Prognostic Indices for Predicting Facial Nerve Outcome following the Resection of Large Acoustic Neuromas

Kurt Grahnke¹ Jonathan R. Garst¹ Brendan Martin¹ John P. Leonetti¹ Douglas E. Anderson¹

¹Department of Neurological Surgery and Otolaryngology, Head and Neck Surgery, Loyola University Chicago, Maywood, Illinois, United States

Address for correspondence Douglas E. Anderson, MD, Department of Neurological Surgery, Loyola University Chicago, Stritch School of Medicine, 2160 S 1st Avenue, Maywood, IL 60153, United States (e-mail: DAnder1@lumc.edu).

J Neurol Surg B 2017;78:454–460.

Abstract

This study analyzes the simple ratio of anterior-to-posterior extension of large (>2.5 cm) acoustic neuromas relative to the internal auditory canal (ICA; anterior-posterior [A/P] index) as a tool for predicting risk of facial nerve (FN) injury. In total, 105 patients who underwent microsurgical resection for large acoustic neuromas were analyzed retrospectively. House–Brackmann (HB) scores were assessed immediately postoperatively, at 1 month, and at 1 year. Lateral–medial, inferior–superior, A/P, and maximum diameters were measured from preoperative magnetic resonance images. These measurements and the A/P index were analyzed using univariable and multivariable statistical models to assess relationship to FN outcomes. The retrosigmoid, translabyrinthine, and combined approaches were used, and the extent of resection was evaluated. For every 1 standard deviation increase in the A/P index, a patient was 3.87 times more likely have a higher postoperative HB score ($p < 0.0001$). Accordingly, for every 1-mm increase anterior to the IAC, a patient was 16% more likely have a higher postoperative HB score ($p < 0.001$). After controlling for tumor size, a patient was still 3.82 times more likely have a higher postoperative HB score for every 1 standard deviation increase in the A/P index ($p < 0.0001$). While larger tumor size trended toward worse postoperative HB scores, it was not statistically significant. Our prognostic index may be useful to assess the risk of FN injury preoperatively for large acoustic neuromas, while also providing information about the tumor–nerve relationship.

Keywords

- ▶ prognostic index
- ▶ facial nerve outcomes
- ▶ acoustic neuroma
- ▶ vestibular schwannoma

Introduction

Large acoustic neuromas can lead to a variety of disabling symptoms including hearing loss, tinnitus, imbalance, facial numbness, and ataxia. Stereotactic radiosurgery (SRS) and gamma knife radiosurgery are possible treatment modalities, but microsurgical management remains the accepted treatment option.^{1–4} As with any procedure, there are associated risks that must be addressed with the patient prior to

surgery. One of the most serious risks is injury to the facial nerve (FN), as damage to this critical neurologic structure can have a severe impact on quality of life.^{5–7}

Acoustic neuromas frequently compress, adhere to, and distort the FN's natural course, making FN injury a primary concern following microsurgical resection. While advancements in technique, intraoperative nerve monitoring, and experience have helped to reduce the risk of FN injury, recent studies report rates ranging from 10 to 60%.^{2,3,8–13} Objective

received

March 16, 2017

accepted after revision

May 25, 2017

published online

July 19, 2017

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Stuttgart · New York

DOI <https://doi.org/10.1055/s-0037-1604077>.
ISSN 2193-6331.

and accurate prognostic tools for predicting postoperative facial function are not always reliable. Many reports link size and overall volume to increased risk of FN injury.^{2,5,13–18} However, these studies often include small and intracanalicular tumors in their analyses, which pose very little risk to the FN during surgery.^{10,15–18} While size may have a correlation with FN injury, anatomical direction of growth, particularly anterior and caudal, may be a more accurate prognostic factor in risk assessment.^{11,13,16,17} In this study, we present a simple, objective index evaluating the anterior–posterior (A/P) relationship of acoustic neuromas relative to the internal auditory canal (IAC) for the purpose of assessing risk of FN injury.

