Endoscopic Cranial Base Surgery: Classification of Operative Approaches

Theodore H. Schwartz, M.D.
Department of Neurological Surgery, Weill Medical College of Cornell University, New York Presbyterian Hospital, New York, New York

Justin F. Fraser, M.D.
Department of Neurological Surgery, Weill Medical College of Cornell University, New York Presbyterian Hospital, New York, New York

Seth Brown, M.D.
Department of Otorhinolaryngology, Weill Medical College of Cornell University, New York Presbyterian Hospital, New York, New York

Abtin Tabaee, M.D.
Department of Otorhinolaryngology, Weill Medical College of Cornell University, New York Presbyterian Hospital, New York, New York

Ashutosh Kacker, M.D.
Department of Otorhinolaryngology, Weill Medical College of Cornell University, New York Presbyterian Hospital, New York, New York

Vijay K. Anand, M.D.
Department of Otorhinolaryngology, Weill Medical College of Cornell University, New York Presbyterian Hospital, New York, New York

Reprint requests:
Theodore H. Schwartz, M.D., Department of Neurological Surgery, Weill Medical College of Cornell University, New York Presbyterian Hospital, New York, NY 10021.
Email: schwarh@med.cornell.edu

Received, May 29, 2007.
Accepted, October 5, 2007.

OBJECTIVE: Endoscopic cranial base surgery is a minimal access, maximally aggressive alternative to traditional transfacial, transcranial, or combined open cranial base approaches. Previous descriptions of endoscopic approaches have used varying terminology, which can be confusing to the new practitioner. Indications for surgery are not well defined. Our objective was to create a comprehensive classification system of the various approaches and describe their indications with case examples.

METHODS: We prospectively compiled a comprehensive database of our endonasal endoscopic operations, detailing the nasal sinus transgressed, the cranial base approach, and the intracranial target for the first 150 consecutive cases performed at our institution. All cases were performed collaboratively by a neurosurgeon and an otolaryngologist.

RESULTS: We categorized the endonasal endoscopic cranial base operations into four nasal corridors, nine cranial base approaches, and 13 intracranial targets. Each of the various approaches is described in detail and illustrated with case examples. Pathology encountered included pituitary tumor (50%), meningocele/encephalocele (14%), craniopharyngioma and Rathke cleft cyst (10%), meningioma (8%), chordoma (5%), esthesioneuroblastoma (2%), and other (11%).

CONCLUSION: Endonasal endoscopic cranial base surgery is a minimal access, maximally invasive alternative to open transcranial cranial base approaches for specific indications. A clear understanding of the possible approaches is facilitated by an awareness of the nasal corridors and intracranial targets.

KEY WORDS: Chordoma, Cranial base, Craniopharyngioma, Esthesioneuroblastoma, Meningioma, Minimally invasive, Pituitary adenoma, Skull base

Neurosurgery 62:991–1005, 2008 DOI: 10.1227/01.NEU.0000313231.81129.66 www.neurosurgery-online.com

The cranial base constitutes an anatomic boundary between the fields of neurosurgery and otolaryngology. Surgery in this region has always been a challenge for both disciplines. As a result of productive collaborations between practitioners in the fields of otolaryngology and neurosurgery, a variety of transcranial and transfacial cranial base approaches have been developed to reach pathology in almost any location (46, 49, 52, 53). However, these open approaches have a complication rate of 18 to 60%; they often involve significant amounts of brain retraction, neurovascular manipulation, and cosmetic compromise; and they frequently rely on complex plastic surgery closures (21, 46, 49, 52, 53). In response, another collaboration between neurosurgeons and otolaryngologists has recently resulted in the development of the new field of endoscopic endonasal cranial base surgery (1–5, 7, 11, 13–15, 19, 23, 24, 29–31, 34, 36–39, 42, 44, 48, 50, 51, 55, 56). These minimally invasive approaches access the midline cranial base using the natural apertures in the face, namely the nostrils. Visualization is provided with rigid straight and angled endoscopes that can illuminate areas of the cranial base that were previously unreachable with standard microscope-based transsphenoidal or transoral approaches. Because the lens sits at the tip of the endoscope and travels to the pathology, magnification is unnecessary and the panoramic 360-degree view facilitates visualization, even around corners. Rather than calling these approaches "minimally invasive," it may be more accurate to say "minimal access," because the ultimate goal is to perform a resection as aggressively as with an open approach.

In recent years, several pioneering groups have published cadaveric studies, small case series, case reports, and conceptual articles illustrating the potential for a purely endonasal endoscopic approach to remove an assortment of pathological lesions in a range of locations throughout the midline cranial base (1–4, 7, 11, 13–15, 19, 23, 24, 29–31, 34, 36–39, 42, 44, 48, 50, 51, 55, 56). A variety of approaches have been described; however, there is little consensus or codification of the available approaches and their indications. In this article, we present a simple and clear methodology for classifying the endoscopic endonasal approaches to the cranial base and provide illustrative cases to demonstrate the indications and goals of surgery. As a result, it is our hope that a clear understanding of these approaches and indications will facilitate the propagation of these new minimal access, maximally invasive, natural aperture endoscopic cranial base techniques.

