Subtemporal Retrolabyrinthine (Posterior Petrosal) versus Endoscopic Endonasal Approach to the Petroclival Region: An Anatomical and Computed Tomography Study

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Abstract

Keywords

- cranial base
- endonasal
- endoscopic
- petroclival region
- posterior petrosal
- skull base surgery
- combined subtemporal retrolabyrinthine transpetrosal

Background The petroclival region seats many neoplasms. Traditional surgical corridors to the region can result in unacceptable patient morbidity. The combined subtemporal retrolabyrinthine transpetrosal (posterior petrosal) approach provides adequate exposure with hearing preservation; however, the facial nerve and labyrinth are put at risk. Approaching the petroclival region with an endoscopic endonasal approach (EEA) could minimize morbidity.

Objective To provide an anatomical and computed tomography (CT) comparison between the posterior petrosal approach and EEA to the petroclival region.

Methods The petroclival region was approached transclivally with EEA. Different aspects of dissection were compared with the posterior petrosal approach. The two approaches were also studied using CT analysis.

Results A successful corridor medial to the internal auditory canal (IAC) was achieved with EEA. Wide exposure was achieved with no external skin incisions, although significant sinonasal resection was required. The posterior petrosal was comparable in terms of exposure medially; however, the dissection involved more bone removal, greater skill, and a constricting effect upon deeper dissection. Importantly, access lateral to the IAC was obtained, whereas EEA could not reach this area.

Conclusion An EEA to the petroclival region is feasible. This approach can be considered in lesions medial to the IAC.

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Introduction

The petroclival region is an important anatomical location that gives rise to a variety of neoplasms. Surgical management of lesions of the deep skull base is critical to avoid impingement of vital neurovascular structures.¹⁻⁴ Complicated anatomy and a narrow surgical corridor create the need for a wide array of surgical approaches to the region. Traditionally, a lateral approach with craniotomy has been utilized with variable resection of the temporal bone.^{3,5} Certain variations, such as the transcochlear approach, involve inevitable hearing loss to improve skull base exposure. The combined subtemporal retrolabyrinthine transpetrosal approach (posterior petrosal) preserves hearing by staying posterior to the inner ear structures, yet the surgical field is minimized. Although these open approaches often allow versatile and complete tumor resection, they carry significant patient morbidity.⁶

The negative outcomes associated with traditional external approaches generated much interest in the utilization of endoscopic endonasal skull base surgery techniques. Brain manipulation, cosmetic deficits, sensory loss, and tedious dissection are common occurrences when managing skull base lesions. Therefore, the endoscopic endonasal approach (EEA) was explored to address these issues.⁷⁻⁹ Working within the nasal cavity obviates the need for external skin incisions and allows for a unique anterior viewpoint. Technology and experience has advanced in the past decade that has allowed the successful expansion of these approaches to the anterior, middle, and posterior cranial fossa.^{10,11} For example, Meckel cave, which traditionally was approached with a wide pterional craniotomy involving brain retraction, has been directly accessed using EEA with minimal brain manipulation and less overall invasiveness.¹² Endoscopic skull base surgery has been widely integrated across skull base practices and warrants further study and improvement.¹³

The challenge remains on deciding when to utilize EEA and when a traditional approach would be more advantageous. Both procedures require an experienced surgical team, yet the relatively newer endonasal approach involves a more limited surgical field through the view of an endoscope and requires an understanding of a unique anatomical viewpoint.⁶ A proper decision can be made by a systematic study of available approaches; however, comparisons between EEA and lateral approaches are still limited in the literature. Our purpose was to generate comparisons between a type of lateral approach, the posterior petrosal, and an EEA to the petroclival region. Anatomical dissections were performed and documented, and computed tomography (CT) analysis allowed for statistical comparisons of surgical bone removal with each approach. We hope the data gathered will help guide the surgeon's selection of an approach.

Methods

Specimens

For cadaveric study, dissections were performed on alcohol-preserved specimens injected with red and blue latex in the arterial and venous systems, respectively, to contrast the vasculature as described by Sanan et al.¹⁴ Posterior petrosal

dissections were performed and compared with EEAs to the same region.

