Surgical technique and results of cable graft interpositioning of the facial nerve in lateral skull base surgeries: experience with 213 consecutive cases

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OBJECTIVE The aim in this study was to review the technique and outcomes of cable graft interpositioning of the facial nerve (FN) in lateral skull base surgeries.

METHODS The authors retrospectively evaluated data from patients who had undergone cable graft interpositioning after nerve sacrifice during skull base tumor removal between June 1987 and May 2015. All patients had undergone lateral skull base approaches to remove tumors at a quaternary referral center in Italy. Facial nerve function was evaluated before and after surgery using the House-Brackmann (HB) grading system.

RESULTS Two hundred thirteen patients were eligible for study. The mean follow-up was 44.3 months. The most common pathology was vestibular schwannoma (83 cases [39%]), followed by FN tumor (67 cases [31%]). Facial nerve tumors had the highest incidence of nerve interruption (67 [66%] of 102 cases). Preoperative FN function was normal (HB Grade I) in 105 patients (49.3%) and mild (HB Grade II) in 19 (8.9%). At the last postoperative follow-up, 108 (50.7%) of the 213 patients had recovered to Grade III nerve function. Preoperative HB grading of the FN was found to have a significant effect on outcome (p = 0.002).

CONCLUSIONS Cable graft interpositioning is a convenient and well-accepted procedure for immediate restoration of the FN. The study results, over a large number of patients, showed that the stitch-less fibrin glue–aided coaptation technique yields good results. The best possible postoperative result achieved was an HB Grade III. The chances of a good postoperative result increase when FN function is normal preoperatively. Slow-growing tumors of the cerebellopontine angle had a favorable outcome after grafting.

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KEY WORDS facial nerve; cable nerve graft interpositioning; sural nerve; cerebellopontine angle; facial nerve tumor; House-Brackmann grading; peripheral nerve; skull base
must be performed immediately to get the best results, either by means of a primary end-to-end coaptation or by a cable nerve graft interposition. In this article, we discuss our experience with intraoperative cable nerve graft interpositioning of the FN in one of the largest published series in the literature.

Methods

We performed a retrospective chart review of all patients who had undergone surgical management of the FN between June 1987 and May 2015 at the Gruppo Otologico, a quaternary referral center for skull base pathology in Piacenza and Rome, Italy. The inclusion criterion for this study was limited to repair of an interrupted FN using the sural nerve (SN) as an interposition cable graft in lateral skull base surgery. Exclusion criteria were as follows: 1) patients who underwent primary end-to-end coaptation, 2) patients who underwent other secondary reanimation procedures like facial-hypoglossal or facial-masseteric nerve coaptation, and 3) patients with incomplete records, less than 1 year of follow-up, or lost to follow-up. Given the referral nature of our practice, we had many patients from Europe, North Africa, and the Middle East, many of whom were not followed up at our center or were lost to follow-up and hence were excluded from this study. The study was cleared by the ethics committee of Casa Di Cura Hospital, Piacenza, Italy.

At the Gruppo Otologico, preoperative and postoperative FN function is classified according to the House-Brackmann (HB) grading system. To precisely evaluate FN function, we take color photographs of a patient’s face in 4 positions—facial muscles at rest, tight closure of the eyes, raised eyebrows, and smiling and pouting lips—both at the preoperative workup and during every postoperative visit. All skull base tumor cases are evaluated with high-resolution CT as well as MRI with contrast enhancement. Angiography or MR angiography is performed in cases in which the tumor is in close association with important vasculature.

The surgical approaches used to treat tumors of the skull base include the translabyrinthine approach, retrosigmoid approach, transcochlear approach, transotic approach, middle cranial fossa approach, transmastoid approach, combined approaches, subtotal petrosectomy, infratemporal fossa approach, and transparotid approach. The detailed steps of the procedures have been described elsewhere.

