Systematic Review of Hearing Preservation After Radiotherapy for Vestibular Schwannoma

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**Objective:** To determine the long-term hearing preservation rate for spontaneous vestibular schwannoma treated by primary radiotherapy.

**Data Sources:** The MEDLINE/PubMed, Web of Science, Cochrane Reviews, and EMBASE databases were searched using a comprehensive Boolean keyword search developed in conjunction with a scientific librarian. English language papers published from 2000 to 2016 were evaluated.

**Study Selection:** Inclusion criteria: full articles, pretreatment and posttreatment audiograms or audiogram based scoring system, vestibular schwannoma only tumor type, reported time to follow-up, published after 1999, use of either Gamma Knife or linear accelerator radiotherapy. Exclusion criteria: case report or series with fewer than five cases, inadequate audiometric data, inadequate time to follow-up, neurofibromatosis type 2 exceeding 10% of study population, previous treatment exceeding 10% of study population, repeat datasets, use of proton beam therapy, and non-English language.

**Data Extraction:** Two reviewers independently analyzed papers for inclusion. Class A/B, 1/2 hearing was defined as either pure tone average less than or equal to 50 db with speech discrimination score more than or equal to 50%, American Academy of Otolaryngology–Head & Neck Surgery (AAO-HNS) Hearing Class A or B, or Gardner-Robertson Grade I or II. Aggregate data were used when individual data were not specified.

**Data Synthesis:** Means were compared with student t test.

**Conclusions:** Forty seven articles containing a total of 2,195 patients with preserved Class A/B, 1/2 hearing were identified for analysis. The aggregate crude hearing preservation rate was 58% at an average reporting time of 46.6 months after radiotherapy treatment. Analysis of time-based reporting shows a clear trend of decreased hearing preservation extending to 10-year follow-up. This data encourages a future long-term controlled trial.

**Key Words:** Acoustic neuroma—CyberKnife—GammaKnife—Hearing preservation—Radiosurgery—Radiotherapy—Vestibular schwannoma.

Sweden, introduced the term “radiosurgery” in 1951 when he described in principle narrow beams of high dose radiation targeted to intracranial structures using a semicircular frame (7). Twenty years later, he described treatment of VS with the cobalt radiation-based stereotactic device that later became the Gamma Knife (8). Over the subsequent years, frame-based stereotactic radiosurgery (SRS) has become widely used to treat intracranial and skull base tumors (9,10). The actual techniques and dose regimens vary based on device and institution. There are three common sources of radiation. Gamma radiation is emitted from a cobalt-60 source; the Gamma Knife is a common application for SRS manufactured by Elekta AB (Stockholm, Sweden). Linear accelerator (LINAC) devices produce high energy x-ray radiation which can be adapted to SRS techniques; CyberKnife is a robotically adapted and image-guided LINAC radiosurgery application produced by Accuray (Sunnyvale, CA). Proton beam therapy is available but less commonly used in treatment of VS. With regards to the patient setup during delivery of the radiation, the Gamma Knife system traditionally used a fixed stereotactic frame, although Elekta AB now produces a model capable of frameless and fractionated treatments. The linear accelerator based systems are more variable but most often use either a moldable face mask or relocatable head frame for fixation; the tumor is localized most often with MRI and CT fusion imaging. Most often, radiosurgery refers to a single dose of therapy. Fractionated stereotactic radiotherapy is traditionally thought of as conventional doses of 2 Gy or less delivered multiple times over the course of several weeks. In between there is a point of contention in the nomenclature, with the current consensus of the definition of radiosurgery being five or fewer sessions (often times called multisession radiosurgery) (11). As with the technology, the terminology is evolving and inconsistently used by even the authors in the field (12,13).

Current literature reporting on the outcomes of VS does not universally report hearing outcomes; furthermore, when the hearing results are reported, audiometric-based methods are not always used. Two scales based on audiometric data have been widely adopted. The Gardner–Robertson scale was designed in 1988 to characterize hearing outcomes after acoustic neuroma surgery (14). In 1995, the American Academy of Otolaryngology—Head & Neck Surgery (AAO-HNS) released a similar grading scale (see Supplemental Digital Content for comparison, http://links.lww.com/MAO/A603) as well as guidelines on uniform reporting mechanisms (15). The “50/50 rule,” i.e., pure tone average (PTA) of 50 dB or less and speech discrimination score (SDS) 50% or greater, has been promoted by some authors as one definition of adequately preserved hearing (16,17). More recently, the AAO-HNS has advocated a newer scattergram reporting scheme to improve the resolution of hearing outcomes (18).

