J Neurosurg 118:160–166, 2013

Hemihypoglossal nerve transfer for acute facial paralysis

Clinical article

Ayato Hayashi, M.D.,[1] Masanobu Nishida, M.D.,[1] Hisakazu Seno, M.D.,[1] Masahiro Inoue, M.D.,[1] Hiroshi Iwata, M.D.,[1] Tomohiro Shirasawa, M.D.,[1] Hajime Arai, M.D.,[2] Ryoji Kayamori, M.D.,[3] Yuzo Komuro, M.D.,[4] and Akira Yanai, M.D.[1]

Departments of [1]Plastic and Reconstructive Surgery and [2]Neurosurgery, Juntendo University School of Medicine; [3]Department of Rehabilitation, Teikyo University School of Medicine, Tokyo; and [4]Department of Plastic, Reconstructive, and Aesthetic Surgery, Urayasu Hospital, Urayasu, Chiba, Japan

Object. The authors have developed a technique for the treatment of facial paralysis that utilizes anastomosis of the split hypoglossal and facial nerve. Here, they document improvements in the procedure and experimental evidence supporting the approach.

Methods. They analyzed outcomes in 36 patients who underwent the procedure, all of whom had suffered from facial paralysis following the removal of large vestibular schwannomas. The average period of paralysis was 6.2 months. The authors used 5 different variations of a procedure for selecting the split nerve, including evaluation of the split nerve using recordings of evoked potentials in the tongue.

Results. Successful facial reanimation was achieved in 16 of 17 patients using the cephalad side of the split hypoglossal nerve and in 15 of 15 patients using the caudal side. The single unsuccessful case using the cephalad side of the split nerve resulted from severe infection of the cheek. Procedures using the ansa cervicalis branch yielded poor success rates (2 of 4 cases).

Some tongue atrophy was observed in all variants of the procedure, with 17 cases of minimal atrophy and 14 cases of moderate atrophy. No procedure led to severe atrophy causing functional deficits of the tongue.

Conclusions. The split hypoglossal-facial nerve anastomosis procedure consistently leads to good facial reanimation, and the use of either half of the split hypoglossal nerve results in facial reanimation and moderate tongue atrophy.
(http://thejns.org/doi/abs/10.3171/2012.9.JNS1270)

Key Words • **facial paralysis** • **facial reanimation** • **nerve graft** • **hypoglossal-facial nerve transfer** • **hypoglossal nerve** • **pain** • **diagnostic and operative techniques**

Surgical reconstruction for the treatment of facial paralysis has been one of the most difficult challenges for reconstructive surgeons in the past century. The first description of a nerve transfer procedure was published at the beginning of the 20th century.[3] More recently, significant innovations in surgical procedures for facial reanimation have resulted from the development of microsurgery.

Various types of procedures have been developed for established facial paralysis, including reanimation of paralyzed facial mimetic muscles using adjacent motor nerves,[4,19,31] as well as free neurovascular muscle transfer using muscles such as the latissimus dorsi[11,12] or gracilis muscle.[26] Indications for these procedures depend largely on the duration of facial paralysis. Several nerves, such as the contralateral facial,[21,31] masseter,[7] hypoglossal,[6,19] and accessory nerves,[4] are described as effective sources to reinnervate the paralyzed facial nerve; each of these nerves presents unique pros and cons. Among them, the hypoglossal nerve has been the most widely used motor source for facial reanimation[22,28,34] since Körte and Bernhardt[19] first documented its use in 1903 and Conley and Baker[6] established the procedure in 1979. Conley and Baker transected the hypoglossal nerve completely and then performed end-to-end neurorrhaphy to the trunk of the facial nerve. However, the disruption of swallowing and speech as a result of tongue paralytic deviation and atrophy was a problematic complication. Pensak et al.[27] noted that 74% of treated patients experienced swallowing dysfunction, and Hammerschlag[10] found that 45% of patients suffered from swallowing and speech dysfunction. Moreover, because of the stimulus strength of the entire hypoglossal nerve, patients experienced severe synkinesis from the excessive contraction of facial mimic muscles.[6]

Abbreviations used in this paper: CFNG = cross-face nerve graft; HB = House-Brackmann; HHFNT = hemihypoglossal-facial nerve transfer.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.

To solve these problems, we developed a procedure in which the hypoglossal nerve is split in half longitudinally and anastomosed to the facial trunk in an end-to-end fashion (Fig. 1). We call the technique "hemihypoglossal-facial nerve transfer," first describing it in 1995.[1] Similar procedures were reported by Cusimano and Sekhar[8] in a case report and recently by Rochkind et al.[29] in 2008.

In this paper, we describe transitions in our procedure in the past 20 years, including an experimental analysis, and we review the procedure for facial reanimation.

