Anterior Extension of Tumor is as Important as Tumor Size to Facial Nerve Outcome and Extent of Resection for Vestibular Schwannomas

Ricky H. Wong¹ William R. Copeland² Jeffrey T. Jacob² Sananthan Sivakanthan⁴
 Jamie J. Van Gompel² Harry van Loveren³ Michael J. Link² Siviero Agazzi³

¹ Department of Neurologic Surgery, NorthShore University Health System, Pritzker School of Medicine, Evanston, Illinois, United States

² Department of Neurologic Surgery, Mayo Clinic, Rochester, Minnesota, United States

³ Department of Neurologic Surgery, University of South Florida, Tampa, Florida, United States

⁴ Department of Neurologic Surgery, University of New Mexico, Albuquerque, New Mexico, United States

Address for correspondence: Siviero Agazzi, MD, Department of Neurological Surgery, University of South Florida, 2 Tampa General Circle, Tampa, FL 33606, United States
 (e-mail: sagazzi@health.usf.edu).

J Neurol Surg B 2017;78:473–480.

Abstract

Objectives We examined vestibular schwannoma tumor dimension and direction of growth to determine whether these correlate with facial nerve outcome as well as extent of resection (EOR).

Design Retrospective review of prospectively maintained databases.

Participants 206 patients were a part of this study.

Main Outcome Measures Tumor dimensions were measured using preoperative magnetic resonance imaging, and a series of ratios were then calculated to further characterize tumor dimension. Regression analyses were performed to investigate correlation with facial nerve outcome and EOR.

Results Patients with tumor extending >1.5 cm anterior to the internal auditory canal (IAC) (AB measurement) were three times more likely to have postoperative House-Brackman grades of 3 or worse. We also found that an EB/BF ratio (representing elongated growth parallel to the IAC axis) ≥ 1.1 was associated with half the risk of poor facial nerve outcome. Tumors with anterior-posterior diameter (AC measurement) >1.9 cm were five times less likely to undergo gross total resection (GTR). Furthermore, an increased degree of tumor extension into the IAC (DE measurement >2.4 cm) or an increased amount of brainstem compression (EB measurement >1.1 cm) were each associated with a nearly 3-fold decrease in the likelihood of GTR.

Conclusion Our study demonstrates that anterior extent of the tumor is as important as tumor size to facial nerve outcome and degree of resection for vestibular schwannomas.

Keywords

- ▶ acoustic neuroma
- ▶ anterior extension
- ▶ facial nerve outcome
- ▶ tumor dimension
- ▶ vestibular schwannoma

Introduction

Many attempts have been made to elucidate both preoperative and intraoperative factors that predict facial nerve outcome after vestibular schwannoma (VS) surgery. Factors that have been associated with poor facial nerve outcome include older patient age, larger tumor size, tumor consistency (soft

or firm), cystic tumors, presence of tumor adhesions to the facial nerve, surgical approach used, and increasing extent of resection (EOR).^{1–6} To better counsel patients preoperatively and assist in surgical planning, various magnetic resonance imaging (MRI) characteristics have been used to predict several of these factors including tumor consistency, adhesions to the facial nerve, and the course of the facial nerve

received

October 27, 2016

accepted after revision

June 8, 2017

published online

July 25, 2017

© 2017 Georg Thieme Verlag KG
 Stuttgart · New York

DOI <https://doi.org/10.1055/s-0037-1604331>
 ISSN 2193-6331.

relative to the tumor.^{7,8} In this report, we examined tumor dimension and direction of growth to determine whether these correlate with facial nerve outcome, as well as EOR. We hypothesized that when a VS has a greater extension anterior to the internal auditory canal (IAC), surgical removal is associated with worse facial nerve outcome and less frequent gross total resection (GTR).

Methods

A retrospective review of prospectively maintained databases of all patients undergoing microsurgical resection of VS, at two tertiary care centers in the United States between 2006 and 2014, was performed. Study protocol approval was obtained from the institutional review board of each institution, and all patients reviewed had given informed consent for research. Patients were included for analysis if they had a cysternal tumor size >1cm in any dimension with at least 6 months of postoperative follow-up. Patients without both pre- and postoperative imaging were excluded. Four surgeons were included, two each from each tertiary care center, and all patients who met criteria were included.

