Audiologic prognostic factors for hearing preservation following vestibular schwannoma surgery

Aleksandra Ochal-Choińska^{1,A–F}, Magdalena Lachowska^{1,A,C–F}, Katarzyna Kurczak^{2,D–F}, Kazimierz Niemczyk^{1,E,F}

¹ Department of Otolaryngology, Medical University of Warsaw, Poland

² Center for Foreign Languages, Medical University of Warsaw, Poland

A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation;

D – writing the article; E – critical revision of the article; F – final approval of the article

Advances in Clinical and Experimental Medicine, ISSN 1899–5276 (print), ISSN 2451–2680 (online)

Adv Clin Exp Med. 2019;28(6):747–757

Address for correspondence

Magdalena Lachowska

E-mail: mlachowska@wum.edu.pl

Funding sources

None declared

Conflict of interest

None declared

Received on July 26, 2017

Reviewed on November 19, 2017

Accepted on May 5, 2018

Published online on February 19, 2019

Abstract

Background. Postoperative hearing loss after vestibular schwannoma (VS) removal still remains a lifelong problem for the patients. The present study analyzes the problem of hearing preservation after VS removal from a different angle than available professional literature on this topic.

Objectives. To identify audiologic factors which determine the extent of hearing loss in patients operated on for VS.

Material and methods. The study group included 86 patients operated on due to VS accessed via the middle cranial fossa. The analyses involved the effect on absolute hearing loss, which was calculated on the basis of the results of pure-tone audiometry performed pre- and postoperatively, and factors included in the preoperative audiologic tests, such as pure-tone audiometry, speech audiometry, auditory brainstem response (ABR), and impedance audiometry.

Results. The following parameters were demonstrated to have a prognostic value: 1. hearing thresholds at 125 Hz, 500 Hz and 1,000 Hz for the operated ear, Pure Tone Average (PTA) – calculated specifically at 500 Hz, 1,000 Hz and 2,000 Hz and at 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz for the operated ear, and normal audiometric curve; 2. speech discrimination ranging from 55 dB to 75 dB for the operated ear, speech detection threshold (SDT) in the operated ear and interaural difference at 25–35 dB (non-operated vs operated ear); 3. presence of wave V, the values of I–V and III–V intervals for the operated ear, the amplitude of wave V, and the interaural ratio of wave V amplitudes; 4. intensity level for obtaining stapedial reflex or an abnormal reflex at Ipsi 500 Hz, 1,000 Hz and 2,000 Hz, and Contra 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz.

Conclusions. The better the preoperative hearing status, the more substantial surgery-related hearing loss was observed. A number of preoperative parameters of the basic diagnostic set of audiologic tests present a prognostic value for the degree of surgery-related hearing loss in VS patients.

Key words: hearing loss, neuroma, middle cranial fossa, audiometry, auditory evoked potentials

Cite as

Ochal-Choińska A, Lachowska M, Kurczak K, Niemczyk K. Audiologic prognostic factors for hearing preservation following vestibular schwannoma surgery. *Adv Clin Exp Med.* 2019;28(6):747–757. doi:10.17219/acem/90768

DOI

10.17219/acem/90768

Copyright

Copyright by Author(s)

This is an article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

Background

The development in the field of medicine has facilitated the shift of the primary aim of vestibular schwannoma (VS) removal surgery from tumor removal to the smallest possible impairment of neurological functions. The impairment of facial nerve function is mostly transient. However, postoperative hearing impairment still remains a lifelong problem for the patients.

It is therefore necessary to determine the factors responsible for the extent of hearing loss resultant from the surgery and to employ them in the optimization of the therapeutic process. A review of the professional literature revealed a paucity of detailed and multidimensional analyses of possible prognostic factors included in the basic panel of audiologic diagnostic tests for VS patients which would determine the extent of surgery-related hearing loss.

Objectives

The main aim of the study was to identify audiologic factors which determine the extent of hearing loss in patients operated on for VS. The analysis included the following audiologic tests: pure-tone audiometry, speech audiometry, auditory brainstem response (ABR), and impedance audiometry with particular attention paid to stapedial reflex.

Some authors have attempted to investigate the role of pure-tone audiometry or speech audiometry outcomes as prognostic factors. However, studies describing the predictive value of ABR are scarce. The available analyses have concentrated on few parameters of response recording, neglecting such data as the values of amplitudes of individual waves.

Material and methods

This retrospective analysis covered data obtained from audiologic tests and case histories of patients operated on for VS via middle cranial fossa approach which is a technique facilitating hearing preservation. The study involved 86 patients with a postoperative histopathological confirmation of VS.

All the surgical procedures were performed by the same experienced otosurgeon with substantial expertise in skull base surgery. The surgeries of the patients analyzed were carried out within 6 years, however, the potential influence of his gradually growing experience and on surgery-related hearing loss was ruled out ($p > 0.05$).

Each study group patient underwent diagnostic and medical procedures according to a standard protocol implemented by Department of Otolaryngology, Medical University of Warsaw (Poland) concerning patients with a suspected tumor of the cerebellopontine angle. According to the

protocol, each patient underwent audiologic tests, including pure-tone audiometry, speech audiometry, impedance audiometry with stapedial reflex testing, and ABR no later than a month prior to the procedure. Magnetic resonance imaging (MRI) was used to confirm the presence of a tumor in the cerebellopontine angle region in each patient.

The follow-up tests included pure-tone audiometry alone or pure-tone audiometry and speech audiometry performed 3 months after the surgery.

This study presents the analysis of a number of factors (157 individual parameters) included in the parameters of the audiologic tests, imaging test data and case histories in terms of their possible influence on surgery-related hearing loss.

The following parameters were assessed with pure-tone audiometry: the values of hearing thresholds at individual frequencies, air- and bone-conduction, Pure Tone Average (PTA) calculated on the side affected with VS based on hearing thresholds at 500 Hz, 1,000 Hz, 2,000 Hz, and 3,000 Hz (this parameter is more commonly used in North America and recommended by the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS)),¹ interaural differences in the values of hearing thresholds for each of the test frequencies from 125 Hz to 8,000 Hz, for air-conduction (the value of hearing threshold in the operated ear minus the value of hearing threshold in the non-operated ear), and interaural differences between PTA (the value of PTA in the operated ear minus the value of PTA in the non-operated ear). Moreover, the preoperative shape of the air-conduction audiometric curve was assessed, with the curve classified as normal, sharply falling, rising, flat, U-shaped, inverted U-shaped, and complete deafness.

