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Long-Term Hearing Preservation After Microsurgical Excision of Vestibular Schwannoma

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Abstract

Objective—To examine long-term hearing outcomes after microsurgical excision of vestibular schwannoma (VS).

Study Design—Retrospective case review.

Setting—Tertiary referral center.

Patients—Forty-nine subjects at a single institution who had undergone microsurgical excision of a VS via middle cranial fossa (MCF) approach between 1994 and 2007 with immediate postoperative (PO) hearing preservation and for whom long-term audiograms were available.

Intervention—Diagnostic.

Main Outcome Measures—Word Recognition Score (WRS) is defined by speech discrimination scores (SDS) greater than 70% (grade I), 50% to 70% (grade II), less than 50% (grade III), and 0% (grade IV).

Results—For subjects with more than 2 years of follow-up, WRS I hearing was present PO in 42 of 49 patients and was preserved at the latest follow-up in 38 (90%) of 42 patients. No subjects fell beyond WRS II. WRS I hearing was maintained in 23 (88%) of 26 patients with more than 5 years of follow-up. Postoperative WRS I to II hearing was maintained in 28 (96%) of 29 patients with more than 5 years of follow-up. The patient who lost significant hearing in the ear operated on had sensorineural hearing loss that paralleled deterioration in her ear that was not operated on.

Conclusion—Most subjects maintain their initial PO SDS after microsurgical VS removal, and therefore, the initial PO WRS is predictive of long-term hearing. Postsurgical changes do not alter the natural rate or pattern of progressive bilateral sensorineural hearing loss in individual subjects.

Keywords

Acoustic neuroma; Hearing preservation; Intracanalicular; Long-term hearing results; Microsurgery; Vestibular schwannoma; Word Recognition Score grading scale

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Vestibular schwannomas (VSs) frequently present with hearing loss and tinnitus. Current technology allows the detection of small VSs. Magnetic resonance imaging (MRI) with gadolinium, especially when coupled with high-definition T2-weighted imaging, detects tumors less than 0.05 cm^3 in size (1). Although some patients still present with a large posterior fossa mass or obstructive hydrocephalus, often the patient is a high-functioning adult with a small tumor and little to no symptoms (2). Although the incidence of VSs diagnosed in the general population is estimated at 13 per 1 million/yr, Schwartz reported in 2006 that the prevalence in Beverly Hills, California, approaches 1 in 20,000, likely because this particular population is more frequently imaged with MRIs (3,4).

The natural history of VSs is slow but steady growth. The majority grow less than 2 mm/yr (5–10); however, tumors may also demonstrate nonlinear growth patterns, including periods of quiescence or erratic growth (5). Patients with asymptomatic presentations frequently have quiescent tumors; however, tumor growth may not parallel hearing deterioration. Patients may progressively lose hearing, even when the tumor appears unchanged on imaging (11–13).

There has been much discussion as to the best therapeutic option for a patient with a small VS and functional hearing. Three options are routinely presented: observation, radiation therapy (RT), or microsurgery. The international trend has been towards more observation and RT and less microsurgery (14–16). These options are popular because of their brief recovery time and efficacy of maintaining both facial nerve and immediate hearing functions.

More long-term outcome data, however, are becoming available. Recent observational data suggest ongoing hearing loss despite minimal or no tumor growth (15). A subset of patients observed will ultimately require intervention, and many will lose functional hearing as a result of “watchful waiting.” Although the local tumor control rate is excellent for RT, studies demonstrate a progressive decline of hearing for months to years after treatment with no plateau (17–19).

Microsurgical treatment of VS has reported initial hearing preservation rates between 50% and 70% (20–28). There are, however, few long-term data on hearing after microsurgery. In 2003, Friedman et al. (29) reviewed long-term hearing results after microsurgery via middle cranial fossa (MCF) approach. This study reported a 70% serviceable hearing rate among 23 patients more than 5 years after surgery. More data, however, are needed to compare long-term hearing results of microsurgery to those after RT or observation. We reported our hearing preservation rates at 1 year on a series of tumors removed using the MCF approach (22). This article reviews the long-term hearing results of this group of individuals.

MATERIALS AND METHODS

Patient Selection

In 2006, we reviewed the outcomes of MCF for the removal of VSs at the University of Iowa (22). We reported preservation of any hearing in 94 of 156 patients who underwent MCF excision from 1993 to 2004. Forty-one patients from this group had audiometric data beyond 2 years of follow-up. In addition, 8 patients who underwent MCF excision of VSs between 2005 and 2007 had more than 2 years of postoperative (PO) audiometric data.

After 2000, all patients had intraoperative ABR and direct nerve monitoring. The surgical technique for MCF has been reviewed in the 2006 paper, as well as in others (20,22,30–32).

The University of Iowa granted institutional review board approval for this study.

Audiometric Testing

The PO baseline hearing was determined at 1 month after surgery, and audiograms were performed at each PO visit. Audiometric testing included pure-tone thresholds, speech reception threshold, and speech discrimination scores (SDS; recorded voice W-22). Pure-tone averages (PTA or 4-tone PTA [PTA4]) were calculated using the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) guidelines for outcomes reporting (500, 1,000, 2,000, and 3,000 Hz pure-tone thresholds) (33).

Data Analysis

Table 1 delineates the 3 grading scales used to report hearing outcomes. The Word Recognition Score (WRS), AAO-HNS guidelines, and the Gardner-Robertson (GR) scale were calculated (22,33,34). For the GR scale, we calculated a 3-tone PTA (PTA3; 500, 1,000, and 2,000 Hz).

"Good" hearing was considered as 70% SDS or higher, and therefore, WRS I, AAO-HNS A, or GR I. A "serviceable" hearing designation was given to patients with 50% SDS or higher and, therefore, WRS grade I to II, AAO-HNS class A–B, or GR grade I to II.

After initial descriptive data analysis, we corrected for bilateral progressive sensorineural hearing loss (SNHL). We set a definition of change in the ear that was not operated on as greater than 10 dB of difference between the preoperative baseline PTA and the PTA at the latest follow-up (ΔPTA). This definition should eliminate test-retest variability and isolate hearing loss due to other causes (e.g., aging), because presbycusis should affect both ears symmetrically. We then subtracted ΔPTA from the surgical ear to arrive at a corrected PTA for those in whom this difference was greater than 10 dB. We used this corrected PTA to reclassify those individuals in the AAO-HNS (designated AAO-HNSc) and GR grading scales.

Statistical Methods

We performed a standard Kaplan-Meier analysis to analyze the time to fall to a "nonserviceable" hearing category from PO WRS I to II and AAO-HNS A–B scores. We used software package R version 2.7 (R Foundation for Statistical Computing, Vienna, Austria) for the analysis and plots.

RESULTS

Demographics

Forty-nine patients were identified with more than 2 years of PO audiometric data (mean, 70.5 mo; range, 25–163 mo). Twenty-nine patients had more than 5 years of follow-up (mean, 85.6 mo; range, 62–163 mo). The mean age of the patient at the time of surgery was 48 years (range, 19–69 yr). Thirty patients were men (61%). Twenty-four tumors were left-sided (48%). Forty-six subjects (96%) exhibited a House-Brackmann 1/6, and 3 subjects were graded 2/6 facial nerve outcome at the last follow-up (35).

Audiometric Results

Table 2 presents the audiometric results for all patients.