MRI axial and coronal T1-weighted post-contrast sequences through the IAC were used for measurement purposes. Slice thickness ranged from 1 to 3 mm. The lines and measurements were done by two people independently. To measure the anterior-posterior and medial-lateral dimensions of a tumor, in the axial plane, a line was drawn from the midpoint of the fundus to the midpoint of the porus acousticus then continuing on to the margin of the tumor in the cerebellopontine angle (CPA) (►Fig. 1A, DE measurement). A line was then drawn along the greatest anterior-posterior diameter of the tumor as measured parallel to the posterior face of the petrous bone (►Fig. 1A, AC measurement). These lines bisected each other to

give the anterior and posterior (►Fig. 1A, AB and BC measurements, respectively) and medial and lateral (►Fig. 1A, EB and BF measurements, respectively) dimensions of the tumor. To measure the cranial-caudal dimensions, in the coronal plane, a line connecting both IACs from the fundus was made. A line perpendicular to this was then made along the greatest cranial-caudal diameter of the tumor (►Fig. 1B, GI measurement), giving the cranial and caudal dimensions (►Fig. 1B, GH and HI measurements, respectively). Once the initial measurement data were collected, a series of ratios were calculated to further characterize the dimensions of the tumor. Anterior divided by posterior extension (AB/BC), medial divided by lateral extension (EB/BF), and cranial divided by caudal extension (GH/HI) provided us with different metrics for defining dimension.

In addition to radiographic measurements, pre- and postoperative facial nerve function and EOR were recorded. Facial nerve function was reported using the House–Brackmann (HB) grading system and was defined as good if HB grade 1 or 2 and poor if HB grade 3, 4, 5, or 6.⁹ EOR was based on intraoperative impression and postoperative MRI findings. GTR was designated when all tumor was microscopically removed and confirmed on the first postoperative MRI scan, near total resection (NTR) when a small amount of adherent tumor (less than $5 \times 5 \times 2$ mm) was left on the facial nerve or brainstem and was not visualized on postoperative imaging,^{10,11} and subtotal resection (STR) when an amount of tumor more than NTR was left in situ. GTR, NTR, and STR were reported in the results section for completeness as customary in the current VS literature, but for statistical analysis, NTR and STR were grouped together and compared with GTR.

Continuous features were summarized with medians, interquartile ranges (IQRs), and ranges; categorical features were summarized with frequency counts and percentages. Associations with postoperative facial nerve outcome and EOR were

Fig. 1 (A) Axial T1-weighted post-contrast MRI. Red dotted line represents the porus acousticus. Line DE bisects the porus and extends from the fundus to the medial aspect of the tumor. Point F represents the intersection of DE with the porus. Line AC represents the greatest anterior-posterior diameter of the tumor as measured parallel to the petrous bone. Point B represents the intersection of AC with DE. (B) Coronal T1-weighted post-contrast MRI. Red dotted line represents the reference line connecting each fundus. Line GI represents the line perpendicular to the reference that incorporates the largest cranial-caudal dimension. AB, anterior extension; AC, anterior-posterior diameter; BC, posterior extension; BF, lateral extension; DE, total cysternal and meatal extension; DF, meatal extension; EB, medial extension; EF, medial-lateral diameter; GH, cranial extension; GI, cranial-caudal diameter; HI, caudal extension; MRI, magnetic resonance imaging.

evaluated using logistic regression models and were summarized with odds ratios (OR) and 95% confidence intervals (CI). Multivariable models were developed using stepwise selection, with the *p*-value for a variable to enter or leave the model set to 0.05. Model discrimination (how well the features in the model separate patients with and without the outcome of interest) was summarized using the area under a receiver operating characteristics curve (AUC). The AUC can range from 0.5 to 1.0, with higher values indicating improved predictive ability or improved discrimination. Statistical analyses were performed using version 9.3 of the SAS software package (SAS Institute Inc., Cary, NC). All tests were two-sided, and *p*-values <0.05 were considered statistically significant.