Methods

Patient Population and Symptoms

After acquiring Institutional Review Board approval, a sequential review of 105 patients with unilateral acoustic neuromas measuring 2.5 cm or greater in largest extracanalicular diameter was conducted. All patients included in this study were operated on by the same neurotologist–neurosurgery team between 2005 and 2016 at the same tertiary care academic medical center. No patients overlap with the authors' previously reported series on large acoustic neuromas and FN outcomes.⁵

Tumor Characteristics

Measurements were made of the largest extracanalicular diameter on the patients' preoperative magnetic resonance imaging (MRI). The mean tumor diameter in its largest dimension was 3.4 cm. Thirty tumors were considered giant (4.0 cm or greater), and the largest tumor was 7.0 cm. We sought to characterize each tumor in three extracanalicular dimensions: lateral–medial (largest diameter perpendicular to the petrous ridge), A/P (largest diameter parallel to the petrous ridge), and inferior–superior (determined in sagittal/coronal planes). The mean lateral–medial tumor length was 2.88 cm, while the mean inferior–superior tumor length was 2.67 cm.

The A/P dimension was measured and analyzed relative to the IAC (► Fig. 1). The mean tumor length anterior to the IAC was 0.89 cm, and the mean length posterior to it was 1.12 cm. To evaluate anatomical position with respect to the IAC, we defined our prognostic index (A/P index) as the ratio of tumor length anterior to the IAC divided by the length posterior to it. Thus, the mean A/P index was $0.89/1.12 = 0.79$.

Surgical Technique

We used three surgical approaches in this study: the retrosigmoid, translabyrinthine, and combined retrosigmoid–translabyrinthine. The selection criteria for these approaches has been previously described,⁵ but the primary factors include the following: (1) tumor size and pathological characteristics, (2) extension of the tumor into the IAC, and (3) distance between the jugular bulb and the superior petrosal sinus, as determined on preoperative MRI. Cranial nerve

Fig. 1 Axial magnetic resonance imaging (MRI) demonstrating the anterior–posterior index (A/P index). White lines parallel to the petrous ridge represent anterior (A) and posterior (P) measurements relative to the internal auditory canal. Double-headed lines represent most anterior and posterior edges of tumor perpendicular to the petrous ridge.

monitoring of the FN was used in all cases, using a 0.1-mA stimulus, looking for a 100-mV response on direct stimulation of the nerve at the end of operation at the brainstem root exit zone.

Outcome Measures

We assessed FN outcomes using the House–Brackmann (HB) scale immediately after surgery, at 1 month, and at 1 year for all patients. For those patients with follow-up over 1 year, we used their most recent HB scores. Extent of tumor resection was evaluated through both intraoperative findings, with a specially designed bayoneted measurement tool, and postoperative MRI, categorized by gross total resection (GTR) and subtotal resection (STR). Similarly, intraoperative electrophysiological FN responses and preservation of FN anatomy were considered.

Statistical Analysis

Significance was determined using univariable and multivariable ordinal logistic regression models to predict patients' odds of having higher postoperative HB scores. In these models, a multinomial distribution was specified for the response variable (originally scaled 1–6), whereas cumulative logit links were used to estimate the odds ratio for each explanatory variable against a referent. The assumption of proportional odds was violated using the full 6-point scale; therefore, patients' HB scores were grouped into three more discrete categories. The groups were as follows: HB I and II, III and IV, and V and VI, which corresponded to “good,” “moderate,” and “poor” levels of FN function, respectively. Using the modified scale, the assumption of proportional odds was retained. In addition, the data were also analyzed using a binary cut point, qualifying HB I and II as good FN

function and HB III and VI as FN dysfunction. The results reported herein correspond to the ordinal logistic regression analyses as they provide more detailed insight into patient outcomes. While the binary logistic regression models confirmed the initial results, they provided less precise estimates of the magnitude of the observed effects as evidenced by wider confidence intervals (CIs). All statistical analyses were conducted using SAS version 9.4 (SAS Institute, Cary, North Carolina, United States).

