Expanded Endonasal Approaches to Middle Cranial Fossa and Posterior Fossa Tumors

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KEYWORDS

- Endoscope • Skull base tumors • Meckel cave
- Posterior fossa • Middle fossa • Endonasal
- Extended transphenoidal • Expanded endoscopic approach

During the past decade, the increasing use of endoscopy in skull base surgery has become an important alternative to traditional transcranial surgery. Anatomic studies coupled with technological advances in endoscopic equipment, surgical instruments, and neurophysiological monitoring have allowed novel and exciting approaches to flourish within the field.[1–6] What once was only a route to the pituitary gland and sellar region has become a major highway to the entire ventral skull base and craniocervical junction.[6–14]

Among these innovations stand the expanded endonasal approaches (EEAs). The philosophy behind these approaches is, as in any skull base approach, to tailor the bone removal to gain a direct access to deep regions, thus minimizing manipulation of the cerebrum, blood vessels, and cranial nerves. Although deemed minimally invasive, these techniques provide a wide exposure of the cranial base and its pathologic conditions, often with early control of tumor-nurturing vessels and minimal or no neural tissue retraction. Furthermore, minimally invasive must not be perceived as less effective but rather as a less-aggressive pathway to reach maximum effectiveness.

The EEA to the anterior cranial fossa and sellar/parasellar regions has already been well described and thus it is not discussed in this article.[6,10,13,15,16] Hence, the authors focus on EEA to the middle cranial fossa (MCF) and posterior fossa (PF).

MIDDLE CRANIAL FOSSA

Traditionally, neurosurgical procedures for the pathologic conditions of the MCF have been performed through lateral craniotomies. Although lesions located at the most lateral aspect of the temporal fossa are directly reached when a lateral approach is used, more medially located mass lesions require various degrees of temporal lobe manipulation and/or retraction. In this article, the endonasal route is presented as an alternative direct approach to the medial compartment of the MCF.

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Indications

Virtually any pathologic process can be accessed through an endonasal route as long as it is located in the medial portions of the middle fossa, dislocating the temporal lobe superolaterally. Several pathologic processes commonly arise in the middle fossa and can be directly reached through an EEA. Of special interest are meningiomas and trigeminal nerve schwannomas. Chordomas and chondrosarcomas can also extend cranially to the middle fossa when they grow to large sizes (**Fig. 1**). Juvenile angiofibromas grow from the pterygopalatine fossa (PPF) and can expand posteriorly into the middle fossa as well. Aggressive pituitary adenomas can also grow laterally into

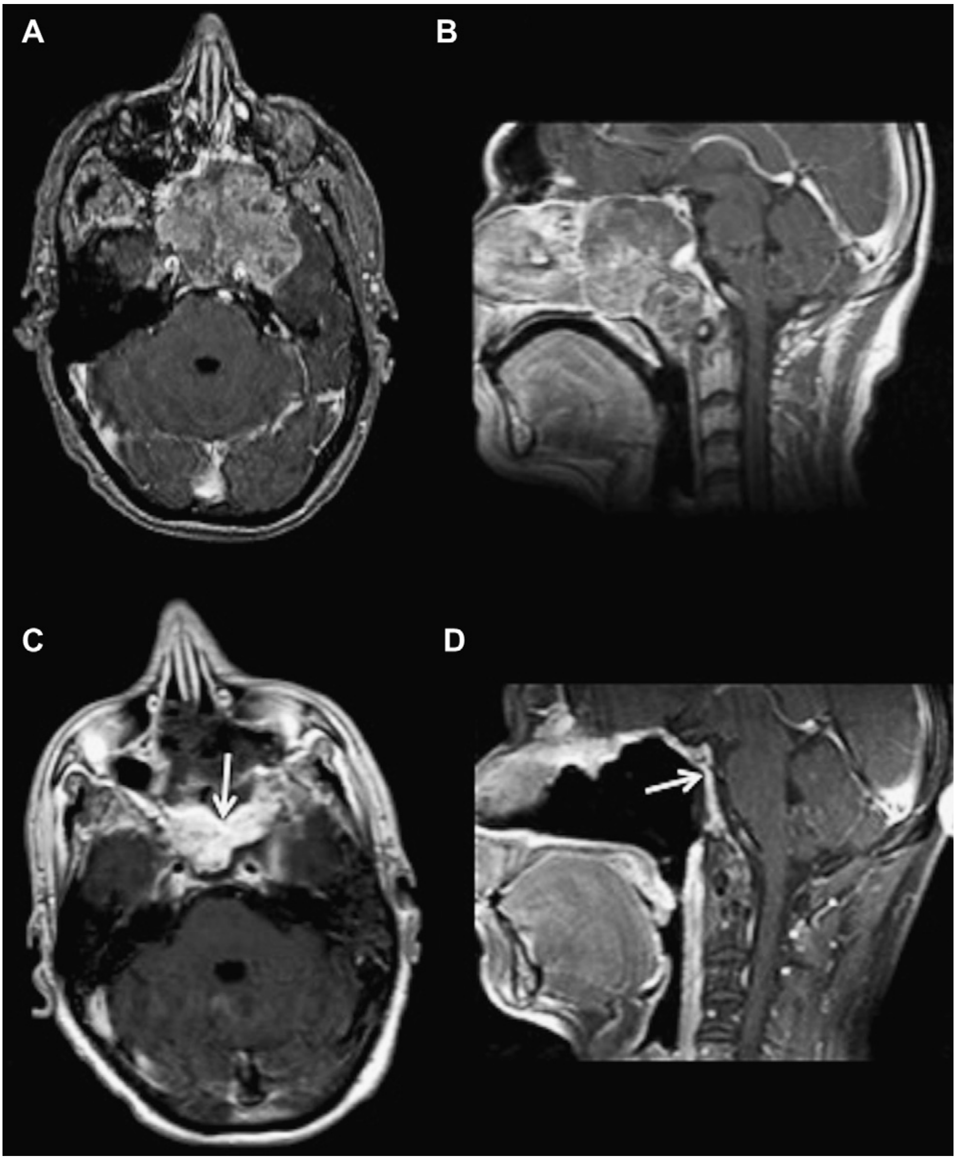

Fig. 1. (*A*) Axial and (*B*) sagittal preoperative magnetic resonance images showing a large clival chordoma in a 41-year-old male patient, which demonstrates heterogeneous enhancement after intravenous contrast injection. This tumor involves the entire midline, extending anteroposteriorly from the posterior portion of the nasal cavities to the clival area and rostrocaudally down to the nasopharynx at the level of the C1-C2 junction, also invading the left cavernous sinus and reaching the ipsilateral MCF. (*C*) Axial and (*D*) sagittal postoperative magnetic resonance images after an endoscopic endonasal approach, demonstrating the complete removal of the lesion. The arrows indicate the enhancing nasoseptal flap that has been used to reconstruct the skull base defect.

the cavernous sinus and Meckel cave. Sinonasal malignancies such as adenoid cystic carcinomas can infiltrate perineural tissue and use it as a gateway to reach the middle fossa. All these pathologic conditions are examples of diseases in which the endonasal route can facilitate resection without brain retraction.

Anatomic Considerations

To access the MCF through an endonasal corridor, one needs to completely understand the ventral cranial base anatomy.

