

Original Investigation

Early Nerve Grafting for Facial Paralysis After Cerebellopontine Angle Tumor Resection With Preserved Facial Nerve Continuity

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 Invited Commentary

IMPORTANCE Preserving facial nerve function is a primary goal and a key decision factor in the comprehensive management of vestibular schwannoma and other cerebellopontine angle (CPA) tumors.

OBJECTIVE To evaluate the use of the pattern of facial paralysis recovery in the early postoperative months as a sole predictor in selecting patients for facial nerve grafting after CPA tumor resection when cranial nerve VII is uninterrupted.

DESIGN, SETTING, AND PARTICIPANTS Sixty-two patients with facial paralysis and uninterrupted cranial nerve VII who developed facial paralysis after CPA tumor resection at The Johns Hopkins Hospital were followed up prospectively to assess for spontaneous recovery and to determine candidacy for facial reanimation surgery. The study dates and dates of analysis were January 1, 2009, to March 31, 2015.

INTERVENTIONS After a minimum of 6 months of clinical follow-up and no signs of clinical recovery, patients underwent facial nerve exploration and a masseteric or hypoglossal nerve transfer. Intraoperative direct nerve stimulation was performed to assess for the presence of subclinical reinnervation. Patients were followed up for a minimum of 18 months after surgery to evaluate outcomes.

MAIN OUTCOMES AND MEASURES Facial function and recovery were studied objectively with a Smile Recovery Scale, Facial Asymmetry Index, and House-Brackmann (HB) grading system. Other outcome measures included the duration of paralysis, time to recovery, and evidence of synkinesis.

RESULTS Sixty-two patients (33 men, 29 women; mean age 51.8 years) with uninterrupted facial nerves after CPA tumor resection developed HB grade IV, V, or VI facial paralysis. Ten patients underwent nerve grafting by 12 months, 9 patients received grafting after 12 months, and 8 patients had no intervention. Thirty-five patients spontaneously recovered. In all patients who underwent nerve grafting, there were no detectable facial muscle movements or electromyographic response to direct facial nerve stimulation suggestive of occult reinnervation. Overall, early facial reanimation surgery resulted in a shorter total duration of paralysis. Masseteric nerve grafting resulted in earlier recovery compared with hypoglossal nerve grafting (5.6 vs 10.8 months, $P = .005$). Patients who showed no signs of recovery by 6 months after CPA surgery but declined facial reanimation surgery demonstrated at best HB grade V recovery after 18 months of observation.

CONCLUSIONS AND RELEVANCE The recovery pattern in the early postoperative period among patients who develop facial paralysis after CPA tumor resection is a useful clinical tool in selecting patients for facial reanimation surgery. Patients can be counseled for facial reanimation surgery as early as 6 months after surgery because satisfactory facial functional recovery is unlikely to occur when there is no clinical evidence of spontaneous nerve regeneration in the first 6 months.

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Preserving facial nerve function is a primary goal and a key decision factor in the comprehensive management of vestibular schwannoma and other cerebellopontine angle (CPA) tumors.¹ Advanced techniques in micro-neurosurgery, high-resolution imaging, microscopic magnification, sensitive electrophysiological monitoring, precise ultrasonic dissectors, and the combined expertise of multidisciplinary teams have all contributed to a high percentage of facial nerve preservation.^{2,3} However, an uninterrupted facial nerve after total and near-total resection of CPA tumors does not always translate into preserved facial animation.²⁻⁴ Depending on the degree of facial nerve injury, the postoperative facial function may be completely normal, partially weak, or totally paralyzed. Fortunately, a high percentage of patients with partial weakness and some with complete paralysis recover spontaneously and regain satisfactory facial movement.⁴ However, some patients do not spontaneously recover facial muscle function and require surgical intervention to restore facial tone and animation. For those patients, timely intervention is critical in minimizing irreversible degeneration of the facial muscles and poor functional outcome after facial reanimation surgery. Early nerve grafting and reinnervation are thought to yield better results by limiting the degenerative effects of denervation and by enhancing accelerated regeneration of motor neurons.^{5,6} Identifying patients who will ultimately require facial reanimation surgery for early nerve grafting is desirable but clinically challenging because, to date, there are no clear patient, tumor, or intraoperative factors that have been reliably predictive.⁷⁻¹⁰

