Prognostic Significance of Preoperative Geometric Changes in the Internal Acoustic Canal for Hearing Preservation in Vestibular Schwannoma Surgery

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■ OBJECTIVE: **This study focused on the changes in the internal acoustic canal (IAC) caused by vestibular schwannomas (VSs) and their prognostic significance for postoperative hearing outcome.**

■ METHODS: **A total of 125 consecutive cases of VS were included. We used a neuronavigation software to perform the following measurements on both the tumor side and healthy side: volume of the IAC (VIAC), maximal diameter of the IAC (DIAC), and length of the IAC (LIAC). A statistical analysis was realized using Spearman correlation to test the correlation of the morphometric measure of the IAC and postoperative hearing. Multivariate analysis was performed to test the impact of measurements of the IAC and preoperative hearing on postoperative hearing.**

■ RESULTS: **The mean VIAC on the tumor side and on the healthy side was 0.271 and 0.169 cm^3, respectively. The mean DIAC was 9.438 mm on the tumor side and 7.034 mm contralateral. The correlations tests showed significant correlations of both postoperative hearing deficit and degree of hearing loss with 1) VIAC on the tumor side, 2) difference between VIAC on the tumor side and healthy side, 3) DIAC on the tumor side, and 4) difference between the DIAC on the tumor side and healthy side. The multivariate analysis showed significant impact of the DIAC ($P = 0.01$) and preoperative hearing status ($P = 0.02$) on postoperative hearing.**

■ CONCLUSIONS: **Enlargement of the VIAC and DIAC are negative prognostic factors for hearing preservation. Reasons may be long-standing compression of the auditory nerve and an increased vulnerability of the inner ear structures during the drilling of the IAC.**

INTRODUCTION

Patient outcome after surgical treatment of vestibular schwannoma (VS) has improved dramatically over the last decades. In its beginnings, this surgery was performed to save a patient's life without any ambition to preserve facial and/or cochlear nerve function.[1] Today, the great challenge for neurosurgeons around the world is the complete removal of the tumor while preserving the facial nerve and, especially for small lesions, auditory function.[2-5] Many prognostic factors correlating with hearing preservation have been examined in previous studies.[6-16] Anatomic features of the tumor, such as its extension, have been described as a negative prognostic factor for hearing preservation. The degree of meatal filling has also been considered; however, there is no consensus on being a positive or negative prognostic factor.[6-16] Here, we focus on the changes in the internal acoustic canal (IAC) caused by the tumor, independently from its size and shape, and their prognostic significance for postoperative hearing outcome.

MATERIALS AND METHODS

Patient Population

A total of 125 individuals who were surgically treated in our institute for VS were included in this study (Table 1). The mean age of the patients was 47 years (range, 19–77 years); participants included 66 men and 59 women. Patients affected

Key words
- Hearing preservation
- Internal acoustic canal
- Vestibular schwannoma

Abbreviations and Acronyms
CT: Computed tomography
DIAC: Diameter of the IAC
IAC: Internal acoustic canal
MRI: Magnetic resonance imaging
VIAC: Volume of the IAC
VS: Vestibular schwannoma

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Table 1. Patients' Characteristics

Variable	Value
Mean age (range) (years)	47 (19–77)
Sex	
Male	66 (52.8)
Female	59 (47.2)
Tumor extension	
T1	7 (5.6)
T2	12 (9.6)
T3a	18 (14.4)
T3b	14 (11.2)
T4a	49 (39.2)
T4b	25 (20)
Preoperative serviceable hearing	
Yes	87 (69.6)
No	38 (30.4)

Values are number of patients (%) or as otherwise indicated.

Table 2. Hannover Tumor Extension Grading System

Tumor Extension	Description
T1	Purely intracanalicular
T2	Intrameatal or extrameatal
T3a	Filling the cerebellopontine cistern
T3b	Reaching the brainstem
T4a	Compression of the brainstem
T4b	Compression of the brainstem with dislocation of the fourth ventricle

by neurofibromatosis were excluded from the study population. Initial symptoms and neurologic status at admission and discharge were considered. Pre- and postoperative hearing was recorded in every patient using pure tone averages calculated from speech discrimination scores and hearing levels at 0.5, 1, and 2 kHz. Postoperative hearing was recorded 10 days after surgery for every patient.

