Hearing Preservation Outcomes and Prognostic Factors in Acoustic Neuroma Surgery: Predicting Cutoffs

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Objective: To investigate the outcomes of hearing preservation surgery (HPS) for acoustic neuroma and quantify tumor and patient characteristics predictive of hearing preservation after surgery.
Study Design: Retrospective study.
Setting: Tertiary referral center.
Patients: A total of 100 consecutive patients diagnosed with acoustic neuroma from 2000 to 2012.
Intervention: Hearing preservation surgery through microscopic retrosigmoid approach combined with a retrolabyrinthine meatotomy.
Main Outcome Measure: Pre- and postoperative hearing stratified according to the American Academy of Otolaryngology—Head and Neck Surgery (AAO-HNS) and the Tokyo classifications. The most accurate cutoff was identified for each tumor and patients' variable affecting the outcome by calculating the Youden index. A multivariable analysis was undertaken at these cutoffs to identify prognostic factors for hearing preservation.
Results: Preoperative hearing class was preserved after surgery in 31% (AAO-HNS), and 39% (Tokyo classification) of patients. According to the AAO-HNS classification, the tumor size in the cerebello-pontine angle, pure-tone average (PTA), and speech discrimination score cutoffs for predicting good postoperative hearing function were 7 mm, 21 dB, and 90%, respectively. With the Tokyo classification, only the PTA cutoff differed, with 27 dB. On multivariable analysis, tumor size and PTA were independent prognostic factors for postoperative hearing with high model's goodness of fit (area under the curve = 0.784; 95% CI = 0.68–0.88 and area under the curve = 0.813; 95% CI = 0.72–0.90), according to both the hearing classifications.
Conclusions: The estimated cutoffs for tumor size and PTA were independently associated with HPS. These factors should be prospectively investigated before they are adopted as selection criteria for HPS. **Key Words:** Hearing preservation—Lateral skull base—Prognostic factors—Retrosigmoid approach—Vestibular schwannoma.

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The early diagnosis of acoustic neuroma (AN) nowadays makes it important to consider hearing preservation in the management of patients with small tumors. There has accordingly been a shift in the focus of treatment to preserving neurological function (including the facial nerve) and hearing. Observation (O), radiotherapy (RT), and surgery are the main options available for the treatment of AN, with similar outcomes in terms of preserving neurological function, while their effects on hearing function are still a matter of debate (1–3).

Hearing deteriorates in AN due both to the mass effect of the tumor on cranial nerve VIII and to the iatrogenic effect of treatments. Hearing preservation surgery (HPS) aims to achieve full tumor resection while preserving hearing function, and is achievable via labyrinth-sparing surgical corridors (4). One of the most debated issues in HPS is how to restrict the loss of sensorineural components of the cranial nerve VIII to the cochlea (or even avoid this as well). Preoperatively, the function of these sensorineural elements is indirectly assessed by means of hearing tests and by tumor size. In case series in the literature, preoperative hearing and tumor size were empirically found to correlate with HPS outcome (5,6). Despite efforts to establish prognostic factors for good hearing after HPS, there is little quantitative evidence regarding the most appropriate thresholds for these parameters.

The purpose of the present study was therefore to retrospectively analyze hearing outcomes in a cohort of patients who underwent HPS at the same center according to two different hearing classification systems, the American Academy of Otorhinolaryngology—Head

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and Neck Surgery (AAO-HNS) (7), and the Tokyo classification (8). In particular, we aimed to identify the optimal cutoff for preoperative quantitative variables and independent prognostic factors for good hearing preservation in patients treated surgically via a retrosigmoid (RS) approach.

METHODS

Patient Selection and Surgical Approach

A retrospective case-note review was conducted on 100 consecutive patients diagnosed with sporadic AN. All patients were treated surgically at a tertiary referral center—by the same surgeon and using the same surgical technique—between January 2000 and November 2012. Exclusion criteria were a diagnosis of neurofibromatosis type 2, and recurrent tumor after previous surgery or RT.

All patients were treated via a RS approach, completed with a retrolabyrinthine meatotomy to fully expose the fundus of the internal auditory canal (IAC) (4,9). Conversely, the RS approach with an incomplete meatotomy would involve only a partial exposure of the IAC fundus and a blind tumor dissection for several millimeters. Figure 1 shows the surgical corridor of the retrolabyrinthine meatotomy technique. The vertical line, defined meato-labyrinthine line, traces the corridor created by the occipital craniotomy medial enough to bypass the labyrinth, and by the petrous bone removal up to the blue line of the superior semicircular canal.

