The significance for postoperative hearing of preserving the labyrinth in acoustic neurinoma surgery

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Among 186 patients with preoperative hearing, a total of 189 acoustic neurinomas were removed through a lateral suboccipital approach with anatomical preservation of the cochlear nerve. Functional hearing was preserved in 92 (49%) of these patients; despite anatomical preservation of the cochlear nerve, deafness was the result in 51% of the series. Many factors have been considered to cause hearing loss in patients whose cochlear nerve was intact after surgery; these include nerve retraction, nerve or cochlear ischemia, overheating and vibration damage to the nerve, and opening of the labyrinth.

To evaluate the significance of injury to the labyrinth in postoperative hearing loss, a prospective study was undertaken. High-resolution computerized tomography studies through the inner ear with bone algorithm were performed pre- and postoperatively. The postoperative status of the labyrinth was classified into three patterns: intact, fenestrated, and widely opened. Injury to the labyrinth occurred in 30% of the cases. The most frequently injured labyrinth structures were the crus commune of the posterior and superior semicircular canals (52%), the posterior semicircular canal (23%), the vestibule (21%), and the superior semicircular canal (4%).

A statistically significant relationship was found between injury to the labyrinth and deafness, elevated thresholds, and lower discrimination values at pure-tone audiograms and speech audiometry (p < 0.0001). The degree of the injury (comparison between fenestration and wide opening of the labyrinth) was also significantly related to postoperative deafness (p < 0.0001). Disturbance of the inner-ear fluids was considered to be the cause of the hearing loss. In 12 patients labyrinth injury was not associated with deafness. This finding may support the existence of mechanisms of cochlear protection. The homeostatic function of the endolympathic sac was considered to play an important role in recovery of damaged hearing in these 12 cases.

KEY WORDS • acoustic neurinoma • computerized tomography • labyrinth • hearing • semicircular canal • vestibule

The challenging goal in acoustic neurinoma microsurgery, namely preservation of hearing, has been achieved in an increasing number of patients in recent years.17,20,21 The chances of saving useful hearing (defined as a threshold < 70 dB and discrimination > 15%) have a direct relationship to tumor size and the preoperative level of hearing.22 With the suboccipital approach, the approximate overall rate of hearing preservation is about 30%.13 In patients with good preoperative threshold and discrimination values, and small tumor sizes (< 3 cm), hearing can be preserved in about 60% of cases.12

Some authors advocate the translabyrinthine1,19 or the middle fossa (trans temporal extradural)1,14,25 approach for acoustic neurinoma removal. The translabyrinthine approach implies destruction of the inner ear and, therefore, should be used only in cases where auditory function is absent or already profoundly impaired.14 In our experience, the middle fossa and lateral suboccipital approaches are comparable regarding hearing preservation for small acoustic neurinomas, but for larger tumors suboccipital microsurgical removal is the method of choice.23 Ojemann,20 like us, prefers the suboccipital-transmeatal approach "because the middle fossa exposure provided limited access to the posterior fossa, was associated with greater technical difficulty in removing the tumor, and was reported to be associated with a higher incidence of facial weakness."

Some authors have suggested that the incomplete exposure of the contents of the internal auditory canal is a disadvantage of the suboccipital approach.3,14 However, we have not seen any recurrence of tumor on follow-up computerized tomography (CT) or magnetic resonance imaging in our patients with unilateral acoustic neurinomas and without any evidence of neurofibromatosis. This has also been the experience of oth-
visual access to the inside of the internal auditory canal can be gained by a suboccipital craniectomy enlarged in a medial direction, providing a view from a better angle. However, opening the internal auditory canal with the diamond drill provides a potential for injury to the posterior semicircular canals and the crus commune.

