Retrosigmoid removal of small acoustic neuroma: curative tumor removal with preservation of function

Clinical article

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Object. Management of small acoustic neuromas (ANs) consists of 3 options: observation with imaging follow-up, radiosurgery, and/or tumor removal. The authors report the long-term outcomes and preservation of function after retrosigmoid tumor removal in 44 patients and clarify the management paradigm for small ANs.

Methods. A total of 44 consecutively enrolled patients with small ANs and preserved hearing underwent retrosigmoid tumor removal in an attempt to preserve hearing and facial function by use of intraoperative auditory monitoring of auditory brainstem responses (ABRs) and cochlear nerve compound action potentials (CNAPs). All patients were younger than 70 years of age, had a small AN (purely intracanalicular/cerebellopontine angle tumor ≤ 15 mm), and had serviceable hearing preoperatively. According to the guidelines of the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology–Head and Neck Surgery Foundation, preoperative hearing levels of the 44 patients were as follows: Class A, 19 patients; Class B, 17; and Class C, 8. The surgical technique for curative tumor removal with preservation of hearing and facial function included sharp dissection and debulking of the tumor, reconstruction of the internal auditory canal, and wide removal of internal auditory canal dura.

Results. For all patients, tumors were totally removed without incidence of facial palsy, death, or other complications. Total tumor removal was confirmed by the first postoperative Gd-enhanced MRI performed 12 months after surgery. Postoperative hearing levels were Class A, 5 patients; Class B, 21; Class C, 11; and Class D, 7. Postoperatively, serviceable (Class A, B, or C) and useful (Class A or B) levels of hearing were preserved for 84% and 72% of patients, respectively. Better preoperative hearing resulted in higher rates of postoperative hearing preservation (p = 0.01); preservation rates were 95% among patients with preoperative Class A hearing, 88% among Class B, and 50% among Class C. Reliable monitoring was more frequently provided by CNAPs than by ABRs (66% vs 32%, p < 0.01), and consistently reliable auditory monitoring was significantly associated with better rates of preservation of useful hearing. Long-term follow-up by MRI with Gd administration (81 ± 43 months [range 5–181 months]; median 7 years) showed no tumor recurrence, and although the preserved hearing declined minimally over the long-term postoperative follow-up period (from 39 ± 15 dB to 45 ± 11 dB in 5.1 ± 3.1 years), 80% of useful hearing and 100% of serviceable hearing remained at the same level.

Conclusions. As a result of a surgical technique that involved sharp dissection and internal auditory canal reconstruction with intraoperative auditory monitoring, retrosigmoid removal of small ANs can lead to successful curative tumor removal without long-term recurrence and with excellent functional outcome. Thus, the authors suggest that tumor removal should be the first-line management strategy for younger patients with small ANs and preserved hearing.

Key Words • acoustic neuroma • hearing preservation • oncology • intraoperative auditory monitoring • microsurgery • tumor removal

Technological developments and the prevalence of MRI have increased the number of small acoustic neuromas (ANs) that are detected. Currently, the 3 management options for small ANs are observation with imaging follow-up (wait-and-scan), radiosurgery, and/or tumor removal.2 Technological developments and the prevalence of MRI have increased the number of small acoustic neuromas (ANs) that are detected. Currently, the 3 management options for small ANs are observation with imaging follow-up (wait-and-scan), radiosurgery, and/or tumor removal.2,3 Magnetic resonance imaging can be used to evaluate the size and volume of small ANs accurately, noninvasively, and repeatedly. Because tumor growth of small ANs is usually slow, wait-and-scan has become a common and valid alternative that allows for documentation of the benign natural history of small ANs while offering the safety and feasibility of observation management.2,4 Radiosurgery, which is much less invasive than tumor removal, offers the most control over small ANs, although it does not eradicate the tumor. Ra-
Retrosigmoid removal of small acoustic neuroma
dosurgery achieves a good functional outcome; facial
testion is preserved for 95%–100% of patients35 and
useful hearing for 61%–78%.4,13,14,45 Under certain circum-
stances, a surgeon might be requested to perform curative
tumor removal of a small AN, usually to preserve facial
function and hearing. To achieve excellent functional
outcome after surgery, we have refined the microsurgi-
tical technique and intraoperative auditory monitoring for
retrosigmoid removal of small ANs. Our newly designed
intracanalicular tumor, the cerebellopontine
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angle arachnoid dissection was limited to the minimal
area near the porus acusticus. The restricted arachnoid
dissection prevented the cerebellum from sinking down-
ward from gravity, which has been shown to be the typi-
cal cause of hearing loss because of longitudinal traction
of the acoustic nerve.30

Petrosus Dura Flap to Protect the Cerebellopontine
Angle. Before the posterior wall of the internal auditory
canal was drilled, the dura of the petrous bone that forms
the posterior wall was peeled off as a flap from the fun-
dus side to the porus side. The petrous dura flap, secured
by using a brain retractor, protected the cerebellopontine
gle during posterior wall drilling (Fig. 1A).

