Factors associated with hearing preservation after Gamma Knife surgery for vestibular schwannomas in patients who retain serviceable hearing

Clinical article

Toshinori Hasegawa, M.D., Yoshihisa Kida, M.D., Takenori Kato, M.D., Ph.D., Hiroshi Iizuka, M.D., and Takashi Yamamoto, M.D.

Department of Neurosurgery, Gamma Knife Center, Komaki City Hospital, Komaki, Japan

Object. Gamma Knife surgery (GKS) has been a safe and effective treatment for small- to medium-sized vestibular schwannomas (VSs) over relatively long-term outcomes. However, even with recent radiosurgical techniques, hearing results following GKS remain unsatisfactory. The purpose of this study was to evaluate the hearing preservation rate as well as factors related to hearing preservation in patients with VSs and serviceable hearing who were treated with GKS.

Methods. Among patients with Gardner-Robertson (GR) Class I or II serviceable hearing and VSs treated with GKS between 1991 and 2009, 117 were evaluable via periodic MR imaging and audiometry.

Results. The median age at the time of GKS was 52 years. Four patients (3%) had undergone prior surgery. Fifty-six patients (48%) had GR Class I hearing and 61 (52%) had GR Class II hearing at the time of GKS. The median tumor volume was 1.9 cm³. The median maximum and tumor margin radiation doses were 24 and 12 Gy, respectively. The median follow-up periods for MR imaging and audiometry were 74 and 38 months, respectively. The overall tumor control rate was 97.5%. Actuarial 3-, 5-, and 8-year hearing preservation rates were 55%, 43%, and 34%, respectively. On multivariate analysis, GR hearing class at the time of GKS and the mean cochlear dose affected hearing preservation significantly. In a limited number of patients who were treated using the most recent dose planning techniques and who had GR Class I hearing before GKS treatment, the 3- and 5-year hearing preservation rates increased to 80% and 70%, respectively.

Conclusions. For the majority of patients with small- to medium-sized VSs, GKS was an effective and reasonable alternative to resection with satisfactory long-term tumor control. Factors related to hearing preservation included a GR Class I hearing pre-GKS and a lower mean cochlear radiation dose. To retain serviceable hearing, it is important to apply GKS treatment while patients retain GR Class I hearing. (DOI: 10.3171/2011.7.JNS11749)

KEY WORDS • vestibular schwannoma • Gamma Knife • stereotactic radiosurgery • hearing preservation • long-term outcome

Abbreviations used in this paper: D95 = radiation dose that includes 95% of the planning target volume; GKS = Gamma Knife surgery; GR = Gardner-Robertson; PTA = pure tone average; SRS = stereotactic radiosurgery; VS = vestibular schwannoma.
Hearing preservation after GKS for vestibular schwannomas

Methods

Since 1991, approximately 1000 patients with VSs have been treated at Komaki City Hospital in Japan. The criteria for inclusion into this study were serviceable hearing (GR Class I or II) at the time of GKS and a periodic audiogram after treatment. One hundred seventeen patients were eligible for the evaluation of long-term hearing outcomes and were retrospectively analyzed.

Clinical Follow-Up

Clinical follow-up data were obtained from either the patients or their referring doctor if the patient lived a considerable distance from our institution. Hearing function was evaluated based on PTA at serial audiometry before and after GKS. The PTA was calculated by using the following formula: \( (a + 2b + c)/4 \), where “a” had a threshold of 500 Hz, “b” had a threshold of 1000 Hz, and “c” had a threshold of 2000 Hz. To evaluate adverse radiation effects for hearing function, PTA on the normal-hearing side was used as a control. In addition, the difference in PTA between pre- and post-GKS was calculated for each patient. Magnetic resonance images and audiograms were requested at 3-month intervals for the 1st year after GKS, at 6-month intervals for the 2nd and 3rd years, and then annually thereafter. On the follow-up images, both tumor control and expansion were assessed. Tumor expansion was defined as any tumor enlargement after GKS. Transient tumor expansion was not considered as treatment failure when calculating the tumor control rate.

