
13	F	46	15	Acoustic neuroma	Right	Complete
14	F	22	11	Acoustic neuroma	Right	Complete
15	F	28	12	Acoustic neuroma	Right	Complete
16	F	31	18	Acoustic neuroma	Left	Complete
Mean		34.7 ± 15.4	10.1 ± 4.1			

[a]Period between the onset of paralysis and reconstructive surgery.

Using Terzis' smile functional evaluation scale,[16] smile outcomes were evaluated preoperatively and postoperatively (Table 2) by video recordings. Using Mehta's synkinesis evaluation scale,[17] the extent of synkinetic movements was evaluated (Table 2). Two types of synkinetic movements were documented: synkinesis 1, chewing with unwanted oral commissure elevation; and synkinesis 2, smiling with unwanted eye closing. Using needle electromyography, the function of the mimetic muscles was assessed preoperatively and postoperatively.

After the reconstruction, each patient was asked to inform the physician when he or she achieved the first lip contraction with biting on the affected side, and the period between the day of the operation and the first contraction was documented (days of muscle motion onset). The follow-up period varied from 3 to 16 months after the surgery. All patients were followed up several times. The first follow-up was performed approximately 1 month after the onset of muscle motion, and the last was performed at a minimum of 12 months postoperatively; the results of both follow-ups were documented for this study and are referred to as outcome 1 and 2, respectively (Table 3). Functional improvement 1 and 2 were obtained from the differences between the preoperative evaluation and mean postoperative outcome 1 and 2, respectively. A questionnaire was administered to evaluate donor-site morbidity, including masticatory function, masseter atrophy (mild to severe), and whether the patient had the ability to smile without biting (ie, whether the patient had more natural emotional expression).

The Wilcoxon signed-rank test was used to compare the mean scores for the preoperative and postoperative smile functions and for the first (improvement 1) and last improvement (improvement 2) in smile function. The patients were divided into 3 groups based on period of denervation: group 1, ≤6 months; group 2, >6 months and ≤12 months; and group 3, >12 months and ≤24 months. The Kruskal-Wallis test was used to compare the clinical outcomes among the 3 denervation period groups. A multiple regression test was performed to confirm the correlation between age, period of denervation, and days to onset of muscle motion after the operation and improvement in smile function. A quadratic regression test was performed to confirm the correlation between age, period of denervation, and days to onset of muscle motion. A linear regression test was performed to confirm the correlation between improvement 1 and 2. Summary statistics for variables, including categorical variable frequency counts and continuous variables, were presented using the mean and SD, except for the days of muscle onset motion, which was presented using the median (p25, p75) because one value (365 days postoperatively) deviated significantly from the other values. Stata version 10.0 (StataCorp, College Station, TX, USA) was used for the regression tests, and SPSS version 13.0 (SPSS, Inc., Chicago, IL, USA) was used for the other statistical analyses. The results of the statistical tests were considered significant at a level of 0.05.

RESULTS

Sixteen patients were included in this study. The first onset of muscle motion ranged from 56 to 365 days postoperatively, with a median of 87 (74, 92) days postoperatively. All patients had restored smile function with biting (Figs. 1–9). Based on Terzis' smile

TABLE 2. Terzis' Smile Function Evaluation Scale and Mehta's Synkinesis Evaluation Scale

Grade	Description of Terzis' Smile Functional Evaluation Scale	Description of Mehta's Synkinesis Evaluation Scale
5	Symmetrical smile with teeth showing, full contraction	All of the time or severely
4	Symmetry, nearly full contraction	Most of the time or moderately
3	Moderate symmetry, moderate contraction, mass movement	Sometimes or mildly
2	No symmetry, bulk, minimal contraction	Occasionally or very mildly
1	Deformity, no contraction	Seldom or not at all

