Endoscopic Cranial Base Surgery: Ready for Prime Time?

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Paradigm shifts, such as changes in the standard way to diagnose or treat diseases in medicine, create controversy. The process of medical evolution must secure the maintenance of human health. Innovations are useless if not based on principles with practical application. Consequently, medical paradigm shifts are often slow, with initial bricks correctly laid so that additional bricks can be properly added on top.

The succeeded evolution of any new procedure necessitates four natural phases or steps: feasibility, safety, efficacy, and generalizability.[39,46] Endoscopic cranial base surgery is a novel surgical procedure that is in the middle of this process.

FEASIBILITY

The feasibility of accessing the entire ventral cranial base transnasally and endoscopically can prove daunting. The field of endoscopic cranial base surgery has, nevertheless, emerged based on the historical foundation of sinonasal and transsphenoidal surgery and progressive advances in technology.

Historical Foundation and Advances in Technology

Combining Walter Messerklinger's understanding of the sinonasal pathophysiology[47] with Hopkins' development of the rod lens systems in the 1960s helped establish the place of endoscopes in sinonasal surgery.[17] Techniques spread, and the treatment of medically refractory sinusitis through antrostomies was refined by Reynolds and Brandow.[49] In 1985, Kennedy et al.[36] coined the term "functional endoscopic sinus surgery" and Kennedy, along with Heinz Stammberger[50] and Wolfgang Draf,[18] popularized the use of modern endoscopy for paranasal sinus disease in the 1980s.[17]

The evolution of the transsphenoidal surgery for the treatment of pituitary disease exemplifies how technological advances can influence a technique's progression. After 15 years of toil, Harvey Cushing abandoned the transsphenoidal approach in 1927 partially because of an inability to properly illuminate the surgical field.[17,43] Norman Dott, a Cushing disciple, persisted and implemented a lighted speculum as an important technological aid for transsphenoidal visualization.[17,43] Gerard Guiot, a Dott apprentice, added additional technology in the form of intraoperative fluoroscopy, which he subsequently taught to Jules Hardy.[17,43] In an attempt to improve visualization, Guiot in 1963 was the first neurosurgeon to use the endoscope for transsphenoidal surgery.[7,17,25] Endoscopes, however, were inadequate at that time, and Jules Hardy finally established the transsphenoidal route in 1967, incorporating the operating microscope.[7,17,43,44] Since then, the microscopic transsphenoidal route has been the standard approach to lesions confined to the sella turcica.

In late 1970s, Apuzzo et al.[1] as well as Bushe and Halves[2,26] reintroduced the endoscope as an adjunct to the microscope for pituitary lesion resection. Endoscopically "assisted" transsphenoidal microsurgery has since been reported by various authors, stressing the advantages of visualization around corners, particularly for tumors that extend beyond the sella.[10,14,16,20,22,23] The endoscope, however, frequently restricts the working space and maneuverability of the instruments within the speculum when the microscope is the primary means of visualization.[10,14,16,20,22,23] This limitation has led to a fully endoscopic, nonspeculum endonasal approach to the ventral cranial base.

The partnership between neurosurgeons and otolaryngologists allowed for the endoscope to be used as the only visualizing tool for transsphenoidal pituitary surgery in the early 1990s.[17] In 1992, Jankowski et al.[28] reported three cases using a pure endoscopic trans-ethmoidal-sphenoidal approach to the sella. Carrau et al.[9] pursued a purely endoscopic endonasal approach to the pituitary fossa described in 1996.[9,29,42] Paolo Cappabianca and Enrico de Divitiis introduced the term "functional endoscopic pituitary surgery"[3] and developed appropriate surgical instrumentation.[3,4,12,13] As a natural progression, various centers around the world subsequently started to perform purely endoscopic approaches to the sella.[17]

At the same time the endoscope was being introduced for transsphenoidal approaches to the sella, the extended transsphenoidal approach was being developed by Edward Laws, Daniel Kelly, William Couldwell, and Martin Weiss.

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These individuals demonstrated the feasibility of gaining access beyond the sella and in particular to the midline anterior cranial base using the microscope as the primary visualization tool.[14,19,20,30,37,40,41]

In late 1997, at the University of Pittsburgh, we began to pursue the expanded fully endonasal purely endoscopic approach to the ventral cranial base in a systematic fashion. Working with a team of otolaryngologists and neurosurgeons during the past 9 years, more than 700 patients have undergone endoscopic cranial base procedures. We have approached this task in a stepwise fashion beginning with the sella and then expanding our experience along the midline in a set of defined anatomic modules from the crista galli through the odontoid. We then moved laterally to learn to access, in a modular fashion, the parapharyngeal petrous and the paraclival carotid arteries, the jugular foramen, the infratemporal region, and the cavernous sinuses.

Modularity of Approaches and Anatomic Relationships

Although cranial base anatomy has been well described, its ventral appearance is not commonly appreciated during standard surgeries. Thus, the most important step in developing endoscopic cranial base surgery skills is familiarization with endoscopic ventral cranial base anatomy. The modular approach to learning the various expanded endonasal approaches is based entirely on a thorough understanding of this anatomy.

All approaches are initiated with a wide sphenoid sinus exposure, which permits the surgeons to maneuver the endoscope and instruments. For all endonasal cranial base procedures, the sphenoid sinus represents a vestibule that serves as an entryway providing access for all expanded approaches.