The following parameters were assessed with speech audiometry in terms of being potentially prognostic factors: 1. speech discrimination for individual sound intensities with particular attention paid to the value of 55–65 dB of sound pressure level (dB SPL) as it corresponds with typical speech intensity; 2. interaural differences in speech discrimination for individual values of sound intensity (speech discrimination for the non-operated minus speech discrimination for the operated ear at a specific intensity); 3. speech detection threshold (SDT) expressed in dB SPL; 4. speech reception threshold (SRT) – expressed in dB SPL; 5. speech discrimination score (SDS) – expressed as percentages; 6. interaural difference between SDS (value for the non-operated ear minus value for the operated ear); 7. achieving 100% of speech discrimination by the patient – with the zero-one method.

Impedance audiometry was used to assess the presence or absence of stapedial reflex and the value of sound intensity at which stapedial reflex was obtained. However, if the reflex was absent, its value was recorded as 130 dB in order to facilitate the analyses. Moreover, the patients were grouped based on normal or pathological stapedial reflex (with the pathological reflex described as: test intensity

exceeding reference values – 100 dB SPL, positive Metz symptom and a complete lack of stapedial response).

Type A tympanograms were obtained in each patient. Therefore, tympanogram curve shape was disregarded as a prognostic factor.

Auditory brainstem response tests were conducted with the Smart Box platform integrated with Smart-EP software (Intelligent Hearing Systems, Corp., Miami, USA). A 90 dB nHL (decibels above normal adult hearing level) broadband click was used as an acoustic stimulus. The rate of stimulus delivery was 31/s.

The following ABR testing parameters were assessed as possible prognostic factors: 1. waveform morphology – the presence of waves I, III and V; 2. the value of wave I, III and V latency; 3. the values of I–III, I–V and III–V intervals; 4. interaural latency differences (ILD) for waves I, III and V; 5. ILD for I–III, I–V and III–V; 6. wave I, III and V amplitudes measured as the average of 3 records for each wave; 7. interaural amplitude differences for waves I, III and V; 8. interaural amplitude ratios of waves I, III and V – the value of amplitudes recorded on the side of the tumor and the value of contralateral amplitudes of individual waves; 9. amplitude ratios of waves V and I (ARI_V); 10. interaural ARI_V ratio – ipsilateral to the tumor vs contralateral side, compliance with referenced values according to Hall et al.²

Apart from the individual parameters for selected audiologic tests (pure-tone, speech, impedance audiometry, and ABR) as possible prognostic factors of hearing preservation, we also assessed the preoperative hearing capacity calculated according to the AAO-HNS classification¹ and the Classification of Hearing Impairments by the International Bureau for Audiophonology (BIAP).³

Assessment of surgery-related hearing loss

The abovementioned parameters of the assessment of pre- and postoperative hearing status, calculated on the basis of data obtained from pure-tone audiometry, were used to evaluate surgery-related hearing loss by determining absolute hearing loss. The majority of analyses in the present study refer to this parameter.

Absolute hearing loss was defined as a difference between PTA before and after the surgery for the operated ear.

Statistical analysis

All statistical calculations were performed with IBM SPSS statistical software (IBM Corp., Armonk, USA). Qualitative data was described with the use of the number and percentage of occurrence of a category, while quantitative variables were characterized with the following descriptive statistics: median (M), mean, standard deviation (SD), minimum (Min), and maximum (Max). Prior to analyses, all the quantitative variables had been examined in terms of data distribution with 2 measures of distribution: skewness and kurtosis. A result was considered statistically significant

with a p-value below 0.05 ($p < 0.05$). The following analyses were conducted in this study: 1. χ^2 test in cross tabulations (combined with comparison of column proportions with Bonferroni correction); 2. correlation analysis (Pearson's r /Spearman's ρ); 3. polynomial logistic regression analysis; 4. k-means cluster analysis; 5. one-way analysis of variance (ANOVA; intra-group and inter-group design).

Ethical considerations

The study was approved by the local Institutional Ethics Committee Review Board. The project conforms to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Results

Study group division into 4 groups based on absolute hearing loss

Based on absolute hearing loss (difference between PTA pre- and postoperatively for the operated ear), the patients were divided into 4 categories of differences: ≤ 10.00 ; 10.01–20.00; 20.01–40.00; and ≥ 40.01 (Table 1). The division aimed at distinguishing groups with low and high grades of hearing loss. This division into 4 groups became the basis for further analyses concerning possible factors influencing surgery-related hearing loss. The table presents the number and percentage of patients along with the average tumor size in each group.

Table 1. The division into groups based on surgery-related hearing loss, comprising the difference in Pure Tone Average (PTA; according to AAO-HNS classification) before and after the surgery. The table presents number and percentage of patients along with average tumor size in each group

Patient group depending on surgery-related hearing loss [dB HL]	Number of patients	Percentage of patients [%]	Average tumor size [mm]
≤ 10.00	27	31.40	10.14
10.01–20.00	21	24.42	11.77
20.01–40.00	16	18.60	13.42
≥ 40.01	22	25.58	10.75

Pure-tone audiometry

One-way ANOVA revealed a correlation between hearing thresholds for individual frequencies before the operation and preoperative PTA and the degree of surgery-related hearing loss. A thorough post hoc analysis with an S-N-K test showed that patients with hearing loss below 10 dB HL (decibels hearing level) preserved considerably higher values of hearing threshold for the 1,000 Hz frequency than the remaining groups (a result at the level of statistical tendency

Table 2. Pure Tone Averages (PTA) at individual frequencies and preoperative PTA [dB HL] depending on the extent of surgery-related hearing loss – statistically significant parameters

The parameter of pure-tone audiometry	Hearing loss in individual groups [dB HL]				F-test	p-value
	≤10.00	10.01–20.00	20.01–40.00	≥40.01		
Hearing threshold at 125 Hz	24.07 ±15.81	17.73 ±8.13	14.67 ±6.67	16.82 ±10.53	2.817	0.044
Hearing threshold at 250 Hz	25.56 ±16.49	15.46 ±11.12	15.33 ±9.90	15.46 ±9.12	4.067	0.010
Hearing threshold at 500 Hz	28.33 ±20.33	19.09 ±15.17	17.67 ±15.34	17.05 ±10.43	2.634	0.055
Hearing threshold at 1,000 Hz	38.33 ±24.22	27.73 ±19.19	25.33 ±21.25	18.41 ±13.49	4.133	0.009