Technique of Cable Graft Interposition

An SN graft is harvested using a 3-cm curvilinear incision 1 cm behind the lateral malleolus. The incision is extended superiorly for a thicker portion of the nerve and inferiorly to obtain a bifurcated nerve (the SN branches into 2 or more branches anteroinferior to the malleolus) that may be needed for coaptation at the parotid bifurcation of the FN. The SN is carefully dissected with minimal trauma and always handled minimally with non-toothed forceps. The length of the FN defect is measured by placing a suture thread between the proximal and distal ends of the sectioned nerve, taking care to avoid any tension and to consider the pulsating brainstem. Parts of the SN that match the diameter of the cut ends of the FN are carefully selected. The SN is cleaned of its nerve sheath, and its edges are beveled at both ends by cutting it sharply with a knife. The proximal and distal cut ends of the FN are also cut sharply and beveled using sharp scissors. The proximal end is anastomosed first. The anastomoses at both the proximal and distal ends are achieved by placing the beveled ends of the FN and the graft together in apposition over a small piece of harvested temporalis fascia that is used to wrap and secure the anastomoses. Fibrin glue is applied after the coaptation and once again after wrapping the fascia over the coaptation. At the proximal coaptation in the cerebellopontine angle (CPA), care is taken to position the length of the graft along the brainstem surface against the fifth cranial nerve root for support (Fig. 1). The distal end is anastomosed in any remaining bone of the internal auditory canal (IAC) or by making a channel in the temporal bone. Fibrin glue is also applied at various points, wherever possible along the length of the graft, to further secure the graft. We use 9-0 monofilament sutures only for extratemporal epineurial coaptation (retroparotid and parotid).

Definitive FN function was accepted as the main outcome measure. Five factors were taken into consideration in the analysis of nerve function: age, sex, preoperative HB grading, etiology of paralysis, and location of coaptation. All patients were followed-up for at least 1 year.

Data analysis was performed using the Statistical Package for the Social Sciences version 17 (SPSS Inc.). Univariate and multivariate analyses were used to test the significance of any difference between quantitative variables and chi-square tests for qualitative variables. A p value < 0.05 was considered statistically significant.

Results

Of the 4192 lateral skull base procedures done for various pathologies in the specified study period, 330 patients
Technique in and results of 213 cases of FN transplantation

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were subjected to surgical management of the FN that included cable nerve graft interpositioning, end-to-end coaptation, and nerve rehabilitation in a second stage like a facial-hypoglossal nerve coaptation or a facial-masseteric nerve coaptation. After applying the inclusion and exclusion criteria, 213 cases were eligible for inclusion and analysis in the study.

Age, Sex, and Pathology

The mean follow-up was 44.3 months (range 12–300 months). One hundred eight lesions were right sided and 105 were left sided. Patient ages ranged from 10 to 80 years with a mean of 45.7 ± 13.9 years. More than one-third (36.2%) of the patients were 40 years of age or younger and were categorized as “young.” One hundred six patients were males and 107 were females. The percentage of females (60%) who recovered to HB Grade III function was significantly higher than the percentage of males who did (46%; p = 0.04). The most common pathology was vestibular schwannoma (VS; 83 cases [39%]), followed by FNT (67 cases [31%]; Table 1). Facial nerve tumors had the highest incidence of nerve interruption (67 [66%] of 102 cases), followed by petrous bone cholesteatomas (PBCs; 29 [14%] of 201 cases). Vestibular schwannomas had the lowest incidence (83 [2.6%] of 3208 cases). The length of the nerve grafts ranged from 1 to 6 cm.

Facial Nerve Results

Preoperative FN dysfunction was absent (normal, HB Grade I) in 105 patients (49.3%), mild (HB Grade II) in 19 (8.9%), moderate (HB Grade III) in 23 (10.8%), moderately severe (HB Grade IV) in 9 (4.2%), severe (HB Grade V) in 7 (3.3%), and complete (paralysis, HB Grade VI) in 50 (23.5%). At the last postoperative follow-up, 108 (50.7%) of the 213 patients had recovered to an HB Grade III nerve function, 46 (21.6%) to Grade IV, 19 (8.9%) to Grade V, and 40 (18.8%) showed no recovery at all (Fig. 2).

Preoperative HB grading of the FN was found to have a significant effect on outcome (p = 0.002; Fig. 3). In a subgroup analysis, the outcome for preoperative HB Grade I function was good in all pathologies and was statistically significant in FNTs (p = 0.02) and in tympanojugular paragangliomas (TJPs; p = 0.01). We analyzed the data to see if patient age had any effect on the recovery of FN function. Results showed that patients who recovered to HB Grade III were younger than those who fared worse (44.1 vs 49.5 years); however, this difference was not significant (p = 0.16).

