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REANIMATION OF EARLY FACIAL PARALYSIS WITH HYPOGLOSSAL/FACIAL END-TO-SIDE NEURORRHAPHY: A NEW APPROACH

ABSTRACT

The classic hypoglossal transfer to the facial nerve invariably results in profound functional deficits in speech, mastication, and swallowing, and causes synkinesis and involuntary movements in the facial muscles despite good reanimation. Techniques such as a hypoglossal/facial nerve interpositional jump graft and splitting the hypoglossal nerve cause poor functional results in facial reanimation and mild-to-moderate hemiglossal atrophy, respectively. Direct hypoglossal/facial nerve cross-over through end-to-side coaptation without tension was done in three fresh cadavers and four patients. The patients had facial paralysis for less than 7 months. Complete mobilization of the facial nerve trunk and its main branches beyond the pes anserinus from the stylomastoid foramen, division of the frontal branch, if necessary, and superior elevation of the hypoglossal nerve after dividing the descendens hypoglossi, thyrohyoidal branches, occipital artery, and retromandibular veins were performed. The end of the facial nerve was hooked up through both a quarter of a partial oblique neurotomy and a perineurial window at the side of the hypoglossal nerve. Temporalis muscle transfer to the eyelids and the first stage of cross-facial nerve transfer were performed simultaneously. None of the patients experienced hemiglossal atrophy, synkinesis, and involuntary movements of the facial muscles. Regarding facial reanimation, one patient had excellent, one patient good, and the others fair and poor results after a follow-up of at least 1 year.

Surgical reconstruction of an established facial paralysis is one of the most demanding tasks for the reconstructive surgeon. Irreversible damage of the facial nerve at the brainstem requires an alternative cortical input to the distal facial nerve remnant in order to reanimate the muscles of facial expression, if they are still viable. Various types of nerve transfer using hypoglossal, accessory, and phrenic nerves as motor neurons and cross-facial nerve grafting have been attempted to combat this condition.[1] Surgery

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on the hypoglossal or contralateral facial nerve leads to far better results, compared to previous surgical trials with the accessory and phrenic nerves.[1–4]

Classic hypoglossal/facial nerve coaptation involves complete division of the ipsilateral hypoglossal nerve, inevitably causing hemitongue paralysis and resulting in significant speech, mastication, and swallowing difficulties.[5] Techniques such as a crossover of the descendens hypoglossi to the facial nerve, coaptation of the descendens hypoglossi to the distal stump of the hypoglossal nerve after classic hypoglossal/facial nerve coaptation, a hypoglossal/facial nerve interpositional jump graft, or splitting the hypoglossal nerve have been described, but either the results are poor or hypoglossal function is preserved with mild-to-moderate hemiglossal atrophy.[5–10] Mobilization of the intratemporal portion of the facial nerve to establish hypoglossal transfer with a single neurorrhaphy is technically difficult, with the added risk of facial nerve injury.[11,12] Direct hypoglossal/facial end-to-side coaptation without splitting or nerve grafting appears to be the most reliable method.

We describe a new hypoglossal/facial end-to-side neurorrhaphy technique with a single coaptation that has been developed to bridge the gap between the hypoglossal and the facial nerves. It also includes the first application of a "perineurial window," together with a small neurotomy on the side of the hypoglossal nerve, to enhance hypoglossal reinnervation of the facial nerve and to eliminate hypoglossal dysfunction. Complete mobilization of the facial nerve trunk and its main branches from the stylomastoid foramen to beyond the pes anserinus within the parotid gland, together with division of the frontal branch, if necessary, and superior elevation of the hypoglossal nerve after dividing the descendens hypoglossi and the thyrohyoidal branches were performed. The occipital artery was also divided to release the hypoglossal nerve. The end of the facial nerve was coapted with both the perineurial window and a smaller oblique neurotomy than is used in other techniques on the side of the hypoglossal nerve.

