Petrous Apex Cholesterol Granulomas: Endonasal Versus Infracochlear Approach

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Objectives/Hypothesis: The aim of this study was to investigate and compare the surgical anatomy of two different routes to access and drain petrous apex (PA) cholesterol granulomas: the expanded endonasal approach (EEA) and the transcanal infracochlear approach (TICA).

Study Design: Anatomic and radiologic study.

Methods: The EEA and TICA to the PA were performed in 11 anatomic specimens with the assistance of imaging guidance. The PA was categorized into three zones: superior PA, anterior-inferior PA, and posterior-inferior PA. The maximum drainage window achieved by each approach was calculated using the imaging studies of each anatomic specimen.

Results: The EEA was able to reach superior PA and anterior-inferior PA in all specimens and posterior-inferior PA in 90%. The TICA did not provide access to superior PA in any case. The TICA was suitable to reach anterior-inferior PA in 80% of specimens and posterior-inferior PA in 60%. Based on the radiologic study, the EEA provided a drainage window three times larger than the TICA.

Conclusions: The transnasal approach provides reliable access to the PA when combined with internal carotid artery exposure and allows for large drainage window. The transcanal approach is less versatile and more limited than the transnasal approach but provides access to the most posterior and inferior portion of the PA without Eustachian tube transection. Here we propose a new surgical classification that may help to decide the most suitable approach to the PA according to the location and extension of the lesion.

Key Words: Petrous apex, cholesterol granuloma, skull base, ear surgery, endoscopic endonasal surgery.

Level of Evidence: 5


INTRODUCTION

The petrous apex (PA) is one of the least accessible areas of the skull base. Cholesterol granuloma (CG) is the most common lesion of the PA.1 A variety of surgical approaches have been used to drain CG when clinically indicated. If the patient presents with preserved hearing, four routes are possible: transcanal infracochlear, transsphenoidal, infralabyrinthine, and middle cranial fossa. If hearing is not preserved, there are two more options: translabyrinthine and transcochlear.2,3 The infralabyrinthine approach may provide limited access, especially in patients with high jugular bulb (JB).3,4 The middle cranial fossa approach does not allow a permanent drainage pathway, and some degree of temporal lobe retraction is necessary, which could result in brain injury.2,5 Despite the high rate of recurrence, the transcanal infracochlear approach (TICA) is the traditional procedure for treatment of PA CG with hearing preservation.6 The transphenoidal approach is appropriate for CGs that protrude medially into the sphenoid sinus; however, it is hindered when the lesion is located more laterally.

Advances in minimally invasive skull base surgery, through careful study of the endoscopic endonasal surgical anatomy allied with accurate intraoperative image guidance and devoted instrumentation, have provided safe access to regions distant from the midline.2,6 Some authors have completed anatomic dissection studies and calculated the distances between relevant structures involved with the infracochlear and endonasal accesses to the PA.7,8 Nevertheless, there are no previous anatomic and/or surgical studies that have compared these two routes or performed a systematic description of which approach would be more suitable for the treatment of CG according to the surgical anatomy of the PA.

The aim of this study was to compare two different approaches to the PA: the endoscopic endonasal approach (EEA) and TICA. The degree of exposure achieved in each approach was evaluated. A new clinical-surgical classification of the PA region is proposed.
MATERIALS AND METHODS

Eleven human anatomic specimens (11 heads, 22 petrosal apices) were prepared for dissection at the Surgical Neuroanatomy Laboratory of the University of Pittsburgh. This research was approved by the Committee for Oversight to Research Involving the Dead (CORID). The common carotid arteries, vertebral arteries, and internal jugular veins were dissected, isolated, and cannulated with flexible tubing. Each vessel was flushed to remove blood clots with approximately 500 mL of warm water in two separate sessions. The vessels were injected with 50 mL of a polymethyl siloxane/silicone conglomerate, in a 2:1 preparation for arteries and 1:1 for veins, dyed with red or blue water-soluble pigments, respectively. Diluteurte calcium carbonate (5 mL) was added as a catalyst immediately before infusion. Specimens were refrigerated overnight and then preserved in 200 mL proof ethyl alcohol diluted in water as a 70% solution. Five screws were placed, distributed in the cranial area, and high-resolution computed tomography (CT) with 1 mm of separation acquisition was performed for neuronavigation protocol (Stryker, Kalamazoo, MI). Two dry skull bases were prepared to study the osseous relationships.