Posterior Wall Drilling. The petrous bone was drilled
wide enough on both sides of the internal auditory canal
to provide a sufficient extraction area; however, to pre-
serve the common crus, we limited drilling on the lateral
(fundus) end. We began drilling with a large (3-mm) steel
bur head and then used a 3-mm diamond bur head to skel-
etonize the internal auditory canal dura. The last stage of
internal auditory canal skeletonization comprised trim-
ing the sides and fundus area of the internal auditory
canal by using a smaller (2-mm) diamond bur head (Fig.
1B). Sufficient drilling caused the meatal tumor to bulge
out by itself; however, at this time, the tumor was still
covered by the dura (Fig. 1C).

Harvesting of the Petrous Dura Flap for Internal Au-
ditory Canal Reconstruction. After completing adequate
posterior wall drilling, we removed the petrous dura flap
and preserved it for subsequent internal auditory canal
reconstruction.

Wide Removal of the Internal Auditory Canal Dura.
To gain wide exposure of the intrameatal nerves and tu-
mor, after cutting the sides and lateral end, we removed
the exposed internal auditory canal dura in its entirety as
a single sheet.

Sharp Tumor Dissection. We then dissected the tu-
mor from the nerves (vestibular, cochlear, and facial) by
using microscissors and microknives in the same way
that they would be used for dissecting the arachnoid
membrane and trabeculae.

Tumor Debulking. The tumor and the surrounding
nerves were tightly packed in the internal auditory canal.
Dissection of the tumor without first debulking it would
have caused unexpected compression or damage to the
preserved nerve. Therefore, intracapsular tumor debul-
k is always mandatory, even in patients with small
ANs. Tumor debulking using ring or blunt dissectors can
compress and damage the nerves surrounding the tumor.
Thus, we debulked the tumor by using microscissors and
microknives. Last, the tumor was removed piece by piece
by using microscissors throughout the dissection.

Tumor Removal Near the Fundus of the Internal Au-
ditory Canal. Tumor excision near the fundus was the last
and most hazardous stage of tumor removal. With direct
visualization of the fundus area, we cautiously and sharp-
ly dissected the tumor out by using microscissors.

Preservation of Nerve Function. For hemostasis, we

Methods
During the period of 1998–2012, we consecutively
enrolled 44 patients (19 men and 25 women, 22–69 years
of age [mean age 52 ± 12 years]) with small ANs and pre-
served hearing who underwent curative tumor removal in
an attempt to preserve facial and hearing functions. To
meet the study inclusion criteria, patients needed to have
a small AN, have serviceable hearing preoperatively, and
be younger than 70 years of age. A small AN was defined
as a purely intracanalicular AN without cerebellopontine
angle extension (6 patients) or an AN with a cerebello-
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Preservation of Nerve Function. For hemostasis, we
used oxidized cellulose, surgical patties, saline irrigation, and, sometimes, an application of gentle pressure, which was sufficient.

Internal Auditory Canal Reconstruction and Restoring the CSF Space in the Internal Auditory Canal. As mentioned, the petrous dura flap was harvested for internal auditory canal reconstruction (Fig. 1D). After completion of the tumor removal, the roof of the internal auditory canal was reconstructed by using the harvested dura flap. Thereafter, muscle or fat grafts were placed on this roof to fill up the removed posterior wall. The new internal auditory canal roof separated the preserved cochlear and facial nerves from the grafts and restored the space in the internal auditory canal (Fig. 2).