Methods

Approval for the study was obtained from the ethical review board of Juntendo University Hospital, and all patients provided written informed consent to participate in the study.

Patient Population

All patients included in the study had complete facial paralysis (HB Grades IV–V) following the removal of a brain tumor (most lesions were vestibular schwannomas). Spontaneous recovery was not expected in these patients, since the facial nerve was completely transected or damaged during surgery. The average age was 54.7 years (range 31–68 years), and the average period of paralysis was 6.2 months (range 1–11 months) prior to reconstructive surgery. The average follow-up period was 3.1 years (range 8 months to 10.5 years), and 36 patients were followed up for at least 8 months.

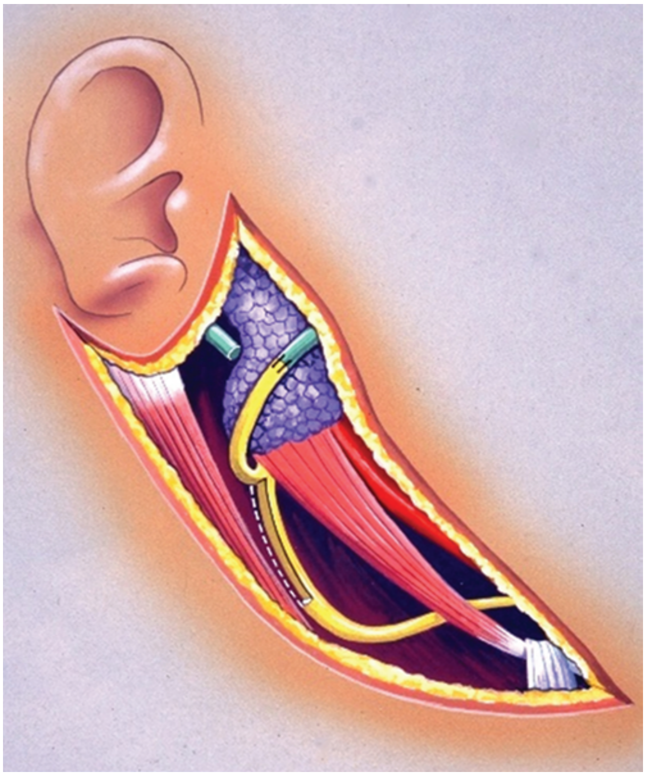

Fig. 1. Drawing featuring the HHFNT procedure. The hypoglossal nerve is split in half longitudinally and anastomosed to the transected facial trunk in an end-to-end fashion. Printed with the permission of Akira Yanai, 2012.

Surgical Procedure

For HHFNT, a Y-shaped skin incision was made from ear front to submandibular lesion. After transecting the skin and platysma, the digastric muscle was located underneath the submandibular gland, and the hypoglossal nerve was located below it. The trunk of the facial nerve was found next to the lower edge of the ear pointer cartilage, and a 5-cm segment of the hypoglossal nerve was detached from surrounding tissue. A lead plate was placed under the hypoglossal nerve, protecting the carotid artery and surrounding tissue from injury while splitting the nerve (Fig. 2A). The extent of hypoglossal nerve splitting was determined by measuring the distance from the proximal edge of the split to the trunk of the facial nerve, approximately 4 cm, and starting from the bifurcation of the ansa cervicalis branch.

A key aspect of the procedure is achieving the finest possible uniform longitudinal dissection of the monofascicular hypoglossal nerve (Fig. 2C). To accomplish this, we attempted to incise the whole trunk of the nerve at once by using a fine microsurgical scalpel intended for eye surgery, sensing the lead plate on the tip of the knife while splitting the nerve (Fig. 2A).

After confirming the length of nerve to transfer and deciding which side, caudal or cranial, would be transferred, the distal edge of the selected hypoglossal nerve was transected. The facial nerve trunk was also transected as proximally as possible, adjacent to the stylomastoid foramen, and flipped toward the split hypoglossal nerve (Fig. 2D). The facial and split hypoglossal nerves were sutured together via end-to-end neurorrhaphy under a surgical microscope (Fig. 2E). A nerve graft was performed to repair the longitudinal nerve defect created in the hypoglossal nerve by the transfer, using the sural nerve (when a CFNG is performed simultaneously) or the great auricular nerve for the graft (Fig. 2B).

The procedure requires selecting 1 portion of the split hypoglossal nerve for anastomosis: the cephalad side or the caudal side. We have changed our strategy 5 times, and therefore we describe the results obtained during 5 different periods in the development of the procedure (Periods 1–5; Table 1). Note that the type of surgery performed was changed mid-year in each period.