Endoscopic Dissection Technique

Endoscopic dissection was completed with 0- and 45-degree rod endoscopes, high-speed drills, sinus instruments, and Kerrison bone rongeurs. The first step was removal of the turbinates and wide clearance of the nasal cavity including the septum and nasal mucosa, accomplished primarily with through cuts. The maxillary sinus was opened to increase visualization. In live surgery, nasoseptal flaps pedicled to the sphenopalatine artery can be harvested and stored within the maxillary cavity for use in repairing the dural defect. The sphenoid sinus was opened with a resection of the anterior face. Superior dissection exposed the pituitary that sits flush on the sphenoid in the hypophyseal fossa and inferior to the optic chiasm and optic nerves. The floor and the lateral walls of the sphenoid sinus were resected posteriorly until the clivus was reached. Lateral and inferior dissection exposed the paraclival carotid arteries down to the foramen lacerum and the second internal carotid artery (ICA) genu.

To access the posterior cranial fossa, the clivus was extensively resected until the fossa dura was exposed. Dissection proceeded meticulously around cranial nerve (CN) VI as they traversed the clivus bilaterally. The clivus was resected laterally and posterior to the ICAs until exposure of the brainstem including the vertebrobasilar system and the medial cerebellopontine angle (CPA). At this point, CNs II to XI were exposed and identified (→Figs. 1 and 2).

Lateral Dissection Technique

The combined subtemporal retrolabyrinthine transpetrosal dissection was accomplished using an operative microscope. For bone removal, a high-speed drill and continuous suction irrigation was utilized that replicated the tools used in live surgery.

Fig. 1 Endoscopic endonasal view through a 0-degree endoscope showing the petroclival region, cranial nerve (CN) III, and CNs V to X. AICA, anterior inferior cerebellar artery; BA, basilar artery; PC ICA, paraclival internal carotid artery; VA, vertebral artery.

Fig. 2 Endoscopic endonasal view through a 45-degree endoscope showing the brainstem, petroclival region, and lower cranial nerves. AICA, anterior inferior cerebellar artery; BA, basilar artery; CN, cranial nerve; SCA, superior cerebellar artery; VA, vertebral artery.

Fig. 3 Dissection view of a combined subtemporal retrolabyrinthine transpetrosal dissection showing the petroclival region and relevant structures. AICA, anterior inferior cerebellar artery; CN, cranial nerve.

Relevant external landmarks were identified before a C-shaped incision exposed the skull periosteum. The mastoid was removed of soft tissue, and a mastoidectomy was performed. The external cavity was extended anteriorly to the level of the external auditory canal. The posteriorly located sigmoid sinus was exposed and skeletonized. After full sigmoid sinus exposure, air cells were continually removed anterior to the sigmoid sinus to expose the middle and posterior fossae reflections of dura. The middle cranial fossa dura was exposed below the linea temporalis, and bone was removed to the mastoid tip. At this point the mastoid antrum was opened along with identification and preservation of the semicircular canals, incus, and other ear structures. A temporo-occipital craniotomy was then performed. Careful and full skeletonization of the bony labyrinth proceeded for maximal exposure. Further deep drilling allowed exposure of the posterior fossa dura near the petrous apex. The dura was opened with an anteriorly based C-shaped flap that exposed the cerebellum. The tentorium was then transected. The cerebellum was freed from meningeal attachments and gently retracted posteriorly (→Fig. 3). At this point the CPA was exposed, allowing visualization of CNs III to XI.

Computed Tomography Analysis

OsiriX (Pixmeo, Bernex, Switzerland), an open-source Digital Imaging and Communications in Medicine (DICOM) image viewer, facilitated virtual dissection and CT analysis. OsiriX was operated on the Macintosh OS, which allowed two-dimensional CT plate viewing and three-dimensional (3D) rendering with the ability to measure length and volume. Our samples were collected from a de-identified database of 173 CT scans, 105 men and 68 women that were > 18 years of age. Our internal review board approved this database. For analysis, 12 men and 12 women were selected. The decision to measure on the right side or left side was chosen at random.

