Analysis of the Petrous Portion of the Internal Carotid Artery: Landmarks for an Endoscopic Endonasal Approach

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Objectives/Hypothesis: While there are many benefits to the endoscopic endonasal approach to the infratemporal fossa, involvement of the petrous portion of the internal carotid artery (ICA) poses a unique challenge. The endoscopic endonasal approach requires establishing the relationship of the petrous ICA to anatomical landmarks to guide the surgeon. This study evaluates the relationship of petrous ICA to specific anatomic landmarks, both radiographically and through cadaveric dissections.

Study Design: Cadaveric and radiographic study.

Methods: An endoscopic endonasal approach was used to access the petrous carotid and infratemporal fossa. Dissections exposed the petrous portion of the carotid artery and identified the foramen rotundum, ovale, and spinosum. Both anatomical and radiographic representations of these landmarks were then evaluated and compared relative to the petrous carotid.

Results: The endoscopic endonasal approach to the infratemporal fossa with exposure of the petrous ICA afforded complete visualization of the entire segment of this portion of the ICA with limited anatomical obstruction. The foramen rotundum, ovale, and spinosum were successfully identified and dissected with preservation of their neurovascular contents. Computed tomography analysis calculated a mean distance to the petrous ICA of 16.34 mm from the foramen rotundum, 4.88 mm from the ovale, and 5.11 mm from the spinosum in males. For females, the values were 16.40 mm from the rotundum and 4.36 mm each from the ovale and spinosum.

Conclusion: An endonasal endoscopic approach to the infratemporal fossa with exposure of the petrous ICA is feasible. The anatomical landmarks can serve as both radiographic and surgical landmarks in this approach.

Key Words: Petrous internal carotid artery, endoscopic, infratemporal fossa, endonasal, skull-base.

Level of Evidence: N/A.

INTRODUCTION

The anatomic complexity and vital structures encountered in the infratemporal fossa (ITF) represent significant challenges for surgical approaches to pathology in this region. Traditional open ITF approaches carry the risk of substantial morbidity and mortality, with limitations frequently imposed by critical anatomic structures. The advent of endoscopic technology and endoscopic endonasal techniques allows for an alternative approach to the ITF and skull base that provides potentially equivalent exposure with decreased morbidity and mortality.1–5

The development of the transnasal approach to the anterior, middle, and posterior cranial fossae allows for appropriate surgical exposure with a minimization of cosmetic defects. Compared to the lateral approaches, the transnasal approach offers a less invasive procedure. Like the lateral approaches, the endoscopic approaches require specialized surgical skill and a specific understanding of the complicated cranial anatomy from a unique viewpoint.6–8

Lateral extension of the endoscopic endonasal approach into the infratemporal fossa has been discussed in the literature.9–13 The petrous portion of the internal carotid artery (ICA) is a critical structure when managing lesions in the superior aspect of the ITF. A thorough understanding of the relationships between the petrous ICA and nearby anatomical landmarks is imperative. The foramina rotundum, ovale, and spinosum—containing V2, V3, and the middle meningeal artery, respectively, represent useful regional landmarks to guide the surgical team near the petrous carotid. Utilizing computed tomographic (CT) analysis and cadaveric dissection, we aim to analyze these landmarks and define their relationship to the petrous ICA in the context of an endoscopic endonasal approach to the infratemporal fossa. In addition, a case example to illustrate the concept is presented.
MATERIALS AND METHODS

CT Analysis

CT scan analysis was performed on randomly selected studies from an internal review board-approved database of deidentified CT angiographies using Osirix (Pixmeo; Bernex, Geneva, Switzerland). Osirix is an open-source, digital imaging and communications in medicine (DICOM) image-viewer with the ability to measure landmark distance and area on CT plates in both 2D and rendered 3D. Twenty males and 20 females were chosen for analysis. For randomization, 10 males and 10 females were measured on the right side, and the remaining half was measured on the left.

A measuring tool was used to calculate distances from the foramina ovale and spinosum to the petrous ICA at their nearest point on the corresponding axial CT. The points represented the same measurement points used to measure the cadaveric dissections. Simple distance measurement was performed with the foramina ovale and spinosum as the landmarks were located on the same axial CT plate as the petrous ICA (Fig. 1).

As the foramen rotundum lies in a different plane from the petrous ICA, this calculation required more complex analysis. The most medial and posterior points of the foramen rotundum were chosen on axial CT, providing an x, y, and z coordinate that represents the transition of V2 from its intracranial to extracranial course. Similarly, a point at the petrous ICA transition to
the second genu on axial CT was chosen, providing the second coordinate. These coordinates allowed for the mathematical calculation of the distance between the two landmarks (Fig. 2).

