Comparative Analysis of Transpetrosal Approaches to the Internal Acoustic Meatus Using Three-Dimensional Radio-Anatomical Models

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J Neurol Surg B 2015;76:310–315.

Abstract

Keywords

- transpetrosal approaches
- internal acoustic meatus
- transcrural approach
- vestibular schwannoma
- retrolabyrinthine approach

Background The transcrural approach that involves partial removal of the labyrinth was recently described to approach lesions of the cerebellopontine angle. It carries the benefit of hearing preservation and was suggested to have equivalent exposure of the petroclival surface compared with the transcochlear/transotic approaches. The current study was designed to assess if the transcrural approach could achieve as good access to the internal auditory meatus (IAM) as the more destructive translabyrinthine exposure.

Methods Fifty disease-free high-resolution computed tomography scans of the temporal bone were reviewed. Surgical freedom, angle of attack, and angle of trajectory to the internal acoustic canal were measured in three-dimensional models.

Results Surgical freedom and angles of attack showed steady increments with the progression of petrous bone resection from the retrolabyrinthine-transcrural-translabyrinthine approaches. The angle of access to the IAM axis was dramatically reduced in the translabyrinthine approach compared with the transcrural and retrolabyrinthine approaches (37.51 ± 5.7 , 24.56 ± 4.6 , and 3.17 ± 2.85 degrees, respectively; $n = 50$; average plus or minus standard deviation, $p < 0.001$).

Conclusion Using this novel radio-anatomical system, we demonstrate the advantage of the translabyrinthine approach to the axis of the internal auditory canal. The transcrural approach lags behind the translabyrinthine corridor and should be considered alongside the subtemporal and retrosigmoid approaches designed to spare hearing.

Introduction

Posterior petrosal approaches provide an anterolateral view of the cerebellopontine angle and adjacent bony structures, the petroclival surface, and the internal auditory meatus (IAM), with the advantages of minimal brain retraction and short

working depth.^{1,2} One widely popularized variant of these approaches is the translabyrinthine exposure, with or without subtemporal/transtentorial extension, recommended in patients with no serviceable hearing.^{3,4} This technique essentially involves the complete drilling of the labyrinth and consequent sacrifice of hearing.

received

April 25, 2014

accepted

January 8, 2015

published online

April 27, 2015

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Stuttgart · New York

DOI <http://dx.doi.org/10.1055/s-0035-1549000>.
ISSN 2193-6331.

For patients with salvageable hearing, a less invasive variant, the retrolabyrinthine exposure, and, most recently, the transcrural approach, was developed.^{1,2} The retrolabyrinthine corridor leaves the labyrinth fully intact because it is limited anteriorly by the edge of the posterior semicircular canal. In the transcrural variant, hearing is preserved by limited drilling of the posterior semicircular canal and step-wise sealing of the endolymphatic space to preserve labyrinthine integrity. These variants have been previously characterized with regard to accessing lesions of the petroclival region. The transcrural variant was found to cover up to 89% of the working area granted by the significantly more invasive approaches such as the transotic and transcochlear approach.⁵ These results would imply that in vestibular schwannoma surgery, the transcrural approach, with its benefit of hearing preservation, may be more desirable than approaches known to sacrifice hearing. The current study uses three-dimensional (3D) reconstructions of high-resolution computed tomography (CT) scans to simulate the dimensions of surgical access to the IAM—the key landmark of vestibular schwannoma surgery—in three posterior petrosal variants: the retrolabyrinthine, transcrural, and translabyrinthine approaches (►Fig. 1).

Materials and Methods

Scans and Database

The audit committee of Royal Preston Hospital approved conducting the measurements. Twenty-five anonymized high-resolution CT scans of the temporal bone were selected from the radiology database of Royal Preston Hospital. Scans reported to have a disease-free temporal bone and skull base were used for 3D reconstructions and analysis.

Three-Dimensional Simulation of Surgical Approaches

Using analysis software of the HP radiology workstation, verified for clinical diagnosis, we generated 3D reconstructions of the temporal bone using the volume viewer function. We quantified surgical freedom as triangular areas in the three increments of the posterior petrosal approaches: the retrolabyrinthine, transcrural, and translabyrinthine exposure. The two posterior edges of surgical freedom were the junction of the superior petrosal and sigmoid sinus superiorly (►Fig. 2C) and the jugular bulb inferiorly (►Fig. 2F). The anterior limit of the triangular area was defined by (1) the arch of the posterior semicircular canal in the retrolabyrinthine approach (►Fig. 2D), (2) the crus of the lateral semicircular canal in the transcrural approach (►Fig. 2E), and (3) the

Fig. 1 Anatomy of the retrolabyrinthine, transcrural, and translabyrinthine approaches. (A–C) Internal and (D–F) external views of superimposed schematics on dried skull model. Our area of interest is the right petrosal bone, highlighted by dotted lines (A). *Panel B:* Relevant surgical landmarks are superimposed over the skull model. The superior petrosal sinus, sigmoid sinus, and jugular bulb embrace the posterior borders of the exposures. The labyrinth is outlined in the petrosal bone. (C) Triangular areas are superimposed on the skull model to outline the surgical bone windows for each approach variant. The posterior semicircular canal demarcates the anterior limit of the retrolabyrinthine exposure, the common crus of the posterior and superior semicircular canal borders the transcrural approach anteriorly, and the translabyrinthine approach extends to the anterior edge of the vestibulum. (D) Lateral/external view of the skull model with the right mastoid outlined. (E) The labyrinth, transverse, sigmoid, and superior petrosal sinuses are superimposed over the skull model. (F) Projection of relevant anatomical structures and working areas depicted in (C) onto the lateral surface of the skull model. IAM, internal acoustic meatus.

