Position of Retrosigmoid Craniotomy in Hearing Preservation Surgery for Vestibular Schwannoma

Leonardo Franz, MD*‡§
Antonio Mazzoni, MD*
Alessandro Martini, MD*
Domenico d'Avella, MD||
Elisabetta Zanoletti, MD*

*Department of Neuroscience DNS, Otolaryngology Section, University of Padova, Padova, Italy; ‡Department of Otolaryngology—Head and Neck Surgery, University of Toronto, Toronto, Canada; §Guided Therapeutics (GTx) Lab, University Health Network, Toronto, Canada; ||Department of Neuroscience DNS, Academic Neurosurgery, University of Padova, Padova, Italy

Correspondence:
Leonardo Franz, MD,
Department of Neuroscience DNS,
Otolaryngology Section,
University of Padova,
Via Giustiniani 2,
35128 Padova, Italy.
Email: leonardo.franz@aopd.veneto.it

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BACKGROUND: Surgical access to the internal auditory canal (IAC) fundus is a crucial aspect of the retrosigmoid approach for hearing preservation surgery in vestibular schwannoma. An appropriate positioning of the retrosigmoid craniotomy is necessary to obtain an adequate surgical corridor for full fundus exposure and labyrinth preservation.

OBJECTIVE: To describe how the position of the posterior edge of the access related to the probability of exposing the fundus and to propose novel criteria for positioning the retrosigmoid craniotomy.

METHODS: Data on fundus exposure were retrospectively collected in 33 consecutive cases of sporadic vestibular schwannoma, submitted to the retrosigmoid craniotomy in a park-bench position. Patients' computed tomography images were analyzed to calculate the position of the posterior edge of the craniotomy with reference to the fundus–labyrinth line (FLL), which starts at the fundus and, running just posterior to the labyrinth, reaches the occipital squama. A logistic regression model was used to correlate the craniotomy position with the probability of exposing the fundus.

RESULTS: The fundus exposure rate was significantly higher (P = .005) for craniotomies located posteromedially to the FLL. In a logistic regression model, the probability of exposing the fundus reached 95% for craniotomies located 11.3 mm posteromedially to the FLL.

CONCLUSION: This study showed a strong association between craniotomy position and fundus exposure rate. Our findings suggest that the posteromedial edge of the retrosigmoid craniotomy should lie approximately 11 mm posteromedially to FLL to maximize the chances of exposing the fundus.

KEY WORDS: Hearing preservation surgery, Retrolabyrinthine meatotomy, Retrosigmoid craniotomy, Vestibular schwannoma

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Early diagnosis, provided by modern imaging techniques, has brought to a dramatic change in number and size of newly diagnosed vestibular schwannomas. Consequently, nowadays the main challenge resides in avoiding functional morbidity.

Facial nerve and hearing functions are critical issues the current therapeutic strategies, including observation, radiotherapy, and surgery, aim to preserve.[1-6]

Hearing preservation surgery (HPS) is currently performed using 2 main approaches, the middle cranial fossa and retrosigmoid craniotomies. The latter is more widely used because it enables one to treat larger tumors because of a better view of the cerebellopontine angle,[7,8] with no risk of jeopardizing the temporal lobe. It has disadvantages, however, including cerebellum retraction and a greater difficulty in exposing the lateral third of the internal auditory canal (IAC).[9,10] In the retrosigmoid approach, retrolabyrinthine meatotomy (RLM)[11,12] allows exposing the IAC fundus, directly controlling the distal portion of the tumor. Such a technique is a fully microscopical alternative to the microendoscopic approach. The RLM[11,12] implies an occipital craniotomy, which is the subject of this article, and petrous drilling, targeted to the IAC.[11,12] This provides a wide, multiangled exposure of the IAC.

The principal aim of this study was to identify the relationship between the position of the posteromedial edge of the access and the probability of a complete exposure of the IAC fundus.

ABBREVIATIONS: FLL, fundus–labyrinth line; **HPS,** hearing preservation surgery; **IAC,** internal auditory canal; **PTA,** pure tone average; **RLM,** retrolabyrinthine meatotomy; **SDS,** speech discrimination score

A secondary aim was to set evidence-based criteria for positioning the retrosigmoid craniotomy.