Results

A total of 206 patients were included in the final analysis; baseline characteristics are summarized in ►Table 1. The median age at surgery was 51 years (range 16–87 years). Average follow-up was 43 months (range 6–168 months). The surgical approach used was retrosigmoid in 135 (66%) patients and translabyrinthine in 70 (34%). The median size of the tumor as measured parallel to the posterior face of the petrous bone (AC measurement) was 2.5 cm (range 0.45–5.70 cm). Ninety-eight (48%) patients had size > 2.5cm measured along the

Table 1 Baseline patient and tumor characteristics^a

	N (%)
Sex	
Female	108 (52)
Male	98 (48)
Surgical approach (N = 205)	
RS	135 (66)
TL	70 (34)
Extent of resection	
GTR	111 (54)
NTR	43 (21)
STR	52 (25)
	Median (IQR; Range)
Age (years)	51 (40–60; 16–87)
AC measurement (anterior-posterior diameter)	2.50 (1.90–3.10; 0.45–5.70)
EF measurement (medial-lateral diameter)	2.00 (1.59–2.54; 0.25–4.60)
DF measurement (meatal extension)	0.71 (0.50–0.93; 0.00–1.72)
GI measurement (cranial-caudal diameter) (N = 198)	1.00 (0.67–1.36; 0.07–29.24)

Abbreviations: GTR, gross total resection; IQR, interquartile range; NTR, near total resection; RS, retrosigmoid; STR, subtotal resection; TL, translabyrinthine.

Linear measurements are given in centimeters.

^aN = 206, unless otherwise specified.

petrous face in the CPA. Tumor dimension did not directly influence surgical approach.

Facial Nerve Outcome

A total of 162 (79%) patients had good postoperative HB grade at the last clinical follow-up. The univariate regression analysis of variables studied for association with poor postoperative HB grades is summarized in ►Table 2. Cut-points

Table 2 Results of univariate regression analysis for postoperative facial nerve outcome^a

	HB 1–2, N (%)	HB 3–6, N (%)	OR (95% CI) ^b	p Value
Sex				0.72
Female	86 (53)	22 (50)	1.0	
Male	76 (47)	22 (50)	1.13 (0.58–2.20)	
Surgical approach (N = 205)				0.28
RS	103 (64)	32 (73)	1.0	
TL	58 (36)	12 (27)	3.81 (0.52–27.85)	
Extent of resection				
GTR	87 (54)	24 (55)	1.0	
NTR	35 (22)	8 (18)	0.83 (0.34–2.02)	0.68
STR	40 (25)	12 (27)	1.09 (0.50–2.39)	0.83
AB (anterior extension)				0.001
< 1.54	129 (80)	24 (55)	1.0	
≥ 1.54	33 (20)	20 (45)	3.26 (1.61–6.60)	
BC (posterior extension)				0.03
< 1.35	106 (65)	21 (48)	1.0	
≥ 1.35	56 (35)	23 (52)	2.07 (1.06–4.07)	
AC (anterior-posterior diameter)				0.01
< 2.62	97 (60)	17 (39)	1.0	
≥ 2.62	65 (40)	27 (61)	2.37 (1.20–4.69)	
EB (medial extension)				0.02
< 1.50	126 (78)	27 (61)	1.0	
≥ 1.50	36 (22)	17 (39)	2.20 (1.08–4.49)	
BF (lateral extension; N = 205)				0.02
< 0.91	99 (61)	18 (41)	1.0	
≥ 0.91	62 (39)	26 (59)	2.31 (1.17–4.55)	
EF (medial-lateral diameter)				0.06
< 2.51	123 (76)	27 (61)	1.0	
≥ 2.51	39 (24)	17 (39)	1.99 (0.98–4.02)	

(Continued)

Table 2 (Continued)

	HB 1–2, N (%)	HB 3–6, N (%)	OR (95% CI) ^b	p Value
DF (meatal extension)				0.03
< 0.79	100 (62)	19 (43)	1.0	
≥ 0.79	62 (38)	25 (57)	2.12 (1.08–4.17)	
DE (N = 196)				0.008
< 3.34	120 (78)	24 (57)	1.0	
≥ 3.34	34 (22)	18 (43)	2.65 (1.29–5.44)	
GH (cranial extension; N = 198)				0.006
< 1.34	123 (80)	26 (59)	1.0	
≥ 1.34	31 (20)	18 (41)	2.75 (1.34–5.64)	
HI (caudal extension; N = 198)				0.01
< 1.34	120 (78)	26 (59)	1.0	
≥ 1.34	34 (22)	18 (41)	2.44 (1.20–4.98)	
GI (cranial-caudal diameter; N = 198)				0.20
< 1.13	92 (60)	31 (70)	1.0	
≥ 1.13	62 (40)	13 (30)	0.62 (0.30–1.28)	
AB/BC				0.10
< 0.84	46 (28)	7 (16)	1.0	
≥ 0.84	116 (72)	37 (84)	2.10 (0.87–5.04)	
EB/BF (N = 205)				0.04
< 1.13	40 (25)	18 (41)	1.0	
≥ 1.13	121 (75)	26 (59)	0.48 (0.24–0.96)	
AC/EF				0.25
< 1.21	71 (44)	15 (34)	1.0	
≥ 1.21	91 (56)	29 (66)	1.51 (0.75–3.03)	