PATIENTS AND METHODS

ANATOMIC DISSECTION. Cadaver studies were carried out to observe whether or not neurorrhaphy is tensionless after the facial nerve trunk and its main branches and the hypoglossal nerve are completely mobilized. The facial and hypoglossal nerves were dissected in three fresh cadavers. The facial nerve was mobilized from its exit through the stylomastoid foramen to beyond the pes anserinus, approximately 3 to 4 cm within the parotid gland. The hypoglossal nerve was released from all its connections, such as the occipital and retromandibular vessels, descendens hypoglossi, and thyrohyoid branches (Fig. 1). It could be pulled up 1.5 cm in the superior direction. The facial nerve reached the hypoglossal nerve in the retromandibular area without tension (Fig. 2). It was not necessary to transect the frontal branch of the facial nerve in the cadaver dissections.

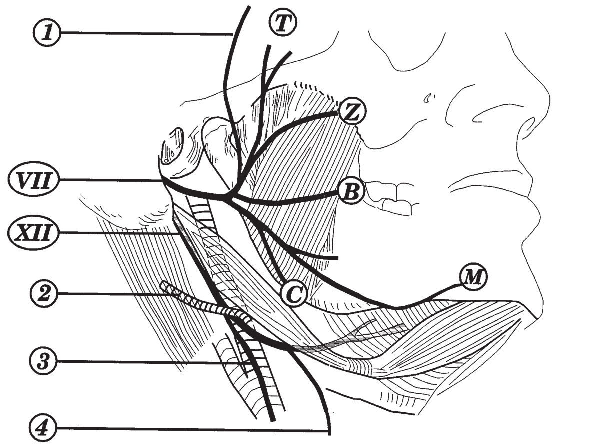

Figure 1. Anatomy of the facial (VII) and hypoglossal (XII) nerves (T = r. temporalis; Z = r. zygomaticus; B = r. buccalis; M = r. marginalis mandibulae; C = ramus colli). It may be necessary to divide the frontal branch (1) which is usually the first superior branch of the facial nerve within the parotid gland. The occipital artery (2), the descendens hypoglossi (3), and the thyrohyoidal (4) branches of the hypoglossal nerve are also divided.

PATIENTS. Four patients, three women and one man, ranging in age from 28 to 55 years (average: 41 years) underwent hypoglossal/facial end-to-side neurorrhaphy without nerve grafting for the treatment of unilateral facial paralysis. The causes of the paralyses are listed in Table 1. All patients were referred from neurosurgery with the facial nerve known to

Figure 2. Hypoglossal/facial end-to-side coaptation without tension in a cadaver dissection.

Table 1. Patient Data

Patients	*Age (yrs)*	*Etiology (After Surgery for)*	*Duration of Facial Paralysis*	*Additional Procedures at the Same Stage*	*Follow-Up*	*Results*
1. MD*	47	Trigeminal neuralgia	5 months	1-CFNG 2-Temporalis transfer	19 months	Excellent
2. NY	28	Acoustic neuroma	3 months	1-CFNG 2-Temporalis transfer	37 months	Good
3. US	55	Acoustic neuroma	1 month	1-CFNG 2-Gold-weight loading	22 months	Fair
4. RA*	34	Acoustic neuroma	7 months	1-CFNG 2-Temporalis transfer	25 months	Poor

*frontal branch was divided.

have been resected or irreversibly damaged. They all had had facial paralysis for less than 7 months.

Direct end-to-side hypoglossal/facial coaptation was essentially planned as a baby-sitting procedure to prevent atrophy of the perioral muscles. A sural cross-facial nerve graft was implanted, coapting a facial nerve branch that strongly innervated the perioral elevator muscles on the non-paralyzed side, and leaving the other end of the nerve graft free in front of the tragus on the paralyzed side in all patients at the first stage. Results at least 1 year after the hypoglossal/facial nerve cross-over without a second stage of cross-facial nerve grafting were evaluated. Additionally, a dynamic temporalis muscle transfer was done to protect the eye at an early stage in three patients and, because one of them had an accompanying trigeminal nerve paralysis, another sural cross-facial nerve graft was done, and hooked up to the nerve which tightly closed the eye. Later, a gold weight was necessary to provide eye closure in this patient.