Sagittal Plane

Transsellar Approach

The transsellar approach is not considered an expanded approach because it is limited to exposing the sella turcica. During this approach, the surgeons initially drill the anterior wall of the sella to expose laterally from cavernous sinus to cavernous sinus and sagittally from the tuberculum sellae to the clivus (*Fig. 9.1*). Wide exposure provides adequate space for intrasellar dissections. The dura is incised and intrasellar disease is resected. The most common indication for this approach is a pituitary adenoma. Purely intrasellar craniopharyngiomas and Rathke cleft cysts are also frequently encountered.

Transplanum Approach

The transplanum approach is indicated for lesions involving both the posterior aspect of the anterior cranial base and the suprasellar region and involves drilling and removal of the planum sphenoidale and the tuberculum sellae. This approach is usually combined with the transsellar approach. The most important neural structures identified during this approach are the optic nerves. The optic canals can often be visualized as they assume a posterior medial trajectory in the orbital apex. Their identification can be facilitated by identifying initially the lateral optic-carotid recess (OCR) at the level of the optic strut and then the medial optic-carotid recess (OCR) just medial to the internal carotid artery (ICA) at the point it bends posteriorly to exit the cavernous sinus (*Fig. 9.1*). The optic nerves mark the lateral limits of the transplanum approach (*Fig. 9.2*). Anteriorly, the bony resection is limited to the level of the posterior ethmoidal artery. Anterior extension from this point involves the cribriform plate and the olfactory fibers, which consequently may result in loss of olfaction if transgressed.

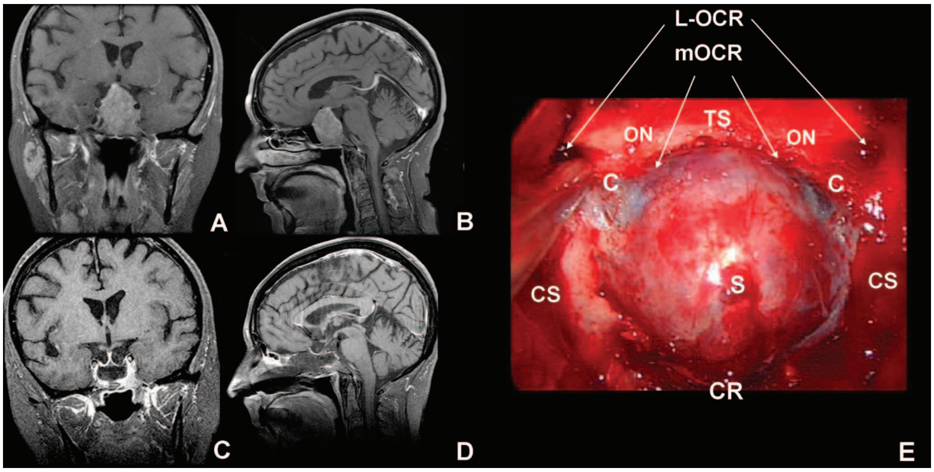

FIGURE 9.1. Transsellar approach. *A* and *B*, magnetic resonance imaging (MRI) scans with contrast showing preoperative images of a macroadenoma (*A*, coronal; *B*, sagittal). *C* and *D*, postoperative MRI scans demonstrating complete resection of the lesion (*C*, coronal; *D*, sagittal). *E*, intraoperative photograph of the face of the sella (*S*) after ample exposure from cavernous sinus (*CS*) to CS laterally and from the tuberculum sellae (*TS*) to the clival recess (*CR*) longitudinally. The bony landmarks of the ICA (*C*) and the optic nerve (*ON*) bilaterally can be seen; L-OCR, lateral OCR; mOCR, medial OCR.

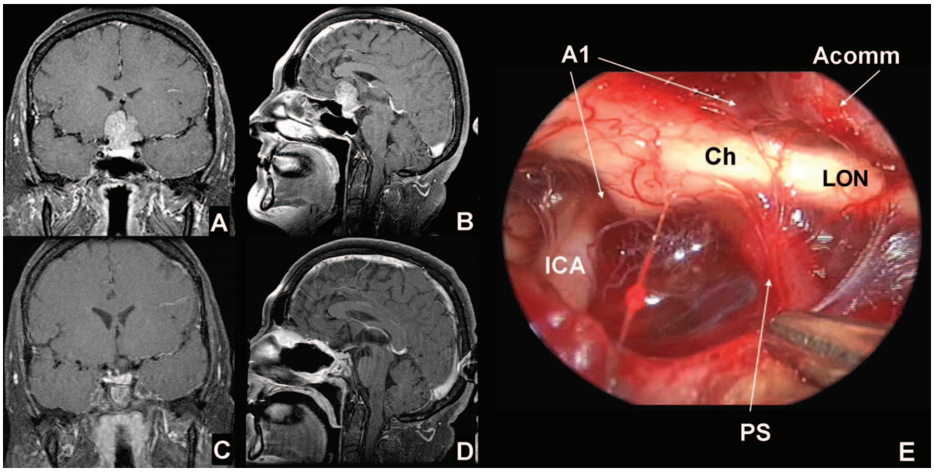

FIGURE 9.2. Transplanum approach, *A* and *B*, MRI scans with contrast showing preoperative images of a tuberculum sellae meningioma (*A*, coronal; *B*, sagittal). *C* and *D*, postoperative MRI scans demonstrating complete resection of the lesion (*C*, coronal; *D*, sagittal). *E*, intraoperative photograph of the suprasellar region during the resection of a tuberculum sellae meningioma showing the chiasm (*Ch*), left optic nerve (*LON*), the pituitary stalk (*PS*), the ICA in the right side and its anterior cerebral branch in its proximal segment (*A1*). The anterior communicating (*Acomm*) complex is also shown.