Intraoperative neuro-monitoring was performed with electromyography on the facial nerve, auditory brainstem response (ABR) and compound nerve action potentials for the cochlear nerve. This retrospective study was conducted in accordance with the principles of the Helsinki Declaration. Written informed consent was obtained from all patients before undergoing any surgery. Data were examined in accordance with National privacy and sensitive data laws, and with the in-house regulations.

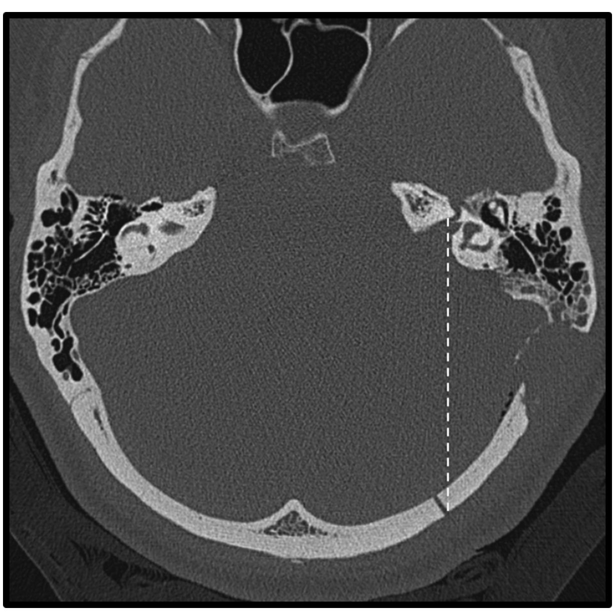

FIG. 1. Axial CT scan, right, showing the meato-labyrinthine line, which traces the surgical corridor of the retro-labyrinthine meatotomy, defined posteriorly by the occipital craniotomy, and anteriorly by the petrous bone removal up to the blue line of the superior semicircular canal and the vestibular aqueduct. CT indicates computed tomography.

Eligibility Criteria for HPS, Clinical Characteristics, and Definition of Outcome

Our eligibility criteria for HPS have evolved over the years, becoming more restrictive in the light of an empirical assessment of our experience (6). In our cohort, 60% of patients met our preset inclusion criteria, i.e., tumor $\leq$10 mm in size in the CPA, with variable intrameatal extension, with or without fundus involvement, pure-tone average (PTA) $\leq$30 dB, speech discrimination score (SDS) $\geq$70%, and presence of ABR. The other patients presented with larger tumors and/or worse hearing function but were strongly motivated to undergo HPS. The diagnosis of AN was established on contrast-enhanced magnetic resonance imaging. Preoperative hearing tests included pure-tone audiometry, speech audiometry, and ABR. Electronystagmography and vestibular function testing were not routinely performed.

Tumor size was measured as the longest diameter in the CPA on axial contrast-enhanced T1-weighted magnetic resonance imaging sequences (8). Patients' audiological profiles were examined on the pure-tone audiogram, considering their PTA, and SDS at an intensity of 40 dB above detection, or at the most comfortable threshold. Hearing was classified according to two systems, the AAO-HNS and the Tokyo classifications (Table 1). The former considers PTA 30 dB and SDS 70% as good hearing, and PTA 50 dB/SDS 50% as serviceable hearing. Additional refinements introduced with the Tokyo classification established that PTA 20 dB/SDS 80% coincides with good hearing. The discrepancy between PTA and SDS due to a better SDS than PTA prompted the upgrading of cases with $\geq$40 PTA to the next (better hearing) class. Our audiological data are presented in the form of pre- and postoperative scattergrams (Fig. 2) (10). Preoperative ABR was divided into four classes: normal (class 1); slight increase in wave III or V latency (class 2); wave III absent, or wave V latency $\geq$7 ms, or I to V interpeak latency $\geq$5.5 ms (class 3); and absent (class 4) (6).

HPS was defined as successful up to postoperative PTA 30 dB and SDS 70%, namely AAO-HNS class A, and Tokyo classes A and B.

Statistical Analysis

Categorical variables were expressed as frequencies and percentages, and quantitative variables as means $\pm$ standard deviations, or medians and interquartile ranges (IQR), as appropriate. The *dependent* variable used in the analysis was surgical failure, defined as the postoperative loss of the preoperative hearing class according to the AAO-HNS classification, and a postoperative class C in patients preoperatively in classes A or B, or a drop of at least one class for patients preoperatively in classes C or D according to the Tokyo classification.