The sphenoid sinus lateral recess is a pneumatized projection of the sinus under the middle fossa. Once the bone that covers the lateral wall of the sphenoid sinus is removed, the periosteum of the middle fossa is exposed. The meningeal layer of the dura is located lateral to the gasserian ganglion.

Meckel cave is basically a small compartment within the 2 layers of dura mater on the anteromedial portion of the MCF containing the trigeminal (gasserian) ganglion. The limits of the Meckel cave include the periosteal dural layer that covers the MCF bone at its medial and inferior aspect and the dural meningeal layer at its lateral and superior aspect that separates it from the subarachnoid space. From the gasserian ganglion, arise the 3 trigeminal branches: ophthalmic (V1), maxillary (V2), and mandibular (V3) nerves (**Fig. 2**A). The 3 nerves exit the skull through the superior orbital fissure (SOF), foramen rotundum, and foramen ovale, respectively.

The gasserian ganglion guards the MCF medially. While dealing with benign disease, the trigeminal nerve must be preserved. The pathway to reach the MCF from the sphenoid sinus is through the 2 anterior triangles of the cavernous sinus: the anteromedial and anterolateral triangles (see **Fig. 2**B). The anteromedial cavernous sinus triangle is limited superiorly by the ophthalmic branch of the trigeminal nerve (V1), pointing toward the SOF, and inferiorly by the maxillary branch (V2). On the other hand, the anterolateral triangle is enclosed within V2 superiorly and the mandibular branch (V3) inferolaterally. After bone removal, the exploration of these spaces allows the direct exposure of the temporal meningeal dura, which if needed can be followed posteriorly into the lateral component of Meckel's cave or opened laterally into the subarachnoid space.

The concept of the quadrangular space (QS) is important to deal with gasserian ganglion disease or pathologic conditions located medial to it. This "window" is bordered by the sixth cranial nerve (abducens nerve) superiorly, the maxillary branch of the trigeminal nerve (V2) laterally, and the internal carotid artery (ICA) medially and inferiorly (see **Fig. 2**B).[12]

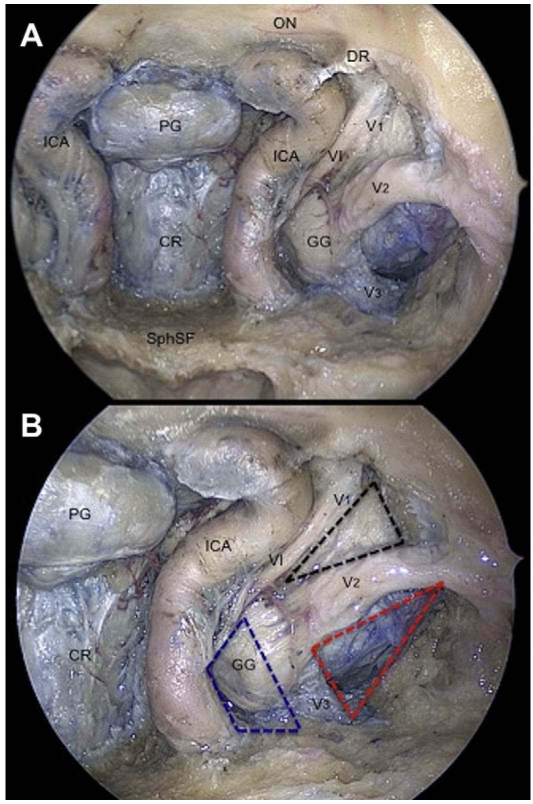

Fig. 2. Cadaveric specimen dissections. (*A*) Panoramic view of a wide opening of the sphenoid sinus with extensive bone removal of the anteromedial wall of the MCF, with exposure of the clival recess (CR), gasserian ganglion (GG) and the 3 trigeminal branches (V1, V2, and V3), internal carotid arteries (ICAs), and pituitary gland (PG). DR, proximal dural ring; ON, optic nerve; Sph SF, sphenoid sinus floor. (*B*) Panoramic view of the anterior left MCF with a 45° endoscope after bone removal. Of particular importance is the quadrangular space (*blue shaded line*), the anteromedial triangle (*black shaded line*), and the anterolateral triangle (*red shaded line*). VI, abducens nerve.

Appreciation of the sixth cranial nerve anatomy is also important for this approach, particularly its trajectory within the cavernous sinus. The sixth cranial nerve pierces the clival dura posterior to the ICA and advances between the dural layers superolaterally toward Dorello canal. Once inside the cavernous sinus, the nerve runs parallel to V1 on its way to the SOF. As the nerve ascends to the SOF, it forms the superior limit of the QS. The abducens nerve must be carefully observed and avoided during the approach to prevent undesirable postoperative sixth nerve palsy.

The medial and inferior aspects of the QS are created by the paraclival (vertical) and petrous (horizontal) portions of the ICA, respectively. Identification of these portions, particularly the paraclival segment, is essential for the proper exposure of the QS. The vidian nerve, formed by the union of the greater superficial petrosal nerve and the deep petrosal nerve, is used as a landmark for identification of the ICA anterior genu, where the petrous ICA turns into paraclival ICA at the foramen lacerum.

Surgical Technique

Preoperatively, computed tomography and magnetic resonance imaging of the head are carried out. Results of both the techniques are combined and fused for comprehensive intraoperative image guidance.

All EEAs are performed with cranial nerve monitoring (using electromyography), with special attention to the third, fourth, motor V3, and sixth cranial nerves ipsilateral to the disease. Also, somatosensory evoked potentials are monitored throughout the surgical procedure.

Once in the operating room, the patient undergoes standard intravenous anesthesia and orotracheal intubation. A 3-pin head holder is placed with a slight neck extension and discreet head rotation to the right and a tilt to the left.

The nasal cavity is decongested with topical 0.05% oxymetazoline; antisepsis is achieved with perinasal and periumbilical povidone solution (in case a fat graft is needed). Intravenous antibiotic, a third- or fourth-generation cephalosporin, is administered at the beginning of the procedure.

The procedure begins with the use of a 0°-lens endoscope. Initially, the inferior turbinates are displaced laterally. Next, the middle turbinate that is ipsilateral to the lesion is removed and its pedicle, a direct branch of the sphenopalatine artery, is identified and coagulated. Constant irrigation with warm saline solution with either an endoscope sheath or a common 60-mL syringe helps to maintain the endoscopic view, avoiding surgical delays.

Before entering the sphenoid sinus, a vascularized flap is elevated for eventual closure of the anticipated skull base defect. A nasoseptal pedicled flap with blood supply from the posterior nasal artery, a branch of the sphenopalatine artery, is elevated from the contralateral side. Once elevated, the flap can be stored in the nasopharynx or in the respective maxillary sinus after an antrostomy, thus still providing the surgeon with direct and detailed visualization of the anterior wall of the sphenoid sinus.

Once the flap is secured, a posterior septectomy is performed to allow the 2-nostrils 4-hands technique. Also, ipsilateral posterior ethmoidectomy and wide anterior sphenoidectomy are performed to improve visualization and achieve an adequate working corridor. Septations within the sinus are then flattened.

