A comprehensive analysis of hearing preservation after radiosurgery for vestibular schwannoma

Clinical article

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Object. Gamma Knife surgery (GKS) has evolved into a practical alternative to open microsurgical resection in the treatment of patients with vestibular schwannoma (VS). Hearing preservation rates in GKS series suggest very favorable outcomes without the possible acute morbidity associated with open microsurgery. To mitigate institutional and practitioner bias, the authors performed an analytical review of the published literature on the GKS treatment of vestibular schwannoma patients. Their aim was to objectively characterize the prognostic factors that contribute to hearing preservation after GKS, as well as methodically summarize the reported literature describing hearing preservation after GKS for VS.

Methods. A comprehensive search of the English-language literature revealed a total of 254 published studies reporting assessable and quantifiable outcome data obtained in patients who underwent radiosurgery for VSs. Inclusion criteria for articles were 4-fold: 1) hearing preservation rates reported specifically for VS; 2) hearing status reported using the American Association of Otolaryngology–Head and Neck Surgery (AAO-HNS) or Gardner-Robertson classification; 3) documentation of initial tumor size; and 4) GKS was the only radiosurgical modality in the treatment. In the analysis only patients with AAO-HNS Class A or B or Gardner-Robertson Grade I or II status at the last follow-up visit were defined as having preserved hearing. Hearing preservation and outcome data were then aggregated and analyzed based on the radiation dose, tumor volume, and patient age.

Results. The 45 articles that met the authors’ inclusion criteria represented 4234 patients in whom an overall hearing preservation rate was 51%, irrespective of radiation dose, patient age, or tumor volume. Practitioners who delivered an average ≤ 13-Gy dose of radiation reported a higher hearing preservation rate (60.5% at ≤ 13 Gy vs 50.4% at > 13 Gy; p = 0.0005). Patients with smaller tumors (average tumor volume ≤ 1.5 cm³) had a hearing preservation rate (62%) comparable with patients harboring larger tumors (61%) (p = 0.8968). Age was not a significant prognostic factor for hearing preservation rates as in older patients there was a trend toward improved hearing preservation rates (56% at < 65 years vs 71% at ≥ 65 years of age; p < 0.1134). The average overall follow-up in the studies reviewed was 44.4 ± 32 months (median 35 months).

Conclusions. These data provide a methodical overview of the literature regarding hearing preservation with GKS for VS and a less biased assessment of outcomes than single-institution studies. This objective analysis provides insight into advising patients of hearing preservation rates for GKS treatment of VSs that have been reported, as aggregated in the published literature. Analysis of the data suggests that an overall hearing preservation rate of ~ 51% can be expected approaching 3–4 years after radiosurgical treatment, and the analysis reveals that patients treated with ≤ 13 Gy were more likely to have preserved hearing than patients receiving larger doses of radiation. Furthermore, larger tumors and older patients do not appear to be at any increased risk for hearing loss after GKS for VS than younger patients or patients with smaller tumors. (DOI: 10.3171/2009.8.JNS0985)

Key Words • vestibular schwannoma • Gamma Knife • radiosurgery • hearing preservation

STEREOTACTIC radiosurgery is becoming an established treatment modality alternative to open microsurgical resection for patients with VS. In most cases GKS is associated with minimal morbidity and complications and does not require overnight admission and hospitalization, but short- and long-term morbidity can occur after the procedure. Radiation exposure to adjacent neurological structures can reach toxic levels and can jeopardize facial nerve function, hearing outcomes, and distort balance. Facial spasm, facial numbness, cerebral edema, cranial

Abbreviations used in this paper: AAO-HNS = American Association of Otolaryngology–Head and Neck Surgery; GKS = Gamma Knife surgery; VS = vestibular schwannoma.
Most reported studies have been small to modest in size, frequently from a single institution, and they lack the objectivity due to potential institutional or practitioner bias. Accordingly it is difficult to simply state reported hearing preservation rates after GKS. Our review of the literature on hearing preservation revealed impressive differences in outcomes for VS patients treated with GKS, with hearing preservation rates varying between 0 and 100% and with recent studies reporting a 50–70% range.