The value of preoperative continuous variables (tumor size, PTA, and SDS) in predicting hearing preservation after surgery for AN was ascertained using logistic regression. The results are expressed as the odds ratio (OR), the area under the curve for the receiver operating characteristic curve, and the corresponding 95% confidence intervals (95% CI). Hearing preservation—the primary endpoint—was classified according to the AAO-HNS and Tokyo systems, as previously explained. The most accurate cutoff was identified for each preoperative variable by calculating the Youden index, defined as $J = \text{sensitivity} - \text{specificity} + 1$ (range 0–1) (11). Sensitivity and specificity were estimated

TABLE 1. *The AAO-HNS and Tokyo hearing classification systems*

AAO-HNS			Tokyo		
Hearing Class	PTA (dB)	SDS (%)	Hearing Class	PTA (dB)	SDS (%)
A	≤ 30	≥ 70	A	≤ 20	≥ 80
B	>30 and ≤50	≥50	B	21–30	79–70
C	>50	≥50	C	31–40	69–60
D	Any level	< 50	D	41–60	59–50
			E	61–80	49–40
			F	≥ 81	≤ 39

AAO-HNS indicates American Academy of Otolaryngology—Head and Neck Surgery.

together with the 95% CI calculated with the exact binomial method. Positive and negative likelihood ratios were estimated along with the 95% CI using the Simel method (12).

A multivariable analysis was conducted to test the ability of the cutoffs identified to predict hearing preservation after AN surgery using a logistic regression model with backward selection of the variables found statistically significant on univariate analysis. A p value <0.05 was considered statistically significant. The statistical analysis was conducted with SAS 9.4 (SAS Institute Inc., Cary, NC) for Windows.

RESULTS

General Characteristics and Hearing Outcome

Patients' characteristics at diagnosis are presented in Table 2. Intrameatal tumors were found in 11% of cases. Extrameatal tumors (89%) presented with a median diameter of 10 mm in the CPA (IQR = 6–17 mm). The median preoperative PTA was 26 dB (IQR = 17–38 dB) and the median SDS was 100% (IQR = 80–100%). According to the AAO-HNS classification, 24 of 61 patients (39.4%) in class A (good hearing) before surgery retained the same class afterward, while serviceable hearing (classes A and B) was preserved in 44 of 93 patients (47%). Of the 61 patients in preoperative Tokyo classes A or B, 32 (52.5%) retained the same hearing class A, B or B upgraded (B*) after surgery. Overall, the same preoperative class was maintained in 31% and 39% of cases according to the AAO-HNS and Tokyo classifications, respectively.

The Role of ABR

Preoperative ABR data were available for 57 patients (Table 2). ABR class 3 was seen in 30% of cases, and represented the most common ABR class in our cohort. The statistical prediction model for ABR was conducted on 49 extrameatal tumors, based on the availability of the test. Patients with absent or severely-impaired ABR (class 3 or 4) preoperatively were at significantly higher risk of hearing impairment after HPS than patients with normal or only slightly impaired ABR (Class 1 or 2) before surgery. The ORs for postoperative hearing deterioration according to the AAO-HNS and Tokyo

