Aesth Plast Surg (2012) 36:1353–1360
DOI 10.1007/s00266-012-9951-9

MULTIMEDIA MANUSCRIPT GENERAL RECONSTRUCTION

Masseter-to-Facial Nerve Transfer: Is It Possible to Rehabilitate the Function of Both the Paralyzed Eyelid and the Oral Commissure?

4

Wei Wang · Chuan Yang · Wei Li · Qingfeng Li · Yixin Zhang

Received: 23 February 2012 / Accepted: 11 June 2012 / Published online: 6 October 2012

Abstract
Background This report addresses the efficiency of masseter-to-facial nerve transfer and investigates the patient's ability to perform the functions of eyelid closure and smile movements independently.
Methods From November 2010 to January 2012, seven patients underwent the reported procedure and were followed 6 to 12 months postoperatively. The patients' ages varied from 22 to 41 years. The etiology of the injuries was resection of cerebellopontine angle tumors in all the patients. Using Terzis' and Mehta's scale, smile outcomes and synkinetic movements were evaluated pre- and post-operatively. The function of eyelid closure was evaluated by measuring the width of the lagophthalmos. A questionnaire was applied to evaluate ocular problems and donor-site morbidity.
Results All the patients were able to close their eyelids and smile with biting. Four of the seven patients were able to smile effortlessly without biting. According to Terzis' scale, the postoperative mean score was 4.3 ± 0.8 compared with 1.0 ± 0.0 at the preoperative evaluation. The improvement in the lagophthalmos varied from 2 to 5 mm. The ocular problems all were resolved. All the patients were able to smile easily without eyelid closure and could close their eyes with minimal oral commissure movement. No patients reported weakness of mastication on the affected side, and only minimal atrophy of the masseter muscle at the donor site was noted.
Conclusions Masseter-to-facial nerve transfer is a highly efficient technique for reanimating paralyzed muscle. After physical training, both eyelid closure and smiling are restored and discriminated after physical training.
Level of Evidence IV This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine ratings, please refer to the Table of Contents or the online Instructions to Authors at www.springer.com/00266.

Keywords Facial nerve · Facial reanimation · Masseter nerve

Electronic supplementary material The online version of this article (doi:10.1007/s00266-012-9951-9) contains supplementary material, which is available to authorized users.

W. Wang · C. Yang · W. Li · Q. Li (✉) · Y. Zhang
Department of Plastic and Reconstructive Surgery, Shanghai No. 9 People's Hospital, School of Medicine, Shanghai Jiaotong University, No. 639 Zhizaoju Rd., Huangpu District, Shanghai 200011, People's Republic China
e-mail: liqfliqf@yahoo.com.cn

Y. Zhang
e-mail: zhangyixin6688@163.com

Facial nerve injury disables mimetic muscle function, which causes not only an asymmetric smile but also a series of ocular problems including conjunctivitis, irritation, tearing, keratitis, corneal ulcerations, and even blindness [1]. Therefore, the functional restoration of both smiling and eyelid closure should be treated equally.

Timely facial nerve reconstruction is crucial for a good recovery [2]. However, it is difficult for patients with acquired proximal injury to the facial nerve because it takes a long time to reinnervate the paretic muscle from the normal side using the cross-facial nerve grafting (CFNG) technique. Therefore, this technique is suitable only for patients with denervation times of less than 5 months. Otherwise, it is necessary to combine this technique with other cranial nerve transfer techniques [3].

Partial hypoglossal nerve transfer was used as a major motor source during the past 30 years [4]. However, sacrificing this donor nerve produces hemiglossal atrophy, which leads to difficulties with effective communication and food intake [5, 6].

To reduce the morbidity after sacrifice of the donor nerve, an alternative technique using the masseter nerve branch from the trigeminal nerve for neurotization of the distal facial nerve was reported recently in several papers [7–9]. However, whether this technique allows for the restoration of both smile and eyelid closure function using the same motor source still is controversial.