METHODS

Patients

This study was conducted in accordance with the Declaration of Helsinki. Data were examined in compliance with Italian privacy and sensitive data laws and with the in-house rules of our institution. All patients preoperatively gave their written consent to the procedure and signed a disclosure form on privacy in managing data for scientific purposes.

A group of consecutive patients, who underwent HPS for sporadic vestibular schwannoma using a retrosigmoid approach in a park-bench position, were retrospectively assessed.

Our inclusion criteria were (1) sporadic vestibular schwannoma diagnosis, (2) primary surgery with retrosigmoid access and RLM,[12] and (3) no previous cranial vault defects or a history of skull base surgery.

Patients lacking radiological or clinical data to adequately address this study's end points were excluded. To evaluate functional outcomes, patients were divided into 2 groups: those who met our institution's eligibility criteria for HPS[12] and those who did not.

The eligibility criteria were

1. tumor size ≤10 mm (calculated as the largest diameter in cerebellopontine angle; for purely intracanalicular tumors, only the longitudinal size within the IAC was considered[13]),
2. ≤30 pure tone average (0.25-4 KHz),
3. ≥70 speech discrimination score, and
4. normal or slightly modified auditory brainstem response (ABR).

Patients not complying with such criteria but willing to attempt surgery with hearing preservation intent as well, because of a counseling in which their lower chance of hearing preservation due to tumor size and/or hearing function at the baseline were carefully disclosed, were also included in this investigation.

All patients underwent preoperative contrast-enhanced magnetic resonance imaging (MRI) and temporal bone computed tomography (CT) scan. MRI showed tumor completely involving the IAC fundus in 20 of 33 (60.6%) patients while cerebrospinal fluid (CSF) between the fundus and the lateral end of the tumor was evident in the remaining cases.

In all procedures, a RLM was performed, with the intent to completely expose both tumor and fundus. After surgery, a CT of the skull was obtained.

CT-Based Preoperative Planning and Postoperative Control

Preoperative CT showed the following landmarks for both the RLM and craniotomy:

1. The bony labyrinth.
2. The fundus–labyrinth line (FLL), which ran tangentially to the labyrinth, starting at the orifice of the fallopian canal and hitting the occipital squama in the area of the retrosigmoid craniotomy (Figure 1). This line indicated the amount of petrous bone removal to preserve the labyrinth and the width of both surgical corridor and cerebellar retraction. The spatial relationship between the IAC, labyrinth, petrous bone, and occipital squama is variable (Figure 2).
3. The posterior margin of the sigmoid sinus because it straightens up distally to the transverse sigmoid knee. The distance from the sinus to the FLL was transferred on the actual patient's head to mark the position of the posteromedial craniotomy edge.

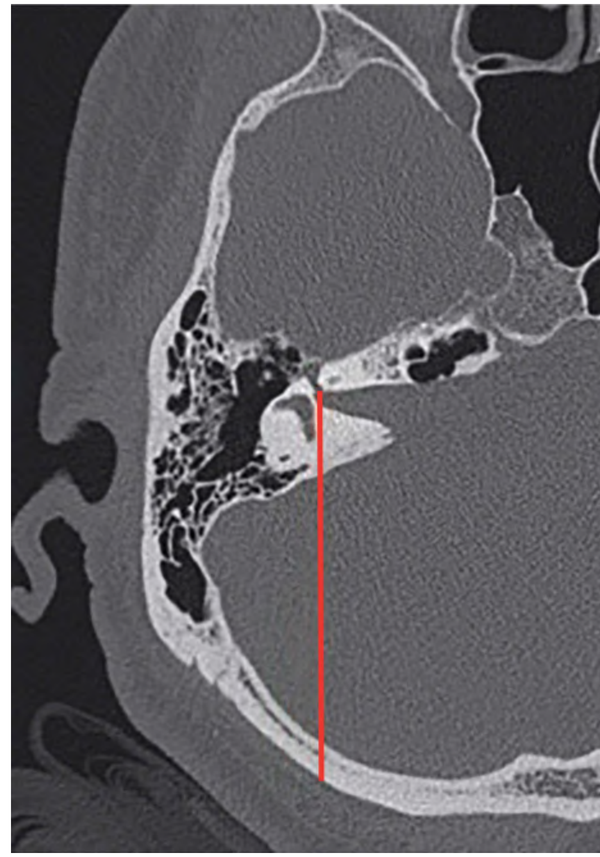

FIGURE 1. *Bone window axial CT. The FLL line starts at the orifice of the fallopian canal and proceeds backward tangentially to the posterior semicircular canal: axial CT scan showing the FLL (in red). CT, computed tomography; FLL, fundus–labyrinth line.*