The mean preoperative PTA and SDS were 29 ± 13 dB and 88% ± 14%, respectively. The mean PO PTA was 37 ± 12 dB. At the latest follow-up, the mean PTA was 47 ± 9 dB, with a mean difference of 10 ± 10 dB from the PO PTA. The mean PO speech reception threshold (SRT) was 30 ± 11 dB. At the latest follow-up, the mean SRT was 38 ± 12 dB, with a mean difference of 8 ± 10 dB from the PO SRT. The mean PO SDS was 84% ± 17%. This

represents a mean difference of −3% ± 12% from the pooled group's preoperative baseline (Fig. 1). At the latest follow-up, the mean SDS was 84% ± 18%, with a mean difference of 0% ± 13% from the PO SDS.

Corrections for Hearing Changes in the Contralateral Ear

Seven patients experienced deterioration in PTA of 10 to 16 dB in the contralateral ear. The changes of progressive bilateral SNHL were dramatic in Patient 37 (Table 2). Her last audiogram (at 90 mo of follow-up) indicated a 45- and 40-dB increase in the PTA and SRT, respectively, in the contralateral ear. When corrected for these changes, the long-term PTA in the surgical ear is approximately the same as her PO score (90 dB – 45 dB = 45 dB versus a PO PTA of 50 dB). The SRT and SDS, however, were completely lost through this patient's progression to profound SNHL.

In our subjects, the SDS in the ear that was not operated on did not deteriorate as the PTAs did. Two patients had remarkable changes. Patient 4 had a preoperative SDS of 76%, improved to 88% after surgery, and declined again to 68% during 28 months of follow-up (Table 2), so that his final audiogram demonstrated a symmetric, bilateral 68% SDS. Patient 49 had a preoperative SDS of 52% in the contralateral ear, which improved to 92% on his last audiogram to equal the SDS of the ear operated on. If we exclude these unique patients from our study group, the mean change in SDS in the ear that was not operated on was 1%, with a range of −12% to +8%.

WRS Grade

The WRS I hearing was present PO in 42 of 49 patients (Fig. 2A). This was preserved at the latest follow-up in 38 (90%) of 42 patients and declined to a WRS II in 10% (Fig. 2B). None of these patients fell to a nonserviceable hearing category.

Of 5 patients with WRS II hearing PO, 3 had improved to a WRS I at the latest follow-up and 1 remained a WRS II. One dropped to a WRS IV because of progressive bilateral SNHL (Patient 37).

Two patients had WRS III hearing PO. One improved to WRS II, and one stayed a WRS III.

In summary, 96% of subjects had serviceable hearing via the WRS scale at the latest follow-up. Of the remaining 2 patients, one had nonserviceable but testable hearing immediately after surgery without further progression, and the other patient (Patient 37) experienced progressive bilateral SNHL, which rendered her deaf in the ear operated on. The other 47 patients retained serviceable hearing with the majority (88%) retaining good (WRS I) hearing. Figure 3A demonstrates the survival curve for retention of WRS I to II, with Patient 37 excluded.

AAO-HNS Grade

Before surgery, 31 patients (63%) had AAO-HNS A hearing, 15 patients (31%) were AAO-HNS B, 2 patients (4%) were AAO-HNS C, and 1 patient (2%) was an AAO-HNS D.

The AAO-HNS A hearing was present PO in 16 patients (Fig. 4A). This grade was preserved at the latest follow-up in 6 (37.5%) of 16 patients, and 9 declined to AAO-HNS B. Two patients (Patients 47 and 48) fell to a nonserviceable hearing category (AAO-HNS C). When corrected for hearing changes in the contralateral ear, both patients' AAO-HNSc was B (Table 3). Therefore, no patient with postoperative AAO-HNS A developed nonserviceable hearing as a direct result of microsurgery.

Of 27 patients with AAO-HNS B hearing PO, 13 remained an AAO-HNS B at the last follow-up, 11 patients had declined to AAO-HNS C hearing, and 1 patient fell to AAO-HNS D (Patient 37). Of the 11 patients with progression to AAO-HNS C hearing, 9 corrected to an AAO-HNSc B result. Therefore, when correcting for progressive bilateral SNHL, 81% of patients with a PO AAO-HNS B retained serviceable hearing long-term.

Four patients had a PO AAO-HNS C hearing. One improved to an AAO-HNS B (noncorrected), and the others remained an AAO-HNS C. One patient had a PO AAO-HNS D. This improved to AAO-HNS C in the follow-up period (noncorrected).

For patients with more than 5 years of follow-up, AAO-HNS A hearing was maintained in 6 (55%) of 11 patients, and serviceable hearing was maintained in 24 (92%) of 26 subjects when corrected for changes in the ear not operated on. Most of the change in grade is due to the PTA change rather than the word understanding score.

Forty-two subjects had serviceable hearing (AAO-HNS A–B) at the PO measurement. Of these 42 patients, 3 fell to nonserviceable hearing (AAO-HNS C or D) at Months 69, 88, and 148. Figure 3B presents the survival curve. The proportion of patients estimated to retain serviceable hearing is greater than 85% for the first 147 mo PO, after correcting for the contralateral ear. The large drop-off at 148 months is due to the method of construction of the Kaplan-Meier estimator because only 2 patients were measured at more than 148 months. Therefore, the curve will not be very accurate in that period (SE = 0.31).

Gardner-Robertson Scale

The mean PTA3 was 40 dB HL, whereas the mean PTA4 (AAO-HNS) was 44 dB HL. Of 17 patients graded as nonserviceable (AAO-HNS C) by the AAO-HNS scale, 6 (47%) were upgraded to serviceable (GR 2) by using the GR scale. The corrected serviceable long-term hearing rate by the GR scale is 93% (43/46 patients with PO GR I–II).

If the PTA3 is applied toward the AAO-HNS scale, 6 patients rise from an AAO-HNS C to a B, and 1 subject rises from an AAO-HNS B to an A.

DISCUSSION

Application of Grading Systems

The many ways to report hearing results may influence the interpretation of a study on hearing preservation. RT studies frequently use the GR scale. One of the important ways that the GR scale differs from the AAO-HNS is that it uses a PTA3 (500, 1,000, and 2,000 Hz), whereas the AAO-HNS scale uses a PTA4 and includes 3,000 Hz (Table 1). As many of our patients experience an increased threshold at greater than 2,000 Hz, the GR scale yields more favorable long-term hearing results than the AAO-HNS scale. In the current study, 1 in 6 patients had a “better” outcome on the GRS versus their AAO-HNS classification.

Niranjan et al. (36) reported hearing outcomes after gamma knife radiosurgery (GKRS) for intracanalicular VSs. We calculated the mean PTA3 and PTA4, from their data figures, and found them to be 30 and 34 dB, respectively. Adding the 3,000-Hz threshold to their outcomes measure therefore reclassifies their mean patient outcome from an AAO-HNS A to B. This is the difference between a “good” and “serviceable” hearing outcome in most studies.

Here, we report the changes in PTA, but score outcomes by the WRS scale. We assert that this method is more representative of the functional ability of an ear than the GR or AAO-

HNS classification schemes because the WRS emphasizes the most important factor in the determination of serviceable hearing: the SDS. With an SDS greater than 50%, most patients may be rehabilitated with amplification, yet the AAO-HNS scale does not consider a Class C result to be “serviceable” hearing. In addition, the progressive bilateral SNHL observed in many of our longest-term subjects affects the AAO-HNS score by elevating the PTA. The SDS, however, is preserved until quite late in the natural history of SNHL. Therefore, the WRS is less affected by aging and more accurately represents the hearing outcome related to the presence of tumor and the results of intervention rather than the development of presbycusis.