Transcribriform Approach

This module extends from the rostral extension of the previous approach to the level of the crista galli. Following the transplanum module, the transcribriform approach can be initiated by resecting the attachment of the anterior portion of the nasal septum to the cranial base. The frontoethmoidal recess is identified and the cranial base is drilled in a rostral-to-caudal direction. The anterior ethmoidal arteries are identified and coagulated to provide for tumor devascularization. The olfactory sulcus extends on both sides of the crista galli, from the cribriform plate rostrally to the anterior margin of the planum caudally. The cribriform plate is removed bilaterally, leaving the crista galli in the midline. This structure can be particularly prominent in the case of olfactory groove meningiomas secondary to hyperostosis. Removal of the crista galli involves additional drilling. The limits of this module are both laminae papyracea laterally, the frontal sinus anteriorly, and the transition with the planum sphenoidale posteriorly. Commonly, a transcribriform approach is associated with a transplanum approach for resection of anterior fossa meningiomas. Although the cribriform exposure damages olfaction, it is likely that olfaction has already been compromised by the disease in question (*Fig. 9.3*).

Transclival Approach

The clivus can be divided into a superior and inferior portion, each containing key anatomic landmarks. In its superior portion, the rostral extension is bounded posteriorly by the dorsum sellae in the midline and the posterior clinoids in the paramedian region. Removal of these structures provides access to the basilar artery and interpeduncular cisterns. The dorsum sellae and posterior clinoids can be removed either intradurally via a transsellar approach or extradurally via a subsellar approach by first performing a pituitary transposition that allows for posterior access.

To gain progressively caudal access, the nasal septum needs to be completely detached from the sphenoid rostrum. The floor of the sphenoid sinus represents the superior ex-

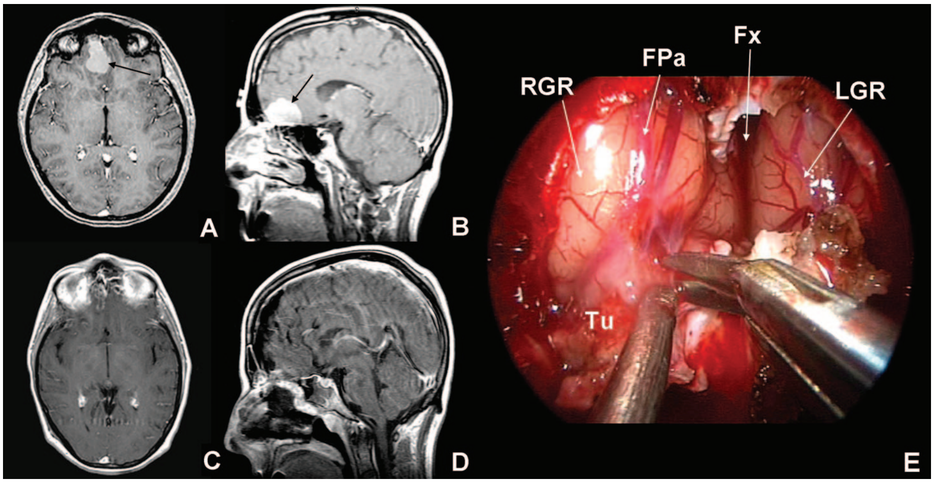

FIGURE 9.3. Transcribriform approach. *A* and *B*, MRI scans with contrast showing preoperative images of a mucoepidermoid carcinoma that was initially interpreted as an olfactory groove meningioma. The *black arrows* indicate the tumor (*A*, axial; *B*, sagittal). *C* and *D*, postoperative MRI scans demonstrating complete resection of the lesion (*C*, axial; *D*, sagittal). *E*, intraoperative photograph of a transcribriform view during sharp dissection of the tumor (*Tu*). Right and left gyrus rectus (*RGR*, *LGR*) can be seen. The frontopolar artery (*FPa*) is shown over the right gyrus rectus. The transected falx (*Fx*) is shown.

tension of the clivus and it must be drilled down to the level of the dura. The surgical field now extends from the sphenoid sinus superiorly, to the level of the soft palate caudally. It is imperative not to transgress the level of the medial pterygoid wedges to not risk injury of the ICAs. This creates an absolute midline corridor exposing the entire clivus. A panclivectomy can extend all the way from the dorsum sellae and posterior clinoids to the anterior aspect of the foramen magnum. It can be combined with other approach modules depending on the tumor in question. A transplanum approach is used when a pituitary transposition is anticipated to allow for a transclival resection of retroinfundibular craniopharyngiomas located in the interpeduncular space. Laterally, the bony exposure is limited by both ICAs ascending in the paraclival areas inside the cavernous sinus at the superior level of the clivus. Inferiorly, the lateral limits are the fossa of Rosenmüller and the torus tubarius.

A transclival approach is frequently used for resection of the clivus in cases involving chordomas and chondrosarcomas. It is also used to access intradural lesions anterior to the brainstem, such as meningiomas and craniopharyngiomas (*Fig. 9.4*). Other indications include vascular lesions and intraaxial pathologies.