Much of the literature published on the outcomes of radiation therapy for VS is not published in otolaryngology journals, and the data are heterogeneous in both radiation technique and reporting outcomes (19). Not surprisingly, the reported rates of hearing preservation vary widely with reported rates between 10 and 90% (20–23). The aim of this paper is to review the literature to more accurately characterize the objective, audiogram-based long-term hearing preservation rate after treatment of sporadic VS with primary radiotherapy so as to inform clinical decision-making in the management of vestibular schwannomas.

METHODS

Literature Search and Selection
A systematic search of the literature was completed using the PubMed/MEDLINE, EMBASE, and Cochrane Library databases for articles on radiation treatment for vestibular schwannoma published between January 2000 and December 2016. We chose a cutoff of January 2000 as the treatment regimens before this are quite different than the modern dosages. A comprehensive search term was developed with the aid of a scientific librarian using Boolean keywords: hearing, gamma knife, radiosurgery, radiotherapy, stereotactic, stereotaxic, acoustic neuroma(s), vestibular schwannoma(s) (exact search terms available upon request). Duplicates were removed. Two reviewers (A.C., T.W.) independently screened abstracts for relevance. The same reviewers then evaluated full text articles based on predetermined inclusion criteria and exclusion criteria. Studies from the same institution were evaluated to determine the likelihood of overlapping datasets based on authorship and dates of treatment and eliminated. The reference list of included articles was then examined to identify any articles not identified in the database search. An overview of the methodology schema is outlined in Figure 1.

Inclusion and Exclusion Criteria
Inclusion criteria: 1) complete journal articles, 2) hearing outcomes recorded pretreatment and posttreatment with audiograms or audiogram-based scoring system, 3) vestibular schwannoma (acoustic neuroma) only tumor type, 4) documented time to follow-up, 5) published after 1999, 6) use of either Gamma Knife or linear accelerator radiotherapy. Exclusion criteria: 1) opinion, editorial, or review articles; 2) case report or series with fewer than five cases, 3) inadequate audiometric data, 4) lack of documented time to follow-up, 5) neurofibromatosis type 2 exceeding 10% of study population, 6) previous treatment exceeding 10% of study population, 7) repeat datasets, 8) use of proton beam therapy, 9) non-English language.

Data Extraction and Synthesis
Two reviewers (A.C., T.W.) independently analyzed papers for inclusion; discrepancies were settled by consensus. “Preserved Class A/B, 1/2 hearing” was defined as either PTA less than or equal to 50 dB and SDS more than or equal to 50%, AAO-HNS Hearing Class A or B, or Gardner–Robertson Grade I or II. Aggregate data were used when individual data were not specified. When applicable and not otherwise specified, actuarial hearing loss data were extracted from Kaplan–Meier curves. Mean time to follow-up was preferentially recorded when available, when not, median was used for average time to follow-up. Crude hearing preservation rate was defined as the ratio of patients with preserved Class A/B, 1/2 hearing at last follow-up to the number with Class A/B, 1/2 hearing before treatment; these were recorded at the average follow-up period.
Some authors also reported hearing preservation rates either at specific follow-up intervals (e.g., all patients had an audiogram at exactly 2 and 5 years after treatment) or calculated actuarial hearing preservation rates based off survival curves; these specific time-based hearing preservation rates (in comparison to the non-specific “at last follow-up” crude rate) were also noted. Also recorded: journal, year of publication, institution, study type, number of subjects in the study, radiotherapy technique and dose, tumor size, patient age, patient sex, number of patients with NF-2, number of patients with previous surgery. Fractionated radiation therapy was operationally defined as any technique using more than one fraction or treatment session. Data for the complete case series were used when desired subgroup data were not reported. These data were documented in a predesigned Microsoft Excel (Redmond, WA) spreadsheet. Means were compared with the student’s $t$ test and one-way analysis of variance (ANOVA).

**RESULTS**

**State of the Literature**

Forty-seven papers met the inclusion and exclusion criteria (Table 1) (20–67). Of the 151 full-text articles reviewed, 43 were excluded for exceeding either the 10% limit of included study population with NF-2 or previous treatment without breaking out these populations for separate analysis; these two variables have known impact on hearing outcomes. Of the included articles, the minority were in otolaryngology journals (21%, Fig. 2A). The articles represented diverse contributions from around the world (Fig. 2B). The vast majority (90%) were either single institution retrospective case series or retrospective reviews of a prospectively maintained institutional database. There were four single-institution single arm non-randomized prospective studies and one two-institution study. There were no controlled trials.