Each head was stabilized with a Mayfield head holder simulating the surgical position obtained in the operating room. Endonasal approaches were performed in five heads (10 sides) under endoscopic visualization (Karl Storz, Tuttinglen, Germany; 4 mm, 18 cm, Hopkins II, 0 and 45 degrees). Transcanal infracochlear approaches were performed in another five heads (10 sides) under optic magnification (3 x to 40 x) with a surgical microscope (OPMI; Zeiss, Oberkochen, Germany); one extra head was used to perform both approaches in the same specimen. The measurements to estimate the maximal drainage window for both approaches were evaluated using the high-definition CT scans in all heads.

Dissection Technique

To compare the accessibility and clinical applicability of both approaches (EEA and TICA), the PA was divided into three zones in accordance with three constant landmarks, foramen lacerum, carotid foramen, and jugular foramen, as follows: superior PA (sup PA), between the level of Dorello’s canal (petrosal segment of sixth nerve) and foramen lacerum; anterior-inferior PA (ant-inf PA), between the foramen lacerum and the carotid foramen; posterior-inferior PA (post-inf PA), between the carotid foramen and the jugular foramen. The zones were considered accessible when optimum visualization and instrumentation were achieved in the PA. Also, to increase the consistency of our method, each approach zone was verified using neuronavigation system in all specimens.

Expanded endonasal approach to the PA. There are three ways to access the PA through the EEA: 1) transphenoidal transclival approach, 2) transsphenoidal transcanal approach with paracralcal internal carotid artery (ICA) lateralization (medial PA approach), and 3) transpterygoid infrapetrous or sublacerum approach (inferior to the horizontal petrous ICA). We performed the three different approaches on each side in all specimens aiming to obtain the largest possible window into the PA. 

TRANSPHENOIDAL TRANSCLIVAL APPROACH. Initially, a wide bilateral sphenoethmoidectomy was done. Approximately 1 cm of the posterior edge of the nasal septum was resected using back-biting rongeurs to expose the sphenoid rostrum. A wide sphenoidotomy was performed with removal of the rostrum. Septations within the sphenoid sinus were removed, and imaging guidance was used to define the course of the ICA. Other anatomic landmarks were identified: planum sphenoidale, sella, clival recess, optic canal, and medial and lateral optic-carotid recesses. The sphenoid floor was drilled back to the clival recess. Subsequently a transclival approach was performed, and the bone between the paracralcal ICAs was drilled until the clival dura was exposed. The paracralcal ICAs were not uncovered (Fig. 3).

TRANSPHENOIDAL TRANSCLIVAL APPROACH WITH ICA LATERALIZATION. This approach consisted of an additional step after the previous one was completed. The bone covering the paracralcal ICA from its medial to lateral surface was removed to allow the vessel to be gently mobilized in a lateral direction; the bone behind the paracralcal ICA (medial-posterior wall of the paracralcal carotid canal) was removed to gain access to the petroclival fissure and most medial aspect of the PA. Then, the petrous bone between the paracralcal ICA and the inferior petrosal sinus (IPS) was removed from the level of Dorello’s canal to the foramen lacerum to maximize the surgical access to sup PA. Special attention was taken in this stage to avoid injury to the sixth nerve superiorly along its petrous segment (Fig. 3).9

TRANSPTERYGOID INFRAPETROUS OR SUBLACERUM APPROACH. After the two previous modules were completed, bilateral maxillary antrostomies were performed. The posterior wall of the maxillary sinus was removed exposing the pterygopalatine fossa. Medially, the palatosphenoidal (palatovaginal) artery, a terminal branch of the maxillary artery, was transected, and soft tissues of the pterygopalatine fossa were mobilized laterally to facilitate identification of the vidian nerve.10 The pterygoid base was drilled out, preserving the vidian nerve. The drilling proceeded circumferentially along the vidian canal (keeping vidian nerve and artery intact) until the foramen lacerum soft tissue and anterior genu of the ICA were reached. These are the most important anatomic landmarks of this module.