Results

Sixty patients (57%) were male and 45 (43%) were female. The mean age was 49 ± 15 years, with the youngest patient 13 years of age and the oldest 79 years. Patients were followed postoperatively for an average of 36.5 months. All of our patients presented with hearing loss. Other common presenting symptoms were as follows: 40 (38%) with tinnitus, 39 (37%) with balance or gait instability, 26 (25%) with facial numbness/paresthesia, 19 (18%) with headache, and 8 (8%) with facial twitching. Two patients were noted to have swallowing discomfort, while one was noted to have abnormal taste sensations. Other physical examination findings included abnormal eye movement, nystagmus, papilledema, facial weakness, and cerebellar ataxia. Immediately postoperatively, 68 (64.8%) patients had good facial function, defined as an HB score of I or II (►Fig. 2). However, this improved to 76 (72.4%) patients at 1 month and 93 (88.6%) patients at 1 year or latest follow-up. Four (3.8%) patients experienced delayed onset FN weakness within the first month postoperatively. No patient experienced increased FN deficit during the interval of 1 month and 1 year. Eleven (10.5%) patients experienced total facial paralysis (HB VI) at

some point during the postoperative period. At their last follow-up, four patients improved to HB II, three patients improved to HB III, one patient improved to HB IV, and two patients improved to HB V. Only one patient with total facial paralysis did not improve.

Thirty patients had giant tumors (diameters ≥ 4 cm), 13 (43.3%) of whom had an HB score of III or worse immediately postoperatively. However, at last follow-up, 2 (6.7%) patients had poor (HB V–VI), 2 (6.7%) patients had moderate (HB III–IV), and 26 (86.7%) patients had good (HB I–II) facial function.

When analyzing tumor size with respect to FN outcome, larger tumor dimensions trended positively toward higher HB scores postoperatively (►Table 1). However, maximum tumor diameter did not significantly predict higher HB scores using univariable and multivariable ordinal logistic models immediately postoperatively or at 1 month ($p = 0.18$ and $p = 0.10$; ►Table 2). Increasing lateral–medial length and inferior–superior length also trended toward higher HB scores, but this trend was not statistically significant. Additionally, length of tumor posterior to the IAC was not meaningfully associated with patients' postoperative HB score.

The mean A/P index was 0.79 (range: 0.10–2.40; standard deviation: 0.36). This unique A/P index was highly predictive of postoperative HB scores as well as FN function at 1 month after surgery. For every 1 standard deviation unit of increase (0.36) in the A/P index, a patient was 3.87 (95% CI: 2.16–6.94) times more likely to have a higher postoperative score HB score ($p < 0.0001$; ►Table 2 and ►Fig. 3). After controlling for maximum tumor diameter, a patient was still 3.82 (95% CI: 2.12–6.92) times more likely to have a higher postoperative HB score for every 1 standard deviation increase in the A/P index ($p < 0.0001$; ►Table 3). In addition, for every 1-mm increase

Fig. 2 Postoperative House–Brackmann scores over time. Black bar represents HB I and II; dark gray bar represents HB III and IV; light gray bar represents HB V and VI.

Table 1 Mean preoperative tumor dimensions (in centimeters) for each facial nerve outcome group in the immediate postoperative period

	Maximum diameter	L-M length	I-S length	A-P ant.	A-P post.	A/P index
HB I–II	3.32	2.76	2.62	0.77	1.13	0.68
HB III–IV	3.46	3.05	2.70	1.03	1.17	0.89
HB V–VI	3.63	3.11	2.82	1.19	1.01	1.17

Abbreviations: A-P ant., anterior–posterior length anterior to the internal auditory canal; A-P post., anterior–posterior length posterior to the internal auditory canal; I-S, inferior–superior length; L-M, lateral–medial length.

Table 2 Univariable ordinal logistic regression results predicting patients' ordinal HB scores postoperatively and at 1 month

	Postoperative		1-mo follow-up	
	Odds ratio (95% CI)	p	Odds ratio (95% CI)	p-Value
A/P index (unit = 0.36)	3.87 (2.16–6.94)	< 0.0001	3.57 (2.02–6.29)	< 0.0001
Tumor size	1.36 (0.87–2.11)	0.18	1.48 (0.92–2.36)	0.10
Length anterior to IAC	1.16 (1.07–1.26)	< 0.001	1.19 (1.09–1.29)	< 0.001
Length posterior to IAC	0.98 (0.90–1.07)	0.70	1.01 (0.92–1.11)	0.83
Lateral–medial length	1.04 (0.99–1.09)	0.07	1.05 (0.99–1.10)	0.08
Inferior–superior length	1.02 (0.98–1.06)	0.41	1.03 (0.99–1.08)	0.18
GTR	0.64 (0.28–1.45)	0.28	0.69 (0.29–1.67)	0.41