During the first period, 1988–1989, the caudal longitudinal half of the hypoglossal nerve was used as a recipient nerve, and we simultaneously performed a CFNG as a baby-sitting procedure. However, none of these patients elected to undergo the second surgery of the baby-sitter procedure, and hence the sural nerve graft remained unconnected to the facial nerve on the paralyzed side.

In all subsequent procedures, we performed an ordinal CFNG simultaneously with the hypoglossal nerve transfer. In the second period, 1989–1994, selection of the recipient nerve was based on movement of the tongue on electrostimulation of each half of the split hypoglossal nerve. The half that showed the least response was selected for anastomosis to the facial nerve to minimize tongue atrophy.

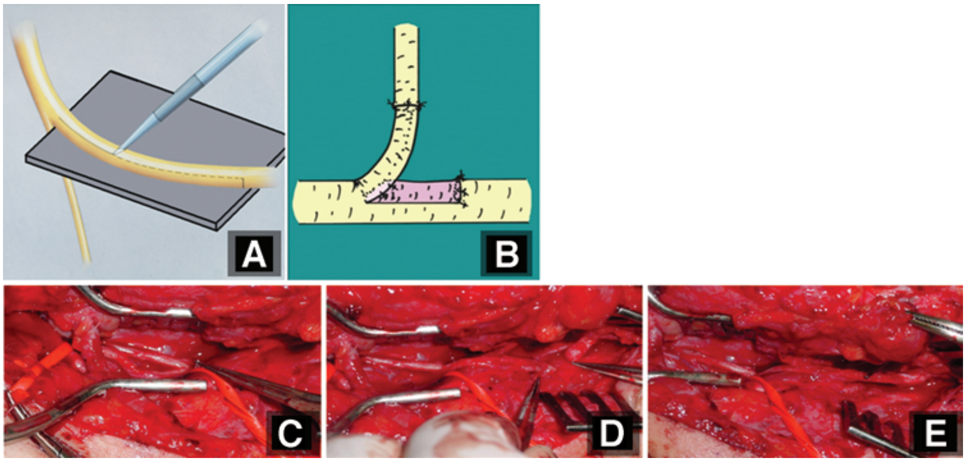

Fig. 2. **A:** Schematic showing a lead plate under the hypoglossal nerve to protect adjacent tissues from injury while splitting the hypoglossal nerve. **B:** Schematic depicting a nerve graft made to fill the longitudinal nerve defect of the hypoglossal nerve after transfer. **C:** Intraoperative photograph showing uniform longitudinal dissection of the hypoglossal nerve. **D:** Intraoperative photograph showing transection of the facial nerve trunk and flipping it toward the split hypoglossal nerve. **E:** Intraoperative photograph showing suturing of the facial and split hypoglossal nerves via end-to-end neurorrhaphy. Schematics printed with the permission of Akira Yanai, 2012.

During the third period, 1994–1995, we used the ansa cervicalis branch as a recipient nerve.

During the fourth period, 1995–1998, each half of the split hypoglossal nerve was electrically stimulated, and the evoked potential of the tongue was recorded via electrodes on the tongue (Fig. 3). The half that showed the smallest response was selected for anastomosis to the facial nerve, to minimize tongue atrophy.

During the fifth period, 1998–present, we used either side of the nerve without any selection procedure, since there was no apparent difference between the cephalad and caudal sides.

Evaluation of Facial Movement

Facial movement was evaluated both pre- and postoperatively using the HB facial nerve grading system.[16] Gross facial appearance was assessed at rest, during movement, and during motion of the forehead and motion around the eyes and mouth. Facial nerve function was graded from I to VI. Facial nerve function in all 36 patients was preoperatively graded as IV or V.

Tongue mobility was evaluated by the same investigator (A.Y.), observing signs of deformity, atrophy, and tongue movements, and was graded as exhibiting little to severe atrophy (Fig. 4). In addition, functional recovery of the mimic muscles was evaluated by electrophysiological examination of 9 patients, and the effects of CFNG and hypoglossal nerve transfer on reanimation were compared.

Results

After treatment, most patients exhibited good facial movement (HB Grade II or III), and no difference was observed between the use of the cephalad or caudal side of the split nerve (Tables 2 and 3), although use of the ansa cervicalis branch was associated with a lower rate of reanimation. Facial movement did not recover in 2 patients in whom we used the ansa cervicalis branch as a recipient (third period), and 1 patient did not attain good recovery (HB Grade IV) because of a surgical field infection. Facial muscle tone generally showed signs of recovery within 4–12 months, with restoration of facial symmetry at rest (Fig. 5). Facial movement was somewhat synkinetic but not excessively so. Involuntary movement associated with eating and drinking was observed in most of the patients but was not a severe symptom.