The WRS classification does not recognize a change in PTA that can also affect performance with a hearing aid. One suggestion to incorporate the PTA would be to score the WRS as previously described (I–IV) and recognize the PTA as a subscore (a–d). The main determinate of WRS class (and therefore serviceability) would still the SDS score; however, a letter (a through d) could be added to an individual’s WRS score to signify the range into which their PTA falls. These subscores should align with the current PTA classifications within the AAO-HNS grading scale (i.e., a = PTA <30 dB HL). for example, a patient with an SDS of 90% and a PTA of 55 dB would be designated WRS Ic. This classification scheme would allow the patient to be classified as serviceable but still provides important information about the PTA.

Microsurgery

A patient with preoperative WRS I hearing and a tumor less than 1 cm in length has a 76% chance of initial hearing preservation in our hands after MCF microsurgical excision (22). After several years, 90% of these patients still maintain WRS I hearing, and all of them still have serviceable hearing. A patient presenting, therefore, with WRS I hearing and a small tumor has a 68% chance of enjoying WRS I hearing at more than 5 years after presentation. Our immediate outcomes are comparable with other large series of microsurgical excision via MCF (Table 4).

Friedman et al. (29) reported a 70% serviceable hearing preservation rate 5 years after microsurgical excision, which was calculated by the AAO-HNS scale. They likewise noted a parallel decline in the PTAs of the surgical and contralateral ears; however, their mean change was greater than in our study (23 versus 13 dB). Chee et al. (23) reported an initial 76% hearing preservation rate in patients with tumors less than 2 cm, but a 56% hearing preservation rate after 3 years. It is unclear why their subjects experienced such a delayed drop in hearing. From their data tables, most of their “significantly deteriorated” subjects experienced declines in PTA or SRT, but only half (6/12) of these specific subjects lost significant SDS.

The literature on microsurgery via the retrosigmoid (RS) approach is less compelling, but is difficult to compare to the MCF outcomes because institutions performing both MCF and RS tend to favor the RS approach for larger tumors. Several studies, however, have focused on patients with small tumors and good preoperative hearing and are listed in Table 4.

Observation

Stangerup et al. (15) recently reported the hearing outcomes of patients observed after the diagnosis of a VS less than 2 cm. Overall, 21% required intervention because of tumor growth. For the remaining patients, hearing deterioration was common. Fifty-three percent of patients had a class I WRS score at presentation, and during the observation period (mean, 4.7 yr), 58% had unchanged hearing, 37% experienced deterioration of at least 1 grade, and 5% improved by 1 or more grades.

This study also introduced the WRS 0 class, defined as a SDS of 100% (15). Of patients presenting with WRS 0, only 12% dropped below a WRS I after 5 years of follow-up. These patients had a steady decline of 2% to 4% SDS/yr. This rate of loss was slower than for the patients with any SDS loss at presentation, even if they were still a WRS I/AAO-HNS A. Those patients lost hearing more precipitously, with 26% of these patients losing AAO-HNS A hearing within the first year and 45% losing class A hearing after 5 years.

There are many studies that have followed the natural history of small VSs, but typically their patient populations have advanced age (>60 yr) compared with surgical arms, which may bias the results (7,10,37,38). These studies, however, report similar rates of hearing deterioration, which seem unrelated to age at presentation, growth pattern, or initial size of tumor. They do, however, highlight the early deterioration of hearing similar to the data from Stangerup et al. (15) and Caye-Thomasen et al. (39).

Smouha et al. (7) performed a meta-analysis in 2005. Their pooled data reported a 43% growth rate, 57% rate of quiescence, and a 49% rate of hearing preservation. Of their own 64 patients, 57% kept serviceable hearing.

Walsh et al. (40) reported a series of 25 patients with tumors less than 1.5 cm, which were observed during a mean of 48 months. During this observation period, 7 of 12 patients lost serviceable hearing. The same group released a later study with an observation time of 80 months for longest follow-up (12). They reported a decline in the SDS of patients with IAC tumors from 77% ± 28% to 36.6% ± 35.7% during the observation period. Although it is not possible to extrapolate changes in SDS from first to second report, it seems that these patients continued to lose hearing after the initial study was published.

Radiation Therapy

During the past 20 years, RT treatment plans have evolved to reduce the marginal treatment dose and the radiation dose to the cochlea. Patients treated today have improved hearing outcomes versus their earlier counter-parts, with the rate of hearing preservation significantly better if the cochlear dose and marginal dose are less than 4 and 13 Gy, respectively (19,41).

Lasak et al. (42), using GKRS, found a significant negative correlation between SDS and the cochlear dose. As 42% of their patients had less than 1 year of audiologic data, their article demonstrates that a higher cochlear dose may be responsible for short-term hearing decline in patients after GKRS, in addition to the long-term deterioration reported by others.

Combs et al. (43) reported their results with a fractionated stereotactic protocol. Their protocol uses a higher isodose line (up to 90%) with a 57-Gy mean tumor dose. This method resulted in good (83% at 1 yr) hearing preservation but with a late steady decline (69% at 10 yr) (17).

At Stanford, Sakamoto et al. (44) reported their results with a trifractionated Cyberknife protocol, which delivers 18 to 21 Gy during 3 days with a 70% to 80% isodense line. Their hearing preservation results seem comparable to the fractionated stereotactic radiation, with 74% of subjects maintaining GR I to II at a mean follow-up of 48 months.

Most of the RT literature consider a wide range of tumor sizes. Therefore, there are few relevant RT studies to compare to our patient population. Iwai et al. (45) examined GKRS outcomes limited to intracanalicular tumors. They reported 64% hearing preservation rate, but used a PTA less than 50 dB as their only criteria, and did not report any SDSs.

The University of Pittsburgh examined a series of patients with a VS isolated to the IAC (36). These patients had AAO-HNS A–B or GR I to II hearing before GKRS with a median follow-up of 28 months. Of 40 patients with pretreatment AAO-HNS class A, 42% maintained this class at the latest follow-up. The serviceable hearing preservation rate was 61% for the AAO-HNS scale.

Iowa Vestibular Schwannoma Management Algorithm

In Figure 5, we outline the algorithm that we use for most new patients presenting with an isolated VS.

We still offer MCF microsurgery to patients who present with a WRS below 50%, if they derive benefit from a hearing aid and have a favorably sized tumor (<1.5 cm). As part of preoperative counseling, we discuss the likelihood of progressive HL with observation or RT versus their individual risk of immediate HL with MCF microsurgery (22). As the current study demonstrates, patients may improve by 1 or 2 WRS/AAO-HNS grades after surgery (Patient nos. 10, 27, and 38 in Table 2) (22). Although this scenario is uncommon, it nonetheless represents a real, long-term benefit to surgical excision.

If a patient elects observation, we obtain an MRI with gadolinium and full audiometry at an initial interval of 6 months, then annually until the tumor has been quiescent for 5 years, and then every other year indefinitely. We generally observe a tumor before recommending RT, reserving RT for those with documented growth.

CONCLUSION

In the current study, patients with initial PO hearing preservation retain their hearing long-term with little to no change. Most changes in patient hearing grade are attributable to progressive SNHL in both ears.

