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ORIGINAL RESEARCH

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Treated large posterior fossa vestibular schwannoma and meningioma: Hearing outcome and willingness-to-accept brain implant for unilateral deafness

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Abstract

Background/Objective: To compare functional hearing and tinnitus outcomes in treated large (~ 3 cm) vestibular schwannoma (VS) and posterior fossa meningioma cohorts, and construct willingness-to-accept profiles for an experimental brain implant to treat unilateral hearing loss.

Methods: A two-way MANOVA model with two independent variables (tumor type; time from treatment) and three dependent variables (hearing effort of tumor ear; abbreviated Speech, Spatial, and Qualities of Hearing scale (SSQ12); Tinnitus Functional Index (TFI)) was used to analyze data from VS ($N = 32$) and meningioma ($N = 50$) patients who were treated at a tertiary care center between 2010 and 2020. A query to probe acceptance of experimental treatment for hearing loss relative to expected benefit was used to construct willingness-to-accept profiles.

Results: Tumor type was statistically significant on the combined dependent variables analysis ($F[3, 76] = 19.172$, $p < .0005$, Wilks' $\Lambda = 0.569$). Meningioma showed better outcome for hearing effort ($F[1, 76] = 14.632$, $p < .0005$) and SSQ12 ($F[1, 76] = 16.164$, $p < .0005$), but not for TFI ($F[1, 76] = 1.247$, $p = .268$) on univariate two-way ANOVA analyses. Superior hearing effort and SSQ12 indices in the short-term (< 2 years) persisted in the long-term (> 2 years) ($p \leq .017$). At the 60% speech understanding level, 77% of respondents would accept an experimental brain implant.

Portions of this work were accepted as a poster presentation at the Triological Society 124th Annual Meeting at COSM, Dallas, Texas, USA, April 29–30, 2022.

Conclusion: Hearing outcome is better for posterior fossa meningioma compared to VS. Most patients with hearing loss in the tumor ear would consider a brain implant if the benefit level would be comparable to a cochlear implant.

Level of Evidence: 2

KEYWORDS
hearing, meningioma, tinnitus, vestibular schwannoma, willingness-to-accept

1 | INTRODUCTION

Vestibular schwannoma (VS) and meningioma are the two most common cerebellopontine angle (CPA) tumors.[1,2] Both of these tumors can present with hearing loss and tinnitus.[3,4] Key decision-making factors for tumor management include tumor size, audiovestibular deficits, brainstem compression, patient age, treatment preference, and co-morbidities. While both tumor types share common presentation symptoms and intervention approaches, there are few studies that have directly compared hearing outcome after surgical resection for similarly sized tumors.[5,6]

From a pathogenesis standpoint, the tumor originating cell-type differs between VS and meningioma suggesting that hearing outcomes may be different between the two. Schwann cells that envelope audiovestibular nerve fibers give rise to VS,[7,8] whereas arachnoid cap cells that surround the brain and spinal cord give rise to meningioma.[9,10] Furthermore, tumor cells from the vestibular nerve of origin in VS may invade the cochlear nerve,[8,11] a finding that has not been reported for meningioma. As such, we hypothesized VS patients will demonstrate poorer hearing outcome compared CPA meningioma patients for the same tumor size.

In addition to evaluating traditional threshold-related audiometric outcomes between VS and meningioma, pre-treatment counseling on hearing expectations could be enriched by the addition of functional features such as, speech comprehension, spatial hearing, and tinnitus. The adoption of a multidimensional approach to assess hearing would be more comprehensive and enable structured data collection that would be suitable for statistical analyses deploying multivariate and linear mixed models,[12,13] which is often used to handle missing data. Moreover, a more detailed understanding of hearing impairment features following treatment is necessary to establish benefit levels for the acceptance of experimental treatments under development consideration. Motivated by the growing success of cochlear implantation for single-sided deafness[14–16] and recognizing the cochlear nerve may not be suitable for electrical stimulation following treatment for VS or meningioma, we probed patient benefit expectation for an experimental brain implant and constructed willingness-to-accept profiles.

