Original Article

Hearing preservation in acoustic neuroma resection: Analysis of petrous bone measurement and intraoperative application

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Abstract

Background: There is an increased risk for labyrinthine injury for the resection of acoustic neuromas (AN) on the suboccipital, retrosigmoid approach. Prognostic factors should be analyzed for the postoperative hearing function.

Methods: We examined 51 patients with ANs using preoperative intact hearing function. Audiological data were obtained by pure tone audiogram (PTA) and speech audiogram. The preoperative and postoperative anatomical localization of the labyrinth was measured with specific distances regarding the tumor and corresponding anatomy of the posterior fossa by high-resolution magnetic resonance imaging (MRI).

Results: Postoperative MRI controls confirmed no injuries to the labyrinth (0%). The postoperative hearing results showed 100% hearing preservation for T1-tumors (<1 ml/<1.1 cm), 50% for T2-tumors (1–4 ml/1.1–1.8 cm), 40% for T3-tumors (4–8 ml/1.8–2.3 cm) and 18% for T4-tumors (>8 ml/>2.3 cm). Postoperative deafness was seen in all cases with ventral tumor extension higher than 5.5 mm. Postoperative loss of hearing was seen in all cases with hearing preservation with 6–8% of speech discrimination and an increase in the hearing threshold of 12 dB in the PTA compared to the preoperative hearing status.

Conclusion: Petrous bone measurement by high-resolution MRI data enables safe surgical exposure of the internal acoustic canal with avoidance of injury to the labyrinth and a better postoperative prognosis, especially for intrameatal ANs and for the resection of intrameatal portions of larger neuromas. The prognostic factors enable the patients and the surgeon a better estimation of postoperative results regarding deafness and postoperative hypacusis and support a consolidated treatment planning.

Key Words: Acoustic neuroma, hearing preservation, high resolution MRI, petrous bone measurement

INTRODUCTION

Exposure of the internal acoustic canal (IAC) has significant risks for injury to the labyrinth for the resection of acoustic neuromas (AN) on the suboccipital, retrosigmoid approach. Former studies showed higher incidences of injury for very medially localized semicircular canals of the labyrinth.[11,18] The insufficient exposure of the IAC is seen as a significant disadvantage of the suboccipital approach.[2] The goal of our prospective clinical study was to develop a safe strategy for the exposure of the IAC in order to avoid injury to the labyrinth by using anatomical data from high-resolution magnetic resonance imaging (MRI). Prognostic factors should be analyzed for the preservation of hearing function from preoperative anatomical findings.

MATERIALS AND METHODS

Clinical data

51 patients (male/female: 42/58%, minimum age: 12, maximum age: 75, mean age: 49) with AN with confirmed and intact preoperative hearing function underwent tumor resection after suboccipital, retrosigmoid craniectomy. One patient (2%) had Type 2 Recklinghausen's disease. Symptoms such as vertigo, tinnitus, ataxia, preoperative hypacusis, headache, and cranial nerve dysfunctions were documented preoperatively. Inclusion criteria were confirmed hearing function on the side of the tumor (see below audiologic parameters), preoperative and postoperative determination of hearing threshold levels (in dB) and speech discrimination, preoperative high-resolution MRI with measurements of the petrous bone, and postoperative MRI after 3–6 months to look for injury of the labyrinth. Exclusion criteria were recurrent ANs, radiated tumors, and other histological entities such as meningiomas in the cerebellopontine angle (CPA).

Audiologic parameters

Four hearing classes A–D were defined according to the Committee on Hearing and Equilibrium of the AAO-HNSF: A – hearing threshold in audiogram <30 dB and language discrimination score >70% (within 70–100 dB), B – hearing threshold >30 dB and <50 dB and language discrimination >50%, C – hearing threshold >50 dB and language discrimination >50%, D – all hearing threshold values, and language discrimination <50%.[1] Class A represents normal hearing function. Class B represents impaired but useable hearing. In class C, hearing is significantly limited, but useable for the localization of noises and for language comprehension and is amendable by the application of a hearing aid. Hearing in class D is formally verifiable but insufficient because of poor language discrimination below 50%.[1]

Preoperative hearing function

A verifiable hearing function was a prerequisite for inclusion in our study. Forty-seven percent of our patients were assigned to hearing class A, 33% to class B, 10% to class C, and 10% to class D. Figure 1 shows the distribution of the hearing classes to tumoral sizes [Figure 1].

Imaging

All patients underwent high-resolution 1.5 Tesla MR imaging at the Department of Neuroradiology at the University of Erlangen-Nuremberg (Siemens Magnetom, T1w: TR 0.6, TE 20, slice thickness 3 mm, matrix 256 × 256; T2w: TR 2.500, TE 45–90, slice thickness 3 mm, matrix 256 × 256). In high-resolution T2 weighted images, all three semicircular canals of the labyrinth, the utricule, and the cochlea are delineated within the petrous bone in correspondence to the IAC. Especially the posterior semicircular canal (PSCC) can be localized quite medially and directly under the surface of the petrous bone, and therefore, can be prone to injury by exposure of the IAC, as shown in Figure 2.