Dose Planning

When dose planning at the time of GKS, the KULA system (Elekta AB) was used until August 1996 and Leksell GammaPlan software (Elekta AB) was used thereafter. On the basis of dose planning methods, the patients were classified into 3 groups: KULA group, GP1 group, and GP2 group. The KULA system was used in the planning for 32 patients (KULA group). Among the 85 patients in whom GammaPlan was used, dose planning was performed on the basis of axial and coronal T1-weighted MR images with Gd enhancement in 53 patients (GP1 group). Most recently, thin-sliced axial 3D spoiled gradient echo-recalled images with Gd enhancement and heavy T2-weighted MR images were used for dose planning in the remaining 32 patients (GP2 group).

Statistical Analysis

Tumor control, tumor expansion, and hearing preservation rates were calculated using the Kaplan-Meier method. Hearing preservation was defined as retaining GR Class I or II hearing. To analyze factors that correlated with hearing preservation, the following were assessed: age, sex, dose planning group, GR hearing class, Koos grade, tumor expansion, tumor volume, treatment dose (maximum, margin, and D95), cochlear dose (maximum and mean), number of isocenters, use of a 4-mm collimator in the intracanalicular portion, and distance from the meatal fundus to the tumor end. Maximum and mean cochlear doses were obtained via volume calculation of the cochlea using GammaPlan, as featured in Fig. 1. These data were available only in the GP2 group. In the GP1 group, the central dose to the cochlea was used instead of the mean cochlear dose, because it was not possible to correctly delineate the cochlea on a T1-weighted MR image. Doses to the cochlea and the D95 in the KULA group and the maximum cochlear dose in the GP1 group were not available. To evaluate lateral extension of the tumor, the distance from the meatal fundus to the tumor end was obtained by drawing a line on the image using the software, as demonstrated in Fig. 2.

Factors affecting hearing preservation were assessed with the log-rank test and the Cox proportional hazards model. A final multivariate analysis was performed using a stepwise backward elimination. A p value < 0.05 was defined as statistically significant.

Results

Patient Characteristics

Patient characteristics are summarized in Table 1. Seventy-three patients (62%) were female and 44 (38%) were male. The median age at the time of GKS was 52 years (range 7–77 years). Four patients (3%) had undergone a prior surgery. One patient had neurofibromatosis Type 2. On the basis of the GR hearing function classification, 56 patients (48%) had Class I hearing and 61 (52%) had Class II hearing at the time of GKS. To describe the relationship between the tumor and the brainstem, the Koos classification scheme was used.

Radiosurgical Techniques

Detailed radiosurgical treatment data are shown in Table 2. The median tumor volume was 1.9 cm³. The median maximum radiation dose, tumor margin dose, and D95 (radiation dose that included 95% of the planning target volume) were 24, 12, and 11 Gy, respectively.

Tumor Control

The median radiological follow-up duration was 74 months (range 6–171 months). During the follow-up period, 2 patients had treatment failure. One patient had tumor progression requiring craniotomy 41 months after GKS. Another patient had cyst formation; however, the cyst collapsed naturally without any additional treatment. With the Kaplan-Meier method, actuarial 5- and 10-year tumor control rates were both 97.5%.

Tumor Expansion

Twenty-five patients demonstrated tumor expansion on follow-up MR images 3 months after GKS. The actuarial tumor expansion rate was 22%. A Kaplan-Meier curve for tumor expansion is shown in Fig. 3.