In acoustic neurinoma surgery, preoperative hearing may be lost completely, even when the cochlear nerve is anatomically preserved. Several factors have been considered to contribute to hearing impairment or loss in such cases. Retraction of the eighth nerve at the cerebellopontine angle may cause disintegration of the myelin sheath. Manipulations in dissecting the tumor from the nerve as well as the coagulation of small vessels may result in ischemia to the nerve or cochlea. Drilling of the posterior wall of the internal auditory canal to permit removal of the intrameatal part of the tumor may result in overheating, despite constant irrigation. Vibration damage to the nerve and opening of the labyrinth are other traumatic factors. Injury to the labyrinth has been reported to be associated with severe hearing loss and vertigo.

The aim of this study was to undertake a definitive evaluation of the importance for postoperative hearing of the preservation of the labyrinth in acoustic neurinoma surgery via the suboccipital route. We have not found a similar study in the literature. Recent advances in high-resolution CT now permit demonstration of both normal anatomy and pathology of the inner ear with great accuracy.

Clinical Material and Methods

Patient Population

Between January, 1985, and December, 1989, a total of 399 acoustic neurinomas were treated surgically through a lateral suboccipital approach (Fig. 1). To expose the intracanalicular portion of the tumor, the posterior wall of the internal acoustic canal was removed. Our surgical technique has been described in detail in previous publications. In 228 cases, the cochlear nerve was anatomically preserved. Of these, 14 “ears” were already deaf preoperatively and, in a further 25 cases, pre- and/or postoperative CT examinations were not adequate to permit evaluation of the bony labyrinth. In three patients with neurofibromatosis type 2, the bilateral acoustic neurinomas were removed with cochlear nerve preservation on both sides. Consequently, a total of 186 patients (189 “ears”) were evaluated in this study. All had functional preoperative hearing and adequate pre- and postoperative CT examinations.

Computerized Tomography Scans

All images were obtained using a 1.5-mm or 3-mm collimator. The axial sections were made through the temporal bone at 30° in relation to the orbitomeatal line, with 1.5-mm section thickness (Fig. 2). In a few cases with wide opening of the labyrinth, 3-mm sections were acceptable for evaluation of the labyrinth. The images were reconstructed from raw data with a standard bone algorithm program, and were displayed with...
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Fig. 2. Computerized tomography scan, axial 1.5-mm thick section (left), and corresponding drawing (right) through the superior part of the right internal auditory canal and the whole lateral semicircular canal, showing the vestibule (1), crus commune of the superior and the posterior semicircular canals (2), lateral semicircular canal (3), and posterior semicircular canal (4).

Fig. 3. Drawings from postoperative computerized tomography scans, axial sections 1.5 mm thick, through the right internal auditory canal. Left: Drawing of an intact labyrinth (note the drilled bone). Center: Drawing of a fenestrated labyrinth with an opening no larger than the transverse diameter of the semicircular canal. Right: Drawing of a widely opened labyrinth with an opening larger than the transverse diameter of the semicircular canal.

<table>
<thead>
<tr>
<th>Labyrinth Status</th>
<th>Definition</th>
<th>CT Slice Thickness</th>
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<tr>
<td>intact</td>
<td>no lesion on CT scan</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>fenestrated</td>
<td>small labyrinth opening no larger than transverse diameter of semicircular canal</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>widely opened</td>
<td>labyrinth opening larger than transverse diameter of canal</td>
<td>1.5 or 3 mm</td>
</tr>
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<td></td>
<td>labyrinth opening demonstrated on 2 or more CT slices</td>
<td>1.5 or 3 mm</td>
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TABLE 1
Criteria for classifying injury of the labyrinth based on computerized tomography (CT)

an extended 4000-matrix window. Further technical data included the following: 510 mA (3-mm sections) to 600 mA (1.5-mm sections), 3-second scan time, 120 kVp, and 512 × 512 matrix.

The parameters analyzed on the CT images were: size of the tumor, existence of malformations of the temporal bone preoperatively, completeness of tumor excision, and the presence of lesions of the labyrinth after surgery. The postoperative status of the labyrinth was classified into three types: intact, fenestrated, and widely opened (Table 1). “Intact” denoted absence of lesion on CT scans with 1.5-mm slice thickness; “fenestrated” denoted a small opening of the semicircular canal not larger than the transverse diameter of the canal on CT scans with 1.5-mm slices; “widely opened” denoted an opening of the semicircular canal larger than the transverse diameter of the canal, or an opening of the canal demonstrated in two or more CT slices of 1.5- or 3-mm thickness (Figs. 3 and 4).