The next stage of the approach encompasses the lateral aspect of the ventral skull base. This part of the procedure is based on bone removal and drilling to progressively expose the elements of the QS and middle fossa.

An ipsilateral transpterygoid approach is required, which starts with an uncinectomy and enlargement of the maxillary ostium to obtain an antrostomy. In some patients, removal of the bulla ethmoidalis is necessary for a better operative field view. Within the posterior wall of the maxillary sinus, the distal segment of V2 (infraorbital nerve [ION]) and the terminal branches of the maxillary artery are visualized. Removal of this bony wall provides access to these branches and the PPF. The maxillary nerve (V2) is encountered superiorly and laterally in the PPF.

Next, the terminal branches of the maxillary, posterior nasal, and sphenopalatine arteries are dissected and coagulated. The vidian nerve is also identified, and the surrounding bone is drilled down in an anterior to posterior direction. Whenever possible, the vidian nerve and artery, if present, are transposed from the vidian canal and preserved. These measures allow the surgeon to precisely delineate the path of the vidian canal toward the anterior surface of the petrous carotid at its emergence at the foramen lacerum area. Once the vidian nerve is transposed or sectioned, the soft contents of the PPF are lateralized and the base of the pterygoid plate is drilled, completely exposing the sphenoid sinus lateral recess.

The surgeon then focuses toward the medial and inferior limits of the QS. These limits are represented by the horizontal (petrous) and vertical (paraclival) segments of the ICA. At this stage of the approach, the surgeon should be able to visualize the vidian nerve, V2, and ION laterally. The ipsilateral optic canal, paraclinoid ICA, and lateral optic-carotid recess (LOCR) must be identified. The region that is anterior to the ICA siphon at the paraclinoid area and inferior to the LOCR (optic strut) represents the SOF, which is the superior limit of any approach to the middle fossa. The carotid protuberances, which are bony impressions around the ICA paraclival canals, can be easily recognized in well-pneumatized sinuses.

The entire bone covering the medial aspect of the middle fossa should be drilled, tailoring the specific needs of the pathologic condition. The periosteum of the middle fossa is exposed completely, and the gasserian impression, with all 3 trigeminal branches, is visualized underneath (see **Fig. 2**A). Usually there is no need for complete ICA skeletonization, which is only performed when there is direct disease encasement or in cases in which ICA mobilization or proximal control is required.

Finally, the periosteum can be opened accordingly. In general, there are 3 areas that are initially explored: Meckel's cave and anteromedial and anterolateral cavernous sinus triangles (see **Fig. 2**B).

When the disease is posterior, medial, or directly related to the gasserian ganglion, an incision is made at the QS. The periosteal dural layer overlying its anterior surface is opened, and the lesion can be directly accessed. To avoid abducens nerve injury, its neurophysiology should be used before any incision is performed and the opening should not transgress the level of the superior border of V2. The MCF can also be reached through the anteromedial (between SOF/V1 and V2) and anterolateral (between V2 and V3) triangles, which provide direct access to the subarachnoid space at the temporal fossa. Consequently, tumors such as meningiomas can be resected at that level (**Fig. 3**). Schwannomas are restricted to Meckel's cave and are reached after the periosteum is opened at the QS and the lateral meningeal dura is preserved (**Figs. 4** and **5**). These lesions can even be followed into the PF in selected cases (see **Fig. 4**).

Closure of the dural defect is achieved with the inlay positioning of a collagen sponge, when possible, followed by the positioning of the previously elevated nasoseptal flap, which is secured with Surgicel (Ethicon Inc, A Johnson & Johnson Company, Somerville, NJ, USA) followed by fibrin glue or Duraseal (Covidien, Hazelwood, MO, USA). Merocel (Medtronic Xomed, Jacksonville, FL, USA) packing or Foley balloon is used to buttress the reconstruction. Silastic splints (Doyle Splints, Medtronic, Minneapolis, MN, USA) are used against the denuded septum to avoid synechiae. Antibiotics are given until packing is removed.

Complications

Potential serious complications with this approach largely involve injury to the cranial nerves and ICA. Transient sixth nerve palsy and V1 and/or V2 sensory deficit can occasionally occur when dissection is pursued in the upper portion of Meckel's cave. Difficulties with mastication can also take place when V3 or the undersurface of the gasserian ganglion is manipulated or injured. In addition, some degree of neural impairment cannot be avoided while resecting certain malignant neoplasms, a fact that should be discussed with the patient during the informed consent process.

Major vascular injuries are not expected with this approach. Nevertheless, the risk for such a complication increases in those cases in which there is ICA involvement or entrapment by the neoplastic process or in cases in which ICA dislocation is required for effective disease removal. Even in these cases, low vascular injury rates can be expected if the surgeon follows basic microneurosurgical principles, uses a detailed knowledge of the vascular anatomy, and carefully manipulates the important neurovascular structures as little as absolutely necessary.

In general, cerebrospinal fluid (CSF) leaks were a major source of complications during the early days of endoscopic endonasal skull base surgery. This risk is markedly lower for the MCF approaches because these approaches generally do not create high-flow leaks. The vascularized mucosal reconstruction technique is ideal to cover the skull base defect and exposed ICA, preventing both CSF leak and ICA adventitia desiccation.

POSTERIOR FOSSA

There are several neurosurgical approaches that can be used for resection of tumors in the PF. Lesions located posterior to the brainstem, including those involving the fourth ventricle, are clearly better accessed through posterior approaches. For example, supracerebellar infratentorial approach is adequate for lesions at the quadrigeminal and cerebellomesencephalic cisterns.[17] Similarly, the suboccipital approach is acceptable for lesions in the posteroinferior compartment of the PF, and telovelar dissection provides excellent exposure for the lesions located superiorly inside the fourth ventricle.[18,19]

Similarly, the posterolateral approaches offer a more comfortable surgical corridor for lesions lateral to the brainstem. The retrosigmoid approach is appropriate for lesions in the cerebellomesencephalic and cerebellopontine cisterns.[19] The far lateral approach is adequate for lesions located at the cerebellomedullary cistern.[20,21]

Thus, transcranial approaches still represent the approach of choice for many masses of the PF. Alternatively, the traditional lateral skull base approaches are not ideally suited for lesions located ventral to the brainstem. Before the development of EEAs, ventrally located lesions of the PF were exposed using complex and often morbid procedures such as the transoral approach, the presigmoid approach,[22] anterior and posterior petrosectomies with or without labyrinthectomy,[22,23]