TABLE 1. Histology

Histology	No. (%)
Pituitary tumor	76 (50%)
Cerebrospinal fluid leak (encephalocele/ meningocele)	21 (14%)
Meningioma (planum sphenoidale, tuberculum sellae, olfactory groove)	12 (8%)
Craniopharyngioma	11 (8%)
Chordoma	7 (5%)
Rathke cleft cyst	3 (2%)
Esthesioneuroblastoma	3 (2%)
Miscellaneous[a]	17 (11%)

[a] Pituitary carcinoma, metastasis, hemangiopericytoma, rhabdomyosarcoma, adenoid cystic carcinoma, malignant salivary gland tumor, juvenile angiofibroma, schwannoma, enterogenous cyst, osteoma, papilloma, nasal glioma, lipoma, gout, rheumatoid pannus.

PATIENTS AND METHODS

The Institute for Minimally Invasive Skull Base and Pituitary Surgery was formed at Weill Cornell Medical College–New York Presbyterian Hospital as a result of collaboration between the departments of neurosurgery and otolaryngology. A database was prospectively compiled to document the details of each approach, including the nasal sinus(es) transgressed, the area of the cranial base exposed, the target, and the extent of resection based on immediate postoperative contrast-enhanced magnetic resonance imaging (MRI) scans, which were reviewed by a radiologist and compared with the preoperative contrast-enhanced MRI scan. In most patients, an attempt at gross total resection was made. Exceptions were made in the following circumstances, in which intended subtotal resection was the goal of surgery: 1) pituitary tumors with cavernous sinus extension lateral to the carotid siphon that would be small enough for postoperative radiosurgery, 2) meningiomas with a long dural tail extending beyond the reach of a midline approach, and 3) chordomas that had failed multiple craniotomies and radiation therapy with significant ventral brainstem compression that required palliative debulking. Complications were also compiled; they will be reported in a separate publication.

From our experience, we organized the endoscopic endonasal cranial base approaches into several categories based on the nasal corridor used for the approach and the region of the cranial base exposed. Institutional Review Board approval was obtained for these studies.

RESULTS

Range of Pathology and Extent of Resection

During a 3-year period, we performed 150 purely endonasal endoscopic operations in which both neurosurgery and otolaryngology were involved. Starting with pituitary tumors, our center quickly progressed to removing a variety of pathology around the midline cranial base. Approximately half of the patients (n = 76) had pituitary tumors, of which only 18 were small hormone-producing tumors, the majority being large macroadenomas. The histological diagnoses are presented in *Table 1*. Gross total resection was achieved in 84% of the patients in whom this was the surgical goal. Residual tumor was left in 14 pituitary tumors (18%), of which seven had tumor in the cavernous sinus that was treated with postoperative radiosurgery. Gross total resection was achieved in all patients with craniopharyngioma, and postoperative radiation therapy was used in only one patient, who had a recurrent tumor after a prior craniotomy. Residual tumor was left in five (41%) of the meningiomas. In four cases, this consisted of a small dural tail extending past the opening in the cranial base. One elderly patient had a nodule attached to the anterior communicating artery, which was left in place to avoid damaging the artery. These patients have been followed for progression with serial scans. Residual tumor was left in three chordomas (42%). One patient had tumor adherent to the basilar artery, which could not be dissected free, and two patients had giant recurrent chordomas that had undergone multiple prior craniotomies and radiation therapy and now required brainstem decompression. Four of these patients, who had not been previously irradiated, were referred for proton beam therapy, and one with a small tumor is being followed with serial imaging. Radiographic gross total resection was achieved in all of the esthesioneuroblastomas. Two (66%) had positive margins in the medial orbital wall and were not willing to undergo orbital exenteration. These patients were referred for radiation therapy.

Endoscopic Cranial Base Approaches

We find it useful to think about endoscopic cranial base approaches as a combination of three factors: 1) a target, 2) a cranial base approach, and 3) a nasal corridor. To begin outlining our surgical plan, we answer the following three questions: 1) Where are we going? (2) How will we get there? (3) Where do we start? The first aspect of the surgical plan is the target. We have defined 12 separate targets (*Fig. 1*). They are: 1) anterior fossa, 2) olfactory groove, 3) orbital apex, 4) sella, 5) suprasellar cistern, 6) cavernous sinus, 7) pterygopalatine fossa, 8) infratemporal fossa, 9) Meckel's cave, 10) petrous apex, 11) upper third of the clivus, 12) lower two-thirds of the clivus, and