Intraoperative Monitoring of Auditory and Facial Function

During surgery, we performed simultaneous and continuous monitoring of the auditory brainstem responses (ABRs) and CNAPs. In brief, ABRs were monitored throughout the duration of the surgery, and CNAPs were monitored continuously throughout intradural microsurgery by using our newly developed intracranial elec-

<table>
<thead>
<tr>
<th>Preop Hearing Class*</th>
<th>Postop Hearing Class*</th>
<th>Rate of Postop Serviceable Hearing Preservation</th>
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<tr>
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<td>A</td>
<td>B</td>
<td>C</td>
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<td>4</td>
</tr>
<tr>
<td>total</td>
<td>5</td>
<td>21</td>
<td>11</td>
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*American Academy of Otolaryngology–Head and Neck Surgery Classification.
†p = 0.01 (chi-square test).
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§50% (4/8), the rate of postoperative serviceable hearing preservation among the 8 patients with preoperative Class C hearing, is statistically significant (p = 0.01) compared with 95% (18/19), the rate of postoperative serviceable hearing preservation among the patients with preoperative Class A hearing, and 88% (15/17), the rate of postoperative serviceable hearing preservation among the patients with preoperative Class B hearing. Moreover, 50% (4/8) is statistically significant (p < 0.01) compared with 92% (33/36), the rate of postoperative serviceable hearing preservation among the patients with Class A or B hearing.

Fig. 1. A: The petrous dura flap (arrows) protecting the cerebellopontine angle. B: Trimming both sides of the internal auditory canal by using a small diamond bur head. C: Sufficient internal auditory canal drilling caused meatal tumor bulging. D: Using the petrous dura flap (arrows) to reconstruct the new roof of the internal auditory canal.
trodes. Facial function was monitored by intermittent electrical stimulation of the intracranial facial nerve with the NIM nerve monitoring system (Medtronic).

Postoperative Follow-Up

After tumor removal, all patients were regularly examined at the outpatient clinic every 3–6 months. To confirm the extent of tumor removal, they underwent the first postoperative Gd-enhanced MRI 12 months after surgery; to evaluate tumor recurrence, they underwent follow-up Gd-enhanced MRI every year thereafter. Data analysis was performed by using StatView software (SAS Institute Inc.), and statistical significance was defined as p ≤ 0.05. Data are expressed as means and standard deviations.

This study adhered to the World Medical Association Declaration of Helsinki and the guidelines for clinical research published by the ethical committee of Chiba Central Medical Center. All patients gave informed consent before inclusion in this study.

Results

Outcomes of Tumor Removal and Preservation of Function

Total tumor removal was achieved for all patients and confirmed by surgical records and the first postoperative Gd-enhanced MRI (12 months after surgery). Postoperative hearing levels were Class A, B, C, and D for 5, 21, 11, and 7 patients, respectively (Table 1). Postoperative rates of preservation of serviceable and useful hearing were 37/44 (84%) and 26/36 (72%), respectively. The postoperative rate for preservation of serviceable hearing was 95% among patients with preoperative Class A hearing, 88% among those with Class B hearing, and 50% among those with Class C hearing (p = 0.01). Serviceable hearing was preserved for 92% of patients with preoperative Class A or B hearing and 50% of patients with preoperative Class C hearing (p < 0.01). A mild facial palsy (House-Brackmann Grade II) occurred in 2 patients (5%) during the first postoperative week, but normal facial function had been recovered (House-Brackmann Grade I) when they were seen in the outpatient clinic. No deaths or other postoperative complications occurred.

Intraoperative Auditory Monitoring (Fig. 3)

Monitoring of ABRs during tumor removal was often disrupted by artifacts from various surgical equipment and procedures. Among the 44 patients, reliable monitoring of ABRs with the distinct wave V was consistently obtained in 14 (32%), was intermittently obtained in 10 (23%), and was either unreliable or not obtained in 20 (45%) (Table 2). Consistently reliable ABR monitoring was obtained in 11 (58%) of 19 patients with preoperative Class A hearing, 3 (18%) of 17 with preoperative Class B hearing, and 0 of 8 with preoperative Class C hearing (p < 0.01). Useful hearing was preserved postoperatively in 12 (86%) of 14 patients with consistently reliable ABRs, but in only 9 (45%) of 20 patients with unreliable/not obtained ABRs (p < 0.05).