After completing these steps, we transected the foramen lacerum soft tissue and drilled the bone between the horizontal petrous ICA and Eustachian tube (ET). Hence, we completed a sublacerum route into the ant-inf PA. To further expose post-inf PA, we transected the ET and drilled the petrous carotid canal inferiorly to provide complete exposure of the horizontal petrous ICA. We followed the horizontal petrous carotid segment in the direction of the carotid and jugular foramina and identified the angle formed between the horizontal petrous ICA and posterior vertical petrous ICA. This provided full access to the posterior-inferior zone of PA (Fig. 4).

Transcanal infracochlear approach. A standard postauricular incision was performed, the auricle was reflected anteriorly, and the external auditory canal was transected at the bony-cartilaginous junction. A tympanomeatal flap was then elevated from the 2 o’clock to the 10 o’clock position, leaving the tympanic membrane attached at the umbo. Using a high-speed drill with continuous suction and irrigation, bone was removed over the anterior, inferior, and posterior portions of the bony canal wall to expose the hypotympanum. A small diamond burr was used to remove air cells below the cochlea to expose the course of the carotid artery and JB. Bony dissection was then carried out in an anterior-medial direction, using the carotid artery as the anterior limit, the round window as the superior limit, and the JB as the posterior limit. This provided exposure of ant-inf PA and post-inf PA. We also extended the dissection anteriorly toward the temporomandibular joint, without its violation; and posteriorly, following the chorda tympani nerve, to achieve the largest window possible (Fig. 5).

Radiologic Study

Cranial CT scans of 11 human heads (22 petrosal bones) were studied. We generated sagittal oblique cuts to simulate the maximal drainage window obtained into the PA by EEA and...
TICA (Fig. 6A and 6B). The measurements to predict the maximum drainage window from both approaches were performed on petrous bones using the software OsiriX for Macintosh, version 3.9.1 (The OsiriX Foundation, Geneva, Switzerland), that permits a dynamic analysis of the images, thus allowing a three-dimensional localization of the structures. The data were analyzed using software SPSS 17.0 for Macintosh (SPSS, Inc., Chicago, IL), and \( P \leq .05 \) was considered significant.

Fig. 1. Anatomy and surgical classification of the petrous apex (PA) in human skull bases. (A) Superior view of skull base. (B) Medial view of the PA showing its zones. (C) Front view simulating endoscopic endonasal view of PA zones in the operation room. Note the relationship of PA zones with internal carotid artery (ICA) divisions. Also, note the illustrative extension reached by expanded endonasal approach (EEA) and transcana~nal infracochlear approach (TICA) on PA. Superior PA: relationship with paraclival ICA. Antero-inferior PA: relationship with horizontal petrous ICA. Posterior-inferior PA: relationship with posterior vertical petrous ICA. Inf = inferior; Fiss = fissure; Sup = superior; Ant-inf = anterior-inferior; Post-inf = posterior-inferior; VI = six nerve; VII = facial nerve; VIII = vestibulocochlear nerve; V2 = maxillary nerve; V3 = mandibular nerve; Paraph = parapharyngeal; IX = glos~soharyngeal nerve; X = vagus nerve; XI = accessory nerve.

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RESULTS

Using the transnasal route it was possible to access all three zones of the PA in nine out of 10 (90%) specimens. In one specimen, the post-inf PA could not be approached endonasally because the posterior vertical petrous ICA was located very close to the IPS and the brainstem.