Principles of petrous bone measurement

The surgeon looks from the dorsolateral aspect of the posterior fossa onto the petrous bone and can see the tumor spreading out of the IAC. For opening of the IAC, a portion of the petrous bone has to be removed without having any safe and clear macroscopic landmarks for the localization of the underlying labyrinth. Therefore, we choose the transversal, highly T2-weighted image slices, which delineate the medially localized portion of the semicircular canals in high resolution, mostly the PSCC. A sagittal line is constructed into this slice, which courses through the fundus of the IAC and tangentially touches the most medial aspect of the semicircular canals [Figure 3]. The extension of this sagittal line to the suboccipital direction results in an intersection point representing the dorsal surface of the petrous bone [see arrow in Figure 3]. The surgeon can measure the distance of this intersection point from the posterior margin of
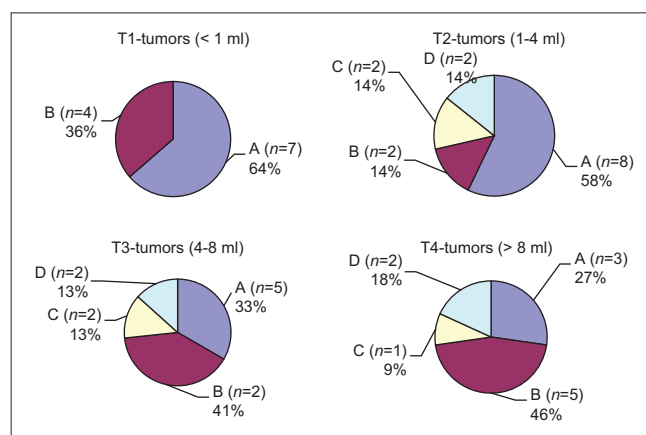

Figure 1: Distribution of tumoral sizes to hearing classes

the IAC with a ruler. This implies that all bony elements of the petrous bone that lie medially to the intersection point can be removed without injury to the semicircular canals to the fundus of the IAC. The sagittal line must always course strongly sagittally through the fundus of the IAC, and all various elements of the semicircular canals have to lay laterally from this line. This method is oriented to the individual anatomy of the patients and gives exact topographical details, which can be reproduced intraoperatively. We did not use coronal or sagittal slices because the transversal slices reproduce the intraoperative angle of the view of the surgeon. Principally, we measured the distances d1–d8 [Figure 4, see figure legend].

Calculation of the tumor volume

a. Extrameatal tumor volume: The extrameatal tumor volume is defined by the volume of a sphere: $V = 4/3 \times \pi \times r^3$. Three diameters, namely, Da, Db, and Dc, from the T1-weighted images in transversal, coronal, and sagittal planes are measured. Note the three diameters Da (parallel to the petrous bone), Db (perpendicular to Db), and Dc (maximal vertical diameter of the tumor from the coronal plane; see Figures 5a-b). r^3 arithmetically represents the product of the halves of the three diameters Da, Db, and Dc, such that the extrameatal tumor volume results from the following formula:
$V = 4/3 \times \pi \times (Da/2 \times Db/2 \times Dc/2)$.

b. Intrameatal tumor volume: The intrameatal tumor volume is defined by the volume of a conus: $V = 1/3 \times r^2 \times \pi \times h$. r is represented by the half of the previously described distance d6 (see petrous bone measurements, see above), and h is the height of the conus represented by the previously describes distance d2 [Figure 5c].

The total tumor volume results from the sum of the extrameatal and intrameatal tumor volumes:

$$V = 4/3 \times \pi \times (Da/2 \times Db/2 \times Dc/2) + 1/3 \times (d6/2)^2 \times \pi \times d2$$

Definition of tumor classes

The tumors were defined by four size categories, T1–T4, in order to evaluate possible or not possible prognosis regarding the expecting postoperative hearing preservation or deafness for each tumor class:

T1: < 1 ml (<1.1 cm diameter)

T2: 1 ml–4 ml (1.1–1.8 cm diameter)

T3: 4 ml–8 ml   (1.8–2.4 cm diameter)

T4: >8 ml (>2.4 cm diameter).

Figure 6 shows the distribution of tumor classes in the examined patient population [Figure 6a and b]. Figure 7 shows examples of examined and resected tumors according to the the aforementioned tumor classes.

