Outcomes of Mini-Hypoglossal Nerve Transfer and Direct Muscle Neurotization for Restoration of Lower Lip Function in Facial Palsy

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Background: Most reconstructions for lower lip palsy focus on paralyzing the contralateral normal lip or providing static support on the affected side. The authors' unit has reported dynamic strategies for lower lip reanimation and use of 40 percent of the hypoglossal nerve (mini-hypoglossal) in facial reanimation. They report their experience with mini-hypoglossal nerve transfer for lower lip palsy.

Methods: Between 1987 and 2005, 29 patients with unilateral facial palsy had lower lip reanimation with the mini-hypoglossal as the motor donor. Twenty patients had transfer of the mini-hypoglossal to the cervicofacial branch of the facial nerve and nine had direct depressor muscle neurotization. Five patients had a mean denervation time of 14.60 ± 4.50 months (<2 years), and the rest had a mean denervation time of 10.63 ± 9.23 years. In late cases, the facial nerve was in-continuity, and preoperative needle electromyographs of depressors showed at least fibrillations. Standardized videos taken preoperatively and at 2 years postoperatively were available for 27 patients and assessed by three independent reviewers. Needle electromyographic results were analyzed.

Results: Thirteen patients (48.15 percent) achieved excellent and good results, nine (33.33 percent) had moderate results, and five (18.52 percent) obtained fair results. The difference between the averaged preoperative and postoperative scores was statistically significant, as was the difference in electromyographic outcomes ($p < 0.0001$, Wilcoxon signed rank test). The nerve transfer and direct neurotization groups had no statistically significant difference in clinical and electromyographic outcomes. Four patients required muscle transfer for further outcome upgrading.

Conclusion: Use of the mini-hypoglossal either for nerve transfer or for direct muscle neurotization of lower lip depressors can provide reinnervation and satisfactory clinical function, even for muscles with prolonged partial denervation. (*Plast. Reconstr. Surg.* 124: 1891, 2009.)

Restoration of form and function of the lower lip has always been an important goal in our unit, with the lower zone of the face given attention equal to that of the upper and middle face.[1,2] The lower lip depressor complex, composed of the depressor anguli oris, labii inferioris, and mentalis muscles, produces facial expressions that range from a full denture smile to demonstration of anguish, rage, and sorrow. Any asymmetry is visible during verbal communication and can cause distress to the afflicted patient. The patient is unable to draw the lower lip downward

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and laterally or evert the vermilion border. During smiling, upward pull occurs. In addition, especially when the orbicularis oris is involved, oral incontinence (with dribbling and impaired fluid management) and speech problems can be sources of embarrassment and frustration. The intricate relationship of the perioral muscles, elevators, and depressors has provoked the interest of several authors.[3–5]

Methods used for correction of lower lip paralysis are static, paralytic, and reanimating. The static methods started with the use of supporting slings[6,7] (most commonly fascia lata) that provided some degree of balance only in repose but not on the animated face. Transposition of the orbicularis oris muscle following wedge resection[8–10] of the skin and muscle, often under local anesthesia, is simple to perform and advantageous in elderly patients. However, the degree of movement is variable and difficult to predict, and the scar can be conspicuous.

Paralytic procedures involve neurotomies of the contralateral marginal mandibular branch for restoring symmetry. Some authors have expressed skepticism regarding these techniques.[11,12] Breslow et al.[13] advocated selective neurectomy of marginal mandibular nerve branches to lip depressors on the unaffected side responsible for the (preoperatively marked) deformity as a reliable technique that does not compromise oral functionality (i.e., eating, speaking, and continence). Botulinum toxin[14,15] has been frequently used as a temporary management option for facial paralysis asymmetry, especially for the forehead. Chen and Tang[16] used it alone or combined with myectomy. The need for repeated injections and recurrence of activity on contralateral depressors following insufficient muscle resection is acknowledged by the authors.[16]

Hussain et al.[17] and Manktelow[18] performed resection of the depressor labii inferioris for restoration of balance. In a survey of 36 patients, they claimed that the speech had either improved or did not change and that there were no problems with oral continence. The same authors[19] advocated a trial of local anesthetic for the patients to see the outcome following the depressor labii inferioris resection.

The previously mentioned techniques, although they can provide symmetry, result in varying degree of lower lip flaccidity and weakness in lip approximation. Dynamic reanimation can be achieved either by neurotization of available but weak muscles or by muscle substitution in cases of late (≥2 years) paralysis.