Because of concerns about synkinetic oral and eyelid closure movements with biting, Klebuc [9] scarified the main zygomatic branches, which were connected to the CFNG, and coaptated the buccal branch to the descending branch of the masseter nerve. This researcher reported that his patients had good recovery of smile function, but he did not address the functional results of eye reanimation, which was accomplished with CFNG. According to the mean denervation period of 12 months documented in that paper, it was difficult to regain good eyelid closure function using only the CFNG technique. This function can be augmented by subsequent static procedures that help eyelid closing in various ways. These procedures include upper eyelid loading, tarsorrhaphy, lower eyelid suspension, medial/lateral canthoplasty, and canthotomy [10–13]. The results often do not last over the long term due to gravity and various other factors.

Long-lasting results can be acquired only with dynamic procedures that rehabilitate the paralyzed eye sphincter function. These procedures include nerve innervation of the paralyzed sphincter muscle, muscle substitution with local muscle transfers, and free muscle transplantation.

Terzis and Tzafetta [14] reported that using the dual innervation of the "baby-sitter" technique, in which 40 % of the ipsilateral hypoglossal nerve is coapted to the facial nerve trunk in stage 1 and previously placed cross-facial nerve grafts are connected to the selected distal facial nerve branches in stage 2, is an effective procedure for reanimating the entire mimetic muscle on the paralyzed side. Although 40 % of the hypoglossal nerve is coapted to the affected facial nerve trunk, the obvious synkinetic movement of eyelid closure and smiling was not observed in the patients in that study.

Therefore, by analogy, is it possible that the descending branch of the masseter nerve (i.e., one motor source) can be connected to the zygomatic and buccal branches to restore eyelid closure and smile function without synkinetic movements? To evaluate this hypothesis, the following study investigated the efficiency of this procedure and determined the patients' ability to perform the functions of eyelid closure and smile movements independently.

Patients and Methods

From November 2010 to January 2012, masseter-to-facial nerve transfers were performed in 20 patients. Of these 20 patients, 7 (2 males and 5 females) were followed up from 6 to 12 months and were available for enrollment in this study. The study was approved by the Ethics Committee in the authors' hospital.

The ages of the patients varied from 22 to 41 years (average, 26.9 ± 2.5 years). For all the patients, the etiology of the nerve injuries was tumor resection in the cerebellopontine angle. The denervation periods before masseter nerve transfer varied from 2 to 15 months (average, 8.9 ± 1.6 months) (Table 1).

Eyelid closure was evaluated by measuring the width of the patients' lagophthalmos, and the smile function was evaluated pre- and post-operatively according to Terzis's smile functional evaluation scales (Table 2) [15]. Two types of synkinetic movements were documented: unwanted eyelid closure action after smiling and unwanted oral commissure elevation after eye closing. The extent of the synkinetic movements was evaluated according to Mehta's synkinesis evaluation scale (Table 2) [16]. Needle electromyography was used to assess the function of the mimetic muscle pre- and post-operatively.

The inclusion criteria specified proximal injury to the facial nerve acquired within 2 years after the denervation

Table 1 Patient demographics

Case	Gender	Age (years)	Etiology	Period (months)[a]	Side	Grade
1	F	27	Acoustic neuroma (L)	2	Left	Complete
2	M	41	Acoustic neuroma (L)	6	Left	Complete
3	F	22	Epithelioma of the fourth ventricle (R)	11	Right	Complete
4	F	27	Acoustic neuroma (L)	15	Left	Complete
5	F	25	Meningioma (L)	10	Left	Complete
6	F	24	Acoustic neuroma (L)	11	Left	Complete
7	M	22	Acoustic neuroma (L)	7	Left	Complete
Mean		26.9 ± 2.5		8.9 ± 1.6		

[a] Period between the onset of paralysis and the masseter-to-facial nerve transfer procedure

Table 2 Terzis' smile function evaluation scale [15] and Mehta's synkinesis evaluation scale [16]

Grade	Terzis' smile functional evaluation scale	Mehta's synkinesis evaluation scale
5	Symmetric smile with teeth showing, full contraction	All 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

period, which meant that the denervated mimetic muscle still was viable. In our series, all the patients except patient 1 underwent the masseter-to-facial nerve transfer procedure a minimum of 6 months after injury to avoid impairing the spontaneous recovery of the facial nerve. Patient 1, whose facial nerve was resected during a tumor resection, underwent the nerve transfer procedure 2 months after injury.

