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CLINICAL ARTICLE - NEUROSURGICAL TECHNIQUES

Treatment of complete facial palsy in adults: comparative study between direct hemihypoglossal-facial neurorrhaphy, hemihipoglossal-facial neurorrhaphy with grafts, and masseter to facial nerve transfer

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Abstract
Background The hypoglossal (with or without grafts) and masseter nerves are frequently used as axon donors for facial reinnervation when no proximal stump of the facial nerve is available. We report our experience treating facial nerve palsies via hemihypoglossal-to-facial nerve transfers either with (HFG) or without grafts (HFD), comparing these outcomes against those of masseteric-to-facial nerve transfers (MF).
Method A total of 77 patients were analyzed retrospectively, including 51 HFD, 11 HFG, and 15 MF nerve transfer patients. Both the House-Brackmann (HB) scale and our own, newly-designed scale to rate facial reanimation post nerve transfer (quantifying symmetry at rest and when smiling, eye occlusion, and eye and mouth synkinesis when speaking) were used to enumerate the extent of recovery.
Results With both the HB and our own facial reanimation scale, the HFD and MF procedures yielded better outcome scores than HFG, though only the HGD was statistically superior. HGD produced slightly better scores than MF for everything but eye synkinesis, but these differences were generally not statistically significant. Delaying surgery beyond 2 years since injury was associated with appreciably worse outcomes when measured with our own but not the HB scale. The only predictors of outcome were the surgical technique employed and the duration of time between the initial injury and surgery.
Conclusions HFD appears to produce the most satisfactory facial reanimation results, with MF providing lesser but still satisfactory outcomes. Using interposed grafts while performing hemihypoglossal-to-facial nerve transfers should likely be avoided, whenever possible.

Keywords Facial paralysis · Facial nerve · Hypoglossal nerve · Hypoglossal-facial anastomosis · Masseter to facial nerve transfer · Nerve graft

This original material has never been presented or published previously

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Introduction

Nerve transfer is widely accepted as a standard treatment for complete facial palsy when a proximal facial nerve segment is unavailable for reconstruction, as in following ablative tumor surgery or trauma involving the skull base. The hypoglossal and masseter nerves are widely accepted axon donors for facial reinnervation [5, 8, 11, 12, 14, 16, 18, 20, 21, 24, 27, 28, 32–34, 38, 40, 45, 48, 50–52, 54, 57, 62, 67].

When employing the hypoglossal nerve, utilizing a partial section via direct neurorrhaphy after exposure of the facial nerve in the mastoid bone (HFD), or using an interposed jump graft connecting the two nerves (HFG) are two available ways of avoiding severe atrophy of the hemitongue [3, 4, 26, 30, 31, 46, 48, 49, 53, 56, 58, 60]. As a consequence, using a complete hypoglossal section is currently considered contraindicated for facial nerve reanimation [48, 56].

Concurrent with these attempts to limit tongue morbidity, masseter-to-facial nerve transfers (MF) have received attention as an alternative for facial reanimation [16, 23, 47, 59, 63, 68]. Figure 1 schematically describes the three aforementioned techniques, together with the classical complete hypoglossal-facial nerve transfer.

The primary purpose of this study was to retrospectively compare the results obtained with all three aforementioned techniques for facial reanimation: (1) hemihypoglossal to facial direct neurorrhaphy after drilling the mastoid bone to expose the proximal facial nerve (HFD); (2) hemihypoglossal to facial nerve transfer with an interposed sural nerve graft (HFG); (3) transferring the masseter muscle branch of the trigeminal nerve to the facial nerve (MF). To aid in distinguishing outcomes between these three techniques, we employed both the House-Brackmann (HB) facial nerve grading score and our own, newly-developed post-operative facial reanimation scale (POFRA) that was created specifically to analyze facial function after nerve transfers. Secondary study objectives were (1) to identify predictors of a good response to surgery,; and (2) to correlate and compare the results obtained with the new versus already-validated (HB) facial reanimation scale.