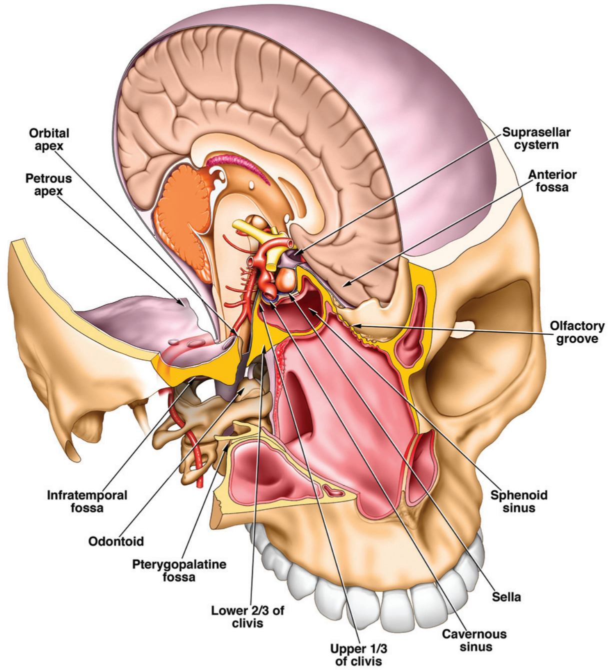


FIGURE 1. *Intracranial targets that can be reached with the endonasal endoscopic cranial base approaches.*

TABLE 2. Endoscopic cranial base corridors, approaches, and targets

Corridor	Approach	Target
Transnasal	Transcribriform	Olfactory groove
	Transclival	Lower two-thirds of clivus
	Transodontoid	Odontoid-cervico-medullary junction
Transsphenoidal	Transsellar	Sella
	Transtuberculum transplanum	Suprasellar cistern
	Transclival	Upper third of clivus
	Transcavernous	Medial cavernous sinus
Transethmoidal	Transfovea ethmoidalis	Anterior fossa
	Transorbital[a]	Orbital apex
	Transsphenoidal	Cavernous sinus
Transmaxillary		Pterygopalatine fossa
	Transpterygoidal[b]	Infratemporal fossa
	Transpterygoidal[b]	Meckel's cave
	Transpterygoidal[b]	Petrous apex
	Transpterygoidal[b]	Lateral sphenoid sinus
	Transpterygoidal[b]	Lateral cavernous sinus

[a] The transethmoidal transorbital approach involves opening the anterior and lateral sphenoid sinus.
[b] The transpterygoid approach also involves opening the ethmoid and sphenoid sinuses.

13) odontoid-cervicomedullary junction. Some targets have one possible approach, whereas other targets have multiple approaches (*Table 2*). The second aspect of the approach involves an understanding of the possible corridors though which one passes on the way to the target. There are four corridors that define the endonasal endoscopic approaches: 1) transnasal, 2) transsphenoidal, 3) transethmoidal, and 4) transmaxillary. The most common corridor is the transsphenoidal, although all corridors are used in our practice (*Fig. 2*). These corridors correspond to the nasal sinuses and can be combined to reach a variety of targets (*Table 2*). The link between the nasal corridor and the surgical target is the approach (*Table 2*). Although the trans-sellar approach is the most common, other frequently used approaches are the transplanum transtuberculum and the transethmoidal transfovea ethmoidalis, followed by the transclival (*Fig. 3*). First, we outline the corridors and then link them with the targets by defining the approaches. Case examples are used for clarification.

Nasal Corridors

Transnasal Corridor

Although all corridors start with the transnasal corridor, it is possible to reach the cranial base using *only* a transnasal corridor without transgressing any sinuses during the operation (*Fig. 4*). The borders of the transnasal corridor are the cribriform plate superiorly; the septum medially; the superior, middle, and inferior turbinates laterally; and the hard palate inferiorly. This surgical corridor may be expanded to a bilateral approach by removal of the posterior and superior segments of the septum or vomer as in the transseptal approach. The transnasal corridor may be followed superiorly to approach the cribriform plate, olfactory groove, and anterior cranial fossa or inferiorly through the choana parallel to the hard palate toward the inferior two-thirds of the clivus and odontoid.

Transethmoidal Corridor

The transethmoidal corridor provides a superior approach that is lateral to the transnasal approach (lateral to the vertical attachment of the middle turbinate) (*Fig. 5*). A total anterior and posterior ethmoidectomy, beginning with an uncinectomy and opening of the ethmoid bulla, provides exposure to the fovea ethmoidalis and frontal fossa superiorly, lamina papyracea and orbital apex laterally, sphenoid sinus posteriorly, and frontal sinus anteriorly. The transethmoidal corridor is often combined with other corridors to provide wide exposure for larger cranial base lesions.