TABLE 3. Outcomes of Reconstructive Surgery

Case	Onset of Motion, d[a]	Smile Preop	Outcome 1 Postoperative (The Time of First Follow-Up)	Outcome 2 Postoperative (The Time of Last Follow-Up)	Improvement 1 of Smile[b]	Improvement 2 of Smile[c]	Smile Without Biting	Synkinesis 1[d]	Synkinesis 2[e]	Moderate Degree of Masseter Atrophy
1	90	1	3	5	2	4	1	2	3	0
2	80	1	5	5	4	4	1	2	1	1
3	102	1	2	3	1	2	0	3	1	0
4	90	1	4	4	3	3	1	3	2	1
5	96	1	2	3	1	2	1	2	2	1
6	74	1	3	5	2	4	1	2	1	0
7	365	1	1	2	0	1	0	2	1	0
8	59	1	4	5	3	4	1	2	2	0
9	130	1	4	4	3	3	1	2	1	1
10	59	1	3	3	2	2	1	2	2	0
11	80	1	3	3	2	2	1	3	2	0
12	92	1	2	2	1	1	0	2	1	0
13	85	1	3	3	2	2	1	2	2	0
14	87	1	4	4	3	3	1	3	2	0
15	56	1	5	5	4	4	1	3	2	0
16	92	1	3	4	2	3	1	3	3	0
Median	87 (74,92)									
Mean		1 ± 0	3.2 ± 1.1	3.8 ± 1.1	2.2 ± 1.1	2.8 ± 1.1				
P			$0.001 < 0.05$[f]	$0.0 < 0.05$[g]		0.014[h]				

[a]Onset of motion indicates the period between the reconstructive surgery and the onset of mimetic muscle contraction.
[b]Functional improvement 1 was obtained from the difference between the mean outcome 1 postoperative and preoperative evaluations.
[c]Functional improvement 2 was obtained from the difference between the mean outcome 2 postoperative and preoperative evaluations.
[d]Synkinesis 1: chewing with unwanted oral commissure movement.
[e]Synkinesis 2: smile with unwanted eye closure.
[f]Using nonparametric tests, a significant difference was found between the pre- and postoperative smile functional evaluations at the first follow-up.
[g]Using nonparametric tests, a significant difference was found between the pre- and postoperative smile functional evaluations at the last follow-up.
[h]Using nonparametric tests, a significant difference was found between the improvements in the smile functional evaluations at the first and last follow-ups.

functional evaluation scale, the mean postoperative score was 3.2 ± 1.1 (outcome 1) at the first follow-up and 3.8 ± 1.1 (outcome 2) at the last follow-up, compared with 1.0 ± 0 in the preoperative evaluation. The improvements in smile function were 2.2 ± 1.1 (improvement 1) at the first follow-up and 2.8 ± 1.1 (improvement 2) at the last follow-up (Table 3). After a minimum 12 postoperative months, the smile function outcomes were as follows: 5 (31.3%) patients were evaluated as grade 5, indicating excellent results with teeth exposure equal to that on the normal side; 4 (25%) were grade 4, indicating good results with reduced teeth exposure on the affected side compared to the normal side; 5 (31.3%) were grade 3, indicating fair results with no teeth showing in the smile; and 2 (12.5%) were grade 2, indicating poor results with minimal oral commissure movement during the

FIGURE 1. A 25-year-old female patient with complete facial palsy 10 months after left acoustic neuroma resection. Her preoperative smile function was classified as grade 1.

FIGURE 2. Smile with biting, classified as grade 2, at the first follow-up 4 months postoperatively.

FIGURE 3. Without biting, this patient did not achieve commissure movement at the first follow-up 4 months postoperatively.