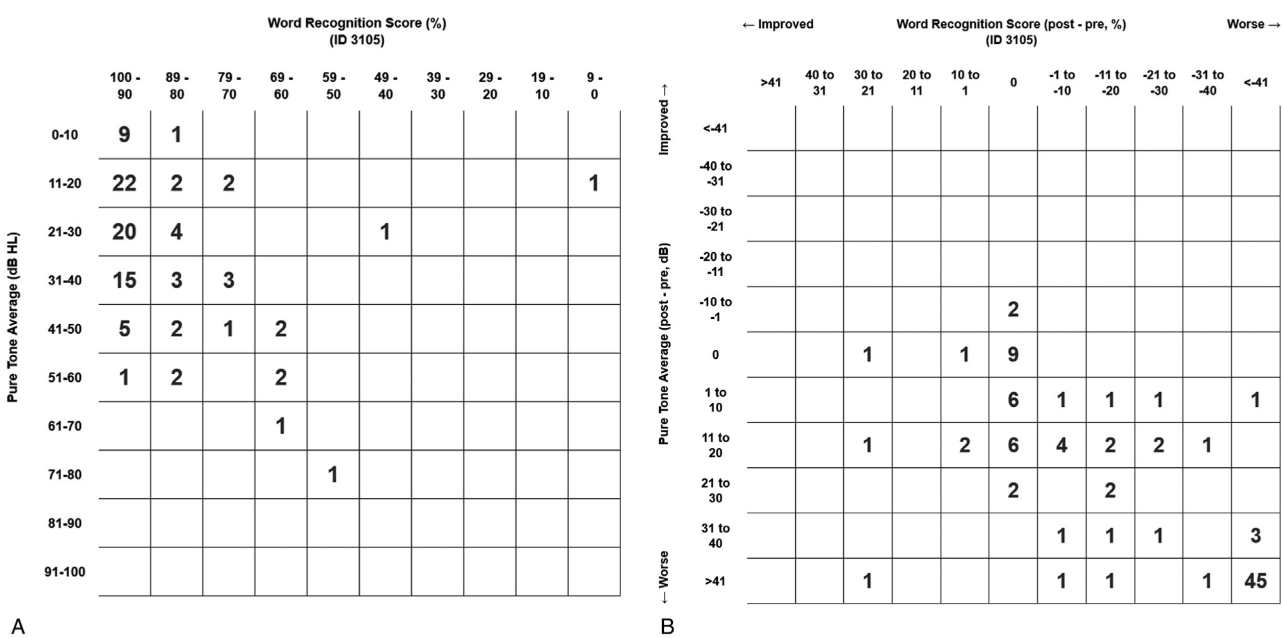

FIG. 2. Preoperative *(A)* and postoperative *(B)* scattergrams showing pure-tone averages and word recognition scores for patients diagnosed with acoustic neuroma.

TABLE 2. *Baseline characteristics of the 100 patients in the study*

Characteristics	Patients, n (%)
Age, y	43.5 ± 11.5[a]
Sex	
Female	51 (51)
Male	49 (49)
Tumor stage	
0	11 (11)
1	19 (19)
2	28 (28)
3	15 (15)
4	12 (12)
5	15 (15)
Tumor size in the CPA, mm	10 [6–17][b]
PTA, dB	26 [17–38][b]
SDS, %	
100	54 (54)
90	19 (19)
80	14 (14)
70	6 (6)
≤60	7 (7)
Auditory brainstem response	
1	8 (14)
2	16 (28)
3	17 (30)
4	16 (28)

[a]Values are expressed as mean ± SD.
[b]Values are expressed as median [interquartile range].
CPA indicates cerebellopontine angle.

classifications were 13.38 ($p = 0.021$; 95% CI = 1.46–122.7) and 8.1 ($p = 0.006$; 95% CI = 1.82–36.10), respectively.

Derivation of the Cutoff for Predicting Hearing Outcome

The analysis to derive this cutoff was performed on 89 patients diagnosed with extrameatal tumors. Receiver operating characteristic analysis of the preoperative parameters was performed separately for the two hearing classifications. For hearing preservation purposes, the optimal cutoff for tumor size in the CPA was 7 mm using the AAO-HNS classification, and the preoperative hearing thresholds predicting good postoperative hearing results were PTA 21 dB and SDS 90%. With the Tokyo classification, the cutoffs were the same for tumor size in the CPA (7 mm) and SDS (90%), while the PTA threshold was 27 dB. The cutoffs, sensitivity and specificity, and positive and negative likelihood ratios are presented in Table 3, while Table 4 shows the hearing preservation rates estimated with these cutoffs for both hearing classifications.

On multivariable analysis tumor size and preoperative PTA were found independently associated with hearing outcome (Table 5). Using the AAO-HNS classification, patients with extrameatal tumors ≥ 7 mm had a six-fold higher risk of their hearing deteriorating after surgery, and those with a preoperative PTA ≥21 dB had a more than six-fold higher risk. Similarly, based again on the Tokyo classification, patients with extrameatal tumors ≥7 mm had a more than eight-fold higher risk of their hearing deteriorating after surgery, and those with a preoperative PTA ≥27 dB had a more than 11-fold increase in this risk.

When the preoperative variables came within the cutoffs for tumor size and PTA, 11 of 14 patients (78.6%) according to the AAO-HNS classification, and 15 of 19 (79%) according to the Tokyo classification retained their preoperative hearing class after surgery (Table 4). Conversely, when tumor size was ≥7 mm in the CPA, and PTA exceeded the proposed cutoff, only 4 of 42 patients (9.5%) according to the AAO-HNS classification, and 3 of 34 (8.8%) according to the Tokyo classification retained their preoperative hearing class.

