Radiological and Clinical Factors Predicting the Facial Nerve Outcome following Retrosigmoid Approach for Large Vestibular Schwannomas (VSs)

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J Neurol Surg B 2013;74:317–323.

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Abstract

Objective The aim of our study was to identify the radiological and clinical factors that predict postoperative facial nerve outcome following retrosigmoid approach for large vestibular schwannomas (VSs).

Methods A total of 72 patients with large (≥ 3 cm) vestibular schwannomas was included in this retrospective study. Various parameters evaluated were age, gender, clinical presentation, tumor diameter in three planes, intrameatal extension, and pattern of growth.

Results Age of the patient and presenting symptoms such as headache, ataxia, or preoperative facial nerve dysfunction correlated with poorer facial nerve outcome ($p < 0.05$). Patients with larger tumor volumes and extrameatal growth experienced a worse outcome ($p < 0.05$). Anterior and caudal extension ($p = 0.001$) correlated with poorer outcome, as well. Intrameatal extension and bony changes of the internal acoustic meatus did not correlate with the outcome ($p > 0.05$). Of the various examined factors, preoperative facial nerve function independently predicted postoperative facial nerve outcome.

Conclusion Our study suggests that young patients with small tumor volume and normal facial nerve function at presentation are more likely to experience a good postoperative facial nerve outcome. These clinical and radiological parameters can be used to predict facial nerve outcome prior to surgery.

Keywords

- ▶ vestibular schwannoma
- ▶ facial nerve
- ▶ outcome
- ▶ predicting factors

Introduction

With the development of microsurgical techniques, facial nerve outcome after vestibular schwannoma (VS) surgery has improved dramatically over the past several decades. The development of the translabyrinthine approach by House in 1960¹ and the introduction of intraoperative facial nerve monitoring² further reduced the morbidity related to the facial nerve outcome. However, despite these advances, the rate of temporary or permanent facial nerve dysfunction after microsurgery or gamma knife radio surgery still ranges from

7 to 48%.^{3–9} Size and staging of the tumor are now well recognized factors influencing the postoperative facial nerve outcome.^{10–12} Moreover, the effect on facial nerve outcome of several other factors such as histological features, clinical presentation, extrameatal tumor extension, bony changes in the internal acoustic meatus, and radiological features has been documented.^{11–15} However, the majority of these studies lacked uniformity in terms of surgical approaches, operating surgeons, techniques of tumor excision, and methods of facial nerve preservation. The aim of our study was to identify various radiological and clinical factors that correlate with the

received

February 27, 2013

accepted after revision

April 30, 2013

published online

June 25, 2013

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Stuttgart · New York

DOI <http://dx.doi.org/10.1055/s-0033-1349060>.
ISSN 2193-6331.

facial nerve outcome after VS surgery using the retrosigmoid approach.

Clinical Materials and Methods

Clinical Data

This study was performed using a protocol approved by the Institutional Review Board at the Louisiana State University Health Sciences Center in Shreveport and in accordance with patient privacy rights protection as enforced by the Health Insurance Portability and Accountability Act (HIPAA).

This retrospective study included 72 consecutive patients with sporadic VSs who were operated on by the senior author (AN) between 1995 and 2012. The senior author used the standard retrosigmoid approach in all cases. The techniques of surgery and facial nerve preservation were similar in all patients. The demographic characteristics of the patient and specific data pertaining to the clinical presentation, Intra-operative details, and postoperative neurological status were obtained from the inpatient case records. Facial nerve function was assessed before surgery and at 1 year following surgery using the House- Brackmann (H&B) grading scale.¹⁶ Grades 1 through 3 (H&B) were classified as good outcome and Grades 4 through 6 (H&B) as poor outcome. The size of the tumor was determined either by computed tomography (CT) or magnetic resonance imaging (MRI) scans, and the maximum transverse diameter was taken for the analysis. VSs measuring 3 cm or greater were included in this study. Patients with recurrent tumor, tumors operated on by any approach other than retrosigmoid, and patients who were previously treated with gamma knife were excluded from the study. Patients for whom all clinical, radiological, operative, and follow-up data was not available were excluded from the study.