Some extent of tongue atrophy was noted in all periods (Table 4), graded as minimal atrophy in 17 patients

TABLE 1: Transitional periods during the development of HHFNT as regards selecting half of the split hypoglossal nerve

Study Period	Years*	No. of Cases w/ Facial Reanimation/Total	Notes
1	1988–1989	5/5	caudal side of hypoglossal nerve used; CFNG (baby-sitting op)
2	1989–1994	11/12	electrostimulation used for selection of nerve (cephalad or caudal side); CFNG (permanent op)
3	1994–1995	2/4	ansa cervical branch used; CFNG (permanent op)
4	1995–1998	7/7	evoked potential measured to decide on recipient nerve (cephalad or caudal side); CFNG (permanent op)
5	1998–present	8/8	no selection (cephalad or caudal side); CFNG (permanent op)

* Type of surgery was changed mid-year for each period.

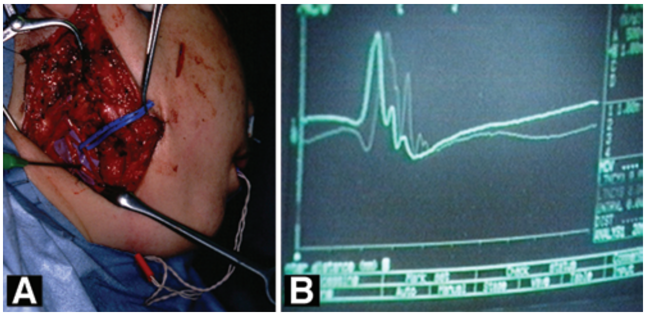

Fig. 3. **A:** Photograph showing electrical stimulation of each half of the split hypoglossal nerve. The evoked potential of the tongue is recorded via electrodes. **B:** Image showing the recorded evoked potential.

and as moderate atrophy in 14 (Fig. 5F). Some patients reported functional deficits immediately after surgery, but these issues disappeared with time. No patients experienced severe atrophy leading to functional deficits in swallowing and speech, and there were no significant differences among the various study (procedure) periods.

Comparing the degree of tongue denervation with the amount of facial nerve improvement, 20 patients showing recovery from HB Grade V to III had minimal or moderate tongue atrophy (Table 5). All of the patients treated using the ansa cervicalis branch (third period) showed little atrophy of the tongue; however, the amount of facial nerve recovery varied (from HB Grade V to Grades II, III, and V). Therefore, the amount of facial nerve improvement is not proportional to tongue atrophy.

Electrophysiological examination showed reinnervation from the hypoglossal nerve in all patients. However, in only 3 of 9 patients could we detect reinnervation from the CFNG.

Discussion

Many types of procedures with varying features have been described for facial reanimation. Cross-face nerve graft was first reported by Scaramella[31] and was thought to be an ideal method to restore a spontaneous smile by synchronizing with the contralateral facial expression. However, the smile obtained via this procedure is usually not satisfactory because of a limited number of regenerated fibers and the long duration of regeneration resulting from a long nerve graft.[21] Frey et al.[9] reported that the regenerated fibers at the edge of CFNG tend to be thin and that, compared with the healthy side, the number of regenerated fibers is limited to 20%.

Fig. 4. Photographs illustrating tongue mobility. By observing signs of deformity, atrophy, and tongue movements, mobility was graded as exhibiting little to severe atrophy. The case of severe atrophy featured here involved complete hypoglossal nerve paralysis due to a brain tumor.

TABLE 2: Postoperative recovery of facial movement

Preop HB Grade	Postop HB Grade	No. of Cases
V	V	2
V	IV	1
V	III	20
V	II	4
IV	III	4
IV	II	5

On the other hand, free muscle grafting can provide sufficient movement for facial reanimation in patients with long-lasting paralysis (usually more than 1 year) that leads to atrophy of the mimic muscles. Various types of muscle grafts have been reported[11,13,35] since Harii et al.[12] first described the procedure in 1976, and free muscle grafting has become the most significant procedure for treating long-lasting facial paralysis.[36–38] Note, however, that bulkiness of the grafted muscle, deviation of the muscle attachment, and limited direction of muscle contracture are reported as problems with this approach.[39]

The hypoglossal nerve is a powerful motor source for facial reanimation, and we hypothesized that reinnervation of primary mimic muscles can provide more natural facial expressions than contraction of a single grafted muscle. However, conventional hypoglossal-facial nerve transfer, originally described by Conley and Baker,[6] leads to problems in speech and swallowing due to hypoglossal nerve transection, as well as severe synkinesis due to excessive stimulus from the whole hypoglossal nerve. Several procedures have been developed in an effort to solve such problems. May et al.[24] reported on the interpositional jump graft, in which an interpositional nerve graft was performed between the facial and hypoglossal nerves using end-to-side neurorrhaphy to the hypoglossal nerve. This technique successfully reinnervates the facial nerve without causing tongue paralysis, and the procedure is widely used. However, the power of innervation is thought to be weak, since it requires a nerve graft (2