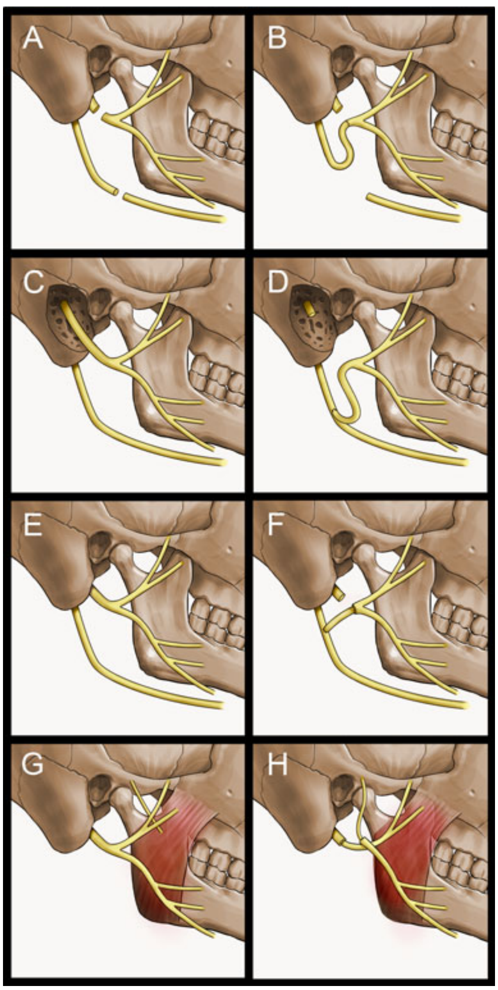

Fig. 1 Four methods for facial reanimation with nerve transfers. Schematic drawing illustrating the lateral view of a classical hypoglossal-facial neurorrhaphy (**a**, **b**), hemihypoglossal to facial direct transfer (**c**, **d**), hemihypoglossal to facial nerve transfer with interposed jump graft (**e, f**), and masseter to facial nerve transfer (**g, h**). **a** Section of hypoglossal and facial nerves. **b** The hypoglossal nerve was moved cranially toward the facial nerve. **c** Facial nerve exposed in the mastoid portion of the temporal bone. **d** Facial nerve sectioned and re-routed towards the hemihypoglossal nerve. **e, f** A section of the hypoglossal nerve is transferred via an interposed nerve graft to the facial nerve. **g, h** Masseter nerve transfer to branches of the facial nerve

Materials and methods

A retrospective survey was conducted of 77 patients with proximal facial nerve injuries who underwent hypoglossal-facial neurorrhaphy between January 2005 and July 2013. Only patients with a House and Brackmann scale preoperative grade of VI (i.e., complete facial palsy) were eligible for inclusion in analysis. Two South American centers that are active in peripheral nerve surgery participated in the study. One of these centers is located in Buenos Aires, Argentina (Nerve and Plexus Surgery Program, Division of Neurosurgery, Hospital de Clínicas, University of Buenos Aires School of Medicine) and the other in São Paulo, Brazil (Peripheral Nerve Surgery Unit of the Department of Neurosurgery, São Paulo University Medical School). Over the 8 years of observation, nerve function was restored by means of hemihypoglossal to facial direct neurorrhaphy (HFD) after drilling the mastoid bone to expose the proximal facial nerve in 51 patients, hemihypoglossal to facial nerve transfer with an interposed sural nerve graft (HFG) in 11 patients, and using a masseter to facial nerve transfer technique (MF) in 15 patients.

Surgery was performed if there was no clinical or electrical evidence of facial nerve function, ideally at 9 months after the injury or as soon as possible thereafter if irreversible nerve damage was identified during a previous surgery. The first choice was always HFD, but in those cases where the facial nerve was damaged in the mastoid bone and therefore HFD was not feasible, either HFG or MF was indicated. Alternatively, in some cases that showed facial nerve preservation at the mastoid bone, HFG and MF were also indicated instead of HFD, due to the preference of some of our patients for avoiding the drilling of the mastoid bone and therefore having a shorter and simpler procedure.

In the case of HFD, standard dissection was employed to expose the hypoglossal and facial nerves at the level of the mastoid process, neck and parotid region [9, 10]. With the patient under general anesthesia and in a supine position on the operating table, the head was turned to the contralateral side. A semicircular retroauricular incision was created, extending 6–8 cm obliquely down the neck, and up 2 cm to just behind the mandibular angle. The tip of the mastoid process was exposed by removing muscle attachments and the periosteum with a periosteal elevator. Aided by the operating microscope, proximal dissection of the facial nerve was then performed by drilling the mastoid bone with a high-speed drill and diamond burr. A limited mastoidectomy, with a rectangular shape not exceeding 2–3 cm in width, was performed, opening the facial canal to expose the facial nerve from the external genu to the stylomastoid foramen. The nerve was then sectioned as proximally as possible and dissected from the mastoid bone. Distal extra-cranial dissection of the facial nerve at the stylomastoid foramen and the preauricular region up to the parotid gland was needed to complete nerve rerouting toward the neck and the hypoglossal nerve. Subsequently, the hypoglossal nerve was dissected at the lowest portion of the cervical incision, lying inferior and medial to the posterior belly of the digastric muscle. A standard nerve stimulator was used to confirm normal function of the hypoglossal nerve. The point where the mobilized facial nerve stumps reached the hypoglossal nerve defined the point of the hypoglossal nerve section. Half of the axial section of the hypoglossal nerve was transected and the facial nerve coapted without tension directly to the proximal hypoglossal stump using three to four stitches of 10–0 nylon interrupted suture reinforced with fibrin sealant.

For HFG, a preauricular incision was employed that extended to the neck in the same manner as with HFD. After extensive dissection of the facial nerve from its exit through the stylomastoid foramen until its bifurcation at the parotid gland, the nerve was sectioned at the foramen and directed to the inferior limit of the exposure. At this point, the hypoglossal nerve was dissected at the lowest portion of the cervical incision, as described for the HFD technique, and sectioned partially. A 3- to 4-cm long, unique nerve graft was harvested from a cervical cutaneous nerve or—if this was unavailable—the sural nerve, to bridge the gap between the facial and the hypoglossal nerves [10]. Sutures were placed, as described previously, using three to four 10.0 nylon stitches and fibrin glue sealant.

For MF nerve transfers, a preauricular incision was created and a skin flap elevated to expose half of the proximal parotid gland [7, 13, 17, 25]. With loupe magnification, dissection was performed by opening the parotid tissue immediately inferior to the lower edge of the zygomatic bone. The purpose of this dissection was to identify a small branch of the zygomatic segment of the facial nerve. Dissection was continued proximally to locate the zygomatic and buccal branches, which were used as receptor nerves for this transfer. The proximal third of the masseter muscle was released from the border of the zygomatic bone. Electrical stimulation was done inside the masseter muscle to help locate the muscle branch. The descending branch of the masseter was divided as far as possible to preserve the proximal branches. The distal buccal and zygomatic branches were also sectioned proximally and moved toward the masseter branch. Neurorrhaphy was then performed using three or four sutures of 10–0 mononylon and fibrin glue.