Because of the high probability of spontaneous recovery, patients with uninterrupted facial nerves after CPA tumor resection are often observed for 12 months before becoming candidates for nerve grafting surgery. This approach delays and negatively affects those patients who ultimately do not recover spontaneously. Physicians are faced with the dilemma of whether to wait for spontaneous recovery but risk increased degeneration and decreased success of subsequent facial reanimation surgery or to proceed with early facial reanimation surgery at the risk of premature intervention, injuring a recovering nerve and performing unnecessary surgery in patients who may otherwise spontaneously recover. In 2011, Rivas et al¹¹ retrospectively reviewed facial functional outcomes among 243 patients who developed facial paralysis after vestibular schwannoma resection, despite an anatomically preserved facial nerve. The review led to the conclusion that the rate of facial nerve recovery over the first 6 months after vestibular schwannoma resection is an early independent predictor of ultimate facial nerve recovery and function, predicting poor facial nerve recovery with 97% sensitivity and 97% specificity.¹¹ We have used this predictive rate of recovery model to select candidates for facial reanimation surgery earlier than the standard 12-month postoperative observation period.

In this study, we prospectively evaluated the accuracy and validity of solely using the postoperative rate of recovery model to select patients for early nerve grafting after resection of CPA tumors in patients with anatomically intact facial nerves. We hypothesized that patients who showed no clinical improve-

ment in facial nerve function 6 months after CPA tumor resection and underwent early facial nerve exploration for grafting would have no facial muscle contraction after direct open facial nerve stimulation. We also postulated that, when there is no clinical recovery 6 months after CPA tumor resection, facial nerve function would remain poor after 18 months or longer with no intervention.

Methods

Design, Setting, and Participants

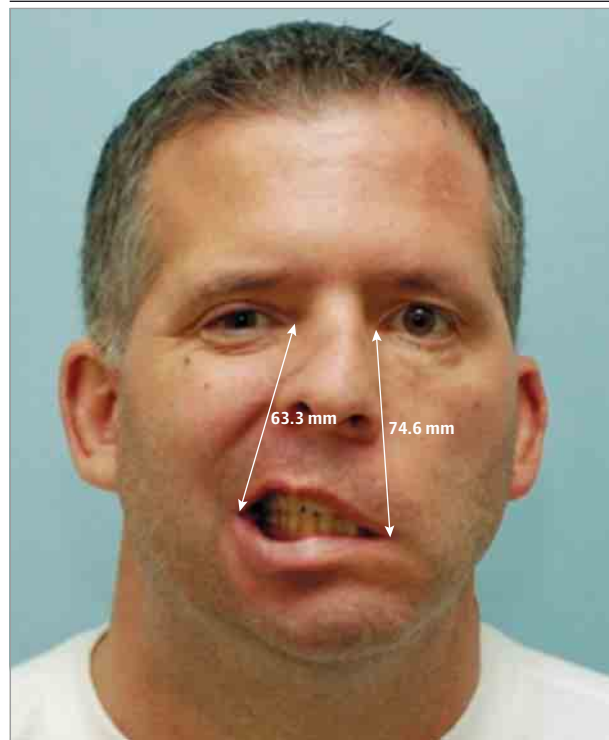
Sixty-two consecutive patients with facial paralysis having uninterrupted facial nerves after CPA tumor resection seen by the senior author (K.D.B.) at The Johns Hopkins Hospital were identified for this study. The study dates and dates of analysis were January 1, 2009, to March 31, 2015. Patients were included if they were seen with House-Brackmann (HB) grading system grade II or higher at the onset of paralysis after CPA tumor resection. Patients with no signs of clinical improvement by 6 months were considered candidates for facial reanimation surgery and were counseled accordingly. Patients who underwent cross-facial and muscle transfer facial reanimation surgery were excluded. In addition, patients with a history of facial weakness before tumor resection, individuals with exposure to radiation therapy, and those in whom the facial nerve was transected were excluded. This study was performed with approval from The Johns Hopkins Hospital Institutional Review Board. Written informed consent was obtained for all interventions in this study.

Intervention

Patients were followed up clinically with serial examinations over the first 6 months after their CPA surgery. Patients who showed evidence of facial muscle recovery were grouped into the nonsurgical arm and followed up until satisfactory recovery (good or excellent smile and HB grade I, II, or III). Patients who showed no clinical recovery after the first 6 postoperative months were counseled for early facial nerve exploration and nerve grafting with a masseteric or hypoglossal nerve transfer. The choice of masseteric vs hypoglossal nerve as a donor source was made based on the preserved function of these 2 nerves and other patient factors.¹² The masseteric nerve was found within the subzygomatic triangle in all patients, with adequate length mobilized for direct coaptation to the facial nerve.¹³ For hypoglossal nerve use, the facial nerve was decompressed from the mastoid and transposed for an end-to-side coaptation to the hypoglossal nerve after 30% to 40% neurotomy.