Radiological Characteristics

T1-weighted, T2-weighted, and gadolinium-enhanced MRI sequences in coronal, sagittal, and axial planes aided preoperative assessment of radiological factors. Tumor diameter (anteroposterior, mediolateral, and vertical), tumor volume, and tumor extension (anterior, posterior, cranial, and caudal) with reference to the internal acoustic meatus were all evaluated. The length and width of the intracanalicular part of the tumor were also assessed. The anteroposterior diameter was defined as parallel to the petrous ridge and the mediolateral diameter as perpendicular to the petrous ridge. High-resolution CT images were used to evaluate the internal auditory canal (IAC) changes preoperatively and postoperatively. The length of the anterior and posterior walls of the internal acoustic canal and the maximum diameter of the canal was measured and correlated with the facial nerve outcome. These factors were measured using Centricity Enterprise Web V3.0 (General Electric Medical system. Electronics, Fairfield, Connecticut, USA) (► **Figures 1–3**).

Statistical Analysis

Statistical analysis was performed using SPSS v20 (IBM, Inc., Chicago, Illinois, USA) and Microsoft Excel (Microsoft, Redmond,

Fig. 1 The T1-weighted gadolinium contrast-enhanced magnetic resonance imaging scan (axial view) of a vestibular schwannoma showing tumor diameters (anteroposterior = green, mediolateral = blue) and extension (anterior = red, posterior = white).

Washington, USA). Nonparametric chi-square and Pearson's correlation tests were used for the statistical analysis. Comparisons were considered significant only if the *p* value was < 0.05 . Univariate analysis was used to identify any covariates that might affect the outcome. Independent predictors of poor outcome were identified by regression analysis and Pearson's bivariate.

Fig. 2 The T1-weighted gadolinium contrast-enhanced magnetic resonance imaging scan (coronal view) of a vestibular schwannoma showing vertical tumor diameter (blue) and extension (cranial = green and caudal = red).

Fig. 3 Computed tomography scan of the internal auditory canal (IAC) (bone window) showing the length of the anterior canal wall (red), length of the posterior canal wall (blue), and maximum canal diameter (green).

Results

Patient Characteristics (►Table 1)

Our series included 39 females and 33 males. The mean age at presentation was 54.48 ± 14.96 years (mean $\pm$ standard deviation [SD]) and ranged from 28 to 85 years. The mean follow-up was 21 months. Hearing loss was present in all our patients (100%), followed by headache (41.7%), dizziness (33.3%), ataxia (29.2%), and tinnitus (9.7%). Sixty patients (83.3%) had Grade 1 and 12 patients (16.6%) had Grade 2 or 3 facial nerve function before surgery (►Table 1).

Clinical Characteristics and Facial Nerve Outcome (►Table 1 & 2)

In all cases, the surgeon employed the retrosigmoid approach, and complete tumor excision was achieved. The anatomical continuity of the facial nerve was maintained in all cases.

Postoperative facial nerve function at 1-year follow-up was poor (H&B Grade 4 to 6) in 23 patients (31.94%) (►Table 2). Patients with preoperative Grade 1 ($n = 26$, 36.11%), as well as 10 patients (13.88%) with preoperative Grade 2 to 3, deteriorated to the higher grades (►Table 2). Of 60 patients with preoperative Grade 1 facial function, 47 (78.33%) had a better postoperative facial nerve outcome (H&B Grade 1 to 3). However, only 2 (16.7%) of 12 patients with preoperative Grade 2 to 3 facial nerve function had a good outcome.

The age of the patient at the onset of symptoms correlates with a poor facial nerve outcome ($p = 0.007$). Patients presenting with headache or ataxia had a worse facial nerve outcome ($p < 0.05$) than did patients presenting with tinnitus or dizziness. Preoperative facial nerve dysfunction correlates significantly to the poor outcome ($p = 0.001$). Trigeminal nerve dysfunction either preoperatively or postoperatively was not correlated with the facial nerve outcome ($p > 0.05$). Of the factors examined, only preoperative facial nerve function was an independent predictor of postoperative facial nerve outcome (►Table 4).

Neuroimaging Characteristics and Facial Nerve Outcome (►Table 3)

Large extrameatal diameter of the tumor in all three planes (anteroposterior, mediolateral, and vertical), as well as tumor volume, were associated with poor postoperative facial nerve outcome ($p < 0.05$). Anterior and caudal extension ($p = 0.001$) of the tumor correlated with a worse facial nerve outcome than posterior and cranial extension ($p = 0.305$, 0.822). Neither intrameatal extension (length and width) of the tumor nor bony changes of the internal acoustic meatus (length of the anterior and posterior wall, maximum diameter of the internal auditory canal) affected postoperative facial nerve outcome ($p > 0.05$).