Table 3. Correlations between surgery-related hearing loss (the difference in pre- and postoperative Pure Tone Averages (PTA)) and the preoperative degree of hearing impairment (according to BIAP classification)

Surgery-related hearing loss	Preoperative degree of hearing impairment				Total [%]
	normal [%]	slight [%]	moderate [%]	severe [%]	
≤10.00 dB HL	22.6 ^a	24.0 ^a	42.9 ^{a,b}	100.0 ^b	31.40
10.01–20.00 dB HL	25.8 ^a	20.0 ^a	32.1 ^a	–	25.60
20.01–40.00 dB HL	16.1 ^a	20.0 ^a	17.9 ^a	–	17.40
≥40.01 dB HL	35.5 ^a	36.0 ^a	7.1 ^b	–	25.60
Total	100.00	100.00	100.00	100.00	100.00

Each superscript letter (^{a,b}) means a subset of “hearing impairment” category whose column proportions do not differ significantly at the level of 0.05.

was obtained only for 500 Hz frequency). The remaining differences revealed no statistical significance (Table 2).

The χ^2 analysis in cross tabulations did not confirm any correlation between the type of audiogram and surgery-related hearing loss ($\chi^2 = 21.81$; $p > 0.05$). It showed no correlation between surgery-related hearing loss (the difference between pre- and postoperative PTA) and the degree of BIAP hearing impairment ($\chi^2 = 13.62$; $p > 0.05$). It is worth mentioning that the column proportions test with Bonferroni correction showed that the lowest degree of surgery-related hearing loss was obtained considerably more frequently in patients who had been preoperatively diagnosed with moderate or severe hearing impairment according to BIAP.³ Detailed results are presented in Table 3.

The χ^2 analysis in cross tabulations showed no correlation between surgery-related hearing loss (the difference between pre- and postoperative PTA) and the preoperative hearing status described with the AAO-HNS classification ($\chi^2 = 4.62$; $p > 0.05$).

Speech audiometry

Pearson's r correlation analysis was used to determine whether there was a correlation between the parameters of speech audiometry and the surgery-related hearing loss. The pre- and postoperative differences between PTA were compared in the analysis.

A correlation between the results of both tests was confirmed. It was demonstrated that the more marked the surgery-related hearing loss, the lower the preoperative SDT and SRT indexes found in the patients and the more patients achieved 100% of speech discrimination in the operated ear preoperatively.

The SDS parameter was found to have the weakest correlation with postoperative hearing loss. However, a trend was visible which showed that hearing loss experienced by patients as a result of surgery was more marked in the case of better preoperative speech discrimination. Detailed results are presented in Table 4.

Pearson's r calculated for the correlation between the percentage of speech discrimination at individual intensities and the surgery-related hearing loss showed a significant correlation for the intensities of 45 dB and higher, the surgery-related hearing loss increased with the increase of the percentage of speech discrimination for the intensities of 45 dB SPL and higher.

The results of Pearson's r correlation between preoperative interaural differences in speech discrimination during speech audiometry for individual intensities and surgery-related hearing loss showed a significant correlation for intensities above 50 dB SPL. Surgery-related hearing loss

Table 4. Correlations between the indexes of speech audiometry (speech reception threshold – SRT, speech detection threshold – SDT, peak percentage of speech discrimination in the operated ear – SDS, and whether the patient achieved 100% of speech discrimination – SDS100) and surgery-related hearing loss (the difference between pre- and postoperative Pure Tone Averages (PTA)) – the values of Pearson's r correlation coefficient

Index	Surgery-related hearing loss
SDT	–0.324**
SRT	–0.341**
SDS	0.220
SDS100	0.325**

* $p < 0.05$; ** $p < 0.01$; ** statistically significant parameters.

Table 5. Correlations between statistically significant preoperative indexes of speech audiometry for the operated ear and surgery-related hearing loss (the difference between pre- and postoperative Pure Tone Averages – PTA) – descriptive statistics ($\pm$ SD) and F statistics

Speech audiometry parameters	≤ 10.00 dB HL	10.01–20.00 dB HL	20.01–40.00 dB HL	≥ 40.01 dB HL	F-test	p-value
SDT	45.42 $\pm$ 18.29	40.00 $\pm$ 17.24	38.33 $\pm$ 18.48	30.26 $\pm$ 10.07	3.047	0.034
55 dB SPL	38.96 $\pm$ 38.95	47.00 $\pm$ 40.80	55.33 $\pm$ 36.03	70.00 $\pm$ 25.66	2.785	0.047
60 dB SPL	47.08 $\pm$ 39.48	54.75 $\pm$ 39.69	65.00 $\pm$ 32.13	78.68 $\pm$ 22.48	3.193	0.028
65 dB SPL	55.63 $\pm$ 38.46	61.25 $\pm$ 36.41	71.33 $\pm$ 28.69	83.95 $\pm$ 19.19	3.031	0.035
70 dB SPL	64.17 $\pm$ 37.20	68.25 $\pm$ 33.57	77.67 $\pm$ 27.70	89.21 $\pm$ 18.20	2.672	0.054
75 dB SPL	69.17 $\pm$ 36.32	73.50 $\pm$ 26.81	79.67 $\pm$ 28.19	91.32 $\pm$ 15.97	2.347	0.080
Interaural difference 25 dB SPL	7.04 $\pm$ 10.63	–0.23 $\pm$ 5.17	1.67 $\pm$ 9.94	7.96 $\pm$ 10.20	4.056	0.010
Interaural difference 30 dB SPL	12.69 $\pm$ 22.11	–0.68 $\pm$ 10.27	2.67 $\pm$ 20.34	13.41 $\pm$ 17.42	3.344	0.023
Interaural difference 35 dB SPL	22.22 $\pm$ 28.31	4.43 $\pm$ 20.40	19.33 $\pm$ 30.79	20.34 $\pm$ 19.08	2.453	0.069

Table 6. The distribution of mean values and standard deviation (SD) of statistically significant parameters in 4 individual groups of surgery-related hearing loss