The postoperative CT images were analyzed using *3DSlicer* software[14,15] to verify the amount of IAC fundus exposure and to appreciate the position of the posterior edge of the craniotomy with reference to the FLL. Particularly, the distance (in mm) between the FLL and the actual posterior edge of the craniotomy was measured.

The positions of craniotomies extending posteriorly to the FLL were indicated by negative values, while those extending anteriorly thereto as positive.

The degree of removal of the posterosuperior wall of the distal IAC at the level of the fallopian canal orifice was to assess whether the fundus exposure was correct. For our purposes, fundus exposure was treated as a binary variable: the fundus was considered as "exposed" when the lateral half of the roof and the posterior wall of the IAC had been removed and

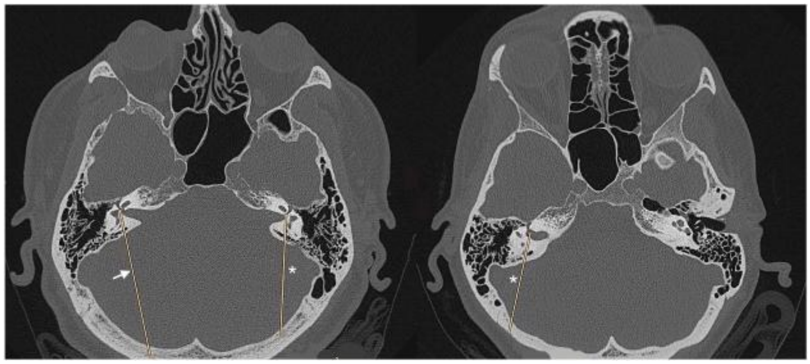

FIGURE 2. *Different spatial relationship between the labyrinth and internal auditory canal: wide (white arrow) and narrow (asterisk) angles in axial computed tomography.*

the meatotomy line could run unhindered by the bone from the fallopian canal orifice to the labyrinth and finally to the craniotomy (Figure 3A) and as "not exposed" otherwise (Figure 3B).

Data about complications and postoperative hearing function were collected. Hearing preservation was defined as postoperatively maintaining class A or B according to the American Academy of Otolaryngology-Head and Neck Surgery.[16]

Statistical Analysis

The Fisher exact test and Mann–Whitney *U* test were used as appropriate. Logistic regression was used to describe the variation in the probability of fundus exposure vis-à-vis the craniotomy position. Statistical analyses were run using Stata/SI version 15.1 (StataCorp LP). Statistical significance was set at $P < .05$, whereas *P*-values in the range between .05 and .10 were assumed to indicate a statistical trend.

RESULTS

Clinical Outcomes

In this study, the last 33 consecutive patients from our series of 366 vestibular schwannomas undergone HPS[11,12], treated in a period from 2012 to 2019 (mean age: 49 ± 8.9 yr), complied with the inclusion and exclusion criteria.