Discussion

Our study confirms the influence of factors previously identified as predictors of facial nerve outcome after VS surgery. These factors include size, volume, staging of the tumor, histological features, clinical presentation, tumor extension, changes in the internal acoustic meatus, radiological features, operative approach, extent of resection, and experience of the surgeon.^{10–15,17,18} A patient's facial nerve function after VS

Table 1 Postoperative (1-year follow up) and preoperative facial nerve grades (H&B)

Preoperative facial grades (H&B) N (%)	Postoperative facial grades (H&B) N (%)				
	Grade 1	Grade 2–3	Grade 4–5	Grade 6	Total
Grade 1	34 (47.22%)	13 (18.05%)	13 (18.05%)	0	60 (83.33%)
Grades 2–3	0	2 (2.78%)	10 (13.88%)	0	12 (16.66%)
Total	34 (47.22%)	15 (20.83%)	23 (31.94%)	0	72 (100%)

Abbreviation: H&B, House-Brackmann.

Table 2 Correlation between clinical factors and post operative facial nerve outcome

Clinical prognostic factors for facial nerve outcome	Postoperative facial nerve outcome		Pearson correlation coefficient <i>p</i> value
	Grade 1–3 <i>N</i> = 49 (%)	Grade 4–6 <i>N</i> = 23 (%)	
Mean age*(yrs ± SD)	57.7 ± 15.04	47.6 ± 12.4	0.007
Gender male:female	25:24	8:15	0.203
Headache†	14 (28.6%)	16(69.6%)	0.001
Ataxia*	9 (18.4%)	12 (52.2%)	0.003
Tinnitus	6(12.2%)	1(4.3%)	0.298
Dizziness	14 (28.6%)	10(43.5%)	0.216
Preop grade 2–3†	2 (4.08%)	10 (43.47%)	0.001
Preop trigeminal symptoms	14 (28.6%)	4(17.4%)	0.314

Abbreviation: SD, standard deviation.

*Correlation is significant at the 0.05 level (2-tailed).

†Correlation is significant at the 0.01 level (2-tailed).

surgery is one of the major determinants of morbidity and quality of life following the surgery.^{19,20} Our study aimed to identify the clinical and radiological factors that can be used to predict the facial nerve outcome after surgery. These

factors can help surgeons to counsel patients preoperatively regarding the risk of facial nerve dysfunction after VS surgery.

In our study, advanced age was correlated with poorer facial nerve outcome after surgery. This finding supports Gray

Table 3 Correlation between radiological factors and postoperative facial nerve outcome

Radiological: prognostic factors for facial nerve outcome	Postoperative facial nerve outcome		Pearson correlation coefficient <i>p</i> value
	Grade 1–3 <i>N</i> = 49 (%)	Grade 4–6 <i>N</i> = 23 (%)	
Anteroposterior diameter* (mm) ± SD	33.28 ± 11.05	38.84 ± 5.23	0.025
Mediolateral diameter†(mm) ± SD	27.58 ± 10.11	37.35 ± 5.93	0.001
Vertical diameter* (mm) ± SD	26.39 ± 7.92	30.37 ± 8.21	0.054
Anterior extension† (mm) ± SD	12.60 ± 6.12	21.60 ± 5.41	0.001
Volume* (ml) + SD	15.99 ± 12.64	24.02 ± 10.88	0.011
Posterior extension (mm) ± SD	15.35 ± 6.05	13.94 ± 3.62	0.305
Caudal extension† (mm) ± SD	10.50 ± 3.85	15.71 ± 5.38	0.001
Cranial extension (mm) ± SD	13.41 ± 4.72	13.13 ± 5.14	0.822
Intrameatal length (mm) ± SD	7.66 ± 3.81	7.29 ± 3.0	0.686
Intrameatal width (mm) ± SD	6.46 ± 3.67	5.77 ± 1.71	0.393
Maximum IAC diameter(mm) ± SD	9.68 ± 4.45	9.92 ± 2.57	0.812
Length of the anterior IAC wall (mm) ± SD	10.50 ± 2.738	10.90 ± 2.50	0.555
Length of the posterior IAC wall (mm) ± SD	10.93 ± 3.29	10.19 ± 2.10	0.322

Abbreviation: IAC, internal auditory canal; SD, standard deviation.