Patients received the same standard postoperative care. For all patients, motor re-education and strengthening exercises were initiated 3 weeks after surgery.

All patients had a minimal follow-up of 12 months, and an independent observer (who was not on either of the two surgical teams) assessed each patient using standardized videotapes of patients both at rest and with specific facial movements. Surgical outcome was rated according to two scales: the already-validated House-Brackmann scale that initially was developed and generally is used to evaluate recovery from Bell's palsy [19, 36] and a new—still not validated—total facial reanimation score developed by the current authors and used in our clinics that encompasses the particularities that a reanimated face has when a nerve transfer is employed (Table 1 describes the scale). To calculate this new total facial reanimation score, five different facial features are evaluated: (1) facial symmetry at rest, (2) smile symmetry, (3) palpebral occlusion, (4) eye synkinesis when smiling or speaking (in those cases of total failure of the facial reanimation procedure, this item was rated 0), and (5) synkinetic movement of the mouth while speaking. A summation score was then generated, with a minimum possible score of 0 and a maximum of 12, and higher scores indicating better function. Each item of the

Table 1 The postoperative facial reanimation scale (POFRA scale) for facial reanimation after nerve transfer

Repose	Points
Facial asymmetry with flaccidity	0
Facial asymmetry without flaccidity	1
Facial symmetry	2
Dynamic	
Smile	
No contraction	0
Asymmetric contraction	1
Symmetric contraction	2
Palpebral occlusion	
Absent	0
Partial	1
Complete	2
Eye synkinesis when smiling or speaking (only when the previous item is more than 0)	
Hemifacial spasm/mass contraction	0
Complete palpebral occlusion	1
Incomplete palpebral occlusion	2
No synkinesis	3
Movement of the mouth when speaking	
Absent	0
Present & asymmetric	1
Present & symmetric	2
Automatization	3

scale can be evaluated separately; therefore it is not only possible to arrive to a single number as a final score—from a minimum of 0 to a maximum of 12—but also each item can be evaluated independently. Note that with the House-Brackmann scale—with which a score of 1 indicates normal facial nerve function; 2 indicates slight dysfunction; 3, moderate dysfunction; 4, moderately severe dysfunction; 5, severe dysfunction; 6, total paralysis. Higher scores indicate worse function, with scores up to 4 generally considered a good result, and of 5 or 6 a poor result after reconstruction for total facial nerve palsy.

Statistical analysis was performed using the statistical software program SPSS version 23.0 for Windows (SPSS, Chicago, IL, USA) and all analyses were two-tailed, with $p = 0.05$ set as the threshold for statistical significance. Means and proportions were calculated for each variable for each of the three treatment arms. For bivariate comparisons of the three treatments, Pearson's χ^2 analysis was conducted to identify differences in proportions, and analysis of variance (ANOVA) with post-hoc Tukey's *b* test to identify difference in continuous variable means. For multivariate analysis, binary logistic and simple linear regression models were generated and tested, with the HB and new total facial reanimation scores treated as binary (good vs poor outcome) and continuous (absolute score), respectively, and set as the dependent variable. Because resection of a cerebellopontine angle (CPA) tumor was determined to be the cause of 87.0 % of the palsies in this series, all analysis were then repeated, restricting patient selection to those 67 patients whose palsy originated secondary to CPA tumor resection. Since exclusion of non-CPA tumor patients generally did not alter results, these data are commented upon, but otherwise not individually presented in this paper. Because higher ratings on the HB scale represent worse function, while higher ratings on the new total facial reanimation scale represent better function, to compare these two scales directly, an inverted HB score was used, calculated as the maximum possible value (6) minus the actual score.

Results

A total of 77 patients underwent facial nerve reconstruction, 51 with direct hemihypoglossal-facial neurorrhaphy (HFD), 11 hemihypoglossal-facial neurorrhaphy with an interposed graft (HFG), and 15 a masseter-to-facial nerve transfer (MF). The demographic and baseline clinical characteristics of the sample are summarized in Table 2. A lower percentage of HFG patients had a cerebellopontine angle (CPA) source of their palsy than in either other two groups, and there was a tendency towards variability in the proportion of patients who were female. No complications were observed regarding the partial section of the tongue in HFD and HFG, neither problems with the bite, chewing or the temporo-mandibular joint were seen in MF.

The mean HB outcome rating at follow-up was lower (i.e., better) among HFD patients than either of the other two groups, with good responses noted in 92.2 % of HFD patients versus just 54.5 % of HFG patients ($p = 0.001$) and 66.7 % of MF patients ($p = 0.01$) (Fig. 2). No significant difference was apparent between the last two groups. On the other hand, when the POFRA scale was used, results in the HFD group (total score 7.14) were clearly superior to that achieved in HFG patients (3.45, $p < 0.05$), but not MF patients (6.53, NS). Again, the last two groups were not statistically different, though the mean score in MF patients was much closer to that of HFD than HFG patients (Table 3).