Transodontoid Approach

This approach is an extension of the transclival approach. When accessing the lower third of the clivus, a direct view caudally defines the boundaries within the fossa of Rosenmüller: the soft palate anteriorly, the floor of the sphenoid rostrally, the eustachian tubes laterally, and the nasopharyngeal mucosa posteriorly.

The lower third of the clivus is exposed as well as the anterior arch of C1 after dissection of the nasopharyngeal mucosa and the rectus capitis anterior muscle. The arch of C1 is drilled and the odontoid process is exposed. This approach can be used for resection of the odontoid process in degenerative or inflammatory diseases or to allow for exposure of the ventral medulla and upper cervical spinal cord. Foramen magnum meningiomas are examples of lesions that can be treated using this approach (*Fig. 9.5*).

Coronal Plane

Expanded coronal approaches are used for dissections lateral to the midline corridor. The anatomic modules are divided into five zones (*Fig. 9.6*), all of which share the same initial phases of dissection. The sphenopalatine and posterior nasal arteries are isolated and ligated, a posterior maxillary antrostomy is performed, and the pterygoid wedge is identified. The vidian nerve and artery are key landmarks for all lateral expanded approaches because the vidian canal leads to the lacerum segment of the ICA. By drilling bone beneath the vidian nerve, one can safely identify the ICA as it ascends paraclivally to enter the cavernous sinus. Once the ICA is identified, it can be unroofed. It is important to resect the bone lateral to the ICA to allow for lateral vessel mobilization without compressing and occluding it in the carotid canal.

Zone 1: Medial Petrous Apex

This module accesses lesions in the medial petrous apex. Thus, the initial exposure is similar to the transclival approach with a lateral extension. After identifying and exposing the lacerum ICA, the artery is mobilized laterally so

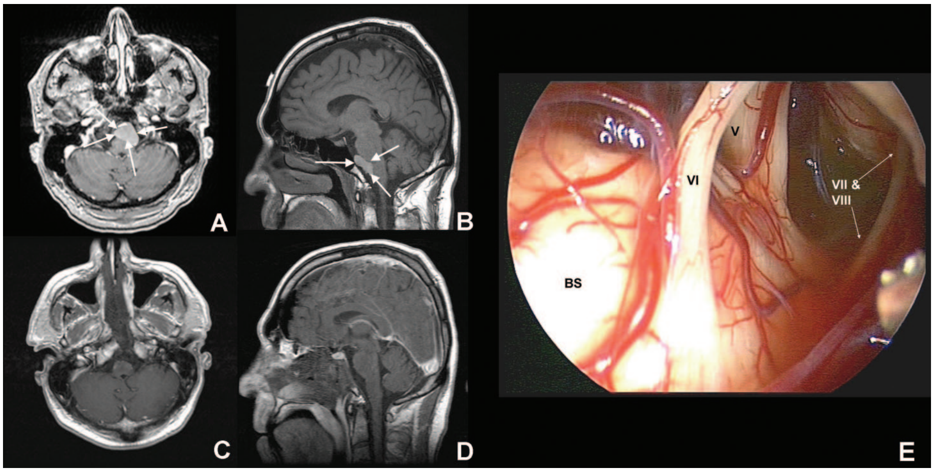

FIGURE 9.4. Transclival approach. *A* and *B*, MRI scans with contrast showing preoperative images of a neuroenteric cyst (*A*, axial; *B*, sagittal). *C* and *D*, postoperative MRI scans demonstrating complete resection of the lesion (*C*, axial; *D*, sagittal). *E*, intraoperative oblique photograph, using an angled scope, of prepontine cistern showing the brainstem (*BS*) at the level of the pons, the Vth cranial nerve (*V*) the VIth cranial nerve (*VI*), and the complex of the VIIth and VIIIth nerves. Reprinted with permission from: Kassam A, Snyderman CH, Carrau RL, Mintz AH, Gardner PA, Thomas AJ, Prevedello DM: *The Expanded Endonasal Approach to the Ventral Skull Base: Sagittal Plane*. Tuttlingen, Germany, Endo-Press, in press, 2007.

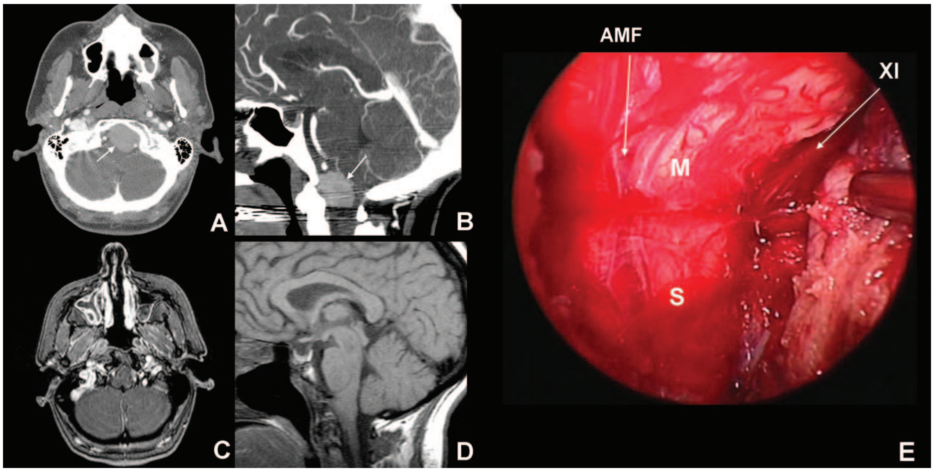

FIGURE 9.5. Transodontoid approach. *A* and *B*, computed tomographic angiograms showing preoperative images of a foramen magnum meningioma. *White arrows* indicate the tumor (*A*, axial; *B*, sagittal). *C* and *D*, postoperative MRI scans demonstrating complete resection of the lesion (*C*, axial; *D*, sagittal). *E*, intraoperative view of the cervicomedullary junction. S, spinal cord; M, medulla. The anterior median fissure (*AMF*) and the ascendant trajectory of the XIth cranial nerve (*XI*) are demonstrated.