Postoperative imaging for evaluation of labyrinth preservation and tumor recurrence

All patients underwent postoperative MRI 3–6 months after the surgery [Figure 8]. T2-weighted high resolution imaging was performed to delineate the status of the labyrinthine system and T1-weighted images were performed to rule our tumor recurrence. The labyrinthine system is intact when all semicircular canals are delineated and an intact bony lamella can be depicted to
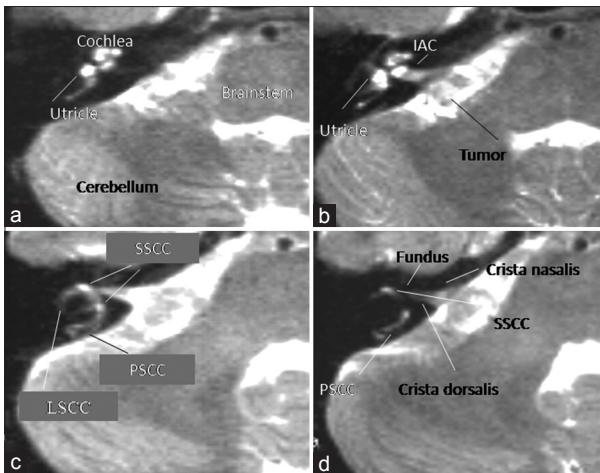

Figure 2: (a-d) Ultra high-resolution T2-weighted MR slice images of a patient with right-sided AN from caudal to cranial direction a>d. Note that the PSCC in (d) is localized quite medially and near to the IAC, so that it might be prone to injury after exposure of the IAC (T2w: T2-weighted magnetic resonance imaging, AN: Acoustic neuroma, IAC: Internal acoustic canal, PSCC: Posterior semicircular canal, LSCC: Lateral semicircular canal, SSCC: Superior semicircular canal)
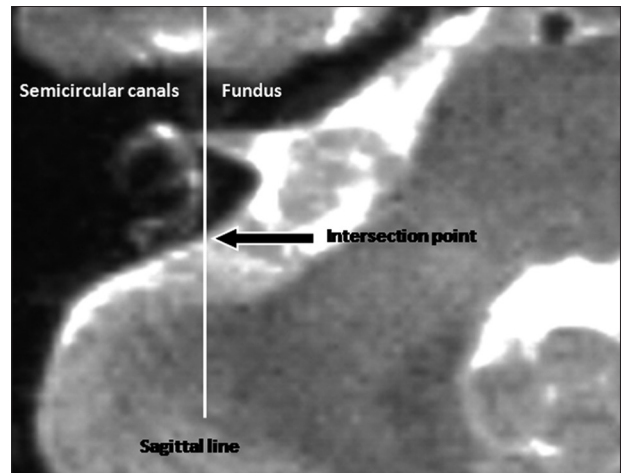

Figure 3: High resolution T2-weighted image slice for the measurement of the anatomical localization of the labyrinth in projection to the dorsal surface of the petrous bone. A sagittal line is constructed through the fundus of the IAC, which tangentially touches the most medially localized portion of the semicircular canals of the labyrinth. The distance of the resulting intersection point from the posterior margin of the IAC can be measured intraoperatively with a ruler
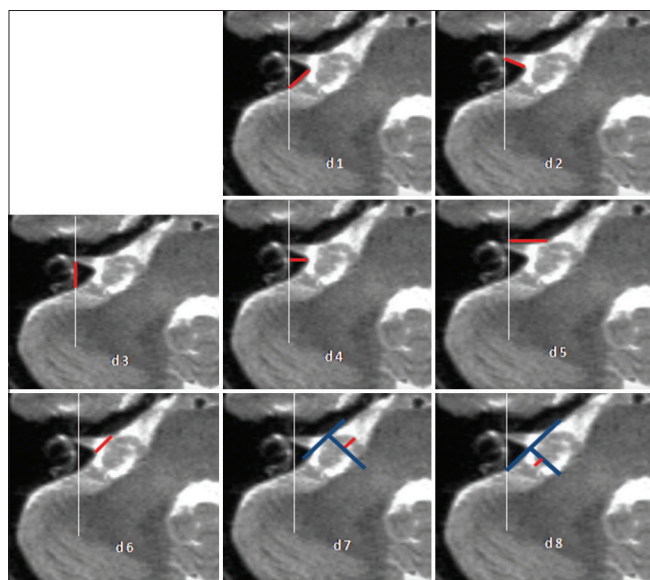
Figure 4: Anatomical measurement of distances d1 to d8 with high resolution T2 weighted images. d1: Distance from Crista dorsalis (dorsal margin) of the IAC to the intersection point of the medial limitation of the labyrinth with the dorsal surface (facies dorsalis) of the petrous bone. d2: Crista dorsalis of the IAC to the fundus. d3: Fundus to the intersection point of the medial limitation of the labyrinth with the facies dorsalis of the petrous bone. d4: Perpendicular line from the sagittal line of the medial limitation of the labyrinth to the crista dorsalis of the IAC. d5: Distance from the Crista nasalis of the IAC to the fundus. d6: Distance from the Crista nasalis to the Crista dorsalis of the IAC. d7: Nasal extension of the tumor over the Crista nasalis of the IAC. d8: Dorsal extension of the tumor over the Crista dorsalis of the IAC
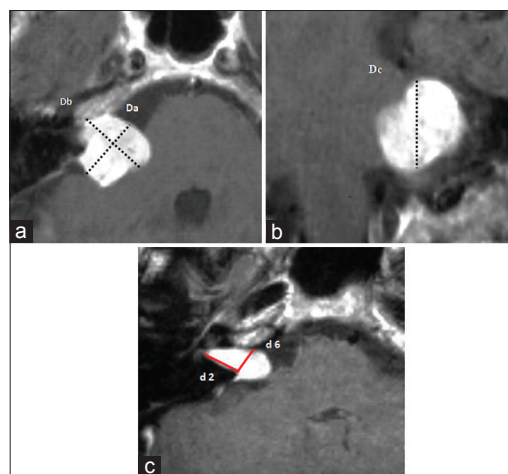