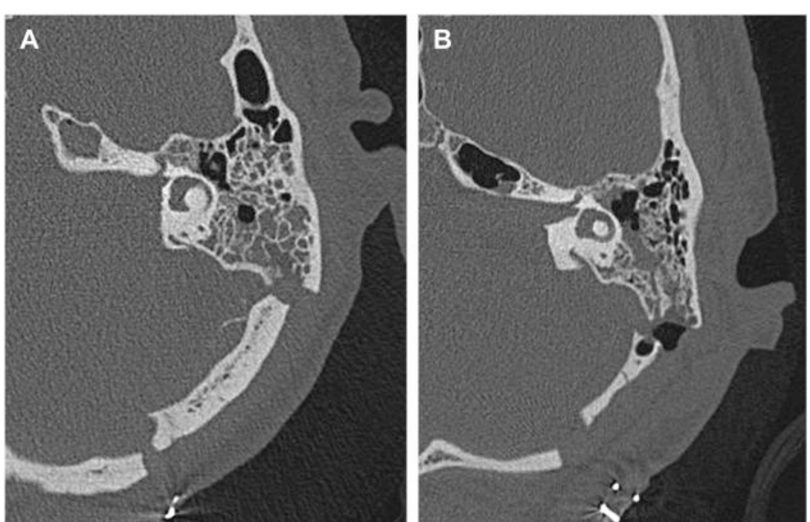

FIGURE 3. *Degrees of fundus exposure at axial computed tomography:* **A**, *fully exposed (surgical corridor from the craniotomy to fallopian orifice after removal of the posterior wall and roof of the IAC) and* **B**, *not exposed (residual lateral part of the posterior superior wall of the IAC at the fundus). IAC, internal auditory canal.*

TABLE 1. Clinical Features and Outcomes of the Included Series

Case	Preoperative PTA (dB)	Preoperative SDS (%)	Tumor size (mm)	Comliance to HPS criteia	Fundus involvement	IAC fundus exposure	Preserved hearing function[a]
1	25	100	11	1	No	Yes	No
2	25	100	8	0	No	Yes	Yes
3	23	100	10	0	Yes	Yes	Yes
4	35	100	8	1	Yes	No	No
5	15	100	5[b]	0	No	Yes	Yes
6	20	100	10[b]	0	Yes	No	Yes
7	26	100	10[b]	0	No	No	No
8	10	100	10	0	Yes	No	Yes
9	32.5	100	5[b]	1	Yes	Yes	No
10	32	100	11	1	No	Yes	No
11	32	100	10	1	No	No	No
12	25	100	5[b]	0	Yes	Yes	Yes
13	25	100	10[b]	0	Yes	Yes	Yes
14	35	100	40	1	Yes	No	Yes
15	22	100	5[b]	0	Yes	Yes	Yes
16	10	100	11	1	Yes	No	No
17	30	100	5[b]	0	Yes	Yes	Yes
18	20	100	9	0	No	Yes	Yes
19	27	100	8	0	Yes	Yes	No
20	34	100	10	1	Yes	No	Yes
21	30	100	10	0	Yes	Yes	Yes
22	30	100	5[b]	0	Yes	Yes	Yes
23	15	100	6	0	No	Yes	Yes
24	14	100	7[b]	0	No	No	Yes
25	22	100	9	0	No	Yes	No
26	30	100	12	1	Yes	No	No
27	12.5	100	10	0	Yes	Yes	Yes
28	32.5	70	10	1	Yes	Yes	No
29	15	100	9	0	No	Yes	Yes
30	50	70	7	1	No	No	No
31	10	100	4	0	Yes	Yes	No
32	12.5	100	12	1	Yes	Yes	No
33	21.5	100	5	0	No	No	Yes

HPS, hearing preservation surgery; IAC, internal auditory canal; PTA, pure tone average; SDS, speech discrimination score.
[a]Postoperative hearing class A/B.
[b]Purely intracanalar (tumor length into the IAC).

Table 1 summarizes each case's radiological and functional features. Twenty-one of the 33 enrolled patients met the eligibility criteria for HPS.[12] The remaining 12 chose surgery despite their lower chance of hearing preservation due to size and/or preoperative hearing function.

Among the 21 patients meeting the eligibility criteria, 17 (81.0%) maintained a postoperative hearing class A or B,[16] in line with the results of our group's larger series.[11,12] Two over 12 patients (16.7%), who were off the mentioned criteria, maintained class A or B hearing.[16]

Figure 4 summarizes the functional hearing results. No significant differences emerged in the postoperative hearing preservation rates (Fisher exact test, P = 1.000) between cases with fundus directly involved by the tumor and those with a CSF layer at MRI.

Three major complications occurred: 1 transient cerebellar edema, 1 subdural, and 1 extradural hematoma. Patients were treated with temporary CSF shunt and hematoma removal, respectively, and they completely recovered with no sequelae.

Thirty patients (90.9%) maintained House-Brackmann (HB) grade I-II facial nerve function. The remaining 3 showed grade III HB: 1 had preoperative facial nerve impairment, 1 had a 40-mm large schwannoma in the cerebellopontine angle, and 1 developed facial nerve palsy after revision surgery for subdural hematoma.