Transsphenoidal Corridor

The sphenoid sinus provides the most versatile endoscopic corridor to the cranial base (*Fig. 6*). The transsphenoidal corridor begins with enlargement of the sphenoid ostia unilaterally or bilaterally. With the bilateral approach, the posterior septum can be removed to access the sinus though either nostril. A wide opening of the front wall of the sinus is performed, and septations are removed as needed. The transsphenoidal corridor can be used to reach the sella posterosuperiorly, the tuberculum sellae and planum sphenoidale superiorly, the cavernous sinus laterally, and the superior third of the clivus

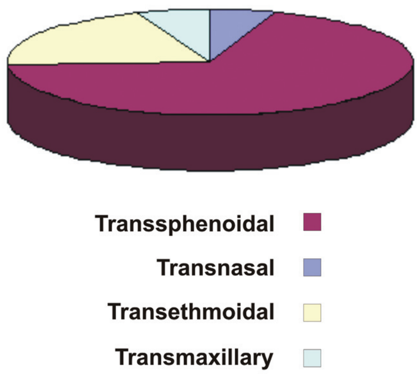


FIGURE 2. *Frequency of nasal corridors used in endoscopic cranial base and pituitary surgery.*

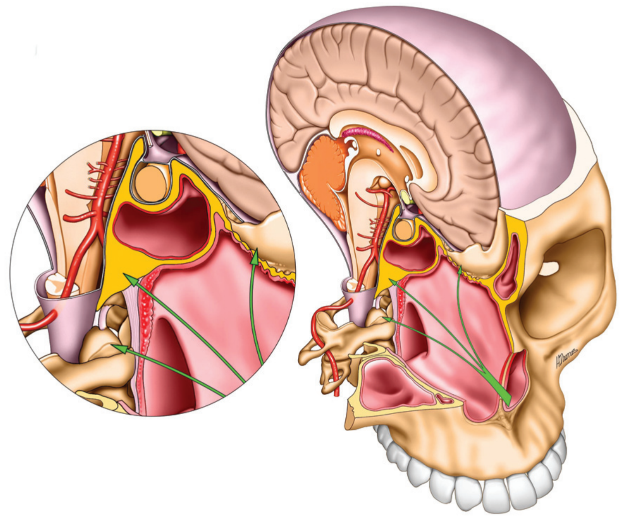


FIGURE 4. *The transnasal corridor leads to the transcribriform approach to the olfactory groove, the transclival approach to the lower two-thirds of the clivus and brainstem, and the transodontoid approach to the cervicomedullary junction.*

posteroinferiorly. In some circumstances, removal of one middle turbinate can increase the working area within the sphenoid sinus and enlarge the corridor.

Transmaxillary Corridor

The transmaxillary corridor, which passes through the pterygopalatine fossa, is the endonasal route to the more lateral cranial base (*Fig. 7*). This corridor is accessed lateral to the middle turbinate by opening the uncinate process, enlarging the ostium of the maxillary sinus, and performing an antrostomy. To reach the infratemporal and pterygopalatine fossa, the ethmoid cells must be opened as well. The lateral and posterior walls of the maxillary sinus are the anterior boundary of the pterygopalatine fossa and pterygomaxillary fissure, which passes between the pterygoid bone and sphenoid sinus. The sphenopalatine artery is cauterized and transected, and the palatine bone is drilled to expose the lateral recess of the sphenoid sinus and pterygopalatine fossa. Further drilling of the pterygoid process exposes the infratemporal fossa Meckel's cave and medial petrous apex; the latter target requires a transclival approach as well.

Approaches

Transcribriform Approach

The transcribriform approach uses the transnasal corridor medial to the middle turbinate to reach the medial anterior fossa and olfactory groove from the frontoethmoidal recess rostrally back to the anterior edge of the planum sphenoidale caudally. This approach by itself is most suitable for repairing encephaloceles and meningoceles that cause cerebrospinal fluid leaks and for removing small olfactory groove meningiomas or esthesioneuroblastomas (*Fig. 8*). If the perpendicular plate is removed, it can be performed bilaterally to reach the crista galli. Damage to the olfactory epithelia almost universally leads to anosmia. The transcribriform approach is often combined with the transfovea ethmoidalis approach to enlarge the access to the anterior cranial fossa to remove larger olfactory groove meningiomas and esthesioneuroblastomas (*Fig. 8*).

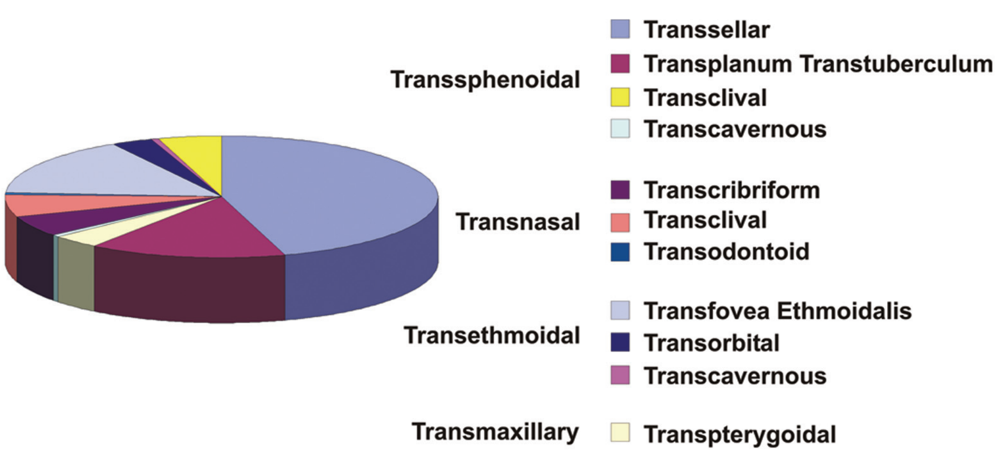


FIGURE 3. *Frequency of each approach used in endoscopic cranial base and pituitary surgery.*