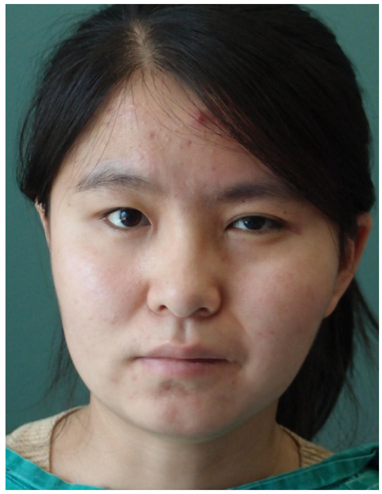

FIGURE 5. Smile without biting, classified as grade 3, at the last follow-up 18 months postoperatively.

smile. In addition, 13 of the 16 (81.3%) patients had the ability to smile without biting at 12 months postoperatively after physical biofeedback training in front of a mirror. The extent of synkinetic movement is presented in Table 3 (Fig. 5). Four of the patients (25%) complained about moderate degree of masseter atrophy and required further revision (Table 3, Fig. 6). In all patients, mastication on the affected side was slightly weaker than that on the normal side, but this difference did not disrupt normal food intake.

The results of the Wilcoxon signed-rank test indicated that there was a significant difference between the mean scores for the preoperative and postoperative smile functions and between the first and last improvement in smile function (Table 3). There was no difference in the mean improvement in smile function and the mean days to the onset of muscle motion among the 3 different denervation period groups (Table 4). The multiple regression test confirmed a positive correlation between the days to the onset of muscle motion and age greater than 40 years ($P = 0.001$) (Fig. 10). Moreover, there was no significant difference in days to the onset of muscle motion between the group of patients older than 40 years (150.4 ± 121.6 days) and the group of patients younger (80.5 ± 16.2 days) than 40 years, according to the results of the independent t test ($P = 0.27 > 0.05$). There was a negative correlation ($P = 0.03 < 0.05$) between days to the onset of muscle motion and improvement in smile function at the first follow-up (improvement 1). No correlation was found between days to the onset of muscle motion and improvement in smile function at the last follow-up (improvement 2), although there was a positive correlation ($P = 0.00 < 0.05$) between improvement in smile function at the first follow-up (improvement 1) and that at the last follow-up (improvement 2). Improvement in smile function was not correlated with patient age ($P > 0.05$). No correlation was found between period of denervation and days to the onset of muscle motion or improvement in smile function at the first or last follow-ups ($P > 0.05$).

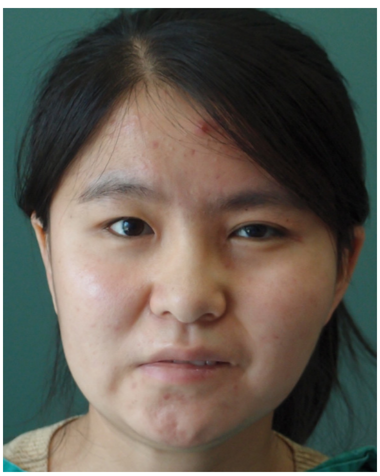

FIGURE 4. Smile with biting, classified as grade 3, at the last follow-up 18 months postoperatively with mild eyelid synkinetic movement, classified as grade 2.

DISCUSSION

The possibility of functional recovery of a denervated mimetic muscle deteriorates as the time of muscle denervation increases.[18] In general, the therapeutic window for a patient who undergoes a CFNG procedure is less than 5 months.[8] Otherwise, the patient will inevitably have a poor recovery due to several factors. First, the long time required for axon regeneration from the healthy contralateral side into the affected side results in chronic denervation in the paretic

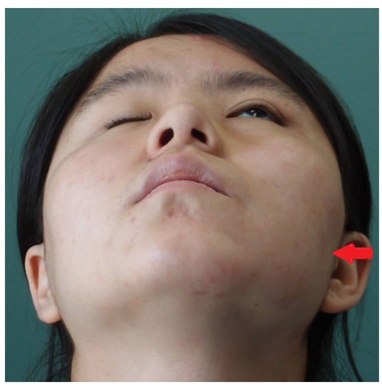

FIGURE 6. This patient complained of concavity at the left parotideomasseteric region (*red arrows*), indicating moderate degree of masseter atrophy.

FIGURE 7. A 31-year-old female patient with complete facial palsy 18 months after left acoustic neuroma resection. Her preoperative smile function was classified as grade 1.