TABLE 3: Facial reanimation success rates, according to recipient nerve

Recipient Nerve	No. of Successful Cases/Total
cephalad side of split nerve	16/17
caudal side of split nerve	15/15
ansa cervicalis branch	2/4

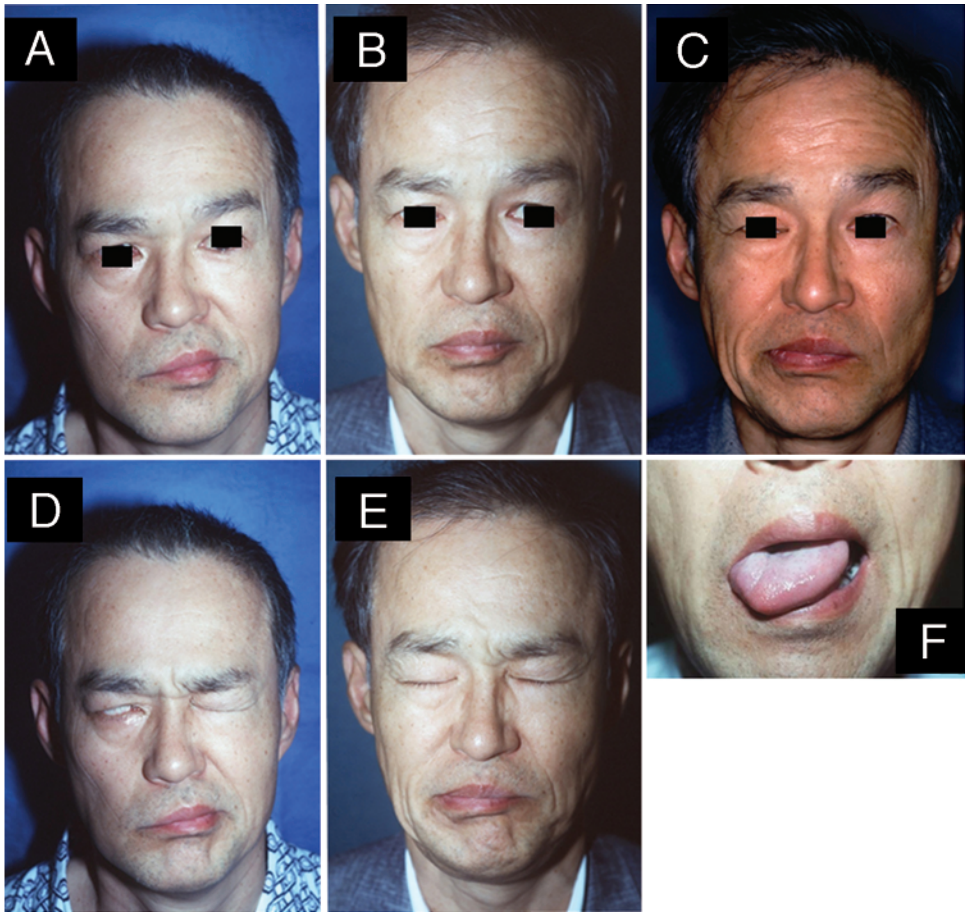

Fig. 5. Case 8. Images obtained in a 59-year-old man, showing the effects of facial paralysis following the removal of a vestibular schwannoma. The facial nerve was transected during surgery, and HHFNT was performed 1.5 months after paralysis using the procedure from our second period (cephalad side of hypoglossal nerve). Preoperative images obtained when the patient had HB Grade V facial nerve function: at rest **(A)** and on closure of the eye **(D)**. Images obtained 2 years postoperatively when the patient had HB Grade III facial nerve function: at rest **(B)** and on complete closure of the eye **(E)**. Facial symmetry was restored. Facial movement with tongue movement was possible **(C)**. Facial reanimation was achieved without excessive movement but was somewhat synkinetic. Tongue appearance exhibited moderate atrophy **(F)**.

anastomosis sites) and end-to-side neurorrhaphy, necessitating significant time for reinnervation. Subsequently, Sawamura and Abe[30] developed direct facial-hypoglossal end-to-side neurorrhaphy, elongating the facial nerve trunk by dissecting the mastoid process. However, this technique requires excessive resection of the mastoid process to harvest the proximal facial nerve trunk into the mastoid cavity, and the procedure itself is thought to be complicated.[20,30,41] Asaoka et al.[2] reported that longitudinally split hypoglossal nerves effectively match the facial nerve, since the cross-sectional area of the facial nerve trunk is 61.5% of the hypoglossal nerve and the number of facial nerve fibers is 73.2% of the number of hypoglossal fibers.