Parameter	≤ 10.00 dB HL	10.01–20.00 dB HL	20.01–40.00 dB HL	≥ 40.01 dB HL	F-test	p-value
Pure-tone audiometry						
Hearing threshold at 125 Hz	24.07 $\pm$ 15.81	17.73 $\pm$ 8.13	14.67 $\pm$ 6.67	16.82 $\pm$ 10.53	2.817	0.044
Hearing threshold at 250 Hz	25.56 $\pm$ 16.49	15.46 $\pm$ 11.12	15.33 $\pm$ 9.90	15.46 $\pm$ 9.12	4.067	0.010
Hearing threshold at 500 Hz	28.33 $\pm$ 20.33	19.09 $\pm$ 15.17	17.67 $\pm$ 15.34	17.05 $\pm$ 10.43	2.634	0.055
Hearing threshold at 1,000 Hz	38.33 $\pm$ 24.22	27.73 $\pm$ 19.19	25.33 $\pm$ 21.25	18.41 $\pm$ 13.49	4.133	0.009
Speech audiometry						
SDT	45.42 $\pm$ 18.29	40.00 $\pm$ 17.24	38.33 $\pm$ 18.48	30.26 $\pm$ 10.07	3.047	0.034
65 dB SPL	55.63 $\pm$ 38.46	61.25 $\pm$ 36.41	71.33 $\pm$ 28.69	83.95 $\pm$ 19.19	3.031	0.035
70 dB SPL	64.17 $\pm$ 37.20	68.25 $\pm$ 33.57	77.67 $\pm$ 27.7	89.21 $\pm$ 18.20	2.672	0.054
75 dB SPL	69.17 $\pm$ 36.32	73.50 $\pm$ 26.81	79.67 $\pm$ 28.19	91.32 $\pm$ 15.97	2.347	0.080
Interaural difference 25 dB SPL	7.04 $\pm$ 10.63	–0.23 $\pm$ 5.17	1.67 $\pm$ 9.94	7.96 $\pm$ 10.20	4.056	0.010
Interaural difference 30 dB SPL	12.69 $\pm$ 22.11	–0.68 $\pm$ 10.27	2.67 $\pm$ 20.34	13.41 $\pm$ 17.42	3.344	0.023
Interaural difference 35 dB SPL	22.22 $\pm$ 28.31	4.43 $\pm$ 20.40	19.33 $\pm$ 30.79	20.34 $\pm$ 19.08	2.453	0.069
ABR						
III–V interval	2.09 $\pm$ 0.44	1.88 $\pm$ 0.15	1.74 $\pm$ 0.24	2.22 $\pm$ 0.49	4.701	0.005
Wave V amplitude	0.23 $\pm$ 0.09	0.30 $\pm$ 0.10	0.23 $\pm$ 0.10	0.22 $\pm$ 0.10	3.129	0.030
Interaural difference of III–V intervals	0.34 $\pm$ 0.41	0.12 $\pm$ 0.08	0.33 $\pm$ 0.30	0.41 $\pm$ 0.37	2.618	0.059
Impedance audiometry						
Reflex normality for 500 Hz in the operated ear	0.30 $\pm$ 0.47	0.71 $\pm$ 0.46	0.67 $\pm$ 0.49	0.76 $\pm$ 0.44	4.313	0.008
Reflex normality for 1,000 Hz in the operated ear	0.22 $\pm$ 0.42	0.52 $\pm$ 0.51	0.5 $\pm$ 0.52	0.71 $\pm$ 0.47	3.643	0.017
Reflex normality for 2,000 Hz in the operated ear	0.09 $\pm$ 0.29	0.33 $\pm$ 0.48	0.33 $\pm$ 0.49	0.53 $\pm$ 0.51	3.392	0.023

increased with a more marked interaural diversity for intensities above 50 dB SPL. The same tendency occurred for the interaural difference of SDS parameters. Therefore, patients who had better preoperative speech discrimination in the operated ear compared to the non-operated ear experienced more marked surgery-related hearing loss.

One-way ANOVA was used to determine if there was a correlation between the indexes of the speech audiometry test and surgery-related hearing loss with the division into 4 groups (Table 5). Significant differences were only obtained for the SDT ($p < 0.05$) in the operated ear.

A detailed SDT analysis showed that the only diversity was observed between groups of patients with the lowest and the most marked surgery-related hearing loss. The highest results were obtained in the group with the lowest hearing loss and the mean SDT value in this group was 45 dB SPL. Patients who lost over 40 dB HL of PTA had had the mean preoperative SDT value of 30 dB SPL. We also observed a trend showing that SDT values decreased with increased surgery-related hearing loss (Table 6).

The analysis of speech discrimination percentage for individual speech intensities showed significant differences

in regard to surgery-related hearing loss observed for the 55 dB to 75 dB SPL band, which includes the key intensity for interpersonal communication and 60 dB SPL band, which is typical for conversation (depending on the source: 55–65 dB SPL).

The analysis of interaural difference of speech discrimination for individual intensities confirmed the presence of differences in interaural difference of speech discrimination only for the intensities from 25 dB to 35 dB SPL. A thorough post hoc analysis with S-N-K test showed that patients with surgery-related hearing loss from 10.01 dB to 40.00 dB HL achieved considerably lower results of the analyzed indexes than the remaining groups (Table 6). The only exception in the case of interaural difference in speech discrimination for 35 dB SPL was noted in patients with the difference in pure-tone audiometry of 10.01–20.00 dB HL. The remaining differences revealed no statistical significance. The analysis proved that the patients more commonly experienced moderate surgery-related hearing loss (10–40 dB HL of PTA) if their speech discrimination on the side of the tumor was better and similar to speech discrimination on the non-operated side for the intensities of 25–35 dB SPL.

No intergroup differences were observed in case of the remaining parameters.

Auditory brainstem response testing

Pearson's r correlation analysis demonstrated an increasing surgery-related hearing loss in the operated ear along with the growing deviation of I–V and III–V intervals from the norm, regardless of the PTA index investigated. It was also demonstrated that the presence of wave V in the operated ear in ABR waveform morphology correlated with lower surgery-related hearing loss. Moreover, the analyses revealed that the hearing loss resulting from the surgery was more marked if the I–V interval presented higher values in the operated ear. Additionally, a negative correlation was observed between surgery-related hearing loss and the presence of wave V. Therefore, patients whose waveform morphology lacked wave V experienced a more marked surgery-related hearing loss. The remaining correlations revealed no statistical significance.

