As a result of recent advances in microsurgical techniques, instrumentation, and intraoperative monitoring of neuronal functions, functional outcomes after VS surgery have significantly improved over the past decade. The authors of numerous studies have analyzed outcomes with respect to facial nerve and hearing function after VS surgery. Nevertheless, the effect of surgery on tinnitus has not been fully evaluated. The aim of this study was to define the effect on tinnitus of tumor removal, cochlear nerve resection, and useful hearing preservation in patients with VSs.

Methods. The authors retrospectively analyzed the status of tinnitus before and after surgery in 242 patients with unilateral VSs who underwent surgery via the retrosigmoid lateral suboccipital approach.

Results. Of 242 patients, 171 (70.7%) complained of tinnitus before surgery; the symptom disappeared in 25.2%, improved in 33.3%, remained unchanged in 31.6%, and worsened in 9.9% of these cases after tumor removal. In the 171 patients with preoperative tinnitus, the cochlear nerve was resected in 85 (49.7%) and preserved in 86 (50.3%), but there was no significant difference in the incidence of postoperative tinnitus between these 2 groups (p = 0.293). In the 71 patients without preoperative tinnitus, the symptom developed postoperatively in 6 cases (8.5%). Among those without preoperative tinnitus, the cochlear nerve was resected in 45 cases (63.4%) and tinnitus appeared postoperatively in 3 (6.7%). The authors also analyzed the association between postoperative tinnitus and useful hearing preservation, but could not find any statistically significant association between the 2 factors (p = 0.153).

Conclusions. Tumor removal via the retrosigmoid lateral suboccipital approach may provide some chance for improvement of tinnitus in patients with VSs; however, neither cochlear nerve resection nor useful hearing preservation affects the postoperative development of tinnitus. (DOI: 10.3171/2009.3.JNS081053)

Key Words • acoustic tumor • cochlear nerve • tinnitus • vestibular nerve • vestibular schwannoma

Abbreviations used in this paper: GKS = Gamma Knife surgery; PTA = pure tone average; SDS = speech discrimination score; VS = vestibular schwannoma.
Tinnitus in VS

<table>
<thead>
<tr>
<th>TABLE 1: Summary of clinical characteristics in 242 patients with VSs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>no. of patients (%)</td>
</tr>
<tr>
<td>sex (male/female)*</td>
</tr>
<tr>
<td>mean age ± SD (yrs)</td>
</tr>
<tr>
<td>mean tumor size ± SD (cm)</td>
</tr>
<tr>
<td>% of patients w/ preop useful hearing†</td>
</tr>
</tbody>
</table>

* Student t-test, p < 0.05.
† Useful hearing was defined as a PTA ≤ 50 dB and SDS ≥ 50%. There was no statistically significant difference between the 2 groups.

We paid special attention to the status of tinnitus in these patients, who were interviewed carefully about this symptom both pre- and postoperatively, and recorded this information in the medical chart. In some patients in the earlier period of our study, however, we could not obtain precise information about tinnitus, and these patients were excluded from the present study. Patients with bilateral acoustic tumors (neurofibromatosis Type 2) were also excluded. As a consequence, 242 patients with unilateral VSs were included in the present study. Patient clinical data, including the pre- and postoperative presence of tinnitus, were obtained by retrospective chart review. The patients included 103 men and 139 women with a mean age of 49.8 years (range 17–76 years) and a mean follow-up period of 97.7 months (range 2–253 months). Measurements of PTA and SDS were performed in these patients by audiologists, and 103 patients had useful hearing (PTA ≤ 50dB and SDS ≥ 50%; Gardner-Robertson Classification 10 1 and 2) on the tumor side preoperatively. No patient harbored a pure intracanalicular tumor. The maximum tumor diameter in the cerebellopontine cistern was measured in all cases on preoperative MR or CT images, as described previously.35

Statistical Analysis

The Student t-test and chi-square test were used to evaluate the differences in significance. Probability values < 0.05 were considered statistically significant.