Cochlear nerve compound action potentials were not affected by artifacts of surgical equipment and procedures. Reliable CNAPs were obtained consistently throughout microsurgical tumor removal in 29 (66%) of the 44 patients, and reliable auditory monitoring was achieved more frequently with CNAPs than with ABRs (66% vs 32%, p < 0.01). Cochlear nerve compound action potentials were intermittently reliable in 7 patients and unreliable/not obtained in 8 patients (Table 2). Useful hearing was preserved postoperatively in 22 (76%) of 29 patients with consistently reliable CNAPs and in 4 (27%)
Long-Term Postoperative Follow-Up Results of Gd-Enhanced MRI and Audiological Examinations

During the long-term Gd-enhanced MRI follow-up period (81 ± 43 months [range 5–181 months], median 7 years), no tumor recurred in any patient. However, for 1 patient (a 42-year-old woman) hearing suddenly worsened 30 months after surgery. No tumor recurrence was demonstrated on Gd-enhanced MRI, so the patient underwent treatment for sudden deafness, which did not ameliorate her hearing impairment (from 36 dB to 70 dB in pure tone averages). No sudden deterioration of the preserved hearing occurred in any other patient; postoperative audiological follow-up examinations for preserved hearing showed a decline of pure tone averages from 39 ± 15 dB to 45 ± 11 dB over 5.1 ± 3.1 years (range 2–13 years); that is, the rate of annual hearing decrease was 1.2 dB per year. Preserved useful hearing remained the same for 12 (80%) of 15 patients, and preserved serviceable hearing was maintained for all 37 patients.

Discussion

Wait-and-Scan for Patients With Small ANs and Preserved Hearing

Observation management with imaging follow-up (wait-and-scan) has become the prevalent strategy for managing small ANs. This approach has revealed that the natural history of ANs as a whole is benign and that the mean tumor growth rate is 1.0–3.0 mm per year. However, the wait-and-scan strategy has also revealed that the growth rate and pattern of small ANs vary widely among patients. Growth rates are less than 1 mm per year for more than 60% of patients and more than 3 mm per year for 12% of patients. Moreover, no significant association has been found between tumor growth rate and factors such as sex, age, initial hearing status, or preliminary

TABLE 2: Results of intraoperative auditory monitoring versus preoperative and postoperative hearing among 44 patients who underwent retrosigmoid removal of small AN

<table>
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<tr>
<th>Type of Monitoring</th>
<th>No. of Cases</th>
<th>ABRs</th>
<th>Preoperative</th>
<th>Postoperative</th>
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<td></td>
<td></td>
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<td>B</td>
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<td>14</td>
<td>11</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>intermittently reliable</td>
<td>10</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>unreliable/not obtained</td>
<td>20</td>
<td>5</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>total</td>
<td>44</td>
<td>19</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>CNAPs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consistently reliable</td>
<td>29</td>
<td>17</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>intermittently reliable</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>unreliable/not obtained</td>
<td>8</td>
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<td>3</td>
<td>5</td>
</tr>
<tr>
<td>total</td>
<td>44</td>
<td>19</td>
<td>17</td>
<td>8</td>
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* American Academy of Otolaryngology–Head and Neck Surgery Classification.
tumor grade. Because the tumor growth of each patient is unpredictable, the ideal interval for imaging follow-up studies is not fixed.

Previous reports of the wait-and-scan approach for patients with small ANs and preserved hearing have indicated that hearing progressively declines regardless of tumor growth. Specifically, 1 study showed that pure tone averages among 47 patients with intracanalicular AN deteriorated from 38 dB to 51 dB and that 26% of useful hearing was lost during the 3.6-year duration of the wait-and-scan management strategy. Another study revealed that over a follow-up period of more than a decade, most patients with preserved useful hearing lost the useful hearing regardless of tumor growth. These studies provide compelling evidence that, to avoid the progressive hearing decline that has been reported for the prevalent wait-and-scan approach, tumor removal should be the first treatment option for younger patients with small ANs and preserved hearing.

Long-Term Outcome of Curative Small AN Removal With Preservation of Function

In our study, retrosigmoid removal of small ANs in 44 patients with preserved hearing was accomplished with excellent functional outcomes. Curative tumor removal was confirmed by long-term MRI follow-up examinations.

One of the main and most challenging focuses in the management of small ANs is preservation of hearing. In our study, the rates of postoperative preservation of useful and serviceable hearing were 72% and 84%, respectively. Table 3 summarizes the outcome of hearing and facial function after tumor removal and radiosurgery of small ANs. Two surgical approaches (the retrosigmoid approach and the middle fossa approach) are currently used for small AN removal in cases where hearing preservation is desired. Although it has previously been claimed that a higher rate of hearing preservation can be accomplished with the middle fossa approach than with the retrosigmoid approach, recent publications have suggested that there is no difference between the 2 approaches (that is, hearing is preserved for 50%–77% of patients after the retrosigmoid approach and for 52%–73% after the middle fossa approach). By using the retrosigmoid approach, we achieved the same level of preservation (72%) in the study reported here.