Hearing Results

The median follow-up period for audiography was 38 months (range 6–174 months). At the last follow-up audiography study, GR Class I hearing was preserved in 25 patients (21%) and Class II hearing in 31 patients (26%); Class III hearing was present in 57 patients (49%) and
Class IV in 4 patients (3%). The time course for the median PTA is demonstrated in Fig. 4. Moreover, the time course for the median differences between the pre- and post-GKS PTA is featured in Fig. 5. Compared with pre-GKS PTA, a decline of approximately 20 dB was found on the tumor side 3–5 years after GKS, whereas hearing function was almost unchanged on the contralateral side even 10 years later. Actuarial 3-, 5-, and 8-year hearing preservation rates were 55% (95% CI 45%–65%), 43% (95% CI 31%–54%), and 34% (95% CI 21%–47%), respectively (Fig. 6).

Factors Associated With Hearing Preservation

Factors affecting hearing preservation are shown in Table 3. On univariate analysis, GR hearing class (p = 0.0003) and mean cochlear dose (p = 0.001) were significant for hearing preservation. On multivariate analysis, both of these factors remained significant (GR class, p = 0.049; mean cochlear dose, p = 0.031). In a comparison between the recent dose planning group (GP2) and the old planning groups (KULA and GP2), the 3- and 5-year hearing preservation rates were 69% and 48% in the former group, and 50% and 40% in the latter group, respectively, demonstrating no significant difference (p = 0.33). In the limited number of patients who were treated with the recent dose planning techniques of the GP2 group and who had GR Class I hearing before treatment, the 3- and 5-year hearing preservation rates increased to 80% and 70%, respectively. Other factors did not affect hearing preservation significantly.

Hearing Preservation Dependence on GR Classification at the Time of GKS

Detailed hearing results on the basis of GR classification at the time of GKS are shown in Table 4. Of 56 patients with GR Class I hearing at the time of GKS, Class I hearing was preserved in 23 (41%) and Class II in 13 (23%). On the other hand, in 61 patients with GR Class II hearing at the time of GKS, 2 (3%) improved to Class I hearing and 18 (30%) maintained Class II hearing. Based on the GR classification, actuarial 3- and 5-year hearing preservation rates were 71% and 64% in patients with GR Class I hearing and 40% and 24% in patients with Class II hearing at the time of GKS, respectively (p = 0.0003; Fig. 7 upper).

Hearing Preservation Dependence on Cochlear Dose

Considering the mean cochlear dose, 3- and 5-year hearing preservation rates were 63% and 50%, respectively, in patients with a dose < 6 Gy; they were 31% and 15% in patients with a dose ≥ 6 Gy (p = 0.008; Fig. 7 lower). On the basis of the mean cochlear dose, detailed 3- and 5-year hearing preservation rates are listed in Table 5.
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Discussion

Currently, the best management for small- to medium-sized unilateral VSs is still controversial, especially in patients who have serviceable hearing or in whom the schwannoma was incidentally found. The treatment options for these lesions include microsurgery, SRS, fractionated radiotherapy, or a wait-and-see approach utilizing serial radiological images. According to several reports on the wait-and-see strategy,1,2,30,31,34,36,38 mean growth rates vary from 1 to 3 mm per year, and approximately 30%–50% of patients have a growing tumor during follow-up periods over 3 years. Eventually, 16%–20% of patients require intervention. These percentages must increase over longer follow-up periods. Although microsurgery offers excellent tumor control, complications, such as facial palsy, hearing loss, CSF leakage, or infection, cannot be eliminated. Yamakami et al.36 documented in a meta-analysis of VSs treated with microsurgery that postoperative facial palsy occurred in 10% of patients with small- to medium-sized tumors, and the mortality rate was 0.6%. A recent large surgical study by Bloch et al.4 demonstrated that 255 (41%) of 624 patients had facial palsy of House-Brackmann Grade III or higher at 6 months after surgery. Pollock et al.,26 in a prospective cohort study of 82 patients harboring unilateral VSs with tumor diameters < 3 cm, compared SRS and resection. Because of the superior functional outcomes in terms of normal facial movement and preserved serviceable hearing after SRS as well as no difference in tumor control between SRS and resection, the authors concluded that SRS should be considered the best management strategy for the majority of their patients unless the long-term follow-up showed frequent tumor progression at the currently used radiation doses. Despite the results of