Patients who agreed to early intervention proceeded to surgery by 12 months after CPA tumor resection. Those who declined early intervention were further observed. A subset of patients with no spontaneous recovery subsequently agreed to intervention and underwent nerve grafting after 12 months. Eight patients who refused nerve grafting procedures even beyond 12 months were followed up clinically without active intervention. All patients who opted for surgical intervention underwent intraoperative electromyography (EMG) with direct

Figure 1. Facial Asymmetry Index Marked on an Image After Calibration



The medial canthus is used as a fixed-point reference, and straight lines are drawn to the angles of the mouth.

facial nerve stimulation at 0.8, 1.0, and 2.0 mA to check for facial muscle response as evidence of subclinical reinnervation. For direct nerve stimulation, the facial nerve is exposed after infiltration of 1:100 000 epinephrine solution without a local anesthetic agent or a general neuromuscular blocking agent.

Main Outcomes and Measures

Demographic data, tumor characteristics, intraoperative findings, and postoperative outcomes were recorded. Details about the facial reanimation surgery were documented in the operative reports. Clinic notes, photographs, and videos were collected and reviewed. The primary study outcome was facial muscle function over a minimum of 18 postoperative months after CPA tumor resection.

All images were analyzed with a software program (Mirror, version 7.4.1; Canfield Imaging Systems). The measurements were calibrated to millimeters using the standardized corneal white-to-white corneal diameter as a reference for measurements.¹⁴ Outcomes were objectively measured using the HB grading system,¹⁵ a Smile Recovery Scale, and the Facial Asymmetry Index. Synkinesis was scored based on the Sunnybrook Facial Grading System.¹⁴ Intraoperative response to direct facial nerve stimulation was recorded using a monitoring system (NIM, version 3.0; Medtronic).

Recovery of Facial Symmetry

The recovery of facial tone and symmetry was assessed using objective measurement of standardized points between the af-

Table 1. Smile Recovery Scale Scoring System for Patient Outcomes After Facial Reanimation Surgery

Score	Description
1 (Poor)	Grossly asymmetric smile with no oral commissure movement
2 (Adequate)	Grossly asymmetric smile with asymmetric oral commissure movement and no dental show
3 (Good)	Symmetric smile indicated by nasolabial fold definition and elevation of malar fat pad but no dental show (Mona Lisa smile)
4 (Very good)	Symmetric smile with symmetric oral commissure excursion, almost equal dental show, and malar fat pad elevation (social smile)
5 (Excellent)	Symmetric smile with equal dental show bilaterally and elevation of malar fat pad (Duchenne smile)

ected and nonaffected sides. The distance between the medial canthus and the ipsilateral oral commissure is measured on the paralyzed and nonparalyzed sides, with the difference in millimeters composing the Facial Asymmetry Index (Figure 1). Smaller values indicate more symmetry and better recovery.

Smile Recovery

A visual Smile Recovery Scale was used to score postoperative smiles. This scale is simple to use and closely reflects how a casual observer sees a smile after brief interactions. Smile recoveries were scored from 1 to 5 (where 1 is poor, 2 adequate, 3 good, 4 very good, and 5 excellent), as summarized in Table 1. Dental show was objectively determined by counting the number of exposed upper teeth on each side of the midline.

Statistical Analysis

Data were analyzed using statistical software (Stata, version 12.1; StataCorp LP). The Fisher exact test was used to compare age, sex, tumor size, degree of tumor resection, facial reanimation surgery graft type, the branch to which the facial nerve was coapted, and the type of coaptation, along with the time to recovery. The Wilcoxon rank sum test was used to compare outcome variables between treatment categories. $P = .05$ was considered a statistically significant result for both tests.