Figure 5: (a, b) Measurement of the extrameatal tumor volume. (a) Transversal image slice with diameters Da (parallel to the petrous bone) and Db perpendicular to Da. (b) Maximal vertical tumor diameter Dc from the coronal plane. (c) Measurement of the intrameatal tumor volume. d2: Crista dorsalis of the IAC to the fundus. d6: Distance from the Crista nasalis to the Crista dorsalis of the IAC

the CPA. Scar tissue also showed contrast enhancement in the T1-weighted images, while the role of postoperative artifacts is also known from literature.[16]

Surgical technique

The suboccipital, retrosigmoid approach was performed in all 51 patients. The patients were positioned with elevation of the ipsilateral shoulder and the head turned horizontally to the contralateral side. Cerebrospinal fluid (CSF) was released after craniectomy from the cisterna magna. After this procedure, one can see the tumor growing out of the IAC. As a next step, intracapsular shrinking of extrameatal tumor portion starts. After the extrameatal tumor shrinkage, the opening of the IAC is delineated with the Crista dorsalis. The distance d1, which is gained by the preoperative T2-weighted images, is marked on a sterile ruler and transferred to the surgical field that shows the distance from the posterior border of the IAC (Crista dorsalis) to the medial limitation of the labyrinth on the dorsal surface of the petrous bone for secure exposure of the IAC [Figure 9]. The IAC is drilled according to the available length. The tumor is then freed from the facial nerve and prepared into the IAC and the fundus. The complete surgical preparation is performed under electrophysiological monitoring of the cochlear nerve by BERA. The facial nerve is identified by electrical stimulation. After tumor resection, the bony defect is covered with gelitta under the application of fibrin glue and standard closure is done.

RESULTS

There was no mortality intra or postoperatively (0.0%). Two out of 51 patients (3.9%) developed transient CSF leak, which was observed conservatively and diminished spontaneously. One patient had immediate postoperative intracerebral hemorrhage (1.96%) within the CPA and underwent emergent revision with good neurological recovery. In 20 of 51 patients (39%), we saw postoperative facial nerve paresis; in 25% of the patients with mild pareses House–Brackmann II°-III° with good remission in follow-up and in 14% of the patients ($n = 7$) with House-Brackmann grades IV°-V°. The preservation of the labyrinthine system could be achieved with the method of petrous bone measurement in all 51 patients (100%). A bony lamella of 1–2 mm thickness stayed to the medial border of the semicircular canals in all 51 cases (100%). Tumor recurrences were not seen on the postoperative MRI scans 3–6 months after the surgery (0.0%). Two hearing tests (pure tone audiogram, PTA and speech discrimination score, SDS) were performed within the first two postoperative weeks. In 26 of 51 patients (51%), a useable hearing function was available with 18% with normal hearing function (Class A), in 27% with impaired but useable hearing function (Class B), and 6% of the patients had a significantly limited function but useful for the localization of noises and language comprehension (Class C). In all patients of Class C, the application of a hearing aid supported the hearing function

because of intact speech discrimination. Postoperative deafness was seen in 25 of 51 patients (49%; Class D). For T1-tumors (<1 ml/<1.1 cm), we saw very good and moderate good hearing function with 36% of T1-tumor patients with Class A and 64% with Class B quality.

In T2-tumors (1–4 ml/1.1–1.8 cm), the success rate was reduced to 50% of not useable hearing function (Class D), 7% to Class C, 29% in Class B, and 14% in Class A. In larger tumors (>8 ml), the success rate was significantly reduced <20% of effective hearing preservation.