The model's goodness of fit, calculated as the area under the curve, was 0.784 (95% CI = 0.68–0.88) when the *dependent* variable of outcome was defined according to the AAO-HNS classification, and 0.813 (95% CI = 0.72–0.90) when the Tokyo classification was used (Fig. 3).

DISCUSSION

Over the years, a growing body of evidence has shown that, whatever the treatment option for AN (O, RT, or

TABLE 3. *Cutoffs, sensitivity, specificity, and positive and negative likelihood ratios of patients' preoperative variables for postoperative hearing preservation, based on the two different hearing classification systems*

	Cutoff	AUC (95% CI)	*p*	Sensitivity % (95% CI)	Specificity % (95% CI)	LR+ (95% CI)	LR− (95% CI)
AAO-HNS hearing classification							
Size (mm)	7	0.676 (0.552–0.8)	0.017	83.8 (72.3–91.9)	51.8 (31.9–71.3)	1.742 (1.16–2.615)	0.311 (0.159–0.61)
PTA (dB)	21	0.716 (0.591–0.841)	0.009	74.2 (61.5–84.5)	66.7 (46–83.5)	2.226 (1.28–3.871)	0.387 (0.235–0.638)
SDS (%)	90	0.608 (0.48–0.736)	0.13	75.4 (62.7–85.5)	44.4 (25.5–64.6)	1.357 (0.941–1.958)	0.553 (0.301–1.017)
Tokyo hearing classification							
Size (mm)	7	0.697 (0.582–0.812)	0.005	85.7 (73.7–93.6)	48.4 (30.8–66.4)	1.664 (1.175–2.356)	0.295 (0.142–0.612)
PTA (dB)	27	0.763 (0.656–0.870)	<0.001	67.8 (54–79.7)	78.8 (61–91)	3.199 (1.618–6.326)	0.408 (0.268–0.621)
SDS (%)	90	0.617 (0.496–0.738)	0.079	76.8 (63.6–87.1)	43.7 (26.3–62.3)	1.365 (0.974–1.914)	0.531 (0.286–0.984)

95% CI indicates 95% confidence interval; AUC, area under the curve; LR−, negative likelihood ratio; LR+, positive likelihood ratio; AAO-HNS, American Academy of Otolaryngology—Head and Neck Surgery.

TABLE 4. *Cutoffs applied to patients' preoperative hearing variables*

	AAO-HNS Hearing Classification		Tokyo Hearing Classification	
Preoperative Variable	n	Postoperative Success n (%)	n	Postoperative Success n (%)
Size				
< 7 mm	24	14 (58.3)	24	16 (66.7)
≥ 7 mm	65	13 (20)	65	17 (26.2)
PTA AA				
< 21 dB	34	18 (53)	–	–
≥ 21 dB	55	9 (16.4)	–	–
PTA TK				
< 27 dB	–	–	44	26 (59)
≥ 27 dB	–	–	45	7 (15.6)
SDS				
≥ 90%	63	24 (38)	63	29 (46)
< 90%	26	3 (11.5)	26	4 (15.4)
Tumor size <7 mm + PTA < 21 / 27 dB	14	11 (78.6)	19	15 (79)

PTA AA indicates cutoff for PTA according to the AAO-HNS classification; PTA TK: cutoff for PTA according to the Tokyo classification.

TABLE 5. *Multivariable analysis of patients' baseline preoperative characteristics*

	AAO-HNS Hearing Classification			Tokyo Hearing Classification		
Preoperative Variable	OR	95% CI	*p*	OR	95% CI	*p*
Tumor size ≥ 7 mm	6.38	2.04–19.95	0.001	8.72	2.44–31.16	<0.001
PTA ≥ 21 dB	6.45	2.17–19.13	<0.001	–	–	–
PTA ≥ 27 dB	–	–	–	11.07	3.33–36.77	<0.001

95% CI indicates 95% confidence interval; OR, odds ratio; AAO-HNS, American Academy of Otolaryngology—Head and Neck Surgery.

