Endoscopic endonasal transcavernous posterior clinoidectomy with interdural pituitary transposition

Technical note

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Object. The object of this paper was to describe the surgical anatomy and technical nuances of the endonasal transcavernous posterior clinoidectomy approach with interdural pituitary transposition and to report the clinical outcome of this technical modification.

Methods. The surgical anatomy of the proposed approach was studied in 10 colored silicon-injected anatomical specimens. The medical records of 12 patients that underwent removal of the posterior clinoid(s) with this technique were reviewed.

Results. The natural anatomical corridor provided by the cavernous sinus is used to get access to the posterior clinoid by mobilizing the pituitary gland in an interdural fashion. The medial wall of the cavernous sinus is preserved intact and attached to the gland during its medial and superior mobilization. This provides protection to the gland, allowing for preservation of its venous drainage pathways. The inferior hypophyseal artery is transected to facilitate the manipulation of the medial wall of the cavernous sinus and pituitary gland. This approach was successfully performed in all patients, including 6 with chordomas, 5 with petroclival meningiomas, and 1 with an epidermoid tumor. No patient in this series had neurovascular injury related to the posterior clinoidectomy. There were no instances of permanent hypopituitarism or diabetes insipidus.

Conclusions. The authors introduce a surgical variant of the endoscopic endonasal posterior clinoidectomy approach that does not require intradural pituitary transposition and is more effective than the purely extradural approach. The endoscopic endonasal transcavernous approach facilitates the removal of prominent posterior clinoids increasing the working space at the lateral recess of the interpeduncular cistern, while preserving the pituitary function.

(http://thejns.org/doi/abs/10.3171/2014.3.JNS131865)

Key Words • cavernous sinus • endoscopic endonasal • pituitary surgery • petroclival meningioma • pituitary transposition • posterior clinoid • chordoma

Abbreviations used in this paper: CN = cranial nerve; DDAVP = desmopressin acetate; DI = diabetes insipidus; ICA = internal carotid artery; IHA = inferior hypophyseal artery.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
the pituitary gland when compared with the intradural approach, but at the same time it provides limited access to the dorsum sellae and posterior clinoids. In our practice, the extradural technique has proven sufficient for the resection of the superior extent of certain extradural chordomas, and may allow the removal of small-size posterior clinoids. However, we have encountered numerous cases in which a purely extradural approach to the posterior clinoid(s) was neither an effective nor a safe maneuver secondary to the inability to directly visualize and access the top of the posterior clinoid and its ligamentous attachments.

Here we describe a surgical variant of the endonasal posterior clinoidectomy approach, which does not require intradural pituitary transposition and is more effective than the extradural approach because it takes advantage of the natural corridor provided by the cavernous sinus to get access to the posterior clinoid and mobilize the pituitary gland in an interdural fashion. The aim of this report is to detail the surgical anatomy and technical nuances of the endonasal transcavernous posterior clinoidectomy approach with interdural pituitary transposition, and to report the clinical outcome (especially with regard to pituitary function) of this technical modification.

Methods

Anatomical Dissection

Ten colored silicon-injected anatomical specimens were dissected at the Surgical Neuroanatomy Lab at the University of Pittsburgh to simulate endonasal access to the sellar, parasellar, and retrosellar regions in a stepwise manner. Particular attention was paid to the anatomy of the posterior clinoids and the surgical anatomy relevant to their removal. The anatomical study was funded by the UPMC Center for Cranial Base Surgery, and approved by the Committee for Oversight of Research Involving the Dead at the University of Pittsburgh.

Surgical Cases

From July 2010 to March 2013, the authors performed 12 cases that required removal of the posterior clinoid(s) with the technique described in this paper (Table 1). The medical records of these patients were reviewed with approval of the University of Pittsburgh institutional review board to assess for intraoperative complications directly related to the transcavernous removal of the posterior clinoid(s) and postoperative pituitary function at 6 months’ follow-up. Cases with complete invasion and occlusion of the cavernous sinus and/or extensive erosion of the posterior clinoid(s) were excluded from this series.