Fig. 2 Anatomical landmarks limiting the transpetrosal approaches identified on computed tomography (CT) imaging. The junction of the superior petrosal and sigmoid sinuses contribute to the posterosuperior limit of the exposure marked on panels A, B, and C, highlighted as (1); the inferoposterior border is the junction of the sigmoid sinus and jugular bulb on panel A, B, and F, highlighted as (2). The anterior limiting landmarks of the triangular areas reside within the temporal bone and are highlighted on single high-resolution CT scans for better visibility (panels D–F). The anterior apex of the approach triangle is defined by the posterior semicircular canal (R) in the retrolabyrinthine approach (panel D), the junction of

anteromedial edge of the vestibulum in the translabyrinthine approach (►Fig. 2E).

Morphometry of Three-Dimensional Models

Superficial landmarks (►Fig. 2B) were highlighted on the 3D model, whereas the deep landmarks (►Fig. 2C–F) were marked on the two-dimensional cuts and transferred onto the 3D models. The numerical value for distances, angles, and areas were calculated based on measurement within these 3D model using the HP software (►Fig. 3G–I). The angle of attack to the IAM was measured along the plane defined by the superomedial and superolateral landmarks of each exposure. The angle of trajectory to the internal acoustic canal was defined as the angle embraced by the axis of the internal acoustic canal and the line connecting the superolateral edge of the exposure with the superior edge of the IAM (►Fig. 3D–F).

Results

Exposed Working Area

The working area for the posterior petrosal approaches progressively increased as more of the temporal bone was removed: $140.30 \pm 30.92 \text{ mm}^2$, $181.63 \pm 38.55 \text{ mm}^2$, and $245.3 \pm 44.27 \text{ mm}^2$ for the retrolabyrinthine, transcrural, and translabyrinthine exposures, respectively (►Fig. 3). A scatterplot of the numeric values revealed a mono-focused distribution in all data sets (►Fig. 3G), and statistical analysis found the increments in areas and angles to be significantly different ($n = 50$; $p > 0.0001$).

Angle of Attack to the Internal Acoustic Meatus

The horizontal angle of attack is a key feature in accessing lesions of the IAM and subsequent tumor resection. Comparing the progressively invasive posterior petrosal approaches,

Fig. 3 Analysis of posterior petrosal approaches to the internal acoustic meatus using three-dimensional models of high-resolution computed tomography (CT) scans. (A, B) Representative three-dimensional models in a right-sided medial view of the right petrous region (internal view), with superimposed triangles outlining surgical freedom granted by the individual exposures. The white arrow highlights the anterior border of the exposure. Inset depicts two-dimensional projection of the anterior border of the exposure: posterior semicircular canal (A), crus of the superior and posterior semicircular canals (B), and the anterior edge of the vestibulum for the translabyrinthine exposure (C). (D–F) Representative CT images of a right-sided temporal bone to demonstrate the horizontal angle of attack for the three exposures and the angle of trajectory in approaching the axis of the internal acoustic canal. The posterior edge of the sigmoid sinus was chosen as the occipital limit of the exposures for calculating the angle of attack (interrupted line). The angle of trajectory was measured relative to the axis of the internal acoustic canal (interrupted line). (G–I) Scatterplot and averaged surgical freedom (G), angle of attack (H), and angle of trajectory (I) for the three posterior petrosal approaches. Note the significant incline in surgical freedom and angle of attack with increasingly invasive exposures. We found a dramatic drop in the angle of trajectory over the internal acoustic canal for the translabyrinthine approach.

we found a steady increment in the angles of attack (► **Fig. 3H**). Numeric values were 20.13 ± 4.7 degrees for the retrolabyrinthine, 35.45 ± 5.74 degrees for the transcrural, and 52.78 ± 6.11 degrees for the translabyrinthine approach ($n = 50$; $p > 0.0001$).

Trajectory to the Internal Acoustic Meatus

In vestibular schwannoma surgery, the preservation of the facial nerve is facilitated by a clear view along the axis of the internal acoustic canal. This helps in establishing the edge of the tumor capsule, which often enters the canal, and creating the dissection plane along the course of the nerve. To demonstrate the benefits of temporal bone removal, we recorded the angle at which the facial canal and the indwelling nerves could be approached at the anterior aspect of the exposures. There was a significant decrease in the trajectory angle when the retrolabyrinthine approach was expanded into the trans-

crural exposure (37.51 ± 5.7 degrees versus 24.56 ± 4.6 degrees; $n = 50$; $p > 0.0001$). The removal of the labyrinth yielded a dramatic shift in the trajectory angle (3.17 ± 2.85 degrees; $n = 50$; $p > 0.0001$) along the entire axis of the internal acoustic canal and thus the facial nerve (► **Fig. 3I**).