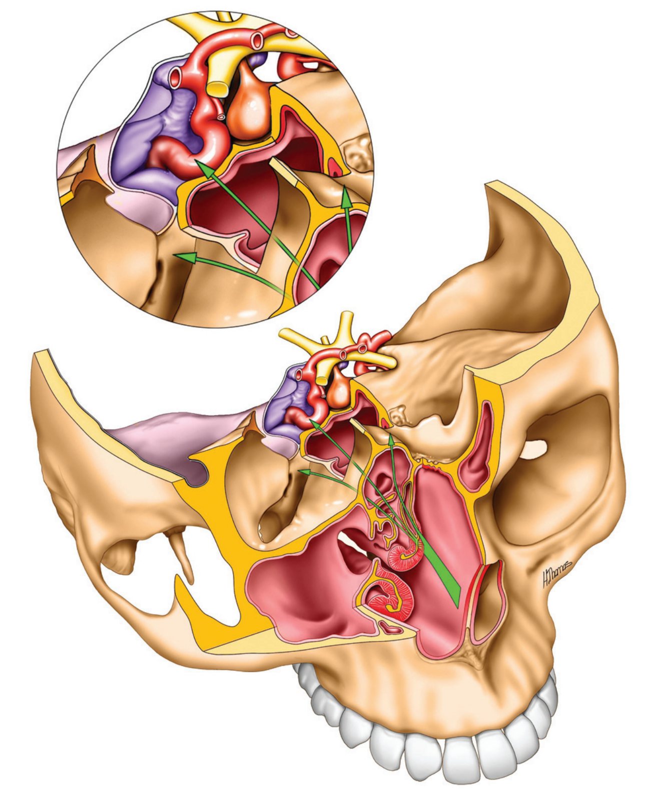


FIGURE 5. *The transethmoidal corridor leads to the transfovea ethmoidalis approach to the anterior fossa, the transsphenoidal approach to the lateral cavernous sinus, and the transorbital approach to the medial orbit (often combined with the transsphenoidal approach to reach the medial orbital apex).*

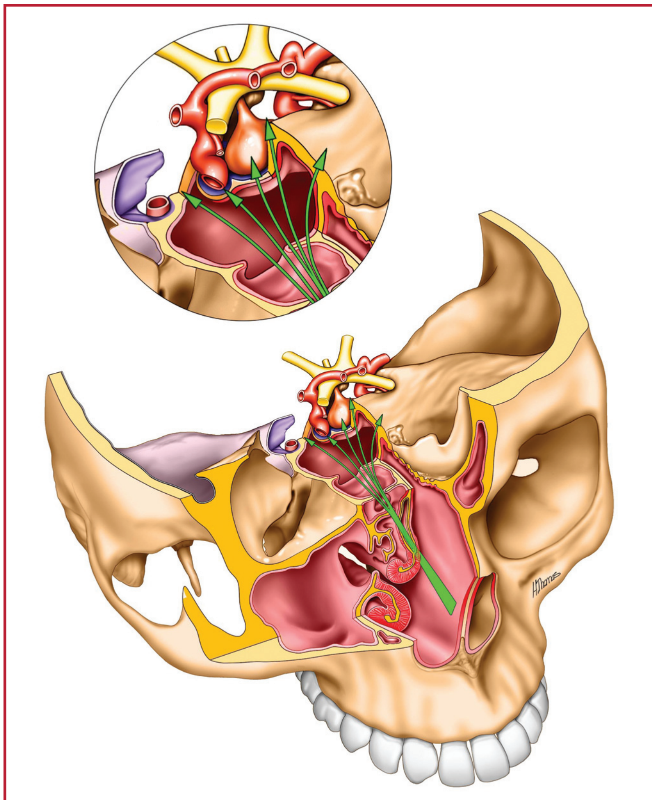


FIGURE 6. *The transsphenoidal corridor leads to the transtuberculum, the transplanum approach to the suprasellar cistern, the transsellar approach to the pituitary gland, the transclival approach to the superior third of the clivus and brainstem, and the transcavernous approach to the medial cavernous sinus.*

Transfovea Ethmoidalis Approach

The transfovea ethmoidalis approach uses the transethmoidal corridor lateral to the middle turbinate to reach the floor of the anterior fossa lateral to the cribriform plate. The lateral limits of this approach are defined by the lamina papyracea. The posterior limit is marked by the sphenoid sinus, and the anterior limit is the frontal sinus. The anterior and posterior ethmoidal arteries traverse this approach and must be transected for vascular control. The transfovea ethmoidalis approach is suitable for repair of encephaloceles and meningoceles. The superior attachment of the middle turbinate may need to be removed to extend the approach medially to combine it with the transcribriform approach. Together, these approaches can open a wide route to the anterior cranial fossa, either unilaterally or bilaterally, for the removal of olfactory groove meningiomas, esthesioneuroblastomas, juvenile angiofibromas, or inverted papillomas (*Fig. 8*).