Results

Patient Clinical Characteristics

The clinical characteristics of patients with unilateral VSs and preoperative tinnitus are summarized in Table 1. Of the 242 included patients, 171 (70.7%) complained of tinnitus preoperatively, and 71 (29.3%) did not. The mean age of patient with tinnitus was 48.6 years, which was younger than that of patients without tinnitus (52.7 years; p < 0.05). The mean tumor size in patients with tinnitus was 2.12 cm in diameter, which was smaller than that in patients without tinnitus (2.47 cm; p < 0.05). There was no significant difference in male/female ratios between the 2 groups (p = 0.255). The percentage of patients with tinnitus who retained useful hearing preoperatively (46.3%) was slightly higher than that of patients without preoperative tinnitus (38.6%); however, this difference was not statistically significant (p = 0.315).

Surgical Outcomes With Regard to Tinnitus

Of patients with preoperative tinnitus, the symptom disappeared in 25.2% (43/171) and improved in 33.3% (57/171) of cases postoperatively (Table 2). Therefore, 58.5% (100/171) of the patients felt some beneficial effect of surgery on tinnitus. On the other hand, the status of tinnitus was unchanged in 31.6% (54/171) and worsened in 9.9% (17/171) of cases. Of the 71 patients without preoperative tinnitus, 65 (91.5%) did not perceive any tinnitus after the operation, and 6 (8.5%) reported that the symptom had newly developed postoperatively.

Effect of Cochlear Nerve Resection on Tinnitus

We next examined the effect of cochlear nerve resection on tinnitus in patients with VS (Table 3). Of patients with preoperative tinnitus, the cochlear nerve was resected in 49.7% (85 of 171 patients). In this group of patients, tinnitus disappeared in 27.1% (23/85), improved in 29.4% (25/85), remained unchanged in 36.5% (31/85), and worsened in 7.0% (6/85) of cases. The cochlear nerve was anatomically preserved in 50.3% (86/171) of patients. In these patients, tinnitus disappeared in 23.3% (20/86), improved in 37.2% (32/86), remained unchanged in 26.7% (23/86), and worsened in 12.8% (11/86) of cases. The percentage of those with worsened tinnitus was slightly higher among patients who did not undergo cochlear nerve resection compared to those who did; however, this difference was not statistically significant (p = 0.293). There was no significant difference in the overall effects of surgery on tinnitus between the 2 groups.

Of those patients without preoperative tinnitus, the cochlear nerve was resected in 63.4% (45/71), and tinnitus newly developed in 6.7% (3/45) of these cases (Table 3). On the other hand, the cochlear nerve was anatomically preserved in 36.6% (26/71) of patients, and 11.5% (3/26) of these patients reported tinnitus postoperatively. The percentage of postoperative tinnitus in the group that did not undergo cochlear nerve resection was also slightly higher than that in the group that did; however, this difference was not statistically significant (p = 0.662).

Postoperative Tinnitus and Useful Hearing

We also analyzed the association between postop-
TABLE 3: Effect of cochlear nerve resection on tinnitus in patients with VS

<table>
<thead>
<tr>
<th>Postop Tinnitus Status</th>
<th>Preop Tinnitus Present</th>
<th>Preop Tinnitus Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cochlear Nerve Resection (85 patients)</td>
<td>No Cochlear Nerve Resection (86 patients)</td>
</tr>
<tr>
<td>disappeared (%)</td>
<td>23 (27.1)</td>
<td>20 (23.3)</td>
</tr>
<tr>
<td>improved (%)</td>
<td>25 (29.4)</td>
<td>32 (37.2)</td>
</tr>
<tr>
<td>unchanged (%)</td>
<td>31 (36.5)</td>
<td>23 (26.7)</td>
</tr>
<tr>
<td>worsened (%)</td>
<td>6 (7.0)</td>
<td>11 (12.8)</td>
</tr>
</tbody>
</table>

* None of these comparisons reached statistical significance (chi-square test).