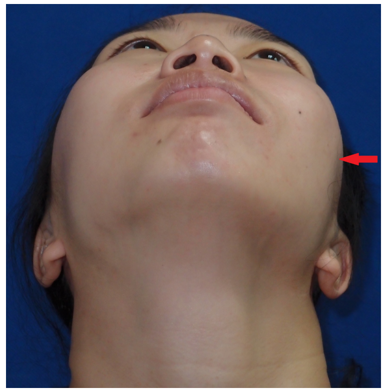

FIGURE 9. Mild atrophy of the masseter muscle and no concavity at the left parotideomasseteric region (*red arrow*).

muscle and therefore poor functional recovery resulting from exhaustion of the satellite cells, which primarily respond to muscle regeneration.[19–21] Furthermore, chronically denervated Schwann cells (SCs) at the distal facial nerve stump eventually stop expressing multiple neural regeneration-associated proteins, which inhibits axon regeneration.[22,23] Second, few motor axons innervate the target muscle because the number of axons from the limited donor motor source is markedly "dropped off" after "traveling" of the long nerve graft and 2 nerve coaptation sites, which causes insufficient innervation and poor functional recovery of the mimetic muscle.[24–29] A histologic study documented that the buccal branch of the facial nerve had 834 ± 285 axons and that after passing the coaptation site, the number of axons at the distal site of the cross-facial nerve graft decreased by 100 to 200, which is insufficient to restore mimetic muscle function.[30]

However, the therapeutic window is widened by crossover nerve transfer. For example, masseter-to-facial nerve transfer is a new and effective procedure that extends the period of reinnervation of the paralytic mimetic muscle compared to cross-facial nerve grafting. Biglioli and Klebuc presented 2 series of patients who underwent masseter nerve transfer for facial nerve functional restoration in 2011.[31,32] In these 2 independent groups, the longest periods of denervation were 48 and 23 months and both groups of patients had good functional recovery, even though the periods of denervation were much longer than the 5-month limit for CFNG alone. In our series, the patient with the 18-month denervation period had good recovery after 12 postoperative months, which was in agreement with previous findings (Figs. 7–9).[31,32]

This procedure not only widened the therapeutic window but also produced stronger muscle contractions compared with the CFNG procedure alone. Bae compared 2 groups of patients with commissure excursion who underwent either free muscle transplantation for facial reanimation using a cross-facial nerve graft versus the motor nerve to the masseter nerve. He found that oral excursion in the masseter group was much higher than that in the CFNG group, reaching almost the same level as the normal side.[33] In our series, 9 of the 16 patients (56.3%) were grade 4 or 5 at 12 months

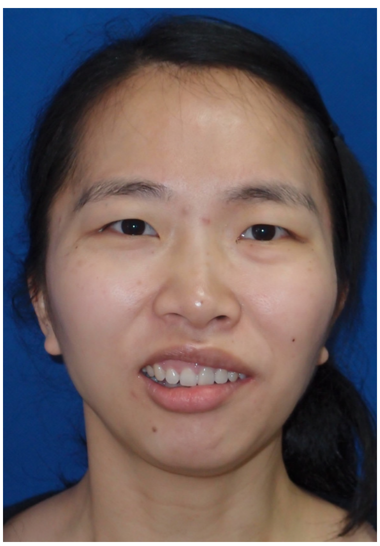

FIGURE 8. Smile without biting, classified as grade 4, at 13 months postoperatively.