**Systematic Review Analysis**

These 47 included papers represent a total 4,689 of patients, of which 2,195 (47%) were analyzed with pretreatment Class A/B, 1/2 hearing, and adequate post-treatment audiometric evaluation.

The unweighted average crude hearing preservation rate was 58% (standard deviation [SD] = 19%) at 46.6 months (SD = 34.9 mo) after treatment; this is irrespective of tumor size, treatment technique, or age at treatment. Weighting for sample size of the Class A/B, 1/2 hearing portion of the study, the average crude hearing preservation rate remained 58% at 48.2 months. Crude hearing preservation rates varied from 14 to 92% with a range of average time to follow-up of 6 to 118 months.

There is a statistically significant difference in hearing preservation rates with time to follow-up after radiotherapy (Fig. 3). Using available crude, actual, and actuarial hearing preservation rates, the rate of hearing preservation is 73% at less than 2 years of follow-up, 60% from 2 to less than 5 years, 48% from 5 to less than 10 years, and 23% at greater than 10 years of follow-up; these are significantly different on ANOVA comparison of means.
This relationship of time-dependent hearing preservation is seen with both crude and time-based (actuarial and actual) hearing preservation rates (Fig. 4A and B).

The unweighted average of the mean age at treatment was 56 years old (SD = 4.6, range, 45–69). The average mean tumor diameter was 15.0 mm (SD = 4.12, range, 7.1–21) and tumor volume 1.48 cm³ (SD = 0.92, range,

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Site</th>
<th>Total Sample Size</th>
<th>Class A/B, 1/2 Hearing Sample Size</th>
<th>Hearing Preservation Rate</th>
<th>Avg Follow-up Time (mo)</th>
<th>Technique</th>
<th>Fractionation</th>
<th>Tumor Size</th>
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<td>38.0%</td>
<td>65</td>
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<td>77</td>
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<td>24</td>
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<td>Single</td>
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<td>2007</td>
<td>Vancouver, Canada</td>
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<td>33</td>
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<td>11</td>
<td>90.1%</td>
<td>45</td>
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<td>219</td>
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<td>46</td>
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</tr>
</tbody>
</table>

aHearing preservation rate is crude hearing preservation rate unless otherwise noted.
bAverage time to follow-up is mean unless only median time to follow-up was available.
cTumor size reported either as diameter or volume as noted.
dIndicates non-continuous variable sizes.

GKS indicates gamma knife surgery.
For single dose radiosurgery, the average mean marginal dose was 12.5 Gy (SD = 0.7, range, 11–18). Twenty-eight studies used GKS (60%) representing 1,488 patients (67.5%) with Class A/B 1/2 hearing, 18 used linear accelerator technologies (38%) representing 675 patients (31.1%), and one study with 32 patients (1.4%) used both (2%). Thirty-two studies used SRS (68%) representing 1,622 patients (73.9%) with Class A/B 1/2 hearing, 12 used fractionated dosing (26%) representing 476 patients (21.7%), and three studies with 97 patients (4.4%) used both (6%). The hearing preservation rate was not dependent on tumor size, patient age, radiotherapy technique, fractionation, or SRS dose on univariate analysis (Table 2).

FIG. 2. Distribution of publications. The majority of papers were published in the neurosurgery literature (A). There is a wide global distribution of institutions represented (B).

FIG. 3. Hearing preservation rate significantly decreases with time from radiotherapy (ANOVA \( p < 0.05 \)).
Hearing preservation is an important factor when considering treatment options for patients initially presenting with vestibular schwannoma. There are many single institution case series in the literature for radiotherapy treatment of vestibular schwannoma but a paucity of controlled trials. The aim of this study was to aggregate these case series data with a focus on the preservation of hearing at audiometric levels of better than 50 dB pure-tone average and better than 50% word recognition. We found the long-term rate of preserved Class A/B, 1/2 hearing after treatment of VS with primary radiotherapy on average was 58% at 47 months of follow-up. There is strong evidence for progressive hearing loss as the time to follow-up extended; there is a sequential and statistically significant difference between hearing preservation from 73% at less than 2 years of follow-up, 59% at 2 to 5 years of follow-up, 48% at 5 to 10 years follow-up, and 23% at 10 years or greater. Importantly, hearing preservation rates continue to decline out to the longest-term follow-up of about 10 years. This is evident in the strong trends seen in Figure 4.