Discussion

Mechanisms of Tinnitus Associated With VSs

The pathophysiology of tinnitus is poorly understood, but several potential mechanisms of this symptom have been suggested in the literature. Baguley et al. previously proposed 4 specific mechanisms of generation of tinnitus in VSs: 1) emphatic coupling of cochlear nerve fibers by compression; 2) cochlear dysfunction by ischemia or by biochemical degradation; 3) efferent system dysfunction following compression of the efferent fibers in the inferior vestibular nerve; and 4) cortical reorganization following hearing loss. Based on our observations, however, the mechanism underlying tinnitus appears to be more complicated, and none of these proposed mechanisms can explain the cause of tinnitus as a single factor. If the origin of tinnitus were cochlear nerve fibers, then tinnitus would be eliminated by cochlear nerve resection. If the cause of tinnitus were compression of cochlear nerve fibers or nuclei by the tumors, then tumor size should be associated with the status of preoperative tinnitus, and the effect of tumor removal on this symptom should be more evident in patients with larger tumors. If tinnitus is caused by cortical reorganization after hearing loss, useful hearing preservation should be associated with postoperative tinnitus. In our analysis, however, no statistical association was found between tinnitus and any of these factors. Further investigation is needed to elucidate the mechanisms that generate tinnitus in patients with VSs.
These outcomes might be due to a degree of variability in the numbers of included patients (ranging 51–273 in the literature) and differences in surgical procedures (including surgical approaches). In previous reports, most tumor resections have been performed via a middle cranial fossa approach or a translabyrinthine approach. Some patients have undergone labyrinthectomy as part of a surgical approach, but this might have affected postoperative tinnitus because it can be destructive to the auditory system. In our patients, all operations were performed consistently via a retrosigmoid lateral suboccipital approach, and tinnitus was relieved in 58.4% of patients postoperatively (Table 2). Therefore, more than half of the patients with preoperative tinnitus had some benefits from the surgery with regard to this symptom.

On the other hand, tinnitus worsened in 9.9% of patients with preoperative tinnitus, and developed for the first time after surgery in 8.5% of patients without preoperative tinnitus (Table 2). Thus, our surgical procedure provides up to a 60% chance for improvement of tinnitus, but it carries up to a 10% risk of worsening tinnitus. This information should be explained to patients planning to undergo VS surgery through a retrosigmoid lateral suboccipital approach. In the literature, there are several reports of tinnitus after radiosurgery in patients with VSs; however, a systematic analysis was rarely conducted. Among the studies to note this phenomenon, Hempel et al. report a systematic analysis was rarely conducted. Among the studies to note this phenomenon, Hempel et al.15 reported the largest series of patients treated with GKS with a median observation period of 98 months. In their report, 84 (70%) of 120 patients complained of tinnitus before GKS. After GKS, 82 patients (68.3%) had tinnitus. Five patients (4.2%) first complained of the onset of tinnitus after GKS, while 7 patients (5.8%) with preoperative tinnitus experienced complete symptom resolution after GKS. The majority of patients (90%) reported no change in the symptom after GKS. Based on these observations, microsurgical tumor removal appears to provide a better possibility of improvement of tinnitus than radiosurgery in patients with VSs.

**Impact of Cochlear Nerve Resection on Tinnitus**

To date, only a few studies have systematically analyzed the impact of cochlear nerve resection on tinnitus in patients with VSs. Goel et al. reported on a case that required a reexploration and cochlear nerve resection to alleviate persistent tinnitus after VS surgery. Cochlear nerve resection did not affect tinnitus in this patient. To define the effect of cochlear nerve resection on tinnitus and avoid continuation of malpractice associated with surgery, we analyzed the results of this surgical procedure in our patients with or without preoperative tinnitus (Table 3). As a consequence, we found that there was no significant difference in the status of postoperative tinnitus between patients who did and did not undergo cochlear nerve resection. Therefore, we concluded that cochlear nerve resection does not affect overall outcomes in terms of postoperative tinnitus and suggest that surgeons should not intentionally perform this procedure with the sole intent to relieve tinnitus in patients with VSs.

**Postoperative Useful Hearing and Tinnitus**

There is some controversy regarding the association between postoperative useful hearing preservation and tinnitus. Catalano and Post previously reported on their experience in 51 patients who underwent hearing preservation surgery for VSs via a retrosigmoid approach. Although the number of included patients was small, the authors concluded that new onset of tinnitus was uncommon after hearing preservation surgery, and that preexisting tinnitus could be reduced or eliminated with surgery, especially when useful hearing was preserved. Conversely, Kanzaki et al. claimed that hearing preservation surgery carried a risk of worsening tinnitus. In their study, the middle cranial fossa approach was performed in candidates for hearing preservation surgery, and labyrinthectomy was added for the remaining patients. The incidence of postoperative tinnitus was significantly higher in the hearing preservation group (89.3%).