2 | MATERIALS AND METHODS

2.1 | Subject Recruitment

This study was approved by the institutional review board and informed consent was obtained from all participants. The study followed the principles outlined in the Declaration of Helsinki and by the STROBE reporting guideline. An online study invitation was distributed to 502 patients with VS or CPA meningioma treated between 2010 and 2020 (SAP QualtricsXM; Provo, Utah). The fully integrated Neurotology and Neurosurgery team at this tertiary care facility attempted to preserve cochlear nerve anatomic continuity in all cases.

2.2 | Survey Instruments

Three survey instruments were used for this study: (1) a 5-point Likert rating scale for hearing effort in the ear impacted by the tumor (i.e., "tumor ear") (1 = not applicable, ear is deaf; 2 = extreme effort; 3 = moderate effort; 4 = minimal effort; and 5 = no effort); (2) Tinnitus Functional Index (TFI);[17] and (3) the abbreviated Speech, Spatial, and Qualities of Hearing scale (SSQ12).[18] Patients who reported deafness in the tumor ear or extreme hearing effort were considered to have functional single-sided deafness (SSD). SSD patients were invited to provide likelihood (never, very unlikely, unlikely, neutral, likely, very likely, and definitely) of willingness-to-accept an experimental brain implant that would deliver benefit along two hearing dimensions: (a) spatial hearing (sound detection in the deaf ear hemifield) and (b) speech understanding at four levels of benefit (20%, 40%, 60%, and 80%). The TFI is a validated self-reported scale for tinnitus severity, where scores between 0 and 18 are low severity; scores between 18 and 42 are lower moderate; scores between 42 and 65 are upper moderate; and scores greater than 65 are high severity.[19] The SSQ12 instrument measures hearing abilities across three subdomains: speech hearing, spatial hearing, and hearing qualities.[18] SSQ12 scores range from 0 to 10, where 0 = significant disability and 10 = no disability.

2.3 | Statistical Analyses

All analyses were performed with SPSS software (IBM; Armonk, NY). A two-way MANOVA model with two independent variables (tumor type; time from treatment) and three dependent variables (hearing effort of tumor ear; SSQ12; TFI) was chosen for primary statistical analysis. The combined dependent variables were used to assess hearing outcome. There was a nonlinear relationship between the dependent variables, as assessed by scatterplot. There was no evidence of multicollinearity, as assessed by Pearson correlation ($|r| < .9$). There were

TABLE 1 Vestibular schwannoma and meningioma cohorts

Cohort	Vestibular schwannoma	Meningioma
Number of subjects	32	50
Gender, male:female	12:20	6:44
Age, mean (95% CI), yr	56 (50–62)	62 (58–65)
Tumor size, mean (95% CI), cm	2.9 (2.8–3.0)	2.9 (2.6–3.3)
Time from treatment, mean (95% CI), yr	3.4 (2.3–4.5)	5.5 (4.3–6.7)
Treatment type, R:S:C	2:9:21	0:32:18
Tinnitus Functional Index, mean (95% CI)	18 (9.6–24)	11 (5.7–18)
SSQ12, mean (95% CI)	4.5 (3.8–5.4)	6.6 (6.0–7.3)
Hearing effort, mean (95% CI)	1.4 (1.0–1.8)	3.4 (3.0–3.8)

Abbreviations: C, combined radiation and surgery; CI, confidence interval; cm, centimeter; R, radiation; S, surgery; SSQ12, the abbreviated Speech, Spatial and Qualities of Hearing scale; yr, year.

rare univariate outliers in the data, as assessed by inspection of a boxplot. These outliers were included in the analysis as the results were not substantially affected. There were no multivariate outliers in the data, as assessed by Mahalanobis distance ($p > .001$). SSQ12 scores were normally distributed as assessed by Shapiro–Wilk's test ($p > .05$), however, TFI scores and hearing effort were not normally distributed ($p < .05$). There was homogeneity of covariance matrices, as assessed by Box's M test ($p < .001$). All data is available upon request.