Individual scores for all five items on the POFRA scale also distinguished the three groups, though some variability existed in ranking order (Fig. 3). Post-hoc analysis revealed that HFD ($n = 51$) was statistically superior to HFG ($n = 11$) in terms of mean scores at rest ($p < 0.001$), with smiling ($p = 0.003$), for eye synkinesis ($p = 0.014$), for eye occlusion ($p = 0.025$), for mouth movement ($p = 0.003$), and overall ($p < 0.001$). Meanwhile, the MF technique ($n = 15$) was statistically superior to HFG in terms of means scores at rest/repose ($p < 0.001$), total score ($p = 0.004$), and eye occlusion ($p = 0.05$), and borderline for smiling ($p = 0.06$) and eye synkinesis ($p = 0.066$), despite the low numbers of patients in each of the groups (Table 3). Comparing HFD and MF, for four of the five measured facial features, HFD yielded a result superior to MF, but only one of these differences (mouth movement with speaking relative to the contralateral side) was statistically significant ($p = 0.04$). The only feature for which the MF technique yielded a better result than HFD was eye closure (1.40 vs 1.31), but this difference was not statistically significant ($p = 0.69$). Restricting analysis to just those patients whose palsy was secondary to CPA tumor resection, the aforementioned results were generally maintained, except that the inter-group difference in mean eye synkinesis score was no longer significant.

Bivariate analysis comparing patients who ultimately achieved a House-Brackmann score ≤ 4 versus those with a score ≥ 5 revealed only one difference, that being in the treatment rendered, with 74.6 % of good responders having undergone the HFD procedure versus just 28.6 % of poor responders ($\chi^2 = 11.48$, $p = 0.003$) (Table 4). When just the 67 patients with CPA origins of their palsy were considered, corresponding percentages were 80.0 and 25.0 % ($\chi^2 = 15.30$, $p < 0.001$). When logistic regression analysis was performed using an outcome based on a binary rating of the HB score (good outcome = 1, vs poor outcome = 0), the surgical technique again emerged as the only predictor of response, whether all patients ($p = 0.004$) or just CPA patients ($p = 0.002$) were considered. Patient age, patient gender, the etiology and duration of palsy, and the length of follow-up ultimately were dropped from both models.

Table 2 Baseline data by surgical technique

		Treatment group			
	Overall sample	HFD	HFG	MF	*p* value
Group size (*n*)	77	51	11	15	
n (%) females	48 (62.7 %)	30 (58.8 %)	8 (72.7 %)	10 (66.7 %)	0.06
Mean age (years)	44.8	45.4	47.7	40.5	0.38
Age range	9–78	23–72	9–78	11–64	
CPA etiology of palsy	67 (87.0 %)	47 (92.2 %)	7 (63.6 %)	13 (86.7 %)	0.04*
Mean duration of palsy (months)	10.5	10.7	10.5	9.8	0.93
Duration of palsy range	1–47	1–47	5–18	1–36	

*$p < 0.05$, significant

On simple linear regression with the new facial reanimation scale used as the dependent variable, two variables—'time between the injury and surgery' ($p<0.001$) and 'surgical technique' ($p=0.005$)—remained as the only statistically significant predictors of the overall facial reanimation score. Further bivariate analysis revealed steadily decreasing total recovery scores as the time between injury and surgery increased, both including ($p=0.009$) and excluding ($p=0.005$) patients whose facial palsy was secondary to CPA tumor resection, with scores declining from a mean total>7.0 for durations≤12 months to roughly 2.0 beyond 24 months (Fig. 4). This contrasts with the results obtained using the binary HB score, with which a good response was noted in 83.6 % operated upon within the 1st year, 80.0 % operated on during the 2nd year, and 75.0 % beyond 2 years. Figure 5 directly compares outcomes measured via the newly designed facial reanimation scale versus the prevalidated House-Brackmann scale with scores inverted to be in the same direction as the other scale. With both scales, the HFD technique achieved statistically better outcomes than either other technique; however, the former suggested at least clinically significant superiority of the MF over the HFG technique, whereas the latter did so to a much lesser degree. The two scales (with the HB score not inverted) were inversely correlated to a moderately strong degree ($r=-0.68$, $p<0.001$), with facial reanimation scores≥7 predictive of a good outcome measured with the HB scale 95.3 % of the time.

Discussion

Previous considerations regarding the different facial reanimation techniques

Hypoglossal-facial neurorrhaphy is a widely-used surgical technique for restoration of facial nerve function when its proximal stump is not available, having been first described in 1903 [39]. Classically, the standard technique includes complete transection of the hypoglossal nerve, followed by

Fig. 2 Percentage of patients with a good versus poor response using the House-Brackmann score