Microsurgery is thus the only treatment modality that has been shown to maintain stable hearing long after treatment. In addition, microsurgical excision is a surgical cure for isolated VS and requires no serial imaging observation. Therefore, we counsel young patients with small tumors and serviceable hearing that MCF excision of their tumors is the treatment option most likely to allow long-term retention of their hearing.

REFERENCES

1. Schmalbrock P, Chakeres DW, Monroe JW, Saraswat A, Miles BA, Welling DB. Assessment of internal auditory canal tumors: a comparison of contrast-enhanced T1-weighted and steady-state T2-weighted gradient-echo MR imaging. AJNR Am J Neuroradiol. 1999; 20:1207–1213. [PubMed: 10472973]
2. Stangerup SE, Tos M, Cayé-Thomasen P, Tos T, Klokker M, Thomsen J. Increasing annual incidence of vestibular schwannoma and age at diagnosis. J Laryngol Otol. 2004; 118:622–627. [PubMed: 15453938]
3. Tos M, Stangerup SE, Cayé-Thomasen P, Tos T, Thomsen J. What is the real incidence of vestibular schwannoma? Arch Otolaryngol Head Neck Surg. 2004; 130:216–220. [PubMed: 14967754]
4. Schwartz, MS.; Fisher, LM. Incidence and clinical characteristics of acoustic neuroma in Beverly Hills. In: Garcia-Ibanez, E.; Tran Ba Huy, P., editors. Proceedings of the 5th International Conference on Vestibular Schwannoma and Other CPA Lesions. Bologna, Italy: Medimond; 2007. p. 111-113.
5. Nikolopoulos TP, Fortnum H, O'Donoghue G, Baguley D. Acoustic neuroma growth: a systematic review of the evidence. Otol Neurotol. 2010; 31:478–485. [PubMed: 20147867]

6. Shin YJ, Fraysse B, Cognard C, et al. Effectiveness of conservative management of acoustic neuromas. Am J Otol. 2000; 21:857–862. [PubMed: 11078076]
7. Smouha EE, Yoo M, Mohr K, et al. Conservative management of acoustic neuroma: a meta-analysis and proposed treatment algorithm. Laryngoscope. 2005; 115:450–454. [PubMed: 15744156]
8. Sughrue ME, Yang I, Aranda D. The natural history of untreated sporadic vestibular schwannomas: a comprehensive review of hearing outcomes. J Neurosurg. 2010; 112:163–167. [PubMed: 19538047]
9. Hajioff D, Raut VV, Walsh RM, et al. Conservative management of vestibular schwannomas: third review of a 10-year prospective study. Clin Otolaryngol. 2008; 33:255–259. [PubMed: 18559034]
10. Roehm PC, Gantz BJ. Management of acoustic neuromas in patients 65 years or older. Otol Neurotol. 2007; 28:708–714. [PubMed: 17667776]
11. Tschudi DC, Linder TE, Fisch U. Conservative management of unilateral acoustic neuromas. Am J Otol. 2000; 21:722–728. [PubMed: 10993466]
12. Raut VV, Walsh RM, Bath AP, et al. Conservative management of vestibular schwannomas—second review of a prospective longitudinal study. Clin Otolaryngol. 2004; 29:505–514. [PubMed: 15373864]
13. Roche PH, Soumare O, Thomassin JM, Régis J. The wait and see strategy for intracanalicular vestibular schwannomas. Prog Neurol Surg. 2008; 21:83–88. [PubMed: 18810203]
14. Tan M, Myrie OA, Lin FR, et al. Trends in the management of vestibular schwannomas at Johns Hopkins 1997–2007. Laryngoscope. 2010; 120:144–149. [PubMed: 19877188]
15. Stangerup SE, Tos M, Thomsen J, Cayé-Thomasen P. Hearing outcomes of vestibular schwannoma patients managed with ‘wait and scan’: predictive value of hearing level at diagnosis. J Laryngol Otol. 2010; 19:1–5.
16. Chen DA. Acoustic neuroma in a private neurotology practice: trends in demographics and practice patterns. Laryngoscope. 2007; 117:2003–2012. [PubMed: 17828042]
17. Combs SE, Welzel T, Schulz-Ertner D, Huber PE, Debus J. Differences in clinical results after LINAC-based single-dose radiosurgery versus fractionated stereotactic radiotherapy for patients with vestibular schwannomas. Int J Radiat Oncol Biol Phys. 2010; 76:193–200. [PubMed: 19604653]
18. Chopra R, Kondziolka D, Niranjan A, Lunsford LD, Flickinger JC. Long-term follow-up of acoustic schwannoma radiosurgery with marginal tumor doses of 12 to 13 Gy. Int J Radiat Oncol Biol Phys. 2007; 68:845–851. [PubMed: 17379451]
19. Tamura M, Carron R, Yomo S, et al. Hearing preservation after gamma knife radiosurgery for vestibular schwannomas presenting with high-level hearing. Neurosurgery. 2009; 64:289–296. [PubMed: 19057423]
20. Arts HA, Telian SA, El-Kashlan H, Thompson BG. Hearing preservation and facial nerve outcomes in vestibular schwannoma surgery: results using the middle cranial fossa approach. Otol Neurotol. 2006; 27:234–241. [PubMed: 16436995]
21. Brackmann DE, Owens RM, Friedman RA, et al. Prognostic factors for hearing preservation in vestibular schwannoma surgery. Am J Otol. 2000; 21:417–424. [PubMed: 10821558]
22. Meyer TA, Canty PA, Wilkinson EP, et al. Small acoustic neuromas: surgical outcomes versus observation or radiation. Otol Neurotol. 2006; 27:380–392. [PubMed: 16639278]
23. Chee GH, Nedzelski JM, Rowed D. Acoustic neuroma surgery: the results of long-term hearing preservation. Otol Neurotol. 2003; 24:672–676. [PubMed: 12851563]
24. Gjuric M, Wigand ME, Wolf SR. Enlarged middle fossa vestibular schwannoma surgery: experience with 735 cases. Otol Neurotol. 2001; 22:223–230. [PubMed: 11300274]
25. Holsinger FC, Coker NJ, Jenkins HA. Hearing preservation in conservation surgery for vestibular schwannoma. Am J Otol. 2000; 21:695–700. [PubMed: 10993461]
26. Kumon Y, Sakai S, Kohno K, et al. Selection of surgical approaches for small acoustic neurinomas. Surg Neurol. 2000; 53:52–60. [PubMed: 10697233]
27. Colletti V, Fiorino F. Is the middle fossa approach the treatment of choice for intracanalicular vestibular schwannoma? Otolaryngol Head Neck Surg. 2005; 132:459–466. [PubMed: 15746862]