TABLE 1: Summary of characteristics in 117 patients with VSs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sex</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>44 (38)</td>
</tr>
<tr>
<td>F</td>
<td>73 (62)</td>
</tr>
<tr>
<td>age in yrs</td>
<td></td>
</tr>
<tr>
<td>median</td>
<td>52</td>
</tr>
<tr>
<td>range</td>
<td>7–77</td>
</tr>
<tr>
<td>GR class</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>56 (48)</td>
</tr>
<tr>
<td>II</td>
<td>61 (52)</td>
</tr>
<tr>
<td>Koos grade</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>20 (17)</td>
</tr>
<tr>
<td>II</td>
<td>48 (41)</td>
</tr>
<tr>
<td>III</td>
<td>31 (26)</td>
</tr>
<tr>
<td>IV</td>
<td>18 (15)</td>
</tr>
</tbody>
</table>
these studies, it remains difficult to draw conclusions because of selection bias and the differences in the follow-up durations in the various studies. A randomized trial would resolve this controversy, although this would not be feasible. The most suitable treatment should be selected for each patient considering age, tumor volume, medical comorbidities, and patient preferences.

**Hearing Preservation**

As many investigators have shown that SRS is effective for long-term tumor control in patients harboring unilateral VSs, it is not surprising that a tumor control rate of 97.5% was demonstrated in the present study of patients with relatively small VSs. In the past, in patients such as these, most attention has been directed at long-term tumor control following SRS. Currently, however, the greatest interest in the treatment of VSs is changing to hearing preservation, especially in patients who retain serviceable hearing. When GKS treatment began to be used at our institute, VSs were treated with a relatively high margin dose of 15 Gy. Consequently, persistent or transient facial palsy developed in some patients after treatment, as did hearing loss. This result led us to a gradual dose reduction toward a current optimal margin dose of 12 Gy. Since a tumor margin dose of 12 Gy was selected, we rarely encounter patients in whom facial palsy develops as an adverse radiation effect. However, the results of hearing function after treatment remain unsatisfactory. In the present study, actuarial 3- and 5-year hearing preservation rates were 55% and 43%, respectively. These rates seem to be relatively lower than those in other recent studies, which are summarized in Table 6. One reason is the inclusion of some patients who were treated with older Gamma Knife techniques. For example, in the early era of GKS, planning was performed not with GammaPlan software but with the KULA system. Also at that time, relatively thick-sliced MR images were used for dose planning, and a 4-mm collimator was not used in many patients. At present, it is common to use 1-mm slice MR images and a 4-mm collimator for the intracanalicular portion. Moreover, the use of a high margin dose of 14–15 Gy was related to a lower hearing preservation rate. In a limited number of patients with GR Class I hearing before treatment and who underwent the recent dose planning techniques used in the GP2 group, 3- and 5-year hearing preservation rates increased to 80% and 70%, respectively. Another reason for the lower hearing preservation rates is the relatively longer-term follow-up in the present study as compared with others. Generally, hearing deterioration as an adverse radiation effect has been considered to develop within 3 years after GKS and not to worsen thereafter. As shown in the present study, however, hearing function continues to deteriorate beyond the first 3 years. On the other hand, hearing function in the contralateral ear was almost unchanged during the follow-up period, even 10 years after treatment, suggesting that hearing deterioration beyond the first 3 years is not caused by aging but by radiation toxicity. This notion supports the fact that hearing preservation rates in the present study were a little lower than those that had been considered in previous reports on the basis of short-term follow-up data. Actuarial hearing preservation rates at the same time point must be compared. According to our data, median differences between PTAs pre-GKS and post-GKS were 12.5, 16.9, and 23.8 dB at 3, 5, and 7 years after treatment, respectively, meaning that patients with GR Class II hearing at the time of GKS would easily lose serviceable hearing in the long