No patient showed any macroscopic tumor residual at the end of procedure, even at the endoscopic assessment of the fundus. At MRI follow-up of at least 18 mo, no patients showed persistent or recurrent tumor.

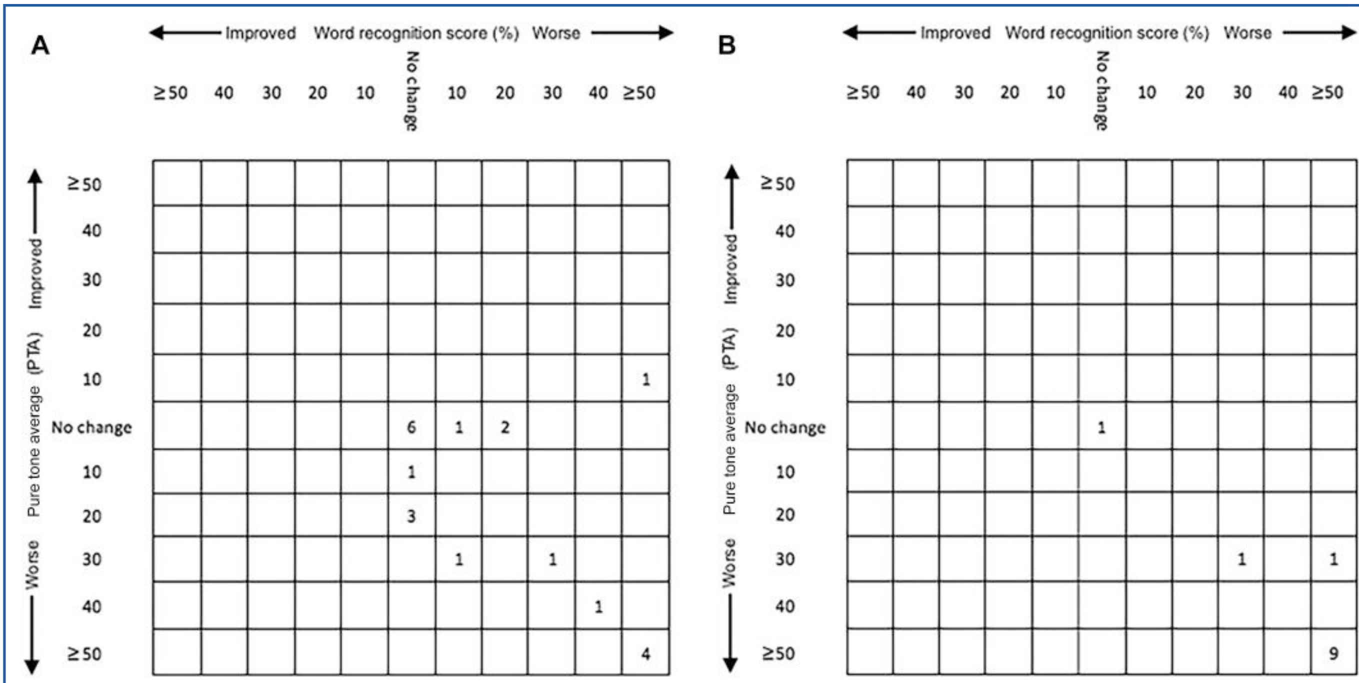

FIGURE 4. *Hearing outcomes* A, *in patients meting the eligibility criteria for hearing preservation surgery*[12] *and* B, *in patients out of the hearing preservation criteria.*

Position of the Retrosigmoid Craniotomy and Surgical Exposure of the Fundus

The posterior edge of craniotomy was located significantly further back in cases where fundus was exposed (Mann–Whitney *U* test, $P = .0002$; see also Table 2).

Binarizing the position of craniotomy as posterior vs anterior to the FLL showed that the proportion of cases with a successfully exposed fundus was significantly higher (Fisher exact test, $P = .005$) for craniotomies posterior (fundus exposure in 79.2% of cases) vs anterior (fundus exposure in 22.2% of cases) to this line.

Correlation Between the Position of Retrosigmoid Craniotomy and Fundus Exposure Probability

On logistic regression, the correlation between the craniotomy position vis-à-vis the FLL and the exposure of the fundus was statistically significant ($P = .003$; odds ratio: 0.76, 95%CI: 0.63-0.91). According to our model, the probability of fundus exposure decreased by 24% for each millimeter of displacement anteriorly to the FLL, and it increased by the same proportion for each millimeter it shifted posteriorly to that line.