Surgical Technique. After completion of cross-facial nerve grafting on the non-paralyzed side, the other end of the graft was left free in front of the tragus on the paralyzed side with the pretragal incision. This incision was extended inferiorly, similar to that of a parotidectomy. The facial nerve was exposed after the parotid had been mobilized. The posterior belly of the digastric muscle attachment to the mastoid bone marks the level at which it exits the stylomastoid foramen. The posterior belly of the digastric muscle was removed between the mastoid and hyoid bones, and the hypoglossal nerve was also isolated where it coursed behind the internal jugular vein. The facial nerve was found at or near the stylomastoid foramen immediately beneath the anterior third of the mastoid process, which could be removed for easy access to the nerve trunk. The facial nerve was divided as far proximally as possible, allowing for greater distal length to be used with the coaptation.

The hypoglossal nerve was dissected as proximally as possible, compressing the jugular vein dorsally. The hypoglossal nerve curves around the occipital artery. At this point, its descending branch leaves the nerve and goes down anterior to the external carotid artery. The hypoglossal nerve gives off the thyrohyoidal branch near the posterior border of the hypoglossus muscle. The occipital artery, the descending, and the thyrohyoid branches were divided to mobilize the hypoglossal nerve superiorly and anteriorly, without division of the main trunk.

The facial nerve was dissected between the parotid lobes and was followed distally past the pes anserinus (Fig. 3). The facial nerve trunk and its main branches were fully mobilized from the surrounding tissues and rerouted inferiorly to the hypoglossal nerve. In two patients, the frontal branch was divided to provide extra length for the facial nerve, after no major loss was seen around the mouth under electro-stimulation.

Technique of Neurorrhaphy. Under the operating microscope, one-quarter of the hypoglossal nerve was transected 45 degrees obliquely, exposing the proximal axons. The main trunk of the distal facial nerve could easily reach the partially transected hypoglossal nerve without tension. The diameter of the atrophic facial nerve was greater than this transection area. The facial nerve generally has one large fascicle and several smaller fascicles at this point. Its large fascicle was hooked up to the partially transected area. The epi- and perineurium were severed around the transection area, and the remaining satellite fascicles were coapted through this perineurial window (Fig. 4). Neurorrhaphy was done with 11-0 monofilament nylon sutures under magnifications of X16 and X25. The epineurium of the facial nerve was then fixed to the hypoglossal epineurium,

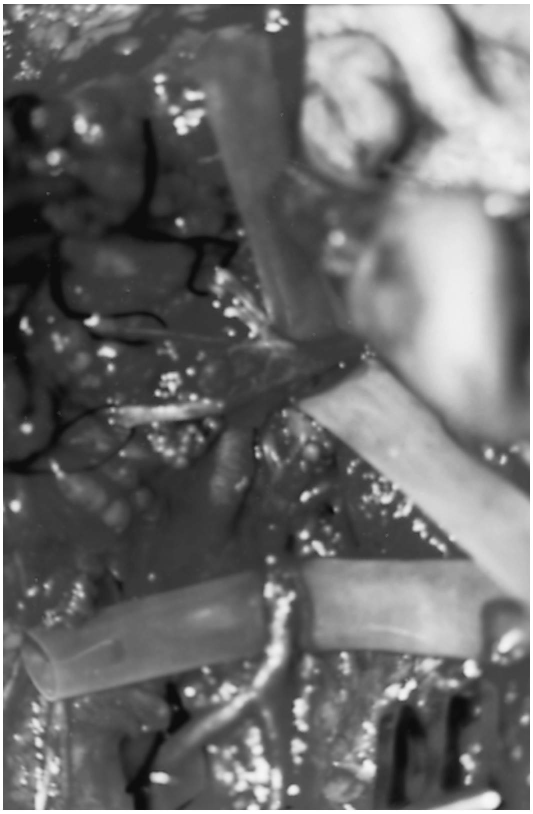

Figure 3. Mobilization of the facial nerve beyond its main branches. Note the atrophic appearance of the nerve in the upper part of the picture. The hypoglossal nerve and the descendens hypoglossi are also seen.

and the hypoglossal nerve was fixed to the surrounding tissues to further reduce tension on this neural tissue coaptation.