We showed that better preoperative hearing resulted in a higher rate of postoperative hearing preservation: 95% preservation for patients with preoperative Class A hearing, 88% for Class B, and 50% for Class C. Therefore, hearing preservation after tumor removal is associated with the preoperative hearing level.

Intraoperative auditory monitoring during this study showed that reliable auditory monitoring was more frequently obtained for patients with better preoperative hearing. Moreover, reliable monitoring was also associated with higher rates of postoperative hearing preservation. In this study, intraoperative auditory monitoring with ABRs and CNAPs was performed simultaneously and reliable auditory monitoring more frequently with CNAPs than with ABRs (66% vs 32%, p < 0.01). Because

<table>
<thead>
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<th>Treatment Modality</th>
<th>Rate of Useful Hearing Preservation</th>
<th>Hearing After Treatment</th>
</tr>
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<tr>
<td>surgery</td>
<td>50–77</td>
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<tr>
<td>middle fossa approach</td>
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<td>retrosigmoid approach</td>
<td>50–77</td>
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<tr>
<td>radiosurgery</td>
<td>usual/definite</td>
<td>90–100</td>
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</table>

* Data from a series of studies published in 2000 or later.
of their large amplitude, CNAPs can almost be monitored in real time, thus giving the surgeon intraoperative feedback. This feedback enables the surgeon to refine the surgical technique in an attempt to preserve hearing and facial function intraoperatively, thereby improving functional outcome. Several points with regard to surgical techniques for preservation of hearing and facial function are detailed above. However, the most critical point for preservation of hearing and facial function is sharp dissection with microscissors and microknives. Blunt dissection not only damages nerves by indirect compression but also damages small vessels that have mild adhesions.

Although removal of medium or large ANs carries a considerable risk for facial palsy, a series of recent studies of removal of small ANs reported high rates of facial function preservation (88%–100%). In reports published during the 1980s–1990s, the rates of good facial function preservation after small AN removal were unsatisfactory (72%–94%). The increased success can be attributed to the development of surgical and monitoring techniques. With regard to surgical approaches, we and others have found that the retrosigmoid approach can offer better postoperative facial function than the middle fossa approach. This is so because for the access route of the middle fossa approach, the facial nerve is located in front of the tumor, but for the retrosigmoid approach, the nerve is located behind the tumor; thus, during tumor removal, the middle fossa approach requires greater manipulation of the facial nerve. Preservation of facial function is also excellent (95%–100%) after radiosurgery.

Progressive Hearing Decline After AN Treatment

The highest rates of hearing preservation after treatment of small ANs are achieved with radiosurgery; useful hearing is preserved for 61%–78% of patients. However, preserved hearing after radiosurgery has been shown to progressively decline. This progressive decline is typical and definite; hearing preservation rates are 43%–57% at 5 years after radiosurgery and decrease to 34%–45% at 10 years.

In our study, after retrosigmoid tumor removal, the occurrence of postoperative decline of preserved hearing was rare and the level of the postoperative decline was minimal; that is, over the long term, useful hearing and serviceable hearing were preserved for 80% and 100% of patients, respectively. Yomo et al. reported that the rate of annual hearing decrease among AN patients was 5.39 dB per year and 3.77 dB per year before and after radiosurgery, respectively. In our study, the rate of annual hearing decrease after retrosigmoid small AN removal was 1.2 dB per year, which is much lower than that after radiosurgery. In addition, it is possible that the postoperative hearing decline found in this study might represent natural hearing decline from aging (presbycusis). Postoperative declines in hearing after tumor removal through the middle fossa approach have been documented. After tumor removal, scarring of the preserved cochlear nerve occurs as a consequence of fat or muscle graft packing of the internal auditory canal and results in delayed hearing declines. We reconstructed the internal auditory canal after tumor removal by using the petrous dura flap to restore the CSF space of the internal auditory canal. Recovery of the CSF space prevents scarring of the preserved nerve, and this method of internal auditory canal reconstruction can contribute to long-term hearing preservation after tumor removal. Mazzoni et al. recently reported that after retrosigmoid AN removal, 87% of preserved useful hearing was maintained at the same level over a long-term follow-up period of 6–21 years. Recent studies of the middle fossa approach tumor removal showed no or minimal hearing decline in the postoperative follow-up period.