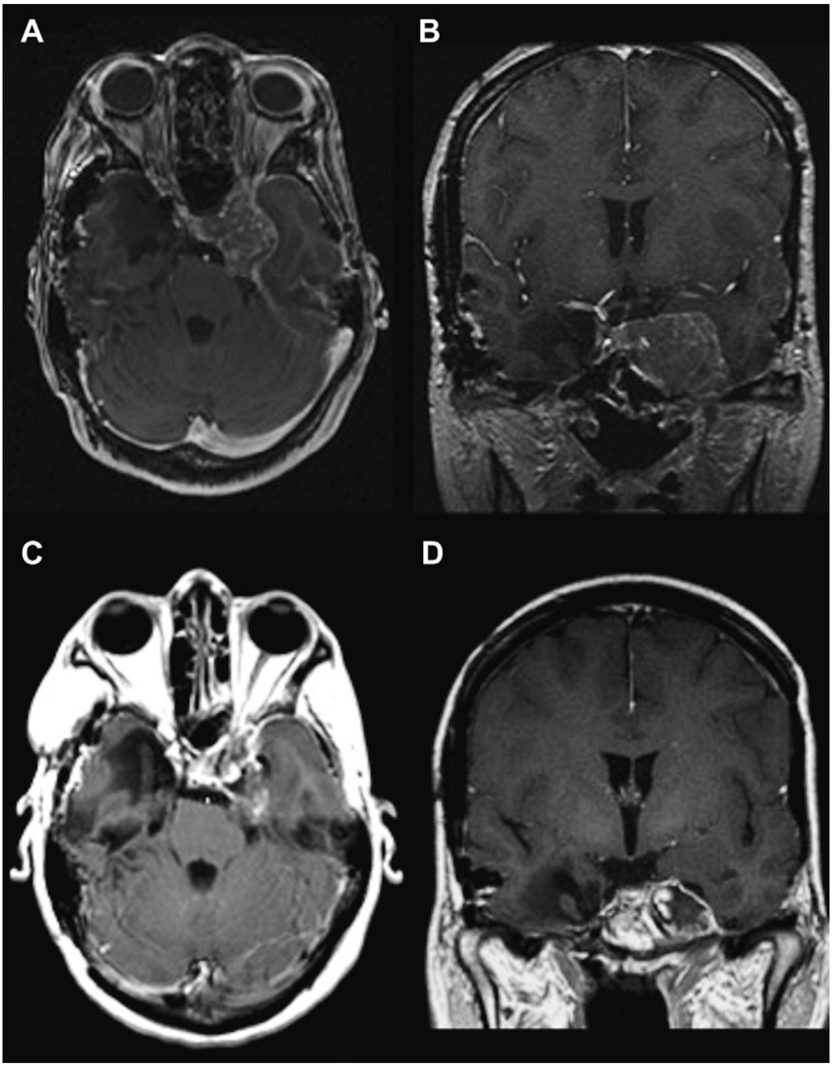

Fig. 3. (*A*) Axial and (*B*) coronal preoperative magnetic resonance images showing a left cavernous sinus tumor in a 34-year-old female patient, consistent with the diagnosis of meningioma. This lesion, which presents a poor hyperintense signal, occupies the entire left cavernous sinus. The lesion extends laterally to the MCF, inferiorly up to the infratemporal fossa, and anteriorly to the orbital apex without invading it. (*C*) Axial and (*D*) coronal postoperative magnetic resonance images after an endoscopic endonasal approach to the middle fossa through the lateral recess of the sphenoid sinus, demonstrating the near total resection with cavernous sinus residual tumor and temporal lobe decompression. On both the preoperative and postoperative images, the right temporal lobe encephalomalacia from a previous craniotomy that was performed elsewhere could be noted.

the extreme lateral approach.[24–26] Often, these approaches provide a limited dissection corridor and force the surgeon to work in the small windows between the cranial nerves, often leading to significant cranial nerve morbidity. Hence, the EEAs provide an ideal alternative to approaching tumors involving the ventral PF, in particular, those with a major component ventral to the brainstem and/or to the lower cranial nerves.[11,14] By using a direct anterior approach, the EEAs allow the surgeon to work in a large window, to work between and not past the cranial nerves, and to devascularize the tumor early in the case, which is not possible using the lateral approaches.

Indications

To determine whether an EEA is an appropriate choice, it is important to identify the center and extent of the tumor's bony and/or dural attachments. The portion of the tumor to be resected should be ventral to the brainstem and medial to the cranial nerves. For lesions in the intrapeduncular cistern, the tumor should be medial to the third

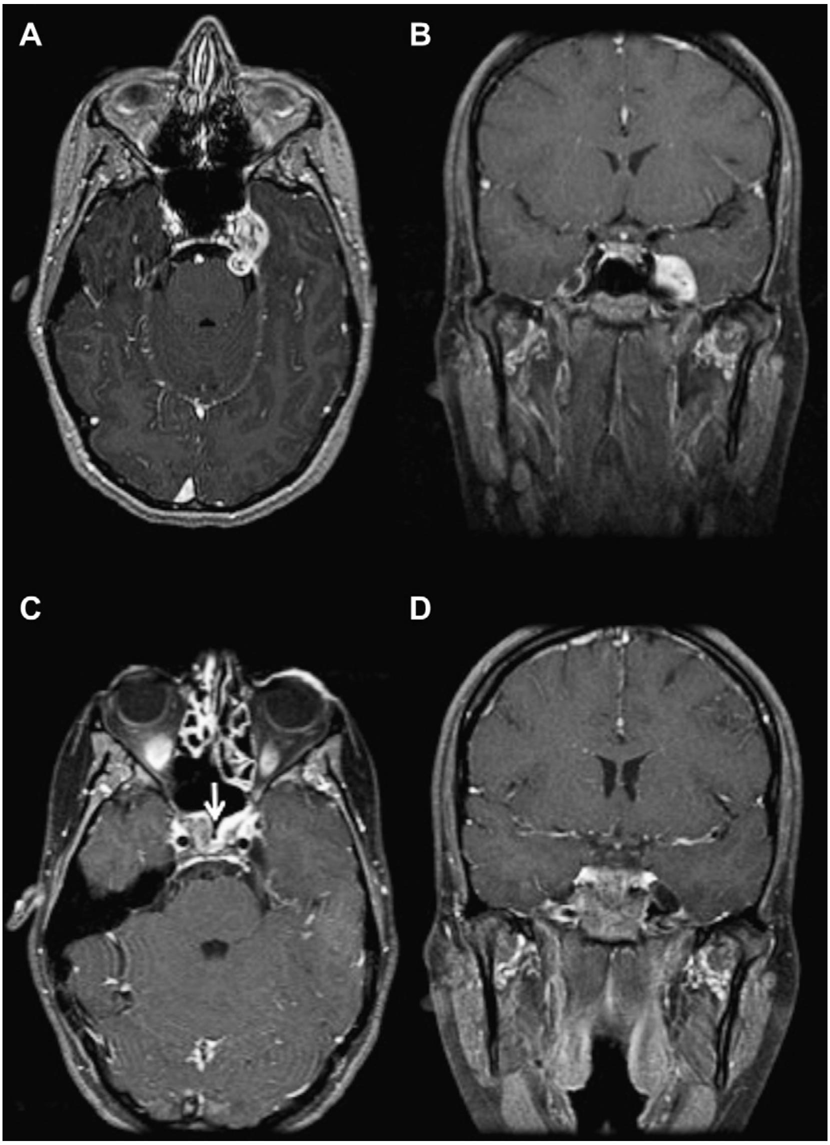

Fig. 4. (*A*) Axial and (*B*) coronal preoperative magnetic resonance images showing a left Meckel's cave schwannoma in a 20-year-old female patient. This lesion, which presents a heterogeneously low to intermediate signal, occupies the inferior cavernous sinus compartment with PF projection. (*C*) Axial and (*D*) coronal postoperative magnetic resonance images after a Meckel's cave endoscopic endonasal approach through the lateral recess of the sphenoid sinus, demonstrating total removal of the lesion.

cranial nerve. For lesions in the prepontine cistern, the tumor should be medial to the sixth cranial nerve. For lesions in the premedullary cistern, the tumor should be medial to the hypoglossal nerves.