Head movements, especially to the counter side, were restricted during the next 15 postoperative days. All patients were encouraged to perform tongue exercises postoperatively and to learn to move the mouth angle efficiently. All patients except one were referred to physical medicine and rehabilitation for biofeedback.

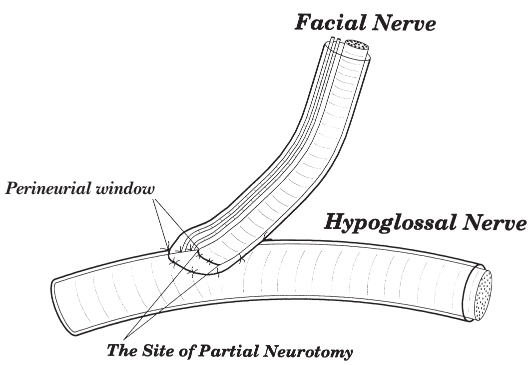

Figure 4. Diagram of nerve coaptation technique that includes the use of the perineurial window along with a small neurotomy.

Table 2. Evaluation of Facial Nerve Function

Excellent	Tone, symmetry, good movement
Good	Tone, symmetry, fair movement
Fair	Tone, symmetry, limited movement
Poor	Tone without symmetry and movement

RESULTS

The return of function began in approximately 6 to 8 months. Results were classified as excellent, good, fair, and poor, according to static tonus, symmetry, movement (Table 2). An excellent result was defined as regained muscle tonus, resting symmetry, and volitional good movement around the mouth on the paralyzed side (Fig. 5). One patient had excellent, one patient good, and the others had fair and poor results after a follow-up of at least 1 year (see Table 1). The patient with the poor result was operated on for recurrence of intracranial tumor 2 months after hypoglossal/facial transfer in the neurosurgery department and was dropped from follow-up because of psychological disturbance. The patients with excellent and good results exercised regularly and went through a biofeedback program postoperatively. The patient with the fair result could do only the exercises (Fig. 6).

None of the patients experienced synkinesis and involuntary mass movement. Hemiglossal atrophy and related difficulties in speaking, mastication, and swallowing were not seen (Fig. 7).

EMG findings were obtained for each patient 1 year later (Fig. 8). Two of the patients refused the second stage of the CFNG operation. Results presented in Table 1 are before the second operation. The facial nerve branches were observed to be viable and trophic perioperatively at the second procedure (Fig. 9).

DISCUSSION

The hypoglossal nerve contains powerful motor axons that control the intricate functions of the tongue; therefore, good facial tonus and motion are obtained in the classic hypoglossal/facial nerve cross-over technique, but it leaves the patient crippled with intraoral complications.[1,5] Hemitongue paralysis can result in profound functional deficits in speech, mastication, and swallowing. Various degrees of synkinesis of the eye sphincter with the lower face occur in all patients. In addition, involuntary movements of the paralyzed face while partaking of food are an unpleasant symptom for patients.[1,5,8]

Some modifications that utilize only a portion of the hypoglossal nerve in the transfer have been developed to avoid or reduce these drawbacks and limi-

Figure 5. Patient #1 in Table 1, 5 months after onset of right facial paralysis (A–C). A, Face in repose. B, Showing teeth. C, With eyes closed. Same patient with excellent results 19 months after hypoglossal/facial nerve end-to-side coaptation (D–F). D, Face in repose. E, Showing teeth. F, With eyes closed tightly without mouth movement. (D and E are the results of hypoglossal stimulus; F is related mainly to temporalis muscle action.)