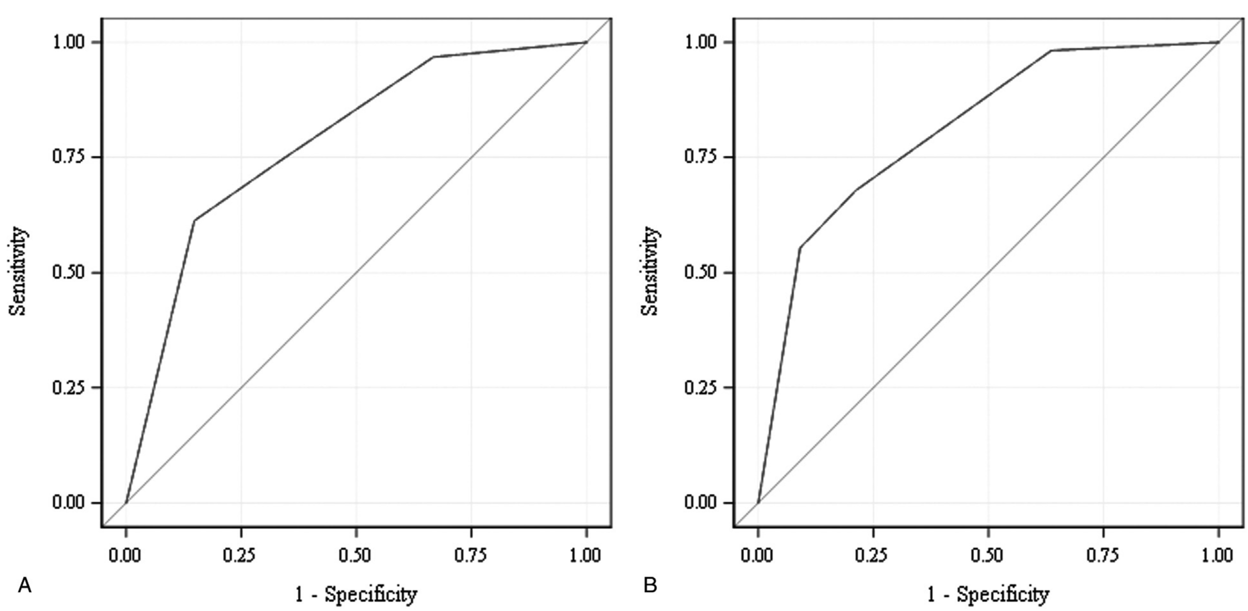

FIG. 3. Model with receiver operating characteristic curve for tumor size and pure-tone averages for predicting hearing preservation after acoustic neuroma surgery via a retrosigmoid approach, according to the AAO-HNS hearing classification *(A)*, and the Tokyo hearing classification *(B)*. AAO-HNS indicates American Academy of Otolaryngology—Head and Neck Surgery.

HPS), hearing outcome is better for patients with small tumors and good hearing at diagnosis (5).

Several factors contribute to the decision whether or not to perform HPS, including tumor size, and patients' preoperative hearing status, age, comorbidities, and preferences. In the setting of HPS, our experience of early surgical AN resection has demonstrated that hearing outcomes are better for patients with favorable preoperative characteristics (so-called *in-protocol* patients) than for those with one or more unfavorable preoperative variables, but very keen to undergo HPS (6). Surgical approaches for hearing preservation include the RS and the middle cranial fossa (MCF) approaches. The former's reported disadvantage of a limited exposure of the fundus of the IAC was overcome in the present cohort by means of a retrolabyrinthine meatotomy technique (4).

Judging from the literature, the rates of preoperative hearing preservation vary considerably after microsurgical AN resection using a RS approach, ranging from 17% to more than 80% in some case series (13,14), due possibly to the different patient selection criteria for HPS adopted by different centers, and the different definitions of hearing function and surgical success.

Potential prognostic indicators for a good hearing outcome after HPS have been extensively investigated over the last three decades (15,16). In a review of the literature concerning 998 patients (17), Sughrue et al. (17) found that tumor size >1.5 mm defined as ''the largest measurable diameter of the tumor including the intrameatal component'' served as an independent prognostic factor for loss of serviceable hearing (OR = 2.81; 95% CI = 1.59–4.95) after removal of the tumor via the MCF or RS approaches. It is a matter of debate if the extrameatal extent of tumor, which is considered representative of the tumor volume (18), is more important than the largest diameter in IAC and CPA as related to HPS. The loss of intraoperative auditory potentials occurred in our experience at dissection on tumor-nerve in the CPA and porus, rather than in the IAC (4), however, no further investigation was undertaken on the topic.