Based on our logistic regression model, the probability of exposing the fundus was 44.2% for craniotomies located on the FLL, 95% for craniotomies located 11.3 mm posteriorly to this line, and 5% for craniotomies located 9.9 mm anteriorly to the FLL. The relationship between craniotomy position and the probability of fundus exposure is shown in Figure 5.

Association Between Retrosigmoid Craniotomy Position and Functional Outcomes

Considering the 21 patients who met the eligibility criteria for HPS, the craniotomy was located further back in subjects who maintained a postoperative hearing class A or B[15] (Mann–Whitney *U* test, $P = .0733$, trend toward signification).

Conversely, no significant differences in craniotomy position emerged between patients who showed a postoperative grade III

TABLE 2. Mean Distance of the Posterior Edge of Retrosigmoid Craniotomy from the FLL, Stratified by IAC Fundus Exposure

Clinical variables	No. of cases and %	Mean distance from FLL (mm ± SD)	*P*-value (*U* Mann–Whitney test)
Fundus completely exposed	21 (63.6)	−8.00 (±5.66)	.0002
Fundus not exposed	12 (36.4)	3.07 (±6.58)	

FLL, fundus–labyrinth line; IAC, internal auditory canal.

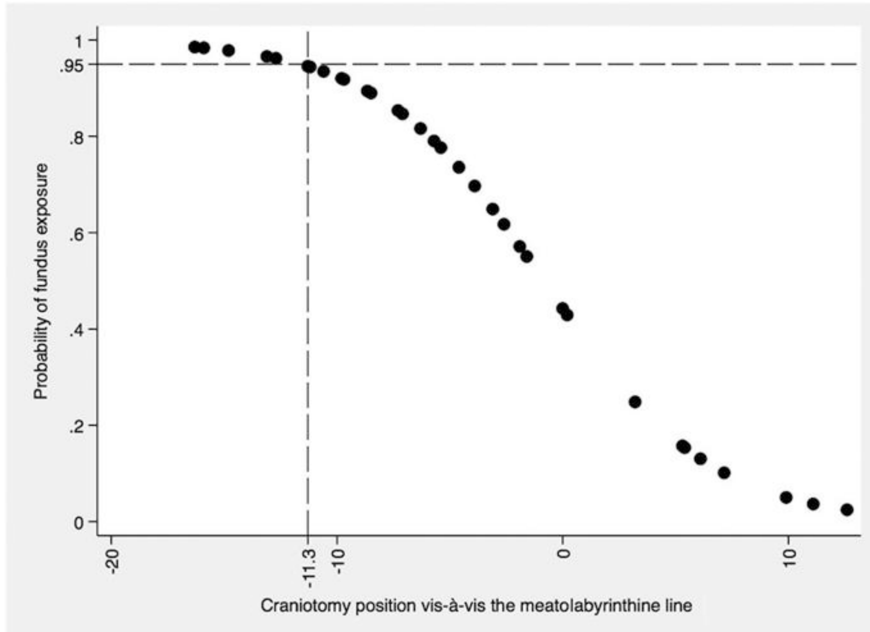

FIGURE 5. *Graph showing the relationship between the distance of the craniotomy from the meatolabyrinthine line and the probability of exposing the fundus, which was 95% for craniotomies located 11.3 mm posteriorly to the FLL. Locations posterior to the FLL are identified by negative values. FLL, fundus–labyrinth line.*

HB facial nerve function and those who maintained grade I-II HB (Mann–Whitney *U* test, *P* = .2104).

DISCUSSION

RLM slowly developed since its first description[11] up to this novel, updated conception. The possibility to accurately plan on patients' CT images of the position of retrosigmoid craniotomy, with reference to the final target of the distal posterosuperior wall of the IAC, represented the ultimate development of the microsurgical access to the IAC using RLM.

In this study, hearing outcome evaluation seemed to indicate a trend toward a more medial position of the craniotomy in patients who maintained postoperative class A-B hearing and supported the idea that a favorable surgical trajectory toward the IAC might allow one to safely perform meatotomy and preserve the labyrinth and hearing function.