TABLE 4. Comparisons Between the Different Groups of Denervation Periods and the Functional Results

Period of Denervation, mo[c]	Case	Improvement 1[a] Mean ± SD	Improvement 2[b] Mean ± SD	Onset of Muscle Motion, d Mean ± SD
G1 ≤ 6 M	3	2.3 ± 1.5	3 ± 1.7	87.3 ± 6.4
6 M < G2 ≤ 12 M	9	2.1 ± 1.3	2.8 ± 1.1	116.6 ± 95.9
12 M < G3 ≤ 24 M	4	2.3 ± 0.5	2.5 ± 0.6	81.5 ± 15.3
Total	16	2.2 ± 1.1	2.8 ± 1.1	102.3 ± 72.4
		0.66 > 0.05[d]	0.17 > 0.05[e]	0.70 > 0.05[f]

[a]Functional improvement 1 was obtained from the difference between the mean outcome 1 of the postoperative and preoperative evaluations.

[b]Functional improvement 2 was obtained from the difference between the mean outcome 2 of the postoperative and preoperative evaluations.

[c]Period between the onset of paralysis and reconstructive surgery.

[d]Using nonparametric tests, no significant difference was found for smile functional improvement at the first follow-up among the different denervation period groups.

[e]Using nonparametric tests, no significant difference was found for smile functional improvement at the last follow-up among the different denervation period groups.

[f]Using ANOVA, no significant difference was found for days to the onset of muscle motion among the different denervation period groups.

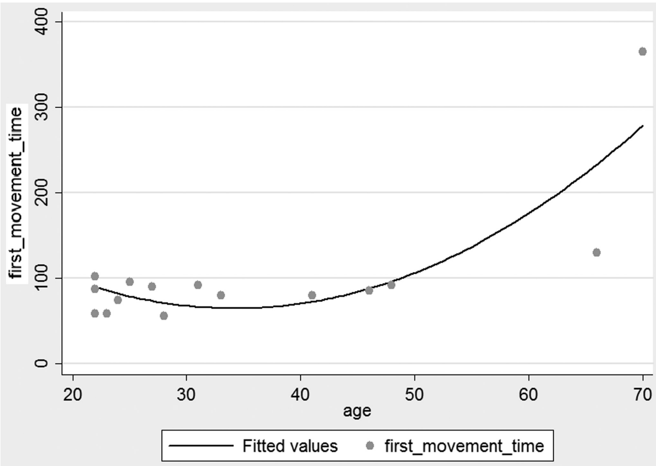

FIGURE 10. The *x* axis represents the patient's age, and the *y* axis represents the day to the onset of muscle motion. By establishing a quadratic regression with age, it was determined that the age cut-off was 40 years.

postoperatively, indicating that the excursion produced by the mimetic muscle innervated by the masseter nerve was of almost the same magnitude as that on the normal side.

These good results can be attributed to several factors: high axon counts, direct nerve coaptation, and a freshly cut masseter nerve stump. Coombs counted 1,542 ± 291.7[14] masseter nerve axons, which was much higher than the number of axons in the buccal branch (834 ± 285).[30] Furthermore, in the absence of a nerve graft, the masseter nerve directly connects with the distal region of the facial nerve, which reduces the number of axons that "drop off" after passing the nerve coaptation site and shortens the time of muscle denervation. In our series, the days to onset of muscle movement after the operation was 87 (74, 92), which was much shorter compared with the period (5.5 ± 1.2 months) reported for Terzis' patients, who underwent a free muscle transfer following a second-stage operation.[34] Moreover, Rueger reported that freshly sectioned uncompromised hypoglossal axons reactivated the "sleeping" denervated Schwann cells at the distal facial nerve stump by direct end-to-end coaptation,[22] which is analogous to the situation involved in masseter-to-facial nerve coaptation. A freshly cut masseter nerve stump might produce multiple proteins to promote axon regeneration and denervated muscle reinnervation. Therefore, high numbers of masseter axons, direct coaptation with the facial nerve, and a favorable nerve regeneration environment produced by a fresh masseter nerve section enhance the capability of the masseter nerve to innervate the paretic mimetic muscle.