Discussion

The current study compares variants of the posterior petrosal exposures with regard to their access to the internal auditory canal and simulates their ease of application in the surgical treatment of vestibular schwannomas. Approach variants were analyzed in 3D skull models built from high-resolution CT scans of disease-free temporal bones. The results showed a steady increase in exposed surgical area and in the angle of access as the exposures progressively removed more bone. Out of the approaches analyzed, the translabyrinthine

exposure grants the most optimal trajectory along the facial nerve. The newly advocated transcrural exposure yielded a moderate increment in the exposure parameters over the retrolabyrinthine approach but was still inferior to the translabyrinthine approach.

The translabyrinthine exposure was first described and popularized by Hitselberger and House in the 1960s as an alternative to the suboccipital craniotomy for the treatment of acoustic schwannomas.^{6,7} Switching to the posterior petrosal trajectory yielded the advantages of a relatively short corridor with direct view along the facial nerve and the anterolateral aspect of the brainstem, with minimal or no cerebral lobe retraction. Besides the risk of a cerebrospinal fluid leak, its drawbacks were the sacrifice of hearing; therefore the application was limited to cases without serviceable hearing. To tackle the disadvantage, consecutive work of McElveen et al,⁸ Hirsch et al,⁹ and Sekhar et al¹⁰ led to the development of a limited labyrinthectomy later named the “transcrural” approach by Horgan and coworkers,¹ which combined the benefits just cited of the transpetrosal corridor with hearing preservation. This technique involves the incremented drilling of the posterior semicircular canal with stepwise plugging of the membranous labyrinth to seal the endolymph and thus preserve hearing.

The transcrural approach was characterized in cadaveric studies¹ and compared with increasingly invasive posterior transpetrosal corridors with regard to their exposure of the petroclival region. In this study, the transcrural approach yielded a dramatic increase in exposed clival surface area ($449 \pm 71 \text{ mm}^2$ versus $108 \pm 51 \text{ mm}^2$) and surgical freedom ($853 \pm 343 \text{ mm}^2$ versus $780 \pm 394 \text{ mm}^2$) relative to the retrolabyrinthine approach. In comparison with the significantly more invasive variants, the transcrural approach approximated the exposed surface area and surgical freedom of the transcochlear approach by 89% and 71%, respectively. The transcrural approach exposed similar lengths of the clivus and the trigeminal nerve segment to those in the transcochlear approach. Parallel and subsequent case series validated the applicability to petroclival lesions in selected groups of patients (series ranging from 6 to 17 cases) demonstrating a 58 to 100% success rate in preserving serviceable hearing.^{5,9,11,12} Based on studies both at the bench and the bedside, the transcrural approach was deemed to be a near substitution of the more invasive petrosal approaches.² The adaptation of the transcrural approach for vestibular schwannomas was reported in single case reports and the largest case series (16 patients) dedicated to vestibular schwannoma surgery via the translabyrinthine approach.¹³ A 43% hearing preservation was achieved with complete tumor removal in all cases.

To supplement these studies, we tested if the benefits of the transcrural exposure in accessing the petroclival region would hold up with the internal auditory canal/porus as the target. Our current radio-anatomical simulation demonstrates some benefit of bone removal in the transcrural approach relative to the retrolabyrinthine exposure, but we found the angle of attack and facial nerve trajectory lagged behind the exposure granted by the translabyrinthine approach.

Our study is the first to use 3D models of high-resolution CT scans in the morphometric characterization of posterior transpetrosal approaches. Previous radio-anatomical studies of the temporal bone have verified measurement accuracy from high-resolution CT scans by paralleling them with wet-bench cadaver measurements of the same specimens.¹⁴ Combined radiological-cadaver measurements have characterized the anatomical landmarks guiding IAM exposure from a subtemporal approach.¹⁵ The 3D distances within the temporal bone were measured using reconstructions of high-resolution CT scans to demonstrate the relationship of the arcuate eminence to the superior semicircular canal.¹⁶ The advantage of the radio-anatomical system we used is that it analyzes information from live patients rather than post mortem specimens burdened with artifacts of conservation, storage, and age-related changes. The radiologic database also offers a high volume of data with a convenient analysis platform widely available at health care centers.

Conclusion

The 3D reconstructions of high-resolution CT scans are a powerful tool in analyzing bony anatomy for skull base approaches. Using the techniques described in this article, we found that the translabyrinthine exposure grants a dramatic increase in facial nerve exposure relative to less invasive variants. The transcrural exposure lags behind in terms of view along the facial canal and the angle of access to the IAM. Its benefit of hearing preservation is appealing in vestibular schwannoma surgery, and it may be considered alongside the retrosigmoid and subtemporal approaches that are also designed to preserve hearing.

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