28. Staecker H, Nadol JB Jr. Ojeman R, et al. Hearing preservation in acoustic neuroma surgery: middle fossa versus retrosigmoid approach. Am J Otol. 2000; 21:399–404. [PubMed: 10821555]
29. Friedman RA, Kesser B, Brackmann DE, et al. Long-term hearing preservation after middle fossa removal of vestibular schwannoma. Otolaryngol Head Neck Surg. 2003; 129:660–665. [PubMed: 14663432]
30. Brackmann DE, House JR III, Hitselberger WE. Technical modifications to the middle fossa craniotomy approach in removal of acoustic neuromas. Am J Otol. 1994; 15:614–619. [PubMed: 8572061]
31. Gantz BJ, Parnes LS, Harker LA, et al. Middle cranial fossa acoustic neuroma excision: results and complications. Ann Otol Rhinol Laryngol. 1986; 95:454–459. [PubMed: 3767216]
32. Weber PC, Gantz BJ. Results and complications from acoustic neuroma excision via middle cranial fossa approach. Am J Otol. 1996; 17:669–675. [PubMed: 8841719]
33. 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; 113:179–180. [PubMed: 7675475]
34. Gardner G, Robertson JH. Hearing preservation in unilateral acoustic neuroma surgery. Ann Otol Rhinol Laryngol. 1988; 97:55–66. [PubMed: 3277525]
35. House JW, Brackmann DE. Facial nerve grading system. Otolaryngol Head Neck Surg. 1985; 93:146–147. [PubMed: 3921901]
36. Niranjan A, Mathieu D, Flickinger JC, Kondziolka D, Lunsford LD. Hearing preservation after intracanalicular vestibular schwannoma radiosurgery. Neurosurgery. 2008; 63:1054–1062. [PubMed: 19057318]
37. Perry BP, Gantz BJ, Rubinstein JT. Acoustic neuromas in the elderly. Otol Neurotol. 2001; 22:389–391. [PubMed: 11347645]
38. Suryanarayanan R, Ramsden RT, Saeed SR, et al. Vestibular schwannoma: role of conservative management. J Laryngol Otol. 2010; 124:251–257. [PubMed: 20003606]
39. Caye-Thomasen P, Dethloff T, Hansen S, Stangerup SE, Thomsen J. Hearing in patients with intracanalicular vestibular schwannomas. Audiol Neurotol. 2007; 12:1–12.
40. Walsh RM, Bath AP, Bance ML, Keller A, Rutka JA. Consequences to hearing during the conservative management of vestibular schwannomas. Laryngoscope. 2000; 110:250–255. [PubMed: 10680925]
41. Yang I, Aranda D, Han SJ, et al. Hearing preservation after stereotactic radiosurgery for vestibular schwannoma: a systematic review. J Clin Neurosci. 2009; 16:742–747. [PubMed: 19303780]
42. Lasak JM, Klish D, Kryzer TC, Hearn C, Gorecki JP, Rine GP. gamma Knife radiosurgery for vestibular schwannoma: early hearing outcomes and evaluation of the cochlear dose. Otol Neurotol. 2008; 29:1179–1186. [PubMed: 18931646]
43. Combs SE, Volk S, Schulz-Ertner D, et al. Management of acoustic neuromas with fractionated stereotactic radiotherapy (FSRT): longterm results in 106 patients treated in a single institution. Int J Radiat Oncol Biol Phys. 2005; 63:75–81. [PubMed: 16111574]
44. Sakamoto GT, Blevins N, Gibbs IC. Cyberknife radiotherapy for vestibular schwannoma. Otolaryngol Clin North Am. 2009; 42:665–675. [PubMed: 19751871]
45. Iwai Y, Yamanaka K, Shiotami M, et al. Radiosurgery for acoustic neuromas: results of low-dose treatment. Neurosurgery. 2003; 53:282–288. [PubMed: 12925242]
46. Pollock BE, Driscoll CL, Foote RL, et al. Patient outcomes after vestibular schwannoma management: a prospective comparison of microsurgical resection and stereotactic radiosurgery. Neurosurgery. 2006; 59:77–85. [PubMed: 16823303]
47. Kaylie DM, Gilbert E, Horgan MA, Delashaw JB, McMenomey SO. Acoustic neuroma surgery outcomes. Otol Neurotol. 2001; 22:686–689. [PubMed: 11568680]

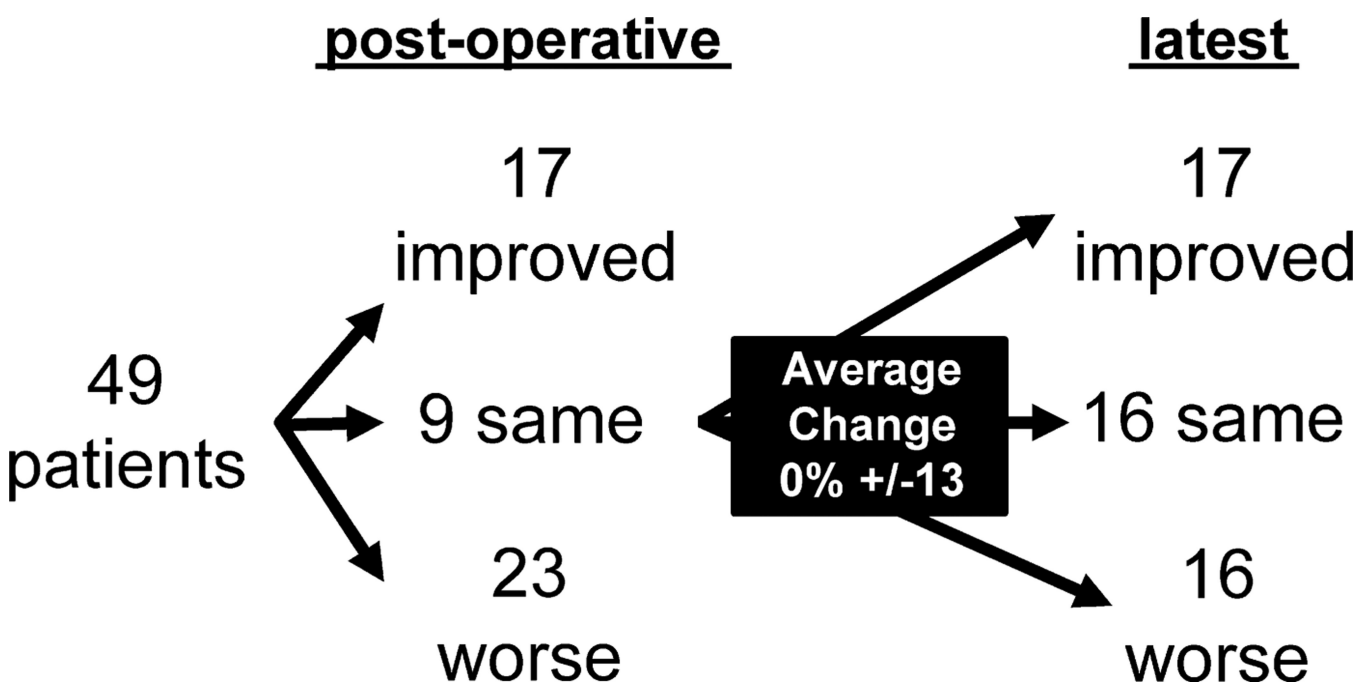

FIG. 1.
Speech discrimination score changes over time.