Abbreviations: AC/BC, anterior divided by posterior extension; AC/EF, antero-posterior diameter divided by medial-lateral diameter; DE, total cisternal and meatal extension; EB/BF, medial divided by lateral extension GTR, gross total resection; HB, House–Brackmann; NTR, near total resection; OR, odds ratio; RS, retrosigmoid; STR, subtotal resection; TL, translabyrinthine.

Linear measurements are in centimeters.

^aN = 206 unless otherwise specified.

^bOR 1.0 serves as reference.

for each MRI measurement that provided the best separation between patients with good and poor postoperative HB grades were identified using the chi-square tests. Since the distributions of most of the measurements were skewed, only these cut-points are summarized in ►Table 2. Measurements that were significantly associated with outcome when analyzed as continuous were also significantly associated with the outcome after categorization. The associations of

Table 3 Results of multivariate regression analysis for poor postoperative facial nerve outcome^a

	OR (95% CI) ^b	p Value
AB (anterior extension)		
< 1.54	1.0	0.001
≥ 1.54	3.34 (1.63–6.84)	
EB/BF (medial divided by lateral extension)		
< 1.13	1.0	0.03
≥ 1.13	0.46 (0.22–0.94)	

Abbreviation: OR, odds ratio.

Linear measurements are in centimeters.

^aOnly statistically significant variables are shown.

^bOR 1.0 serves as reference.

the measurements with poor HB grades were also evaluated after adjusting for surgical approach and EOR and were similar to those shown in ►Table 2 (data not shown).

The multivariable model developed to predict poor HB grades is summarized in ►Table 3. The MRI measurement of AB (extension anterior to the IAC) and the ratio of EB/BF (growth parallel to the long axis of the IAC or perpendicular to the petrous temporal bone) were each statistically significantly associated with poor HB grades. Patients with AB measurements ≥1.54 cm were over three times more likely to have poor HB grades compared with patients with AB measurements <1.54 cm (OR 3.34; *p* = 0.001). After adjusting for AB measurements, patients with EB/BF ratios ≥1.13 were approximately half as likely to have poor HB grades compared with patients with EB/BF ratios <1.13 (OR 0.46; *p* = 0.03). The AUC for this multivariable model was 0.67.

The effect of these two measurements on postoperative HB grades can be further illustrated by investigating the four groups created by the combination of low/high AB measurements and low/high EB/BF ratios. For example, 109 patients had AB measurements <1.54 and EB/BF ratios ≥1.13, which represent the group with the lowest likelihood of poor HB grades based on the multivariable model. Of these 109 patients, 14 (13%) had poor HB grades. In comparison, 10 (23%) of the 43 patients with AB measurements <1.54 and EB/BF ratios <1.13 (intermediate risk), 12 (32%) of the 38 patients with AB measurements ≥1.54 and EB/BF ratios ≥1.13 (intermediate risk), and 8 (53%) of the 15 patients with AB measurements ≥1.54 and EB/BF ratios <1.13 (highest risk) had poor HB grades (►Fig. 2).

Extent of Resection

There were 111 (54%) patients who underwent GTR. The univariate regression analysis of variables studied for association with GTR is summarized in ►Table 4. Cut-points for each MR measurement that provided the best separation between patients with NTR/STR and GTR were identified using the chi-square tests. Since the distributions of most of the measurements were skewed, only these cut-points are summarized in ►Table 4. Measurements that were significantly associated with outcome when analyzed as continuous were also significantly associated with the outcome after categorization.