An algorithm for dynamic depressor restoration has been reported previously by the senior author (J.K.T.).[1] This study analyzes our experience with the use of the mini-hypoglossal transfer to the cervicofacial branch of the facial nerve or as a motor neurotizer of the partially innervated depressor complex.

PATIENTS AND METHODS

Over an 18-year period (1987 to 2005), 29 patients with unilateral facial paralysis had reanimation of the lower lip depressors with use of 40 percent of the hypoglossal nerve (mini-hypoglossal). Twenty of those patients had transfer of the mini-hypoglossal to the cervicofacial branch of the facial nerve, and nine had direct neurotization of the depressor muscle complex (Table 1). The nerve transfers were performed either end-to-side following partial neurotomy of the hypoglossal nerve and coaptation of the proximal part of the cervicofacial branch to the neurotomy site or end-to-end after raising a longitudinal segment of 40 percent of the hypoglossal nerve and coapting its end to the proximal part of the cervicofacial branch (Fig. 1, *above*). The direct neurotizations were performed with partial neurotomy (up to 40 percent of circumference) of the hypoglossal nerve and coaptation with nerve grafts which had their distal end split into fascicles and implanted into the lower lip depressors (Fig. 1, *below*). The study was conducted following approval by the Eastern Virginia Medical School Institutional Review Board.

These surgical procedures were combined with the first stage of cross-facial nerve grafting that addressed the upper and middle part of the face for eye closure and smile restoration, respectively. At the second stage, these patients would have coaptation of the distal end of the cross-facial nerve grafts to selected upper zygomatic or lower zygomatic branches of the afflicted facial nerve, with or without muscle transfers. The purpose of the present study is to report and analyze the results obtained by the use of the mini-hypoglossal nerve solely for reanimation of lower lip depression. The hypoglossal nerve was approached by means of a 3- to 4-cm submandibular incision that also gave access to the ipsilateral seventh cervicofacial branch. Once explored, this was divided from its exit from the main extratemporal seventh nerve trunk and brought inferiorly and medially for end-to-side coaptation with the hypoglossal nerve (Fig. 1, *above*). In the direct neurotization group, the proximal end of the nerve graft was similarly coapted in an end-to-side fashion with

Table 1. Operations Performed

Patient	Type of Operation	Nerve Graft	Muscle Transfer	Type of Muscle
1	Nerve transfer	No	No	
2	Nerve transfer	No	No	
3	Direct neurotization	Yes	No	
4	Nerve transfer	No	No	
5	Nerve transfer	No	No	
6	Nerve transfer	No	No	
7	Direct neurotization	Yes	No	
8	Nerve transfer	No	No	
9	Direct neurotization	Yes	No	
10	Nerve transfer	No	No	
11	Direct neurotization	Yes	No	
12	Nerve transfer	No	No	
13	Nerve transfer	No	No	
14	Direct neurotization	Yes	No	
15	Nerve transfer	No	No	
16	Nerve transfer	No	No	
17	Direct neurotization	Yes	No	
18	Nerve transfer	No	No	
19	Direct neurotization	Yes	No	
20	Nerve transfer	No	No	
21	Nerve transfer	No	No	
22	Nerve transfer	No	No	
23	Nerve transfer	No	Yes	Platysma
24	Direct neurotization	Yes	No	
25	Nerve transfer	No	Yes	Digastric
26	Nerve transfer	No	No	
27	Nerve transfer	No	Yes	Platysma
28	Direct neurotization	Yes	No	
29	Nerve transfer	No	Yes	Platysma