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**TABLE 2: Radiosurgical techniques among 117 patients with VSs**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Median</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>tumor vol (cm³)</td>
<td>1.9</td>
<td>3.0</td>
<td>0.1–20.6</td>
</tr>
<tr>
<td>max dose (Gy)</td>
<td>24.0</td>
<td>23.1</td>
<td>15–32</td>
</tr>
<tr>
<td>margin dose (Gy)</td>
<td>12.0</td>
<td>12.4</td>
<td>10–17</td>
</tr>
<tr>
<td>D95 (Gy)</td>
<td>11.0</td>
<td>10.9</td>
<td>6.0–13.7</td>
</tr>
<tr>
<td>isodose line (%)</td>
<td>50.0</td>
<td>54.0</td>
<td>45–75</td>
</tr>
<tr>
<td>no. of isocenters</td>
<td>3.0</td>
<td>5.0</td>
<td>1–23</td>
</tr>
</tbody>
</table>

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**TABLE 3: Factors affecting hearing preservation**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Univariate</th>
<th>Multivariate</th>
<th>Favorable Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>age</td>
<td>0.33</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>sex</td>
<td>0.79</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>tumor vol</td>
<td>0.057</td>
<td>0.35</td>
<td>smaller vol</td>
</tr>
<tr>
<td>tumor expansion</td>
<td>0.087</td>
<td>0.68</td>
<td>none</td>
</tr>
<tr>
<td>dose planning group</td>
<td>0.93</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>distance from fundus to tumor</td>
<td>0.58</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>Koos grade</td>
<td>0.4</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>GR hearing class</td>
<td>0.0003†</td>
<td>0.049†</td>
<td>GR Class I</td>
</tr>
<tr>
<td>max dose to tumor</td>
<td>0.82</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>tumor margin dose</td>
<td>0.24</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>D95 to tumor</td>
<td>0.41</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>max dose to cochlea</td>
<td>0.4</td>
<td>NT</td>
<td></td>
</tr>
<tr>
<td>mean dose to cochlea</td>
<td>0.001†</td>
<td>0.031†</td>
<td>lower dose</td>
</tr>
<tr>
<td>D95 to cochlea</td>
<td>0.063</td>
<td>0.93</td>
<td>lower dose</td>
</tr>
<tr>
<td>no. of isocenters</td>
<td>0.72</td>
<td>NT</td>
<td></td>
</tr>
</tbody>
</table>

* NT = not tested.
† Significant.
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Thus, overall hearing preservation rates are most attributable to patient selection. Kano et al.\textsuperscript{14} reported the results of GKS in 77 patients who retained GR Class I or II serviceable hearing. At a median follow-up of 20 months, 71\% of patients retained serviceable hearing. In a limited number of patients who retained GR Class I hearing at the time of GKS, hearing preservation rates increased to 89\%. Tamura et al.\textsuperscript{32} also reported the results of GKS in 74 patients with GR Class I hearing in whom follow-up data were available 3 or more years after treatment. At the last follow-up, serviceable hearing was preserved in 78\% of the patients. The authors described a Kaplan-Meier actuarial curve for hearing preservation that showed a plateau at \( > \) 70\% at 6–7 years after treatment. These results are consistent with our limited data in the patients with the recent dosing techniques of the GP2 group and GR Class I hearing before treatment.