Fig. 2 Illustrative examples of (A) large anterior extension with low EB/BF ratio, and (B) small anterior extension with high EB/BF ratio. The green line represents DE bisecting the porus acousticus. The red double-headed arrow represents AB, the measurement of anterior extension. DE, total cisternal and meatal extension; EB/BF, medial divided by lateral extension.

Table 4 Results of univariate regression analysis for extent of resection^a

	GTR, N (%)	NTR/STR, N (%)	OR (95% CI) ^b	p Value
Sex				0.74
Female	57 (51)	51 (54)	1.0	
Male	54 (49)	44 (46)	1.10 (0.63–1.90)	
Surgical Approach (N = 205)				0.18
RS	77 (70)	58 (61)	1.0	
TL	33 (30)	37 (39)	0.67 (0.38–1.20)	
AB (anterior extension)				<0.001
< 1.21	71 (64)	26 (27)	1.0	
≥ 1.21	40 (36)	69 (73)	0.21 (0.12–0.39)	
BC (posterior extension)				<0.001
< 0.93	44 (40)	8 (8)	1.0	
≥ 0.93	67 (60)	87 (92)	0.14 (0.06–0.32)	
AC (anterior-posterior diameter)				<0.001
< 1.93	48 (43)	7 (7)	1.0	
≥ 1.93	63 (57)	88 (93)	0.10 (0.04–0.25)	
EB (medial extension)				<0.001
< 1.11	74 (67)	27 (28)	1.0	
≥ 1.11	37 (33)	68 (72)	0.20 (0.11–0.36)	
BF (lateral extension; N = 205)				<0.001
< 0.76	59 (53)	18 (19)	1.0	
≥ 0.76	52 (47)	76 (81)	0.21 (0.11–0.39)	
EF (medial-lateral diameter)				<0.001
< 1.92	69 (62)	21 (22)	1.0	
≥ 1.92	42 (38)	74 (78)	0.17 (0.09–0.32)	
DF (meatal extension)				0.003
< 0.52	38 (34)	15 (16)	1.0	
≥ 0.52	73 (66)	80 (84)	0.36 (0.18–0.71)	

(Continued)

Table 4 (Continued)

	GTR, N (%)	NTR/STR, N (%)	OR (95% CI) ^b	p Value
DE (N = 196)				<0.001
< 2.44	60 (58)	14 (15)	1.0	
≥ 2.44	44 (42)	78 (85)	0.13 (0.07–0.26)	
GH (cranial extension; N = 198)				0.003
< 1.14	75 (72)	48 (51)	1.0	
≥ 1.14	29 (28)	46 (49)	0.40 (0.22–0.73)	
HI (caudal extension; N = 198)				<0.001
< 0.92	55 (53)	17 (18)	1.0	
≥ 0.92	49 (47)	77 (82)	0.20 (0.10–0.38)	
GI (cranial-caudal diameter; N = 198)				0.002
< 1.22	59 (57)	73 (78)	1.0	
≥ 1.22	45 (43)	21 (22)	2.65 (1.42–4.93)	
AB/BC				0.22
< 1.15	73 (66)	70 (74)	1.0	
≥ 1.15	38 (34)	25 (26)	1.46 (0.80–2.66)	
EB/BF (N = 205)				0.27
< 1.10	31 (28)	20 (21)	1.0	
≥ 1.10	80 (72)	74 (79)	0.70 (0.37–1.33)	
AC/EF				0.13
< 1.29	56 (50)	58 (61)	1.0	
≥ 1.29	55 (50)	37 (39)	1.54 (0.88–2.68)	

Abbreviations: AC/BC, anterior divided by posterior extension; AC/EF, antero-posterior diameter divided by medial-lateral diameter; DE, total cisternal and meatal extension; EB/BF, medial divided by lateral extension; GTR, gross total resection; NTR, near total resection; OR, odds ratio; RS, retrosigmoid; STR, subtotal resection; TL, translabyrinthine.

Linear measurements are in centimeters.

^aN = 206 unless otherwise specified.

^bOR 1.0 serves as reference.

Table 5 Results of multivariate regression analysis for gross total resection^a

	OR (95% CI) ^b	p Value
Age (years)	0.64 (0.50–0.83) ^c	<0.001
AC (anterior-posterior diameter)		0.003
< 1.93	1.0	
≥ 1.93	0.20 (0.07–0.57)	
EB (medial extension)		0.04
< 1.11	1.0	
≥ 1.11	0.42 (0.18–0.97)	
DE		0.04
< 2.44	1.0	
≥ 2.44	0.39 (0.15–0.97)	

Abbreviation: CI, confidence interval; DE, total cisternal and meatal extension; OR, odds ratio.