Results

Surgical Anatomy of the Posterior Clinoid

The posterior clinoid is a key structure in the architecture of the cavernous sinus. It is located at the posterior-medial and superior corner of the cavernous sinus and provides attachment to the interclinoid and posterior pet-
roclinoid ligaments (Fig. 1). The interclinoid ligament is a short dural band that runs from the anterior to the posterior clinoid and forms the anterior-medial limit of the oculomotor triangle; from the surgical point of view, the interclinoid ligament is a reliable landmark to identify the course of the oculomotor nerve in the roof of the cavernous sinus when working inside the cavernous sinus from the endonasal route, since it always runs immediately lateral to the ligament. The posterior petroclinoid ligament is a strong dural band that joins the posterior clinoid and petrous apex to define the posterior-medial boundary of the oculomotor triangle and cavernous sinus roof. The dural layer located medial to the interclinoid ligament forms the dural diaphragm, which covers the anterior-medial portion of the cavernous sinus roof before it becomes the roof of the sella turcica. The dural layer that continues medial to the posterior petroclinoid ligament covers the dorsum sellae and forms the meningeal layer that lines the drainage of the basilar plexus into the cavernous sinus (Fig. 1).

Understanding the dural layering of the anterior (sphenoidal) and medial (sellar) walls of the cavernous sinus is crucial to obtaining surgical access to the posterior clinoid via a transsphenoidal transcavernous approach. As it is well known, the 2 layers of dura mater—meningeal or inner and periosteal or outer—that cover the anterior wall of the pituitary gland separate from each other at the lateral margin of the sella: the outer layer continues laterally to form the anterior or sphenoidal wall of the cavernous sinus, while the inner layer remains attached to the pituitary gland and runs back toward the posterior clinoid to form the medial wall of the cavernous sinus. Consequently, both the anterior and medial walls of the cavernous sinus are single layered (Fig. 2C). When looking at the anatomy of the cavernous sinus

**TABLE 1: Endoscopic endonasal transcavernous posterior clinoidectomy and pituitary function**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Pathology</th>
<th>Side</th>
<th>IHA Sacrifice</th>
<th>Pituitary Function</th>
<th>Transient DI</th>
<th>Permanent DI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60, F</td>
<td>petroclival meningioma</td>
<td>rt</td>
<td>unilat</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>27, M</td>
<td>clival chordoma</td>
<td>bilat</td>
<td>bilat</td>
<td>intact</td>
<td>yes; 1 day DDAVP</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>44, F</td>
<td>petroclival meningioma</td>
<td>lt</td>
<td>unilat</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>41, M</td>
<td>clival chordoma</td>
<td>rt</td>
<td>unilat</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>58, M</td>
<td>petroclival meningioma</td>
<td>lt</td>
<td>unilat</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>51, M</td>
<td>clival chordoma</td>
<td>rt</td>
<td>unilat</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>7</td>
<td>54, F</td>
<td>petroclival meningioma</td>
<td>lt</td>
<td>unilat</td>
<td>intact</td>
<td>yes; 1 day DDAVP</td>
<td>no</td>
</tr>
<tr>
<td>8</td>
<td>19, F</td>
<td>clival chordoma</td>
<td>bilat</td>
<td>bilat</td>
<td>intact</td>
<td>yes; 2 days DDAVP</td>
<td>no</td>
</tr>
<tr>
<td>9</td>
<td>23, F</td>
<td>petroclival meningioma</td>
<td>rt</td>
<td>unilat</td>
<td>intact</td>
<td>yes; 3 days DDAVP</td>
<td>no</td>
</tr>
<tr>
<td>10</td>
<td>48, M</td>
<td>retroclival epidermoid</td>
<td>lt</td>
<td>none</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>11</td>
<td>63, M</td>
<td>clival chordoma</td>
<td>rt</td>
<td>none</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>12</td>
<td>56, M</td>
<td>clival chordoma</td>
<td>rt</td>
<td>unilat</td>
<td>intact</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>
and posterior clinoid from above, we can observe that the posterior clinoid is located posterior and lateral to the pituitary gland and posterior and medial to the horizontal cavernous segment of the internal carotid artery (ICA). This is precisely the surgical corridor that gives access to the posterior clinoid: between the pituitary gland medially and the horizontal cavernous ICA laterally (Fig. 3).