The volume of a potential posterior petrosal dissection was calculated on our samples. This was accomplished with the use of a measuring tool to outline bone on each CT plate corresponding to the bone that would be removed in live dissection. The inferior limit was chosen at the base of the mastoid tip, and outlining continued superiorly until the full dissection was recreated. OsiriX then computed a 3D rendering of the outlined bone and calculated a volume. Data were collected similarly for an endoscopic endonasal dissection to the petroclival region, allowing for comparison (→Fig. 4). In addition, virtual dissections were performed on 3D renderings of CT samples to highlight the vascular relationships (→Fig. 5).

Results

Both the EEA and the posterior petrosal approach were performed successfully, affording views from an anteromedial and posterolateral direction, respectively. A sufficient area was exposed in both dissections that would allow versatile resection of petroclival pathology.

Endoscopic Endonasal Approach

Access to the petroclival region and visualization of the CPA was achieved successfully with EEA. The brainstem was exposed at the level near the foramen magnum and superiorly to the superior medulla. CNs II to VI were visualized clearly at or near the brainstem. The exposure achieved of CNs VII to XI at the petroclival region would allow versatile pathology removal, albeit from a challenging angle circumventing the paraclival ICA.

Removal of the turbinates significantly improved access of the surgical tools and endoscope. In addition, nasal cavity excavation was an important step for visualization and mobility in approaching the sphenoid bone and clivus. The

Fig. 4 Combination figure showing axial computed tomography and three-dimensional volume rendering used to calculate the amount of bone removed in each dissection. The green line represents the outline of the dissection. Red indicates the internal carotid arteries. Blue indicates the sigmoid sinus.

Fig. 5 Three-dimensional virtual dissections of the endoscopic endonasal and the combined subtemporal retrolabyrinthine transpetrosal approaches to illustrate the vascular anatomy as seen in the dissection field. BA, basilar artery; cICA, cavernous internal carotid artery; ICA, internal carotid artery; IJV, internal jugular vein; JB, jugular bulb; SS, sigmoid sinus; TS, transverse sinus; VA, vertebral artery.

area of the sphenoid sinus was easily recognized superiorly within the nasopharynx. Once sphenoidotomies were performed, resection of the sphenoid sinus walls and floor allowed wide exposure of the clivus. Clival resection proceeded efficiently until CN VI was reached. The nerve has an

anterior and lateral trajectory toward the dissector as it crosses into the middle cranial fossa, at risk of injury during clivus removal. However, with careful dissection around the CN, the posterior fossa dura was completely exposed posterior to the clivus. A takedown of the dura resulted in near-

complete visualization of the central brainstem and CNs II to VI. Further lateral bone removal behind the paraclival carotid arteries was necessary to visualize CNs VII to XI. This became tedious with our instruments due to the depth of the cavity and the hard angle to work around. Visualization, however, was not an issue with angled endoscopes.

Combined Subtemporal Retrolabyrinthine Transpetrosal Approach

The posterior petrosal approach afforded visualization of CNs III to XI with ease from a posterolateral viewpoint in our dissections. Tentorium transection was important for exposure of CNs III and VI. The contents of the middle and inner ear, including the semicircular canals, ossicles, and internal auditory canal (IAC), were preserved. This would allow preservation of hearing and vestibular function if used in clinical practice. This approach required a higher level of expertise relating to drilling. Dissection near the otic capsule and incus was more challenging for the novice driller. Also, cerebellar retraction is needed for petroclival visualization, introducing the risk of damage.

For dissection lateral to the IAC, the posterior petrosal is far superior in terms of access and visualization. With the medial to lateral approach, EEA lacks direct access to the lateral skull base. The subtemporal retrolabyrinthine approach became progressively more limited as the dissection proceeded medially. Although the contents of the medial skull base could be visualized clearly, the dissection field narrowed and the view at times became obstructed.

Computed Tomography Analysis

Virtual dissections of the EEA and the posterior petrosal approach were successfully recreated on OsiriX with our collection of CT plates. Landmarks, such as the mastoid tip, the clivus, and the bony labyrinth, were seen clearly on CT imaging for an accurate representation of the two dissections. Boundaries for the dissections correlated with those utilized in live surgery, allowing for a reliable comparison of bone removal volume between EEA and the retrolabyrinthine approach.