Transorbital Approach

The medial orbit can be reached using the transethmoidal corridor combined with the transsphenoidal corridor. The medial orbital apex generally presents to the lateral wall of the sphenoid sinus, although in 12 to 25% of cases, a posteriorly located ethmoid air cell or "Onodi cell" will contain the medial orbital apex (62). The lamina papyracea can be removed, exposing the periorbita and periorbital fat. Care must be taken not to damage the medial rectus muscle. The transorbital approach is useful not only for decompression of the optic nerve and orbital apex, but also for removal or biopsy of other pathology in this area, such as pseudotumor, hemangiomas, osteomas, and angiofibromas, as well as malignant pathology that may extend into this area, such as esthesioneuroblastomas, squamous cell carcinomas, or lymphomas (*Fig. 9*).

Transsellar Approach

The transsellar approach uses the transsphenoidal corridor to reach the sella. This approach is most suitable for intrasellar pathology with little or modest suprasellar extension. With the use of angled endoscopes, the transsellar approach can be used to reach the medial cavernous sinus if the tumor extends through the medial wall of the cavernous sinus. Likewise, angled scopes can be used to reach the inferior aspect of the suprasellar cistern. The most common suitable pathological conditions are micro- and macroadenomas, intrasellar craniopharyngiomas, and Rathke cleft cysts (*Fig. 9*). If there is signif-

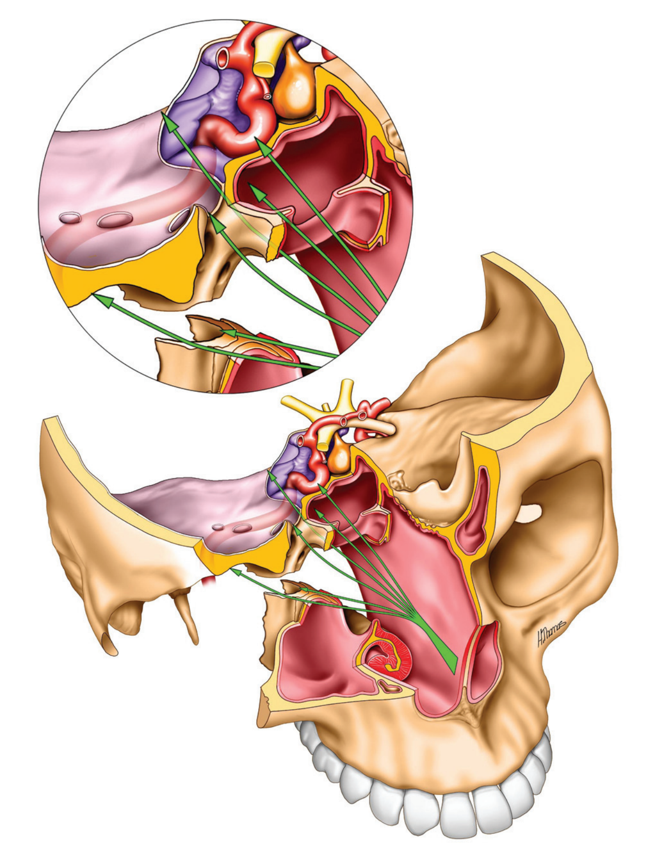


FIGURE 7. *The transmaxillary corridor leads to the transpterygoidal approach to the pterygopalatine fossa, lateral sphenoid and cavernous sinus, Meckel's cave, infratemporal fossa and petrous apex.*