Results

Participant Characteristics

Sixty-two patients developed significant facial paralysis immediately after CPA tumor resection and were included in this study. There were 33 men (53%) and 29 women (47%). Patients were followed up for a mean duration of 27.9 months. The patient age ranged from 24 to 87 years, with a mean age of 51.8 years. Fifty-six patients had vestibular schwannomas, 4 had cerebellopontine meningiomas, 1 had a cavernous angioma, and 1 had a glossopharyngeal neuroma. The mean tumor size was 28.75 mm. Among 19 patients who subsequently underwent nerve grafting (intervention groups), 12 had complete resection of the CPA tumor, and 7 had only partial resection. Statistical analysis revealed no significant associations among age, sex, tumor size, tumor type, and early recovery.

Table 2. House-Brackmann Grading System Grades Before and After Facial Reanimation Surgery in the Intervention Groups and at Baseline and Follow-up in the Nonintervention Group

Intervention Groups				Nonintervention Group (n = 8)	
Nerve Grafting Within 12 mo (n = 10)		Nerve Grafting After 12 mo (n = 9)		Baseline	Follow-up
Before	After	Before	After		
VI	III	VI	II	VI	VI
VI	III	VI	III	VI	V
V	II	VI	III	VI	VI
VI	II	VI	III	VI	V
VI	III	VI	III	VI	V
VI	II	VI	III	VI	V
V	IV	VI	III	VI	V
VI	II	VI	III	VI	V
V	IV	VI	III	NA	NA
VI	IV	NA	NA	NA	NA

Abbreviation: NA, not applicable.

Direct Intraparotid Nerve Stimulation and EMG Response

As a test of subclinical or impending facial nerve recovery, all surgically explored facial nerves were incrementally stimulated at 0.8 to 2.0 mA. In all patients, there were no detectable facial muscle movements or EMG response suggestive of occult reinnervation.

Facial Nerve Grafting

Among 19 patients who underwent nerve transfer facial reanimation surgery, 10 patients had surgery 12 months or earlier after the onset of paralysis (mean, 8.3 months), and 9 patients had surgery more than 12 months after the onset of paralysis (mean, 16.3 months). Fourteen patients underwent masseteric nerve transfer while 5 patients underwent hypoglossal nerve transfer. Nerve transfers were to the main facial nerve branch (n = 16) or to a buccal branch (n = 3).

Patterns of Recovery

Thirty-five of 62 study patients (57%) showed clinical signs of recovery over the first 6 postoperative months after CPA surgery. By 12 months after CPA tumor resection, this subgroup of patients had good to excellent smile recovery and oral commissure symmetry.

Twenty-seven patients showed no signs of recovery by 6 months after the onset of paralysis and were counseled for facial reanimation surgery. Nineteen of them agreed to undergo nerve transfer surgery at various time points while 8 of them declined surgery. All 8 patients who refused surgery did not achieve satisfactory facial nerve recovery, with HB grade V or VI after a mean follow-up of 20 months (range, 14-55 months) (Table 2).

Among 19 patients who underwent nerve grafting surgery, there were no statistically significant differences in the Smile Recovery Scale score ($P = .43$), synkinesis ($P = .94$), HB grade ($P = .93$), or Facial Asymmetry Index ($P = .56$) between patients who underwent repair within 12 months vs after 12 months. These results are summarized in Table 3.

Patients who received masseteric nerve grafts recovered earlier than patients who received hypoglossal nerve grafts ($P = .005$, Fisher exact test). The mean times to the onset of

recovery were 5.6 months in those who received masseteric grafts and 10.8 months in those who received hypoglossal nerve grafts. The onset of recovery was similar among patients undergoing masseteric nerve grafts repaired within 12 months (mean, 5.4 months) vs after 12 months (mean, 6.0 months). Figure 2 shows the recovery of a patient who received a masseteric nerve transfer 9 months after the onset of paralysis.

The HB grade outcomes before and after facial reanimation surgery are summarized in Table 2. Patients who showed no signs of recovery by 6 months after CPA surgery but declined nerve grafting surgery demonstrated at best an HB grade V recovery after 18 months of observation.

Discussion

In humans, the intricate network of nerve fibers connecting the motor cortex, limbic system, facial nucleus, and muscles is unique in projecting individual identities by maintaining facial form, characteristic animation, and emotional expression. Injury to the facial nerve results in changes to all components of this delicate network that may be irreversible unless timely spontaneous recovery or intervention occurs. Surgical resection of CPA tumors particularly subjects the facial network to injury because of dissection close to the brainstem and the proximal aspects of the facial nerve. In a study by Falcioni et al¹⁶ of patients who underwent CPA tumor resection, 65% had regained normal or near-normal facial nerve function (HB grade I or II) at 12 months and 29.4% reported satisfactory facial nerve recovery (HB grade III) at 12 months. Unfortunately, anatomic preservation of the facial nerve after CPA tumor resection does not always translate into satisfactory functional recovery. In a subgroup of patients with preserved facial nerve continuity after CPA tumor resection, early postoperative facial nerve function was poor.¹⁶ In the same study,¹⁶ poor functional recovery (HB grade IV, V, or VI) was reported in 5.6% of the study population.