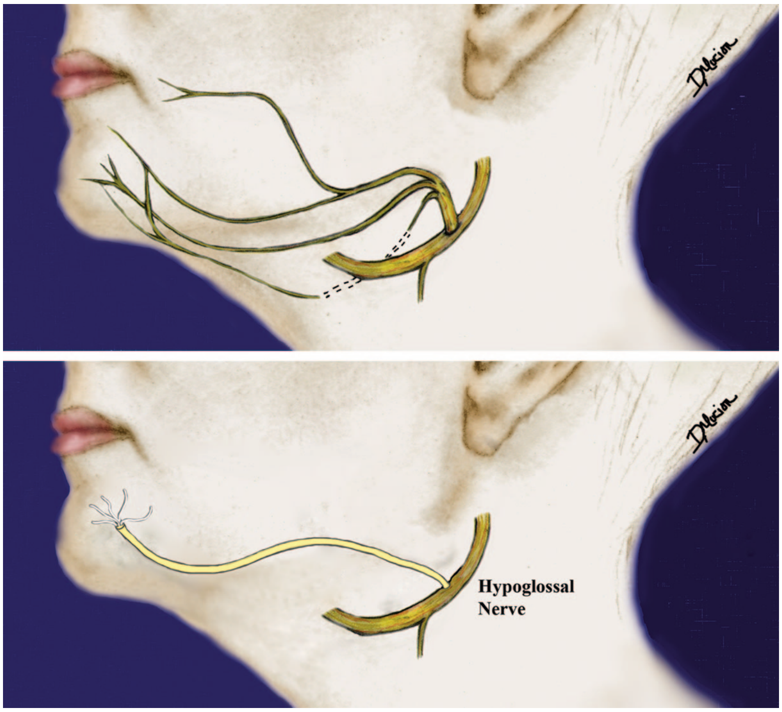

Fig. 1. (*Above*) Mini-hypoglossal transfer to the cervicofacial branch of the facial nerve and (*below*) direct neurotization (mini-hypoglossal to lower lip depressor muscles by means of nerve graft).

the hypoglossal nerve (Fig. 1, *below*), after the nerve graft was passed subcutaneously up to the lower lip. Through an intraoral incision, the distal end of the graft was divided into three or four fascicles, and each fascicle was implanted in the epimysium of the depressor muscles. Detailed description of these techniques is included in previous publications.[1,2,20]

The patients' demographic characteristics are listed in Table 2. All patients suffered unilateral facial paralysis; the right side was involved in 17 patients and the left side was involved in 11. The cause included posttumor resection, usually acoustic neuroma (nine patients), Bell's palsy (six patients), trauma (six patients), infection (two patients with poliomyelitis and Lyme disease), iatrogenic injury (two patients, one after rhytidectomy at another institution 2 years prior and one after mastoidectomy for cholesteatoma), developmental facial palsy (two patients) and arteriovenous malformation of the brain stem (two patients). The denervation was less than 2 years in five patients (mean, 15.60 ± 4.50 months). The mean denervation time for patients longer than 2 years was 10.57 ± 9.23 years. The mean age of the patients was 31.55 ± 17.42 years. Patients were divided into three age groups: younger than 20 years (10 patients), between 20 and 40 years (10 patients), and older than 40 years (nine patients).

Table 2. Patient Demographics

Patient	Sex	Age (yr)	Side	Cause	Denervation Time (yr)	Follow-Up Time (mo)
1	F	61	L	T	1.3	6
2	M	40	L	TR	24	18
3	M	54	L	T	4	36
4	M	40	R	T	5	24
5	M	56	R	T	2.3	48
6	F	44	L	T	2.2	36
7	F	71	R	Ia	1.5	24
8	F	41	R	T	27	36
9	F	13	R	De	13	106
10	F	13	L	T	9.8	36
11	M	14	R	De	14.5	24
12	F	32	R	AVM	2.5	54
13	F	22	R	B	11	60
14	F	8	L	T	8	24
15	M	33	R	TR	1	46
16	F	23	R	B	19	48
17	M	12	L	TR	3.7	26
18	M	29	R	B	10.8	24
19	F	33	R	Ia	17	6
20	M	18	R	TR	1.9	38
21	F	43	L	T	2.2	30
22	F	40	R	I	38	38
23	F	34	L	B	8.2	126
24	F	14	R	AVM	4	28
25	M	18	R	TR	16.3	40
26	M	7	R	I	3.4	132
27	M	49	L	B	5.5	28
28	M	8	L	TR	2.5	30
29	F	45	L	B	1	36

F, female; M, male; R, right; L, left; AVM, arteriovenous malformation; B, Bell's palsy; De, developmental; Ia, iatrogenic; I, infection; T, tumor; TR, trauma.

Selection Criteria

At the first office visit, all patients underwent detailed needle electromyographic examination of the lower lip depressors. To be selected for the procedure, patients with denervation time longer than 12 months, the depressors had to elicit fibrillation potentials and positive sharp waves indicative of active denervation (but still functioning depressor muscles) and the presence of some reinnervation. Clinically, the patients demonstrated some or no movement. Those with some movement received mini-hypoglossal–to–depressor muscle direct neurotization for further enhancement. The patients with minimal or no movements received the mini-hypoglossal transfer. A grading system for electromyographic studies that was based on preoperative and postoperative volitional effort (evoked potentials) is shown in Table 3.