After the reconstruction, the patients were asked to contact the physician as soon as their first lip contraction with biting on the affected side occurred, and the period between the contraction and the operation date was documented. Furthermore, the patients were followed up by the physician 6 to 12 months postoperatively. At this time, a questionnaire was applied to evaluate ocular problems and donor-site morbidity including mastication function, facial synkinetic movements with mastication, and symmetry in the parotideomasseteric region.

Preoperatively, four of the seven patients had mild ocular problems such as conjunctivitis and irritation. The remaining three patients had severe problems, including repetitional keratitis and corneal ulcerations and needed to use eye ointment continuously to protect their corneas.

The mean scores of the smile functional evaluation were compared using the Wilcoxon signed-rank test. The mean distances of the lagophthalmos were compared using the paired-sample t test. Statistical analysis was performed using SPSS version 13.0 (SPSS, Chicago, IL, USA). The significance level was set at 0.05.

Surgical Technique

Along the preauricular incision, the dissection was started from the temporal region down to the mandibular region, which overlies the superficial musculoaponeurotic system (SMAS). Using a fine-mosquito forceps, the temporal branch of the facial nerve was identified following the line between the tragus and a point 1 cm superior to the lateral end of the eyebrow. By tracing this branch into the parotid gland, which was divided and ligated with a 1–0 silk suture, the plexus of the facial nerve was exposed to the facial nerve bifurcation into the temporofacial and the cervicofacial main branches.

Following the temporofacial branch distally, the zygomatic and buccal branches extended to the lateral side of the orbicularis oculi and zygomaticus major. Furthermore, the masseter muscle beneath the facial nerve is easily identified with palpation. The surgeon then can locate the region of the masseter muscle overlying the mandibular notch. This region, located within the middle third of the muscle between the coronoid process anteriorly and the condyloid process posteriorly, is inferior to the zygomatic arch. Because the masseter nerve always branches from the mandibular nerve diagonally to cross the notch within the muscle, the described technique is most effective for exploring the descending branch of the masseter nerve [17–19]. By carefully retracting the zygomatic and buccal nerve branches, the overlying muscle in this region can be excised carefully to expose the deep running nerve.

Initially, the superficial layer of the masseter muscle was excised parallel to the zygomatic arch with fine scissors until the middle layer was reached, which was covered with the aponeurosis. Next, using fine-mosquito forceps, the masseter was bluntly dissected parallel to its fibers. At that point, use of the electrical stimulator was helpful for locating the position of the nerve when the muscle contracted strongly.

When the nerve was identified, the surrounding muscle fibers were excised, and the descending branch of the nerve was freed from the masseter muscle. To facilitate masseter nerve coaptation with the facial nerve, the longest possible length of the masseter nerve was freed and resected for transposition to a superficial plane.

To rehabilitate both eyelid closure and smile function, the temporofacial branch of the facial nerve was sectioned. This branch was freed carefully until its estimated length was sufficiently long for tension-free coaptation between the end of the temporofacial branch and that of the masseter nerve. Using microsurgical techniques, both nerve ends were coapted with 9–0 epineuria sutures.

To reduce axon dispersion, the frontal branch of the facial nerve was sectioned from the temporofacial branch. Next, the separated masseter muscle was connected together with 1–0 mattress silk sutures to protect the nerve coaptation site. The same process was performed on the ligated parotid to prevent the formation of a fistula of the parotid gland. The parotid fascia was closed, and the skin incision was closed with 5–0 absorbable Vicryl sutures and 6–0 nonabsorbable proline sutures.

After the operation, the patient consumed a liquid diet for 1 week and a soft diet for 4 weeks. Beginning 5 weeks postoperatively, the patient started biofeedback physical training in front of a mirror. First, the patient tried to enhance the strength of the muscle contraction with or without biting and subsequently tried to smile symmetrically with or without biting according to the movement of the commissure on the normal side.