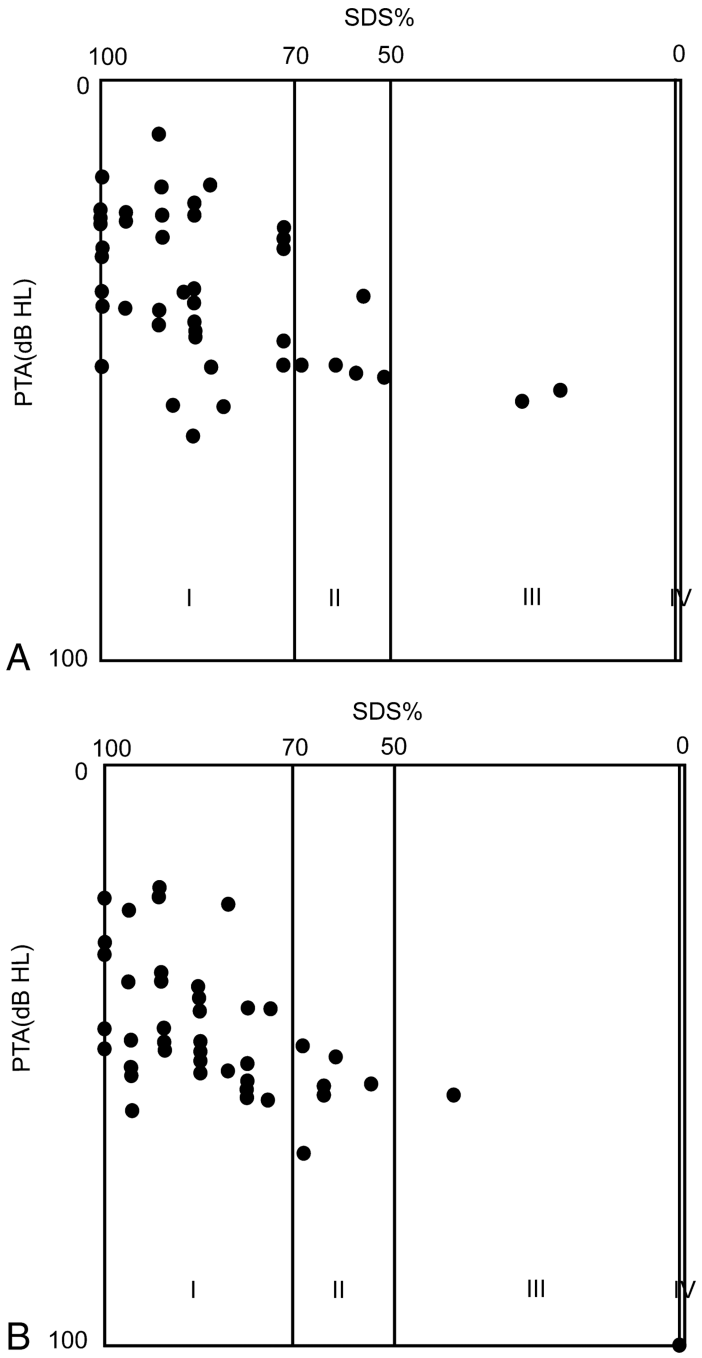

FIG. 2.

Word Recognition Score hearing results. *A*, Initial PO hearing results, SDS plotted versus 4-tone PTA, on the WRS grading scale (22). *B*, Hearing results at the latest follow-up (mean, 70.5 mo) on the WRS grading scale.

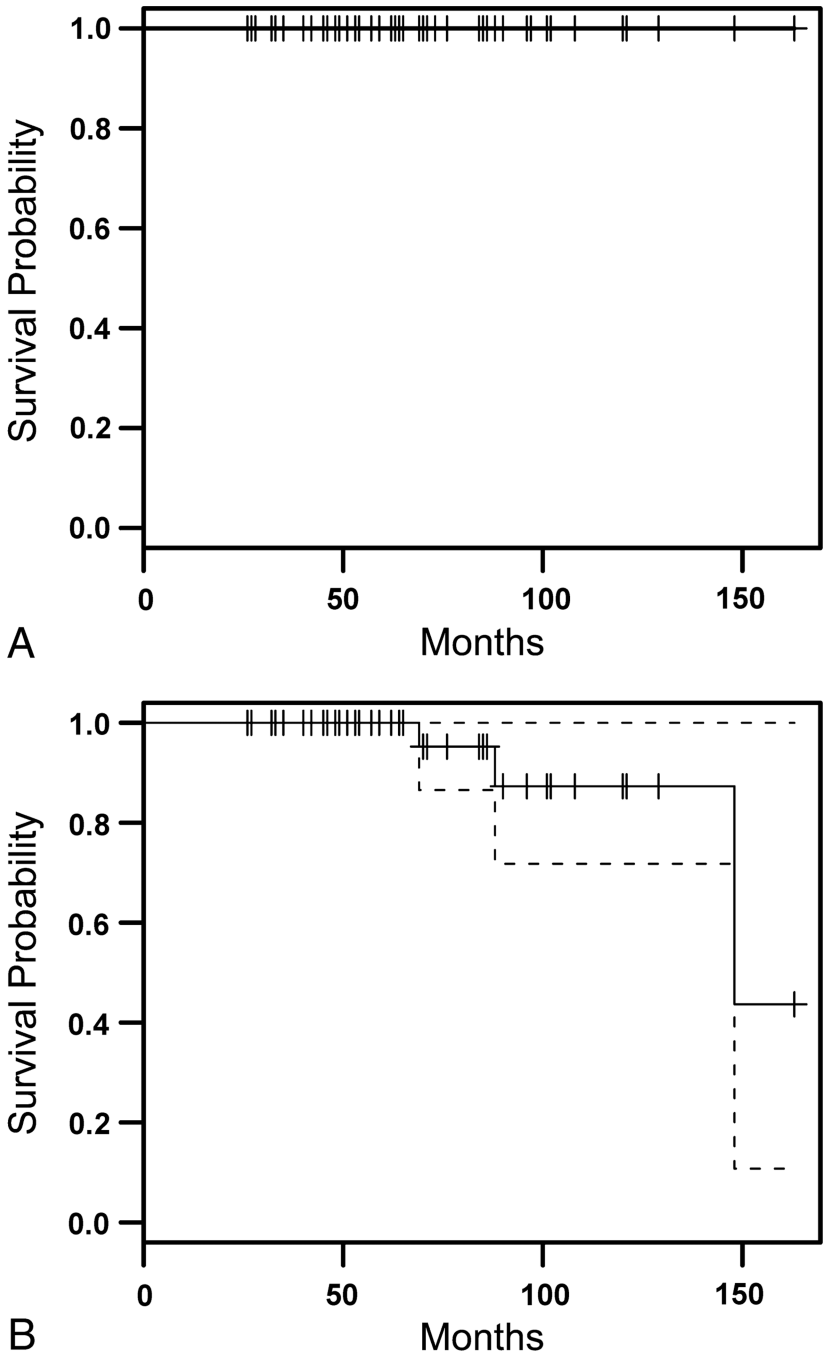

FIG. 3.

Kaplan-Meier survival curves for preservation of serviceable hearing. The patient with bilateral sensorineural hearing loss was excluded. *A*, Preservation of serviceable (WRS I–II) hearing over time of patients with PO WRS I to II hearing. *B*, Preservation of serviceable (AAO-HNSc A–B) hearing over time of patients with PO AAO-HNS A to B hearing. Dashed lines indicate SE (0.31).