One-way ANOVA between ABR parameters and surgery-related hearing loss in the 4 groups demonstrated significant differences for the value of III–V interval ($p < 0.01$). A detailed post hoc analysis with S-N-K test showed that patients with the most abundant hearing loss (≥ 40.01 dB HL) achieved considerably higher values of III–V interval before the surgery than patients with a surgery-related PTA reduction ranging from 10.01 dB to 40.00 dB HL. The lowest values of III–V interval were achieved if PTA reduction ranged from 20.01 dB to 40.00 dB HL. No difference was observed between patients with the lowest and the most abundant surgery-related hearing loss. The resultant relationship is presented in Table 6. A significant difference was also found as regards the value of wave V amplitude

($p < 0.05$). S-N-K test analysis revealed that the subjects with a pre- vs postoperative difference between PTA ranging from 10.01 dB to 20.00 dB HL had markedly higher values of preoperative wave V amplitude compared to the remaining groups ($p = 0.050$). The remaining differences revealed no statistical significance. Differences at the level of statistical tendency ($p = 0.059$) were obtained for the interaural difference of III–V intervals. A detailed post hoc analysis with S-N-K test revealed that the patients with a pre- vs postoperative difference between PTA ranging from 10.01 dB to 20.00 dB HL had markedly lower values of interaural difference of III–V intervals compared to the remaining subjects.

The χ^2 test in cross tabulations also indicated a significant relationship in the assessment of normal values of III–V interval in the operated ear ($\chi^2 = 9.06$; $p < 0.05$). A thorough analysis of column comparisons with Bonferroni correction showed that III–V interval was more commonly normal in the group with surgery-related hearing loss ranging from 10.01 dB to 40.00 dB HL compared to the subjects with surgery-related hearing loss below 10 dB HL or over 40 dB HL. The remaining ABR parameters revealed no statistical significance.

Impedance audiometry

One-way ANOVA demonstrated significant differences for a parameter predefined as normal stapedial reflex at 500 Hz on the operated side ($p < 0.01$). A detailed S-N-K analysis showed that the subjects with surgery-related hearing loss lower than 10 dB HL significantly more often had an abnormal ipsilateral stapedial reflex at the frequency of 500 Hz in the operated ear compared to the remaining groups of patients (Table 6).

Moreover, significant differences were observed for the normality of ipsilateral stapedial reflex at 1,000 Hz and 2,000 Hz on the operated side ($p < 0.05$). S-N-K test analysis revealed significant differences between groups with the lowest and the most severe surgery-related hearing loss. Normal stapedial reflexes were observed in the group with surgery-related hearing loss of over 40 dB HL. The differences between the remaining groups revealed no statistical significance.

Significant differences at the statistical trend level were obtained for the index of stapedial reflex at the frequency of 4,000 Hz for the contralateral non-operated ear ($p = 0.085$). The obtained results indicate the presence of a negative correlation – the value of the parameter decreased with the increased surgery-related hearing loss.

The χ^2 analysis in cross tabulations was used to determine if there was any correlation between the normality of stapedial reflex (at the frequencies of 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz) in the operated ear (ipsi) and surgery-related hearing loss. A correlation was confirmed for reflex normality at 500 Hz ($\chi^2 = 11.53$; $p < 0.01$). A thorough analysis of column comparisons with Bonferroni

correction showed a significantly lower percentage of reflex normality at 500 Hz in the operated ear in the group with the lowest surgery-related hearing loss in comparison to the remaining groups. The analysis also confirmed a correlation for reflex normality at the frequency of 1,000 Hz ($\chi^2 = 9.98$; $p < 0.05$) and 2,000 Hz ($\chi^2 = 9.38$; $p < 0.05$). A thorough analysis of column comparisons with Bonferroni correction showed a significantly lower percentage of reflex normality at 1,000 Hz in the group with the lowest surgery-related hearing loss in comparison with the remaining groups (except the group in which pure-tone audiometry revealed differences between 20.01 dB and 40.00 dB). However, no correlation was found for reflex normality at 4,000 Hz ($\chi^2 = 3.11$; $p < 0.05$). It is worth emphasizing that the results obtained match the trend observed for reflex normality at 500 Hz, 1,000 Hz and 2,000 Hz. Pearson's r correlation analysis confirmed a correlation between the indexes of impedance audiometry and surgery-related hearing loss (pre- and postoperative differences between PTA). The analysis revealed an increase in absolute surgery-related hearing loss with the increasing reflex normality at 500 Hz, 1,000 Hz and 2,000 Hz. Moreover, surgery-related hearing loss became more marked with the reduction in the values of preoperative parameters of impedance audiometry, such as ipsilateral sound intensity for the stapedial reflex in the operated ear at the frequency of 2,000 Hz, and contralateral sound intensity for stapedial reflex in the non-operated ear at the frequencies of 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz. The remaining correlations revealed no statistical significance.

Discussion

The present study analyzes the problem of hearing preservation after VS removal at a slightly different angle than available professional literature concerning this topic. In principle, previous studies classified patients according to various scales to assess the initial hearing status on a 3- to 5-grade scale according to which it was stated whether the hearing status improved, deteriorated or remained at the same level.^{1,4–14}

The present study concentrates on the assessment of absolute hearing loss in order to identify the factors which influence the absolute value of “lost decibels” in pure-tone audiometry, and, what follows, the factors which determine the preservation or loss of initial hearing status irrespective of the preoperative status. The problem of “hearing preservation” was specifically approached in this study – to preserve hearing as similar as possible to the preoperative status. The study did not exclusively concern the issue of serviceable hearing criteria which may differ to a large extent depending on an implemented scale. Dugar et al. and Lassaletta et al. observed that the preservation of serviceable hearing may range from 0% to 56% depending on the selected scale.^{15,16}

It is worth emphasizing that no scales were used to calculate the results in this study. Surgery-related hearing loss was reviewed objectively, exclusively on the basis of study group analysis. At the same time, our intention was not to use the described techniques of determining serviceable hearing and not to use scales (largely based on speech audiometry) for the main calculations. Nonetheless, a certain amount of data concerning not only hearing sounds but also sound perception as speech are not available. However, the aim of this study was not to repeat available studies, but to focus on a new approach to the topic.

To the best of our knowledge, detailed analyses concerning the possible prognostic audiologic factors of hearing preservation in patients with VS have not been published so far.

Pure-tone audiometry

The present study demonstrated that surgery-related hearing loss is influenced by BIAP hearing impairment degree determined before the surgery.³ The lowest degree of surgery-related hearing loss, below 10 dB HL of PTA, was obtained considerably more frequently in patients who had been preoperatively diagnosed with moderate or severe hearing impairment. Additionally, it was demonstrated that the most marked surgery-related hearing loss was observed in patients with previously normal hearing status.