3 | RESULTS

Five-hundred and two survey invitations were sent to prospective respondents. Fifty out of one-hundred and ninety-eight CPA meningioma patients completed the entire survey. The average preoperative linear tumor size was 29 mm, measured as the largest diameter in the axial plane, parallel to the petrous apex. One–hundred and twenty-one CPA VS patients completed the entire survey. Thirty-two VS patients matched by tumor size to the meningioma cohort were included in the study.

3.1 | Meningioma Cohort

There were 6 males and 44 females (Table 1), consistent with the female predisposition for this tumor type.[20] The mean age was 62 years (95% CI: 58–65 years). The average tumor size was 29 mm (95% CI: 26–33 mm). The mean time from treatment was 5.5 years (95% CI: 4.3–6.7 years). Fifty meningioma patients underwent primary microsurgical tumor excision (39 retrosigmoid/suboccipital, 5 translabyrinthine/retrolabyrinthine, 6 middle fossa). Meningioma cohort hearing outcome descriptive statistics showed mean hearing effort = 3.4 (95% CI: 3.0–3.8), mean TFI = 11 (95% CI: 5.7–18), and mean SSQ12 = 6.6 (95% CI: 6.0–7.3).

TABLE 2 Effect on combined hearing and Tinnitus outcome by factor

Factor	F value	p value
Tumor type	$F(3, 76) = 19.17$	< .0005
Time from treatment	$F(3, 76) = 1.050$	.376
Tumor type × time from treatment	$F(3, 76) = 0.622$	.603

Note: Combined dependent variables are hearing effort of the tumor ear, the abbreviated Speech, Spatial, and Qualities of Hearing scale, and the Tinnitus Functional Index.

TABLE 3 Main effect of tumor type on hearing and Tinnitus

Outcome	F value	p value
Hearing effort of the tumor ear	$F(1, 76) = 14.63$	< .0005
SSQ12	$F(1, 76) = 16.16$	< .0005
Tinnitus Functional Index	$F(1, 76) = 1.247$	.268

Abbreviation: SSQ12, the abbreviated Speech, Spatial, and Qualities of Hearing scale.

3.2 | VS Cohort

There were 12 males and 20 females (Table 1). The average age was 56 years (95% CI: 50–62 years). The average pre-operative tumor size was 29 mm (95% CI: 28–30 mm). The average time from treatment was 3.4 years (95% CI: 2.3–4.5 years). Thirty VS patients underwent primary microsurgical tumor excision (27 retrosigmoid, 3 translabyrinthine) and two received radiation therapy only. VS cohort hearing outcome descriptive statistics showed mean hearing effort = 1.3 (95% CI: 0.8–1.8), mean TFI = 18 (95% CI: 9.6–24), and mean SSQ12 = 4.5 (95% CI: 3.8–5.4).

3.3 | Outcome Data

Tumor type was statistically significant on the combined dependent variables analysis ($F[3, 76] = 19.172$, $p < .0005$, Wilks' $\Lambda = 0.569$). The interaction effect between tumor type and time from treatment on the combined dependent variables was not statistically significant, $F(3, 76) = 0.622$, $p = .603$, Wilks' $\Lambda = 0.025$, partial $\eta^2 = 0.024$ (Table 2). However, there was a statistically significant tumor type effect on the combined dependent variables, $F(3, 76) = 19.172$, $p < .0005$, Wilks' $\Lambda = 0.569$, partial $\eta^2 = 0.431$. The main effect of time from treatment on the combined dependent variables was not statistically significant, $F(3, 76) = 1.050$, $p = .376$, Wilks' $\Lambda = 0.960$, partial $\eta^2 = 0.040$.

