Posterior Transpetrosal Approaches to the Posterior Cranial Fossa: radiological preoperative assessment and microneurosurgical anatomy

Abordagens Transpetrosas Posteriores à Fossa Craniana Posterior: avaliação radiológica pré-operatória e anatomia microneurocirúrgica

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ABSTRACT
The posterior transpetrosal approaches involve removing portions of the petrous bone and creating a pathway to access the posterior cranial fossa. The Trautmann’s triangle, delimited by the superior petrosal sinus, posterior semicircular canal, jugular bulb and sigmoid sinus, is the window through which the posterior fossa is accessed, and its exposure is a common step in all variants of the posterior transpetrosal approaches: the retrolabyrinthine, the translabyrinthine and the transcochlear approaches. Preoperative radiological assessment plays a critical role in planning and performing these approaches, and different imaging modalities, such as CT and MRI, may be used. However, due to significant anatomical variability, the ease of the approach, may be greatly affected. Detailed information on the bony anatomy, including the degree of mastoid aeration, the position and dominance of the sigmoid sinus as well as the height of the jugular bulb are important parameters to be considered to ensure safe and effective surgery while minimizing the risk of complications. Therefore, the aim of this manuscript is to review the radiological assessment and correlation as well as the microneurosurgical anatomy of the posterior transpetrosal approaches.

Keywords: Posterior cranial fossa; Posterior transpetrosal approaches; Trautmann’s triangle; Radiological assessment

RESUMO
As abordagens transpetrosas posteriores envolvem a remoção de porções do osso petroso e a criação de uma via de acesso à fossa craniana posterior. O triângulo de Trautmann, delimitado pelo seio petrosal superior, canal semicircular posterior, bulbo jugular e seio sigmoide, é a janela através da qual a fossa posterior é acessada, e sua exposição é um passo comum em todas as variantes das abordagens transpetrosas posteriores: a retrolabiríntica, a translabiríntica e a transcoclear. A avaliação radiológica pré-operatória desempenha um papel importante no planejamento e execução dessas abordagens, e diferentes modalidades de imagem, como TC e RM, podem ser usadas. No entanto, devido à variabilidade anatômica significativa, a facilidade da abordagem pode ser muito afetada. Informações detalhadas sobre a anatomia óssea, incluindo o grau de aeração do mastoide, a posição e dominância do seio sigmoide, bem como a altura do bulbo jugular são parâmetros importantes a serem considerados para garantir uma cirurgia segura e eficaz, minimizando o risco de complicações. Portanto, o objetivo deste artigo é revisar a avaliação radiológica e a correlação, bem como a anatomia microneurocirúrgica das abordagens transpetrosas posteriores.

Palavras-chave: Fossa craniana posterior; Abordagem transpetrosa posterior; Triângulo de Trautmann, Avaliação radiológica
INTRODUCTION

The fundamental principle of skull base surgery is to achieve adequate exposure for maximal tumor resection while minimizing brain retraction and reducing the risks of complications such as inadvertent neurovascular injuries and infection. Proper skull base reconstruction is also mandatory for good outcomes. However, achieving these goals is often challenging due to its deep location, complex anatomy, and intricate relationship with the basal surface of the brain and important neurovascular and aerodigestive structures.

From a historical perspective, larger craniotomies were initially favored because they provide wide access for visualization of the operative field and maneuvering of instruments while obviating brain retraction. The introduction of the operating microscope, microsurgical instrumentation, better understanding of microneurosurgical anatomy and increased collaboration among different specialties (i.e. neurosurgery, ENT, head and neck surgeons, plastic surgeons) made safe and effective tumor resection through smaller exposures feasible. Over the past decades, the development of the “key-hole” and “surgical corridor” concepts, the use of the surgical endoscope and other technological advancements such as intraoperative navigation and monitoring have allowed less invasive and safer approaches.

In general, the most direct and least destructive surgical route that will allow the most complete resection with fewest complications is the preferred one. The site of origin and the pattern of extension of the tumor will dictate the displacement of the surrounding structures and determine the most appropriate surgical approach, although a combination of multiple approaches from different “surgical corridors” may be necessary for larger tumors affecting multiple compartments of the skull base. Therefore, sound knowledge of the three-dimensional skull base anatomy is of paramount importance for the thoughtful design and meticulous implementation of surgical strategies that must follow the fundamental principle of adequate exposure for safe resection and proper reconstruction.