Several factors have been implicated in post-GKS hearing loss including the radiation dose, tumor volume, and patient age. In this study we performed an extensive systematic and comprehensive review of the English-language literature to methodically analyze the reported results of patients treated with GKS for VS. We compiled an aggregated database of patients and investigated specific variables that could influence rates of hearing preservation. The primary aim of this study was to provide an objective summary of the published literature on hearing preservation after GKS for VS.

Methods

Article Selection

Articles were identified via Boolean PubMed searches using key words “Gamma Knife,” “radiosurgery,” “acoustic neuroma,” “hearing,” “vestibular schwannoma,” and “hearing preservation,” alone and in combination. This query identified 254 papers describing > 50,000 patients from which all quantifiable and assessable data regarding GKS-treated patients were analyzed for satisfying our inclusion criteria. Papers published between 1998 and 2007 were evaluated in this methodical analysis. Inclusion criteria for articles were: 1) hearing preservation rates reported specifically for VS, 2) hearing status reported using the AAO-HNS or Gardner-Robertson classification, 3) documented initial tumor size, and 4) GKS used was the only radiosurgical modality in the report.

Data Extraction

Data from individual and aggregated cases were extracted from each paper. Only patients who had AAO-HNS Class A or B or Gardner-Robertson Grade I or II hearing at last follow-up visit were defined as having preserved hearing. This classification for hearing preservation was used to note the serviceable functional hearing status of those patients with preserved hearing, utilizing the standard 50/50 criterion for pure tone average and speech discrimination (as defined by the AAO-HNS and Gardner-Robertson hearing grades) (Table 1). For those articles that report an overall hearing preservation rate without giving further specific patient data, these overall hearing preservation rates were used as reported. We excluded cases involving loss of hearing (AAO-HNS Class C or D or Gardner-Robertson Grade III, IV, or V) prior to GKS. All patients with VS who had undergone recent microsurgery were also excluded. Author contact was initiated to accumulate non-aggregated data when necessary. Repeated cases from the same institution, when described and ascertained in different published reports, were excluded to eliminate redundancy within the database.

Data were analyzed as a whole and also stratified into 3 groups. The first analysis divided the data according to the average marginal radiation dose delivered, whether the dose was greater than or less than 13 Gy. The second cluster breakdown segregated the data based on tumor volume with a cut-off of 1.5 cm³. The final analysis divided the data based on patient age at the time of GKS treatment, with a cut-off of 65 years.

Statistical Analysis

The raw data were tabulated using Microsoft Excel. All results were analyzed using a Fisher exact chi-square test or a t-test when appropriate for statistical evaluation of the data. Comparison of different medians was made using the Wilcoxon rank-sum test. For these statistical investigations, tests for significance were 2 sided, with a (2-tailed) p value threshold of 0.05 considered statistically significant. Unless otherwise stated, all continuous values are presented as the mean ± SD.

Results

Results of Systematic Review

A total of 45 articles, involving 4234 patients, met the criteria of the established protocol and were evaluated (Table 2). The overall hearing preservation rate was 51% irrespective of radiation dose, tumor size, or patient age. The mean of the reported average patient age was 51.8 ± 12.6 years, and the average follow-up duration was 44.4 ± 32 months. The median reported follow-up time was 35 months. The age range of patients treated varied widely, from 20 years to 73.5 years. In this systematic analysis, the mean GKS radiation dose was 14.2 ± 2.4 Gy. There was no significant correlation between reported follow-up duration and hearing preservation (r = 0.126, p = 0.41).

Effect of Radiation Dose on Hearing Preservation

A total of 542 patients were cited as receiving an av-

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(continued)
Hearing preservation rate (62%) as those with larger tumors did not have lower rates of post-GKS hearing preservation (14.3 vs 14.1 Gy, p = 0.4860). Patients with larger tumors received a comparable average marginal radiation dose of > 13 Gy whereas 671 patients received an average dose of > 13 Gy. The lower-dose (≤ 13 Gy) group had superior hearing preservation rates (60.5% compared with 50.4%, p = 0.0005) (Fig. 1). Radiation dose with marginal tumor dose of ≤ 13 Gy may be a significant prognostic factor for improved hearing preservation after GKS treatment for VS. Tumor control rates, as reported in these studies, were slightly worse in the lower-dose radiation group than in the patients receiving > 13-Gy dose of radiation (90% compared with 94%, p < 0.0001).