Meningioma exhibited better hearing outcome on follow-up univariate two-way ANOVA analysis (Table 3). There was a statistically significant main effect of tumor type for SSQ12 score, $F(1, 76) = 16.164$, $p < .0005$, partial $\eta^2 = 0.172$ and hearing effort score, $F(1, 76) = 14.632$, $p < .0005$, partial $\eta^2 = 0.158$, but not for the TFI score, $F(1, 76) = 1.247$, $p = .268$, partial $\eta^2 = 0.016$.

TABLE 4 Hearing difference between vestibular schwannoma and meningioma

Time after treatment	Mean (95% CI)	*p* value
< 2 years after treatment		
Hearing effort (M)	3.2 (2.4–4.0)	
Hearing effort (VS)	1.4 (0.8–1.9)	
Hearing effort difference (M-VS)	1.8 (0.7–2.5)	<.001
SSQ12 (M)	6.5 (5.6–7.4)	
SSQ12 (VS)	4.1 (3.0–5.3)	
SSQ12 difference (M-VS)	2.4 (0.9–3.9)	.002
> 2 years after treatment		
Hearing effort (M)	3.5 (3.0–4.1)	
Hearing effort (VS)	1.1 (0.9–1.2)	
Hearing effort difference (M-VS)	2.5 (1.8–3.4)	<.001
SSQ12 (M)	6.8 (5.8–7.7)	
SSQ12 (VS)	5.1 (4.2–6.0)	
SSQ12 difference (M-VS)	1.7 (0.3–3.0)	0.017

Note: Positive difference indicates better hearing.
Abbreviations: CI, confidence interval; M, meningioma; SSQ12, the abbreviated Speech, Spatial, and Qualities of Hearing scale; VS, vestibular schwannoma.

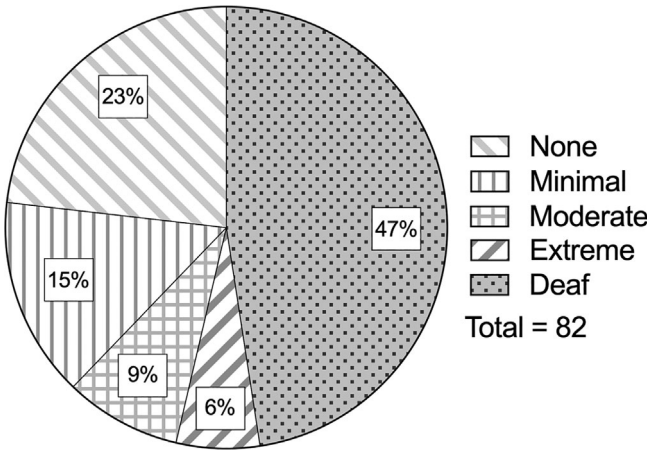

FIGURE 1 Hearing effort of the tumor ear

Meningioma superior hearing effort and SSQ12 indices persisted beyond 2 years. Tukey pairwise comparisons were performed for short-term (< 2 years) and long-term (> 2 years) time intervals (Table 4). Meningioma hearing effort mean score at < 2 years after treatment was 1.836 (95% CI: 0.726–2.524) higher compared to VS ($p < .001$). Meningioma hearing effort mean score at > 2 years after treatment was 2.485 (95% CI: 1.805–3.437) higher compared to VS ($p < .001$). Meningioma SSQ12 mean score at < 2 years after treatment was 2.402 (95% CI: 0.914–3.890) higher compared to VS ($p = .002$). Meningioma SSQ12 mean score at > 2 years after treatment was 1.655 (95% CI: 0.305 3.005) higher to VS ($p = .017$).