Prognostic Factors Related to Hearing Preservation

Prognostic factors affecting hearing deterioration must be determined to improve hearing preservation rates in the future. According to previous reports, there is no doubt that a higher radiation dose to the tumor margin is significantly associated with hearing deterioration.\textsuperscript{7,8,19,20,25,27,37} Ischemic damage to the cochlea or cochlear nerve can cause hearing loss because of high-dose radiation. Moreover, tumor expansion can cause hearing loss by compression of the cochlear nerve. In our study, however, tumor expansion did not affect hearing preservation significantly. When considering that hearing continues to worsen beyond the first 3 years after treatment, tumor expansion may be less related to hearing deterioration, because tumor expansion commonly occurs within a year and expanded tumors gradually decrease in size beyond 3 years. Recently, Tamura et al.\textsuperscript{32} reported that patients presenting with an initial symp-
tom other than hearing disturbance, those younger than 50 years of age, and those treated with a dose < 4 Gy to the cochlea retained significant hearing function. Similarly, Kano et al.\textsuperscript{14} reported that significant prognostic factors for hearing preservation were GR Class I hearing at the time of GKS, speech discrimination \( \geq 80\% \), PTA < 20 dB, patient age < 60 years, intracanalicular tumor location, and tumor volume < 0.75 cm\(^3\). Additionally, a radiation dose < 4.2 Gy to the central cochlea was significant in retaining the same GR class post-GKS. Both of these studies showed that hearing preservation was significantly related to the central cochlea dose. However, simple questions are raised, such as whether a radiation dose as low as 4 Gy to the cochlea can cause hearing loss as a result of radiation toxicity and whether there are any other cochlear factors significantly associated with hearing preservation after treatment. To answer these questions, the cochlea-related factors were highlighted in the present study. Our results indicated that the GR hearing class at the time of treatment and the mean cochlear dose were significant factors for hearing preservation. It makes sense that the GR class significantly affects hearing preservation, as has been reported by several investigators.\textsuperscript{14,15} Note that higher cochlear doses lead to lower hearing preservation rates. According to the literature concerning radiation tolerance in conventional fractionated radiotherapy,\textsuperscript{3,6,24} to minimize the risk of hearing loss, the mean cochlear dose should be limited to < 45 Gy. Actually, the tolerance dose of the cochlea may be almost the same as or lower than that for the optic apparatus. On the basis of the linear quadratic model, assuming that the \( \alpha/\beta \) ratio for the cochlea is 2, up to 12 Gy must be safe in a single fraction. Considering the experience with conventional fractionated radiotherapy, the risk associated with 4–6 Gy applied to the cochlea is unacceptable. Accordingly, it may simply show a cutoff point for hearing preservation. Probably, multiple factors—such as the tumor margin dose (that is, the dose to the cochlear nerve), tumor volume, hearing function at the time of GKS, and tumor location—must influence hearing deterioration. If the \( \alpha/\beta \) ratio for the cochlea were much less than 2, a radiation dose of 4–6 Gy might cause hearing deterioration. Because the threshold for hearing impairment remains unclear, efforts should be made to reduce the cochlea dose if possible, although it is usually not possible in cases of lateral extended VSs, which should be treated with a margin dose of 12 Gy.

Age was not significant for hearing preservation in our analyses with a categorical variable (< 50 vs \( \geq 50 \) years) as well as with a continuous variable.

### TABLE 4: Hearing results on the basis of preradiosurgical hearing

<table>
<thead>
<tr>
<th>GR Class Post-GKS</th>
<th>GR Class I Pre-GKS</th>
<th>GR Class II Pre-GKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>23 (41)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>II</td>
<td>13 (23)</td>
<td>18 (30)</td>
</tr>
<tr>
<td>III</td>
<td>18 (32)</td>
<td>39 (64)</td>
</tr>
<tr>
<td>IV</td>
<td>2 (4)</td>
<td>2 (3)</td>
</tr>
</tbody>
</table>

### TABLE 5: Hearing preservation on the basis of mean cochlear dose\textsuperscript{*}

<table>
<thead>
<tr>
<th>Cochlear Dose (Gy)</th>
<th>No. of Patients</th>
<th>3-Yr HPR (%)</th>
<th>5-Yr HPR (%)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>13</td>
<td>80</td>
<td>80</td>
<td>0.02</td>
</tr>
<tr>
<td>&lt;4</td>
<td>34</td>
<td>69</td>
<td>53</td>
<td>0.04</td>
</tr>
<tr>
<td>&lt;5</td>
<td>51</td>
<td>64</td>
<td>48</td>
<td>0.03</td>
</tr>
<tr>
<td>&lt;6</td>
<td>64</td>
<td>63</td>
<td>50</td>
<td>0.008</td>
</tr>
</tbody>
</table>