We experimentally examined the value of split hypoglossal nerve transfer. Through canine studies, we found that this method of transfer leads to less atrophy of the tongue and less facial synkinesis than transfer using the entire hypoglossal nerve.[17,32] Regarding the choice of split hypoglossal nerve—that is, which side to use, caudal or cranial—we performed intraoperative evaluations with electrical stimulation, and we initiated study of the process in cadavers.[33] Note, however, that it was very difficult to detect which side mainly innervates the intrinsic lingual muscles and whose denervation causes tongue atrophy.[33] Even when some tongue atrophy developed, com-

TABLE 4: Postoperative tongue atrophy*

Study Period	No. of Cases/Total			
	Little	Minimal	Moderate	Severe
1	1/5	3/5	1/5	0
2	0	6/12	6/12	0
3	4/4	0	0	0
4	0	3/7	4/7	0
5	0	5/8	3/8	0
total	5/36	17/36	14/36	0

* Some atrophy was observed in all periods. No significant differences were noted among the various study periods.

TABLE 5: Degree of tongue denervation compared with amount of facial nerve improvement*

Facial Reanimation		Tongue Atrophy (no. of cases/total)			
HB Grade Preop	HB Grade Postop	Little	Minimal	Moderate	Severe
V	V	2/2	0	0	0
V	IV	0	1/1	0	0
V	III	0	9/20	11/20	0
V	II	1/4	2/4	1/4	0
IV	III	0	3/4	1/4	0
IV	II	2/5	2/5	1/5	0
total		5/36	17/36	14/36	0

* The amount of facial nerve improvement is not proportional to tongue atrophy.

pensatory tongue movement was supported by extrinsic lingual muscles, which masks the effects of atrophy on articulation. Our clinical results also showed no severe dysfunction in swallowing and speech, even though a certain amount of overall tongue atrophy was prevalent (Table 4). Furthermore, no significant differences were observed between the study periods for our procedure. There was also no difference in the rate of successful facial reanimation based on the use of the cranial or caudal side of the split hypoglossal nerve. Neither was the amount of facial nerve improvement proportional to tongue atrophy. Therefore, we concluded that either side of the split hypoglossal nerve can be effectively used for transfer.

On the other hand, using the ansa cervicalis branch yielded a lower rate of facial reanimation (2 of 4 cases) compared with previous reports. We hypothesized that this branch did not provide enough power for facial reanimation, even though atrophy of the tongue was minimal, and we discontinued its use.[5,23]

Recently, end-to-side neurorrhaphy has been used to reduce the donor nerve deficit, and we have studied mechanisms of axonal sprouting following this procedure.[15,25] We demonstrated collateral sprouting using DiI staining,[15] and we found that some type of injury to the donor nerve seems to be necessary to induce motor axonal regeneration through end-to-side neurorrhaphy.[14] In this procedure, we performed a nerve graft to replace the transferred hypoglossal nerve and end-to-side neurorrhaphy to the proximal edge of the defect. This nerve graft may also serve to reduce the donor nerve deficit while providing sufficient regenerated fibers for facial reanimation.

Cross-face nerve grafts performed with the HHFNT were evaluated using electromyography. Only 3 of 9 cases showed effective evoked potentials from the CFNG. Therefore, once the hypoglossal nerve reinnervates the paralyzed mimic muscles, before the CFNG can do so, there is little opportunity for the CFNG to reinnervate the remaining paralyzed muscles.[18] Thus, we consider the value of CFNG (with HHFNT) to be low and only supplemental. It would be effective in cases in which the hypoglossal nerve cannot reinnervate the mimic muscles for some reason.

For a successful HHFNT procedure, the finest possible uniform longitudinal dissection of the hypoglossal nerve should be achieved and a sufficient length of the split hypoglossal nerve should be secured for transfer. Using a lead plate underneath the hypoglossal nerve is an important factor in allowing uniform splitting without the nerve becoming spiral. The lead plate is also important for protecting the carotid artery and adjacent tissues during the splitting procedure, and less traumatic manipulation is essential in this operation. Using a surgical microscope is another important factor.

Recently, Yamamoto et al.[40] described the neural supercharge concept for patients with incomplete, or reversible, facial palsy. In this procedure, the nerve graft is inserted between the facial and hypoglossal nerves using end-to-side neurorrhaphy at both graft ends. We suggest that a longer split hypoglossal nerve could reach the side of the facial nerve trunk and could serve as a powerful neural supercharge source. Such an innovation could expand the use of our procedure into the treatment of incomplete paralysis without transecting the facial nerve trunk.