The Hannover classification was used to assess the extension of the tumor (Table 2).[5]

Each patient underwent complete tumor removal with the same technique performed by the senior author in a semi-sitting position via a lateral suboccipital retrosigmoid approach, as previously described.[2,5]

Image Processing

The following preoperative imaging was performed for each patient: computed tomography (CT) scan (1-mm slice thickness) with bone window, T1-weighted (1-mm slice thickness) magnetic resonance imaging (MRI) with and without intravenous contrast, and T2-weighted MRI (constructive interference steady state) (0.5-mm slice thickness). The images were transferred via network to a neuronavigation planning workstation (Brainlab AG, Heimstetten, Germany) for image processing (Figure 1). After automatic fusion of the CT scan and MRI sequences and its verification, the following measurements were performed on both the tumor side and healthy side: 1) volume of the IAC (VIAC), 2) maximal diameter of the IAC (DIAC), and 3) length of the IAC (from the posterior margin of the porus to the fundus) (Figure 2).

Statistical Analysis

A statistical analysis was performed to correlate the performed measurements with pre- and postoperative hearing deficit. Spearman correlation was performed to test the correlation of different morphometric measures of the IAC and postoperative hearing loss (in decibels). To test the impact of each parameter on hearing deficit (in decibels), a multivariate regression analysis was performed using postoperative hearing deficit (in decibels) as a dependent variable, and preoperative hearing and morphometric measures of the IAC as independent variables. Results were considered significant with $P < 0.05$.

RESULTS

All patients underwent total removal of the VS. The distribution of patients with respect to the extension of the tumor was as follows: T1 (n = 7), T2 (n = 12), T3a (n = 18), T3b (n = 14), T4a (n = 49), and T4b (n = 25). Eighty-seven of the 125 patients had preoperative serviceable hearing on the tumor side (Table 1).

The mean VIAC on the tumor side and on the healthy side was 0.271 and 0.169 cm^3, respectively. The mean DIAC was 9.438 mm on the tumor side and 7.034 mm contralateral. The mean length of the canal was 10.192 mm on the tumor side and 9.810 mm on the healthy side (Table 3).

The correlations tests showed significant correlations of both postoperative hearing deficit and degree of hearing loss (difference between preoperative and postoperative pure tone average hearing level) with the following: 1) VIAC on the tumor side, 2) difference between the VIAC on the tumor side and healthy side (VIAC tumor side − VIAC healthy side = difference), 3) DIAC on the tumor side, and 4) difference between the DIAC on the tumor side and the healthy side. The correlation coefficients and P values are presented in Table 4.

The multivariate regression analysis showed that the maximal diameter of the canal (coefficient, 11.9; $P = 0.01$) and preoperative hearing (coefficient, 0.6; $P = 0.022$) had significant impact on postoperative hearing deficit.

DISCUSSION

Improving patient's postoperative quality of life has been a constant challenge in surgical treatment of VS. Naturally, the main