Ferber-Viart et al. assessed the prognostic value of selected parameters of pure-tone audiometry for hearing preservation in patients operated on due to VS.¹⁷ Hearing preservation was defined by the maintenance of AAO-HNS hearing status grade A, B or C. The assessment covered the hearing thresholds for individual frequencies: 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, and 8,000 Hz, and PTA for the following frequencies: 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz. Statistical significance was confirmed for hearing threshold values at 250 Hz, 4,000 Hz and 8,000 Hz, and PTA. The authors stated that the possibility of hearing preservation significantly decreased above the value of 50 dB HL PTA. According to Rohit et al., preoperative PTA markedly contributes to surgery-related hearing loss.¹⁸ However, the value of postoperative PTA negatively correlated with the size of the tumor. Similar correlations were not confirmed by a study by Slattery et al.¹⁹ and Brackmann et al.,²⁰ as well as the results of the present analyses. Rastogi et al. analyzed the influence of preoperative hearing thresholds at 4,000 Hz and 8,000 Hz on surgery-related hearing status in patients operated on due to VS.²¹ However, no statistically significant correlations were demonstrated.

Speech audiometry

The present study revealed a trend showing that preoperative SDT values decreased with increased surgery-related hearing loss. Based on statistical analyses, patients with SDT ≥ 45 dB SPL are expected to lose ≤ 10 dB HL of PTA as a result of the surgery, while patients with SDT ≤ 30 dB

SPL are at risk of the most marked surgery-related hearing loss (loss of >40 dB HL of PTA). The analysis of the influence of speech discrimination for individual intensities on surgery-related hearing loss, both with and without the division into 4 groups, showed that surgery-related hearing loss increased with the percentage of speech discrimination for individual intensities. Moreover, correlation analysis demonstrated that surgery-related hearing loss significantly increased with the growing percentage of speech discrimination for the intensities of 45 dB SPL and above. Significant differences concerning surgery-related hearing loss in the specified 4 groups were observed for speech discrimination for the 55 dB to 75 dB SPL band, which includes the key intensity band for interpersonal communication typical for conversation (55–65 dB SPL). The present study results may indicate that the surgery affects those parameters of hearing which appear to be critical for interpersonal communication and a similar physical nerve fiber destruction is responsible for a disproportionately large reduction in perception. The issue requires confirmation in further research because of the lack of other publications in this field.

The analysis of interaural differences in speech discrimination for individual intensities and surgery-related hearing loss without the division into 4 groups showed that surgery-related hearing loss became more marked with increasing interaural diversity for intensities above 50 dB SPL. The division into 4 groups additionally showed that the better the speech audiometry result in the operated ear for the intensities of 25–35 dB SPL, the more frequently the patients experienced moderate surgery-related hearing loss (10–40 dB HL PTA).

Therefore, the analyses of speech audiometry results showed that patients who had had better preoperative speech discrimination in the operated ear vs non-operated ear experienced more marked surgery-related hearing loss. The review of the professional literature revealed that speech audiometry parameters including speech detection threshold (SDT), speech reception threshold (SRT) and speech discrimination score (SDS) were most commonly assessed in terms of their influence on hearing loss. According to some previous research, mean preoperative SDS was estimated at 66–96%.^{8,9,18,22,23}

Shelton et al.⁸ stated that SDT and SDS did not affect hearing status postoperatively, while 10 years later a similar study conducted by Ferber-Viart et al.¹⁷ revealed a significant influence of SDT on hearing preservation postoperatively. Moreover, it was stated that 45 dB SPL was the SDT level above which patients experienced a marked surgery-related deterioration of hearing. The present study also indicated no influence of SDS on postoperative hearing status. Rohit et al. also found no correlation between SDS and surgery-related hearing loss.¹⁸ Rastogi et al. conducted a study including 44 VS patients which demonstrated no influence of SRT or SDS on postoperative hearing status²¹.

Auditory brainstem response testing

The present analyses which did not comprise the division into groups demonstrated increasing surgery-related hearing loss in the operated ear along with a growing deviation of I–V and III–V intervals from the reference values, regardless of the PTA parameter investigated. Moreover, the analyses revealed that the hearing loss resulting from the surgery was more marked if the I–V interval presented higher values in the operated ear (according to BIAP³).

Additionally, a negative correlation was observed between surgery-related hearing loss and the presence of wave V. Therefore, patients whose waveform morphology lacked wave V experienced a more marked surgery-related hearing loss. Additionally, the analysis of surgery-related hearing loss including the division into 4 groups showed that patients in whom hearing loss was the most marked (≥ 40.01 dB HL) achieved considerably higher values of III–V interval before the surgery. It was also demonstrated that the subjects with a pre- vs postoperative difference between PTA ranging from 10.01 dB to 20.00 dB HL achieved markedly higher values of preoperative wave V amplitude compared to the remaining groups.

The analysis of the normality of selected ABR parameters in terms of reference values according to Hall et al. in 4 selected groups demonstrated that III–V interval was more commonly normal compared to subjects whose surgery-related hearing loss was below 10 dB HL or above 40 dB HL.² This may indicate that patients with the abnormal value of III–V interval had poorer conduction of bioelectric arousal, and what follows, poorer hearing. Therefore, surgery-related hearing loss was not as marked. However, this requires further study due to the fact that hearing loss is the most marked in such patients. It was demonstrated that surgery-related hearing loss was not affected by the normality of parameters like I and V latency for the operated and non-operated ear, I–III intervals for the operated and non-operated ear, I–V intervals for the operated and non-operated ear, interaural latency difference for wave V, and the amplitude ratio of waves I and V for the operated and non-operated ear.

Additionally, cluster analysis demonstrated that surgery-related hearing loss most commonly ranged between 10.01 dB and 40.00 dB HL in patients with normal ABR parameters according to Hall's reference values,² while patients whose ABR parameters were abnormal most commonly lost over 40 dB HL. This was consistent with the tendency identified in the present study which was observed in all audiologic tests and indicated that the absolute surgery-related hearing loss was more marked if the preoperative hearing status was better.

Ferber-Viart et al. analyzed ABR recordings in terms of their prognostic value for the postoperative hearing status in order to assess the presence of waves I, III and V, their latency and the duration of I–V interval.¹⁷ The study demonstrated that wave III was present in waveform morphology

and wave V latency was over 6.5 ms in a group with preserved postoperative hearing, which was defined by the authors as the preservation of hearing at the level of AAO-HNS class A, B or C.¹ Matthies and Samii analyzed 420 preoperative ABRs and proved that the presence of waves I, III and V in waveform morphology correlated with a higher SDS in postoperative speech audiometry.²⁴ Shelton et al. confirmed a negative correlation of postoperative SDS with abnormal interaural latency difference for wave V.⁸ Patients with a value of interaural latency difference for wave V not exceeding 0.4 ms preserved hearing at a rate of 78% (according to the authors' own classification). In the case of values ranging from 0.5 ms to 2 ms, the percentage of patients with preserved hearing decreased to 58%.