*Correlation is significant at the 0.05 level (2-tailed).

†Correlation is significant at the 0.01 level (2-tailed).

Table 4 Regression analysis was used to identify the independent predictors of postoperative facial nerve outcome

Model		p value	95.0% Confidence interval for B	
			Lower bound	Upper bound
1	(Constant)	.768	-.730	.984
	Age	.552	-.007	.004
	Headache	.803	-.313	.244
	Ataxia	.333	-.449	.155
	Preop facial dysfunction	.009*	.187	1.253
	Anteroposterior diameter	.577	-.023	.041
	Mediolateral diameter	.256	-.008	.029
	Sagittal diameter	.136	-.007	.050
	Preop. tumor volume	.973	-.022	.022
	Anterior extension	.140	-.005	.036
	Caudal extension	.813	-.042	.033

*Significant predictors.

et al¹⁸ in their study of 276 patients. However, other studies do not agree that age is a negative predictor of facial nerve outcome.^{13,14,17,21} Therefore, alternative treatment such as gamma knife radiosurgery might be a better option for older patients.

Other factors such as gender and preoperative facial nerve function do not seem to be correlated with facial nerve outcome in some studies.¹³ Our study, however, shows that preoperative facial function, headache, and gait ataxia on presentation correlate significantly with facial nerve outcome 1 year after surgery. Gerganov et al¹⁴ reported similar results at 2 weeks after surgery in their study of 99 patients. Our study also concludes that preoperative facial nerve function is an independent predictor of facial nerve outcome. In our study, other factors such as facial numbness, tinnitus, and dizziness on presentation do not correlate with the outcome, similar to previous studies.¹⁴

Previous studies have demonstrated that the size and staging of the tumor influence postoperative facial nerve outcome.^{10–15} Our study also confirms that large tumors correlate with poor facial nerve outcome. Similarly, in their series of 129 patients, Lalwani et al²¹ describe the facial nerve outcome at 1 year or greater following surgery as being inversely correlated with the size of the tumor ($p < 0.02$). However Megerian et al²² do not support the correlation between size and poor facial nerve outcome. In their study of 99 patients, Gerganov et al¹⁴ conclude that a tumor's size and volume are important predictors of immediate facial nerve outcome. Similar results were shown by Gray et al¹⁸ and Couloigner et al¹³ in their series of 276 and of 35 patients, respectively. In our study, patients with either large extracanalicular tumor diameter or large tumor volume experienced worse facial nerve outcomes after VS surgery. There is no consensus in the literature regarding the correlation between tumor volume and facial nerve outcome. In their study of 515 patients, Arriaga et al²³ reported that postoperative facial nerve function was not linearly related to tumor

volume, especially in large tumors. Similarly, Moulin et al¹² found no correlation between long-term facial nerve outcome and tumor volume, though they did suggest that the maximum tumor diameter on imaging was the best predictor of outcome.

As the tumor grows, it results in the anterior and cranial displacement of the facial nerve.^{5,24} Therefore, tumors with more anterior extension can lead to a greater stretching of the nerve and do increase the risk of facial nerve injury. Similarly, large caudal extension of the tumor can stretch the facial nerve in a particular direction for a prolonged period of time, increasing the chances of injury.¹⁴ We observed this in our study. As well, we observed that neither intrameatal extension (length and width) of the tumor nor bony changes of the internal acoustic meatus (length of the anterior and posterior wall, maximum diameter of the internal auditory canal) correlates with facial nerve outcome. Gerganov et al¹⁴ reported similar results in their study of 99 patients. In their study of 69 patients, Yamakami et al¹⁵ reported no significant correlation between IAC changes (destruction) and facial nerve outcome 1 year after surgery. However, studies have shown a negative correlation between a narrow IAC/VS angle and facial nerve outcome.^{10,17} A narrow angle leads to compression of the facial nerve between the edge of the meatus and the tumor, which may impair the vascularization of the nerve and increase the risk of injury.