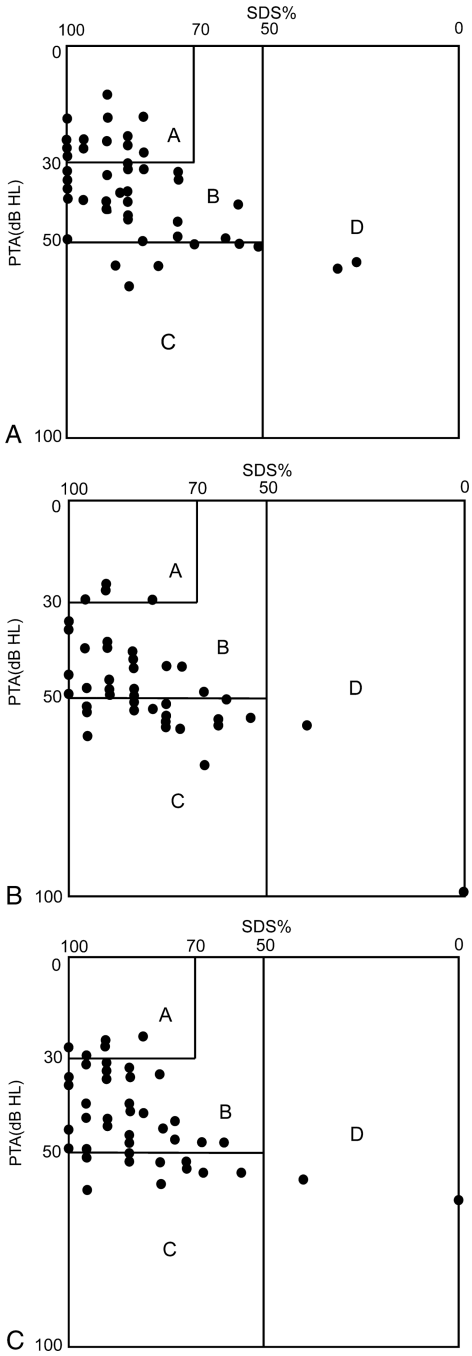

FIG. 4.

The AAO-HNS hearing results. *A*, Initial PO hearing results, SDS plotted versus 4-tone PTA, on the AAO-HNS grading scale (33). *B*, Hearing results at the latest follow-up (mean, 70.5 mo) on the AAO-HNS grading scale (noncorrected for changes in the ear not operated on). *C*, Hearing results at the latest follow-up on the AAO-HNSc grading scale (corrected for changes in the ear not operated on).

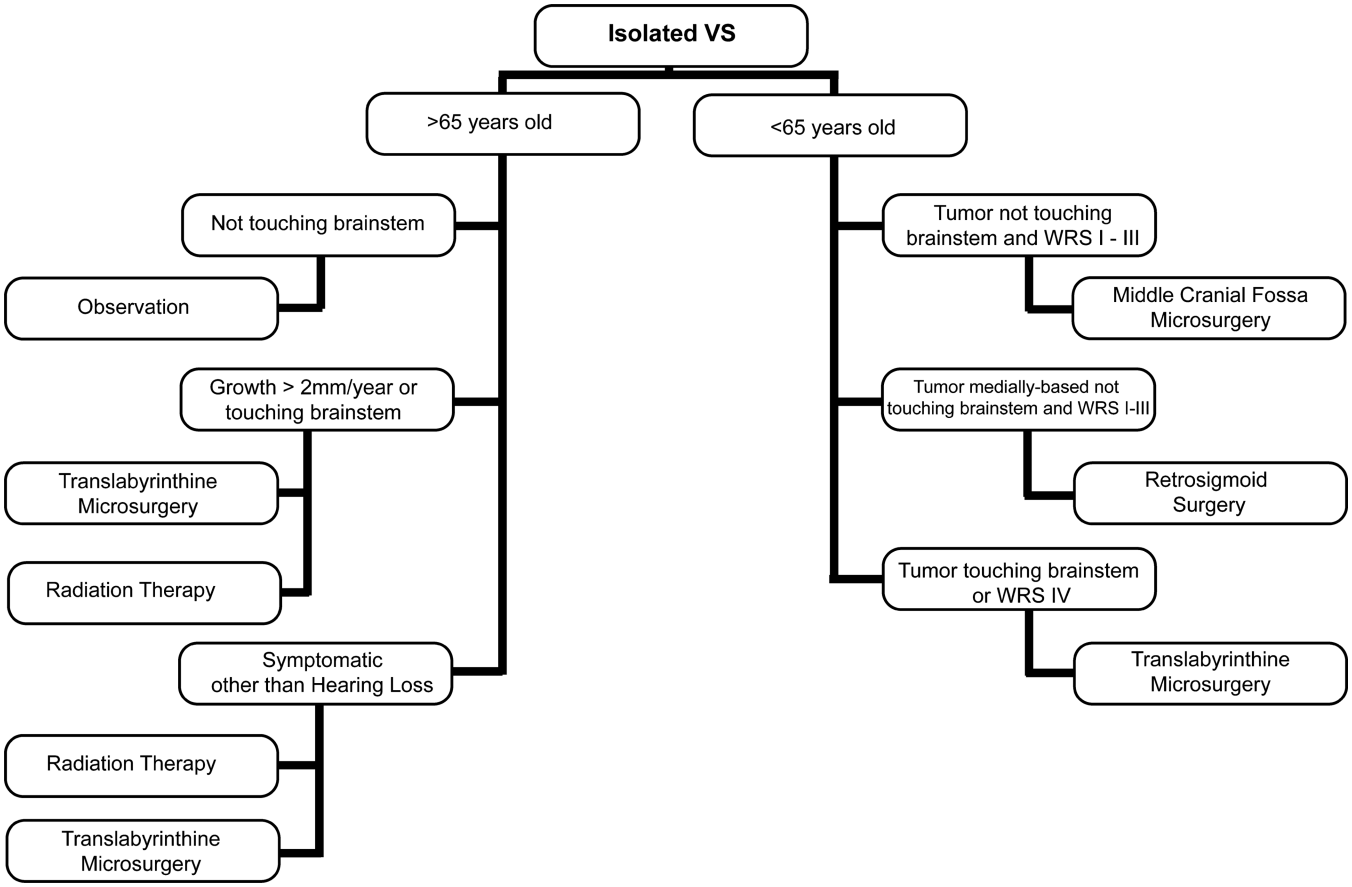

FIG. 5.
Iowa algorithm for management of small VS.

TABLE 1

Comparison of different grading scales for reporting hearing outcomes

Classification scheme	SDS	PTA
WRS		
I	70–100	
II	50–69	
III	1–49	
IV	0	
AAO-HNS		
A	70–100	0–30
B	50–69	31–50
C	>50	50+
D	<50	50+
GR		
I	70–100	0–30
II	50–69	31–50
III	5–49	51–90
IV	1–4	91+
V	0	

The AAO-HNS scale is based on PTA4 (500, 1,000, 2,000, and 3,000 Hz) (33). The Gardner-Robertson scale is based on PTA3 (500, 1,000, and 2,000 Hz) (34). The WRS does not have a PTA component (22). The SDS is percent correct of the W-22 recorded word list.