**Effect of Tumor Volume on Hearing Preservation**

A total of 454 patients had an average tumor volume of > 1.5 cm³, and 71 patients had an average tumor volume of ≤ 1.5 cm³. Patients with smaller tumors had a similar hearing preservation rate (62%) as those with larger tumors (61%) (p = 0.8968) (Fig. 2). Both groups of patients received a comparable average marginal radiation dose (14.3 vs 14.1 Gy, p = 0.4860). Patients with larger tumors did not have lower rates of post-GKS hearing preservation.

**Effect of Age at GKS Treatment on Hearing Preservation**

A total of 989 patients were an average age < 65 years, and 34 patients were an average age of ≥ 65 years at the time of GKS. Age was not a significant prognostic factor for hearing preservation rates, as older patients had a trend toward improved hearing preservation during reported the follow-up periods (56% at < 65 years of age compared with 71% at ≥ 65 years of age; p < 0.1134) (Fig. 3). Older patients did not have inferior hearing but in fact exhibited a slight trend toward improved hearing preservation.

**Discussion**

Hearing preservation continues to be an importantly critical issue for patients with VS undergoing GKS. A large number of individual results have been reported, but to date there have been few efforts to aggregate this research to achieve the statistical power and methodological objectivity to systematically characterize the hearing preservation outcomes after GKS for VS. Our composite aggregation and systematic review has an advantage in that the effect of bias in any given study may be diluted by the results from numerous other studies and mitigated by the statistical power in aggregation. Aggregate data can effectively address clinical issues summarizing multiple studies.

Our methodical analysis revealed that patients treated with an average marginal radiation dose of ≤ 13 Gy were more likely to have preserved hearing after GKS than those in whom higher doses of radiation were administered. A higher incidence of cranial nerve toxicity has been associated with higher radiation doses, and several recent studies have demonstrated that low-dose radiosurgery has a favorable efficacy/toxicity ratio compared with higher doses. It appears that a lower risk of cranial nerve neuropathy is associated with doses of ≤ 12.5 Gy. Because of the trend toward lower-dose GKS in the modern era, one would expect patients with longer follow-up in our aggregated series from older studies would have lower hearing preservation rates, but this was not suggested in our analysis; instead, we found no significant correlation between reported follow-up length and hearing preservation (r = 0.126, p = 0.41). Furthermore, our data suggests that this radiation effect was independent of tumor control rates, as those patients who received higher radiation doses (> 13 Gy) had slightly improved tumor control but significantly worse hearing preservation. Our cumulative analysis confirms the safety of utilizing GKS to treat VSs with a lower radiation dose of 13 Gy.

In our systematic analysis, hearing preservation rates in patients with an average tumor volume of ≤ 1.5 cm³ were similar to those in studies treating larger-volume tumors (62 vs 61%, p = 0.8968) (Fig. 2). The lack of significant difference in a large cohort of patients suggests that increased tumor volume is not a negative clinical prognostic factor for hearing preservation. Other factors such as tumor growth rate may be a more important factor than actual size of the VS. Furthermore, these data suggests that patients with larger tumors may be effectively treated.

**TABLE 2: Summary of data obtained from PubMed and listed according to identification number**

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* Empty data fields are from data that was not reported, not accessible, or could not be disaggregated for analysis in this study.
Hearing preservation after radiosurgery for VS

with GKS for VSs without an increased risk of hearing loss compared with patients harboring smaller tumors.

Older patients typically have higher rates of medically related comorbidities that can preclude them from consideration for open surgery. Despite these comorbidities, patients aged ≥ 65 years exhibited a trend toward improved hearing preservation rates compared with younger patients (56% in those < 65 years of age and 71% in those ≥ 65 years of age; \( p = 0.1134 \)). Advanced age was not a significant prognostic factor for increased risk of hearing loss after GKS in our systematic analysis.