Focusing on the RS approach, several articles have proposed prognostic factors (19–33), with widely variable conclusions (Table 6). In descending order of importance, tumor size, preoperative hearing status, extension in the fundus, tumor origin, preoperative ABR, patient's age, and sex have all been proposed as factors for predicting hearing preservation. Only six articles identified independent prognostic factors using a multivariable statistical analysis, which is more informed than univariate or correlation methods (21,22,25–27,29).

To the best of our knowledge, no studies have estimated optimal cutoffs for the preoperative variables capable of predicting good hearing after AN removal via a RS approach. For a good hearing outcome after using the MCF approach, Kutz et al. (34) established a tumor size threshold of ≤10 mm, defined as ''the maximum length of the tumor along the plane of the internal auditory canal.'' They reported reaching a serviceable hearing rate of 73.3% for tumors below this cutoff, whereas for tumors >10 mm the hearing preservation rate was 25%. A different cutoff was proposed by Han et al. (28), who reported hearing preservation rates of

TABLE 6. *Reported prognostic factors for hearing preservation surgery for acoustic neuroma via a retrosigmoid approach*

Author	Year	No.	Statistical Multivariable Adjustment	Hearing Classification	PTA/SDS	ABR	Size	Fundal Extension	Origin	Age	Sex
Kemink et al.	1990	20	No	n.a.	n.a.	–	+	n.a.	n.a.	n.a.	n.a.
Mangham et al.	1992	77	No	n.a.	–	n.a.	+	n.a.	n.a.	n.a.	n.a.
Fischer et al.	1992	99	Yes	Los Angeles	±	–	+	n.a.	n.a.	–	n.a.
Nadol et al.	1992	144	Yes	n.a.	±	–	+	n.a.	n.a.	n.a.	+
Cohen et al.	1993	161	No	n.a.	+	–	+	n.a.	+	–	n.a.
Post et al.	1995	56	No	n.a.	+	–	+	n.a.	n.a.	n.a.	n.a.
Rastogi et al.	1995	30	Yes	n.a.	–	n.a.	–	+[a]	n.a.	n.a.	n.a.
Robinette et al.	1997	104	Yes	n.a.	±	–	+	n.a.	n.a.	n.a.	n.a.
Mohr et al.	2005	128	Yes	Gardner-Robertson	+	n.a.	+	+	n.a.	n.a.	n.a.
Han et al.	2010	18	No	AAO-HNS	n.a.	n.a.	+	n.a.	n.a.	n.a.	n.a.
Tringali et al.	2010	278	Yes	AAO-HNS	n.a.	n.a.	n.a.	+	n.a.	n.a.	n.a.
Di Maio et al.	2011	28	No	AAO-HNS	+	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Rachinger et al.	2011	90	No	AAO-HNS	n.a.	n.a.	n.a.	n.a.	+	n.a.	n.a.
Nguyen et al.	2012	53	No	AAO-HNS	n.a.	n.a.	n.a.	+[b]	n.a.	n.a.	n.a.
Hummel et al.	2016	46	No	Hannover Classification	n.a.	+[c]	n.a.	n.a.	n.a.	n.a.	n.a.
Present study	2019	100	Yes	Tokyo / AAO-HNS	±	+	+	n.a.	n.a.	n.a.	n.a.

[a]Porus acusticus widening.
[b]A more lateral extension of the tumor predicted a better hearing outcome.
[c]The presence or absence of intraoperative ABR after resecting 60% of the tumor.
No., indicates number of patients; n.a., not available; +, prognostic; –, not prognostic.
AAO-HNS indicates American Academy of Otolaryngology—Head and Neck Surgery.

69.2 and 40%, respectively, for tumors smaller and larger than 20 mm. In the present cohort, the 7 mm cutoff for CPA size showed a sensitivity and specificity in predicting the event of 83.8 and 51.8%, respectively. The success rate for tumors measuring <7 mm in the CPA was 58.3 to 66.7% according to the AAO-HNS and Tokyo classifications. The present results are difficult to compare with previous literature reports, mainly due to the differences in the definition of tumor size, the variable presence of tumors extended to the fundus, and the heterogeneous criteria for patient selection across studies.

The contribution of preoperative hearing function to postoperative hearing preservation is debated, and the different classification systems used to report hearing outcomes greatly reduce our ability to compare our findings with those of others. The now most commonly-used AAO-HNS classification was only adopted by the scientific community after 1995. In the present study, hearing results were stratified according to both the AAO-HNS and the Tokyo classifications for two reasons: 1) because the latter seems to give more consideration to voice perception; and 2) because this would enable comparisons with other published studies. The PTA cutoff identified in our cohort was 21 dB according to the AAO-HNS classification, and 27 dB using the Tokyo classification. The 6 dB difference is probably due to the different success rate obtained according to the two classification systems. The possibility of the SDS prompting patient upgrading by one class with the Tokyo system gave rise to a higher success rate within the limits of the 30 dB/70% rule.