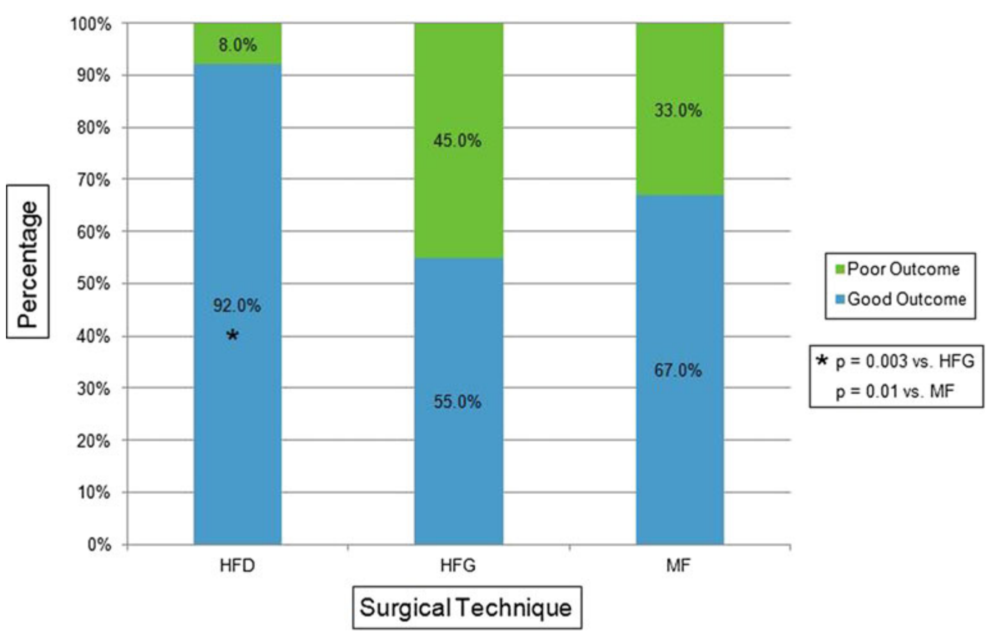

Table 3 Treatment data by surgical technique

	Overall sample	Treatment group			*p* value
		HFD	HFG	MF	
Group size (*n*	77	51	11	15	
Mean follow-up (months)	29.7	31.5	32.9	21.3	0.049*
Follow-up range	12–120	13–120	19–48	12–43	
Mean repose score	1.52	1.69	0.64	1.60	<0.001*
Mean smile score	1.05	1.16	0.64	1.00	0.007*
Mean L occlusion score	1.25	1.31	0.73	1.40	0.052
Mean synkinesis score	1.68	1.82	0.91	1.73	0.042*
Mean movement score	1.01	1.18	0.55	0.80	0.003*
Mean total	6.49	7.14	3.45	6.53	<0.001*
House-Brackmann score	3.65	3.45	4.27	3.87	0.003*
Good outcome (HBS ≤4)	82 %	92 %	55 %	67 %	0.016*

*$p < 0.05$, significant

its cranial rerouting to suture it to the facial nerve in an end-to-end fashion [10, 14, 50, 51]. With an appropriate rehabilitation program, a satisfactory functional outcome can usually be achieved; but sacrificing the hypoglossal nerve unavoidably results in paralysis and atrophy of the ipsilateral tongue. Hemiglossal paralysis may thereby interfere with chewing, swallowing and speech [4, 14, 18, 30, 31, 48, 52]. Although many patients with unilateral deficits only experience transient disturbances and ultimately suffer from only minimal functional impairment [42], some patients have permanent deficits that can be quite disabling. Consequently, there is a general consensus in trying to avoid this defect.

In light of this, data obtained by morphometric analysis of human nerves, in addition to results from animal experiments evaluating regeneration after partial hypoglossal neurectomy, suggest that half of the hypoglossal nerve may be adequate to provide good functional muscle reinnervation when hypoglossal-facial neurorrhaphy is performed [3, 65, 67].

To provide a length of facial nerve sufficient to permit its mobilization toward the hypoglossal nerve, in 1997 Sawamura and Abe [58], followed by Atlas and Lowinger [4] and Darrouzet et al. [20, 21], introduced a technique that included intratemporal dissection of the facial nerve, which was transected, reflected inferiorly to the neck, and sutured directly to a partially sectioned hypoglossal nerve (HFD). This procedure allowed the facial nerve to be extended far enough to create tensionless sutures without the need for an interposed nerve graft.

In a previous publication by the same group of authors as the present study [48], HGD was clearly demonstrated to yield

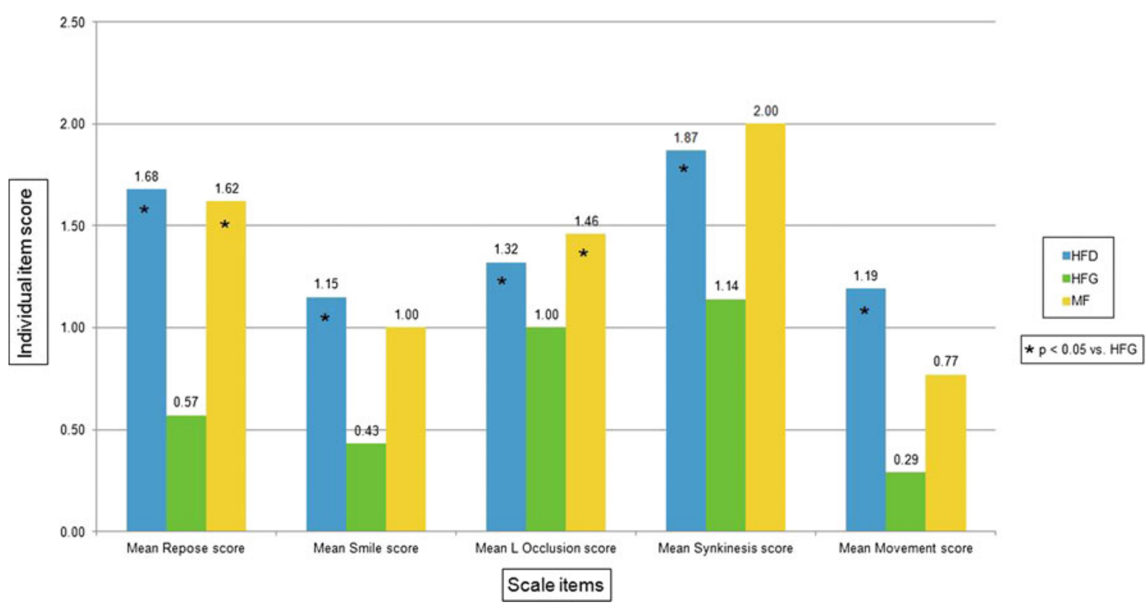

Fig. 3 Comparing feature-specific outcomes with the Post-Op Facial Re-Animation (POFRA) scale