In addition to neurophysiologic studies, the patients had extensive clinical evaluation. Photographs and standardized video recordings were also acquired. For the purpose of the present study, the preoperative and 2-year postoperative video recordings were evaluated by three independent assessors who were fellows in the Microsurgical Program, and had no knowledge of the performed procedures. The videos recorded the patient's smile and also depression of the lower lip without smile so that lip excursion could be assessed. The Terzis grading system was used (Tables 4 and 5).

Two patients (6.9 percent) were lost to follow-up after 6 months postoperatively and were not included in the assessment. The mean follow-up period for the remaining patients was 37.44 ± 22.84 months. The present study assessed the results at 2 years after all operations.

Statistical Analysis

The data obtained from the clinical evaluation was averaged across the three assessors. To com-

Table 3. Grading for the Electromyographic Studies (Volitional Effort)

Grade	Definition	
0	No evoked potentials	−
1	Some evoked potentials	+/−
2	Moderate evoked potentials (incomplete interference pattern)	++
3	Full electrogenesis (complete interference pattern)	+++

Table 4. Terzis Grading System for Assessment of Lip Depressors

Score	Description	Designation
0	Total paralysis	Poor
0.5	Trace contraction, no movement	Fair
1	Observable movement but no symmetry	Moderate
1.5	Almost complete excursion of lower lip	Good
2	Normal symmetrical movement of lower lip	Excellent

pare preoperative and postoperative averaged scores, the Wilcoxon signed rank test was used. The results of statistical tests were considered significant at an α level of 0.05. The Kruskal-Wallis test was used to compare the clinical outcome among the three different age groups. The Mann-Whitney *U* test was used to compare clinical and electromyographic outcomes between the groups with nerve transfer and direct neurotization. The Spearman correlation coefficient was used to identify the correlation between outcomes and parameters such as denervation time, and the Fisher's exact test was used to establish the association between the two types of neurotization and different outcomes. SPSS version 12.0 (SPSS, Inc., Chicago, Ill.) was used for statistical analysis.

RESULTS

Four patients (13.8 percent) required regional muscle transfer for further outcome upgrading (Table 1). They all underwent nerve transfer of the mini-hypoglossal to the cervicofacial branch. The muscle transfers included three platysma transfers and anterior belly of the digastric muscle (neurotized with a cross-facial nerve graft) in one patient. Although none of the patients with direct depressor neurotization needed any further operations, there was a nonsignificant association between type of surgery (nerve transfer or direct neurotization) and requirement for muscle transfer ($p < 0.29$, Fisher's exact test). Similarly, no correlation was found between denervation time and requirement for muscle transfer. The techniques for platysma and anterior belly of digastric muscle transfer have been described in previous publications.[1,2] Two patients (6.9 percent; patients 1 and 19) were lost to follow-up 6 months after surgery, one from each

Table 5. Preoperative and Postoperative (at 2 Years) Electromyography Results (Volitional Effort) and Preoperative and Postoperative (at 2 Years) Averaged Clinical Evaluation

Patient	Preoperative EMG	Postoperative EMG	Preoperative Evaluation	Postoperative Evaluation
2	2	3	1.17	1.50
3	1	2	0.50	0.83
4	1	2	0.67	1.33
5	2	3	0.67	1.00
6	2	3	1.00	1.17
7	2	2	0.67	1.50
8	2	2	0.50	1.00
9	1	3	0.67	1.33
10	1	3	0.33	2.00
11	1	3	0.67	1.33
12	1	2	0.33	0.67
13	1	3	0.67	1.33
14	1	1	0.50	1.00
15	1	3	0.67	1.17
16	2	3	1.00	1.50
17	1	2	0.50	0.83
18	1	2	0.33	0.67
20	1	3	0.67	1.50
21	1	2	0.33	0.83
22	2	3	0.50	1.33
23	2	2	0.67	1.00
24	2	3	0.83	1.33
25	1	2	0.67	1.00
26	2	3	0.50	1.67
27	1	3	0.17	1.17
28	2	3	0.33	1.33
29	2	3	0.67	1.00

EMG, electromyography.
The mean of the electromyography results was 1.444 ± 0.506 preoperatively and 2.555 ± 0.577 postoperatively. The mean of the preoperative evaluation was 0.598 ± 0.227, and the mean of the postoperative evaluation was 1.197 ± 0.313. The preoperative and postoperative difference was statistically significant ($p < 0.0001$) for both electromyography results and clinical evaluation (Wilcoxon signed rank test).

group (Table 2), and were excluded from statistical analysis.