In our study, the functional recoveries of the patients were not correlated with their period of denervation, which could be explained by the theory of sensory nerve protection and possible continuity of the facial nerve. Some studies have reported that a connection between a sensory nerve and the distal region of a motor nerve could alleviate muscle denervation.[35–37] There are many connections between the sensory branches of the fifth cranial nerve and the facial nerve.[38,39] Hence, a sensory nerve, such as the infraorbital nerve, innervates the paretic mimetic muscle through its communicating branches. Moreover, in a previous study, the rate of anatomic preservation of the facial nerve was greater than 90% following the removal of an acoustic neuroma.[1] Although the patients had a poor functional recovery, the few continuous axons remaining in the facial nerve were able to prevent atrophy of the paretic mimetic more than could a nerve with a completely sectioned injury at the extremity.

Some studies have shown that the ability of nerves to regeneration is likely to be poor if the patient is older than 60 years.[40] In our primary study, a correlation between age and days to the onset of muscle motion was confirmed: patients older than 40 years were likely to begin smiling later. In our 16 cases, the oldest patient (70 years old) had the longest time (365 days) to the onset of muscle motion after the operation and the poorest functional recovery (grade 2). However, a significant difference in improvement in smile function was not found between patients older and younger than 40 years, though such a difference might have been found with a higher number of cases. In our series, days to the onset of muscle motion was negatively correlated with improvement at the first follow-up (improvement 1), indicating that the earlier the patient began to experience muscle contraction, the better the functional recovery would be at the first follow-up, which was attributed to potential for nerve regeneration. However, days to the onset of muscle motion was not correlated with improvement at the last follow-up, though it might have been in a larger patient cohort.

Physical biofeedback training has been found to improve functional recovery in many studies.[41,42] In our study, patients had better functional recovery at the last follow-up than at the first follow-up ($P = 0.01 < 0.05$) (Figs. 1–6). Furthermore, improvement 1 positively influenced improvement 2 ($P = 0.00 < 0.05$), indicating that the better the outcome was at the beginning of the recovery period, the better the outcome was at 12 months postoperatively. Moreover, 13 of the 16 patients (81.3%) could smile without biting at 12 months postoperatively (Fig. 5), which is higher than the number of patients in Manktelow's study (59%).[43] This high recovery rate could be attributed to central cortical adaption from the "mastication center" to the "facial movement center" and to peripheral nerve connectedness between the trigeminal and facial nerves. Central cortical adaption has been observed in brachial plexus-injured patients whose biceps function was reestablished by the transfer of intercostal nerves to the musculocutaneous nerve. After reinnervation, the patients were first asked to flex their elbow while taking a deep breath. Eventually, they were able to move their arms independently of respiration. It is thought that the inactive connections between these different centers were activated by continuing physical training and that one center later took over control of the other. Transcranial magnetic stimulation and functional magnetic resonance imaging showed that this was indeed the case.[44] Although the interaction between the "mastication center" and "facial movement center" is considered to be similar, it cannot be confirmed that the shift in the control proceeds via the same mechanism because these 2 centers are too close in proximity to influence each other.[45]

Peripheral nerve connectedness between the fifth and seventh nerves is supported by anatomic and embryologic evidence.[38,39] Furthermore, various clinical case reports have shown that patients had spontaneous facial motion recovery with biting after the removal of the facial nerve during total parotidectomy, which suggests that latent connectedness can be activated by injury.[46,47] Both central cortical adaption and peripheral nerve connectedness allow the patient to have an easy, effortless smile.

Moderate deficits of dissymmetry at the donor site were noted in 4 of the 16 patients (25%) (Fig. 6); these deficits were caused by the resection of the descending branch of masseter nerve whereas the other branches were spared.[12] After physical training, only slight commissure synkinetic movement was noted. The degree of postoperative synkinesis (Table 3) varied from minimal to mild, but it was observed in all 16 patients. These deficits were minimized by biofeedback training.[41,42]

CONCLUSION

Masseter-to-facial nerve transfer successfully reanimates a paralytic muscle in patients who acquired intracranial facial nerve injury within 2 years after tumor resection. After continued biofeedback physical training, some patients can regain symmetrical and effortless smile with only slight synkinetic movements.

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