Abbreviations: A/P, anterior–posterior; CI, confidence interval; HB, House–Brackmann; GTR, gross total resection; IAC, internal auditory canal. Note: valid $N = 105$ patients.

anterior to the IAC, a patient was 16% (odds ratio [OR] = 1.16; 95% CI: 1.07–1.26) more likely to have a higher postoperative HB score ($p < 0.001$).

Thirty-five (33%) patients had STRs, whether due to adherence of the tumor to the FN or due to other surrounding

parenchyma that would lead to undue injury if further resected. The mean maximum tumor diameter of tumors with STR was 3.68 cm versus 3.26 for those with GTR, which achieved statistical significance ($p = 0.02$). At latest follow-up, the mean maximum diameter of residual tumor was

Fig. 3 Side-by-side comparison of the anterior–posterior index (A/P index) (A) below and (B) above the mean A/P index (0.53 and 2.40, respectively). Their latest HB scores were II and VI, respectively.

Table 3 Multivariable ordinal logistic regression results predicting patients' postoperative ordinal HB scores

	Adjusted odds ratio	95% CI	p-Value
A/P index (unit = 0.36)	3.82	(2.12–6.92)	< 0.0001
Tumor size	1.06	(0.66–1.73)	0.80

Abbreviations: A/P, anterior–posterior; CI, confidence interval; HB, House–Brackmann.
Note: valid N = 105 patients.

10.9 mm (range: 3–24 mm). Two of those patients with STRs underwent SRS at intervals of 2 and 4 months from the time of the original resection. One patient underwent repeat microsurgical resection 70 months after the original resection. One patient underwent both repeat microsurgical resection and SRS at 28 and 50 months, respectively, from the initial resection. Patients with GTR had an average postoperative HB score of 2.45, whereas those with STR had an average HB score of 2.47. Forty-eight (68%) patients with GTR and 21 (60%) patients with STR had good (HB I or II) postoperative FN function. Extent of resection did not significantly predict a patient's odds of developing worse postoperative HB scores ($p = 0.28$).

FN preservation results were analyzed under the subcategories of surgical approach. Immediately postoperatively, the rates of good postoperative FN function (HB I or II) for the retrosigmoid, translabyrinthine, and retrosigmoid–translabyrinthine combined approach were 74, 60, and 60%, respectively. This improved to 92, 88, and 86% at 1 year or latest follow-up, respectively. When analyzed with reference to the retrosigmoid approach, neither the translabyrinthine approach nor the retrosigmoid–translabyrinthine combined approach was significant in predicting postoperative HB scores or FN function at 1 month ($p = 0.50$).

Discussion

Although some studies suggest that there is no correlation between tumor size and FN injury,^{19–21} most studies and surgeons who operate on these tumors agree that as tumor size increases, physiological preservation of the FN becomes more difficult.^{2,5,9,13–18,22} Also, many studies that link FN dysfunction to increased tumor size include small and intracanalicular tumors in their analyses, which typically pose less risk to the FN.^{10,15–18} While this trend of larger acoustic neuromas posing greater risk of FN dysfunction may be true in general, our experience tells us that not all large tumors pose the same level of risk. In this study, we included only tumors larger than 2.5 cm in extracanalicular diameter and evaluated information regarding anatomical position and extension, which may explain increased risk of FN damage. Although tumor diameter did trend slightly upward with increasing postoperative HB scores, we found this relationship to be statistically insignificant. Therefore, it is difficult to determine whether sheer size is the cause of higher HB scores.

We found that increased length of tumor extending anterior to the IAC as well as increases in our unique A/P

index significantly predicted worse postoperative HB scores. Several studies have reported the correlation between anterior extension and worsened FN outcomes.^{11,13,17} This is presumably because as the tumor extends anterior to the IAC, it stretches and distorts the nerve along its natural course out of the IAC, making it more susceptible to injury.^{11,16,23} Similarly, tumors positioned predominantly posterior to the IAC (low A/P index) typically do not distort the FN and pose less risk during resection. This suggests that some large and even giant tumors should be considered as low risk for developing FN injury if their position is such that they are mostly posterior to the IAC (►Fig. 2).