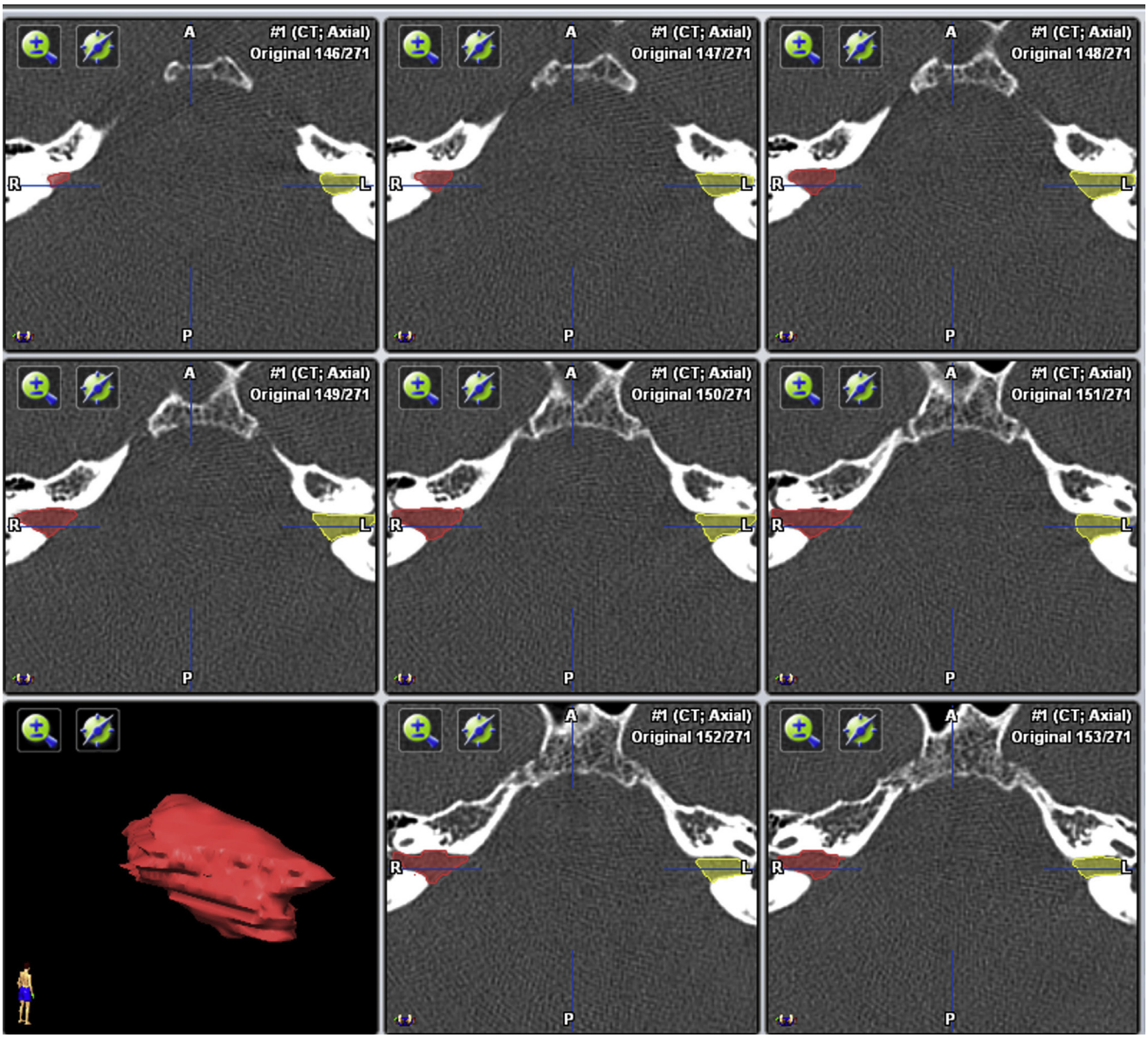

Figure 1. Volumetry of the internal acoustic canal (IAC) using the neuronavigation software: the computed tomography images with bone window are selected and the IAC is segmented on both the tumor side and healthy side.

concern is the preservation of facial nerve function. Because of advancements in surgical techniques and intraoperative monitoring, addressing this concern has been highly successful.[2,4,17,18] Many studies have addressed the topic of hearing preservation in VS surgery and its prognostic factors including tumor size,[8,19,20] timing of surgery,[9,14] type of surgical approach,[6,10,16] nerve of origin,[11] and MRI features.[15,21] Other studies have considered the anatomic characteristics of the tumor, such as the studies by Gjuric and Rudic[8] and Dornhoffer et al.,[19] in which the tumor extension beyond the IAC and the degree of invasion of the cerebellopontine angle are strongly related to a negative prognostic factor for postoperative hearing outcome. In the same way, in the study by Hecht et al.,[20] the maximum diameter of the tumor was negatively correlated with postsurgical hearing function. On the other hand, contrasting observations with respect to the grade of meatal filling have