For T3-tumors (4–8 ml/1.8–2.3 cm), in 40% of the patients, postoperative hearing function was preserved

Figure 6: (a and b) Distribution of tumor classes in the examined patient population (SD: standard deviation, n: number of patients)

with 20% Class A quality, 13% Class B, and 7% Class C. For T4-tumors (4–8 ml/>2.3 cm) deafness was seen in 80% of cases (Class D) and 9% moderate to useable hearing function in each Classes A–C. The results of the measured clinical, audiological, and anatomical parameters are shown by Table 1. The distances d5, d2, and d6 have the largest standard deviations of all petrous bone parameters according to the anterior and posterior wall and the width of the IAC. The distances d1 and d4 referring to the localization of the labyrinthine system and the crista dorsalis of the IAC ranged from 4.5–5.9 mm to 12–14 mm. There was no significant, preferred direction of tumor growth to ventral or dorsal direction according to the distances d7 and d8. There was a mean postoperative increase of the hearing threshold in PTA for the postoperative hearing-intact patients with 11.5 dB, and a decrease in the SDS with 6.8 dB. There was no clinically relevant correlation between the preoperative and postoperative hearing function of the acoustic neuromas. The preoperative speech comprehension correlated more with the postoperative PTA than with the postoperative SDS ($P < 0.012$). The preoperative hearing function could be seen as a safe prognostic factor for postoperative hearing preservation for the T1-tumors (<1 ml/1.1 cm) and with limitation for T2-tumors (2–4 ml/1.1–1.8 cm). The extrameatal tumor volume correlated significantly with the postoperative hearing preservation ($P < 0.01$) in contrast to the intrameatal tumor volume. The results of postoperative deafness, increase of hearing threshold in the PTA in case of hearing preservation, and the loss of hearing in speech discrimination in case of hearing preservation are shown by Table 2. The risk for postoperative deafness in ventral tumor growth beyond the crista nasalis of the IAC with more than 5.5 mm was nearly 100%, independent of the tumor size. Especially, the distance d4 with the localization of the labyrinthine system, the depth of the IAC, or the width of the orifice
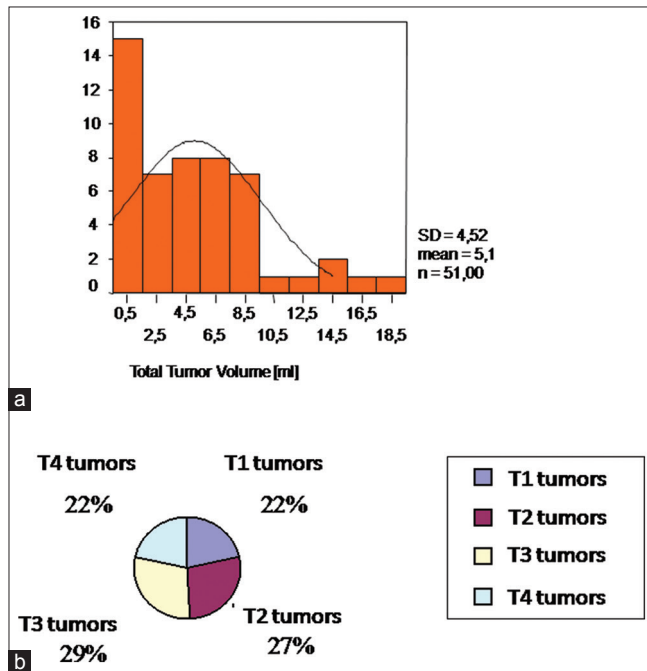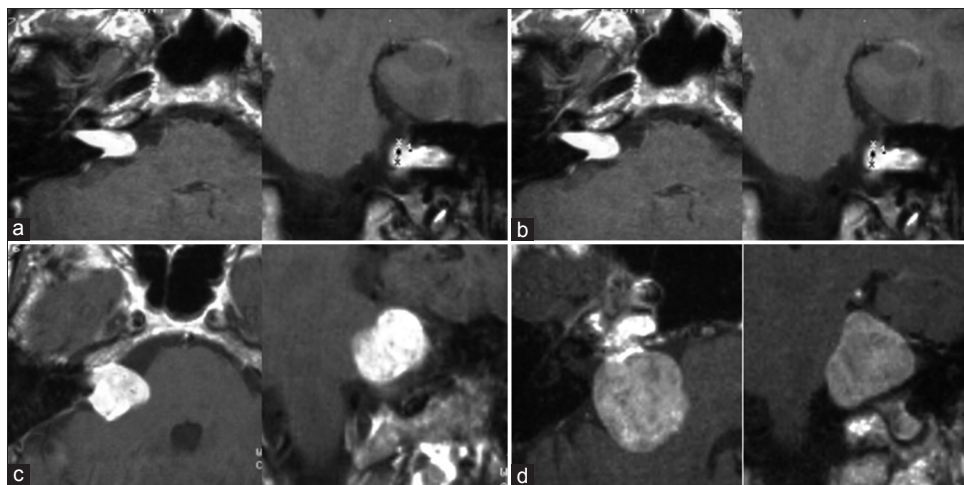
Figure 7: Examples of examined and resected tumors according to the defined tumor classes T1-T4. (a) small T1 tumor without contact to the brainstem, 0.42 ml. (b) T2 tumor with contact to the brainstem without significant compression, 3.6 ml. (c) T3 tumor with brainstem compression, 5.6 ml. (d) T4 tumor with compression and dislocation of the brainstem, 13 ml

the IAC did not show a correlation with postoperative hearing loss.