Second, the patient tried to contract the antagonistic muscle to minimize the unwanted synkinetic movements, as when smiling. To do this, the patient could keep his or her affected eye opened, which was antagonized by the uncompromised function of the levator palpebrae superioris. Analogously, for eye closing, the patient could pucker his lips to attenuate the unwanted upper lip movement, which also was useful for reducing the synkinetic oral commissure movement with mastication.

The physical training requires 30 min per session three times a day, and it should be continued for 3–6 months based on the pace of the patient's functional recovery.

Results

Seven patients were followed up for 6–12 months (average, 8.3 ± 2.1 months). The first muscle contractions started 59–102 days postoperatively (average, 84.4 ± 14.6 days). All the patients experienced restored eyelid closure and smile function with biting (Figs. 1, 2, 3, 4, 5, 6, 7, 8, and 9). The improvement in lagophthalmos varied from 2 to 5 mm. According to Terzis' smile functional evaluation scales, the postoperative mean scale was 4.3 ± 0.8 compared with the preoperative mean scale of 1.0 ± 0.

Fig. 1 Patient 4 in Table 1: a 27-year-old patient with left complete facial palsy 15 months after left acoustic neuroma resection. The preoperative smile was classified as grade 1

Fig. 2 Preoperatively, the patient had 6 mm of lagophthalmos and severe ocular problems; Note the left lower eyelid retraction, keratitis, and eye ointment protecting her left eye

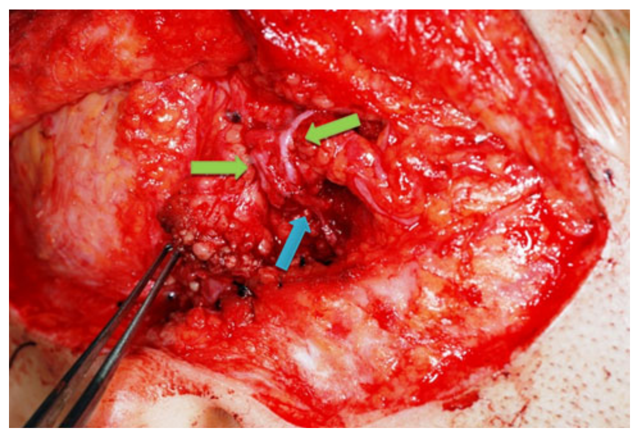

Fig. 3 Microsurgical coaptation between the descending branch (*blue arrow*) of the masseter and the zygomatic and buccal branches (*green arrows*)

Four of the seven patients were able to smile effortlessly without biting (Table 3; Fig. 8). No patient reported weakness of mastication on the affected side, and atrophy of the masseter muscle at the donor site was minimal (Figs. 4, 5, 8, and 9). All the patients were able to smile easily without eyelid closure and could close their eyes with only slight oral commissure synkinetic movement (Figs. 4, 5, 8, and 9), which was acceptable based on the benefits of the improved eyelid closure. The ocular problems of all the patients were markedly improved, particularly for three patients whose continuous keratitis resolved,

Fig. 4 Smile with biting and the grade 4 smile at 6 months postoperatively. Note the improvement in lower eyelid retraction, relief from keratitis, continued use of eye ointment for corneal protection, and mild atrophy of the left masseter muscle (*green arrows*)

Fig. 5 Eyelid closure with biting postoperatively and 1 mm of lagophthalmos with minimal oral commissure movement

thereby eliminating the need for eye ointment protection (Figs. 4, 5).

Discussion

Masseter-to-facial nerve transfer is a new effective procedure for reinnervating a paralyzed mimetic muscle caused by a proximal injury to the facial nerve. Klebuc [9] reported that the therapeutic "window" was up to 23 months, which was much longer than the window for the CFNG technique alone (<5 months) [3].