Of all the tumors encountered, the best results—that is, the maximum number of cases with an HB Grade III—were achieved in patients with meningiomas (80%), followed by those with TJPs (57.1%) and VSs (56.6%; Fig. 4). The worst outcomes occurred in patients with PBCs and those with FNTs (37.9% and 41.8%, respectively, with HB Grade III outcome). Multivariate analysis showed significant differences between groups (p = 0.001).

The site of coaptation was also analyzed based on the

![FIG. 2. Comparison between preoperative and postoperative FN results in all pathologies (213 cases). Figure is available in color online only.](image-url)
proximal and distal sites of coaptation. The 3 types of coaptation were designated as follows: 1) intradural coaptation, wherein the proximal coaptation was at the brainstem and the distal site was in the IAC (Fig. 5A); 2) transdural coaptation, wherein the proximal site was in the CPA or the IAC and the distal site was in the part of the temporal bone that remained after excision of the lesion (Fig. 5B), 3) extradural coaptation, wherein both the proximal and distal sites of coaptation were in the temporal bone or extratemporal (preparotid and parotid parts of the FN; Fig. 5C and D). In the multivariate analysis, there was a significant difference among the results in the 3 groups (p = 0.001; Fig. 6). In a subgroup analysis, transdural coaptation was found to have a worse outcome as compared with both intradural and extradural coaptation. The difference between intradural and transdural coaptation as well as between transdural and extradural coaptation was also significant (p = 0.006 and 0.01, respectively). On subgroup analysis, 80% of the intradural coaptations had preoperative HB Grade I nerve function. In comparison, only 35% of the transdural and 3.22% of the extradural group had preoperative HB Grade I.

The length of the graft was measured using a suturing thread. The intradural graft measured from 3.5 to 4 cm long, transdural grafts were between 4.5 and 5.5 cm long, and extradural grafts were between 3 and 7 cm long. Note that 67.5% of the nerve grafts with a length ≤ 4 cm, 17.59% of the nerve grafts with a length 4.1–5 cm, and 14.81% of the nerve grafts with a length ≥ 5.1 cm recovered to HB Grade III. There was a significant difference among the 3 groups (p = 0.01) in the multivariate analysis.

Finally, FN results were analyzed according to tumor size. In the VS subgroup, the tumors were between 3 and 5.5 cm in their maximum dimension. Larger tumors had worse postoperative FN function results; however, this finding was not statistically significant (p = 0.81). In the PBC group, the massive type of lesion had a worse outcome than all other types, but again this finding was not statistically significant (p = 0.13).

Discussion

Sural nerve cable graft interpositioning is a standard procedure for interruptions of the FN in the skull base.
In 1885, Albert Einige described the first 2 cases of SN reconstruction for a 3-cm median and a 10-cm ulnar nerve defect. Seventy years later, in 1955, John Conley performed the first case of greater auricular nerve interposition of the FN following total parotidectomy. Recent studies have shown that cable nerve graft interposition provides as good a result as a primary end-to-end coaptation. However, the best possible postoperative outcome is HB Grade III, regardless of the graft material used or the technique employed, because the frontal muscle function rarely recovers and a certain degree of synkinesis is unavoidable after grafting.

The factors that could influence the results of FN reconstruction are discussed below.

**Pathophysiology**

Nerve regeneration after grafting does not involve mitosis and multiplication of nerve cells. Instead, the cell body restores nerve continuity by growing a new axon. The cable nerve graft acts as a nerve conduit with empty endoneurial tubes, a reserve of viable Schwann cells, and nerve growth factors through which the regenerating axons can be directed. The use of stem cells and nerve conduits to substitute for the nerve grafts has been tried with promising results. However, a sensory nerve graft is still considered a better alternative as it is an excellent biocompatible, resorbable nerve conduit with a basal lamina, preformed guidance channels, a reserve of viable Schwann cells, and nerve growth factors.

**Demographic Factors**

It has been reported that after a neural injury, women tend to maintain the viability of the facial musculature longer than men; hence, the results of grafting could be better in women. This finding was supported by our study, wherein more females (60%) than males (46%) had a significantly better outcome in recovering to HB Grade III (p = 0.04). Kimata et al. reported that outcomes of FN grafting were better in younger patients. In our series, postoperative HB Grade III function was more frequent in the group with an age ≤ 40 years (60%) than in the group with an age > 40 years (45%), but the difference was not statistically significant.