that the underlying petrous apex can be accessed directly. Drilling the portion of the clivus at its junction with the petrous apex further facilitates this medial-to-lateral access. This approach provides access as far as the medial anterior margin of the internal auditory canal.

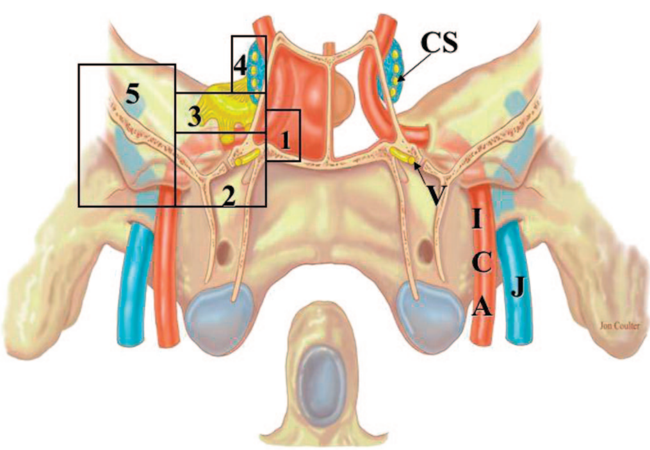

FIGURE 9.6. Drawing of the coronal plane of the cranial base demonstrating the zones of approach from 1 to 5. All of these approaches are based on the localization of the ICA along the cranial base; the vidian nerve and artery (*V*) are valuable landmarks for localization of the second genu. Zone 1 provides access to lesions in the petrous apex. Zone 2 provides access to lesions under the horizontal segment of the petrous ICA. Zone 3 is a supracarotid approach to lesions in the Meckel's cave. Zone 4 approaches are rarely used for lesions inside the cavernous sinus (*CS*). Zone 5 is used to approach the infratemporal fossa and the jugular foramen, J, internal jugular vein. *Reprinted with permission from*: Kassam AB, Gardner P, Snyderman C, Mintz A, Carrau R: Expanded endonasal approach: Fully endoscopic, completely transnasal approach to the middle third of the clivus, petrous bone, middle cranial fossa, and infratemporal fossa. **Neurosurg Focus** 19:E6, 2005.[33]

Zone 2: Petroclival Approaches

This module is designated for resection of lesions deeper along the mid portion of the petrous bone, such as those extending into the body of the petrous bone beneath the petrous internal ICA. An initial transclival exposure provides access to more caudally oriented regions. After identifying and isolating the lacerum ICA, the bone over the petrous segment (horizontal), lacerum and paraclival (cavernous) ICA is removed using a high-speed extended drill and fine Kerrison rongeurs. The lateral clivus at the petroclival junction is drilled laterally beneath the horizontal (petrous) ICA until the underlying dura mater of the posterior fossa and venous plexus is identified. The middle fossa represents the superolateral boundary. The horizontal segment of the petrous carotid and overlying cavernous sinus represents the superior boundary of this exposure (*Fig. 9.7*). If required, the dura mater posterior to the drilled petrous bone can be opened to provide access to the paramedian segment of the prepontine cistern.

Zone 3: Anterior Portion of Meckel's Cave/Quadrangular Space Approach

This module is used for resection of Meckel's cave lesions. The exposure is initiated as described in the petroclival (Zone 2) module. The maxillary antrostomy is widened laterally to expose the posterior maxillary wall. The infraorbital nerve is isolated and followed superiorly until the foramen rotundum is identified. Bone is removed until V2 pierces the middle cranial fossa dura mater. The key anatomic landmark in this module is V2. The ICA is followed laterally and superiorly and the bone over its horizontal and ascending portions is removed. The dura is opened with the quadrangular space bounded by the ICA medially, V2 laterally, and the horizontal petrous ICA inferiorly. The abducens nerve will be seen running obliquely and superiorly (*Fig. 9.8*).