**Endoscopic Endonasal Posterior Clinoidectomy: Technical Nuances**

The standard endonasal endoscopic surgical approach to the sphenoid sinus is performed as described elsewhere. Once the sphenoid sinus opening has been maximized, extensive sellar and parasellar exposure, including the anterior wall of the cavernous sinus and paraclinoid segment of the ICA, is completed (Fig. 4). The middle clinoid, when present, serves as reference for the location of the roof of the cavernous sinus and the transition between cavernous and paraclinoid ICA segments. Removal of the middle clinoid is required, except when a caroticoclinoidal bony ring is identified; in this case, reduction of the middle clinoid is sufficient and safer. The surgical steps to accomplish a middle clinoidectomy have been recently described. The exposure of the sellar dura
Interdural pituitary transposition

continues superiorly up to the tuberculum sellae and medial optic-carotid recesses, which typically do not have to be removed unless suprasellar access is required. Inferiorly, it is important to drill out the sellar floor all the way back to the dorsum sellae; the use of a 45° endoscope may facilitate this “infrasellar approach.”9 Then the bone that covers the most inferior aspect of the anterior wall of the cavernous sinus is carefully removed; this is an essential step that exposes the critical area where the paraclival segment of the ICA enters the cavernous sinus to become the short vertical ascending portion of the cavernous ICA segment. Full skeletonization of the paraclival ICA, from the foramen lacerum to the cavernous sinus, is performed when access to the petroclival fissure and medial aspect of the petrous apex is needed; however, this is not the case for the completion of the transcranial posterior clinoidectomy itself.

After this extensive bony work, the transcranial approach is initiated. A sharp vertical incision is made with a retractable knife at the anterior wall of the cavernous sinus, just medial to the cavernous ICA (Fig. 4B); this provides direct access into the cavernous sinus, where prominent venous bleeding is controlled with intracavernous injection of Surgifoam (Ethicon, Inc.) and gentle...
packing with cottonoids. These hemostasis maneuvers are repeated as many times as needed during the approach. When the location of the cavernous ICA is not clearly discernible or when the cavernous ICA is tortuous and forms a medial loop, the sharp incision can be performed just at the transition between the sellar dura and the anterior wall of the cavernous sinus to eliminate the risk of direct injury to the ICA; in this case, we will obtain bleeding from the intercavernous venous channels, which can be controlled as stated above. By means of meticulous dissection, the interdural plane in between the outer dural layer and the inner layer is developed from medial to lateral until they separate to form the cavernous sinus cavity. The opening into the cavernous sinus should be maximized to allow for full intracavernous access, extending from the transition between the cavernous sinus floor and clival dura to the transition between the roof of the cavernous sinus and paraclinoid ICA. This is particularly important when tall and prominent posterior clinoids have been identified in the preoperative studies. It is possible to further extend the cavernous sinus opening by transecting the roof of the cavernous sinus just medial to the paraclinoid ICA; this delicate maneuver will not provide increased surgical exposure of the posterior clinoid but just further lateral mobilization of the ICA and exposure of the suprasellar cistern, which is typically not needed. Dissecting in and packing off this medial portion of the cavernous sinus carries little or no risk to the cranial nerves (CNs), as they are purely ensheathed in the lateral compartment (CNs III, IV, and VI) or running lateral to the carotid artery (CN VI).