Table 4 Comparing good and poor responders

Variable	Good Result (HB ≤4)	Poor Result (HB ≥5)	Test statistic	Significance
$n = 77$	63	14		
Mean age	43.8	49.2	$t = 1.31$	$p = 0.20$
% males	41.3 %	21.4 %	$\chi^2 = 1.92$	$p = 0.17$
% CPA tumors	87.3 %	85.7 %	$\chi^2 = 0.03$	$p = 0.87$
% duration < 1 year	81.0 %	71.4 %	$\chi^2 = 0.63$	$p = 0.73$
% duration 1–2 years	14.3 %	21.6 %		
% duration ≥2 years	4.8 %	7.2 %		
% post HFD	74.6 %	28.6 %	$\chi^2 = 11.48$	$p = 0.003$*
% post HFG	9.5 %	35.7 %		
% post MF	15.9 %	35.7 %		
% follow-up < 2 years	52.4 %	50.0 %	$\chi^2 = 0.57$	$p = 0.90$
% 3rd year follow-up	27.0 %	28.6 %		
% 4th year follow-up	17.5 %	21.4 %		
% FU > 4 years	3.2 %	0.0 %		

*$p < 0.05$, significant

similar levels of facial reanimation as the classical full-section technique. With this variant technique, the hypoglossal nerve is only partially sectioned transversally to between 30 and 50 % of its cross-sectional area, the remaining intact axons preserving good hemitongue function. Other groups have published similar results using the same technique [32, 56, 60].

Utilizing the masseter nerve was described as an alternative to using the hypoglossal in 1925 [22]. Many series from the late 1970s and thereafter [16, 23, 35, 38, 59, 61, 63, 67] demonstrated good facial reanimation with this technique.

Interposition of a free nerve graft between the hemihypoglossal nerve and the facial nerve stump (HFG) was proposed by May et al. [49]. Some authors have reported good results using this technique [26, 66], though this method has some theoretical disadvantages, including donor site morbidity and the occurrence of two suture lines, which may act as obstacles to the regenerating axon sprouts. The results obtained in the current series, together with several other reports [32, 35, 43, 45, 46, 55], demonstrate that this technique should be avoided if an alternative direct nerve transfer option exists. Grafts should only be used as a last resort in a nerve transfer, as a direct coaptation is almost always better than grafts.

Several other techniques have been described to reanimate the face and avoid tongue morbidity. Complete division of the hypoglossal nerve using the ansa cervicalis to reanimate the tongue results produces poor outcomes, according to the literature, though some positive experiences have been reported [11, 14, 51]. Longitudinal dissection of the hypoglossal nerve after its partial transection (one half routed cranially and connected in an end-to-end fashion with the proximal stump of the facial nerve) is another possibility [2, 18]. In terms of facial reanimation, good results have been obtained with this technique, but mild to moderate glossal atrophy has been described in all of the patients treated this way, possibly because

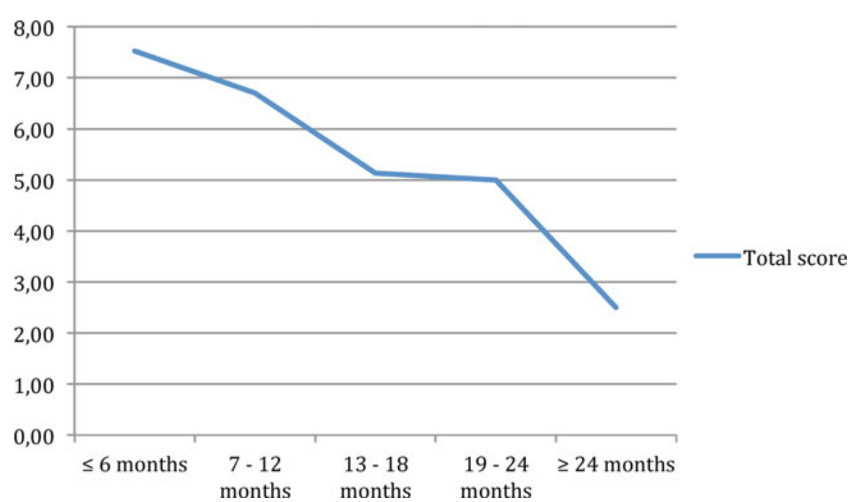

Fig. 4 Comparing outcomes with the newly designed facial reanimation versus inverted House-Brackmann score