Using Osirix, a virtual dissection was performed on a 3D rendering of a CT sample that exemplifies the course of the petrous internal carotid artery as viewed endonasally (Fig. 3).

**Cadaveric Dissection**

Four anatomical specimens were preserved and injected with red- and blue-colored latex in the arterial and venous systems, respectively, as reported by Sanan et al. These cadaveric specimens differed from those utilized in radiologic analysis. Bilateral endoscopic endonasal dissections were performed on each specimen, exposing the petrous ICA and relevant landmarks. Rod-lens 0°-, 30°-, and 45°-endoscopes were used for visualization. High-speed drills, sinus instruments, and bone rongeurs were used for soft tissue and bone dissection.

Each dissection began with a middle turbinectomy and total ethmoidectomy. Next, takedown of the posterior one-third to one-half of the nasal septum was completed. Medial maxillectomy allowed for removal of the posterior wall of the maxillary sinus and exposure of the sphenopalatine ganglion. An endoscopic Denker’s approach (endoscopic drilling of the pterygoid aperture) provided increased lateral access with extended dissection of the sphenopalatine artery (SPA) within the pterygopalatine fossa. This exposure allowed dissection of the internal maxillary artery with identification of its branches. Wide sphenoidotomies and drilldown of the sphenoid sinuses and floor were performed. The vidian canal and foramen rotundum were identified along the face of the pterygoid base. The medial aspect of the pterygoid base was addressed as the vidian canal was drilled. This provided exposure of the vidian nerve from its exit of the vidian canal anteriorly toward the second genu of the internal carotid artery. V2 was identified at its exit at the foramen rotundum and dissected posteriorly by drilling toward Meckel’s cave.

With the SPA identified in the pterygopalatine fossa, the cartilaginous portion of the Eustachian tube was encountered. As previously described, the internal maxillary artery was divided and soft tissue/muscular elevation from the lateral pterygoid plate was performed. On exposure of the medial and lateral pterygoid plates, both plates were resected until flush with the middle cranial fossa, achieving a type D dissection. Next, V3 was identified and traced superiorly toward its exit from the foramen ovale. Just posterolaterally, the middle meningeal artery was traced from the internal maxillary artery, superiorly to the foramen spinosum. Bone was dissected around the foramen ovale, allowing for exposure of the carotid canal. The canal was resected toward the first carotid genu, completing the dissection. This dissection allowed for clear identification of the proposed landmarks, the foramen rotundum, ovale, and spinosum, and evaluation of their relationship to the petrous carotid artery (Fig. 4a–4d). Laminated millimeter rulers were inserted into the dissection cavity for gross measurements corresponding to our CT analysis.

**Clinical Example**

A 41-year-old man with a history of severe mental retardation and seizure disorder presented after an episode of bacterial meningitis. A head CT demonstrated a smooth expansile lesion of the right sphenoid sinus extending intracranially and into the infratemporal fossa.

Preoperative magnetic resonance imaging demonstrated right middle cranial fossa meningoecephaloecele decompressing into the pterygoid recess of the right sphenoid sinus, causing prominent asymmetric expansion of the right sphenoid sinus and pterygoid recess with extension into the infratemporal fossa (Fig. 5). The patient underwent endoscopic excision of the mass with image guidance. A middle turbinectomy was performed. The mass had eroded through the bony sphenoid and much of the posterior ethmoid cells. A medial maxillectomy was performed, and the bony portion posterior maxillary wall was taken down to reveal the mass protruding into the nasal cavity (Fig. 6a). The mass eroded the intersinus sphenoid septum and some of the posterior nasal septum. The mass was dissected from the paracalval and petrous ICA and resected from the infratemporal fossa. Figure 6b shows the relationship of the V3/foramen ovale and the middle meningeal artery with the petrous ICA. The residual dural defect was repaired with DuraGen (Intergrafa LifeSciences Corporation, Plainsboro, NJ), abdominal fat graft, and a nasal septal flap.

**RESULTS**

**CT Analysis**

The CT angiograms used in our study provided consistent and easily reproducible measurements. The foramina rotundum, ovale, and spinosum were easily recognizable on axial CT plates. With Osirix, identifying a specific landmark on an axial CT plate provides a 2D orthogonal view of the same structure within the coronal and sagittal planes, as shown in Figure 2. In our selected sample, the ovale, spinosum, and petrous carotid were all identifiable on the same CT plate, allowing facile and direct length measurement. The clear identification of the foramen rotundum and petrous ICA at a reproducible point on the axial CT allowed for consistent calculation of length in each specimen.