Linear measurements are in centimeters.

^aOnly statistically significant variables are shown.

^bOR 1.0 serves as reference.

^cOR for each 10-year increase in age.

The multivariable model developed to predict NTR/STR is summarized in ►Table 5. Age at surgery and the MRI measurements of AC (anterior-posterior diameter), EB (medial extension), and DE (extension into the IAC) were each statistically significantly associated with NTR/STR. Older patients were significantly more likely to undergo NTR/STR (OR for each 10-year increase in age of 1.55; $p < 0.001$). Patients with AC measurements ≥ 1.93 cm were five times more likely to undergo NTR/STR compared with patients with AC measurements < 1.93 cm (OR 4.97; $p = 0.003$). Similarly, high EB (OR 3.40; $p = 0.04$) and high DE (OR 2.60; $p = 0.04$) measurements were significantly associated with increased odds of NTR/STR compared with low EB and DE measurements. The AUC for this multivariable model was 0.81.

Discussion

Effect of Anterior Tumor Extension on Facial Nerve Outcome

Our results confirmed the hypothesis that when a VS has a greater extension anterior to the IAC, surgical removal is associated with poorer facial nerve outcome. Specifically, we

found that patients with tumor extending >1.5 cm anterior to the IAC (AB measurement) were three times more likely to have poor postoperative HB grades. This is likely due to the anterior anatomic position of the facial nerve and the increased stretch placed on it by an anteriorly extending tumor, making the nerve more vulnerable to dissection. Gerganov et al found similar results while reviewing a consecutive series of 99 patients who underwent complete resection of a VS via a retrosigmoid approach.¹² In their study, although tumor growth in all directions had significant correlation with facial nerve outcome at 2 weeks after surgery, anterior and caudal tumor extension had the most significant correlation. A similar impact of anterior and caudal tumor extension on facial nerve outcome at 1 year following surgery was reported by Sharma et al in a consecutive series of 72 patients who also underwent complete resection of their tumor via a retrosigmoid approach.¹³ It has been theorized that when dissecting tumor off the facial nerve in a caudal-to-cranial direction, as many surgeons do, a larger caudal tumor extension subjects the superiorly displaced nerve to more prolonged stretching during dissection.¹² While both cranial and caudal tumor extensions reached statistical significance as univariates in our study, their impact on facial nerve outcome failed to reach significance on multivariable analysis.

We also found that an EB/BF ratio ≥ 1.1 was associated with approximately half the risk of poor facial nerve outcome. This ratio represented tumor growth parallel to the axis of the IAC, with a higher ratio corresponding to a more elongated tumor with less growth perpendicular to the IAC. This finding supports our conclusion that growth anterior to the IAC is associated with poorer facial nerve outcome.

Effect of Tumor Size on Facial Nerve Outcome and Extent of Resection

Our results confirm the significant impact of tumor size on surgical outcome.^{2,6,14–22} The AC measurement, which is conventionally how studies have reported tumor size, was a statistically significant predictor of postoperative facial nerve outcome on univariate analysis. However, on multivariate analysis, only the AB measurement (anterior tumor extension) and the EB/BF ratio (growth parallel to the IAC) remained significantly associated with facial function, suggesting that tumor dimension is as important as tumor size to facial nerve outcome.

Similarly, we found that both tumor size and dimension affected EOR. Specifically, patients with an AC measurement >1.9 cm were five times less likely to undergo a GTR. Furthermore, an increased degree of tumor extension into the IAC (DE measurement >2.4 cm) or an increased amount of brainstem compression (EB measurement >1.1 cm) were each associated with a nearly three-fold decrease in the likelihood of GTR.

Limitations

These results need to be interpreted with a clear understanding of this study's limitations. In particular, the retrospective nature of the study, limited amount of patients, and interdependence of certain tumor measurements (for

example, AB-BC-AC) could obscure other factors that might have influenced facial nerve outcome. Furthermore, non-measurable factors, such as tumor consistency or tumor vascularity, could not be analyzed.