Browning et al. conducted a study on a group of 36 patients operated on with a hearing preservation technique.²⁵ They demonstrated a correlation between preserved intraoperative ABR waveform morphology and a slight loss in postoperative PTA. However, the correlation revealed no statistical significance. Auditory brainstem response waveform morphology as a factor contributing to hearing loss was undermined by a study conducted by Kanzaki et al., who analyzed the recordings of 27 patients who had undergone hearing preservation surgery.²⁶ They demonstrated a correlation between the presence of wave V and the interaural latency difference for wave V vs postoperative hearing preservation, but the factors were not statistically significant.

A study including 71 patients was conducted by Dornhoffer et al., who demonstrated a statistically significant correlation between wave V latency and low surgery-related hearing loss.²³ The patients with results not exceeding 6.8 ms had significantly better hearing after the surgery. However, interaural latency difference for wave V appeared to have no influence on postoperative hearing status.

A study including 104 patients conducted by Rohit et al. showed no statistically significant difference in regard to ABR waveform morphology, I–V interval and interaural latency difference for wave V between a group with preserved hearing and a group with surgery-related hearing loss.¹⁸ Vincent et al. conducted a study in which they assessed hearing after VS removal in 77 patients.²⁷ They demonstrated that prolonged wave V latency in preoperative ABR recording is linked to a poorer prognosis regarding hearing status. Gardener et al. emphasized that even the preoperative lack of ABR data was not a factor which negatively correlated with postoperative hearing preservation.¹⁰ However, the study was conducted on a small sample size (9 subjects). Therefore, it requires a confirmation by research covering a larger population.

Impedance audiometry

The analysis of the normality of the stapedial reflex conducted in the present study, with the study group divided into patients with a normal and pathological reflex,

demonstrated a trend which indicates that normal stapedial reflex was correlated with more marked hearing loss and a pathological reflex – with a less marked hearing loss. This was probably due to the initial hearing status on the side of the tumor and remained consistent with a tendency demonstrated in the present paper indicating that more marked absolute surgery-related hearing loss was observed in patients with better preoperative hearing status.

Berrettini et al. analyzed a pathological reflex as abnormal reflex, the lack of stapedial reflex and a positive Metz test result in patients with VS only at 1 frequency of 1,000 Hz.²⁸ Abnormal reflex was found in 59.5% of patients, which is consistent with the present study group (53%) and confirms a proper selection of patients for further analyses.

This study shows that the subjects with surgery-related hearing loss lower than 10 dB HL significantly more often had an abnormal ipsilateral stapedial reflex at the frequency of 500 Hz in the operated ear compared to the remaining groups of patients. Regarding the frequency of 1,000 Hz, it was demonstrated that the patients with a normal stapedial reflex significantly more commonly experienced major hearing loss (over 40 dB HL of PTA). Analogous results were also obtained for the frequency of 2,000 Hz.

A significant correlation was observed between surgery-related hearing loss and intensity value for the contralateral stapedial reflex at the frequency of 2,000 Hz for the non-operated ear. Considerably lower intensities were obtained in the group where the absolute hearing loss was the most marked (PTA over 40 dB HL), and the highest intensities were obtained in the group where surgery-related hearing loss was the least marked (PTA below 10 dB HL).

Moreover, surgery-related hearing loss increased with a reduction in the values of some preoperative parameters of impedance audiometry. This also indicates that a higher risk of marked absolute hearing loss did not only correlate with better hearing status.

To the best of our knowledge, no professional literature is available which would cover the topic of possible prognostic factors of hearing preservation regarding impedance audiometry.

Conclusions

Univariate analyses of audiologic results, such as pure-tone audiometry, speech audiometry, ABR test, and impedance audiometry coherently demonstrated that the better the preoperative hearing, the more substantial surgery-related hearing loss was observed.

The following preoperative audiologic parameters were demonstrated to have a prognostic value for the extent of surgery-related hearing loss in patients with vestibular schwannoma (Table 7): 1. pure-tone audiometry parameters such as: hearing threshold at 125 Hz, 500 Hz, 1,000 Hz,

Table 7. Statistically significant ($p < 0.5$) parameters influencing the extent of hearing loss following VS removal

Parameter
Pure-tone audiometry
hearing threshold at 125 Hz
hearing threshold at 250 Hz
hearing threshold at 500 Hz
hearing threshold at 1,000 Hz
Pure Tone Average – PTA
Hearing capacity
Hearing impairment according to BIAP
Speech audiometry
SDT
SRT
Did the patient achieve 100% of speech discrimination?
55 dB SPL
60 dB SPL
65 dB SPL
70 dB SPL
75 dB SPL
interaural difference 25 dB SPL
interaural difference 30 dB SPL
interaural difference 35 dB SPL
Auditory brainstem response testing
the presence of wave V
the value of I–V interval
deviation from the reference values of I–V interval
deviation from the reference values of III–V interval
normality of the amplitude ratio of waves V and I against reference values
Impedance audiometry
Ipsi 2,000 Hz for the operated ear
Contra 500 Hz for the non-operated ear
Contra 1,000 Hz for the non-operated ear
Contra 2,000 Hz for the non-operated ear
Contra 4,000 Hz for the non-operated ear
reflex normality for 500 Hz in the operated ear
reflex normality for 1,000 Hz in the operated ear
reflex normality for 2,000 Hz in the operated ear

and PTA for the affected ear; 2. speech audiometry parameters such as: speech discrimination between 55 Hz and 75 dB SPL, SDT for the affected ear, interaural difference in speech discrimination between 25 dB and 35 dB SPL; 3. speech audiometry showed that the surgery mostly affects those parameters of hearing which appear to be critical for interpersonal communication (speech intensity of 60 dB SPL) and a similar physical nerve fiber destruction is responsible for a disproportionately large reduction in perception compared to the perception of a different range of speech intensity; 4. auditory brainstem response test parameters such as: the presence of V wave, the values of I–V and III–V intervals and the amplitude of wave V; 5. impedance audiometry with parameters such as intensity level for obtaining stapedial reflex or an abnormal reflex at Ipsi 500 Hz, 1,000 Hz and 2,000 Hz, and Contra 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz.