Clinical Assessment

One patient (3.70 percent) achieved an excellent result, 12 patients (44.45 percent) had good results, nine patients (33.33 percent) had moderate results, and five patients (18.52 percent) obtained fair results. The difference between the averaged preoperative and postoperative scores (Fig. 2) was statistically significant ($p < 0.0001$, $Z = -4.555$, Wilcoxon signed rank test). Although the patients with the excellent to good results seemed to have better preoperative clinical scores compared with the moderate to fair outcome group, no significant correlation was established (correlation coefficient, 0.293). The median of the preoperative evaluation was 0.67 (range, 0.17 to 1.17), and that for the postoperative evaluation was 1.17 (range, 0.67 to 2.00). The median for clinical improvement (difference between preoperative and postoperative grading) was 0.50 (range, 0.17 to 1.67) for the nerve transfer group and 0.50 (range, 0.33 to 1) for the direct neurotization group. There was no statistically significant difference for the clinical outcome between the nerve transfer and direct neurotization groups (asymptotic significance, $p = 0.571$, $Z = -0.566$, Mann-Whitney U test).

No significant correlation was found between denervation time and clinical outcome (Spearman correlation coefficient, 0.180; two-tailed $p = 0.365$). This is most likely related to the fact that there was partial denervation in all cases preoperatively and therefore none of the muscles was totally fibrosed.

Despite expectations that age would play a role in clinical outcome, statistical analysis showed no significant difference among the three age groups [asymptotic significance (two-tailed), $p = 0.444$; $Z = -0.765$, Kruskal-Wallis test].

Needle Electromyographic Studies

The mean of the preoperative electromyographic results (volitional effort/motor unit potential) was 1.44 ± 0.50, whereas the mean of the postoperative electromyographic results was 2.55 ± 0.57 (mean difference, 1.11 ± 0.64). There was a statistically significant difference ($p < 0.0001$, $Z = -4.423$, Wilcoxon signed rank test) between pre-

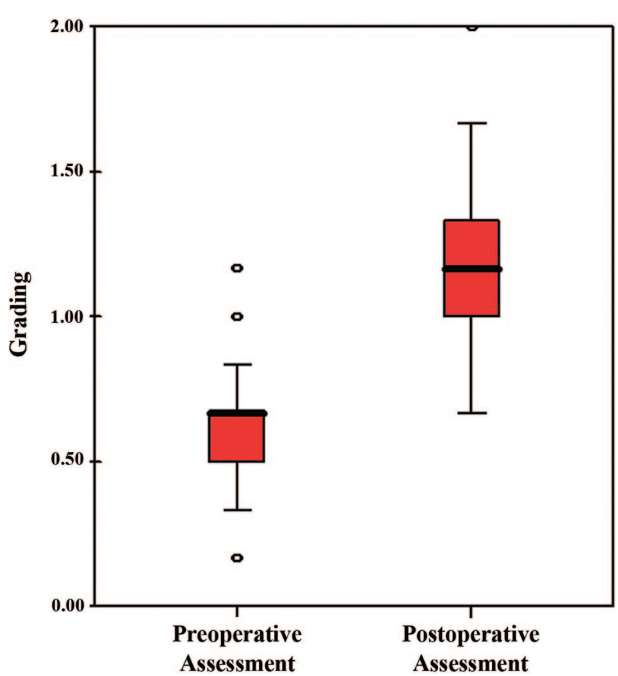

Fig. 2. Grading of the preoperative and postoperative lower lip depression. The *dark line* is the median value and outliers are marked by *circles*. The difference of the *ends of the whiskers* is the range. The *end of the box* is the interquartile range. The upper limit is 2 (excellent) and the lower limit is 0 (poor). The difference is statistically significant ($p < 0.0001$, $Z = -4.555$, Wilcoxon signed rank test).