Learning Curve for Microsurgery and Radiosurgery

Surgical removal of ANs requires a profound knowledge of anatomy and long-standing experience with sophisticated microsurgical technique. The expertise of the surgeon and/or surgical teams affects the outcome of this technically demanding procedure, and the existence of a learning curve has been reported. To attain surgical results similar to those reported by expert surgeons, experience with 20–50 cases is necessary. Before starting the series of cases reported here, the senior author had removed more than 60 ANs, most of which were large/giant tumors. Despite the relatively small number of patients in this series, we removed 240 previously untreated ANs during the same period. Our study shows excellent results regarding preservation of hearing and facial function as well as total tumor removal; therefore, no learning curve was observed. Radiosurgical treatment of ANs requires precise anatomical definition and optimal dose distribution. Because of continuous advances in imaging technology and the refinement of radiosurgical technology, radiosurgery requires improvement of skill and knowledge. A learning curve exists for radiosurgical dose planning of AN treatment, although the effect on the clinical outcome has not yet been elucidated.

Management Paradigm for Small ANs

In this study, we analyzed the long-term outcome of 44 patients with preserved hearing who had undergone removal of small ANs; we showed that retrosigmoid tumor removal with auditory monitoring can accomplish curative tumor removal and excellent functional outcome without deaths or other postoperative complications. During wait-and-scan of small ANs in patients with preserved hearing, progressive hearing decline occurs frequently, irrespective of tumor growth. After radiosurgery, progressive hearing decline is inevitable. Therefore, we propose that tumor removal, with preservation of hearing and facial function, should be the first-line management for small ANs in younger patients with preserved hearing. Figure 4 outlines this management algorithm. Briefly, patients younger than 70 years of age with preserved hearing and a small AN should be offered tumor removal with preservation of hearing and facial function. For patients 70 years of age or older, the wait-and-scan approach should be offered; thereafter, patients with tumor growth during the wait-and-scan
period should be offered either tumor removal or radiosurgery.

**Study Limitations and Strengths**

This study has some limitations and several strengths. The limitations include the retrospective nature of the study, limited number of patients, potential biases of patient selection, and unknown natural history of AN. At the start of this study, we determined the inclusion criteria for patients who would undergo curative tumor removal with preservation of hearing and facial function (small AN, serviceable hearing, and age younger than 70 years). However, not all patients conforming to the inclusion criteria underwent this surgery because each patient selected his or her own treatment plan after being informed of the 3 treatment options (wait-and-scan, radiosurgery, or tumor removal). Not being a prospectively controlled trial, this study could not evade patient selection bias. Although the natural history of hearing and tumor growth of small ANs is discussed above in relation to the results of wait-and-scan study series, the real natural history of small ANs is unknown. The long-term outcomes after tumor removal and radiosurgery should be determined with regard to the real natural history of small ANs by using a well-controlled, randomized trial. However, the nature of ANs makes a well-controlled, randomized trial unpractical because attaining statistical significance would require sample sizes of more than 6700 patients in each study group. Despite the limited number of patients in our study, the auditory monitoring using CNAPs and ABRs might have contributed to the excellent functional results achieved in this study. A major strength of this study is the long-term postoperative follow-up result obtained by Gd-enhanced MRI and audiological examinations.

**Conclusions**

Using the surgical technique, including sharp dissection and internal auditory canal reconstruction, in concert with intraoperative auditory monitoring of CNAPs and ABRs, we found that removal of small ANs via a retrosigmoid approach accomplished curative removal and excellent functional outcomes. No tumor recurred and the preserved hearing demonstrated no decline or minimal decline during the long-term follow-up period. Hearing decline during wait-and-scan and after radiosurgery is common and inevitable for patients with small ANs; therefore, we propose that curative tumor removal with preservation of hearing and facial function should be the
first-line management strategy recommended for younger patients with a small AN and preserved hearing.

**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: Yamakami, Ito. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Yamakami, Ito. 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: Yamakami. Statistical analysis: Yamakami, Higuchi. Administrative/technical/material support: Yamakami. Study supervision: Yamakami.

**References**

33. Pennings RJ, Morris DP, Clarke L, Allen S, Walling S, Bance...
Retrosigmoid removal of small acoustic neuroma