tations of the classic procedure. Conley's initial experience with splitting the hypoglossal nerve or utilizing the descendens hypoglossi nerve was unsatisfactory.[5] The descendens hypoglossi alone does not have an adequate number of axons to supply either the facial musculature or the whole tongue musculature.[6] Arai et al. reported successful facial reanimation with direct splitting of the hypoglossal/facial nerve coaptation.[8] However, they found mild-to-moderate glossal atrophy on the operated site in all of the patients. The hypoglossal nerve is monofascicular up to its distal third portion, and a long split along the distal half proves harmful and appears to cause hemiatrophy of the tongue.[13] Axons in the hypoglossal nerve thread their way through neural tubules in a random, interweaving fashion; therefore, splitting the nerve invariably results in the transection of axons at multiple points. This leads to degeneration, not only of the segment split for coaptation to another nerve, but also of the main trunk of the nerve.[7]

May et al., reported the placement of an interpositional nerve graft between the facial and hypoglossal nerves.[7] Facial motion is not strong in the jump-graft procedure. It requires a long nerve graft, usually 5 to 7 cm, and therefore contains two neurorrhaphy sites. Two-fold loss of axons at the two neurorrhaphy sites, together with fewer axons being transferred from an end-to-side coaptation, are responsible for weak facial motion.[14]

Atlas and Lowinger mobilized the intratemporal portion of the facial nerve to gain extra length and hooked it up to the side of the hypoglossal nerve in three relatively early cases.[12] This was combined with gold weight-loading to the eye and a medial canthoplasty to enhance hypoglossal/facial nerve transfer. The results were found to be successful, but this procedure is technically difficult and carries a high risk of injury to the main trunk within the temporal bone.

Extensive mobilization of both facial and hypoglossal nerves was carried out to accomplish ten-