DISCUSSION

Functional hypacusis after resection of acoustic neuromas, even in anatomically well preserved cochlear nerve is a disappointing event for each surgeon by preparation of the tumor at the cochlear nerve with coagulation of small vessels and subsequent ischemic events and nerval damage by vibration and hyperthermia of the petrous bone during drilling of the posterior elements of the petrous bone and affection of the labyrinthine system.
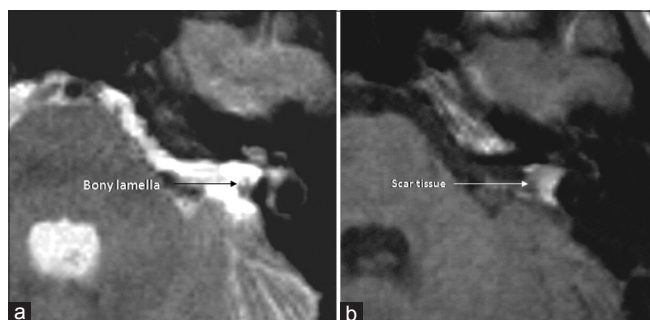

Figure 8: Postoperative MRI after resection of the AN. (a) T2-weighted image showing the postoperative integrity of labyrinthine system with an intact bony lamella to the CPA. (b) Postoperative enhanced T1 weighted imaging showing scar tissue

Multiple possibilities were introduced into this field during surgery.[8,14,15] Our prospective, clinical study with 51 patients introduced a new procedure of extension and optimization of the suboccipital, retrosigmoid approach for hearing-preserving resection of ANs. This technique had the goal to deal with the major problems of the retrosigmoid approach such as the injury to the labyrinth during exposure of the IAC with the application of detailed, preoperative petrous bone measurement and intraoperative reproduction of these parameters. Removal of the dorsal wall of the IAC is needed in order to delineate the tumor within the IAC. As described in literature, this region is very variable referring the localization of the labyrinth and the pneumatization
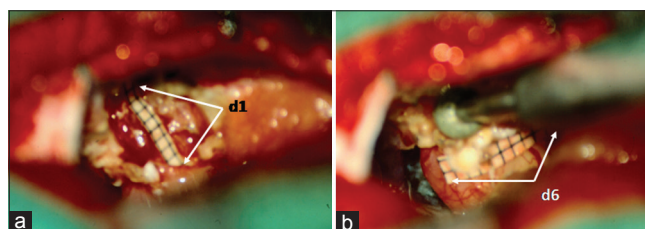

Figure 9: Microsurgical view onto the CPA with depiction of the distances d1 and d6. (a) d1: Distance from Crista dorsalis – dorsal margin – of the IAC to the intersection point of the medial limitation of the labyrinth with the dorsal surface of the petrous bone. (b) d6: Distance from the Crista nasalis to the Crista dorsalis of the IAC

Table 1: Results of the measured clinical, audiological and anatomical parameters

	n	Minimum	Maximum	Mean	Standard deviation
Patient age	51	12.00	75.00	49.7059	14.2538
Preoperative hearing function (dB)	51	7.50	73.00	32.4549	15.2945
Preoperative Speech discrimination score (dB)	51	0.00	100.0	74.1176	28.0661
Tumor volume, extrameatal	51	0.03	18.80	4.7269	4.5064
Tumor volume, intrameatal	51	0.07	1.35	0.4002	0.2648
Distance d1	51	5.90	14.00	9.7039	1.9777
Distance d2	51	5.00	13.00	9.2176	2.0678
Distance d3	51	5.70	15.00	10.1120	1.9331
Distance d4	51	4.60	12.00	7.6804	1.6722
Distance d5	51	8.10	23.00	15.0902	3.3954
Distance d6	51	5.00	18.00	10.7902	3.0475
Distance d7	51	0.00	14.00	4.4176	3.9379
Distance d8	51	0.00	15.00	5.5843	3.8496
Postoperative hearing function (dB)	51	7.50	100.00	65.3863	30.9413
Postoperative Speech discrimination score (%)	51	0.00	100.00	40.8824	40.7886

Table 2: Results of postoperative deafness, increase of hearing threshold in the PTA in state of hearing preservation and the loss of hearing in speech discrimination in case of hearing preservation