Once within the cavernous sinus, the inferior hypophyseal artery (IHA) should be identified before performing any further dissection between the medial wall of the cavernous sinus and the cavernous ICA (Fig. 4C–D). The IHA is a branch of the meningohypophyseal trunk (and occasionally a direct branch of the cavernous ICA) that courses within the cavernous sinus from lateral to medial and from posterior to anterior on its way to the dura that covers the posterior lobe of the pituitary gland; it is a constant artery but it is often hypoplastic on one side. The coagulation and transection of the IHA is often necessary and recommended to get access to the posterior clinoid. This surgical maneuver facilitates medial mobilization of the medial wall of the cavernous sinus (and pituitary gland) and lateral mobilization of the cavernous ICA, preventing any risk for avulsion of the IHA from the ICA wall. Occasionally, we have encountered an IHA with a long loopy trajectory that facilitates dissection, mobilization, and preservation of the artery. Blunt dissection is employed to develop the transcavernous corridor between the cavernous ICA and the pituitary gland, with more emphasis on the medial mobilization of the pituitary gland than on the lateral mobilization of the cavernous ICA (Fig. 3). Occasionally, the cavernous ICA might be adherent to the medial wall of the cavernous sinus, which poses more difficulty in the development of the transcavernous corridor.

After successful completion of the transcavernous approach with interdural pituitary transposition, the posterior clinoid can be completely identified and accessed. Then, we perform careful coagulation of the dural covering of the posterior clinoid and dorsum sella in preparation for the dissection of the dural attachments to the posterior clinoid, namely the interclinoid and posterior petroclinoid ligaments. Next, the posterior clinoid is disconnected from the dorsum sella using a small Kerrison rongeur or high-speed drill. The superomedial displacement of the pituitary gland (interdural pituitary transposition), and in particular the mobilization of the posterior lobe, facilitates full access to the most superior aspect of the dorsum sellae allowing its complete removal. It is important to recognize that the dural lining of the posterior lobe of the gland is thinner than the lining at the anterior lobe, and therefore the posterior gland is more delicate and sensitive to mechanical manipulation and subsequent injury (Fig. 4D).

Once the posterior clinoid is separated from the dorsum sellae and detached from its dural covering, a blunt dissector is employed to complete the dissection of the dural attachments from the posterior clinoid. When removing the posterior clinoid, it is important to remember that it not only has an apex (projecting superiorly) but also has a prominence projecting posterolaterally, which relates to the attachment of the posterior petroclinoid ligament (Figs. 1 and 4D). This posterolateral prominence is, indeed, the most adherent segment of the posterior clinoid process, and its full detachment is required for successful completion of the transcavernous posterior clinoidectomy. When necessary, the contralateral posterior clinoid is removed following the same steps (Fig. 4G–I). Importantly, it is critical to examine the preoperative fine-cut CT scan to identify prominent posterior clinoids or osseous bridges with the anterior and/or middle clinoids; in the event these bridges are identified, a partial posterior clinoidectomy leaving the osseous bridge without attempting fracturing is preferable.

The posterior clinoidectomy significantly increases the working space within the cavernous sinus for tumors that invade this region, such as chordomas. It also provides a more superior and lateral intradural corridor, as it is needed for tumors with intradural location or extension such as petroclival meningiomas and chordomas, respectively. The dura is opened at the clival region and extended supr medially toward the dura exposed after the posterior clinoidectomy. This provides access to the lateral recess of the interpeduncular cistern or oculomotor cistern, and more specifically, to the inferior aspect of the oculomotor nerve before it enters the interdural segment at the roof of the cavernous sinus (Fig. 4E and F). The posterior communicating artery travels along with CN III in the lateral recess of the interpeduncular cistern. The lateral limit of the approach intradurally is the anterior petroclinoid ligament or petrotentorial ligament that forms the free edge of the tentorium, and CN IV can be identified entering the dura toward the cavernous sinus wall posteriorly. The superomedial surface of the uncus and anterior choroidal artery become visible at the most superior and lateral aspect of the exposure (Fig. 4J–L).