► **Table 1** lists the volume data analysis. For men, the volume of bone removed in the posterior petrosal dissection was $19.98 \pm 2.022 \text{ cm}^3$. Bone removal in women was slightly reduced at $16.71 \pm 1.891 \text{ cm}^3$. These values were over three times the volumes of the EEA to the region. Male and female EEA bone removal was $6.36 \pm 1.64 \text{ cm}^3$ and $5.64 \pm 1.46 \text{ cm}^3$, respectively.

Discussion

The skull base is a clinically important anatomical region that gives rise to a variety of benign and malignant neoplasms. In the petroclival region, meningiomas are the most common.^{15–17} Pioneering clinicians such as William House and Ugo Fisch developed innovative techniques to manage these deep lesions surgically. Fisch utilized the infratemporal fossa to dissect deep within the lateral skull base to the pterygopalatine fossa and petroclival region. House contributed to the development of a variety of lateral external techniques involving temporal bone resection that are still used extensively in skull base surgery. The combined subtemporal retrolabyrinthine transpetrosal approach is arguably one of the less invasive techniques of the lateral approaches to the skull base. By dissecting posterior to the inner ear, hearing is preserved and manipulation of the facial nerve is avoided while still allowing successful management of lesions at the clivus, CPA angle, and the deep posterior/middle fossa. The unavoidable shortcomings of lateral approaches are the external incisions and bone defects requiring reconstruction, variable levels of brain retraction that can be minimized with appropriate cerebrospinal fluid (CSF) drainage, high risk to CNs, and the often necessary destruction of critical sensory and neuronal structures. Due to these factors, the resulting morbidity and mortality with external approaches can be high.^{3,18–22}

In an attempt to refine skull base techniques, minimally invasive surgery has been a hot topic of interest. Surgical experience, anatomical knowledge, and advanced microsurgical instrumentation have allowed increased success in terms of patient outcomes.^{5,23} Wu and Lan²⁴ were successful with presigmoid transpetrosal keyhole approaches that miniaturize the surgical cavity. In a retrospective review, Chen et al²⁵ found that less invasive microsurgical resection of brainstem cavernous malformations could achieve complete surgical removal with careful planning and the use of neuronavigation and neurophysiologic monitoring. A shortcoming in minimally invasive external approaches is the significantly reduced surgical mobility. The small corridors can make complete en bloc resection of neoplasms difficult or impossible.^{24,25} Endoscopic endonasal techniques were developed more recently to access the skull base in a minimally invasive fashion. Surgical corridors created inside the nasal cavity have had significant success in the complete resection

Table 1 Posterior petrosal and endoscopic endonasal transclival dissection volumes

Anatomical location	Sex	Average volume, cm ³	SD, cm ³	95% confidence interval	95% confidence
Transclival	Male	6.36	1.64	5.71–7.02	0.656
	Female	5.64	1.46	5.06–6.23	0.586
Posterior petrosal	Male	19.98	2.02	18.84–21.12	1.144
	Female	16.71	1.89	15.64–17.78	1.070

Abbreviation: SD = standard deviation.

of skull base tumors with minimal cosmetic and neurologic deficits.⁷⁻¹²

This study provides useful points of comparison to help the surgical team when deciding between a posterior petrosal approach and an EEA. With the wide craniotomy and extensive temporal bone resection, there was more than three times the amount of bone removal with the transpetrosal approach for both men and women. However, EEA to the skull base is relatively new, and surgeon experience is still variable. Cosmetically the EEA is superior, and it obviates the need for brain manipulation. EEA also avoids the high risk of destruction of temporal bone structures and nerves. Stepwise dissection of both approaches provided knowledge and experience with the different nuances and possible pitfalls of each technique.

Clinically, it remains a challenge to reconstruct the large skull base defects associated with EEAs due to the difficulty in working with endoscopic tools and the high risk of CSF leak,²⁶ one of the most common complications.^{27,28} These can occur weeks postoperatively and are associated with infection and delayed hematoma formation. In addition, reports have discussed high-volume CSF leaks immediately postoperatively causing subdural hematoma and tension pneumocephalus requiring immediate and skilled repair.²⁹ An important component of successful EEA is the use of vascularized pedicled flaps to repair large skull base defects. This has resulted in an acceptable rate of CSF leaks.^{30,31} However, reports have shown the EEA has been used successfully for pathology at the petroclival region, especially with regard to gross total or near-total resection.³²⁻³⁴ Petroclival tumors, such as chondrosarcomas, are typically slow growing and capable of reaching sizes that create significant displacement of important neurovascular structures. Preoperative and intraoperative imaging can result in improved preparation and outcomes. Magnetic resonance imaging is especially helpful in evaluating tumor involvement of adjacent structures. In terms of safety, the EEA may be more desirable when compared with traditional lateral approaches because critical neural and vascular structures are located away from the surgical field, reducing risk.³⁵ An important risk, however, is the limited workspace and viewpoint through the endoscope during EEA. If vascular injuries arise, visualization and methods to achieve hemostasis would be difficult. All of these factors should be taken into consideration.