\* HPR = hearing preservation rate.
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**Limitation of This Study**

Between the wait-and-see strategy and GKS, management, that is, the wait-and-see strategy, was compatible with modern GKS techniques. Long-term hearing preservation rates in this study are not necessarily demonstrated those in patients treated with old GKS techniques. In the early years of GKS treatment, conservative management, that is, the wait-and-see strategy, was common in patients harboring small-sized VSs who retained serviceable hearing, especially in those with intracanalicular tumors. However, our results indicate that the best timing of treatment to retain hearing function is while GR Class I hearing remains in patients. If the patient underwent radiosurgery after hearing declined to the level of GR Class II, the possibility of preserving serviceable hearing would be much lower in the long term. Régis et al. evaluated hearing preservation in a comparison between the wait-and-see strategy and GKS. Serviceable hearing preservation rates at 3, 4, and 5 years demonstrated 75%, 52%, and 41% in the wait-and-see group compared with 77%, 70%, and 64% in the GKS group, respectively. The authors concluded that the wait-and-see strategy elevated the risks of tumor growth and hearing loss. Considering hearing preservation as a final goal of treatment, SRS should be offered as soon as possible. Hence, it is important to detect VSs before hearing deteriorates, although early detection is extremely difficult.

**Conclusions**

For the majority of patients with small- to medium-sized VSs, GKS was an effective and reasonable alternative to resection with satisfactory long-term tumor control as well as many fewer complications other than hearing deterioration. Patients with GR Class I hearing and a lower cochlear dose at the time of GKS treatment retained significant serviceable hearing after treatment. It is necessary to collect detailed radiosurgical treatment data in more patients treated with recent techniques and to establish a methodology to achieve both long-term tumor control and hearing preservation.

**Timing for GKS**

In the early years of GKS treatment, conservative management, that is, the wait-and-see strategy, was common in patients harboring small-sized VSs who retained serviceable hearing, especially in those with intracanalicular tumors. However, our results indicate that the best timing of treatment to retain hearing function is while GR Class I hearing remains in patients. If the patient underwent radiosurgery after hearing declined to the level of GR Class II, the possibility of preserving serviceable hearing would be much lower in the long term. Régis et al. evaluated hearing preservation in a comparison between the wait-and-see strategy and GKS. Serviceable hearing preservation rates at 3, 4, and 5 years demonstrated 75%, 52%, and 41% in the wait-and-see group compared with 77%, 70%, and 64% in the GKS group, respectively. The authors concluded that the wait-and-see strategy elevated the risks of tumor growth and hearing loss. Considering hearing preservation as a final goal of treatment, SRS should be offered as soon as possible. Hence, it is important to detect VSs before hearing deteriorates, although early detection is extremely difficult.

At our institute, many of the treated patients were followed up by referring doctors. Consequently, more than 100 patients who retained serviceable hearing at the time of GKS were excluded from our study because there was no follow-up audiogram available. Accordingly, patient enrollment bias should be taken into consideration. Furthermore, there may be other biases, such as those associated with a retrospective analysis, single institutional study, use of different software (KULA or GammaPlan), and changes in practice. In particular, special attention should be paid to long-term hearing preservation rates in this study, because the majority of patients followed up for >5 years were treated with old GKS techniques. Thus, long-term hearing preservation rates in this study do not necessarily demonstrate those in patients treated with modern GKS techniques.

**References**

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**Disclosure**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Hasegawa, Kida. Acquisition of data: Hasegawa, Kato, Iizuka, Yamamoto. Analysis and interpretation of data: Hasegawa. Drafting the article: Hasegawa. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Hasegawa. Statistical analysis: Hasegawa. Study supervision: Hasegawa.

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