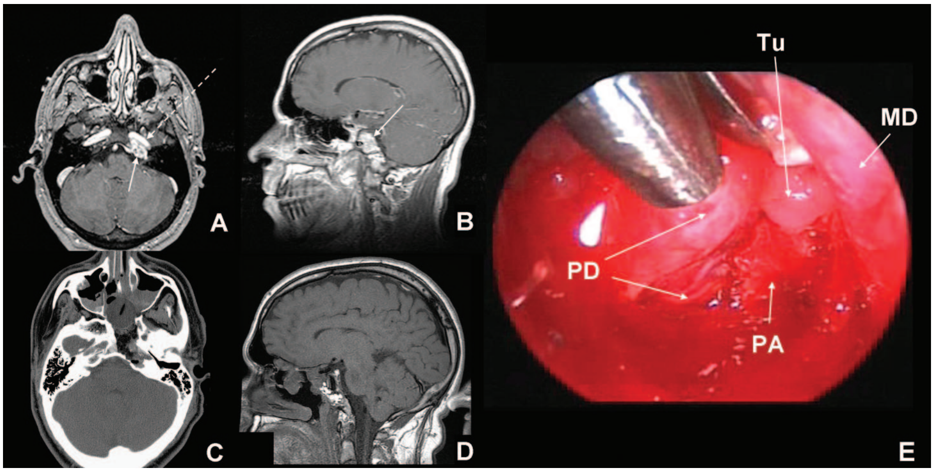

FIGURE 9.7. Transpterygoid approach (Zone 2). *A* and *B*, MRI scans showing preoperative images of a petrous chondrosarcoma (retrocarotid). *White arrows* indicate the tumor, *dashed arrow* indicates the petrous carotid artery (*A*, axial; *B*, sagittal). *C*, axial postoperative computed tomographic scan. *D*, sagittal postoperative MRI scan demonstrating complete resection of the lesion. *E*, intraoperative view inferior to the left petrous ICA showing the remaining petrous apex (*PA*) after drilling. The dura mater of the posterior fossa (*PD*) and the middle fossa (*MD*) were completed exposed. The last portion of the tumor (*Tu*) is about to be removed.

Zone 4: The Cavernous Sinus

We rarely use this approach because of the risk of cranial nerve injury. It is most commonly applied in cases in which the patient has already suffered cranial nerve deficits (III, IV, VI), such as apoplectic pituitary adenomas that invade the cavernous sinus, causing a cavernous sinus syndrome. Because meningiomas may invade the nerves inside the cavernous sinus, we generally prefer to radiate such residual cavernous disease. The ICA exposure and bone resection is undertaken as described in the quadrangular (Zone 3) module. The dural opening, however, is made above the quadrangular space. In the majority of cases, the tumor has already thrombosed the sinus and little venous bleeding is encountered during the initial opening. It is often advisable to open the sella turcica and identify the medial margin of the ICA in the sella. Once the ICA is identified medially, it can be protected with a dissector during the lateral opening.

Zone 5: Transpterygoid/Infratemporal Approach

This module begins once the medial pterygoid plate is isolated and the maxillary antrostomy is completed. Tumors often create a corridor through the pterygomaxilary fissure, extending rostrally to the middle cranial fossa and laterally to the infratemporal fossa. The foramen rotundum and the lacerum ICA are identified as previously described. During the lateral dissection, the internal maxillary artery and its

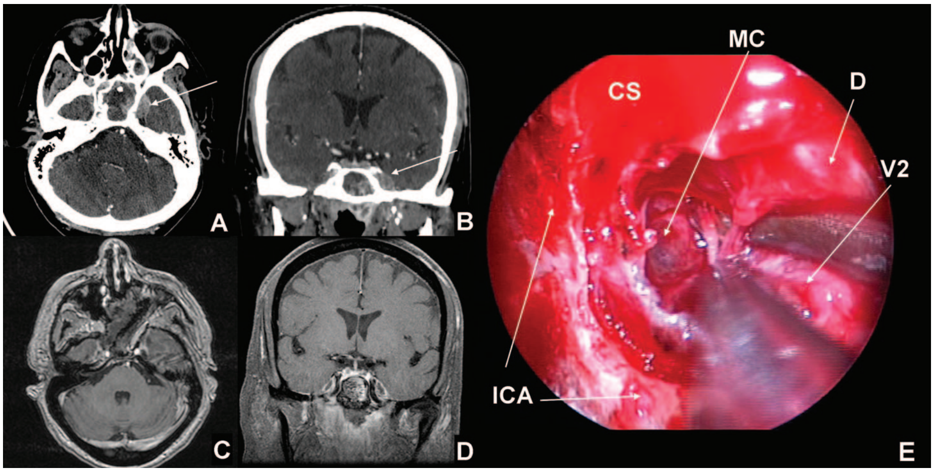

FIGURE 9.8. Transpterygoid approach (Zone 3). *A* and *B*, computed tomographic scans showing preoperative images of an adenoid cystic carcinoma invading Meckel's cave in the left side. *White arrows* indicate the tumor (*A*, axial; *B*, coronal). *C* and *D*, postoperative MRI scans demonstrating complete resection of the lesion (*C*, axial; *D*, coronal). E, intraoperative view of Meckel's cave (*MC*) after resection of the tumor that was infiltrating the maxillary nerve (*V2*). All of the dissection occurred immediately superior to the petrous segment of the ICA and lateral to the vertical paraclival/cavernous ICA. The middle fossa dura (*D*) was exposed and free of tumor. The superior limit of the exposure is the VI nerve inside the cavernous sinus (*CS*) and the lateral limit is the maxillary nerve (*V2*) itself.

branches must be systematically isolated and ligated. The dissection is pursued laterally until the lateral pterygoid plate (LPP) is identified. The LPP is drilled rostrally until it is flush with the middle cranial fossa and foramen ovale. Dissection in this space requires the use of a series of 45-degree- and 70-degree-angled endoscopes. It is common to encounter profuse venous bleeding from the pterygopalatine venous plexus, which is controlled with packing. On occasion, one may have to pack this plexus and return 48 hours later to allow thrombosis to occur. The anatomy in this space can be difficult to navigate because the osseous landmarks (medial pterygoid plate and LPP) are often destroyed by the tumor, thus, making image guidance imperative.