The willingness-to-accept experimental brain implant profile to mitigate SSD was constructed from 39 patients reported who reported deafness in the tumor ear or extreme hearing effort (Figure 1 and Table 5). Twenty-five of the 39 respondents (62%) were willing to consider an experimental brain implant to improve hearing in the deaf ear. For the benefit of sound detection in the hemifield of the deaf ear, 74% of respondents would likely accept (likely, very likely, or definitely categories) an experimental brain implant. For speech: at the 80% of speech understanding level, 100% would likely accept, and at the 60% of speech understanding level, 77% would likely accept (Figure 2). At the 40% and 20% speech understanding levels, the willingness-to-accept a brain implant dropped off steeply to 32% and 18%.

The willingness-to-accept experimental brain implant profile to mitigate SSD was dichotomized to examine the spatial and speech subdomains of the SSQ12. A chi-square test for association was used for the analysis. There was a statistically significant association between SSQ12 spatial hearing subdomain scores and willingness-to-accept, $\chi^2(1) = 22.800$, $p < .001$. There was also a statistically significant association between SSQ12 speech perception subdomain scores and willingness-to-accept, $\chi^2(1) = 20.119$, $p < .001$.

4 | DISCUSSION

In this comparison study of treated, size-matched meningioma and VS, hearing outcome was better for meningioma. Using a multidimensional features approach to assess hearing outcome, and multivariate and univariate analytics, hearing effort of the tumor ear and SSQ12 features were found to be superior and persisted in the long term. This clinical outcome difference may be used to guide pre-treatment counseling of patient expectations.

Few studies directly evaluated hearing outcomes between treated CPA VSs and meningiomas. A prior study by Cohen et al. reviewed 161 patients with CPA tumors and reported tumor type did not have prognostic value on hearing outcome.[5] However, sampling was strongly biased toward VS, which accounted for 146 cases. The remainder was distributed between meningioma and neurofibroma. Tumor size was not controlled for tumor type comparisons. Joarder et al. reported on hearing outcome for 34 CPA tumors (27 VSs, 6 meningiomas, and 1 epidermoid).[6] Hearing preservation was attempted in three VS and two meningioma cases. Post-operative hearing was preserved in three of the five cases, but limited sample sizes precluded comparison by tumor type.

Tumor pathophysiology may be an important contributor of the differential hearing outcome. VS originates within the internal auditory canal[7,8] and may interdigitate into the auditory nerve,[8,11] whereas meningioma arises from arachnoid and displace the auditory nerve without invasion.[9,10] Additionally, VS may be more intimate with the labyrinthine artery. Inner ear ischemia risk during surgical manipulation may differ between the two tumor types, although this has not been directly studied.[21] There have been reports of hearing loss recovery after surgical resection of CPA meninigioma,[22–28] whereas this has been rarely described for VS.[29,30] A plausible explanation for meningioma hearing loss recovery is resolution of transient

TABLE 5 SSQ12 and willingness-to-accept experimental brain implant

Spatial subdomain	Low score (1–5)	High score (6–10)	*p* value
Willing	17	7	
Not willing	9	6	< .001
Speech subdomain			
Willing	20	4	
Not willing	9	6	< .001

Abbreviation: SSQ12, the abbreviated Speech, Spatial, and Qualities of Hearing scale.