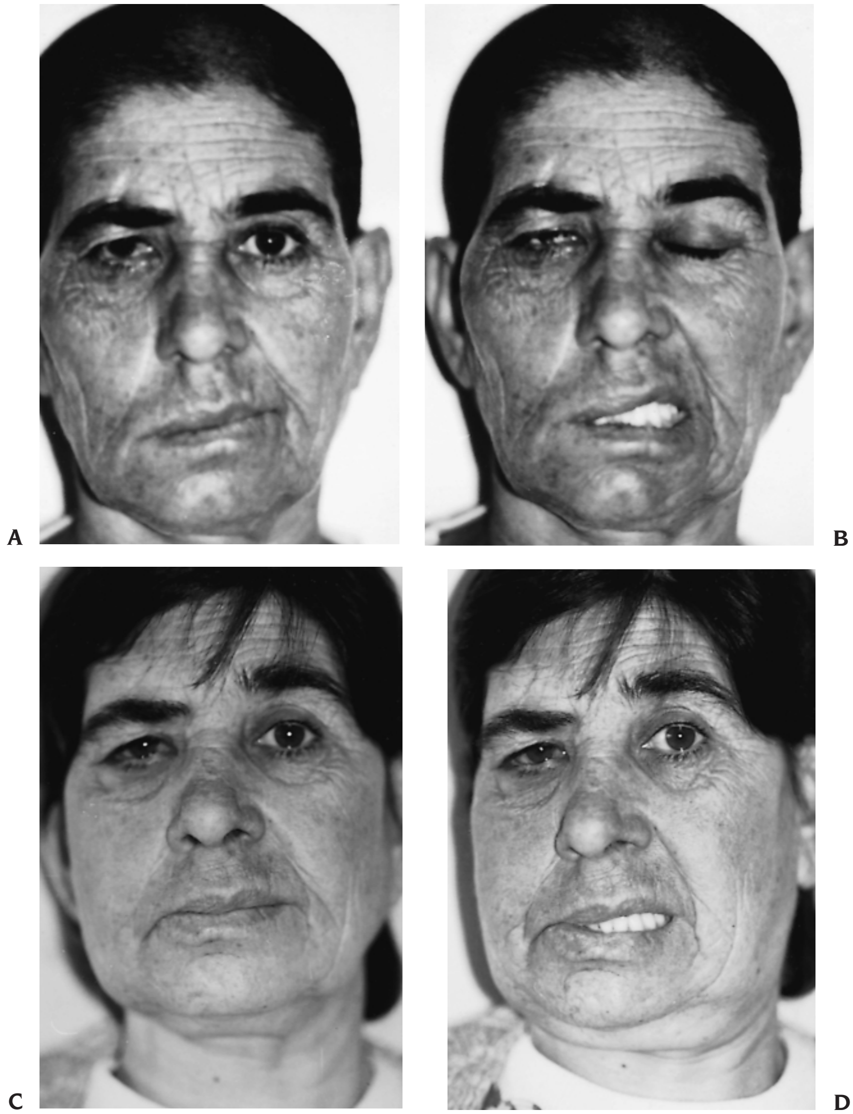

Figure 6. Patient #3 in Table 1, with fair result 1 month after right acoustic tumor surgery (A, B). A, Face in repose. B, Showing teeth. Same patient 22 months after hypoglossal/facial nerve end-to-side coaptation (C,D). C, Face in repose. D, Showing teeth. Nasolabial fold is more prominent on the operated side and oral continence is accomplished. Sufficient tone but limited movement are observed.

sionless end-to-side neurorrhaphy. The facial nerve trunk and its main divisions were dissected and mobilized in the inferior direction. The frontal branch was sectioned, if necessary, to gain extra length. The frontal branch was the first one arising from either the main trunk or the temporal division in both the cadaver and perioperative dissections. According to the 1995 38th edition of *Gray's Anatomy*,[15] the frontal branch is the first branch and leaves the parotid 1.5 cm in front of the tragus in most dissections. Fixation points of the hypoglossal nerve, such as the occipital artery, descendens hypoglossi, and thyrohyoid branches are divided and elevated superiorly and anteriorly. This provides for a 1.5-cm approximation of the hypoglossal nerve to the facial nerve. The descending hypoglossi gives only a branch to the superior belly of the omohyoid before it joins the lower root of the ansa. The thyrohyoid branch supplies the thyrohyoid and geniohyoid muscles. Functional loss to these branches is not significant.[15]

Figure 7. Patient's tongue without atrophy.