In our series, the patient with a 15-month denervation period showed a good recovery 6 months postoperatively, which is consistent with previous findings. Bae et al. [20] compared two groups who experienced commissure excursion after free muscle transplantation for facial reanimation using a cross-facial nerve graft versus the motor nerve procedure with the masseter nerve. These authors found that oral excursion in the masseter group was much higher than in the CFNG group and was almost the same as that of the normal side. In three of our seven cases, the patients had grade 5 smiles, which meant the same teeth exposure as on the normal side, and three of the seven patients were classified as grade 4, which meant slightly less teeth exposure than on the normal side.

These results were attributable to several factors. First, direct nerve coaptation shortened the period of paralytic

Fig. 6 Patient 2 in Table 1: A 41-year-old patient with left complete facial palsy 6 months after left acoustic neuroma resection. The preoperative smile was classified as grade 1

Fig. 7 Preoperatively, 2 mm of lagophthalmos and mild ocular problems

Fig. 8 Smile without biting classified as grade 5 at 10 months postoperatively. Note the symmetry of both sclera shown with smiling and the mild atrophy of the left masseter muscle (*green arrows*)

Fig. 9 Postoperatively, complete eyelid closure with biting and minimal oral commissure movement

muscle reinnervation, which reduced the extent of muscle denervation. In general, the period until muscle contraction after surgery is 84.4 ± 14.6 days, which is considerably shorter than with the CFNG technique (mean, 546 days) [21].

Second, a fresh cut to the proximal end of the masseter nerve may awaken the "sleeping" chronic denervation of the Schwann cells at the distal end of the facial nerve. Rueger et al. [22] reported in their study that freshly sectioned uncompromised hypoglossal axons reactivated the "sleeping" denervated Schwann cells at the distal facial nerve stump after direct end-to-end coaptation. This scenario is analogous to the masseter-to-facial nerve coaptation.

The fresh cutting of the masseter nerve stump may produce multiple proteins that promote axonal regeneration and denervated muscle reinnervation. Furthermore, a high number of axonal inputs enhanced the muscle innervation. According to the report of Coombs et al. [23], the number of axons in the masseter nerve was 1.542 ± 291.7, which is much higher than in the buccal branch (834 ± 285) [24], and direct nerve coaptation reduced the "dropped off" numbers of axons compared with the two coaptation sites with nerve graft.

Not only did the patients regain their symmetric smiles, but they (4 of 7, 57 %) also regained the ability to smile effortlessly after biofeedback training, which is similar to the findings of Manktelow et al. [25] (59 %). Moreover, by learning to contract the antagonistic muscle, all the patients were able to smile without eyelid closure and could close the affected eye with only minimal oral commissure movement. These results are attributable to the central cortical adaption between the "mastication center" and the "facial movement center" and to the peripheral nerve connectedness between the trigeminal nerve and the facial nerve.

Central cortical adaption had been identified in a patient with an injured brachial plexus whose biceps function was restored after a procedure involving transfer of the intercostal nerves to the musculocutaneous nerve. The success of this procedure was proved by transcranial magnetic stimulation and functional magnetic resonance imaging [26].

Although the mastication center and the facial movement center are considered to be similar, they cannot be identified based on the shift of control because they are located too close to each other [27]. However, the success of the procedure can be demonstrated based on the outcomes. After intensive training, the patient's latent connections were activated in the different centers. Subsequently, concordant facial expression and independent movements of eyelid closure and smiling were obtained.

Peripheral nerve connectedness between the trigeminal nerve and the facial nerve are supported by anatomic and embryologic evidence [28, 29]. Furthermore, reports of certain clinical cases show that patients had spontaneous facial motion recovery with biting after removal of the facial nerve during total parotidectomy, which indicates that the latent peripheral connectedness is activated by the injury [30, 31]. Both central cortical adaption and peripheral nerve connectedness help the patient to achieve an easy, effortless smile.