The endoscopic endonasal dissection proceeded well, especially when clearing the nasal cavity and resecting the sphenoid bone. Difficulty arose when resecting the clivus and exposing the brainstem and CNs. A significant challenge in exposing the posterior fossa dura behind the clivus was the course of the abducens nerve. The intra- to extradural path anteriorly toward the dissector put the nerve at risk of transection during removal of the clivus. This is particularly true when dealing with petroclival intradural tumors as meningiomas because they start laterally and can medialize CN VI even to the extreme of crossing to the contralateral side. Hereafter, the dural opening should always be below the vertebrobasilar junction to avoid injuring CN VI, and image guidance and intraoperative neuromonitoring is indicated.

Once the nerve was freed, clivus bone removal laterally to the paracervical carotid arteries was uncomplicated. An additional challenge was dissection posterior and lateral to the carotids. The bone to be dissected is deep within the cranial cavity and densely compact. Sinus tools were able to operate at such an angle behind the ICA but were not strong enough to remove bone efficiently. Further complicating the lateral dissection, drills and rongeurs could not work as effectively at that angle. Lateral retraction of the ICA was limited as well by the floor of the middle cranial fossa. Successful dissection involved piecemeal removal of bone utilizing all the tools available. However, at some point the difficulty in endoscopic endonasal dissection should indicate an external lateral technique is needed if a lesion is to be resected more laterally in the skull base. We noticed that this is particularly significant to reach lateral to CN VI, a landmark point of transition in which the surgeon should consider a lateroposterior approach.

The posterior petrosal approach afforded successful exposure of the petroclival region and lateral CPA, yet in this anatomical study it required one of the senior authors (C.A.S.) to perform the dissections because of the technical difficulties. The learning curve is steep for inexperienced dissectors, and it requires a very thorough knowledge of skull base and temporal bone anatomy to understand landmarks and relationships. The craniotomy and mastoidectomy proceeded well without the need for an operative microscope. However, upon deeper dissection a microscope is a requirement to note the subtle anatomical landmarks. Difficulty can arise upon skeletonization of the bony labyrinth. To create a sufficient corridor to the CPA, the bone must be removed as much as possible over the labyrinth. This creates the risk for damage and subsequent hearing loss. Bone wax can often be used to seal the defect if need be.²² Deeper dissection also creates a progressively constricted surgical field. There is a relatively small gap between the posterior fossa dura and the bony labyrinth that could potentially hinder tumor removal in certain cases. Regardless, the posterior petrosal approach appears to be far superior for lesions extending laterally.

OsiriX continues to prove itself as a highly useful tool to provide quantitative analysis of skull base anatomy and surgical approaches. The precision of measuring tools and the clarity of anatomical landmarks in the program allows for a reproducible comparison of volume. Although there is variation in a given surgical procedure, repeat measurement provides a reliable average volume. Landmark distances have been successfully analyzed in our research and found to correlate well between CT in OsiriX and live dissection.³⁶ Imaging modalities continue to have an important place in skull base surgery as a way to increase anatomical knowledge and to analyze the different surgical approaches available.

Conclusion

The EEA to the petroclival region compares well with the combined subtemporal retrolabyrinthine transpetrosal approach. The high risk to hearing and vestibular structures with the transpetrosal approach could potentially be avoided with an overall more beneficial cosmetic outcome and

minimal brain manipulation. Both techniques have their risks and potential pitfalls, which emphasizes the importance of a thorough consideration of the approach based on the location of the lesion. Our ability to resect skull base lesions continues to expand as our anatomical knowledge increases.

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