	T1-tumors <1ml (<1.1 cm)	T2-tumors 1-4ml (1.1-1.8 cm)	T3-tumors 4-8ml (1.8-2.4 cm)	T4-tumors >8ml (>2.4 cm)
frequency of postoperative surditas	<20%	20-40%	40-70%	>70%
Increase of hearing threshold in PTA	+12 dB	+11.5dB	Not defined	Not defined
Decrease of hearing in speech discrimination	−6.5%	−7.7%	Not defined	Not defined

below the surface of the petrous bone.[11] Studies by Matthies *et al.* showed injury to the posterior semicircular canals with a frequency of 20% and of the lateral semicircular canal with 10% in cases of very medially localized labyrinthine systems.[11] In studies of Tatagiba *et al.*, a so called "sinus-fundus-line" was introduced and described to measure the risk for opening of the labyrinth, which was marked in the preoperative CT scan as the line from the sigmoid sinus to the fundus of the IAC.[18] In studies of Yokoyama *et al.*, 25% of labyrinthine elements were on the described sinus-fundus-line or even coursed medially to this line, and therefore, on the surgical route for opening of the IAC.[19] A significant relation between a reduced postoperative hearing capacity and increased fenestration of the semicircular system of these patients could be shown.[18,19] Low *et al.* introduced the projection of landmarks with the operating microscope onto the petrous bone, where a border of maximum 3 mm for the opening of the IAC to laterally was maintained.[10] In our study, the distance d4, which is similar to this landmark, was never smaller than 4 mm but 9 mm in the mean. Therefore, Low *et al.* introduced and described the technique of endoscopic visualization of the lateral IAC.[10] Some studies prefer the middle fossa approach for the resection of small, intrameatal tumors up to a diameter of 2 mm. Staecker *et al.* showed a frequency of 47% of postoperative hearing preservation for the retrosigmoid approach versus 57% for the middle fossa approach with a dominance of the retrosigmoid approach for the large and extrameatal tumors.[17] There might be the hypothesis that the cause for worsening hearing function for the retrosigmoid approach is possibly based on frequent and unrecognized injuries to the labyrinth. Matthies *et al.* showed an increased rate of intraoperative injuries to the posterior and lateral semicircular canals in very medially localized labyrinthine systems, so that fenestration of one semicircular canal reduces the success rate of hearing preservation.[11] For small, intrameatal tumors there should be an improvement of the rate of hearing preservation because of the good preoperative hearing function. Referring to the middle fossa approach, a complete intrameatal tumor resection is partially based on a blind dissection. Discroll *et al.* showed in a CT-based study that the inferior compartment with the facial nerve is covered by the transverse crest at a frequency of 25%.[5] This might be the reason for the higher incidence of facial nerve lesions for the middle fossa approach.[17] Our considerations to solve the problem of labyrinthine system injury was based on the anatomical documentation of the localization of the labyrinth in the preoperative imaging in relation to the IAC and the implementation of the preoperatively acquired anatomical data to the intraoperative surgical domain with exact measurement values, which could be reproduced intraoperatively in all 51 patients. The sinus-fundus-line has the disadvantage that a very medially localized semicircular

canal, especially the PSCC, cannot be exclusively seen as a safe line for the surgeon for the preservation of the labyrinth [Figure 10]. Our presented method deals with the anatomical localization of the labyrinthine system itself and always was localized medially to the labyrinthine system. With our introduced method, we think that we have found a safe retrosigmoid approach to the fundus of the IAC. In the postoperative MRI scans, we could not find any injuries (0%) to the labyrinthine system in all 51 patients. Even in very medially localized posterior semicircular canals, a sufficient bony lamella of 1–2 mm was seen. Therefore, we could achieve similarly good postoperative hearing results such as the middle fossa approach. This corresponds to our results for the small T1-tumors with postoperative hearing preservation >90%, which corresponds to the best postoperative results for intracanalicular tumors via the middle fossa approach of 93%, as described by Kumon *et al.*[9] There is a rate of 51% (n = 25) for the preservation of a useable hearing function independent of the tumor sizes. Former studies also describe a rate of hearing preservation of 31% to 59%.[3,6,7,13] The chance for postoperative useable hearing function is higher because the tumor sizes are smaller and the preoperative hearing function is better.[3,6,7,13] Tumors larger than 2–3 cm show a hearing preservation rate of 0% in general, corresponding to our tumor class T4 with 18% hearing preservation. As a possible cause we see the exclusion of labyrinthine injury during the exposure of the IAC with the described method of petrous bone measurement. The postoperative deafness for tumors larger than 4 ml (>1.8 cm) with more than 50% in our series is a very unsatisfactory result. Comey *et al.* suggested a two-staged surgery for large tumors; they described the advantage of this staged procedure in the reduction of mortality and cranial nerve morbidity.[4] As a cause they reported that there is a devascularization of the
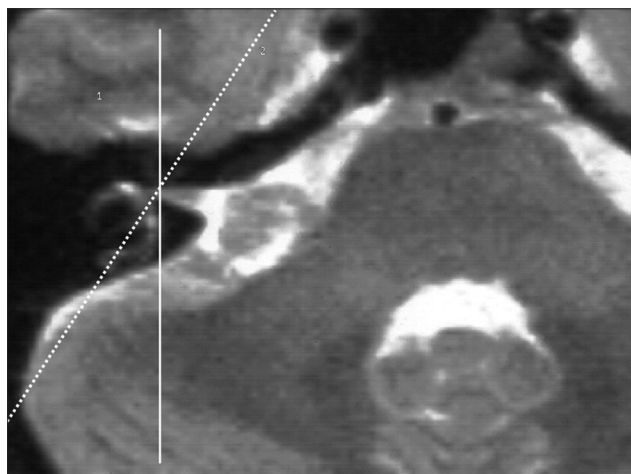