Regarding RLM, few anatomic issues are worth to be clarified. The fundus is exposed with an angled view suitable to visualize the fallopian canal and cochlear nerve orifices, as well as the interposed *crista transversalis*. It entails nerves affecting the fundus and entering the bone but partly masking the orifice margins.

The main strength of RLM lies in the possibility to directly visualize the distal projection of the tumor on the facial and cochlear nerves. This also applies to the tumor part laying on the vestibular quadrants, whereas, the orifice is hardly seen because it lies on a parasagittal plane tangential to the view.

The position of the medial border of craniotomy is crucial for meatotomy's final step, in which the distal ring-like wall of IAC is drilled out.[12] As fundus and vestibular wall of labyrinth do not overlap and are separated by a 2- to 3-mm thick bone, the IAC bony ring can be safely drilled with a 2- to 3-mm burr, without opening into the labyrinth, as long as the RLM adopted the FLL as guide and the craniotomy border as proximal landmark (Figure 1).

The sight line to the fundus runs tangentially to the medial margin of the craniotomy and allows one to stop drilling as the fundus becomes visible, before opening into the vestibule. This final step is important especially for tumors arising from the superior vestibular nerve and adhering to its orifice.

During the procedure, the aqueduct and labyrinth are identified and preserved: First, the dura is removed just medially to the entrance of the aqueduct into the petrous bone; the blue line of the posterior semicircular canal and the other labyrinthine landmarks (the common crus and the superior semicircular canal) are identified by drilling. Such landmarks are exposed up to the level of the dural layer of the IAC.

In case of significant pneumatization, the air cells are filled with wax, thus preventing CSF leakage. In our series, a strong correlation was found between craniotomy position and the probability of fundus exposure, which was 95% for craniotomies located 11.3 mm posteromedially to the FLL. This deserves a comment on the relationship between FLL and fundus exposure. The FLL lies on a linear optical plane while the corresponding surgical corridor requires a larger space, being rather a cone-