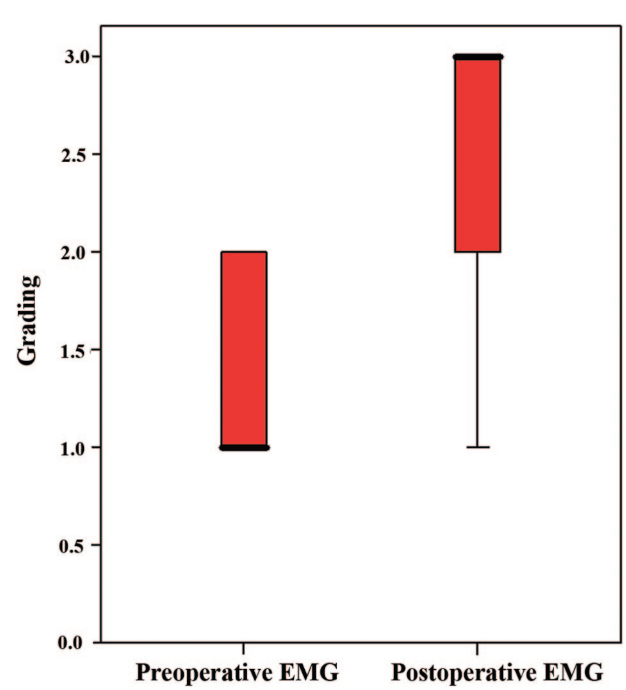

Fig. 3. Preoperative and postoperative needle electromyographic grading of the lower lip depressors. The *dark line* is the median value. The difference of the *ends of the whiskers* is the range. The *end of the box* is the interquartile range. The lower limit is 0 (no evoked potentials) and the upper limit is 3 (full electrogenesis with complete interference pattern). *EMG*, electromyograph.

operative and postoperative electromyographic outcomes (Fig. 3). There was no statistically significant difference between the two groups regarding improvement in electromyographic outcomes ($p = 0.587$, $Z = -0.544$, Mann-Whitney U test).

Tongue Innervation

Needle electromyographs of the tongue obtained preoperatively ensured that the hypoglossal nerve was intact; those obtained postoperatively documented any loss of tongue innervation. In all cases, the electromyographs at 2 years after surgery showed full electrogenesis in the tongue, and no patient developed hemitongue atrophy.

At 6 months after the nerve transfer or direct muscle neurotization, the patients were instructed to follow a rehabilitation regimen in front of a mirror, with exercises for the lower lip. They were asked to isolate the movements from each side and depress the lower lip on the affected side by pushing the tongue against the teeth. Eventually (much sooner in the young population), a varying degree of spontaneity developed so that depression of the lower lip was occurring without conscious effort. In addition, no obvious undesirable lower lip movements were observed during mastication or oral communication. Cases of the nerve transfer group are shown in Figures 4 through 7 and cases for the direct muscle neurotization group are shown in Figures 8 through 10.

DISCUSSION

Our approach to treatment of lower lip palsy has always favored dynamic reanimation. Besides the denervation time and detailed clinical analysis, preoperative needle electromyography has been an essential tool in selecting the appropriate pro-

Fig. 4. Patient 13, a 22-year-old woman, presented with right-sided facial paralysis following unresolved Bell palsy 11 years previously. The preoperative needle electromyographs for depressors showed some evoked potential (grade 1). She underwent mini-hypoglossal–to–cervicofacial branch transfer (end-to-end). Preoperative (*above*) and postoperative (*below*) views of lip depressors are shown. Her averaged preoperative clinical score was moderate (0.67) and her postoperative clinical score was good (1.33).

Fig. 5. Patient 16 was a 23-year-old woman who developed right-sided facial paralysis when she was 4 years old. There were moderate evoked potentials on the needle electromyographs of the depressors. She underwent t mini-hypoglossal–to– cervico-facial branch transfer. Preoperative (*above*) and postoperative (*below*) views of lower lip depression are shown. Her clinical scores were moderate (1.00) and good (1.50), respectively.

Fig. 6. Patient 20, an 18-year-old male patient, suffered a road traffic accident and basal skull fracture. He sustained injuries to multiple cranial nerves, with involvement of the third, fourth, fifth, sixth, and seventh nerves. Transfer of the mini-hypoglossal nerve to the cervicofacial branch was performed after the electromyographs showed the presence of some evoked potentials. Preoperative (*above*) and postoperative (*below*) views of lip depressors are shown. He achieved a good result (1.50), although the preoperative score was fair (0.67).

cedure. In 1967, Edgerton[21] recognized the importance of electromyography in determining the chance of success in reinnervating a paralytic muscle, especially in Bell's palsy. Emphasizing the need for constant evolution in reconstruction of facial palsy and dynamic correction of the lower lip, he stated that "no plastic surgeon is happy with the concept of further reducing function in a face that is already deficient in motor control." He first described the transfer of the anterior belly of the digastric muscle to correct lower lip depression, which was used or modified by others.[1,14,22,23] Conley et al.[12] also performed transposition of the anterior belly of the digastric muscle while preserving its nerve. Rose[24] advocated platysma transfer with fascia lata extension.