One would expect that increased lateral–medial extension may negatively impact FN outcome due to brainstem compression. While our data showed trends that may suggest lateral–medial extension worsens FN outcome, it was not statistically significant. This does not undermine the possibility that significant lateral–medial extension puts stress on the FN and distorts its course, but it does strengthen the assumption that anterior extension may be the most meaningful dimension of tumor extension to evaluate preoperatively when predicting FN outcome.

While both increasing length of tumor extending anterior to the IAC and increasing A/P index were important factors in predicting worse HB scores, the magnitude of the effect associated with the A/P index was over three times greater than that of the anterior to IAC measurement (OR = 3.87 vs. 1.16). As the A/P index takes into account the length of the tumor anterior to the IAC as it relates to the posterior length, rather than a single unidirectional measurement, it also serves as a more complete and thereby effective predictor of patients' postoperative HB scores. Furthermore, the A/P index was still a significant predictor of postoperative HB score after controlling for tumor size, suggesting that the relationship of the tumor relative to the IAC is indicative of risk for FN injury independent of sheer size.

Given the detrimental effect of FN dysfunction on quality of life,^{5–7} it is critical to provide the patient with reliable and objective information regarding their risks. While tumor size is a logical point to bring up preoperatively, we believe that the A/P index may provide a more reliable risk assessment of FN injury in the setting of acoustic neuromas greater than 2.5 cm in diameter.

This study also analyzed the relationship between the extent of resection (GTR vs. STR) and HB scores. Although radical resection with preservation of the cranial nerves and brain parenchyma remains the goal of acoustic neuroma microsurgery, STR in certain cases has been shown to

improve postoperative HB scores.^{24–26} Our results show a meaningful difference between the sizes of tumors treated with STR versus GTR, with larger tumors being more prone to STR, as expected. However, we did not find a significant relationship between the extent of resection and postoperative FN function, nor did the A/P index show statistical significance in predicting GTR or STR. Moving forward, we believe that an increasing A/P index should suggest less aggression during preoperative surgical planning. However, the decision of GTR versus STR is most appropriately made intraoperatively on a case-by-case basis when one can assess the anatomy and degree of tumor adherence to the nerve. Although GTR and STR had similar FN outcomes, this should not be interpreted to push harder for GTR. Rather, when necessary, the surgeon should strategically leave behind tumor to preserve FN function. STR is typically associated with recurrence,^{12,14,24–26} but adjuvant SRS²⁵ or repeat microsurgery can be used as necessary to preserve FN function.

While a few older studies found better FN outcomes with the translabyrinthine approach,^{27–29} multiple other studies since then have found no meaningful difference between approach and FN outcomes.^{5,8,14–16} Our analysis aligns with these newer studies in that we found no meaningful difference in FN outcomes between the retrosigmoid, translabyrinthine, and combined approaches. Ultimately, we believe that the operative approach should be an individualized decision based on several factors including size and anatomy of the tumor, preoperative hearing deficit, and surgeon experience.

While our A/P index is highly predictive of FN outcomes following surgery, there are other factors to be considered. For example, cystic tumors are notoriously adherent to the FN, increasing the risk of FN injury during surgery. Numerous studies have reported worse outcomes with cystic tumors compared with solid tumors and recommend STR when GTR is not feasible.^{30–37} Also, this study did not consider intracanalicular extension nor bony changes to the IAC as they have been reported to be insignificant factors for predicting FN outcome.^{13,14,17,38} Additionally, increased overall tumor volume has also been linked to worse FN outcomes, as one would expect, but it is still uncertain whether tumor volume is more predictive than maximum tumor diameter.^{13,19,20} In the past few years, there have been an increasing number of studies, which use diffusion tensor imaging (DTI) to analyze the spatial relationship of the FN to the tumor.^{39–42} While DTI may provide a detailed analysis of the risk for FN injury, it is susceptible to error. The A/P index provides a simple tool, which can be readily calculated on standard MRI to provide meaningful FN risk assessment.