Conclusions

We have reported details and transitions in the use of a facial reanimation procedure called "hemihypoglossal-facial nerve transfer." Although the treatment causes some tongue atrophy, there is no severe dysfunction in swallowing and speech. This procedure consistently leads to good facial reanimation, and either half of the split hypoglossal nerve can be used effectively.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Hayashi, Yanai. Acquisition of data: Kayamori, Yanai. Analysis and interpretation of data: Hayashi, Nishida, Seno, Inoue, Iwata, Shirasawa, Arai, Kayamori, Komuro, Yanai. Drafting the article: Hayashi. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Hayashi. Administrative/technical/material support: Nishida, Arai, Yanai. Study supervision: Yanai.

References

1. Arai H, Sato K, Yanai A: Hemihypoglossal-facial nerve anastomosis in treating unilateral facial palsy after acoustic neurinoma resection. **J Neurosurg 82:**51–54, 1995
2. Asaoka K, Sawamura Y, Nagashima M, Fukushima T: Surgical anatomy for direct hypoglossal-facial nerve side-to-end "anastomosis." **J Neurosurg 91:**268–275, 1999
3. Ballance CA, Ballance HA, Stewart P: Remarks on the operative treatment of chronic facial palsy of peripheral origin. **BMJ 1:**1009–1013, 1903
4. Caldwell EH: Anastomosis of the branches of the facial and spinal accessory nerves for facial paralysis. **Surgery 44:**978–983, 1958
5. Conley J: Hypoglossal–facial nerve anastomosis, in Brackmann DE (ed): **Neurological Surgery of the Ear and Skull Base.** New York: Raven Press, 1982, pp 93–98