Static reconstruction with slings, wedge resections,[9,11] or orbicularis oris muscle transposition can improve oral sphincter tone and symmetry[10] but without animation and with visible scars. Conley[25] combined these techniques for maximum improvement in long-standing facial paralysis with severe muscle atrophy. The purpose of cheiloplasty was to eliminate the paralyzed portion of the lip and transpose the viable contralateral lip. Mahler et al.[26] reported plication of the orbicularis oris muscle by means of a vermilion border incision for partial paralysis. Pickrell et al.[27] used Z-plasties after having unsatisfactory results from static support. For drooling and speech improvement, Miglets[28] performed lip transposition with Z-plasties at the corner of the mouth.

Fig. 7. Patient 26 was a 7-year-old boy who developed partial right facial palsy as a result of Lyme disease. He had a denervation period of 40 months before he underwent mini-hypoglossal–to–cervicofacial branch transfer and cross-facial nerve grafting (×2). Free gracilis muscle was transferred to the right cheek 10 months later. The preoperative needle electromyographs of depressors showed moderate evoked potentials. He was called in for final review to assess the outcome 11 years after the operations. The lower lip depression was maintained the same at 11 years as at 2 years postoperatively. Photographs obtained preoperatively (*above*) and 11 years postoperatively (*below*) showing lower lip depression. The preoperative and postoperative scores were fair (0.50) and good (1.67), respectively.

Several authors have emphasized the importance of dynamic reanimation of the lower lip. Harrison[23] and Tulley et al.[14] have reported use of the anterior belly of the digastric muscle and extensor digitorum brevis to the lower lip. Koshima et al.[29] classified the smile into two patterns: the "usual" smile that involves use of the zygomatic major muscle and the "square" smile in which the depressor labii inferioris muscle is also involved. Recognizing the importance of the depressor mechanism, they performed double-muscle transfer using a divided rectus femoris for one-stage reconstruction. A contralateral buccal branch and the ipsilateral masseteric nerve were used as motor donors. Two years previously, Ueda et al.[30] had published a free double-muscle transfer using latissimus dorsi and serratus anterior muscle segments for lip elevation and depression as a one-stage procedure. The latissimus dorsi muscle was innervated with the contralateral seventh nerve and the serratus anterior muscle was innervated with the ipsilateral mini-hypoglossal nerve. In the discussion, Rubin et al.[31] (Rubin had classified the smile[3] as "Mona Lisa" smile in 67 percent of the population, "canine" smile in 31 percent, and "full denture" smile in 2 percent) emphasized the importance of lower lip depressors in balancing the smile by preventing the corner of the mouth from

Fig. 8. Patient 28 was an 8-year-old boy with right-sided facial palsy following temporal bone fracture from an overturned car accident. The denervation time at the time of the operation was 2½ years. He had direct neurotization of the mini-hypoglossal to lower lip depressors by means of two sural nerve grafts and a cross-facial nerve grafting procedure. The second procedure was free gracilis muscle for smile restoration. Preoperative view of the depressors (*above*). Note the lower lip deformity. During preoperative needle electromyography of lip depressors, he had moderate evoked potentials (grade 2). There was a trace of contraction on the right side of the lower lip (averaged preoperative score, 0.33). (*Below*) Postoperative view at 2 years after the direct neurotization procedure. Note correction of the deformity. The averaged clinical grade was 1.33 (good).

moving upward and laterally. They routinely transferred muscles to both lips for all paralyzed faces. They described[31] an alternative method for control of the lower lip and corner of the mouth using a 3-cm-wide strip of the anterior part of the masseter muscle, used in conjunction with temporalis muscle transfer to the upper lip. However, the direction of the masseteric pull was dissimilar to the one from lower lip depressors.