The transclival approach can be used for either extradural or intradural lesions of the PF. Chordomas and chondrosarcomas are examples of lesions that can be purely extradural; however, these lesions may often have an intradural component (**Fig. 6**). Alternatively, meningiomas and neurenteric cysts are lesions that mainly occur intradurally in the PF. Some tumors such as craniopharyngiomas and some pituitary adenomas can also descend from the sellar and suprasellar areas and require an endonasal transclival approach for complete resection.

The main advantage of an endonasal route for appropriate lesions is that in these approaches, the vital structures are located lateral to the tumor and there is no need for neural tissue retraction or dissection in between cranial nerves. Frequently, the nerves and perforating arteries are pushed

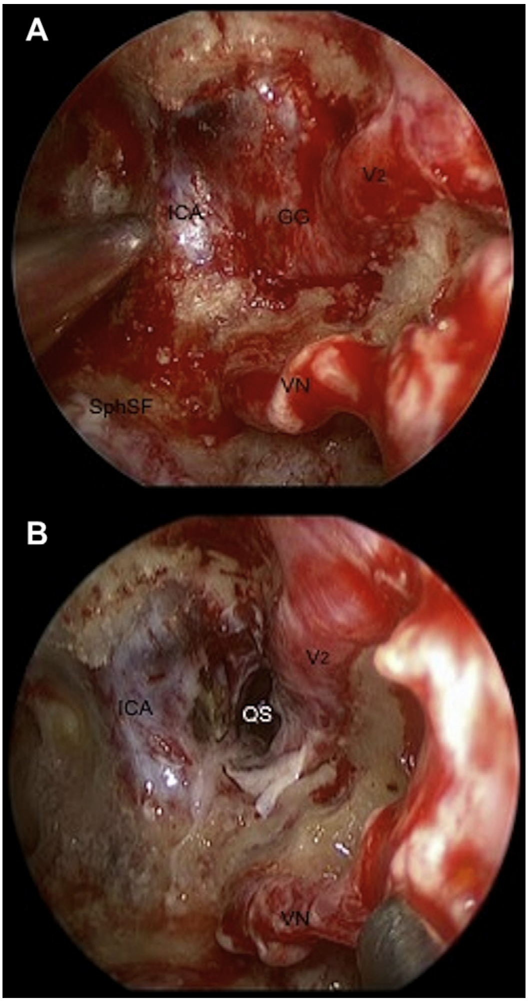

Fig. 5. Intraoperative view of an endoscopic endonasal approach to the MCF for a trigeminal schwannoma. (*A*) Bone removal in the ventral cranial base with exposure of the gasserian ganglion (GG), ICA, and maxillary nerve (V2). The relation of the vidian nerve (VN) and the sphenoid sinus floor (Sph SF) to the ICA can be observed. (*B*) Intraoperative view at the end of the tumor resection through the QS.

away by the tumor, which allows direct visualization and safe tumor debulking. Furthermore, these approaches devascularize durally based lesions, such as clival meningiomas, during the tumor exposure, allowing most of the dural origin of these lesions to be resected early in the case and providing a more thorough tumor resection (**Fig. 7**).

Anatomic Considerations

The clivus can be divided into 3 portions along its rostrocaudal axis (**Fig. 8**). The upper third includes the dorsum sellae and posterior clinoids down to the level of the sellar floor. The middle third extends from the lower extent of the sella down to the sphenoid floor. The lower third extends from the sphenoid floor to the foramen magnum.

Each third of the clivus has a respective subarachnoid anatomy that can be analyzed in 3 different modules.

Upper third of the clivus

The rostral extension of the superior portion of the clivus is bound by the dorsum sellae in the midline and the posterior clinoids in the paramedian region.

It is important to understand that 2 layers of dura cover the inner side of the sella: the periosteal and the meningeal layers. These layers are found only where there is bone; indeed, the sella has 2 layers in the face, floor, and back wall, between which run the venous channels that communicate both cavernous sinuses, such as the superior, inferior, and posterior intercavernous sinuses (PIS), respectively. The sella has only a single meningeal layer laterally separating it from the cavernous sinus. This concept is important when performing a pituitary transposition, in which the capsule of the gland should not be transgressed and the pituitary ligaments should be detached from the medial cavernous sinus wall. This way, the pituitary gland can be transposed superiorly.

The PIS is located behind the pituitary and is exposed once the gland is elevated. The dorsum sellae is posterior to the PIS. The clival dura harboring the basilar venous plexus is also posterior to the dorsum sellae. Dural opening at that level exposes the interpeduncular cistern guarded laterally by Liliequist membrane and the posterior communicating arteries, the respective perforating arteries, and the third nerves. Posteriorly, the mesencephalon, the basilar bifurcation, the posterior cerebral arteries, and the superior cerebellar arteries limit the area. Inferiorly, the area is bound by the inferior horizontal lamina of Liliequist membrane (**Fig. 9**A).

Middle third of the clivus

The bony aspect of this region is limited superiorly by the sellar floor and inferiorly by the sphenoid rostrum, which is found at the level of the sphenoid floor in well-pneumatized sphenoid sinuses. Laterally, the ICA paraclival protuberances limit the area. Once the bony structures are removed, the clival dura is exposed with the basilar venous plexus within. It is important to understand that a segment of the sixth cranial nerve's pathway is between the 2 layers of clival dura just before reaching Dorello's canal.

Intradurally, the prepontine cistern is found with the bilateral sixth cranial nerves limiting the space