We did not find any significant differences in hearing preservation outcomes with respect to tumor size, patient age, radiotherapy technique, fractionation, or SRS dose on univariate analyses. The power of these subgroup analyses is somewhat diluted secondary to the fact that the analysis was completed using the averages of each study as the individual patient datapoints were not available. This also limits multivariate analysis. Furthermore, our exclusion criteria intentionally limit some of the variation in the data to focus only on the current best practices with a focus on hearing outcomes. For example, limiting the publication date to no earlier than the year 2000 intentionally decreased the range of marginal doses; of the 32 SRS studies, only two had an upper range of mean marginal dose higher than 14 Gy.

The strength of this paper is its broad inclusion of radiotherapy techniques and dose regimens while at the same time focusing on high quality audiometric reporting with long-term follow-up. Previous reviews of radiosurgical outcomes for treatment of VS lacked one or both of these features (19,68–71), although the average crude hearing preservation rate of 58% at 47 months is in agreement with Yang et al. (68) whose GKS review reported a 51% AAO-HNS Class A/B or Gardner–Roberson Class 1/2 hearing preservation rate at 44 months.

An inherent challenge when studying long-term hearing loss in an adult population is that there is expected hearing loss with aging, and furthermore, an apparent progressive hearing loss attributable to the pathology of VS with respect to the eighth cranial nerve. It is, therefore, difficult to attribute a certain portion to natural hearing loss and another portion to posttreatment neuropathy. An ideal study of long-term hearing outcomes after VS treatment would account for the effect of the natural, age-related decline in hearing, and also to make comparisons to patients with untreated, observed tumors. A few studies have looked at using the contralateral ear as a control. Carlson et al. (49) examined 44 patients undergoing GKS with a median audiometric follow-up time of 9.3 years. Their study included an interaural correction and showed, in the contralateral ear, a 8.5 dB increase in PTA and a 1.8% drop in SDS over the long follow-up course. Even accounting for this adjustment, the treated ear demonstrated continued hearing loss throughout the course of long-term follow-up. Roos et al. (42) reviewed their experience with single dose LINAC SRS. While they lacked speech discrimination scoring, they reported...
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Audiometric testing reporting is also widely variable in the current literature. This review eliminated papers with subjective hearing scores or otherwise poor audiomtric reporting. Twenty-six of the 962 articles were eliminated on abstract screening, and another 38 of the 148 full text screening articles failed to pass the audiometric exclusion criteria. However, even for papers with good audiometric hearing outcomes, there is a not insignificant difference between the widely reported grading systems. The Gardner–Robertson (GR) scale was designed by the otolaryngologist Gale Gardner and neurosurgeon Jon Robertson of Memphis, Tennessee in their 1988 microsurgical case series with review of the literature as a modification of the Silverstein et al. (72) classification which calculates pure-tone average at 0.5, 1.0, and 2.0 kHz. The need for more standardized reporting has long been recognized; it was even discussed by Drs. Gardner and Robertson in their paper, and has been addressed twice by the AAO-HNS. The 1995 position paper (15) used a similar scale and nomogram calculated with the addition of a fourth frequency at 3 kHz (see Supplemental Digital Content for comparison, http://links.lww.com/MAO/A603). The addition of a higher frequency is an important difference as high frequencies are important in speech quality, localization, and intelligibility (73). The addition of another high frequency in the calculation of PTA using the AAO-HNS system may receive a less favorable overall grade compared with the same patient under the GR score. Some authors even favor using speech discrimination alone without pure-tone average with the argument that, in part, amplification is more successful with retained speech discrimination than retained pure-tone average or speech reception thresholds; the Word Recognition Score (WRS) (74) is one such classification. None of the included papers used the current recommended AAO-HNS reporting standard of a scattergram (18). Furthermore, optimally going forward, future studies would include not only audiometric data, but also patient reported outcomes such as the Hearing Handicap Inventory for Adults (75) to better assess overall hearing ability. The combination of audiometric data and patient reported outcomes would come closer to the ideal of assessing overall hearing function. In addition to these technical differences in scoring system calculations, there is the further problem of grouping scores together and assigning descriptive terms to these groups. The terms “serviceable” and “useful” abound in the literature; however, there is no consensus definition of these terms nor guidelines in how to use such descriptions. Furthermore, the connotation that a patient with Class 2 hearing has “serviceable hearing” implies that they should be able to adequately function, but this may not be the case. It is for this reason that the authors decided to use the term “preserved Class A/B, 1/2 hearing” as a composite of the AAO-HNS and GR scales rather than any descriptive terms, even when the original paper reported the results with such terminology.