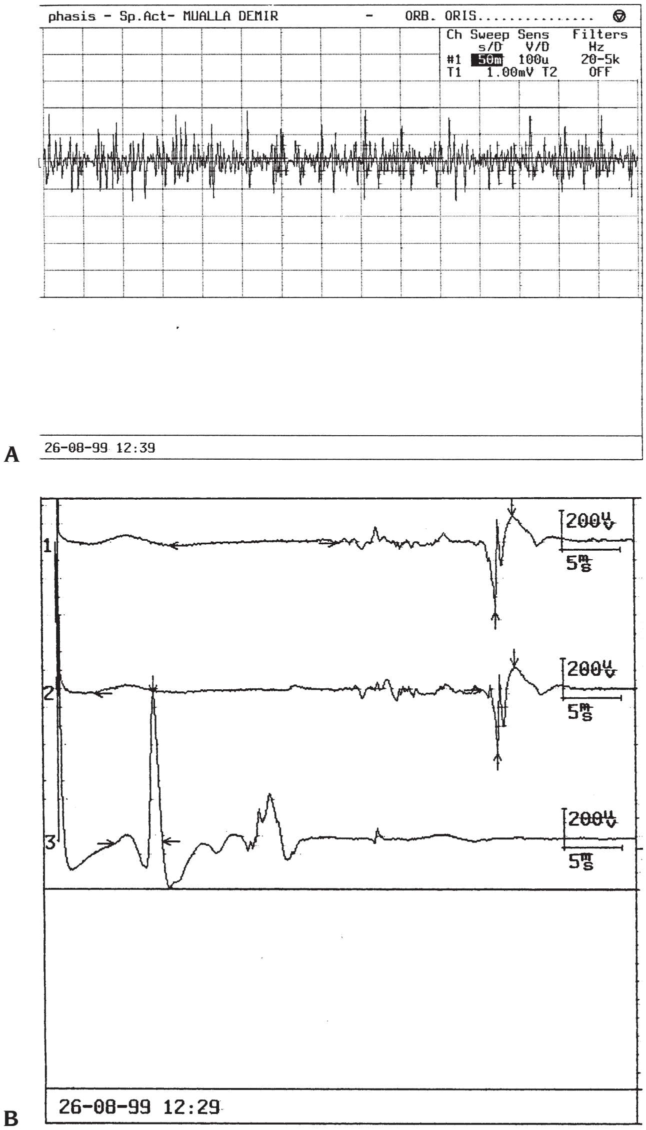

Figure 8. Electromyography and electroneuromyography of Patient #1, Table 1, 1 year after surgery. A, EMG with a full interference pattern in the perioral muscles of the operated side while she was pushing her tongue against her teeth. B, Action potential obtained from the perioral levator muscles after stimulation of the ipsilateral hypoglossal nerve in the lowermost trace. The upper two traces are related to contralateral facial nerve stimulation via CFNG.

Figure 9. Trophic appearance of facial nerve branches seen during the second stage of CFNG indicates that they received powerful hypoglossal reinnervation. Compare these branches with the atrophic facial nerve trunk in Figure 3.

Axonal escape and subsequent loss of reinnervation due to the division of the frontal branch of the facial nerve are controversial topics. The frontal branch of the facial nerve has a relatively low number of nerve fibers.[16] The aim of the hypoglossal/facial transfer is directed mainly toward mouth reanimation, and the axonal loss through the frontal branch is not significant. Transfer of the hypoglossal nerve to the facial nerve leads to sufficiently adequate results around the perioral region, because these nerves have a cortical topographic proximity in the motor cortex, with a large cortical representation for the tongue.[6] Both nerves receive afferent input from the trigeminal nerve in mechanosensory-motor reflex arcs, and they act synergistically in the coordination of some mimetic and prandial functions.[17]

Temporalis transfer to the eyelids was performed to protect the eye at an early stage.[18] The eyelid movements are controlled mainly by the temporalis muscle, and this prevents involuntary mass motion of the periorbital and perioral muscles. Involuntary movements in the perioral muscles were not observed in the patients either, probably due to the fact that fewer axons were transferred than with the classic hypoglossal/facial nerve cross-over.

The transection of the hypoglossal nerve and the type of neurorrhaphy we present are different in some ways from previous techniques. A bevelled incision was made one-third to halfway through the hypoglossal nerve to match the size of the facial nerve stump by other reporters.[7,9–11] Using the operating microscope, we made an oblique incision up to the upper quarter of the hypoglossal nerve, partially transecting the nerve and exposing the proximal axons. A 45°oblique transection increases the diameter of the coaptation area. One large fascicle of the facial nerve was united with the proximal cut end of the partially transected hypoglossal nerve and the remaining smaller fascicles of the facial nerve, usually two to three in number, were sutured to the perineurial window on the hypoglossal nerve around the transection area.

Millesi[19] stated that the main trunk of the facial nerve near the stylomastoid foramen consists of one large fascicle and a few small fascicles like satellites. A smaller cut in the hypoglossal nerve decreases the risk of injuring more axons and thus minimizes postoperative sequelae. No functional deficits in speech, mastication, and swallowing were seen by us. Direct neurorrhaphy without nerve grafting or splitting provides stronger motion. The degree of reinnervation in the facial nerve was also believed to increase with coaptation through a perineurial window. In her experimental study, Terzis et al.[20] stated that the degree of reinnervation was greatest in nerve grafts that had a perineurial window or partial neurectomy, possibly due to nodal and/or collateral sprouting. Lundborg and colleagues[21] reported that an end-to-side attached nerve segment attracted axons from an intact nerve. A predegenerated segment was superior to a fresh end-to-side attachment and the attracted axons were able to innervate a foreign peripheral target.