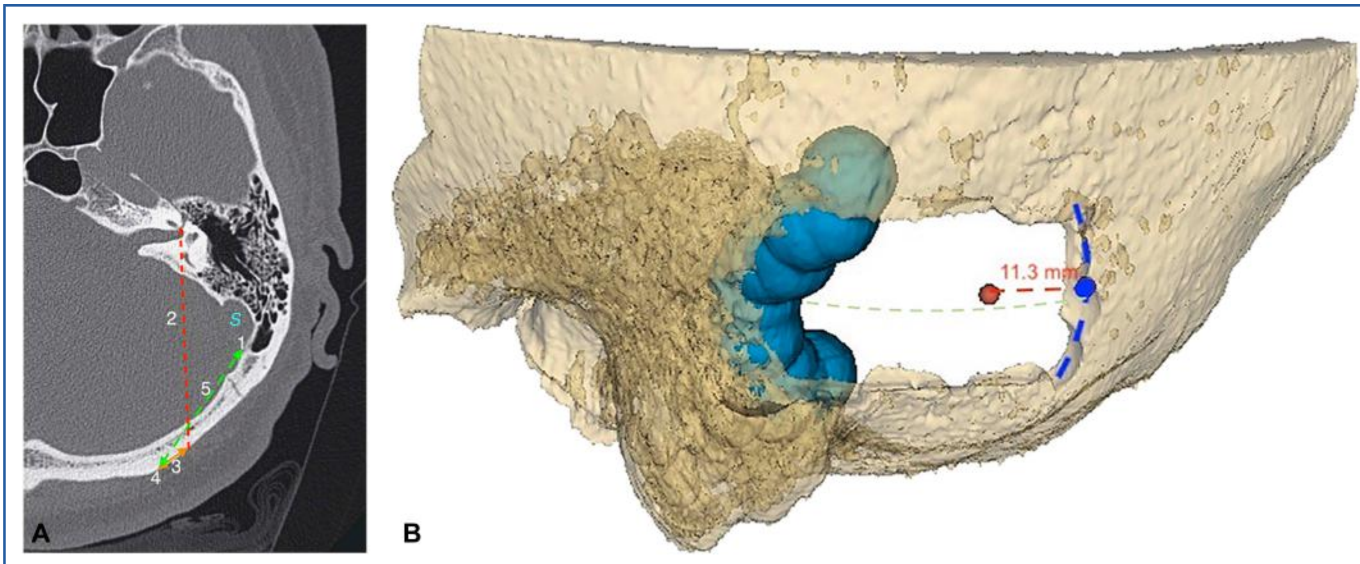

FIGURE 6. *The steps to set the posteromedial edge of the craniotomy in axial computed tomography:* A, *(1) sigmoid sinus (S) reference identification, (2) fundus–labyrinth line as it hits the occipital squama, (3) addition of 11.3 mm, (4) site of posteromedial edge of the craniotomy, and (5) distance in mm from the sinus to craniotomy.* B, *3D rendering of the craniotomy.*

shaped volume from the craniotomy to the IAC fundus. It also allows handling the instruments and compensating for variational anatomy.

In practice, the process of virtually planning the position of craniotomy on preoperative CT and transposing it on the operating field (Figure 6) can be detailed as follows:

1. The sigmoid sinus landmark is identified on CT.
2. The FLL is traced.
3. The edge of the craniotomy is set 11 mm posteromedial to the point where the FLL hits the occipital squama.
4. The distance between the sigmoid sinus and to the planned craniotomy edge is measured.
5. Such distance is translated on the actual patient's head, starting from the sigmoid sinus, to exactly locate the posteromedial edge of craniotomy.

RLM meets several issues, including the variable anatomy of both temporal bone and cerebellopontine angle, as well as tumor-to-nerves spatial relationships and cerebellar retraction. The preoperative assessment of the FLL and surgical corridor may help to estimate the amount of cerebellar retraction necessary to reach the fundus. In our series, no broad retraction was needed. The cerebellum was only gently displaced by surgical instruments when working on the lateral half of the IAC.

The question as to when a complete RLM may be unnecessary raises some issues. Cases with tumor involving the whole IAC include both tumor adherent to the fundus and tumor contacting it without adherence.[12,17] In both conditions, a full control of fundus seems necessary. When tumor adheres to the fundus, completely drilling the distal bony ring at the IAC fundus (far lateral meatotomy) may be necessary. This allows controlling the tumor's distal projection, especially when it adheres to the vestibular quadrants of the fundus. A flexible standing seems reasonable in case of a CSF layer between tumor and fundus is visible at MRI. In this case, the choice of a partial or a complete meatotomy depends on tumor extent into the IAC. In case of a tumor not exceeding IAC proximal half, a partial meatotomy can be sufficient, while when the tumor extends more distally, a complete meatotomy, not necessarily including the distal ring of the canal, is indicated. In our series, no patient showed a tumor limited to the proximal half of the IAC, so all procedures were intended to obtain a complete meatotomy.

Limitations

The main strength of this study lies in the homogeneity of both the included cases, which were treated by the same surgical team, and the quantitative data from CT images, obtained from an advanced imaging software. Conversely, the main weaknesses concern the retrospective design and the limited number of cases.

CONCLUSION

This investigation showed how craniotomy and petrosectomy mutually concur to IAC exposure, suggesting a strong association between the craniotomy position and the probability of fundus exposure. Based on such results, placing the posteromedial boundary of the retrosigmoid craniotomy about 11 mm posteromedially to the FLL may maximize the chances of IAC fundus exposure. Further prospective studies are advocated to better characterize the functional implications of such results in HPS.

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COMMENT

For many years, surgeons have known that in order to preserve hearing in retrosigmoid surgery to remove a vestibular schwannoma, the drilling of the meatus must stop short of the posterior semicircular canal. This is an interesting article that aims to help the skull base surgeon determine the optimal posteromedial extent of the craniotomy in order to completely unroof the internal auditory canal to the fundus in a retrosigmoid craniotomy. The authors make the case that in order to expose the fundus of the internal auditory canal (IAC), the posterior aspect of the craniotomy must be back a certain distance to give the optimal trajectory to be able to unroof the canal to the fullest extent. On its face, this seems intuitive—a more tangential approach (laterally directed) will help the surgeon to uncover the IAC more completely.

The authors are to be congratulated in putting some thought and data into quantifying the location of the posteromedial extent of the craniotomy for these lesions for maximal IAC exposure in hearing preservation cases.

Paul J. Camarata
Kansas City, Kansas