**Surgical Results**

The endoscopic endonasal transcavernous posterior clinoidectomy approach with interdural pituitary trans-
Interdural pituitary transposition

position was successfully performed in all 12 patients, including 6 with chordomas, 5 with petroclival meningiomas, and 1 with an epidermoid tumor. Importantly, in all chordoma cases the posterior clinoidectomy was useful to increase the surgical exposure and to facilitate a more complete resection, as some of these tumors tend to grow behind the posterior clinoid and dorsum sellae. From a subjective point of view, the posterior clinoidectomy provided a wider exposure and better visualization of the intradural neurovascular structures, allowing for not only more accurate but also safer resection in cases of petroclival meningiomas and chordomas with intradural extension (Fig. 5). No patient in this series had vascular injury or cranial nerve palsies directly related to the posterior clinoidectomy. In regard to pituitary dysfunction, 1 patient required replacement with hydrocortisone for several months preoperatively, and 4 patients (30%) suffered transient diabetes insipidus (DI) requiring 1 to 3 doses of DDAVP. However, there were no instances of long-term hypopituitarism or diabetes insipidus (DI). Remarkably, 2 patients had transection of the IHA bilaterally and 8 unilaterally, and the IHA was preserved bilaterally in 2 patients. Although these subgroups had no differences in their final endocrinological outcome, the incidence of transient DI was 100% (occurring in 2 of 2 cases) in the first, 25% (2 of 8) in the second, and 0% (0 of 2) in the third (Table 1).

**Discussion**

In this paper we describe the surgical anatomy and technical nuances of the endoscopic endonasal transcavernous posterior clinidectomy with interdural pituitary transposition. Here we show that this modality of pituitary transposition minimizes the risk of pituitary dysfunction and is ideal for lesions located in the parasellar and retrosellar space, such as chordomas with parasellar-retrosellar-suprasellar extension and petroclival meningiomas. The interdural transposition provides wide access to the cavernous sinus, facilitates the removal of prominent posterior clinoids, and opens a corridor toward the lateral recess of the interpeduncular cistern, where the oculomotor nerve and posterior communicating artery are located.

Remarkably, none of our patients suffered permanent anterior and/or posterior pituitary dysfunction, in spite of unilateral sacrifice of the IHA in 8 patients and bilateral transection in 2. This demonstrates that the vascular supply for both anterior and posterior pituitary lobes can be exclusively provided by the superior hypophyseal artery system. The incidence of transient DI in the subgroup with bilateral IHA sacrifice was higher, but the number of patients in this study was too low to allow for any definitive conclusions in this regard, and the occurrence of postoperative DI was likely a reflection of other factors such as the degree of manipulation of the posterior pituitary gland, which was facilitated by the greater mobilization provided by bilateral sacrifice of the IHA. We believe that preservation of the attachment of the medial (sellar) wall of the cavernous sinus to the pituitary gland during medial and superior mobilization provides additional protection to the glandular tissue and allows for preservation of the remaining venous drainage pathways, namely the superior intercavernous sinus and paraclinoid venous channels. This is the main difference with the intradural pituitary transposition that may explain the potential improvement in preservation of pituitary function.

In our experience, the purely intradural transposition is reserved for highly selected midline tumors with intimate relation to the posterior surface of the pituitary stalk and infundibulum, such as retroinfundibular craniopharyngiomas, pituicytomas, and infundibular-hypothalamic gliomas. The resection of these types of lesions, as opposed to petroclival meningiomas or chordomas, already carries significant risk of pituitary dysfunction in itself, and for large and complex lesions the benefit of enhanced visualization and access to the interpeduncular cistern might outweigh the risk of pituitary dysfunction.