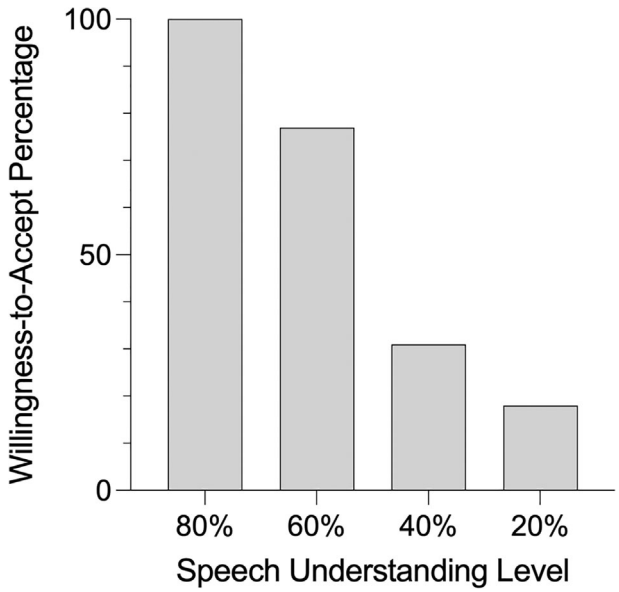

FIGURE 2 Willingness-to-accept an experimental brain implant for hearing improvement across decreasing levels of expected speech understanding in patients with single-sided deafness. Willingness-to-accept was defined as responses reporting "likely", "very likely", or "definite" acceptance

auditory nerve edema or stretch, in contrast to VS irreversible hearing loss from permanent cochlear ischemia or infarction. However, auditory nerve functional integrity may be compromised by microsurgical treatment of either tumor type.

Current management options for SSD following CPA tumor intervention are no treatment, cochlear implants, bone conduction hearing devices, and contralateral routing of signal (CROS) hearing aids.[31] In the non-tumor SSD populations, cochlear implantation has been demonstrated to improve sound localization,[14,15,32] speech understanding,[14,15,32] and disease-specific quality of life outcomes[14,15,33] in children and adults.[34] This success has led to the consideration of ipsilateral cochlear implantation in patients with a sporadic, non-growing VS[35,36] and Neurofibromatosis type 2 (NF2).[37–41] The enthusiasm for cochlear implantation in those patients and other tumor patients should be balanced against the need for tumor surveillance by magnetic resonance imaging[42] and generally poorer benefit due to cochlear nerve impairment by tumor infiltration or intraoperative injury.[35]

Auditory brainstem implantation (ABI) is an option for patients with SSD who are not candidates for cochlear stimulation.[43] Hearing benefit remains rather limited, however, with an average score of 10% on open-set speech test.[44–46] Auditory midbrain implantation (AMI) of the inferior colliculus to bypass compromised brainstem areas attributable to tumor or microsurgery has been proposed by Lim and Lenarz.[47] Early trial data show improvement in lip-reading capabilities and environmental awareness, but speech understanding benefit is limited (~10%).[48,49]

Auditory thalamic implantation (ATI) is potentially an option in the future for posterior fossa tumor-related SSD. In a preclinical animal study,[50] cortical activation dynamic ranges were similar to those reported for cochlear stimulation, suggesting a deep brain stimulation probe may be developed to deliver an MR conditional central auditory prosthesis for clinical evaluation.[51] In this study, we queried patients who reported deafness in the tumor ear or extreme hearing effort to construct willingness-to-accept profiles. Patients with poor SSQ12 subdomain scores in spatial localization or speech understanding were more likely to accept an experimental brain implant than those with high subdomain scores. Notably, a brain implant under development consideration would need to provide at least a 60% speech understanding level to be of interest to this patient population. Remarkably, this benefit level is similar to the speech perception outcome of cochlear implantation in adults with sensorineural hearing loss.[52,53]

4.1 | Limitations

There are two main limitations to this study. First, unilateral profound hearing loss in the tumor ear is based on a qualitative Likert scale for categorization, without quantitative threshold data for confirmation. While the addition of audiometry at the time of survey would have been more rigorous, patient qualitative assessment of complete dependence on the better ear maps to ≥45 dB interaural threshold difference.[54] Second, both tumor cohorts show a female respondent bias. The somewhat higher female bias in meningioma may have had an unclear increment impact on hearing outcome analyses.

5 | CONCLUSION

CPA meningioma is associated with better hearing outcomes compared to VS after treatment. This difference may be used to guide pre-treatment counseling of patient expectations. Most patients with hearing loss in the tumor ear would consider a brain implant if the benefit level would provide at least a 60% speech understanding level.

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CONFLICTS OF INTEREST

None.

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