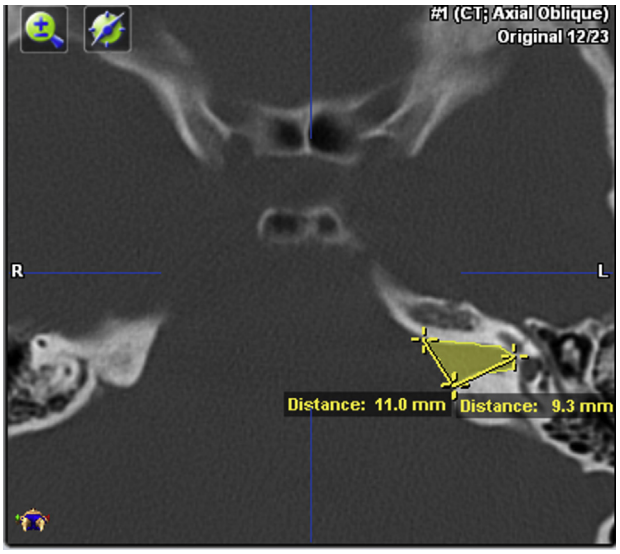

Figure 2. Detailed image of the measurements of maximal diameter of the internal acoustic canal and length of the internal acoustic canal using the neuronavigation software and computed tomography images.

Table 4. Spearman Correlation Test

	Postoperative Hearing		Degree of Hearing Loss	
Factor	Correlation Coefficient	*P* Value	Correlation Coefficient	*P* Value
VIAC of the tumor side	0.31161	0.0033	0.28521	0.00741
Difference between VIAC of the tumor side and healthy side	0.41328	0.000	0.35688	0.00069
DIAC	0.42488	0.000	0.41301	0.000
Difference between DIAC of the tumor side and healthy side	0.39348	0.00016	0.35719	0.00068

Spearman correlation test shows significant correlations of both postoperative hearing deficit and degree of hearing loss with 1) VIAC on the tumor side, 2) difference between the VIAC on the tumor side and healthy side, 3) DIAC on the tumor side, and 4) difference between the DIAC on the tumor side and healthy side.
VIAC, volume of the internal acoustic canal; DIAC, diameter of the internal acoustic canal.

been made. Although some papers report it as a negative prognostic factor,[10,12,21-23] others show a higher degree of hearing preservation when the IAC is completely filled, at least for intracanalicular VSs.[13]

In this work, we examined the geometric changes of the IAC (volume, diameter, and length) as potential prognostic factors for postoperative hearing outcome: the results show that volume, diameter, and their change with the healthy side significantly correlate with hearing outcome, whereas there is no correlation considering the length of the IAC. A possible explanation may lie in the natural history of VS and the theorized mechanisms of hearing loss.[24] Cochlear nerve compression and restriction of blood supply seem to play a major role.[25,26] The enlarged diameter and volume of the canal are an indirect sign of long-standing high intracanalicular pressure that can influence the blood supply and make the auditory nerve vulnerable to surgical manipulation. These hypotheses are supported by the previously cited papers about tumor size; however, in our study, the statistical analysis shows that the differences in VIAC and DIAC impact on postoperative hearing function independently from tumor extension, probably for characteristic features of the tumor itself, such as its tendency to erode the surrounding bone or to grow within the IAC rather than outside, causing the increase of intracanalicular pressure. Also, the increase in VIAC and DIAC at the meatus decreases the distance of the inner ear structures, in particular the vestibule and the crus, which may result in an increased vulnerability of the IAC during drilling.

Table 3. Internal Acoustic Canal Measurements

Variable	Value
Volume of the internal acoustic canal	
Healthy side (cm^3)	0.169
Tumor side (cm^3)	0.271
Diameter of the internal acoustic canal	
Healthy side (mm)	7.034
Tumor side (mm)	9.438
Length of the internal acoustic canal	
Healthy side (mm)	9.810
Tumor side (mm)	10.192

Values listed are means.

CONCLUSIONS

Many factors may influence postoperative hearing outcome after VS surgery. In the study at hand, we observed that enlargement of VIAC and enlargement of DIAC are negative prognostic factors for hearing preservation. Reasons may be long-standing compression of the auditory nerve and an increased vulnerability of the inner ear structures during the drilling of the IAC.

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