Hearing Tests
Pre- and postoperative hearing was evaluated on the basis of pure-tone audiograms and speech audiometry. Results of auditory evoked potentials were not used in this study. Postoperative examinations were performed between the 2nd and 3rd week after surgery. The results of the pure-tone audiograms between frequencies of 500 and 3000 Hz were classified into four categories (Table 2): good, hearing level not exceeding threshold elevation of 30 dB; fair, hearing level with elevation of threshold between 31 and 60 dB; poor, hearing with threshold elevation of 61 to 90 dB; and deafness, hear-
Hearing loss of more than 91 dB. The results of the discrimination scores were included for patients in whom speech audiometry was performed. "Functional hearing" denoted average speech discrimination of at least 80% (good hearing) or 30% (fair hearing).

**Statistical Analysis**

Comparisons of different groups of patients, according to the labyrinth status with regard to hearing function, were made by the chi-squared test and Fisher's exact analysis.

**Results**

A total of 189 "ears" were evaluated. The patient female: male ratio showed little significant gender difference. The average age was 44 years (range 14 to 78 years). In all but three cases, the acoustic neurinomas were completely removed. A total of 116 acoustic neurinomas (61%) were larger than 20 mm. Preoperative CT revealed no abnormalities of the temporal bone in these 189 cases.

**Hearing Function**

The preoperative hearing was good in 79 cases (42%), fair in 70 cases (37%), and poor in 40 cases (21%). Of 70 patients tested by speech audiometry, average discrimination was 70% ± 33% (± standard error of the mean).

Postoperative results showed deafness in 97 cases (51%). In 92 cases (49%) the hearing function could be preserved. A total of 16 patients (17%) had good postoperative hearing function, 44 patients (48%) had fair hearing postoperatively, and 32 patients (35%) had poor hearing postoperatively. Speech audiometry tests were performed in 56 cases with postoperative hearing. Patients with good postoperative hearing had an average speech discrimination of 93% ± 7%, and patients with fair and poor hearing had an average discrimination of 66% ± 29% and 19% ± 18%, respectively. Thus, 60 patients (32%) had functional hearing postoperatively (good and fair hearing groups).

**Labyrinth Injury and Hearing**

After acoustic neurinoma surgery via the lateral suboccipital approach, CT studies demonstrated an "intact" labyrinth in 133 cases (70.4%), a fenestrated labyrinth in 25 cases (13.2%), and a widely opened labyrinth in 31 cases (16.4%). The postoperative hear-
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Fig. 6. Schematic diagram of an axial slice through the internal auditory canal showing the entry to the internal auditory canal via the suboccipital route. The imaginary line (broken lines) from the medial side of the sigmoid sinus to the fundus of the internal auditory canal indicates whether there is potential for injury to the labyrinth. On the right side, the labyrinth is located lateral to the line and is therefore not in danger of being opened. On the left side, the labyrinth is located more medial; if the tumor extends so far laterally that the fundus of the internal auditory canal has to be exposed, the labyrinth will probably be opened.

<table>
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<th>Variable</th>
<th>Hearing Function</th>
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<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>total cases</td>
<td>16 (9%)</td>
</tr>
<tr>
<td>sex (F:M)</td>
<td>6:10</td>
</tr>
<tr>
<td>mean age (yrs)</td>
<td>38 ± 12</td>
</tr>
<tr>
<td>state of labyrinth†</td>
<td>intact</td>
</tr>
<tr>
<td></td>
<td>fenestrated</td>
</tr>
<tr>
<td></td>
<td>widely opened</td>
</tr>
<tr>
<td>location of lesion</td>
<td>SSC</td>
</tr>
<tr>
<td></td>
<td>PSC</td>
</tr>
<tr>
<td></td>
<td>crus commune</td>
</tr>
<tr>
<td></td>
<td>vestibule</td>
</tr>
<tr>
<td>mean speech discrimination (%)†</td>
<td>93 ± 7</td>
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* SSC = superior semicircular canal; PSC = posterior semicircular canal; NA = not applicable. Mean values are expressed ± standard error of the mean.
† Significance of association between labyrinth status and speech discrimination: p < 0.0001.