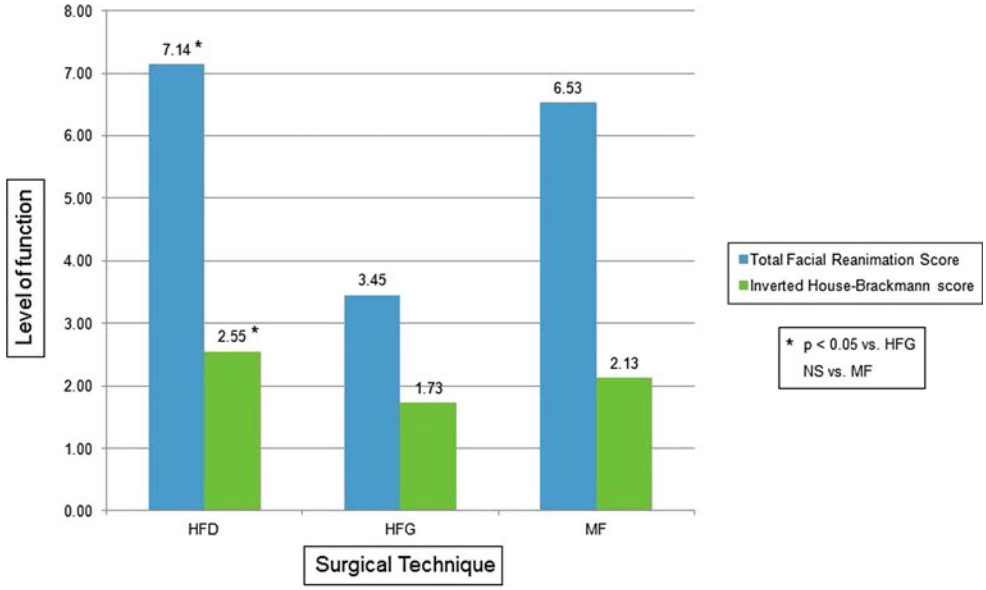

Fig. 5 Bivariate analysis showed decreasing total recovery scores as the time between injury and surgery increased

the hypoglossal nerve is not poly-fascicular and the longitudinal incision may transect interweaving axons [14, 58, 65]. Moreover, according to Magliulo et al. [45], fibrosis involving the exposed nerve after it is split might be a complication of this technique.

As described in a previous report, we have determined that hemihypoglossal to facial direct neurorrhaphy (HFD) generates a similar degree of facial reanimation as the classical technique of sectioning the entire hypoglossal nerve, with the advantage of avoiding partial tongue paralysis and its associated morbidity (Fig. 6). In the present study, we compared HFD with hemihypoglossal to facial nerve transfers using an interposed sural nerve graft (HFG, Fig. 7) and masseter to facial nerve transfers (MF, Fig. 8), with the degree of facial reanimation used as the primary outcome of interest.

Reviewing the results of the present study

The main conclusion we can draw from our series is that the HFG technique provides inferior facial reanimation than either HGD or MF. This result was observed using both the classical House-Brackmann scale and our own, newly-developed facial reanimation scale. Being that the three groups of patients were similar in terms of age, time to surgery, and all other clinical parameters except the percentage of paralysis cases attributable to CPA tumor resection, and that our results do not change even when non-CPA tumor-related cases are excluded, we feel that this statistically significant difference should not be ignored.

There are several potential explanations for the relatively poor outcomes we achieved with the HFG technique, which include: the decreased number of axons that reach target muscles after going through two nerve sutures; the longer time it takes for regenerating axons to reach the muscles; potentially a combination of these two effects. The good results that other authors have ascribed to the HFG technique could be linked to procedures performed sooner after injury than in our series, so that further investigation remains necessary before final conclusions regarding the value of this procedure should be drawn.

Comparing HFD with MF, the latter generated less facial animation at rest and with smiling, and less movement of the mouth while speaking, but only the last of these differences was statistically significant; the global facial recovery score was also not statistically different between the two groups. The only facial feature for which MF out-performed HFD was eye synkinesis when speaking; but again, this difference was small and not statistically significant and probably is related to the fact that the MF technique directs the masseter nerve to the lower branches of the facial nerve (as described, to the buccal and zygomatic) and not to the superior ones. We believe that one single fact could explain all these small differences between our HFD and MF results: the number of axons transmitted to the facial nerve was greater with the former than the latter procedure. The number of transferred axons available for reanimation is an important determinant of facial reanimation, as already demonstrated in another recently published study [61]. According to the literature, one-third to one-half of the hypoglossal nerve, in direct neurorrhaphy without an interposed graft, directs approximately 4,000–5,000 healthy axons to the facial nerve [3], versus just 1,500 axons that the masseter nerve directs to the same target [16].

Other issues that might be considered regarding postoperative eye synkinesis were not a problem in this series. On one hand, the decreased power that the HFG technique produced might explain its absence (the mean synkinesis score was just 0.91 out of 3). On the other hand, probably because of the fewer axons they input into the facial nerve, both the HGD and

Fig. 6 Results obtained with the HFD technique in a 51-year-old patient with right facial palsy. **a**–**c** Preoperative photographs showing repose, eye closure and smile. **ce** Repose, eye closure and smile 18 months after surgery

MF techniques are less prone to facial synkinesis (with scores of 1.82 and 1.73, respectively). According to the literature, the classical hypoglossal-facial technique is more prone to this kind of complication, with some authors suggesting that delaying use of this surgical technique is preferable to immediate repair to prevent synkinesis [2, 29, 31]. With complete sectioning and transfer of the hypoglossal nerve, some degree of synkinesis is identified in almost all patients [2, 14, 29, 31, 49]; also, if severe, it may be a disabling complication that compromises the final outcome. Synkinesis after hypoglossal-facial neurorrhaphy has been attributed to misdirection of regenerating axons resulting in random muscle reinnervation [1]. Some authors suggest that these complications often occur when hypoglossal-facial neurorrhaphy is done early after injury, resulting in excessive muscle innervation [6, 12, 20, 21, 30, 44]. This has been explained by the fact that the axons contained in the donor nerve outnumber those in the recipient nerve, as described previously [3, 15, 64]. Furthermore, the calibers of myelinated axons in the hypoglossal nerve are generally larger than those in the facial nerve [3]. Based upon these observations, we speculate that using a partially sectioned hypoglossal nerve, and thereby providing a sufficient

Fig. 7 Results with HFG Results obtained with the HFG technique, in a 56-year-old patient with left facial palsy. **a**–**c** Preoperative photographs showing repose, eye closure and smile. **c**–**e** Repose, eye closure and smile 23 months after surgery

Fig. 8 Results with MF Results obtained with the MF technique in a 63-year-old patient with right facial palsy. **a**–**c** Preoperative photographs showing repose, smile and eye closure. **c**–**e** Repose, eye closure and smile 18 months after surgery

but not excessive number of axons, could prevent severe synkinesis, which is another benefit, besides tongue preservation, that both techniques offer over complete hypoglossal or HFG nerve transfers. Since no severe synkinesis occurred in our series, we cannot recommend delaying facial reanimation with HFD.