It is worth adding a few words on the Youden index, which identifies the best cutoff by optimizing the balance between specificity and sensitivity. In the clinical setting before HPS, striking the right balance between sensitivity and specificity is particularly important. Sensitivity indicates the probability of patients at risk of hearing loss being identified, and thus offered a more conservative treatment, such as wait-and-scan. On the other hand, a high specificity is important to ensure that patients with appropriate preoperative parameters are given the chance of successful HPS.

The predictive role of preoperative PTA varies, depending on what is considered a successful outcome. In fact, when hearing outcome was assessed according to the AAO-HNS classification (Table 3), a PTA $\geq$21 dB was found more likely to identify patients at risk of hearing loss (sensitivity = 74%). On the other hand, a PTA $\geq$27 dB calculated according to the Tokyo classification proved more likely to identify patients with the best chances of retaining their hearing function (specificity = 79%).

Preoperative SDS had no impact as an independent predictor of hearing preservation after HPS. SDS $\geq$90% also revealed a low specificity (Table 3).

The role of preoperative ABR is well known, since their impairment or absence before surgery predicted an 8- to 13-fold higher risk unfavorable hearing outcome afterward. In the literature, the correlation between intraoperative ABR and hearing outcome has also been investigated. The Würzburg group reported a significant correlation between the absence of intraoperative ABR after about 60% of the tumor had been dissected and a poor postoperative hearing function (33).

Finally, the present study confirmed the prognostic role of preoperative tumor characteristics and hearing function using multivariable analysis (Table 5). The combination of extrameatal tumor <7 mm in size and a PTA < 21/27 emerged as the most favorable preoperative conditions for HPS. Results differed, however, depending on the classification used to measure hearing outcome. Applying the AAO-HNS classification, extrameatal tumor size $\geq$7 mm and PTA $\geq$21 dB had the same influence in predicting results after surgery, with OR = 6.38 and 6.45, respectively. Using the Tokyo classification, patients with PTA $\geq$27 dB were at higher risk of a poor hearing outcome after surgery than patients with a tumor $\geq$7 mm inn size, with OR = 11 and 8.72, respectively.

While SDS alone revealed a low predictive power, it is valuable as an indicator of hearing quality. Speech discrimination is the main factor for patients' perceived hearing function. It is part of the currently-used classifications of hearing in the setting of AN, though it cannot be used alone as a parameter for predicting the success of HPS.

The present study has several limitations, including: 1) the small sample size; 2) the retrospective analysis with consequent referral and selection biases; 3) the two-dimensional rather than volumetric measurement of tumor size; 4) the lack of intraoperative details such as tumor-nerve adhesiveness and fundus involvement. On the other hand, the strengths of the study lie in: 1) the homogeneity of the consecutive cohort of patients; 2) the homogeneous criteria used for preoperative patient selection; and 3) the statistical approach to investigate the predictive power of preoperative parameters, that were earlier considered empirically valuable. Once prospectively validated, these findings may be used for a quantitative preoperative assessment of the HPS eligibility.

Are these findings generalizable to acoustic neuroma surgery? The predictive value of tumor size and hearing as obtained with the present statistical method is valuable to any hearing preservation procedure. In particular, we can speculate that the smaller is the tumor, the lower is the associated surgical trauma, whereas patients with good preoperative hearing function, which reflects the presence of functioning auditory cells and fibers, are more likely to withstand the functional loss inflicted by surgical damage, regardless of the specific surgical technique.

In conclusion, our retrospective multivariable analysis of quantitative audiological and tumor parameters identified extrameatal tumor size, preoperative PTA, and ABR as the most important indicators for predicting postoperative hearing function. The estimated PTA cutoffs of <21 dB and < 27 dB (adopting the AAO-HNS and Tokyo classifications, respectively), and an extrameatal tumor size < 7 mm independently predicted a good hearing outcome after surgery. Their combination gave rise to a valid model for predicting postoperative hearing function. Our results should be validated prospectively and confirmed before these prognostic factors can be adopted in the preoperative assessment of a patient's eligibility for HPS.

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