The literature yields descriptions of various predictors of postoperative facial nerve outcome. For instance, studies have shown that those VSs with cystic and heterogeneous appearance on MRI and Antoni Type B tissue on histology negatively correlate with postoperative facial nerve outcome.^{13,17,24–27} In their series of 1,000 cases, Samii et al²⁶ report facial nerve preservation rate of 93% in noncystic tumors and 88% in cystic VSs. Other studies have shown that intraoperative facial nerve monitoring can predict postoperative facial nerve outcome, and it has become the standard of care in VS surgery.^{10,18,28–30} However, its role in predicting long-term

facial nerve outcome is a matter of debate.³¹ In their study, Goldbrunner et al²⁹ report that the proximal/distal amplitude ratio is the most powerful parameter for intraoperative assessment of postoperative facial nerve function. Couloigner et al¹³ show that the absence or the desynchronization of the auditory brain stem response as well as the light microscopic features of tumor edema and inflammation correlate with postoperative facial nerve outcome independent of tumor staging.

Conclusion

Based on our study, we can conclude that young patients with small tumors (size and volume) and normal facial nerve function at presentation are more likely to experience good postoperative facial nerve function after retrosigmoid surgery for VSs. Moreover, tumor extension (anterior or caudal) and clinical presentation (headache or ataxia) correlate with poor facial nerve outcome. Intrameatal extension of the tumor and bony changes of the internal acoustic meatus do not influence facial nerve outcome. Surgeons can use these clinical and radiological parameters to predict a patient's facial nerve outcome before performing the surgery.

Disclosures

The authors have no conflicts of interest or financial disclosures.