Although slight synkinetic lip movements can be found when patients close their eyes, these movements are acceptable because the previous deficits from the ocular problems have been resolved. Mild deficits of mastication and dissymmetry at the donor site were noted in our seven patients (Figs. 4, 5, 8, and 9), which were caused by the

Table 3 Eye closure and smile functional results

Case	Lagophthalmos preop (MM)	Lagophthalmos postop (MM)	Improvements of eye closure (MM)	Smile preoperative	Smile postoperative	Improvements of smile	Synkinesis 1[a]	Synkinesis 2[b]	Smile with biting	Onset motion (days)[c]	Follow-up (months)
1	3	0	3	1	4	3	2	2	N	90	12
2	2	0	2	1	5	4	2	1	N	80	10
3	3	1	2	1	4	3	2	1	Y	102	8
4	6	1	5	1	4	3	2	1	Y	90	6
5	7	2	5	1	3	2	2	1	Y	96	8
6	4	1	3	1	5	4	2	1	N	74	7
7	4	0	4	1	5	4	2	1	N	59	7
Mean	4.1 ± 1.7	0.7 ± 0.8	3.4 ± 1.3	1	4.3 ± 0.8	3.3 ± 0.8	2.0 ± 0	1.1 ± 0.4		84.4 ± 14.6	8.3 ± 2.1
p value		0.038[d]			0.016[e]						

[a] Synkinesis 1 means the evaluation of synkinesis (i.e., unwanted oral commissure movement after eye closure)

[b] Synkinesis 2 means the evaluation of synkinesis (i.e., unwanted eye closure after smile)

[c] Onset motion indicates the period between the masseter-to-facial nerve transfer procedure and the onset of "new" muscle contraction

[d] Using nonparametric tests, a significant difference was found between pre- and postoperative smile functional evaluation

[e] Using paired-sample *t* test, a significant difference was found between pre- and postoperative distance of lagophthalmos

specific resection of the descending branch of the masseter nerve together with the sparing of the other branches [7]. After physical training, only slight commissure synkinetic movements with mastication were noted, which was much less than the deficits that result after hypoglossal-facial nerve transfer.

Conclusion

Masseter-to-facial nerve transfer is a highly efficient technique for reanimating paralyzed muscle. This technique not only enhances the strength of muscle contraction but also widens the therapeutic window for facial nerve functional restoration, with minimal deficits at the donor site. Using this technique, the functions of eyelid closure and smiling are both restored, and patients can perform these functions independently after physical training.

References

1. Jelks GW, Smith B, Bosniak S (1979) The evaluation and management of the eye in facial palsy. Clin Plast Surg 6:397–419
2. Gagnon NB, Molina-Negro P (1989) Facial reinnervation after facial paralysis: Is it ever too late? Arch Otorhinolaryngol 246:303–307
3. Frey M, Givannoli P, Michaelidou M (2006) Functional upgrading of partially recovered facial palsy by cross-facial nerve grafting with distal end-to-side neurorrhaphy. Plast Reconstr Surg 117:597–608
4. Kalantarian B, Tiangco DA, Terzis JK (1998) Gains and losses of the XII–VII component of the "baby-sitter" procedure: a morphometric analysis. J Reconstr Microsurg 14:459–471
5. May M (2000) Nerve substitution techniques: XII–VII hook-up, XII–VII jump graft and cross-face graft. In: May M (ed) The facial nerve, 2nd edn. Thieme Medical Publishers, New York, pp 611–633
6. Conley J (1977) Hypoglossal crossover: 122 cases. Trans Am Acad Ophthalmol Otolaryngol 84:763–768
7. Spira M (1978) Anastomosis of masseteric nerve to lower division of facial nerve for correction of lower facial paralysis. Plast Reconstr Surg 61:330–334
8. Brenner E, Schoeller T (1998) Masseteric nerve: A possible donor for facial nerve anastomosis? Clin Anat 11:396–400
9. Klebuc MJA (2011) Facial reanimation using the masseter-to-facial nerve transfer. Plast Reconstr Surg 127:1909–1915
10. Jobe RP (1974) A technique for lid loading in the management of the lagophthalmos of facial palsy. Plast Reconstr Surg 53:29–32
11. Pickford MA, Scamp T, Harrison DH (1992) Morbidity after gold weight insertion into the upper eyelid in facial palsy. Br J Plast Surg 45(6):460–464
12. Dinces EA, Mauriello JA, Kwartler JA (1997) Complications of gold weight eyelid implants for treatment for 5th and 7th nerve paralysis. Laryngoscope 107:1617–1622
13. Morel-Fatio D (1964) Palliative surgical treatment of facial paralysis: the palpebral spring. Plast Reconstr Surg 33:446–456
14. Terzis JK, Tzafetta K (2009) The "babysitter" procedure: mini-hypoglossal to facial nerve transfer and cross-facial nerve grafting. Plast Reconstr Surg 123:865–876
15. Terzis JK, Noah ME (1997) Analysis of 100 cases of free-muscle transplantation for facial paralysis. Plast Reconstr Surg 99: 1905–1921
16. Mehta RP, WernickRobinson M, Hadlock TA (2007) Validation of the synkinesis assessment questionnaire. Laryngoscope 117:923–926
17. Cotrufo S, Hart A, Payne AP et al. (2011) Topography anatomy of the nerve to masseter: an anatomy and clinic study. J Plast Reconstr Aesthet Surg. doi:10.1016/j.bjps.2011.05.026
18. Borschel GH, Kawamura DH, Kasukurthi R, Hunter DA, Zuker RM, Woo AS (2011) The motor nerve to the masseter nerve: an anatomic and histomorphometric study to facilitate its use in