Discussion

Functional hearing loss following acoustic neurinoma surgery with anatomical preservation of the cochlear nerve is a surgical disappointment, although it is a well-recognized event. Some factors have been considered to contribute to the impairment of hearing during posterior fossa acoustic neurinoma surgery: retraction of the eighth nerve at the cerebellopontine angle, ischemia of the nerve due to manipulations in dissecting the tumor from the nerve and coagulation of small vessels, overheating and vibration damage to the nerve, and opening of the labyrinth while the internal auditory canal is drilled open. Although the cause of hearing loss in acoustic neurinoma surgery seems to be a multifactorial event, the exact evaluation of each factor is difficult.

Technical Aspects of the Suboccipital Approach

Exposure of the acoustic neurinoma in the internal auditory canal involves drilling away the posterior wall of the auditory canal. Unfortunately, there are no exact anatomical landmarks that identify the location of the posterior semicircular canal and the crus commune (Fig. 1). The so-called “blue lines,” seen in the middle fossa approach, indicating the semicircular canals cannot always be identified in the suboccipital approach, probably because of the tangential view one has in this approach.

Therefore, we rely upon high-resolution preoperative CT scans to identify the relationships between the semicircular canals, the vestibule, and the internal auditory canal. Computerized tomography slices through the internal auditory canal demonstrate whether the post-
terior semicircular canal and the crus commune lie medially or laterally in relation to an imaginary line extending from the medial side of the sigmoid sinus to the fundus of the internal auditory canal. If these structures are located lateral to this line, there is no risk of injuring them, but if the structures are located medial to the line and the fundus of the internal auditory canal has to be exposed, they are in danger of being opened. A CT study permits one to measure the distance between the posterior semicircular canal and the crus commune, with this line as a medial reference (Fig. 6).

Anatomical dissections have demonstrated that exposure of the fundus of the internal auditory canal via a suboccipital approach is impossible without injury to the labyrinth. The medial 80% to 90% of the internal acoustic canal is accessible through the suboccipital approach, but its lateral 1 to 2 mm might cause problems in cases of tumors filling the entire canal. In order to remove this lateral part of the tumor and simultaneously avoid injury to the labyrinth, the lateral 1 to 2 mm of the internal acoustic canal is kept intact. We use angled round cutting knives * when drilling the posterior wall of the internal auditory canal in order to establish the distance of the canal opening to its fundus. In the majority of cases, opening the medial 80% to 90% of the internal auditory canal allows complete removal of the intracanalicular part of the tumor.

Generally, wide openings of the labyrinth may be detected by the surgeon intraoperatively, although small penetrations may easily be overlooked. However, these latter are well demonstrated on CT scans. Bone wax and muscle, used as plugging material to prevent cerebrospinal fluid (CSF) leakage due to opened mastoid air cells, should also be inserted into the areas where the canal may have been opened.

Mechanisms of Cochlear Injury

Trauma to the labyrinth has been reported to be associated with severe hearing impairment and vertigo or even with complete and irreversible hearing loss. Some authors have reported a reversible postoperative decrease of inner-ear function after surgery of the round window. Cochlear symptoms that occur after fenestration surgery for otosclerosis were reported by Beickert in connection with: trauma to the labyrinth during surgery, the mixture of blood and bone fragments with perilymph fluid, and inflammatory reactions of the inner ear. Similar processes may occur in acoustic neurinoma surgery by opening the labyrinth while drilling the posterior wall of the internal auditory canal. Use of the aspirator during drilling may occasionally cause additional damage by direct suction of the inner-ear fluids.