Primarily extradural or meningeal lesions such as chordomas or meningiomas, respectively, may grow into the interdural space at the clival region and extend superiority behind the dorsum sellae and laterally into the cavernous sinus. In these cases, the completion of unilateral or bilateral transcavernous posterior clinidectomies is critical to facilitate complete tumor removal. The performance of the transcavernous approach follows basic principles of surgical neuroanatomy. For instance, the clival chordoma that extends from the clivus to the interdural space and through Dorello’s canal into the cavernous sinus requires the same transcavil approach with transcavernous access to Dorello’s canal as the tumor followed. In a case of a petroclival meningioma attached to the posterior clinoid, a transcranial transsellar transcavernous approach allows the surgeon to approach the attachment directly and also provides greater access to the rostral pole of the tumor. For chordomas and petroclival meningiomas with extension into the interpeduncular cistern, the interdural transposition is generally sufficient. In cases of chordomas and meningiomas that completely invade the cavernous sinus (including its medial wall), however, only an intradural transposition would be feasible (and this approach would be facilitated by tumor invasion).

Considerable variation has been identified in the height of the posterior clinoid process above the sellar floor, with heights ranging from 5.8 to 14.1 mm (mean 9.5 mm). The transcavernous approach presented here provides a more superior exposure of the posterior clinoid when compared with a purely extradural approach, and this is particularly important with prominent posterior clinoids. Importantly, the interdural transcavernous approach allows for full visualization of the posterior clinoid and its complex dural attachments, facilitating its removal in a controlled fashion. However, it may not be necessary for patients with small posterior clinoids, in whom in our experience a purely extradural infrasellar approach, although partially blind, is safe and effective. The main disadvantage of the proposed approach is the increase in blood loss as a consequence of the direct transcavernous approach. Consequently, extensive endonasal endoscopic surgical experience and familiarity with hemostatic techniques are mandatory for any surgeon attempting this otherwise highly useful technical modification.
Conclusions

The natural anatomical corridor provided by the cavernous sinus can be used to get access to the posterior clinoid and to mobilize the pituitary gland in an interdural fashion. This endonasal endoscopic transcraniovenous approach facilitates the removal of prominent posterior clinoids, increasing the working space within the cavernous sinus and at the lateral recess of the interpeduncular cistern, while preserving the function of the gland. Here we show the clinical application of this technical maneuver for the removal of selected chordomas, petroclival meningiomas, and epidermoid tumors.

Fig. 5. Case 7. A: Preoperative axial T1-weighted MR image showing a left petroclival tentorial meningioma at the level of the posterior clinoid process compressing the brainstem. B: Preoperative coronal T1-weighted MR image showing the craniocaudal extension of the tumor occupying the interpeduncular and prepontine cisterns on the left side. C: Intraoperative image of the left transcraniovenous interdural approach to the posterior clinoid. After incision of the periosteal layer of the dura mater between the pituitary gland medially and the left ICA laterally, the posterior clinoid process and IHA are exposed. D: Intradural view after posterior clinoidectomy and tumor removal. The posterior communicating artery and CN III are visualized in the lateral recess of the left interpeduncular cistern. E and F: Postoperative axial (E) and coronal (F) T1-weighted MR images showing complete removal of the tumor preservation of the pituitary gland. A. = artery; Hyp. = hypophyseal; ICA = internal carotid artery; Inf. = inferior; P. Com. = posterior communicating; Pit. = pituitary; Post. = posterior.
Disclosure

Dr. Gardner is a consultant for Integra LifeSciences. Dr. Snyderman is a consultant for SPIWay, LLC.

Author contributions to the study and manuscript preparation include the following. Conception and design: Fernandez-Miranda. Acquisition of data: Fernandez-Miranda, Rastelli, Peris-Celda, Koutourousiou. Analysis and interpretation of data: Fernandez-Miranda. Drafting the article: Fernandez-Miranda. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Fernandez-Miranda. Administrative/technical/material support: Rhoton. Study supervision: Fernandez-Miranda, Rhoton. Medical illustrator: Peace.

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Manuscript submitted August 30, 2013. Accepted March 19, 2014. Please include this information when citing this paper: published online May 9, 2014; DOI: 10.3171/2014.3.JNS131865. Address correspondence to: Juan C. Fernandez-Miranda, M.D., Department of Neurosurgery, UPMC Presbyterian Hospital, 200 Lothrop St., Ste. B400, Pittsburgh, PA 15213. email: fernandezmirandajc@upmc.edu.