facial reanimation. J Plast Reconstr Aesthet Surg. doi:10.1016/j.bjps.2011.09.026
19. Hwang K, Kim YJ, Chung IH et al (2005) Course of the masseteric nerve in masseter muscle. J Craniofac Surg 16:197–200
20. Bae Y, Zuker RM, Manktelow RT et al (2006) A comparison of commissure excursion following gracilis muscle transplantation for facial paralysis using a cross-face nerve graft versus the motor nerve to the masseter nerve. Plast Reconstr Surg 117:2407–2413
21. Kumar PA, Hassan KM (2002) Cross-face nerve graft with free-muscle transfer for reanimation of the paralyzed face: a comparative study of the single-stage and two-stage procedures. Plast Reconstr Surg 109:451–462
22. Rueger MA, Aras S, Guntinas-Lichius O et al (2008) Re-activation of atrophic motor Schwann cells after hypoglossal-facial nerve anastomosis. Neurosci Lett 434:253–259
23. Coombs CJ, Ek EW, Wua T et al (2009) Masseteric-facial nerve coaptation: an alternative technique for facial nerve reinnervation. J Plast Reconstr Aesthet Surg 62:1580–1588
24. Frey M, Happak W, Girsch W et al (1991) Histomorphometric studies in patients with facial palsy treated by functional muscle transplantation: new aspects for the surgical concept. Ann Plast Surg 26:370–379
25. Manktelow RT, Tomat LR, Zuker RM et al (2006) Smile reconstruction in adults with free muscle transfer innervated by the masseter motor nerve: effectiveness and cerebral adaptation. Plast Reconstr Surg 118:885–899
26. Chen R, Anastakis DJ, Haywood CT, Mikulis DJ, Manktelow RT (2003) Plasticity of the human motor system following muscle reconstruction: a magnetic stimulation and functional magnetic resonance imaging study. Clin Neurophysiol 114:2434–2436
27. Ziemann U, Muellbacher W, Hallett M, Cohen LG (2001) Modulation of practice-dependent plasticity in human motor cortex. Brain 124:1171–1181
28. Gasser RF (1967) The development of the facial nerve in man. Ann Otol Rhinol Laryngol 76:37–56
29. Baumel JJ (1974) Trigeminal-facial nerve communications: their function in facial muscle innervation and reinnervation. Arch Otolaryngol 99:33–44
30. Cheney ML, McKenna MJ, Megerian CA et al (1999) Trigeminal neo-neurotization of the paralyzed face. Plast Reconstr Surg 103:1725–1728
31. Adour KK, Klein JC, Bell DN (1979) Trigeminal neurotization of paralyzed facial musculature. Arch Otolaryngol 105:13–16