Predicting long-term facial nerve recovery in patients with preserved facial nerve continuity after CPA tumor resection has been the subject of many studies because of the quality-of-

Table 3. Patterns of Recovery After Nerve Grafting in 19 Patients

Patient No./ Sex/Age, y	Type of Nerve Graft	Time to Facial Reanimation Surgery, mo	Time to Recovery, mo	Total Paralysis Duration, mo	Smile Recovery Scale Score	Synkinesis	Change in Facial Asymmetry Index, mm	
							At Rest	With Smile
1/F/55	Masseteric	6	6	12	3	1	2.8	4.0
2/M/59	Masseteric	7	12	19	3	1	1.3	22.2
3/F/28	Masseteric	7	6	13	4	0	4.3	10.8
4/M/36	Masseteric	8	6	14	3	1	2.3	8.9
5/F/50	Masseteric	8	6	14	4	2	1.9	13.1
6/F/53	Masseteric	9	3	12	3	1	0	11.1
7/F/60	Masseteric	9	3	12	3	2	NA	NA
8/M/41	Masseteric	9	3	12	4	0	2.3	13.1
9/M/69	Masseteric	9	6	15	3	1	NA	NA
10/M/42	Masseteric	11	3	14	3	1	NA	NA
11/M/38	Masseteric	12	6	18	4	1	0.2	8.4
12/M/47	Hypoglossal	12	12	24	3	1	10.4	18.0
13/M/38	Masseteric	14	6	20	3	1	0	7.7
14/M/46	Hypoglossal	16	6	22	3	1	9.5	18.5
15/M/37	Hypoglossal	18	12	30	3	1	5.1	5.1
16/F/47	Hypoglossal	18	12	30	3	1	3.4	15.0
17/M/63	Masseteric	18	6	24	2	1	NA	NA
18/F/35	Masseteric	19	6	25	3	1	2.1	6.5
19/F/46	Hypoglossal	20	12	32	3	1	2.5	9.2

Abbreviation: NA, not available.

life implications and time-sensitive nature of any potential intervention. Several studies⁷⁻¹⁰ have failed to show any correlation among tumor size, intraoperative response to nerve stimulation, intraoperative stimulation thresholds, and patient age, sex, and postoperative EMG. Axon and Ramsden¹⁷ evaluated 184 patients with facial paralysis after vestibular schwannoma resection and concluded that the severity of immediate postoperative clinical facial function was the most accurate predictor of long-term outcomes. For patients starting with HB grade V or VI function after vestibular schwannoma resection, our group previously reported that the postoperative rate of recovery was the most reliable predictor of poor outcome after 1 year.¹¹ Our group's predictive model using the rate of functional improvement as the sole independent variable anticipated poor outcome before 1 year in more than 50% of cases with 97% sensitivity and 97% specificity.¹¹ Using the postoperative rate of recovery during the first 6 months after CPA tumor resection as a sole predictor, we prospectively stratified patients herein with facial paralysis, despite a preserved facial nerve, into an intervention group and a nonintervention group. The nonintervention group was expected to have satisfactory spontaneous facial function recovery without nerve grafting. We offered the intervention group facial nerve grafting (before 12 months after surgery) using the masseteric or hypoglossal nerve as the donor nerve if they showed no clinical signs of recovery over the first 6 postoperative months. The rationale for grafting the nonfunctional yet anatomically intact facial nerve is to provide axonal input distal to the site of injury in the internal auditory canal. Recommending early nerve grafting to a patient with facial paralysis, despite an anatomically intact facial nerve, has the poten-

tial benefit of shortening the overall duration of significant paralysis, as well as earlier and better recovery. However, early nerve grafting may be premature and unnecessary if spontaneous recovery is impending but not detected at the time of intervention. Premature nerve grafting may subject some patients to unnecessary surgery, with associated morbidities.