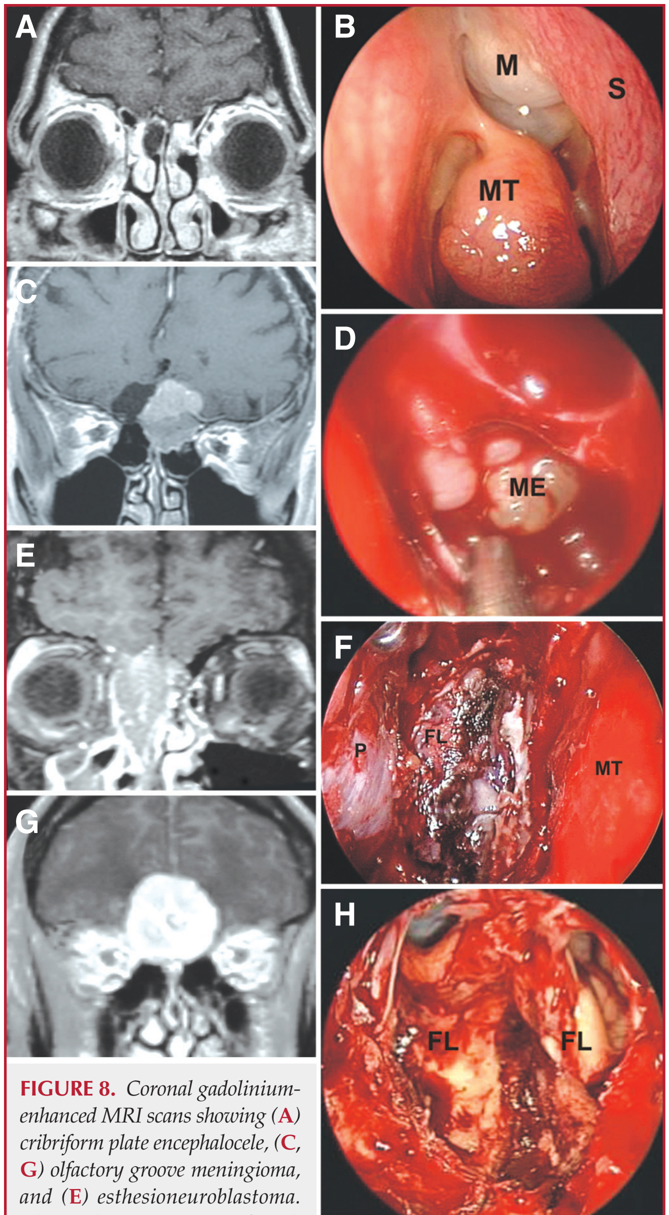


FIGURE 8. *Coronal gadolinium-enhanced MRI scans showing (***A***) cribriform plate encephalocele, (***C***,* **G***) olfactory groove meningioma, and (***E***) esthesioneuroblastoma. The endoscopic view of each approach is presented in the corresponding panel to the* right. **B***, transnasal corridor to the transcribriform approach passes between the middle turbinate (MT) and septum (S) to reach the meningocele (M).* **D***, transethmoidal corridor to transfovea ethmoidalis approach to an olfactory groove meningioma (ME).* **F***, combined bilateral transnasal corridor and unilateral transethmoidal corridor to transfovea ethmoidalis and transcribriform approach passes between the MT and the periorbital fascia (P) to expose the frontal lobe (FL) of the anterior fossa and olfactory groove.* **H***, combined bilateral transnasal and transethmoidal corridors to bilateral transcribriform and transfovea ethmoidalis approaches to expose the frontal lobes bilaterally (FL).*

icant suprasellar extension, we prefer to use the transplanum transtuberculum approach.

Transplanum Transtuberculum Approach

The transplanum transtuberculum approach uses the transsphenoidal corridor to reach the suprasellar cistern. Often, the posterior ethmoid air cells must be removed to achieve adequate exposure of the most anterior aspect of the planum sphenoidale. Both the tuberculum sellae and planum sphenoidale are thinned with a diamond drill and then removed with a Kerrison rongeur (Codman/Johnson & Johnson, Raynham, MA). In addition, the superior aspect of the anterior wall of the sella is removed. The dura is then opened above and below the intercavernous sinus, which is cauterized and cut. Dissection is then carried out through the Liliequist membrane either above the optic nerves toward the anterior communicating artery, or below the optic nerve and above the pituitary gland upward into the third ventricle or downward into the interpeduncular cistern. This approach is useful to remove meningiomas of the tuberculum sellae and planum as well as suprasellar craniopharyngiomas that extend into the third ventricle above a normal-sized sella and down into the interpeduncular cistern. For meningiomas that extend along the optic nerves, the optic canals must be drilled open bilaterally for complete excision. The resection of large pituitary adenomas with significant suprasellar