The infracochelear route did not provide access to sup PA because the cochlea blocked the superior extension of the dissection in all specimens. This approach offered access to ant-inf PA in eight of 10 (80%) specimens and post-inf PA in six of 10 (60%) specimens. In two specimens we could not access any area of the PA by TICA because the posterior genu of ICA was located adjacent to the JB. In two other specimens, the access to ant-inf PA was achieved, but the inferior extension to post-inf PA was prevented by the posterior vertical petrous ICA, which was situated close to the JB.

In one extra head we conducted a demonstrative EEA and TICA to the PA in the same specimen (right side) to provide a simultaneous comparison between both approaches. By EEA we were able to find the route previously created by TICA into the PA and enlarge it inferiorly and superiorly (Figs. 6C, 6D, and 7).

Comparison of Surgical Approaches to the PA

To access the sup PA by EEA, we performed a transsphenoidal transclival approach with ICA laterализation; this approach also allowed for preservation of the foramen lacerum soft tissue and ET. The approach to ant-inf PA was accomplished by a transpterygoid infrapetrous approach with transection of the foramen lacerum soft tissue and preservation of the ET. In one specimen, in addition to the transection of the lacerum soft tissue, we required ET sacrifice to access the ant-inf PA. To access post-inf PA, we always required transection of the ET.

By applying the TICA, we first reached the ant-inf PA at the level of posterior genu of ICA. Then we followed the dissection in an anteromedial direction, drilling parallel to the horizontal petrous portion of the ICA. After completing this step, we followed the posterior genu of ICA inferiorly to enter post-inf PA, until we reached the corner between posterior vertical petrous ICA and JB. Most of the time, the maximal drainage window created by TICA was a small triangle between the ICA, JB, and basal turn of the cochlea (Fig. 5D). Using the EEA, the maximal drainage window had a large oval shape between the ICA, IPS, and brainstem (Fig. 4D).

On the radiologic study of specimens, the average of the maximal drainage window provided by the EEA was 1.19 cm² and for TICA was 0.38 cm² ($P < .001$) (Table I).