References

- House WF. Acoustic neuroma. Case summaries. *Arch Otolaryngol* 1968;88(6):586–591
- Delgado TE, Bucheit WA, Rosenholtz HR, Chrissian S. Intraoperative monitoring of facialis muscle evoked responses obtained by intracranial stimulation of the facialis nerve: a more accurate technique for facialis nerve dissection. *Neurosurgery* 1979;4(5):418–421
- Samii M, Gerganov V, Samii A. Improved preservation of hearing and facial nerve function in vestibular schwannoma surgery via the retrosigmoid approach in a series of 200 patients. *J Neurosurg* 2006;105(4):527–535
- Samii M, Matthies C. Management of 1000 vestibular schwannomas (acoustic neuromas): the facial nerve—preservation and restitution of function. *Neurosurgery* 1997;40(4):684–694, discussion 694–695
- Sampath P, Holliday MJ, Brem H, Niparko JK, Long DM. Facial nerve injury in acoustic neuroma (vestibular schwannoma) surgery: etiology and prevention. *J Neurosurg* 1997;87(1):60–66
- Lunsford LD, Niranjan A, Flickinger JC, Maitz A, Kondziolka D. Radiosurgery of vestibular schwannomas: summary of experience in 829 cases. *J Neurosurg* 2005;102(Suppl):195–199
- Hasegawa T, Kida Y, Kobayashi T, Yoshimoto M, Mori Y, Yoshida J. Long-term outcomes in patients with vestibular schwannomas treated using gamma knife surgery: 10-year follow up. *J Neurosurg* 2005;102(1):10–16
- Gormley WB, Sekhar LN, Wright DC, Kameron D, Schessel D. Acoustic neuromas: results of current surgical management. *Neurosurgery* 1997;41(1):50–58, discussion 58–60
- Lanman TH, Brackmann DE, Hitselberger WE, Subin B. Report of 190 consecutive cases of large acoustic tumors (vestibular schwannoma) removed via the translabyrinthine approach. *J Neurosurg* 1999;90(4):617–623
- Deguine O, Maillard A, Bonafe A, el Adouli H, Tremoulet M, Frayssé B. Pre-operative and per-operative factors conditioning long-term facial nerve function in vestibular schwannoma surgery through translabyrinthine approach. *J Laryngol Otol* 1998;112(5):441–445
- Ruth HR, Luetje CM, Whittaker CK. Acoustic tumors: preoperative measurement and correlation with postoperative facial nerve function. *Otolaryngol Head Neck Surg* 1985;93(2):160–163
- Moulin G, Dessi P, André P, et al. Role of magnetic resonance imaging in predicting late facial motor function after removal of vestibular schwannomas by the translabyrinthine approach. *J Laryngol Otol* 1995;109(5):394–398
- Couloigner V, Gervaz E, Kalamirides M, et al. Clinical and Histologic Parameters Correlated with Facial Nerve Function After Vestibular Schwannoma Surgery. *Skull Base* 2003;13(1):13–19
- Gerganov VM, Klinge PM, Nouri M, Stieglitz L, Samii M, Samii A. Prognostic clinical and radiological parameters for immediate facial nerve function following vestibular schwannoma surgery. *Acta Neurochir (Wien)* 2009;151(6):581–587, discussion 587
- Yamakami I, Uchino Y, Kobayashi E, Saeki N, Yamaura A. Prognostic significance of changes in the internal acoustic meatus caused by vestibular schwannoma. *Neurol Med Chir (Tokyo)* 2002;42(11):465–470, discussion 470–471
- House JW, Brackmann DE. Facial nerve grading system. *Otolaryngol Head Neck Surg* 1985;93(2):146–147
- Zaouche S, Ionescu E, Dubreuil C, Ferber-Viart C. Pre- and intraoperative predictive factors of facial palsy in vestibular schwannoma surgery. *Acta Otolaryngol* 2005;125(4):363–369
- Grey PL, Moffat DA, Palmer CR, Hardy DG, Baguley DM. Factors which influence the facial nerve outcome in vestibular schwannoma surgery. *Clin Otolaryngol Allied Sci* 1996;21(5):409–413
- Anderson DE, Leonetti J, Wind JJ, Cribari D, Fahey K. Resection of large vestibular schwannomas: facial nerve preservation in the context of surgical approach and patient-assessed outcome. *J Neurosurg* 2005;102(4):643–649
- Cross T, Sheard CE, Garrud P, Nikolopoulos TP, O'Donoghue GM. Impact of facial paralysis on patients with acoustic neuroma. *Laryngoscope* 2000;110(9):1539–1542
- Lalwani AK, Butt FY, Jackler RK, Pitts LH, Yingling CD. Facial nerve outcome after acoustic neuroma surgery: a study from the era of cranial nerve monitoring. *Otolaryngol Head Neck Surg* 1994;111(5):561–570
- Megerian CA, McKenna MJ, Ojemann RG. Delayed facial paralysis after acoustic neuroma surgery: factors influencing recovery. *Am J Otol* 1996;17(4):630–633
- Arriaga MA, Luxford WM, Atkins JS Jr, Kwartler JA. Predicting long-term facial nerve outcome after acoustic neuroma surgery. *Otolaryngol Head Neck Surg* 1993;108(3):220–224
- Matthies C, Samii M, Krebs S. Management of vestibular schwannomas (acoustic neuromas): radiological features in 202 cases—their value for diagnosis and their predictive importance. *Neurosurgery* 1997;40(3):469–481, discussion 481–482
- Charabi S, Tos M, Børgesen SE, Thomsen J. Cystic acoustic neuromas. Results of translabyrinthine surgery. *Arch Otolaryngol Head Neck Surg* 1994;120(12):1333–1338
- Samii M, Matthies C. Management of 1000 vestibular schwannomas (acoustic neuromas): surgical management and results with an emphasis on complications and how to avoid them. *Neurosurgery* 1997;40(1):11–21, discussion 21–23
- Gomez-Brouchet A, Delisle MB, Cognard C, et al. Vestibular schwannomas: correlations between magnetic resonance imaging and histopathologic appearance. *Otol Neurotol* 2001;22(1):79–86

- 28 Bozorg Grayeli A, Kalamarides M, Frayse B, et al. Comparison between intraoperative observations and electromyographic monitoring data for facial nerve outcome after vestibular schwannoma surgery. *Acta Otolaryngol* 2005;125(10):1069–1074
- 29 Goldbrunner RH, Schlake HP, Milewski C, Tonn JC, Helms J, Roosen K. Quantitative parameters of intraoperative electromyography predict facial nerve outcomes for vestibular schwannoma surgery. *Neurosurgery* 2000;46(5):1140–1146, discussion 1146–1148
- 30 Isaacson B, Kileny PR, El-Kashlan HK. Prediction of long-term facial nerve outcomes with intraoperative nerve monitoring. *Otol Neurol* 2005;26(2):270–273
- 31 Schmitt WR, Daube JR, Carlson ML, et al. Use of supramaximal stimulation to predict facial nerve outcomes following vestibular schwannoma microsurgery: results from a decade of experience. *Journal of neurosurgery* Jan 2013;118(1):206–212