**Duration of Paralysis**

One of the most important factors that determines the ultimate success of any reinnervation procedure is the duration of facial paralysis. An interrupted FN should be promptly surgically repaired either with a direct end-to-end coaptation when feasible or with an interposition graft. Facial muscles completely denervated for less than a year respond to nerve grafting. The response to reinnervation after a year of paralysis diminishes significantly and becomes unpredictable. In cases of incomplete denervation, the facial muscles can remain viable for longer and may respond to reinnervation techniques. We perform cable graft interpositioning of the FN only in cases of paralysis lasting 1 year or less. In all cases with paralysis lasting longer than 1 year, the patients are managed with a hypoglossal or masseteric nerve coaptation with the FN.

**Tumor Factors**

The FN, as most motor nerves, is quite resistant to infiltration by pathologies. Axon and Ramsden stated that HB Grade I FN function could be maintained until the motor neuron reserve is ≥ 10%. Neuronal degeneration and axonal demyelination is counterbalanced with the collateral sprouting and hypertrophy of the innervated muscle fibers. Furthermore, the absence of epineurium around the CPA and IAC segments of the FN allows effacement of the nerve fibers and spreading of the nerve over large tumors. Facial nerve function was preserved until more than 50% of the motor neurons had been degenerated. In slow-growing pathologies such as VS and meningioma, the FN fibers are stretched slowly over many months, eventually leading to kinking. This may lead to a disruption in axoplasmic flow, which is a Type 1 reversible nerve injury. When such a nerve is interrupted and grafted, a satisfactory outcome is achievable since all the fibers are still viable and available for regrowth. However, other variable factors, such as the loss of blood supply to the nerve, tumor infiltration, or the inflammatory insult, are likely to influence the results of grafting. In our study, we observed that slow-growing tumors such as TJPs, VSs, and meningiomas had favorable outcomes (HB Grade III in 57.1%, 56.6%, and 80%, respectively). Data analysis revealed that the rate of recovery to HB Grade III FN function is better.
when the preoperative nerve function is HB Grade I, and
this finding was statistically significant (p = 0.02; Fig. 3).
This finding has been validated in other series as well.2,31
Hence, preoperative FN function is a very important factor
in determining the outcome of FN grafting. Statistically,
the size of the tumor, excluding PBCs and temporal bone
malignancies, did not significantly influence the outcome
of grafting (p = 0.81).

The inflammatory insult to the FN caused by a choleste
tatoma is very high, leading to interruption of the nerve
by scarring.1 In our series of PBCs, only 38% of the nerves
grafted were associated with a postoperative HB Grade
III. The results were even worse in temporal bone malig
nancies, as none of the grafted cases recovered to Grade
III postoperatively. This result could be attributed to the
fact that apart from the infiltrative nature of the disease,
the grafted nerves were subjected to further insult from
the postoperative radiation, although none of the patients
have developed a recurrence so far.

Characteristics of the Donor Nerve Graft

The SN has emerged as an ideal graft material because
of its ease of access, abundant length, sufficient thickness,
branching (which can be used to reconstruct the peripheral
branches of the FN), and its ability to be harvested out-
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combined. The rate of HB Grade III function ranges from 5% to 86%. The results of the present study were consistent with those in the literature, with 51% of patients achieving HB Grade III. Postoperatively, most authors managed to achieve HB Grade III in at least 50% of their patients.

Conclusions

Cable graft interpositioning is a convenient and well-accepted procedure for immediate restoration of the FN. Our results, over a large number of patients, show that the stitch-less fibrin glue–aided coaptation technique yields good results. The best possible postoperative result achieved in our series was an HB Grade III. The chances of a good postoperative result increase when FN function is normal preoperatively. Slow-growing tumors of the CPA in cerebellopontine angle tumor surgery.

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Disclosures
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**
Conception and design: He, Balasubramanian, Sanna. Acquisition of data: He, Prasad, Balasubramanian, Piccirillo, Taibah, Russo. Analysis and interpretation of data: He, Prasad, Balasubramanian, Taibah, Sanna. Drafting the article: Prasad, Balasubramanian. Critically revising the article: He, Prasad, Balasubramanian. Reviewed submitted version of manuscript: He, Prasad, Taibah, Russo. Approved the final version of the manuscript on behalf of all authors: He. Statistical analysis: He, Prasad, Balasubramanian.

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