Illustrative Case

Presentation and examination. A 66-year-old female presented with headache on the right side, dizziness, tinnitus, and previous diagnosis of PA CG. She had two operations (TICA) to drain the CG at another institution, with recurrence of the granuloma. Preoperative CT findings were compatible with a CG of the PA (sup PA and ant-inf PA), without protrusion into the sphenoid sinus, and with intracystic septations (Fig. 8A).
Fig. 3. Cadaveric stepwise dissection by expanded endonasal approach. Transsphenoidal transclival approach and transsphenoidal transcilm approach with internal carotid artery (ICA) lateralization to petrous apex (PA) on right side. Photographs obtained using 0-degree endoscope. (A) Nasal cavity inspection with sphenoid ostium identification. (B) Wide sphenomethoidectomy exposing anterior ethmoidal artery (ant eth art), posterior ethmoidal artery (post eth art), sphenoid sinus, and resection of posterior nasal septum. (C) Wide bilateral sphenoethmoidectomy. (D) Close-up view of transclivus approach; the clivus was drilled until a thin layer of bone; the right paraclival ICA was completely exposed. (E) Exposure of superior PA. View with 45-degree endoscope: the dura is exposed, and the bone between paraclival ICA and inferior petrous sinus was drilled, opening the superior PA (sup PA); note that inferior petrous sinus was removed to show its relationship with petrous segment of the sixth nerve. (F) Endoscopic endonasal neuronavigation. The PA was approached medially, and the neuronavigation confirmed that we achieved the sup PA; note the straight relationship between paraclival ICA and sup PA. Op carot = optic-carotid; VI (petr seg) = abducens nerve (petrosal segment); Inf = inferior.
Fig. 4. Cadaveric stepwise expanded endonasal approach. Transpterygoid infrapetrous or sublacerum approach on the right side. Photographs obtained using 0-degree endoscope. (A) The components of the pterygopalatine fossa (Pterygop fossa) were lateralized to show the palatophysoideal artery. (B) Transclival and transpterygoid approach. The pterygoid base was drilled out, preserving the vidian nerve. (C) The Eustachian tube (ET) was partially opened, and a lapel pin was placed to show its lumen. The bone between horizontal petrous (Horiz petr) internal carotid artery (ICA) and ET was drilled, the lacerum soft tissue was partially transected, and the jugular tubercle was exposed. (D) View with 45-degree endoscope. The carotid canal was drilled out and horizontal petrous ICA was complete exposed. A small window was opened in the parapharyngeal ICA (Paraph ICA) to evidence its relationship with ET. The petrous bone between the segments of ICA and inferior petrosal sinus were removed to achieve all zones of petrous apex (PA). (E) Endoscopic endonasal neuronavigation showing the correlation between horizontal petrous ICA and anterior-inferior PA (ant-inf PA). (F) Endoscopic endonal laryngeal neuronavigation exhibiting the relation between posterior vertical petrous (Post vert petr) ICA and posterior-inferior PA (post-inf PA). Proc pal = process of palatine; Inf = inferior; VI = sixth nerve; XII = hypoglossal nerve; Fiss = fissure; Sup = superior.
Fig. 5. Transcanal infracochlear approach (TICA) on the right side. Microscopic view. (A) External auditory canal and tympanic membrane view after standard postauricular incision and transection of the bony-cartilaginous junction. (B) The inferior, anterior, and posterior canaloplasty was performed, the tympanic membrane was elevated, and the chorda tympani, promontory, and hypotympanum air cells were identified. (C) Demonstrative view obtained using 0-degree endoscope. Exposition of middle ear and hypotympanum is shown; note the course of facial nerve (typanic segment) and Jacobson nerve. (D) The window obtained by TICA (triangle). The air cells below the cochlea were removed to expose the posterior genu petrous internal carotid artery (ICA), posterior vertical petrous ICA (post vert petr ICA), and jugular bulb; note the lateral projection of anterior-inferior petrous apex (PA) (ant-inf PA) and posterior-inferior PA (post-inf PA) under the cochlea. (E) Neuronavigation obtained by TICA. Note the relationship between horizontal petrous ICA (petr ICA) and ant-inf PA. (F) Neuronavigation obtained by TICA. Note the relation between post vert petr ICA and post-inf PA. Seg = segment; Sup = superior.
Operation and postoperative course. A fully endoscopic endonasal transsphenoidal transclival approach combined with a transpterygoid infrapetrous approach was performed. After wide bilateral sphenoidotomies, the clivus was drilled until a thin layer of cortical bone was left covering the clival dura. The vidian canal was drilled out until the nerve reached to the lateral portion of the lacerum segment of the ICA (Fig. 8B). The right paracaval ICA was completely skeletonized up to the lacerum foramen to allow gentle lateralization of the ICA and access to the PA (Fig. 8C). Neuronavigation was used to identify the course of ICA and PA areas (Fig. 8D); the lacerum soft tissue was identified and partially transected, and the IPS was identified on the most lateral aspect of the clivus, running at the petroclival fissure (Fig. 8C). Finally, the CG was readily drained by
Here we present a surgical classification of the PA (Fig. 7). The paraclival ICA, horizontal petrous ICA, and posterior vertical petrous ICA sit at the level of sup PA, ant-inf PA, and post-inf PA, respectively (Fig. 2). This proposed classification is merely a schematic way of analyzing the location and extension of CG within the PA. Most CGs will not be limited exclusively to one zone. This is particularly true when dealing with large granulomas that may require surgical drainage. The simplified classification proposed here may help the skull base surgeon in choosing the most suitable approach according to the topography of the lesion on preoperative imaging.