ESTABLISHED FEASIBILITY

Regarding endoscopic cranial base surgery, we think that during the past decade there has been a substantial movement to establish the feasibility of accessing extradural and intradural lesions via fully endoscopic transnasal routes.[6,8,13,15,17,21,22,27,29,31–35] During the past decade, we have demonstrated the feasibility of accessing lesions using each of the above-described modules. The anatomic corridors and instrumentation have been established and feasibility of access has been proven.[4,21,22,34] With feasibility established and surgical anatomy defined, the safety and efficacy of accessing pathologies using a new technique must be documented.

SAFETY AND EFFICACY

Endoscopic cranial base surgery necessitates learning unfamiliar surgical anatomy using new technologies and developing new microsurgical skills. The surgeon must acquire the ability to identify and preserve the ICA, optic nerves and chiasm, and the large and small blood vessels in and adjacent to the surgical field. The potential for disaster is great if surgeons are unfamiliar with the cranial base's ventral anatomic perspective, lack of proper equipment and resources, and/or are unable to maintain adequate visualization with the endoscope.

We think the latter is best facilitated by performing this procedure as a team, with one dissecting surgeon and one endoscopist maintaining visualization, particularly in the setting of adverse events and bleeding. During intradural surgery, the team needs to function fluidly so that they can perform delicate dissections even in the presence of a major vascular compromise.

Although safety and efficacy need to be established, it is very difficult, if not impossible, to control the practice of a large body of surgeons to ensure that each individual has acquired the skill set to proceed safely and efficaciously. Safety and efficacy, therefore, are best studied by analyzing the accumulated data from the practices of neuroendoscopy's early adapters. Only by looking at large case series of experience surgeons can procedure validation, replicability, and safety be established. We think that endoscopic cranial base surgery is currently at this stage. An increasing body of literature is available that provides safety and efficacy data.[5,11,22,24,34]

There is, we think, a strong probability that expanded endonasal approaches will prove to be a viable part of the cranial base surgeon's armamentarium, if certain principles are adhered to.

Principles

1) Anatomic corridors must make sense. Specifically, critical neurovascular structures must be located around the perimeter of the lesion. This allows for direct attack of the lesion, minimizing the need to manipulate neurovascular structures when coming from an endonasal route.

2) Exposure must be created in a manner that allows for bimanual, binarial access. The binostril approach with posterior septectomy allows for bimanual direct access. As we have previously described,[34,35] we think that inability to perform bimanual surgery represents an absolute contraindication to proceeding further with endoscopic cranial base surgery.

3) Use of principles of microsurgical tumor resection that have withstood the test of time. Specifically, the concepts of capsular bipolar coagulation, internal debulking, meticulous extracapsular sharp dissection, and isolation of critical neurovascular structures followed by repeat internal debulking are paramount. Once bimanual exposure has been achieved, all lesions should be removed using the above sequence. Grasping and pulling must be avoided. If a lesion cannot be removed in the above-described manner, then the endoscopic approach should be abandoned.

4) The fundamental principle of reconstruction for traditional cranial base surgery has been the use of vascularized flaps. Early in our endoscopic experience, this technique was not available and we aggressively sought its development. To reduce cerebrospinal fluid leaks, the use of vascularized flaps for large dural defects, we think, is of major importance. We think that this represents a significant factor, and that the principles of reconstruction should preferentially adhere to the use of vascularized tissue (*Fig. 9.9*).

5) There are some features of the surgical team that we think are an absolute requirement for the pursuit of endoscopic cranial base surgery. First, it is imperative that the procedure be performed by one endoscopist and one dissecting surgeon. Although it is tempting to use an endoscopic holder, we think that this represents a poor surrogate for a co-surgeon and can be extremely problematic during adverse situations. The team that examines the lesion and considers it for endoscopic surgery must also be able to offer and perform its resection through conventional open approaches.

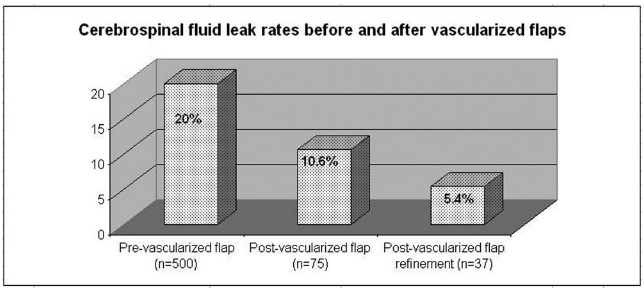

FIGURE 9.9. Graphic showing the evolution of cerebrospinal fluid (CSF) leak rates following expanded endonasal approaches (EEA). Comparison is made between pre and post vascularized flap era. Prior to the development of the flap, one hundred of 500 patients (20%) that underwent an EEA experienced a CSF leak. These patients were reconstructing using on multilayer grafts. Whereas, eight of 75 patients (10.6%) who had a skull base reconstruction with nasoseptal flap during the year of 2006 developed postoperative CSF leak. Following the initial learning curve associated with the use of the nasoseptal flap, significant refinement were made in the technique. When considering the last 50 patients in this cohort, the leak rate was reduced to 4% (2/50). Restricting the analysis to only those patients with intra-arachnoid dissection within this group (n=37), the current CSF leak is 5.4% (2/37).

6) Endoscopic cranial base surgery must be performed using incremental skill acquisition, progressing from Levels 1 through 5 as detailed in *Table 9.1*. This progression must be followed step by step and the next level should not be pursued if the previous level is not mastered.