References

1. AAO-HNS. Committee on Hearing and Equilibrium guidelines for the evaluation of hearing preservation in acoustic neuroma (vestibular schwannoma). American Academy of Otolaryngology-Head and Neck Surgery Foundation, INC. *Otolaryngol Head Neck Surg.* 1995; 113(3):179–180. doi:10.1016/S0194-5998(95)70101-X
2. Hall JW III, Mueller HG III, eds. *Audiologists' Desk Reference: Volume I. Diagnostic Audiology Procedures and Practices.* San Diego, CA: Singular Publishing Group; 1997.
3. International Bureau for Audiophonology BIAP. Recommendation 02/1 bis – Audiometric classification of hearing impairments. www.biap.org. <https://www.biap.org/en/recommendations/recommendations/tc-02-classification>. Published October 26, 1996. Updated July 10, 2017. Accessed July 21, 2017.
4. Sanna M, Khrais T, Piccirillo E, Russo A, Augurio A. Hearing preservation surgery in vestibular schwannoma: The hidden truth. *Ann Otol Rhinol Laryngol.* 2004;113(2):156–163.
5. Samii M, Matthies C. Management of 1000 vestibular schwannomas (acoustic neuromas). The facial nerve: Preservation and restitution of function. *Neurosurgery.* 1997;40(4):684–695.
6. Kanzaki J, Tos M, Sanna M, Moffat DA. New and modified reporting systems from the consensus meeting on systems for reporting results in vestibular schwannoma. *Otol Neurotol.* 2003;24(4):642–649.
7. Kanzaki J, Kunihiro T, Inoue Y. Some proposals on reporting systems in acoustic neuroma. In: Kanzaki J, ed. *Acoustic Neuroma: Consensus on Systems for Reporting Results.* Keio University International Symposia for Life Sciences and Medicine. Vol 10. Tokyo–New York: Springer; 2003:107–112.
8. Shelton C, Brackmann DE, House WF, Hitselberger WE. Acoustic tumor surgery: Prognostic factors in hearing conservation. *Arch Otol Head Neck Surg.* 1989;115(10):1213–1216.
9. Hecht CS, Honrubia VF, Wiet RJ, Sims HS. Hearing preservation after acoustic neuroma resection with tumor size used as a clinical prognosticator. *Laryngoscope.* 1997;107(8):1122–1126.
10. Gardner G, Robertson JH. Hearing preservation in unilateral acoustic neuroma surgery. *Ann Otol Rhinol Laryngol.* 1988;97(1):55–66.
11. Koos WT, Day JD, Matula C, Levy DI. Neurotopographic considerations in the microsurgical treatment of small acoustic neurinomas. *J Neurosurg.* 1998;88(3):506–512.
12. Caye-Thomasen P, Dethloff T, Hansen S, Stangerup S-E, Thomsen J. Hearing in patients with intracranial vestibular schwannomas. *Audiol Neurotol.* 2007;12(1):1–12.
13. Kanzaki J, ed. *Acoustic Neuroma: Consensus on Systems for Reporting Results.* Keio University International Symposia for Life Sciences and Medicine. Springer. 2003;10:183–192.
14. Fukushima T. Patient selection and method of evaluation for hearing preservation in acoustic neuroma surgery. In: Kanzaki J, ed. *Acoustic Neuroma: Consensus on Systems for Reporting Results.* Keio University International Symposia for Life Sciences and Medicine. Vol 10. Tokyo–New York: Springer; 2003:101–105.
15. Dugar J, Nikolopoulos TP, O'Donoghue GM. Hearing preservation in acoustic neuroma surgery: The impact of different patient selection criteria. *Laryngoscope.* 2002;112(11):2051–2053.
16. Lassaletta L, Fontes L, Melcon E, Sarria MJ, Gavilan J. Hearing preservation with the retrosigmoid approach for vestibular schwannoma: Myth or reality? *Otolaryngol Head Neck Surg.* 2003;129(4):397–401.
17. Ferber-Viart C, Laoust L, Boulud B, Duclaux R, Dubreuil C. Acuteness of preoperative factors to predict hearing preservation in acoustic neuroma surgery. *Laryngoscope.* 2000;110(1):145–150.
18. Rohit, Piccirillo E, Jain Y, Augurio A, Sanna M. Preoperative predictive factors for hearing preservation in vestibular schwannoma surgery. *Ann Otol Rhinol Laryngol.* 2006;115(1):41–46.
19. Slatery WH III, Brackmann DE, Hitselberger W. Middle fossa approach for hearing preservation with acoustic neuromas. *Otol Neurotol.* 1997; 18(5):596–601.
20. Brackmann DE, Owens RM, Friedman RA, et al. Prognostic factors for hearing preservation in vestibular schwannoma surgery. *Otol Neurotol.* 2000;21(3):417–424.
21. Rastogi P, Cacace AT, Lovely TJ. Factors influencing hearing preservation in acoustic tumor surgery. *Skull Base Surg.* 1995;5(3):137–142.

22. Glasscock ME III, Hays JW, Minor LB, Haynes DS, Carrasco VN. Preservation of hearing in surgery for acoustic neuromas. *J Neurosurg.* 1993;78(6):864–870.
23. Dornhoffer JL, Helms J, Hoehmann DH. Hearing preservation in acoustic tumor surgery: Results and prognostic factors. *Laryngoscope.* 1995;105(2):184–187.
24. Matthies C, Samii M. Management of vestibular schwannomas (acoustic neuromas): The value of neurophysiology for evaluation and prediction of auditory function in 420 cases. *Neurosurgery.* 1997;40(5):919–930.
25. Browning S, Mohr G, Dufour JJ, et al. Hearing preservation in acoustic neuroma surgery. *J Otolaryngol.* 2001;30(5):307–315.
26. Kanzaki J, Ogawa K, Inoue Y, Shiobara R. Hearing preservation surgery in acoustic neuroma patients with normal hearing. *Skull Base Surg.* 1997;7(3):109–113.
27. Vincent C, Bonne N-X, Guérin C, et al. Middle fossa approach for resection of vestibular schwannoma: Impact of cochlear fossa extension and auditory monitoring on hearing preservation. *Otol Neurotol.* 2012;33(5):849–852.
28. Berrettini S, Ravecca F, Sellari-Franceschini S, Bruschini P, Casani A, Padolecchia R. Acoustic neuroma: Correlations between morphology and otoneurological manifestations. *J Neurol Sci.* 1996;144(1):24–33.