In this study, we have shown that the risk of premature facial nerve exploration based on a lack of recovery over the first 6 postoperative months was 0% (0 of 10). This finding was supported by the complete absence of EMG response and facial muscle contraction to direct facial nerve stimulation. At the main facial branch, pes, or individual peripheral facial nerve branches, direct facial nerve stimulation is expected to capture any axonal response, without the ambiguity of surface EMG or percutaneous electroneurography.

The clinical course of 8 patients herein who declined nerve grafting provides insight into the natural course of the anatomically intact but injured facial nerve after CPA resection when the early facial nerve function is poor. Without surgical intervention, facial nerve function in patients with HB grade V or VI after CPA tumor resection will likely remain poor when there is no clinical evidence of improvement over the first 6 postoperative months. Nerve grafting in this group offers the potential for restoring function of their native facial muscles. Furthermore, satisfactory facial reanimation surgery in this group after excessive delay before intervention will likely require transfer of functional muscle units such as the temporalis or gracilis.

The total duration of paralysis is a reflection of how long the facial muscles are denervated. While this duration is shortened by early nerve grafting, it also depends on the type of

Figure 2. Masseteric Nerve Transfer 9 Months After the Onset of Paralysis, With Signs of Recovery by 3 Months After Facial Reanimation Surgery



A-D, Views before reanimation surgery are shown at rest (A), attempting a Mona Lisa smile (B), attempting a Duchenne smile (C), and attempting a Duchenne smile with maximal dental show (D). E-H, Views after reanimation

surgery are shown at rest (E), attempting a Mona Lisa smile (F), attempting a Duchenne smile (G), and attempting a Duchenne smile with maximal dental show (H).

nerve grafting performed. To shorten the duration of total paralysis, the distance across which axons grow to reach the facial muscles should be minimized. The masseteric nerve is in proximity to the facial muscles and when coapted to the facial nerve has a shorter distance to grow compared with cross-facial nerves or grafts from the hypoglossal nerve. When intervention is performed early, there may be no difference in long-term outcomes whether a masseteric or hypoglossal nerve graft is used. However, when facial reanimation surgery nerve grafting is delayed, the use of a hypoglossal nerve or cross-facial nerve graft may further prolong the duration of paralysis and affect the ultimate outcome. Given the enhanced proximity of the masseteric nerve to the facial muscles and the earlier onset of recovery seen with masseteric nerve grafts compared with hypoglossal nerve grafts, we advocate a masseteric nerve transfer in patients who undergo delayed repair.

In this study, we detected no difference in the ultimate Smile Recovery Scale score or Facial Asymmetry Index between patients who underwent repair within 12 months vs after 12 months. As would be expected, patients who underwent nerve grafting after 12 months showed a longer duration of paralysis overall.

This study supports the use of the postoperative rate of recovery from facial paralysis in the early postoperative months after CPA tumor resection as a predictor of long-term facial recovery when continuity of the nerve is preserved. Our find-

ings support facial nerve exploration and grafting when there is no evidence of recovery after 6 months. Selecting patients for early nerve exploration and grafting using the recovery pattern over the first 6 postoperative months resulted in no false-negative results of facial nerve exploration. Delaying nerve grafting after 12 months of paralysis may yield good smile recovery and correction of asymmetry, as seen in this study, but unnecessarily prolongs the duration of paralysis.

This study mostly relied on clinical evidence of facial recovery recorded at scheduled follow-up visits and may have overreported the time to recovery. The use of masseteric and hypoglossal donor nerves introduces inherent differences between the treatment groups that complicate their comparison. A larger cohort in which all patients undergo the same intervention at the same time is needed to more accurately evaluate outcomes after facial reanimation surgery.

Conclusions

The recovery pattern in the first 6 postoperative months among patients who develop facial paralysis after CPA tumor resection is a useful clinical tool in selecting patients for early facial reanimation surgery. Occult reinnervation is unlikely or imminent when there is no clinical improvement in paralysis after 6 months. Patients with poor facial nerve function after CPA

tumor resection who show no clinical signs of improvement over the first 6 postoperative months are unlikely to regain satisfactory facial function without surgical intervention. Earlier nerve grafting shortens the total duration of paralysis. Patients may be counseled for facial nerve grafting as early as 6

months after CPA tumor resection when they show no clinical signs of improvement. Using the predictive model of clinical facial nerve function in the 6 months after CPA tumor resection, patients may receive counseling about the prognosis of their facial recovery with vs without intervention.

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