GENERALIZABILITY

Feasibility, safety, and efficacy phases for a specific procedure or surgical technique are usually established by early adapters. Once such issues have been addressed, issues of procedure generalization to a larger population of surgeons become relevant. This latter phase requires the systematic development of educational programs, the collection of complications data, and the institution of measures to ensure that safety and efficacy are being maintained. Unfortunately, the evolution often moves from feasibility to generalizability without clearly established safety and efficacy data. If, however, the procedure cannot be performed with safety and efficacy, it is likely to become extinct as early adapters lose interest and cease driving the procedure's forward evolution.

The first question is whether endoscopic skills need to be truly generalized and, if so, to what degree. The second question is how to best educate and generalize endoscopic endoneurosurgical skills for the upcoming generation. The acquisition of innovative surgical skills is an ongoing challenge for surgeons.[38,45,48] After completing residency training, much is learned in an unstructured environment with limited access to training facilities. A suggested means for training includes attendance at courses with anatomic models and laboratory skills sessions, observing and assisting an experienced surgeon in the field, performing cases with supervision, and finally performing cases independently. Although we think that the teaching of endoscopic neurosurgical skills will some day become a regular part of the resi-

TABLE 9.1. Level of complexity of endoscopic endonasal skull base procedures

Level I	Sinunasal surgery	
	Pituitary surgery	
Level II	CSF leaks	
		• Transclival
		• Transodontoid
Level III	Extradural	• Transplanum
		• Transcribriform
		• Transorbital
		A) With cortical cuff
		• Transplanum
		• Transcribriform
		• Pre-infundibular craniopharyngiomas
		B) Without cortical cuff
Level IV	Intradural	• Transplanum
		•Transcribriform
		• Infundibular craniopharyngiomas
		• Retro-infundibular craniopharyngiomas
		• Transclival intradural
Level V	Cerebrovascular	• Coronal plane
	Surgery	• AVMs and aneurysms

dency curriculum, currently there are few academic centers performing such surgeries with sufficient volume.

In our opinion, although much learning occurs in the operating theater, time must be spent in the dissection laboratory to acquire sufficient anatomic knowledge and familiarity with endoscopic techniques before proceeding to live operations, especially when moving from one module to the next. This should include involvement in both basic and advanced endoscopic surgery courses, preferably with an emphasis on cranial base applications. Courses should be followed by additional laboratory practice with cadaveric dissections. Cadaveric work continues to be valuable even after earlier level procedures have been mastered because it provides an enhanced understanding of anatomic relationships that cannot be adequately explored in the operative setting. It is also useful to receive additional training after Level II procedures (pituitary surgery) have been mastered because the educational needs and focus of the surgeon change with experience.

Cadaveric work, although valuable, cannot be a substitute for operative experience. It is unlikely that the more complex levels can be mastered on the basis of cadaveric work or weekend courses alone. It is our recommendation that the evolving endoscopic surgeon initiate their career with appropriate scrutiny of anatomic literature. After this, a cadaveric dissection course with an experienced group may be useful to provide fundamental principles and an understanding of Levels 1, 2, and 3 under direct supervision (*Table 9.1*). At this point, the surgeon can then proceed with well-selected Level 1, 2, and 3 cases in a systematic incremental fashion. We then strongly recommend that the surgeon return for more formalized training, having two goals in mind. The first is to understand the barriers and obstacles in performing Level 1, 2 and 3 procedures and to try to address these in a problem-solving manner. The second is to begin gaining insight into Levels 4 and 5 and to seek more sustained periods of training to be able to perform such procedures.

The endoscopic surgical team should feel comfortable with each level before proceeding to the next. Performing at least 30 to 50 pituitary procedures and/or cerebrospinal fluid repairs together before undertaking advanced stage operations is suggested. Many surgeons may plateau at mid-level (Level 2 and 3) and may not want or need to progress to more difficult and complex procedures. If surgeons choose to perform Level 4 procedures, there needs to be a commitment to endoscopic cranial base surgery with the development of a stable surgical team that operates together regularly with an adequate volume of cases. Sufficient institutional resources need to be available to enable the surgery. Whatever level of competence is achieved, it is important for surgeons to recognize their own limitations and not attempt procedures that are beyond their training and institutional capabilities.

CONCLUSION

We think that endoscopic cranial base surgery has tremendous potential for carefully selected lesions and that it is likely to become a staple of the cranial base surgeon's armamentarium during the ensuing decades. We further think that safety and efficacy data that are now emerging will determine the procedure's eventual limitations and define its ultimate place within the spectrum of cranial base surgery. We certainly do not think that it will replace all of the techniques for conventional cranial base surgery, because the anatomic corridors do not always lend themselves well to a direct ventral access. Specifically, there are situations in which the neurovascular structures are not found along the perimeter of a lesion when accessing through a ventral corridor, thus, requiring a conventional dorsal open transcranial corridor to minimize brain manipulation. Lack of adherence to modular skill acquisition will likely result in an increased level of complications, and will prove to be an obstacle in establishing the safety and efficacy data required to provide procedure durability.

If centers evolve responsibly, we think that endoscopic cranial base surgery will be validated. The durability and survivability of the procedure is directly contingent on this process. Currently, EEA is an evolving field that has demonstrated tremendous potential but only with time will the safety and efficacy data determine whether generalizability is warranted, and only this will determine when the procedure is ready for prime time.

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