Studies that analyze the A/P index in terms of volume, in addition to two-dimensional measurements, could potentially enhance the validity of the A/P index as a preoperative risk assessment tool. Also, a prospective study, which uses the A/P index in determining extent of resection, would be useful.

Conclusions

Given the impact of FN dysfunction on quality of life, it is imperative to provide reliable preoperative risk assessment. Most surgeons would agree that larger acoustic neuromas are associated with a greater risk of FN injury. However, in the case of large tumors (>2.5 cm), we believe that direction of growth is of utmost importance, specifically the degree of anterior relative to posterior extension from the IAC. The novel A/P index we present in this study was more predictive of FN injury than overall tumor size as well as lateral–medial, inferior–superior, and individual anterior and posterior components.

Conflict of Interest

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

Acknowledgments

Portions of this work were submitted in abstract form as proceedings for the 13th International Facial Nerve Symposium, Los Angeles, California, United States, August 3–6, 2017. The authors have no further acknowledgments.

References

- 1 Silva J, Cerejo A, Duarte F, Silveira F, Vaz R. Surgical removal of giant acoustic neuromas. *World Neurosurg* 2012;77(5-6):731–735
- 2 Samii M, Gerganov VM, Samii A. Functional outcome after complete surgical removal of giant vestibular schwannomas. *J Neurosurg* 2010;112(04):860–867
- 3 Milligan BD, Pollock BE, Foote RL, Link MJ. Long-term tumor control and cranial nerve outcomes following γ knife surgery for larger-volume vestibular schwannomas. *J Neurosurg* 2012;116(03):598–604
- 4 Apicella G, Paolini M, Deantonio L, Masini L, Krengli M. Radiotherapy for vestibular schwannoma: review of recent literature results. *Rep Pract Oncol Radiother* 2016;21(04):399–406
- 5 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(04):643–649
- 6 Carlson ML, Tveiten OV, Driscoll CL, et al. Long-term quality of life in patients with vestibular schwannoma: an international multicenter cross-sectional study comparing microsurgery, stereotactic radiosurgery, observation, and nontumor controls. *J Neurosurg* 2015;122(04):833–842
- 7 Turel MK, Thakar S, Rajshekhar V. Quality of life following surgery for large and giant vestibular schwannomas: a prospective study. *J Neurosurg* 2015;122(02):303–311
- 8 Gurgel RK, Dogru S, Amdur RL, Monfared A. Facial nerve outcomes after surgery for large vestibular schwannomas: do surgical approach and extent of resection matter? *Neurosurg Focus* 2012;33(03):E16
- 9 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(05):561–570