For males, the mean distance between the petrous ICA and foramen rotundum was 16.94 mm with a
standard deviation of 1.826 mm. The value was similar for females at 16.40 mm with a greater standard deviation of 2.583 mm. From the foramen ovale to the petrous ICA, the value for males was 4.88 ± 0.932 mm, and for females the value was 4.36 ± 0.845 mm. The difference in distance means was similar between males and females at the foramen spinosum. The values were 5.11 ± 0.956 mm and 4.46 ± 1.055 mm for males and females, respectively (Table I).

**Cadaveric Dissection**

All eight specimens underwent full bilateral dissection of the petrous ICA, with adequate identification and preservation of the landmarks and their contents. The medial maxillectomy and Denker’s approach provided an open visual field that facilitated deeper dissection. Drill out and preservation of the vidian canal allowed for orientation throughout the dissections.

Significant soft tissue and vascular dissection is required to expose the pterygoid plates. Careful subperiosteal detachment of the pterygoid muscles from the lateral pterygoid plate is necessary to avoid injury to V3, branches of the internal maxillary artery, or the pterygoid plexus as the dissection proceeds from an anterior to posterior direction. Ultimately, V3 can be identified and traced to the foramen ovale. With proper exposure and careful dissection, the middle meningeal artery can be traced from its branching point off of the internal maxillary artery up to the foramen spinosum.

In our eight dissections, the average distance from the foramen rotundum to the petrous ICA was 18.88 ± 2.532 mm. The foramen ovale was found at an average distance of 5.31 ± 0.704 mm. The foramen spinosum was measured at a similar distance, with increased variation at 5.13 ± 1.217 mm.

Although these cadaveric measurements were calculated from different specimens, the distances roughly correspond to those calculated on CT analysis. As the basis of stereotactic navigation, CT-scan measurements were chosen for superior accuracy, whereas the cadaveric measurements allow for a closer correlation to a live dissection (Table II). Angled endoscopes improved lateral
visualization in our cadaveric dissections, but they were not necessary because a 0° endoscope afforded complete visualization of the target anatomy.

DISCUSSION

The continued advancement of endoscopic surgical techniques and instrumentation allows for a reasonable
alternative to open/lateral approaches to skull base lesions. Substantial challenges encountered in adopting these techniques involve operating with the unique visual perspective seen through the endoscope and a distortion of depth perception. Along with the limited mobility of surgical tools, the learning curve is steep and there are valid concerns of patient safety. This emphasizes the need for thorough understanding of anatomy, as well as rigorous training methods in approaching endoscopic surgery.\textsuperscript{16}

Utilizing consistent and easily identifiable landmarks is critical to endoscopic endonasal surgery.\textsuperscript{2,3,17} Positional awareness can reduce the risk of intraoperative complications and postoperative morbidity that can occur when operating around the critical and often delicate structures of the ITF. While the endoscopically visualized surgical field is optimized, the limited access afforded by these techniques can make significant bleeding extremely difficult to control and adequate visualization difficult to maintain.\textsuperscript{18} Maintaining a systematic approach allows for an optimized orientation and provides the surgeon with greater operative control, helping to avert potential morbidity.\textsuperscript{8}

This study supports the notion that the foramina rotundum, ovale, and spinosum serve as consistent and easily identifiable surgical landmarks. Although there was variation between specimens and sexes, the amount can be considered relatively negligible clinically. However, it is important to recognize where the exact points of measure were located. For example, if the measurements for distance to the foramen rotundum had been measured from the anterior aperture instead of from the posterior aperture, the measured results would have been significantly different. Likewise, often the foramen ovale and spinosum travel posteriorly as they move superiorly. It is important to note that our distances from the ovale and spinosum reflect the most inferior and posterior point of the foramina possible. Without these considerations in mind, the data would be irrelevant or potentially applied incorrectly.

Our cadaveric dissection further exemplifies the usefulness of reliable landmarks. Understanding landmark relationships serves to enhance orientation within the cranial cavity and approximate the location of the petrous ICA. Dissection to the ICA without a systematic method greatly increases the risk of injury. Pathology that involves or obstructs critical structures may compromise orientation, emphasizing the importance of established landmark relationships relative to these structures.