The posterior transpetrosal retrolabyrinthine approach was considered “the unsung hero” of skull base surgery for providing shorter working and less cerebellar retraction compared to the traditional retrosigmoid approach. However, due to significant variability on bony anatomy, the ease of the approach may be greatly affected. Therefore, the aim of this manuscript is to review the radiological assessment and correlation as well as the microneurosurgical anatomy of the posterior transpetrosal approaches, including its translabyrinthine and transcochlear variants, to the posterior fossa.

PREOPERATIVE ASSESSMENT

Preoperative assessment should always include medical, neurologic, otolaryngological, and radiographic evaluation and only after careful consideration of the surgical goals in the context of the risks of perioperative complications the surgery may proceed. Clinically, patient’s overall medical condition, including comorbidities, must be evaluated to determine fitness for substantial and aggressive surgery and possibly lengthy recovery. Evidence of cranial neuropathies and brainstem compression must be sought. Hearing deficits mandate formal audiological evaluation whereas tumors compromising the lower cranial nerves mandate formal swallowing evaluation. Importantly, the retrolabyrinthine approach is suitable only for patients with serviceable hearing.

High-quality neurodiagnostic imaging is essential for effective preoperative assessment and planning. The Trautmann's triangle (TT), an area of dura delimited by the superior petrosal sinus, the posterior semicircular canal, the jugular bulb and the sigmoid sinus, provides surgical access to the posterior fossa via the retrolabyrinthine approach (Figure 1). Because of its remarkable variability in terms of size and shape, it is of utmost importance for the surgeon to address the anatomical constraints that may restrict the working space through this area.

CT angiography (CTA) scans, which may be windowed for increased bone detail, reveals the position and dominance of the sigmoid sinus (SS), the degree of pneumatization of the mastoid portion of the temporal bone and the distance between the semicircular canals (SCCs) and the SS as well as their relation with the external acoustic canal (EAC). The position and dominance of the SS as well as the height of the jugular bulb (JB) may have an adverse impact upon the retrolabyrinthine approach. Lateral or anteriorly displaced sinuses may restrict the surgical corridor through TT. A dominant SS also restricts the corridor as well as requires a more cautious approach because an inadvertent injury to a dominant sinus may have catastrophic consequences to the patient.
Moreover, high-riding JB may significantly limit surgical access and working space to the posterior fossa, including the surroundings of the internal acoustic canal (IAC), via retrolabyrinthine approach\textsuperscript{13,15}.

Poorly aerated mastoids may increase the time of surgical exposure and the risk of inadvertent facial nerve injury during mastoidectomy. Moreover, a shorter distance between the EAC and the SS usually anticipates a contracted TT. If combined with a deeper-seated lateral SCC and a laterally displaced SS, a narrower and longer surgical corridor is expected.

On the other hand, increased mastoid aeration usually facilitates early identification of relevant landmarks and reduce time of surgical exposure, even though the risk of postoperative cerebrospinal fluid (CSF) leakage may be increased in these cases\textsuperscript{10,11}.

Altogether, careful analysis of these variables must be considered during preoperative planning because it enables the surgeon to appropriately design combined surgical approaches whenever deemed necessary (Figure 2). In cases of restricted access to the IAC, a retrosigmoid approach may be considered. Tumors with significant anterolateral extension commonly require a combined anterior transpetrosal approach whereas those extending posteromedially require a combined far-lateral approach\textsuperscript{1,16}. A translabyrinthine variation of the posterior transpetrosal approach may be also considered in tumors with anterior extension in patients with unserviceable hearing\textsuperscript{17}.

Importantly, other pathological conditions, such as bone erosion and tumor calcification, which are important preoperative considerations as it may increase the risk of complications, must be carefully analyzed. Magnetic resonance (MR) imaging, in addition to CTA, is essential for determining the signal characteristics of the tumor and its relationship to soft tissue and neurovascular structures. MR sequences should always include T1-weighted precontrast, T1-weighted postcontrast (with fat-suppressed images if necessary), T2-weighted and diffusion-weighted.