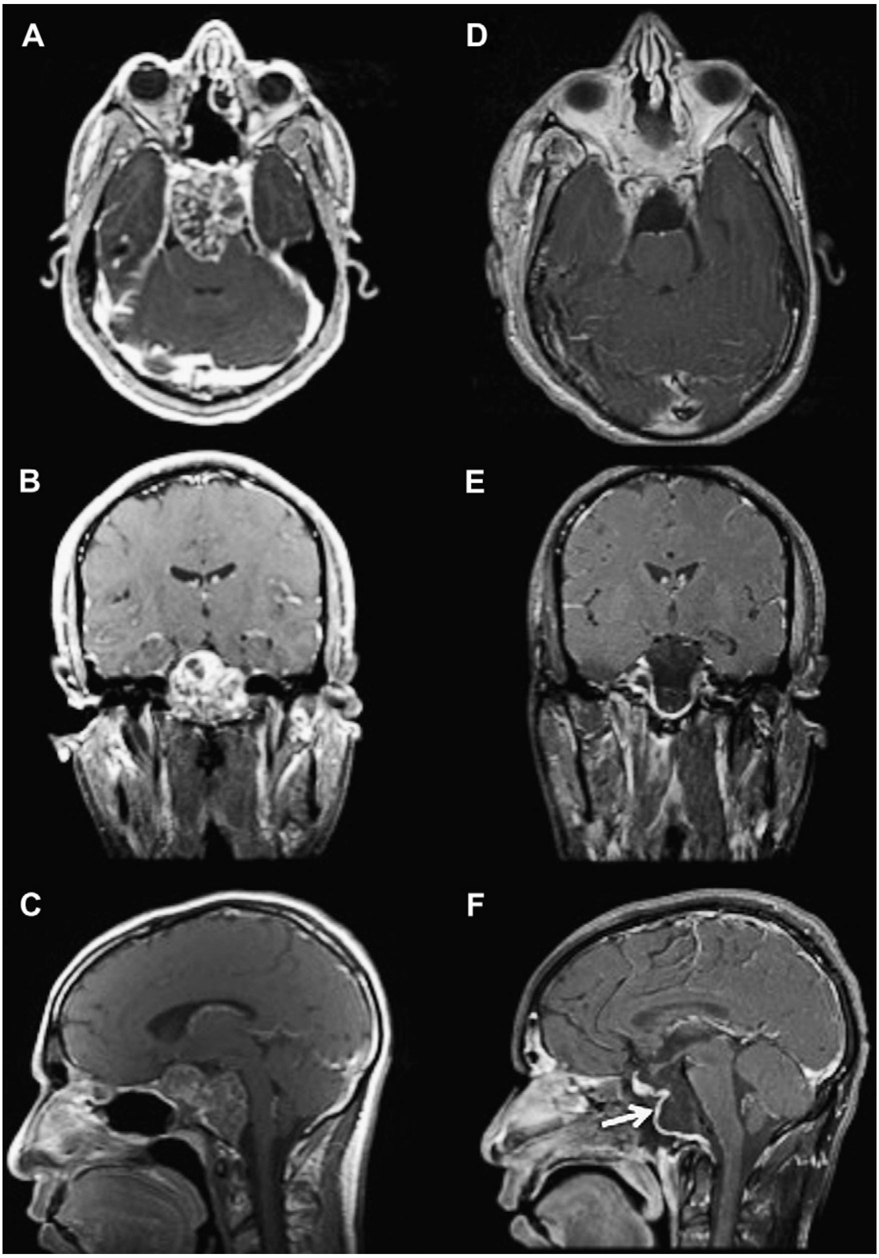

Fig. 6. (*A*) Axial, (*B*) coronal, and (*C*) sagittal preoperative magnetic resonance images showing a large recurrent clival chordoma in a 27-year-old male patient. This heterogeneously hyperintense lesion involves the entire clival area, with posterior dislocation of the pons, lateral extension up to both petrous apexes, and invasion of the cavernous sinuses. (*D*) Axial, (*E*) coronal, and (*F*) sagittal postoperative magnetic resonance images after an endoscopic endonasal approach to the clival area, demonstrating the complete removal of the lesion. The arrow shows the enhancing nasoseptal flap that has been used to reconstruct the skull base defect.

laterally. Posteriorly, the pons is seen with the basilar artery and its branches, including the anteroinferior cerebellar artery (see **Fig. 9**B). The inferior limit of this space is the pontomedullary junction and the vertebrobasilar junction (VBJ).

Inferior third of clivus

The inferior third of the clivus encompasses the anterior aspect of the foramen magnum inferiorly. The superior border is at the sphenoid rostrum junction at the level of the floor of the sphenoid

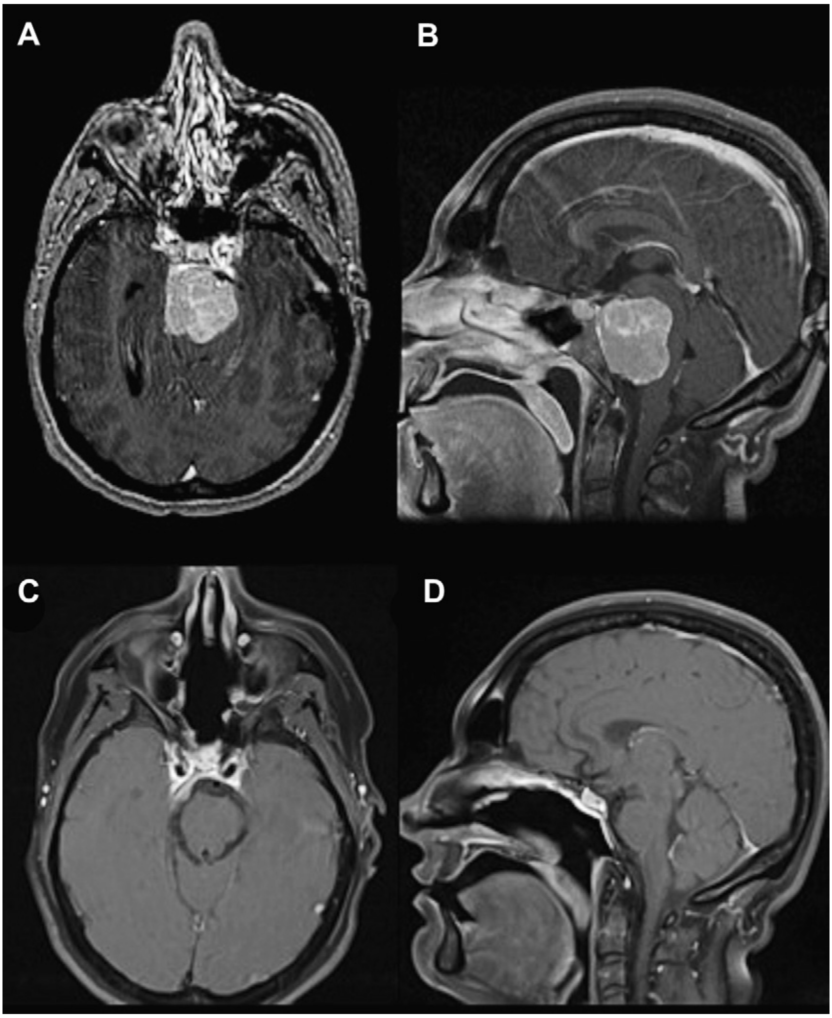

Fig. 7. (*A*) Axial and (*B*) sagittal preoperative post contrast-enhanced T1-weighted magnetic resonance images showing a clival meningioma in a 32-year-old female patient. The lesion appears slightly enhanced after intravenous contrast injection and is located posterior to the clivus mostly on the midline. Dural attachment on the right tentorial edge can also be seen. (*C*) Axial and (*D*) sagittal postoperative magnetic resonance images after an endoscopic endonasal approach to the clival area, demonstrating the complete removal of the lesion.

sinus. Bilaterally, the inferior third of the clivus is not limited directly by the ICA as in the middle third, and thus, further lateral dissection can be safely pursued.

The petroclival synchondrosis is present laterally and can be followed all the way to the jugular foramen. The occipital condyles are positioned in the anterior portion of the foramen magnum and limit the amount of lateral exposure at the inferior part of the clivus. When medial condilectomy is performed to augment the lateral exposure to include the subarachnoid origin of the vertebral artery, the lateral limit is the twelfth cranial nerve traveling inside the hypoglossal canal.