6. Conley J, Baker DC: Hypoglossal-facial nerve anastomosis for reinnervation of the paralyzed face. **Plast Reconstr Surg 63:**63–72, 1979
7. Coombs CJ, Ek EW, Wu T, Cleland H, Leung MK: Masseteric-facial nerve coaptation—an alternative technique for facial nerve reinnervation. **J Plast Reconstr Aesthet Surg 62:** 1580–1588, 2009
8. Cusimano MD, Sekhar L: Partial hypoglossal to facial nerve anastomosis for reinnervation of the paralyzed face in patients with lower cranial nerve palsies: technical note. **Neurosurgery 35:**532–534, 1994
9. Frey M, Happak W, Girsch W, Bittner RE, Gruber H: Histomorphometric studies in patients with facial palsy treated by functional muscle transplantation: new aspects for the surgical concept. **Ann Plast Surg 26:**370–379, 1991
10. Hammerschlag PE: Facial reanimation with jump interpositional graft hypoglossal facial anastomosis and hypoglossal facial anastomosis: evolution in management of facial paralysis. **Laryngoscope 109 (2 Pt 2 Suppl 90):**1–23, 1999
11. Harii K, Asato H, Yoshimura K, Sugawara Y, Nakatsuka T, Ueda K: One-stage transfer of the latissimus dorsi muscle for reanimation of a paralyzed face: a new alternative. **Plast Reconstr Surg 102:**941–951, 1998
12. Harii K, Ohmori K, Torii S: Free gracilis muscle transplantation, with microneurovascular anastomoses for the treatment of facial paralysis. A preliminary report. **Plast Reconstr Surg 57:**133–143, 1976
13. Harrison DH: The pectoralis minor vascularized muscle graft for the treatment of unilateral facial palsy. **Plast Reconstr Surg 75:**206–216, 1985
14. Hayashi A, Pannucci C, Moradzadeh A, Kawamura D, Magill C, Hunter DA, et al: Axotomy or compression is required for axonal sprouting following end-to-side neurorrhaphy. **Exp Neurol 211:**539–550, 2008
15. Hayashi A, Yanai A, Komuro Y, Nishida M, Inoue M, Seki T: Collateral sprouting occurs following end-to-side neurorrhaphy. **Plast Reconstr Surg 114:**129–137, 2004
16. House JW, Brackmann DE: Facial nerve grading system. **Otolaryngol Head Neck Surg 93:**146–147, 1985
17. Inoue M, Yanai A: [Physiological effects of longitudinally-split hypoglossal-facial nerve anastomosis: an experimental study in dogs.] **J Jpn P R S 22:**709–715, 2002 (Jpn)
18. Iwata H, Yanai A: [Electrophysiological evaluation after nerve reconstructive surgery for acute facial nerve palsy.] **J Jpn P R S 26:**557–565, 2006 (Jpn)
19. Körte W, Bernhardt M: Ein fall von nervenpfropfung des nervus facialis auf den nervus hypoglossus. **Dtsch Med Wochenschr 29:**293–295, 1903
20. Kumar PA, Hassan KM: 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:**451–464, 2002
21. Lee EI, Hurvitz KA, Evans GR, Wirth GA: Cross-facial nerve graft: past and present. **J Plast Reconstr Aesthet Surg 61:** 250–256, 2008
22. Linnet J, Madsen FF: Hypoglosso-facial nerve anastomosis. **Acta Neurochir (Wien) 133:**112–115, 1995
23. Martins RS, Socolovsky M, Siqueira MG, Campero A: Hemihypoglossal-facial neurorrhaphy after mastoid dissection of the facial nerve: results in 24 patients and comparison with the classic technique. **Neurosurgery 63:**310–317, 2008
24. May M, Sobol SM, Mester SJ: Hypoglossal-facial nerve interpositional-jump graft for facial reanimation without tongue atrophy. **Otolaryngol Head Neck Surg 104:**818–825, 1991
25. Nishida M: [End-to-side neurorrhaphy with nerve grafting: an experimental study of rats.] **J Jpn P R S 18:**644–651, 1998 (Jpn)
26. O'Brien BM, Franklin JD, Morrison WA: Cross-facial nerve grafts and microneurovascular free muscle transfer for long established facial palsy. **Br J Plast Surg 33:**202–215, 1980
27. Pensak ML, Jackson CG, Glasscock ME III, Gulya AJ: Facial reanimation with the VII-XII anastomosis: analysis of the functional and psychologic results. **Otolaryngol Head Neck Surg 94:**305–310, 1986
28. Pitty LF, Tator CH: Hypoglossal-facial nerve anastomosis for facial nerve palsy following surgery for cerebellopontine angle tumors. **J Neurosurg 77:**724–731, 1992
29. Rochkind S, Shafi M, Alon M, Salame K, Fliss DM: Facial nerve reconstruction using a split hypoglossal nerve with preservation of tongue function. **J Reconstr Microsurg 24:** 469–474, 2008
30. Sawamura Y, Abe H: Hypoglossal-facial nerve side-to-end anastomosis for preservation of hypoglossal function: results of delayed treatment with a new technique. **J Neurosurg 86:** 203–206, 1997
31. Scaramella LF: Anastomosis between the two facial nerves. **Laryngoscope 85:**1359–1366, 1975
32. Seno H: [Functional and histological evaluation of the tongue after hypoglossal nerve splitting: experimental study using dogs.] **J Jpn P R S 20:**173–178, 2000 (Jpn)
33. Shirasawa T, Yanai A: [Anatomy of hypoglossal nerve for hypoglossal-facial nerve anastomosis.] **J Jpn P R S 21:**300–304, 2001 (Jpn)
34. Sood S, Anthony R, Homer JJ, Van Hille P, Fenwick JD: Hypoglossal-facial nerve anastomosis: assessment of clinical results and patient benefit for facial nerve palsy following acoustic neuroma excision. **Clin Otolaryngol Allied Sci 25:** 219–226, 2000
35. Terzis JK: Pectoralis minor: a unique muscle for correction of facial palsy. **Plast Reconstr Surg 83:**767–776, 1989
36. Terzis JK, Noah ME: Analysis of 100 cases of free-muscle transplantation for facial paralysis. **Plast Reconstr Surg 99:** 1905–1921, 1997
37. Terzis JK, Olivares FS: Long-term outcomes of free-muscle transfer for smile restoration in adults. **Plast Reconstr Surg 123:**877–888, 2009
38. Terzis JK, Olivares FS: Long-term outcomes of free muscle transfer for smile restoration in children. **Plast Reconstr Surg 123:**543–555, 2009
39. Terzis JK, Olivares FS: Use of mini-temporalis transposition to improve free muscle outcomes for smile. **Plast Reconstr Surg 122:**1723–1732, 2008
40. Yamamoto Y, Sekido M, Furukawa H, Oyama A, Tsutsumida A, Sasaki S: Surgical rehabilitation of reversible facial palsy: facial—hypoglossal network system based on neural signal augmentation/neural supercharge concept. **J Plast Reconstr Aesthet Surg 60:**223–231, 2007
41. Yoleri L, Songür E, Yoleri O, Vural T, Cağdaş A: Reanimation of early facial paralysis with hypoglossal/facial end-to-side neurorrhaphy: a new approach. **J Reconstr Microsurg 16:**347–356, 2000

Manuscript submitted January 10, 2012.

Accepted September 17, 2012.

Please include this information when citing this paper: published online October 26, 2012; DOI: 10.3171/2012.9.JNS1270.

Address correspondence to: Ayato Hayashi, M.D., Department of Plastic and Reconstructive Surgery, Juntendo University School of Medicine, 2-1-1 Hongo, Bunkyo-ku, Tokyo 113-8421, Japan. email: ayhayasi@juntendo.ac.jp.