Moreover, our results clearly demonstrate, as shown in Fig. 4, the negative impact of delay since injury on the results of facial reanimation surgery. Although the time between facial nerve injury and repair has been identified as an important predictor of final outcome in both animal models and clinical trials [14, 20, 27, 30, 41, 44, 51, 57], some previous investigators have failed to identify any adverse effect of delaying surgery. Good outcomes have been described even 2 years after facial nerve lesions [37, 54, 58, 62], an observation supported by at least some animal experiments [55]. Some explanations for this have been proposed, including the shorter distance between the facial nerve and muscles, the relative tolerance of facial muscles to chronic denervation, and the maintenance of trophic influences on muscle fibers of a partially, but clinically imperceptibly injured facial nerve. That we identified a clear negative impact of delayed surgery on outcomes which others have not might be related to the prior sole use of the House-Brackmann scale, which was developed as a means to measure recovery from transient Bell's palsy, rather than the results of facial reanimation for total facial nerve palsy [43]. In this study, we used the HB scale as well as our own, and again failed to identify any significant worsening of results with delayed surgery using the HB scale, despite the obvious deterioration over time that our own scale revealed. Though our scale requires further validation, we believe that it, with five measurements instead of just two, might be more sensitive to changes than the HB score. Another potential reason for differences between our results and those of prior reports could be that prior facial reanimations employed the facial nerve rather than the hypoglossal or masseter nerve, and subtle differences that occur over time might have been missed.

Current strategies and potential limitations of this study

HFD and MF have been routinely adopted by authors as treatments of choice for complete facial paralysis following proximal injuries of the facial nerve in patients having less than 18 months of palsy. However, some important issues must be considered when choosing one technique over the other. With HFD, facial nerve dissection demands accurate anatomical knowledge of temporal bone anatomy, and mastoid mobilization of the facial nerve is a time-consuming procedure, since dissection should be performed carefully to avoid nerve injury. On the other hand, facial nerve anatomy and its dissection near the mastoid should be well-known to surgeons who perform hypoglossal-facial nerve transfers. Conversely, the MF technique requires no bone dissection, and has proved to be a less time-consuming procedure in our hands. The slight superiority that HFD exhibited over MF in our series was too small to be clinically significant, except for facial movement while speaking relative to the healthy side; nevertheless, this one difference was documented and might be of clinical importance to some. Consequently, the pros and cons of each procedure must be considered thoroughly when deciding which surgical approach to pursue.

Given that both HFD and MF techniques are safe and produce excellent results, we believe that the personal preferences of the patient and surgeon are probably paramount. Currently at our two institutions, both techniques are offered to patients, who then are allowed to watch videos of the procedures and the results obtained by other patients. This plays an important role in the decision-making process to determine which technique ultimately is performed. At present, we consider that the "gold standard" approaches for facial reanimation, when the proximal facial nerve is not available, are the HFD and MF techniques.

We freely admit that our study has limitations, even beyond the retrospective nature of data collection and the lack of validation of one of the scales that we have used, which is actually a work in process. One limitation relates to the nonrandomized allocation of patients to treatment arm, which could bias results if the decision to select one procedure over another was somehow made based upon, for instance, the severity of injury or an a priori estimation of success. In fact, some of the patients who underwent the HFG or MF technique were selected for these procedures because the facial nerve was not healthy at the level of the mastoid bone, due to mastoiditis or some other localized process. For this reason, randomized, prospective studies remain necessary to confirm the relative value of these procedures. Until that occurs, however, we believe that the results presented here are reliable enough to be taken into consideration for everyday practice.

Conclusions

The results of the current series suggest that both hemihypoglossal-to-facial direct neurorrhaphy, after drilling the mastoid bone to expose the proximal facial nerve, and masseter-to-facial nerve transfers are effective and reliable techniques for facial reanimation, yielding much better results than those obtained with jump graft interpositions. Nevertheless, the former technique shows better results than the latter, with the facial reanimation scale that was developed specifically for this study able to identify subtle differences between the former two techniques, albeit only significant for one facial feature. The results with that scale also largely agreed with those obtained using the prevalidated House-Brackmann scale. The number of axons provided by each technique could explain the subtle difference in facial recovery scores that we observed. Finally, functional results appear to be enhanced when nerve transfers are performed early after facial nerve injury, especially within the first 12–24 months.

Compliance with ethical standards

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Conflicts of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Being this a retrospective study, formal consent is not required.

Informed consent Informed consent was obtained from all individual participants included in the study. When identifying information about participants is available in the article, additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

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Comment

A well done study that confirms that facial reanimation, as assessed by either a standard (House-Brackmann) or newly developed as yet unverified grading system by the authors, gets better results when either a direct hemihypoglossal-to-facial nerve or masseter-to-facial nerve transfer is performed compared to the former combined with a nerve graft. In addition, the results are better when the nerve repair procedure is done within 2 years of the initial injury. Although these results are neither new or surprising, the data is believable and well presented.

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