Canalis, * et al.* described cochlear injury after rupture of the membranous labyrinth to both mechanical and chemical mechanisms. Widespread capillary rupture, hemorrhage, and cellular damage were reported after labyrinthectomy. Chemically, perilymph-endolymph fluid contamination involving the whole labyrinth and the cochlea leads to electrolyte disequilibrium of the inner-ear fluids and causes irreversible functional damage. These findings may support the morphological changes of the vestibule described by some authors who studied the inner ear of patients with acoustic neuromas after posterior fossa surgery. Yaku, * et al.* found accumulated gelatinous substance in the membranous labyrinth, which they considered to be degenerated and condensed endolymph fluid.

Size and Location of Lesion

Canalis, * et al.* suggested that there is an association between the size and location of labyrinth trauma and the severity of hearing dysfunction. Recent studies confirming that the secretion of endolymph occurs in the ampulla may support the statements of Canalis, * et al.*, that clean lesions far from the ampulla might carry a better prognosis than ampullar trauma. In our series, the single patient with labyrinth trauma and good postoperative hearing only exhibited a fenestration of the posterior semicircular canal. A total of 28% of the patients with fenestrated labyrinths could hear postoperatively, compared to 16% of the patients with widely opened labyrinths. This difference was statistically significant (p < 0.0001). However, we did not find that a lesion location in the bony labyrinth had a significant relationship to postoperative hearing.

Mechanism of Cochlear Protection

The mechanisms of functional cochlear preservation in labyrinth injuries are still unknown. In our series, four patients who had opening of the labyrinth did not suffer functional hearing loss. Canalis, * et al.* reported hearing preservation in 12 cases collected from the literature with iatrogenic lesions of the labyrinth, and added six cases of their own. Some possibilities for cochlear protection have been suggested: the development of a seal in some parts of the labyrinth, the presence of an utriculo-endolymphatic valve, and local factors such as collapse of the torn open ends of the canal and a "sealing-off" effect. We believe that, in some cases, incidental closure of the opened canal by bone fragments may occur during drilling, thereby preventing endolymph leakage. Since the endolymphatic sac is considered to be a dynamic organ that regulates inner-ear homeostasis, we believe that it may play an important role in recovery from cochlear damage in cases of injury to the labyrinth. Takumida, * et al.*, studied this structure in mice and concluded that it may be essential for the regulation of inner-ear homeostasis, particularly under pathological conditions.

Intraoperative use of bone wax and muscle or fascia as plugging material and application of intravenous antibiotics have been recommended by some authors. We always use bone wax, muscle, and fibrin glue to prevent or treat CSF leakage through the opened mastoid air cells. With this procedure, we usually include

* Knives manufactured by Aesculap, Tuttingen, Germany.
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the drilled area of the petrous bone (in which the bony labyrinth is located) to prevent or treat eventual inner-ear fluid leakage.

Conclusions

In this study, we found that injury to the labyrinth occurred in approximately 30% of cases treated with suboccipital transmeatal acoustic neurinoma surgery. Although there are many factors responsible for hearing loss in acoustic neurinoma surgery despite anatomical preservation of the cochlear nerve, we conclude that postoperative hearing is very much influenced by the postoperative state of the labyrinth. Injury to the labyrinth did not result in deafness in all cases, but the degree of labyrinth injury does seem to play a decisive role in the impairment of postoperative hearing.

We do not believe that labyrinth injury can be avoided completely and invariably during surgery. The surgical technique presented here may facilitate complete tumor removal with preservation of the inner-ear structures. If the labyrinth is opened, direct suction at the site of penetration should be avoided, and the defect should be closed using bone wax or muscle as plugging material. This latter procedure is not always effective in preventing reopening. The mechanisms of cochlear protection must still be identified and understood. An intact endolymphatic sac probably plays a significant role in restoring homeostasis after the intraoperative disturbance of inner-ear fluids due to perilymph-endolymph contamination.

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References


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