**Figure 1.** Lateral view of the left Trautmann’s triangle and its boundaries. The Rhoton Collection.

**Figure 2.** A. Axial view of CT scan of the head showing the position and dominance of the SS and the degree of mastoid aeration. B. Sagittal view of CT scan of the head showing a high-riding JB. Note its dome (asterisks) located above the inferior margin of the posterior SCC (arrow).
Additional sequences useful in obtaining additional information include gradient echo T2*, fluid-attenuated inversion recovery (FLAIR) and heavily T2-weighted steady-state imaging also called fast imaging employing steady-state acquisition (FIESTA) or constructive interference in steady state (CISS). The steady-stated sequences are especially helpful in skull base surgery for evaluating small structures that traverse the basal cisterns.

**MICRONEUROSURGICAL ANATOMY**

The posterior transpetrosal approaches are part of what is called the posterolateral corridor to the skull base. The posterolateral corridor is limited anterolaterally by the posterior limits of the lateral corridor and posteromedially by the lateral limits of the inferior aspect of the anterior corridor (hypoglossal nerve and vertebral artery) (Table 1).

This corridor is further divided into superolateral (i.e., posterior transpetrosal) and inferomedial (i.e., retrosigmoid and far-lateral approaches) components by the sigmoid sinus, jugular bulb and the glossopharyngeal, vagal and accessory nerves (Figure 3).

The posterior transpetrosal approaches have in common traverse of the posterior portion of the petrous temporal bone and can be considered as a series of progressive openings involving a simple mastoidectomy and successively greater posterolateral to anteromedial removal of the petrous bone.

### Table 1. Surgical routes to the skull base.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Limiting Structures</th>
</tr>
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<tbody>
<tr>
<td><strong>Anterior Midline</strong></td>
<td></td>
</tr>
<tr>
<td>Subfrontal</td>
<td>Orbits, optic nerves, cranial nerves III-VI, cavernous/paraclival/petrous ICA, cranial nerve XII, vertebral arteries</td>
</tr>
<tr>
<td>Transfacial</td>
<td></td>
</tr>
<tr>
<td>Endoscopic endonasal</td>
<td>Optic nerves, cranial nerves III-VI, cavernous/paraclival/petrous ICA, cranial nerve XII, vertebral arteries</td>
</tr>
<tr>
<td><strong>Anterolateral</strong></td>
<td></td>
</tr>
<tr>
<td>Pterional</td>
<td>Cavernous/supraclinoid ICA, cranial nerves III-VI, SOF, BA, PCA, PComA</td>
</tr>
<tr>
<td><strong>Lateral</strong></td>
<td></td>
</tr>
<tr>
<td>Extended MCF</td>
<td>Cavernous/petrous ICA, cranial nerves III-VI, SOF, cochlea, SCC, cranial nerves VII-VIII</td>
</tr>
<tr>
<td>ST-IT</td>
<td>Petrous ICA, V3, cochlea, SCC, cranial nerves VII-VIII</td>
</tr>
<tr>
<td><strong>Posterolateral</strong></td>
<td></td>
</tr>
<tr>
<td>Posterior Transpetrosal</td>
<td>Cochlea, SCC, cranial nerves VII-VIII, sigmoid sinus, JB, cranial nerves IX-XI</td>
</tr>
<tr>
<td>Far-lateral/Retrosigmoid</td>
<td>Vertebral artery, cranial nerves VI-XII, sigmoid sinus, JB, cranial nerves IX-XI</td>
</tr>
</tbody>
</table>

Legend: ICA, internal carotid artery; JB, jugular bulb; SOF, superior orbital fissure; BA, basilar artery; PCA, posterior cerebral artery; PComA, posterior communicating artery; SCC; MCF, middle cranial fossa; ST-IT, subtemporal-infratemporal; V3, mandibular division of trigeminal nerve. Adapted from Vaz-Guimaraes, Harsh.
They include the retrolabyrinthine, the translabyrinthine and the transcochlear approaches. This progression simultaneously exposes larger areas of presigmoid dura and removes osseous obstruction of microsurgical views of the petrous apex, the middle half of the clivus, and the prepontine cistern (Table 2). However, this increased exposure comes at the expense of increased risk of loss of hearing and facial palsy.