A systematic review is, by definition, dependent upon the quality of the data in the included articles. There are some limitations to this. Oftentimes, there were not discrete datapoints for individuals or groups of individuals. Therefore, averages for the entire case series were assumed to be the same for the group analyzed. For example, while the subset of the case series with pretreatment Class A/B, 1/2 hearing may have only been 25% of the given study population, the tumor size was reported for the entire group and may not be representative of the subset used in this paper’s analysis. Another common datapoint which required grouping is the time to follow-up. This may have been either clinical, radiographic, or audiometric follow-up but was not often specified or broken down for audiometric only; when not otherwise specified, audiometric follow-up was assumed to be the same as overall follow-up. Furthermore, the lack of homogeneity in the individual case series inclusion criteria, patient demographics, and treatment techniques, combined with the need to group patients as a whole rather than individuals limited the statistical analysis and precluded true meta-analysis. This also limits a risk of bias analysis, as recommended by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (76), as treatment choices are not attempted to be completed in a randomized fashion.

There are additional limitations which must be acknowledged. Stereotactic radiosurgery is an evolving technology. The outcomes of radiation therapy are, of course, dependent on the technique of radiation delivery, among many other factors. The exact treatment planning details which optimize patient hearing outcome while maximizing tumor control remains an active ongoing area of research. There is evolving evidence that cochlear dose (43,44,56,77), pretreatment hearing class (42,43,45,49), and tumor size (49,77) are important factors affecting hearing preservation. As an attempt to include high quality modern studies, the inclusion criteria limited to publications from 2000 and later; thus eliminating higher dose earlier reports. Still, case series reporting specific technical metrics such as cochlear dose or conformity index are not the norm;ru the dosimetry and complete treatment planning details are often absent from these case series, and the degree of conformity and other quality metrics cannot be fully assessed. These important factors remain an uncontrolled variable for this study and other such reviews of the literature.

Another aspect of the evolving technologies of radiosurgery lies in the controversy between frame-based and
frameless devices. Stereotactic radiosurgery was initially designed with a frame mechanically connecting the patient to radiation source to maximize target localization. As the technology has evolved, relocatable frames (e.g., the Gill–Thomas–Cosman frame (78)) and image-guided frameless technologies (e.g., an optical bite-plate fiducial array (79)) have evolved with the purported benefits of decreased invasiveness for the patient and increased ease of fractionated regimens. Like other areas of controversy in this field, there is at this time a lack of comparative or long-term trials to answer the question of whether precision is as good with these newer techniques as compared with the fixed frame techniques. Regardless of the specific techniques used, there must be a strong emphasis by the treating physicians to design a treatment field with accuracy and precision, and in the case of fractionated treatment repeatability, to irradiate the tumor while sparing the important nearby cochlear and nerve structures. Overall, to the best of our ability, the studies included in this analysis represent case series in which the authors used modern conformal techniques with intent on hearing preservation therapy. While the techniques are variable, the goal was uniform, and therefore the results should be broadly applicable.

Due to the strict inclusion criteria, several studies with relatively large numbers of patients with long-term data were not included. This includes several of the more well-known articles in this field. Most commonly, these were excluded as they represented overlapping institutional datasets or exceeded the allowed number of patients with previous treatment or NF-2. For example, the non-overlapping case series from Chopra et al. (32) and Kano et al. (22) were chosen to represent the University of Pittsburgh GKS experience rather than perhaps the better-known larger Lunsford article from 2005 (80). A sampling of long-term case series not included in this analysis report hearing preservation rates of 37 to 74% (77,80–84)—all with at least 5 years average follow-up. Of particular interest is an excellent recent paper from Watanabe et al. (77) which retrospectively reviewed 183 patients who underwent GKS and included a calculated 15-year actuarial hearing preservation rate of 12%; they also identified age more than or equal to 65, tumor volume more than or equal to 8 cm$^3$, and mean cochlear dose more than 4.2 Gy as predictive for poor hearing preservation.