Intradurally, the inferior third of the clivus approaches the premedullary cistern, with the medulla located posteriorly. Superiorly, the limit is at the pontomedullary junction, which generally coincides with the VBJ (see **Fig. 9**C). Consequently, the sixth cranial nerve is not considered at risk at this level. On the other hand, if lateral extension through the condyle is performed, the twelfth cranial nerve limits the approach laterally. If a supracondylar approach is extended through the jugular tubercle, direct exposure of the ninth, tenth, and eleventh cranial nerves is obtained, guarding the cistern laterally.

Surgical Technique

The initial steps of the approach are the same as described for the MCF. However, once the

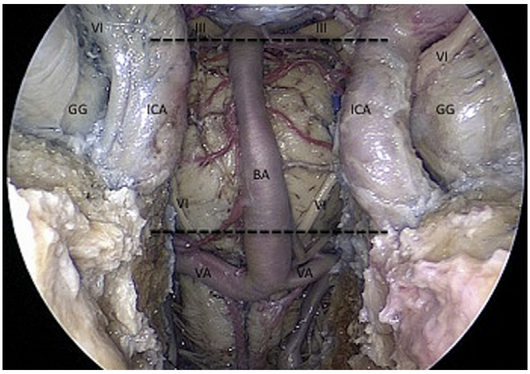

Fig. 8. Panoramic view of a panclivectomy performed on a cadaveric specimen. The boundaries between the upper and middle and the middle and lower thirds of the clivus (*dashed lines*) are visible. BA, basilar artery; GG, gasserian ganglion; VA, vertebral artery; III, oculomotor nerve; VI, abducens nerve.

sphenoid sinus is exposed, a few different steps are necessary to achieve a complete exposure of the clivus, which can be didactically divided into 3 portions based on the clival segments.

Superior third (pituitary transposition/transdorsum sellae)

The surgeon should have a direct view of the sellar protuberance, bilateral ICA impressions, optic canals and optic-carotid recesses, and the clival recess. The bone covering the sellar face is removed to expose the superior intercavernous sinus (SIS), inferior intercavernous sinus (IIS), and the sella-clival junction. Cruciform dural openings are performed above the SIS and on the face of the sella, with care not to transgress the pituitary capsule. After SIS ligation, the dural openings are connected, and the diaphragm is opened all the way to the central aperture to free the pituitary stalk. The ligaments connecting the pituitary capsule to the medial cavernous sinus wall are systematically cut along the lateral contour of the gland. The gland may be mobilized superiorly, enabling exposure of the posterior sellar dura, which is coagulated, and the PIS is transected exposing the dorsum sellae and posterior clinoids.[27] These bony structures are then drilled until eggshell thickness and carefully removed avoiding injury to the ICA and third and sixth cranial nerves. Once these structures have been drilled, the retroclival dura harboring the basilar plexus is visualized. Transgressing the basilar plexus can generate intense venous bleeding, which can be controlled with hemostatic agents such as microfibrillar collagen and absorbable gelatin powder with thrombin.

Intradurally, the dissection follows standard microneurosurgical principles. Tumor debulking should precede extracapsular dissection. Tumors in this location can be firmly attached to the branches of the superior hypophyseal artery, which should be preserved. The basilar apex and perforators are usually pushed posteriorly and attached to tumor capsule. Laterally, the third cranial nerve and the posterior communicating artery with its perforator branches can be densely attached to the capsule and should be dissected carefully (see **Fig. 9**D). Extracapsular dissection should be performed sharply under direct visualization. Craniopharyngiomas can invade the third ventricle, and, consequently, tumor removal can lead the dissection into the ventricle. Care should be taken with the lateral hypothalamic walls and mamillary bodies in these situations. Tumors of the interpeduncular cistern usually push the inferior horizontal lamina of Liliequist membrane downwards, and its preservation helps to decrease subarachnoid blood dissemination to other cisterns.

Middle third (clival recess of sphenoid sinus)

The middle third of the clivus is mostly accessed directly. In well-pneumatized sphenoid sinus, the middle third of the clivus can be a very thin bone forming the deep aspect of the clival recess of the posterior sphenoid sinus. However, rarely the approach is limited to this segment of the clivus, and it is generally combined with the approach for the inferior third of the clivus or with a panclivectomy.

The clival bone is drilled, and the dura and basilar plexus are exposed. Laterally, the approach is limited by the paraclival ICAs, which constrain the approach, particularly in cases in which the disease is located immediately behind the ICA. This is often the case with chordomas and petroclival meningiomas. In such situations, there is a need for further exposure; the ICA canals should be drilled and the periosteum exposed to allow ICA mobilization and better exposure of the anterolateral PF compartment (**Fig. 10**). An important landmark for this exposure is the vidian nerve. The vidian nerve points toward the anterior genu of the ICA, at the level of the foramen lacerum, and helps to identify the petrous ICA in nonpneumatized sphenoid sinuses and/or cases in which the anatomy is deformed by disease. Thus, the ICAs can be mobilized laterally, allowing retrocarotid visualization and dissection.

After meticulous coagulation, the underlying dura is opened at the midline. Neurophysiology and nerve stimulation should be used to identify a sixth cranial nerve that could have been displaced by the tumor. Petroclival