After removal of the posterior maxillary wall, significant muscle and fat obstruct the visual field. The foramen rotundum serves as an important landmark for orientation at this point, as its identification allowed for dissection of the middle cranial fossa floor, which slopes downward as it moves posteriorly toward the petrous ICA. Although not on the same plane, the foramen rotundum provides a useful reference point for orientation in a changing surgical field. The vidian nerve is another important landmark in the central skull base that has been extensively analyzed and leads to the second genu of the ICA.\textsuperscript{19} An understanding of the anatomy of CN V as it branches into V1, V2, and V3 from the Gasserian ganglion facilitated an approximate location of the foramen ovale as well. In our experience, the foramen ovale is most safely approached from a medial to lateral direction until either V3 or its branches were encountered within the infratemporal fossa as the lateral pterygoid is taken down. After V3 was encountered, careful lateral and slightly posterior dissection exposed the middle

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\begin{tabular}{|l|c|c|c|c|}
\hline
\textbf{Approach} & \textbf{Sex} & \textbf{Average Distance (mm)} & \textbf{Standard Deviation (mm)} & \textbf{95\% CI range (mm)} & \textbf{95\% CI (mm)} \\
\hline
Foramen rotundum to petrous ICA & male & 16.34 & 1.826 & 15.54–17.14 & 0.800 \\
& female & 16.40 & 2.583 & 15.27–17.53 & 1.132 \\
Foramen ovale to petrous ICA & male & 4.88 & 0.932 & 4.47–5.29 & 0.408 \\
& female & 4.36 & 0.845 & 3.99–4.73 & 0.370 \\
Foramen spinosum to petrous ICA & male & 5.11 & 0.956 & 4.69–5.53 & 0.419 \\
& female & 4.36 & 1.055 & 3.90–4.82 & 0.463 \\
\hline
\end{tabular}
\caption{CT Analysis: Foramina Rotundum, Ovale, and Spinosum to the Petrous Internal Carotid Artery.}
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\hline
\textbf{Approach} & \textbf{Average Distance (mm)} & \textbf{Standard Deviation (mm)} & \textbf{95\% CI Range (mm)} & \textbf{95\% CI (mm)} \\
\hline
Foramen ovale to petrous ICA & 5.31 & 0.704 & 4.83–5.80 & 0.488 \\
Foramen spinosum to petrous ICA & 5.13 & 1.217 & 4.28–5.97 & 1.21 \\
\hline
\end{tabular}
\caption{Cadaver Analysis: Relevant Distance to the Petrous Internal Carotid Artery.}
\end{table}
meningeal artery as it entered the foramen spinosum. Laterally, the foramen spinosum, with the middle meningeal artery traversing it, is in proximity to the first genu. Identification of the foramen ovale denotes a point anterior to the petrous ICA that is roughly halfway between the first and second genu. Identification of these structures enhances orientation and allows for an approximation of the distance to the petrous portion of the ICA along the length of the vessel. Pathology will dictate the necessary ICA exposure. A thorough understanding of the relationships of relevant landmarks is paramount to successful tumor removal with the most minimal bone and soft tissue resection.

Gross measurements of landmark distances accurately corresponded to measurements calculated on the CT. Having previously defined these distances would have helped in approximating our location within the nasal cavity and infratemporal fossa and relative to the petrous ICA. Our results showed a near equal distance from the petrous ICA to both the foramen ovale and spinosum. With this relationship in mind, short posterior dissection from either landmark would efficiently locate the carotid. Defining these landmarks also opens up the possibility of more controlled dissection. Lateral petrous ICA identification may be needed, depending on pathological location. Although medial to lateral identification is commonly used, the landmarks discussed here could provide a path obviating the need for more medial bone removal. For example, since the foramen spinosum also approximated the transition to the petrous ICA from the first genu, that landmark could be used to approximate the location of the parapharyngeal carotid or the lateral petrous carotid near the first genu. This could be a more efficient method, requiring less reconstruction than complete medial to lateral dissection.

Our experience highlights the utility of CT analysis with a program such as OsiriX. OsiriX has been successfully utilized to examine anatomical relationships between important structures. These methods can be extended into preoperative planning.19,20 The open-source DICOM viewer provides the possibilities of analyzing any chosen CT collection both as normal scans and with 3D reconstruction or virtual dissection. Combined with the establishment of known landmarks such as those described in this article, programs such as OsiriX may greatly assist the surgical team in planning for and approaching pathology in this region. The clinical vignette presented in this publication may have previously been difficult to address without a procedure that carries greater morbidity. The use of such imaging programs and continued anatomical studies performed from an endoscopic perspective are paramount to better understand the anatomy and further refine endoscopic skull-base approaches to the infratemporal fossa.

CONCLUSION

With the advent of endoscopic endonasal surgery, familiarity with techniques and their relevant anatomy is crucial to successful patient outcomes. The complexity of the infratemporal fossa and the path from the nasal cavity necessitates a clear understanding of nuanced anatomical relationships. As demonstrated in this study, CT analysis and cadaveric dissection afford the establishment of reliable surgical relationships between the petrous internal carotid artery and the foramen rotundum, ovale, and spinosum, allowing successful utilization of these relationships in clinical practice.

BIBLIOGRAPHY