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**TABLE 4: Postoperative useful hearing and tinnitus**

<table>
<thead>
<tr>
<th>Postop Tinnitus Status</th>
<th>Preoperative Tinnitus Present</th>
<th>Preoperative Tinnitus Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Postop Useful Hearing Present</td>
<td>Postop Useful Hearing Absent</td>
</tr>
<tr>
<td></td>
<td>40 patients</td>
<td>37 patients</td>
</tr>
<tr>
<td>disappeared (%)</td>
<td>10 (25.0)</td>
<td>10 (27.1)</td>
</tr>
<tr>
<td>improved (%)</td>
<td>17 (42.5)</td>
<td>9 (24.3)</td>
</tr>
<tr>
<td>unchanged (%)</td>
<td>6 (15.0)</td>
<td>13 (35.1)</td>
</tr>
<tr>
<td>worsened (%)</td>
<td>7 (17.5)</td>
<td>5 (13.5)</td>
</tr>
<tr>
<td></td>
<td>Postop Useful Hearing Present</td>
<td>Postop Useful Hearing Absent</td>
</tr>
<tr>
<td></td>
<td>12 patients</td>
<td>14 patients</td>
</tr>
<tr>
<td>disappeared (%)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>improved (%)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>unchanged (%)</td>
<td>10 (83.3)</td>
<td>12 (85.7)</td>
</tr>
<tr>
<td>worsened (%)</td>
<td>2 (16.7)</td>
<td>2 (14.3)</td>
</tr>
</tbody>
</table>

* No comparison reached statistical significance (chi-square test).

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**TABLE 5: Tumor size and effects of surgery on tinnitus**

<table>
<thead>
<tr>
<th>Postop Tinnitus Status</th>
<th>No. w/ Small Tumors</th>
<th>No. w/ Large Tumors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(83 patients)</td>
<td>(88 patients)</td>
</tr>
<tr>
<td>disappeared (%)</td>
<td>23 (27.7)</td>
<td>20 (22.7)</td>
</tr>
<tr>
<td>improved (%)</td>
<td>26 (31.3)</td>
<td>31 (35.2)</td>
</tr>
<tr>
<td>unchanged (%)</td>
<td>23 (27.7)</td>
<td>31 (35.2)</td>
</tr>
<tr>
<td>worsened (%)</td>
<td>11 (13.3)</td>
<td>6 (6.8)</td>
</tr>
</tbody>
</table>

* Small tumors were defined as < 2 cm diameter, and large tumors were ≥ 2 cm diameter. There was no statistically significant difference between the 2 groups (p = 0.367).
than in the non-hearing preservation group (67.3%). The authors also stated that when tinnitus was absent preoperatively, tinnitus developed in 85% of the hearing preservation group postoperatively compared to only 31% of the patients in the non-hearing preservation group. Among our patients, however, there was no apparent association between postoperative tinnitus and useful hearing. The status of postoperative tinnitus in patients with useful hearing was quite similar to that in patients who lost useful hearing. We suppose that this discrepancy is probably caused by the difference in surgical procedures, such as surgical approach and tumor dissection. We consistently performed a retrosigmoid lateral suboccipital approach in all cases, and no labyrinthectomy has been applied. In addition, we used a subcapsular dissection technique when tumor adhesion to the cochlear nerve was severe. Consequently, the rate of useful hearing preservation in our series (50.5%; 52/103) was much higher than that in theirs (24.5%; 25/102). Our surgical approach might reduce the risk of injury to the cochlear nerve that may result in generation of postoperative tinnitus.

Conclusions

Tumor removal via a retrosigmoid lateral suboccipital approach carries an up to 60% chance for improvement of tinnitus, and an up to a 10% risk of worsening existing tinnitus in patients with VS. In our patients, neither cochlear nerve resection nor useful hearing preservation affected the incidence of postoperative tinnitus. Therefore, we suggest that when a patient has useful hearing preoperatively, surgeons should try to preserve it and should not intentionally resect the cochlear nerve to eliminate tinnitus.

Disclaimer

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

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References

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Address correspondence to: Katsuharu Kameda, M.D., Department of Neurosurgery, Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan. email: kcameta@ns.med.kyushu-u.ac.jp.