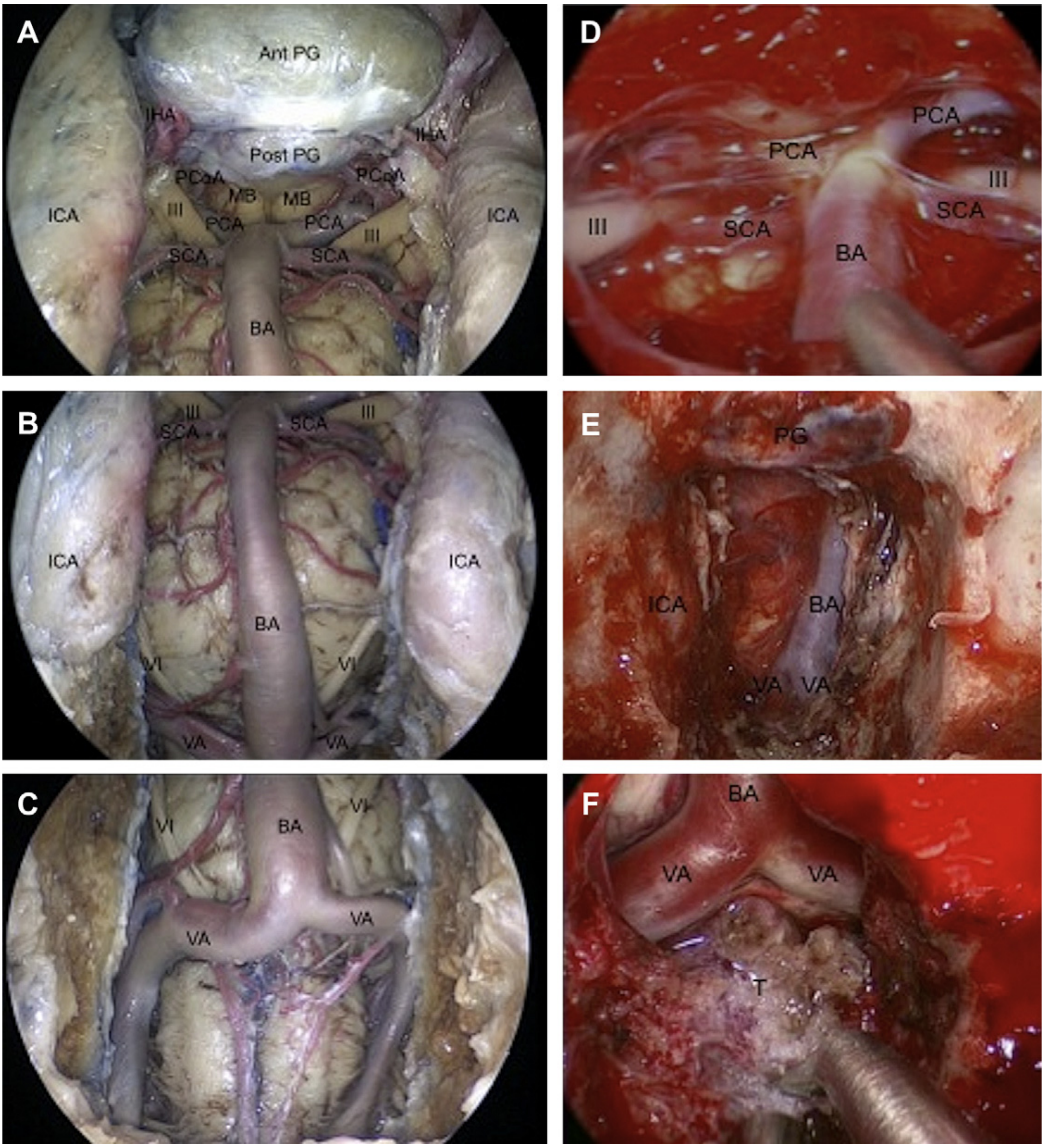

Fig. 9. Cadaveric specimen dissections. (*A*) View of the upper third of the clivus with a 45° endoscope. Ant PG, anterior pituitary gland; BA, basilar artery; IHA, inferior hypophyseal artery; MB, mamillary body; PCA, posterior cerebral artery; PCoA, posterior communicating artery; Post PG, posterior pituitary gland; SCA, superior cerebellar artery; III, oculomotor nerve. (*B*) View of the middle third of the clivus with a 0° endoscope. VA, vertebral artery; VI, abducens nerve. (*C*) View of the lower third of the clivus with a 0° endoscope. Intraoperative views of the endonasal approach to the (*D*) upper third of the clivus, (*E*) middle third of the clivus, and (*F*) lower third of the clivus. T, tumor (meningioma).

meningiomas can displace the sixth cranial nerve medially toward the midline. Image guidance should also be used under computed tomography angiogram visualization to determine the location of the VBJ. Dural opening is performed below the VBJ to assure that the sixth cranial nerve origin at the brainstem remains above.[14]

When performing posterior extracapsular dissection, one must consider the position of the basilar artery and its branches as well as their relationship with the pons (see **Fig. 9**E).

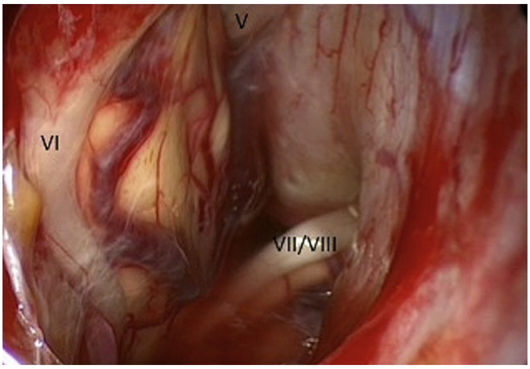

Fig. 10. Lateral view of the brainstem and cranial nerves from a 45° endoscope after resection of a chordoma invading the PF. The left fifth (V) and sixth (VI) cranial nerves as well as the seventh and eighth nerve complex (VII/VIII) are seen.

Inferior third

Initially, the nasal septum is detached from the anterior surface of the sphenoid bone. Extensive mucous removal is necessary for satisfactory exposure of bony landmarks. The basopharyngeal fascia is then stripped from the sphenoid rostrum and clival bone. Next, the sphenoid sinus floor is completely drilled down to the clival dura.

The procedure continues with careful and progressive drilling of the anterior surface of the clivus down to the foramen magnum. Kerrison rongeurs can also be used once the bone has been drilled down to an eggshell thickness. The amount of dural exposure and whether or not the dura itself is opened depends on the nature of the lesion, each approach being tailored to the patient's needs. Because the dura is opened, the medulla is the posterior limit of dissection, and the vertebral arteries must be identified before beginning extracapsular dissection (**Fig. 9**F).

In cases in which there is tumor extension laterally at the level of the lower third of the clivus, further lateral dissection is required. This dissection can conceptually be divided into 3 parts from superior to inferior below the level of the petrous ICA:

1. Infrapetrous (petrous bone below the ICA is removed)

   The area of the foramen lacerum should be exposed, and the dense fibrous tissue connections with eustachian tube should be transected. The infrapetrous bone is drilled under V3 and below the petrous ICA.

2. Supracondylar or transjugular tubercle approach (occipital bone medial to the petroclival synchondrosis and above the occipital condyle is removed)

   As the dissection follows the petroclival synchondrosis inferiorly, ninth, tenth, and twelfth cranial nerves should be investigated with neurophysiology monitoring.

3. Transcondylar (medial condylectomy is performed)

   The hypoglossal nerve is the lateral limit; once again neurophysiology monitoring is essential. This lateral extension allows for identification of the proximal aspect of the vertebral artery.

Finally, reconstruction of the cranial defect is achieved with inlay collagen matrix, followed by the pedicled vascularized flap. Occasionally, a foramen magnum exposure cannot be totally covered by the nasoseptal flap. In these situations, reconstruction augmentation is necessary and can be usually obtained with fat graft and/or Alloderm (LifeCell Corp, Woodlands, TX, USA). The reconstruction is then buttressed with Merocel packing or Foley balloon. Silastic splints are used against the denuded septum to avoid synechiae. Antibiotics are given until packing is removed. Rarely, a lumbar drain is placed. However, the lumbar drain is often installed for obese patients, for high flow leaks, and/or in situations with hemorrhage into the subarachnoid space.

Complications

As in the EEA to the MCF, cranial nerves pose a major source of potential complications in EEAs to the PF. Specifically at risk are the third cranial nerve in approaches to the superior third of the clivus, the sixth nerve in approaches to the middle third, and the twelfth cranial nerve in approaches to the inferior third. Meticulous dissection and detailed knowledge of the course of the sixth cranial nerve from the PF to the SOF is mandatory to avoid palsies. Continuous nerve monitoring can be helpful in identifying and avoiding the nerve, especially when dealing with extensive clival deformities caused by tumor growth.

Because the ICA is generously exposed, and even at times manipulated, there is a potential risk for vascular injuries. Once again, anatomic knowledge and a proper surgical technique are the surgeon's best allies to avoid these highly undesirable events.

CSF leaks were a major source of complications during the early days of endoscopic endonasal skull base surgery. Nevertheless, with the introduction and refinement of the pedicled nasoseptal flaps and other vascularized alternative reconstructions,[28–33] the incidence of CSF leaks and postoperation-related morbidity has decreased dramatically, rendering the technique feasible and safe in experienced hands.

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