Conclusion

Our study has confirmed the well-established role of tumor size in VS surgery, but adds to the current knowledge by offering different predictive properties for different directions of tumor growth on facial nerve outcome and EOR. Based on our analysis, we conclude that direction of tumor growth is also an independent predictor of outcome, and in particular, the degree of tumor extension anterior to the IAC is significantly correlated with the postoperative HB grade. When using a strategy of attempted GTR while optimizing facial nerve outcome, an anterior-posterior tumor diameter >1.9 cm was a significant predictor of NTR/STR. It is hoped that these measurement cutoffs, if reproduced by other surgical teams, will become useful in further refining preoperative planning and in setting reasonable surgical expectations when managing medium and large VS.

Conflict of Interest

None.

Acknowledgment

The authors wish to thank Christine Lohse MS, Department of Biostatistics and Informatics, Mayo Clinic for the statistical analysis of the study data. They also wish to thank Vimal Patel, PhD, medical and scientific writer at NorthShore Neurological Institute, for copy editing this manuscript and preparing it for submission.

References

- 1 Ansari SF, Terry C, Cohen-Gadol AA. Surgery for vestibular schwannomas: a systematic review of complications by approach. *Neurosurg Focus* 2012;33(03):E14
- 2 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
- 3 Chen Z, Prasad SC, Di Lella F, et al. The behavior of residual tumors and facial nerve outcomes after incomplete excision of vestibular schwannomas. *J Neurosurg* 2014;120(06):1278–1287
- 4 Copeland WR, Hoover JM, Morris JM, Driscoll CL, Link MJ. Use of preoperative MRI to predict vestibular schwannoma intraoperative consistency and facial nerve outcome. *J Neurol Surg B Skull Base* 2013;74(06):347–350
- 5 Sameshima T, Morita A, Tanikawa R, et al. Evaluation of variation in the course of the facial nerve, nerve adhesion to tumors, and postoperative facial palsy in acoustic neuroma. *J Neurol Surg B Skull Base* 2013;74(01):39–43
- 6 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
- 7 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
- 8 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
- 9 House JW, Brackmann DE. Facial nerve grading system. *Otolaryngol Head Neck Surg* 1985;93(02):146–147
 - 10 Carlson ML, Van Abel KM, Driscoll CL, et al. Magnetic resonance imaging surveillance following vestibular schwannoma resection. *Laryngoscope* 2012;122(02):378–388
 - 11 Jacob JT, Carlson ML, Driscoll CL, Link MJ. Volumetric analysis of tumor control following subtotal and near-total resection of vestibular schwannoma. *Laryngoscope* 2016;126(08):1877–1882
 - 12 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
 - 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 Ryzenman JM, Pensak ML, Tew JM Jr. Facial paralysis and surgical rehabilitation: a quality of life analysis in a cohort of 1,595 patients after acoustic neuroma surgery. *Otol Neurotol* 2005;26(03):516–521, discussion 521
 - 15 Ruth HR, Luetje CM, Whittaker CK. Acoustic tumors: pre-operative measurement and correlation with postoperative facial nerve function. *Otolaryngol Head Neck Surg* 1985;93(02):160–163
 - 16 Symon L, Bordi LT, Compton JS, Sabin IH, Sayin E. Acoustic neuroma: a review of 392 cases. *Br J Neurosurg* 1989;3(03):343–347
 - 17 Lee TK, Lund WS, Adams CB. Factors influencing the preservation of the facial nerve during acoustic surgery. *Br J Neurosurg* 1990;4(01):5–8
 - 18 Hardy DG, Macfarlane R, Baguley D, Moffat DA. Surgery for acoustic neurinoma. An analysis of 100 translabyrinthine operations. *J Neurosurg* 1989;71(06):799–804
 - 19 Sterkers JM, Morrison GA, Sterkers O, El-Dine MM. Preservation of facial, cochlear, and other nerve functions in acoustic neuroma treatment. *Otolaryngol Head Neck Surg* 1994;110(02):146–155
 - 20 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
 - 21 Brackmann DE, Cullen RD, Fisher LM. Facial nerve function after translabyrinthine vestibular schwannoma surgery. *Otolaryngol Head Neck Surg* 2007;136(05):773–777
 - 22 Falcioni M, Fois P, Taibah A, Sanna M. Facial nerve function after vestibular schwannoma surgery. *J Neurosurg* 2011;115(04):820–826