Our results showed the endonasal route was more consistent because it reached sup PA and ant-inf PA in all specimens and post-inf PA in most specimens. The transcanal infracochlear route was never suitable for accessing sup PA but provided direct access to ant-inf PA and post-inf PA without transection of the ET whenever the anatomy was favorable (large window between cochlea, ICA, and JB). Importantly, based on our radiologic study, the EEA can provide a large drainage window, allowing placement of a Silastic stent three times larger than the infracochlear approach; this statistically significant difference in size of the drainage window may have a direct impact on postoperative recurrence rates.

In our experience, the EEA provides a comfortable route with wide operative field, direct access to the midline, and potential to extend the approach to the superior and inferior PA (Figs. 1C, 6A). When CGs protrude into or are directly behind the posterior wall of the sphenoid sinus, the endonasal approach is technically straightforward and is the preferred surgical option. Furthermore, by EEA, the surgeon is able to drain an uncommon bilateral CG using the same corridor. Others advantages of the endonasal route include wide drainage window into the PA connected with the natural nasal corridor and sinonasal mucociliary system and postoperative endoscopic surveillance in the office. It also can be performed in patients with high JB, carries no risk for the facial nerve or the auditory and vestibular systems, and allows for fast recovery with minimal postoperative symptoms, no external scars, and short hospitalization.

On the other hand, the advantages of the TICA include preservation of normal external and middle ear conduction mechanism. It also allows drainage of the granuloma in a well aerated portion of the middle ear.
near the ET, fast postoperative recovery without requirement several office visits for debridements, and re-exploration through a simple inferior myringotomy.

Nevertheless, the access to PA by EEA can be difficult when the brainstem and anterior vertical segment of the ICA are nearby or when there is a poor
pneumatization of the sphenoid sinus. However, intraoperative image guidance and meticulous surgical technique allows the precise removal of bone from the clival region with minimal risk to the ICA to reach PA medially. Similarly, the access to PA by TICA can be difficult when there is a high or anteriorly placed JB, if the lesion is located anterior and superior to the cochlea, and if there is poor pneumatization of hypotympanum.

In addition to some risk of ICA injury, the potential risks of EEA include diplopia from abducens nerve palsy and dry eye from vidian nerve damage. All of these risks can be minimized with the use of imaging guidance and exquisite surgical anatomy knowledge. Another theoretic risk would be otitis media with effusion due to narrow field of dissection; facial nerve and chorda tympani nerve injury; and conductive hearing loss secondary to postoperative chronic inflammation of the middle ear and intraoperative damage of the Jacobson's nerve.

Contemporary skull base surgery requires multidisciplinary evaluation, selection, and execution of surgical approaches. Rather than reducing surgical options to a single approach, different alternatives should be available to offer patients the best choice for each individual case. Here we propose the endonasal approach as the preferred surgical option for CGs that require drainage and extend into the sphenoid sinus and those in the sup and ant-inf PA. The infracochlear approach would be ideal for those located in the post-inf PA, because the endonasal access may require ET transection. Finally, these challenging endonasal approaches should only be attempted after significant and successful experience has been acquired with less demanding surgical cases.

CONCLUSION

The ICA is of critical importance for approaches to the PA; hence it is useful to categorize the PA into zones based on the relationship with ICA. The EEA provided a wide surgical field to PA with full preservation of important structures such as cochlea, vestibular system, and facial nerve. The endonasal route afforded exposure to all zones of PA in most specimens (90%); moreover, on radiologic study of specimens, the petrous bones provided a large drainage window for EEA, three times larger than TICA. TICA did not achieve access to sup PA in any specimen but allowed access to ant-inf PA in most specimens (80%) and to post-inf PA in 60% of specimens; it did not entail transection of the ET. The choice of surgical approach to PA CGs depends on preoperative status of the patient's hearing, the surgeon's skills, and exhaustive study of PA anatomy and its relationship with the pathology on preoperative image.

BIBLIOGRAPHY