- 10 Huang X, Xu M, Xu J, et al. Complications and management of large intracranial vestibular schwannomas via the retrosigmoid approach. *World Neurosurg* 2017;99:326–335
- 11 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(03):469–481, discussion 481–482
- 12 Monfared A, Corrales CE, Theodosopoulos PV, et al. Facial nerve outcome and tumor control rate as a function of degree of resection in treatment of large acoustic neuromas: preliminary report of the acoustic neuroma subtotal resection study (ANSRS). *Neurosurgery* 2016;79(02):194–203
- 13 Sharma M, Sonig A, Ambekar S, Nanda A. Radiological and clinical factors predicting the facial nerve outcome following retrosigmoid approach for large vestibular schwannomas (VSs). *J Neurol Surg B Skull Base* 2013;74(05):317–323
- 14 Rinaldi V, Casale M, Bressi F, et al. Facial nerve outcome after vestibular schwannoma surgery: our experience. *J Neurol Surg B Skull Base* 2012;73(01):21–27
- 15 Bloch O, Sughrue ME, Kaur R, et al. Factors associated with preservation of facial nerve function after surgical resection of vestibular schwannoma. *J Neurooncol* 2011;102(02):281–286
- 16 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(01):60–66
- 17 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(06):581–587, discussion 587
- 18 Kunert P, Dziedzic T, Podgórska A, Nowak A, Czernicki T, Marchel A. Surgery for sporadic vestibular schwannoma. Part IV. Predictive factors influencing facial nerve function after surgery. *Neurol Neurochir Pol* 2016;50(01):36–44
- 19 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(05):394–398
- 20 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(03):220–224
- 21 Megerian CA, McKenna MJ, Ojemann RG. Delayed facial paralysis after acoustic neuroma surgery: factors influencing recovery. *Am J Otol* 1996;17(04):630–633
- 22 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(05):409–413
- 23 Rhoton A. Microsurgical anatomy of posterior fossa cranial nerves. In: Barrow DL, ed. *Surgery of the Cranial Nerves of the Posterior Fossa*. Park Ridge, IL: American Association of Neurological Surgeons; 1993:67–73
- 24 Gurgel RK, Theodosopoulos PV, Jackler RK. Subtotal/near-total treatment of vestibular schwannomas. *Curr Opin Otolaryngol Head Neck Surg* 2012;20(05):380–384
- 25 Haque R, Wojtasiewicz TJ, Gigante PR, et al. Efficacy of facial nerve-sparing approach in patients with vestibular schwannomas. *J Neurosurg* 2011;115(05):917–923
- 26 Schwartz MS, Kari E, Strickland BM, et al. Evaluation of the increased use of partial resection of large vestibular schwannomas: facial nerve outcomes and recurrence/regrowth rates. *Otol Neurotol* 2013;34(08):1456–1464
- 27 House WF. Translabyrinthine approach. In: House WF, Leutje CM, eds. *Acoustic Tumors*. Vol. 2. Baltimore, MD: University Park Press; 1979:43–87
- 28 King TT, Morrison AW. Translabyrinthine and transtentorial removal of acoustic nerve tumors. Results in 150 cases. *J Neurosurg* 1980;52(02):210–216
- 29 Leonetti JP, Brackmann DE, Prass RL. Improved preservation of facial nerve function in the infratemporal approach to the skull base. *Otolaryngol Head Neck Surg* 1989;101(01):74–78
- 30 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(01):11–21, discussion 21–23
- 31 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
- 32 Benech F, Perez R, Fontanella MM, Morra B, Albera R, Ducati A. Cystic versus solid vestibular schwannomas: a series of 80 grade III-IV patients. *Neurosurg Rev* 2005;28(03):209–213
- 33 Yashar P, Zada G, Harris B, Giannotta SL. Extent of resection and early postoperative outcomes following removal of cystic vestibular schwannomas: surgical experience over a decade and review of the literature. *Neurosurg Focus* 2012;33(03):E13
- 34 Tang IP, Freeman SR, Rutherford SA, King AT, Ramsden RT, Lloyd SK. Surgical outcomes in cystic vestibular schwannoma versus solid vestibular schwannoma. *Otol Neurotol* 2014;35(07):1266–1270
- 35 Piccirillo E, Wiet MR, Flanagan S, et al. Cystic vestibular schwannoma: classification, management, and facial nerve outcomes. *Otol Neurotol* 2009;30(06):826–834
- 36 Fundová P, Charabi S, Tos M, Thomsen J. Cystic vestibular schwannoma: surgical outcome. *J Laryngol Otol* 2000;114(12):935–939
- 37 Sinha S, Sharma BS. Cystic acoustic neuromas: surgical outcome in a series of 58 patients. *J Clin Neurosci* 2008;15(05):511–515
- 38 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
- 39 Gerganov VM, Giordano M, Samii M, Samii A. Diffusion tensor imaging-based fiber tracking for prediction of the position of the facial nerve in relation to large vestibular schwannomas. *J Neurosurg* 2011;115(06):1087–1093
- 40 Romano A, D'Andrea G, Minniti G, et al. Pre-surgical planning and MR-tractography utility in brain tumour resection. *Eur Radiol* 2009;19(12):2798–2808
- 41 Taoka T, Hirabayashi H, Nakagawa H, et al. Displacement of the facial nerve course by vestibular schwannoma: preoperative visualization using diffusion tensor tractography. *J Magn Reson Imaging* 2006;24(05):1005–1010
- 42 Ung N, Mathur M, Chung LK, et al. A systematic analysis of the reliability of diffusion tensor imaging tractography for facial nerve imaging in patients with vestibular schwannoma. *J Neurol Surg B Skull Base* 2016;77(04):314–318