The retrolabyrinthine approach removes the posterior petrous bone up to but short of the bony labyrinth so as to preserve the integrity of all three SCC. As with all these posterolateral approaches, the anteriorly directed view is improved by posterior displacement of the SS. This is facilitated by removal of retrosigmoid occipital bone. The retrolabyrinthine approach has the advantage of a low risk of hearing loss. It provides a presigmoid view that is usually limited to the adjacent cerebellopontine angle (CPA) cistern and differs little from that provided by a retrosigmoid approach. Nonetheless, this approach is indicated in cases in which serviceable hearing is present preoperatively and a tumor has extended intradurally from the posterior petrous region.

The translabyrinthine approach removes the labyrinth at the cost of ipsilateral hearing loss. The labyrinth is removed along with bone about the internal auditory canal including toward the petrous apex. Although labyrinthectomy substantially increases the exposure of the CPA and prepontine cisterns, a high-riding JB, an anteriorly displaced SS and a low-lying middle cranial fossa floor can block surgical access to the inferior, middle and superior portions of clivus, respectively.

Lastly, the transcochlear approach is a transotic procedure that removes the mastoid, labyrinth, posterior acoustic canal wall, the middle ear and its ossicles. The external auditory canal is divided and oversewn. Bone is drilled from around the facial nerve, and the liberated nerve is then mobilized and transposed posteriorly to permit removal of the bone of the facial canal, the cochlea, and the petrous apex towards the carotid canal.

The transcochlear approach thus removes petrous bone up to the petroclival fissure medially and the horizontal petrous ICA laterally, which provides broad, proximal exposure of the clivus and prepontine cisterns. Unfortunately, this results in hearing loss and facial palsy that is often permanent. A modification of the transcochlear approach, the transotic approach, removes the cochlea and skeletonizes, but does not transpose, the facial nerve. This opens much of the visual field of the transcochlear approach, but room for surgical manipulation is restricted by the intervening facial nerve.

The posterior transpetrosal approaches are versatile and can be promptly combined with other approaches from different surgical corridors. As a matter of fact, for tumor growth beyond the posteromedial face of the petrous bone and adjacent cisterns, each of these posterolateral approaches can be enlarged superiorly, anteriorly, and medially (with increased exposure of the MCF and superior CPA and lateral prepontine cisterns adjacent to the petrous apex) by combining them with a temporal craniotomy and by dividing the superior petrous sinus and the tentorium. The bone forming the inferior lateral wall and lateral floor of the middle cranial fossa is removed. The superior petrosal sinus (from inferior cavernous sinus to its end at the sinodural angle) and attached tentorium (from the point of entry of the trochlear nerve anteriorly to the posterior part of the incisura) are resected. Gentle elevation of the middle and posterior temporal lobe, with care to preserve the vein of Labbé and its tributaries, and posterior displacement of the sigmoid sinus open a wide corridor to the inferolateral middle cranial fossa, the pre-pontine cistern, the CPA, the superolateral cerebellar cisterns, and the petrous apex up to Meckel cave. This transpetrosal, transtentorial extension of the posterior petrosectomy approaches results in a parallel series of combined supratentorial–infratentorial presigmoid approaches.

**Table 2.** Area of exposure following a posterior petrosectomy.

<table>
<thead>
<tr>
<th>Posterior Petrosectomy</th>
<th>Access to CPA</th>
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<tbody>
<tr>
<td>Retrolabyrinthine</td>
<td>Access to CPA</td>
</tr>
<tr>
<td>Translabyrinthine</td>
<td>Access expanded to middle petrous bone</td>
</tr>
<tr>
<td>Transcochlear</td>
<td>Access expanded to entire petrous bone, middle clivus and entire prepontine cistern</td>
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</tbody>
</table>

Legend: CPA, cerebellopontine angle. Adapted from Vaz-Guimarães, Harsh.

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**CONCLUSIONS**

The posterior transpetrosal approaches involve removing portions of the petrous bone and creating a pathway to access the posterior cranial fossa. The Trautmann’s triangle, delimited by the superior petrosal sinus, posterior semicircular canal, jugular bulb and sigmoid sinus, is the window through which the posterior fossa is accessed, and its exposure is a common step in all variants of the posterior transpetrosal
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