Figure 10: Comparison of the "sinus-fundus-line" (1) to the sagittal fundus-line (2). Note that very medially localized labyrinthine systems are not contained by the sinus-fundus-line but by the sagittal fundus-line

residual tumor and "self decompression" of the brainstem and the root entry zones of the cranial nerves after the first surgery. As a second step, a complication-reduced resection of the residual tumor is possible. It should be discussed if tumors above 2 cm in size should be operated in this two-staged procedure regarding the results of postoperative hearing preservation; during the first surgery, a primary volume reduction is obtained, which is oriented to the acoustic evoked potentials, and residual tumor resection on the brainstem and intrameatal with the second surgery.

We saw a significant relationship between preoperative hearing function and postoperative hearing result for all tumor sizes in our series ($P < 0.05$) for the pre and postoperative PTA and the speech audiogram for the T1-tumors (<1 ml/<1 cm). If the tumor is localized primarily intrametally, the postoperative hearing preservation is nearly equal to the preoperative hearing level with a frequency of more than 80% (80–83%). If the tumor is small and primarily extending extrameatally, the postoperative hearing quality is reduced for one hearing class (in our series Class B). For patients with larger tumors (T3 and T4: >4 ml/>2.3 cm), there is no relationship between preoperative hearing function and postoperative hearing result. Obviously, there are other factors, e.g., intraoperative lesions during extended preparation or preoperative tumor-associated lesion of the cochlear nerve in the audiogram for the T3 and T4-tumors. The difference is primarily noticed in a worsened speech discrimination. A possible cause for this significant difference might be the different influence of the tumor on the blood supply of the cochlear nerve intra and extrameatally. For T2-tumors (1–4 ml/1.1–1.8 cm), we saw a narrow correlation of total tumor volume and especially speech discrimination ($P < 0.01$). The risk for postoperative deafness for T2-tumors was 20–45%, whereas the intrameatal tumor portion did not play a role. In T3 (4–8 ml/1.8–2.3 cm) and T4-tumors (>8 ml/>2.3 cm), there was no correlation with the preoperative data, whereas the risk for postoperative deafness was 50–80% for T3-tumors and >80% for T4-tumors. In the analysis of the petrous bone and tumor measurements, we saw a very interesting and highly significant influencing factor ($P < 0.001$), the ventral tumor extension above the Crista nasalis of the IAC. From our data, we can give a superior limit of 5.5 mm for the ventral tumor extension above the Crista nasalis in our patient population where postoperative deafness occurred independent of the tumor size.

In this study, we saw a very good postoperative prognosis for the small tumors (<2 ml/<1.4 cm) as a good argument for an early, surgical resection, whereas stereotactic radiosurgery was established with excellent hearing preservation rates of 60–75% and reduced morbidity, especially for patients with preoperative good

hearing function and medium-sized and large tumors as an appropriate alternative.[12]

We could implement the method of preoperative petrous bone measurement into the surgical setup. By the transfer of preoperatively acquired individual, anatomical data from high-resolution MRI to the operative field we could avoid any injury to the labyrinthine system on the suboccipital, retrosigmoid approach in a prospective manner. We think that this gives the possibility to reduce an important risk factor of postoperative hearing preservation, especially in small, intrameatal tumors. Of course, gammaknife radiosurgery is an excellent alternative with excellent risk profile and outcome statistics in comparison to our work. With our study we were able to give a prognosis of postoperative hearing preservation, which contributed to patient and physician relationship as well as patient consultation.

CONCLUSION

Petrous bone measurement by high-resolution MRI data enables the safe surgical exposure of the IAC with avoidance of injury to the labyrinthine system along with a better postoperative prognosis especially for intrameatal acoustic neuromas and the resection of intrameatal portions of larger neuromas. The prognostic factors enable the patients and the surgeon a better estimation of postoperative results regarding deafness and postoperative hypacusis and support a consolidated treatment planning.

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Conflicts of interest
There are no conflicts of interest.

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