Our analysis was not primarily designed to identify treatment or demographic factors influencing hearing preservation rates. On univariate analysis of tumor size, patient age, radiation source, dose fractionation, or marginal dose, none were found to be significant predictors of hearing preservation. As mentioned above, other papers investigating factors influencing hearing preservation rates have identified initial speech discrimination scores (43,85,86), marginal dose (68), and cochlear dose (56,64,84,87) to be important factors. The effect of fractionation on hearing preservation is still not settled. While some earlier reports described very favorable hearing preservation rates (88–90), more recent comparative studies with low-dose treatments show similar hearing preservation outcomes between radiosurgery and fractionated radiotherapy (91–93).

Hearing preservation in the treatment of vestibular schwannoma remains a challenge regardless of treatment modality. In the long-term analysis from the large Danish cohort of observed patients (86), of the 178 patients with AAO-HNS Class A hearing at the start of observation, Class A hearing was preserved in 46% at 10 years. Quist et al. (94) reported 5-year follow-up results of patients treated by middle cranial fossa surgical approach. Of the 49 patients with AAO-HNS Class A or B hearing preoperatively, 55% maintained Class A/B hearing immediately postoperative. Of these patients followed for 5 years, 75% maintained Class A/B hearing. Similarly, Meyer et al. (74) and Woodson et al. (95) reviewed the University of Iowa experience with small tumors resected via middle cranial fossa surgery. Meyer showed a 57% AAO-HNS Class A/B hearing preservation rate immediately postoperative; Woodson showed that of these patients with initial preserved postoperative AAO-HNS Class A/B hearing, the long-term crude hearing preservation rate at minimum 2 years of follow-up was 65%, and when corrected for contralateral hearing loss it was 93%. Mazzoni et al. (96) reviewed 200 cases of retrosigmoid approach to VS: 47% had immediate postoperative AAO-HNS Class A/B hearing, and of these 87% maintained Class A/B hearing at a minimum of 6 years and median 9 years follow-up. Chee et al. (97) also reviewed outcomes after the retrosigmoid approach. Thirty-four percent of 126 cases had initial hearing preservation, and of the cases with initial preservation, at last follow-up, 65% of patients with AAO-HNS Class A/B hearing maintained hearing at these levels; the minimum follow-up was 36 months and the mean was 113.6 months. Selection bias greatly limits direct comparison of these results. Regardless of selection criteria, however, long-term hearing preservation rates remain lower than desired for all current treatment strategies, especially for larger tumors or patients with less than excellent initial hearing.

For future directions, ideally one would design a multi-institutional long-term prospective, randomized control trial of primary radiosurgery versus primary hearing-preservation approach microsurgery (i.e., via middle fossa or retrosigmoid craniotomy approaches) versus conservative wait-and-scan management in patients with Class A/B, 1/2 hearing without tumor compressive symptoms. Treatment techniques would be homogeneous and hearing would be measured at set intervals with audiograms and patient-reported functional analysis. In the likely absence of this, standardized high quality reporting criteria should continue to be encouraged across disciplines. Fundamental to this is the current AAO-HNS standardized format of scattergram hearing outcomes using PTA calculated at 0.5-, 1-, 2-, and 3-KHz and a minimum 50-word list word recognition score. An effort should be made to encourage our colleagues treating vestibular schwannoma of all disciplines to continue to
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CONCLUSIONS

The crude rate of preserved hearing at audiometric levels of better than 50 dB pure-tone average and better than 50% word recognition after treatment of vestibular schwannoma with primary radiotherapy on average was 58% at 47 months of follow-up. There is strong evidence for progressive hearing loss as the time to follow-up extended; there is a sequential and statistically significant difference between hearing preservation from 73% at less than 2 years of follow-up, 59% at 2 to 5 years of follow-up, 48% at 5 to 10 years follow-up, and 23% at 10 years or greater. Importantly, the hearing preservation rate continues to decline with long-term follow-up—with the current longest term follow-up averaging about 10 years after treatment. This highlights the need to state the time to follow-up when reporting hearing outcomes in future studies, as well as the need to explain to patients the progressive nature of possible hearing loss that can occur following treatment of vestibular schwannoma rather than quoting a hearing preservation rate in isolation. Hearing preservation rate after primary radiotherapy was not dependent on tumor size, patient age, radiation source, dose fractionation, or marginal dose in this study.

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REFERENCES


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