TABLE 2

Hearing outcomes for all patients

	Before surgery					After surgery					Latest follow-up					
Patient	**PTA**	**SRT**	**SDS**	**WRS**	**AAO-HNS**	**PTA**	**SRT**	**SDS**	**WRS**	**AAO-HNS**	**Months**	**PTA**	**SRT**	**SDS**	**WRS**	**AAO-HNS**
1	54	45	36	III	D	53	50	28	III	D	25	58	50	56	II	C
2	18	15	96	I	A	28	15	100	I	A	26	26	10	92	I	A
3	21	10	92	I	A	39	35	96	I	B	27	54	35	96	I	C
4	63	40	76	I	C	65	45	88	I	C	28	70	45	68	II	C
5	40	35	52	II	B	55	45	32	III	D	28	60	50	40	III	D
6	41	35	76	I	B	43	40	56	II	B	32	60	60	76	I	C
7	16	10	100	I	A	26	20	100	I	A	33	35	30	100	I	B
8	24	15	100	I	A	40	40	92	I	B	35	39	39	96	I	B
9	9	10	100	I	A	18	25	92	I	A	40	39	25	92	I	B
10	43	30	68	II	B	50	35	84	I	B	40	53	35	80	I	C
11	21	15	100	I	A	38	25	100	I	B	42	49	40	100	I	B
12	45	20	76	I	B	44	20	88	I	B	45	50	50	88	I	B
13	24	25	96	I	A	31	30	100	I	B	46	39	35	96	I	B
14	34	25	92	I	B	28	25	96	I	A	48	38	25	92	I	B
15	24	20	96	I	A	40	35	88	I	B	49	54	55	88	I	C
16	31	20	92	I	B	39	20	72	I	B	51	49	40	88	I	B
17	40	30	88	I	A	30	25	88	I	A	53	39	30	92	I	B
18	28	15	96	I	A	33	25	100	I	B	54	45	30	92	I	B
19	20	10	100	I	A	36	35	100	I	B	57	45	35	88	I	B
20	24	5	88	I	A	50	20	68	II	B	59	48	20	68	II	B
21	15	20	80	I	A	23	20	88	I	A	62	28	25	92	I	A
22	65	45	76	I	C	60	40	80	I	C	63	58	30	80	I	C
23	25	15	76	I	A	25	30	88	I	A	64	43	30	88	I	B
24	41	20	96	I	B	45	30	72	I	B	64	43	35	88	I	B
25	34	25	96	I	B	30	30	88	I	A	65	40	30	88	I	B
26	26	15	96	I	A	28	15	100	I	A	69	28	15	92	I	A
27	41	25	68	II	B	33	25	84	I	B	69	59	60	80	I	C
28	28	25	88	I	A	50	55	100	I	B	70	54	50	96	I	C

	Before surgery					After surgery					Latest follow-up					
Patient	**PTA**	**SRT**	**SDS**	**WRS**	**AAO-HNS**	**PTA**	**SRT**	**SDS**	**WRS**	**AAO-HNS**	**Months**	**PTA**	**SRT**	**SDS**	**WRS**	**AAO-HNS**
29	38	20	88	I	B	49	30	60	II	B	71	56	45	80	I	C
30	39	25	92	I	B	58	50	92	I	C	73	61	50	96	I	C
31	9	0	88	I	A	9	15	92	I	A	76	29	25	96	I	A
32	26	15	96	I	A	43	35	92	I	B	84	48	35	92	I	B
33	30	10	80	I	A	43	20	92	I	B	84	51	35	88	I	C
34	23	30	88	I	A	31	15	88	I	B	85	54	40	84	I	C
35	19	15	96	I	A	34	45	92	I	B	86	45	45	100	I	B
36	35	25	92	I	B	38	35	88	I	B	88	53	35	88	I	C
37	**29**	**20**	**96**	**I**	**A**	**50**	**35**	**56**	**II**	**B**	**90**	**CNT**	**NR**	**0**	**IV**	**D**
38	41	20	56	II	B	38	20	72	I	B	93	44	25	80	I	B
39	19	10	100	I	A	45	30	88	I	B	96	46	40	96	I	B
40	18	10	100	I	A	25	15	96	I	A	96	26	20	100	I	A
41	33	15	64	II	B	51	30	52	II	C	97	44	35	76	I	B
42	32	30	96	I	A	50	35	84	I	B	101	58	50	64	II	C
43	11	15	100	I	A	24	20	100	I	A	102	34	30	100	I	B
44	21	10	96	I	A	38	40	90	I	B	108	50	60	60	II	B
45	46	15	72	I	B	49	45	72	I	B	120	59	45	64	II	C
46	8	5	100	I	A	17	25	84	I	A	121	30	35	84	I	A
47	8	5	100	I	A	19	35	100	I	A	129	53	50	96	I	C
48	15	10	100	I	A	27	25	84	I	A	148	54	50	88	I	C
49	12	10	96	I	A	25	15	92	I	A	163	49	45	92	I	B

The PTA4 (500, 1,000, 2,000, and 3,000 Hz) is listed. We recorded SRTs via live Spondees. The SDS is percent correct of the W-22 recorded word list. The AAO-HNS is outcome grade by Academy guidelines (33). The WRS is bases on Meyer et al. (22). “Months” column refers to the number of months PO. The patient in boldface lost residual hearing. This patient also had an increase of 45 dB in PTA and 40 dB of SRT in the contralateral ear.

TABLE 3

The AAO-HNS scores corrected for changes in the contralateral ear

Patient	Preoperative contralateral PTA	Latest contralateral PTA	ΔPTA	Latest PTA	Corrected PTA for surgical ear	AAO-HNS	AAO-HNSc
4	49	65	16	70	54	C	C
6	8	21	14	60	46	C	B
29	8	19	11	48	36	B	B
32	3	16	14	54	40	C	B
34	14	26	13	54	41	C	B
37	***15***	***56***	***41***	***NR***	***>60***	***D***	***D***
42	6	18	11	59	48	C	B
49	21	33	11	56	45	C	B

Corrected PTA4 in the surgical ear was calculated for patients with greater than 10 dB change to the PTA in the ear not operated on. Corrected PTA was calculated by the following formula: (latest contralateral PTA) – (preoperative contralateral PTA) = ΔPTA. (Latest PTA) – (ΔPTA) = corrected PTA for the surgical ear. AAO-HNS is the outcome grade by Academy guidelines (33). AAO-HNSc refers to outcome graded by the latest SDS (Table 2) and corrected PTA for the surgical ear. The patient in bold face lost residual hearing. This patient also had an increase of 45 dB in PTA and 40 dB of SRT in the contralateral ear.

TABLE 4

Postoperative hearing outcomes of different reported surgical series

Study	No. patients	Mean tumor size (cm)	Approach	Percent serviceable hearing
Arts et al. (20)	62	0.9 (IC)	MCF	73
Brackmann et al. (21)	300	1.12 (IC)	MCF	62
Meyer et al. (22)	77	<1.0 IC)	MCF	66
Chee et al. (23)	29	<2.0	MCF	59
Gjuric et al. (24)	114	IC	MCF	60
Holsinger et al. (25)	24	0.9	MCF/RS	83
Kumon et al. (26)	15	IC	MCF	66
	17	<1.0	MCF	52
Colletti and Fiorino (27)	25	0.6 (IC)	MCF	52
	25	0.65 (IC)	*RS*	*40*
Staeker et al. (28)	13	IC	MCF	61
	15	*IC*	*RS*	*47*
Pollock et al. (46)	11	1.5	RS	5
Kaylie et al. (47)	27	<2.0 (IC)	RS	29

Percent of postoperative serviceable hearing considered in the number of patients with preoperative AAO-HNS A to B, GR I to II, or WRS I to II (usually a subset of their entire reported study population).

IC indicates intracanalicular. Measurements with the IC designation measure the entire long axis of the tumor, including the intracanalicular portion of the tumor.