This study demonstrates outcomes from direct muscle neurotizations that were as satisfactory as those obtained from mini-hypoglossal nerve transfer (Fig. 2). After the first report by Heineke[32] in 1914, direct muscle (nerve-to-muscle) neurotization was the subject of several experimental and clinical studies.[33–38] The fascicles of the distal end of the implanted nerve were usually separated, allowing neural branching.[39] According to Brunelli and Brunelli,[40] the biological basis of direct muscle neurotization is that a denervated muscle will accept new innervation by a foreign nerve even in an aneural zone because its sensitivity to acetylcholine is present throughout the muscle, whereas in a normally innervated muscle it is confined to the motor endplates. They have performed direct muscle neurotizations in patients since 1974, with satisfactory outcomes. The morphology of reinnervation was influenced[39,41] by the site of implantation, with ectopic motor endplates formed when the nerve is implanted away from the native motor endplate zone and native motor endplates increased by near implantation. A successful intramuscular neurotization is dependent on the denervation period. Becker et al.[36] reported 10 clinical cases with direct muscle neurotization in the upper extremities performed by three different surgeons, with successful outcomes, supporting the reliability of the method.

Frey et al.,[42] following reinnervation of the rectus femoris muscle in a rabbit model, reported twitch tension of 75 percent and tetanus tension of 84 percent in the nerve suture group as compared with 67 and 72 percent, respectively, in the nerve implantation group. Both types of reinnervation achieved good recovery of function, with the nerve suture being slightly better than nerve implantation. Ueda and Harii[43] reported that the effects of direct neurotization may compete with those of a nerve repair at an early denervation stage. They proposed it as an alternative method to the "babysitter" procedure to prevent muscle atrophy. Mersa et al. [44] experimentally demonstrated the efficacy of mini-hypoglossal nerve transfer to the main zygomatic branch of the facial nerve after prolonged denervation, by means of behavioral analysis of blink reflex, electrophysiology, and axon and motor endplate counts.

The present study demonstrated improvement following the mini-hypoglossal–to–cervicofacial branch transfer. This is also supported by other studies that reported more powerful reinnervation produced by the mini-hypoglossal nerve transfer compared with cross-facial nerve grafting

Fig. 9. Patient 24, a 14-year-old girl, developed right-sided facial palsy after removal of a vascular anomaly of the brain stem. On the preoperative needle electromyograph of the depressors, she had moderate evoked potentials (grade 2) and the clinical preoperative score was moderate (observable movement with no symmetry). She had a denervation time of 48 months before having direct neurotization of the right mini-hypoglossal to lower lip depressors with a single nerve graft. Preoperative view showing lower lip depression (*above*) and postoperative view showing correction (*below*). Her preoperative grading was moderate (0.83), and the postoperative outcome was graded as good (1.33).

on patients with the babysitter procedure.[45,46] Chen et al.[47] reported "good-quality" regeneration in the facial nerve 6 months after hypoglossal transfer.

All of the direct muscle neurotizations and some of the mini-hypoglossal nerve transfers were performed after end-to-side neurorrhaphy following partial neurotomy of the hypoglossal nerve. The effectiveness of this type of neurorrhaphy has been demonstrated.[48,49] In addition, several studies looked at the consequences following splitting of a motor nerve for transfer on a new target and donor-site morbidity.[45,50] Forty percent of the hypoglossal nerve is ideal for successful nerve transfer and avoidance of effects on tongue innervation.[45,51]

In our series, preoperative needle electromyographs demonstrated the presence of remaining active muscle even in the face of clinical paralysis. Direct muscle neurotization strengthens existing activity, as no disconnection of the cervicofacial branch is performed. Thus, no preoperative clinical motion is downgraded. In the nerve transfer group, despite the electrophysiologic muscle activity, there was no movement or it was significantly diminished. By coapting the cervicofacial branch to a powerful neighboring motor donor, target resuscitation was achieved.

CONCLUSIONS

Neurotization of lower lip depressors in incomplete facial paralysis can be achieved by the use of the mini-hypoglossal nerve either as a nerve transfer or as donor for direct muscle neurotiza-

Fig. 10. Patient 9, a 13-year-old girl, presented with developmental right-sided facial paralysis. She had reconstruction with mini-hypoglossal direct neurotization of lower lip depressors by means of a single nerve graft and also cross-facial nerve grafts during the same procedure. Free gracilis muscle transfer for smile restoration was performed 11 months later. Her last follow-up visit was 9 years (106 months) after the neurotization. The preoperative needle electromyographs showed some evoked potential (grade 1) in the depressors. Preoperative (*above*) and postoperative (*below*) lower lip depression is shown. Her clinical scores were moderate (0.67) preoperatively and good (1.33) postoperatively.

tion. Upgrading of function was demonstrated clinically and electrophysiologically.

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