The wide variability of data reported in the papers included in our systematic review precluded further investigation to stratify and determine if other statistically significant cut-off points existed. Although actuarial time-dependent data would be desirable, this was not possible in our retrospective, objective analysis and is an inherent limitation in the methodology of our study. Prospective studies could be designed to further elucidate the actuarial nature of hearing preservation over time after GKS. Future prospective studies may also provide further insight into the exact relationship between the prognostic variables we investigated and hearing preservation, perhaps, though, with fewer patients or less statistical power than the present study. Our analysis is the first reported attempt to methodically aggregate and summarize the

![Fig. 1. Bar graph showing hearing preservation stratified by radiation dose (≤ 13 Gy vs > 13 Gy).](image)

![Fig. 2. Hearing preservation analyzed by tumor volume stratified by tumor size (≤ 1.5 cm³ vs > 1.5 cm³).](image)
overall impact of GKS for VS on hearing preservation by drawing on data in the published literature.

Variables of possible interest that are inconsistently presented in different studies cannot be analyzed with multiple or logistic regression, and analysis across a considerable number of studies that adhere to differing formats of data presentation is problematic to do. In addition to radiosurgery dose, other factors, such as fractionation, brainstem anatomy, tumor characteristics, and cochlear nerve and temporal bone features, have been recently noted to potentially affect hearing preservation after GKS for VS.49 Aggregated systematic reviews as reported here may help to further characterize these prognostic factors and also help elucidate which aspects contribute to these clinically relevant issues.49,57

With systematic reviews and analysis as we report here, there are several inherent limitations. One obvious limitation is that any aggregation of data is only as good as its composite studies, and the aggregation may reflect source study biases. For example, the majority of this data set was derived from self-reported outcomes assessed by the treating physicians. The quality of the data reported in the literature, the effect of failure to detect, or unwillingness to report complications, and other such omissions would inevitably change the result reported in our aggregated analysis. In addition, due to the diverse range and methods of data presentation in various papers and journals, the number of variables able to be analyzed and controlled for is limited. Several papers with redundant data and overlapping cases had to be excluded, and because of our strict inclusion criteria, several papers with various data reports had to be excluded despite accurate data because of missing or incompletely reported and presented data in their series.8,17,30,51,85 Furthermore, small sample-size studies that met our inclusion criteria were also included in our analysis. However, the nature of our analytical review minimized the biases and diluted the inherent error of any individual study in our comprehensive report; also it had the advantage of providing expansive results from multiple national and international regions of the world.

Conclusions

We report the results from a large aggregated analysis of a systematic review for hearing outcomes in patients with VS specifically treated with GKS. Utilizing a systematic data set from the available published literature minimizes the effect of bias from individual institutions, increases the statistical power of the analysis, and aggregates expansive results to determine accurate and overall hearing preservation prognostic characteristics.57 The results of our systematic analysis suggest that radiation dose is an important and critical prognostic factor for hearing preservation irrespective of tumor size or age in patients with VS treated with GKS. Our data also confirm that patients treated with a ≤ 13-Gy radiation dose are associated with superior hearing outcomes compared with patients treated with higher doses. Older patients had hearing preservation outcomes comparable with younger patients, and patients with large and small tumors also had similar hearing preservation rates, suggesting that age and tumor size may not be critical prognostic factors in predicting hearing preservation after GKS for VS.

Disclosure

Dr. Yang received a UCSF Clinical and Translational Scientist Training Research Award that partially supported this investigation. Dr. Parsa was partially funded by the Reza and Georgianna Khatib Endowed Chair in Skull Base Tumor Surgery. The authors report no other conflicts of interest concerning the materials or methods used in this study or the findings specified in this paper.

References

1. Andrews DW, Suarez O, Goldman HW, Downes MB, Bednarz
Hearing preservation after radiosurgery for VS


78. Pollock BE, Lunsford LD, Kondziolka D, Flickinger JC, Biss...
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Manuscript submitted January 20, 2009. Accepted August 3, 2009. Please include this information when citing this paper: published online September 11, 2009; DOI: 10.3171/2009.8.JNS0985. Address correspondence to: Andrew T. Parsa, M.D., Ph.D., Department of Neurological Surgery, University of California at San Francisco, 505 Parnassus Avenue, San Francisco, California 94117. email: parsaa@neurosurg.ucsf.edu.