Ballance et al. proposed the first end-to-side repair of the facial nerve using the spinal accessory nerve in 1903.[22] The procedure was reintroduced by Viterbo et al. in 1992.[23] Since then, there have been several studies evaluating end-to-side reinnervation.[24] This concept is now accepted, although extensive clinical studies have not, as yet, been done to confirm the efficacy in humans. Viterbo also has reported cross-facial nerve transplantation with end-to-side neurorrhaphy without removal of the perineurial window.[25]

The restoration of spontaneous emotional expression did not occur with the hypoglossal/facial nerve transfer. The contralateral facial nerve is most suitable because this nerve performs the same task on the normal side and works simultaneously with its counterpart.[26] But it requires two coaptation sites, causing a two-fold loss of axons, and a long nerve graft to mimic muscles that have undergone irreversible atrophic changes during the long regeneration time. Terzis and colleagues have advocated a two-stage CFNG procedure in which the hypoglossal nerve is used as a "baby sitter" of the mimic muscles at the first stage.[14]

Cooperative patients understand that, although spontaneous emotional facial response is not regained, they are able to produce a synchronous strong smile with tongue movement (Fig. 10). This requires long practice, applied concentration, and sustained motivation. The only fair and poor results might be related to poor postoperative compliance.

The problem of bridging the gap between the hypoglossal and facial nerves is overcome by releasing the hypoglossal nerve and mobilizing the facial nerve beyond the pes anserinus and dividing the frontal branch, if necessary. Direct coaptation through both the neurotomy and the perineurial window decreases the risk of damage to the hypoglossal nerve and increases the possibility of reinnervation of the paralyzed facial nerve. The successful use of the "perineurial window," along with a small neurotomy, is a novelty for peripherial nerve surgery in humans. This new method is advocated as a primary treatment of facial paralysis or as a baby-sitting procedure in two-stage cross-facial nerve grafting.

Figure 10. Synchronized smile.

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INVITED DISCUSSION

Ronald M. Zuker

This paper presents a new technique for preservation of the musculature innervated by the facial nerve, following central intracranial acquired facial paralysis. The four clinical cases reported were all surgically addressed less than 7 months after the onset of paralysis, so the musculature still had the potential of being reinnervated. The procedure described involves a direct anastomosis of the proximal facial nerve stump to the side of the intact hypoglossal, with various maneuvers undertaken to facilitate this. The technical description of nerve positioning and nerve repair is clear and comprehensive.

On a positive note, the authors have shown that the end-to-side technique does not clinically downgrade the function of the tongue, despite the 45-degree oblique transection of 25 percent of its circumference. This addresses one of the major criticisms of the hypoglossal/facial anastomosis. Thus, the lack of donor problems with the use of the side of the hypoglossal is encouraging. Without an intervening nerve graft, one would anticipate excellent functional return in the facial nerve musculature.

In evaluating the results of the transfer with respect to facial nerve function, one is struck by the lack of a systemized evaluation system. This reinforces the need for more objective criteria in describing results in facial paralysis reconstruction. Of their four patients, only one had an excellent result and, even here, symmetry was not fully realized. The good result is not depicted and the fair result shows little, if any, movement. The poor result is also not depicted, but is explained on the basis of poor compliance with the exercise program. Actually, reinnervated muscle should contract, even without any rehabilitation; the latter is useful to encourage symmetry and to provide a degree of spontaneity, but not for movement itself. Thus, one cannot attribute the poor and fair results to the lack of patient compliance. Age could be a factor and, in the case of the fair result, the 55-year-old patient perhaps did not reinnervate as well as a younger patient might. Time of denervation could also be a factor and, in the poor result, the paralysis was present 7 months before the procedure.

One of the principal benefits of the baby-sitter concept is to maintain tone so that true spontaneous reinnervation can be provided later. If this tone is not provided very rapidly, the full benefit of baby-sitting will not be realized. That is why the standard XII-VII technique has worked so well in the past, and perhaps why this new reported technique is not as effective as one might think. If excellent results could be achieved by the end-to-side technique in case #1, why could they not be repeated in the others? The timing of reinnervation and, consequently, the elapsed time post onset of paralysis, and the site of repair, are crucial.

I congratulate the authors on a novel approach to maintain the function of the denervated facial musculature, without compromising tongue function, with a modified XII-VII technique. Clearly, the procedure has merit, but needs to be done early to minimize denervation time.

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