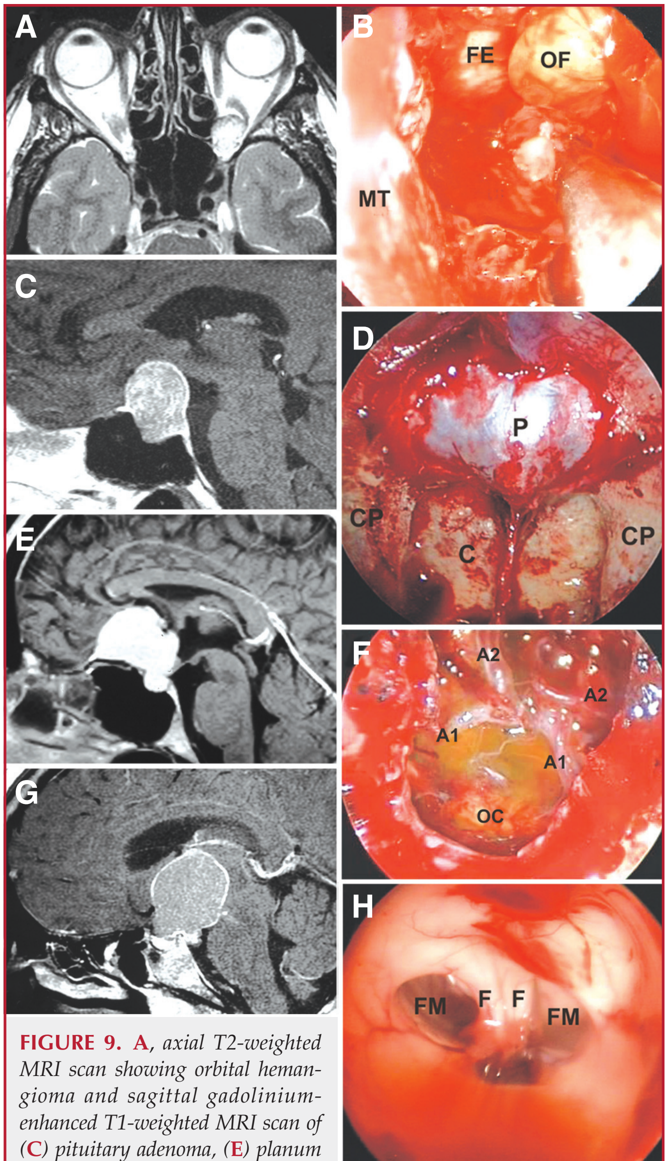


FIGURE 9. A, *axial T2-weighted MRI scan showing orbital hemangioma and sagittal gadolinium-enhanced T1-weighted MRI scan of* (**C**) *pituitary adenoma,* (**E**) *planum sphenoidale meningioma, and* (**G**) *craniopharyngioma. The endoscopic view of each approach is presented in the corresponding panel to the right.* **B**, *transethmoidal corridor to the transorbital approach passes lateral to the middle turbinate* (MT) *to expose the fovea ethmoidalis* (FE) *and orbital fat* (OF) *of the medial orbit.* **D**, *transsphenoidal corridor to the transsellar approach, the pituitary dura* (P) *also exposes the upper third of the clivus* (C) *and the carotid protuberances* (CP). **F**, *transsphenoidal corridor to the transtuberculum transplanum approach to the suprasellar cistern exposes the optic chiasm* (OC) *and bilateral A1 and A2 segments of the anterior cerebral artery after removing a planum meningioma.* **H**, *transsphenoidal corridor to the transtuberculum transplanum approach to the suprasellar cistern can also expose the roof of the third ventricle to demonstrate the foramina of Monro* (FM) *and fornices* (F).

extension is also facilitated by removal of the tuberculum sellae and planum sphenoidale to gain visualization over the top of the tumor to ensure complete removal (*Fig. 9*).

Transcavernous Approach

The cavernous sinus can be reached through a variety of corridors and approaches. The simplest is the transsphenoidal transsellar approach, which can lead into the medial cavernous sinus if the medial wall of the cavernous sinus is breached by tumor. However, this is an indirect route. Alternatively, the transsphenoidal corridor can be used to open the bone over the carotid siphon, thus exposing the medial cavernous sinus. However, exposure of the lateral cavernous sinus is often inadequate, and instruments with a significant distal bend are required to reach laterally. A more direct route is through the transethmoidal corridor into the sphenoid sinus. This approach runs lateral to the middle turbinate, which can also be removed to increase the working space. The success of this approach will, to some extent, depend on the lateral aeration of the sphenoid sinus. Additional lateral exposure can be achieved by removing the medial pterygoid bone and using the transmaxillary corridor and transpterygoidal approach, which also exposes the lateral sphenoid sinus. This approach is useful for tumors of the cavernous sinus and pathology of the lateral sphenoid, such as meningiomas, pituitary adenomas, encephaloceles of Sternberg's canal, and chordomas (*Fig. 10*).

Transpterygoidal Approach

The transpterygoidal approach uses the transmaxillary corridor in combination with the transethmoidal and transsphenoidal corridors, and sometimes the transnasal corridor, to facilitate exposure, depending on the target. The posterior wall of the maxillary sinus is the anterior wall of the pterygopalatine fossa, which houses the vidian nerve and artery, the pterygopalatine ganglion and its branches (the infraorbital nerve, vidian nerve, and palatine nerve), and the maxillary nerve and artery and its branches (the descending palatine artery and the sphenopalatine artery and its branches, the nasopalatine and posterior nasal arteries). At the medial border of the maxillary sinus, the sphenopalatine artery is identified and transected. The bone behind the artery, housing the sphenopalatine foramen, is the orbital process of the palatine bone, which is removed with a high-speed drill along with the posterior wall of the maxillary sinus to expose the pterygopalatine fossa. The second division of the fifth cranial nerve can be followed through the foramen rotundum into the middle cranial fossa. Further drilling laterally through the pterygomaxillary fissure will expose the infratemporal fossa, pterygoid canal, foramen rotundum, and superior orbital fissure. Further drilling medially and posteriorly through the medial pterygoid bone exposes the lateral recess of the sphenoid sinus, the lateral cavernous sinus and Meckel's cave (*Fig. 10*). In combination with the transnasal approach to the ipsilateral inferior third of the clivus, with further drilling inferiorly, the petrous apex is exposed.

Transclival Approach

The transclival approach can use either the transsphenoidal or transnasal corridor, depending on the rostral-caudal extent of the pathology. The upper third of the clivus is identical to the

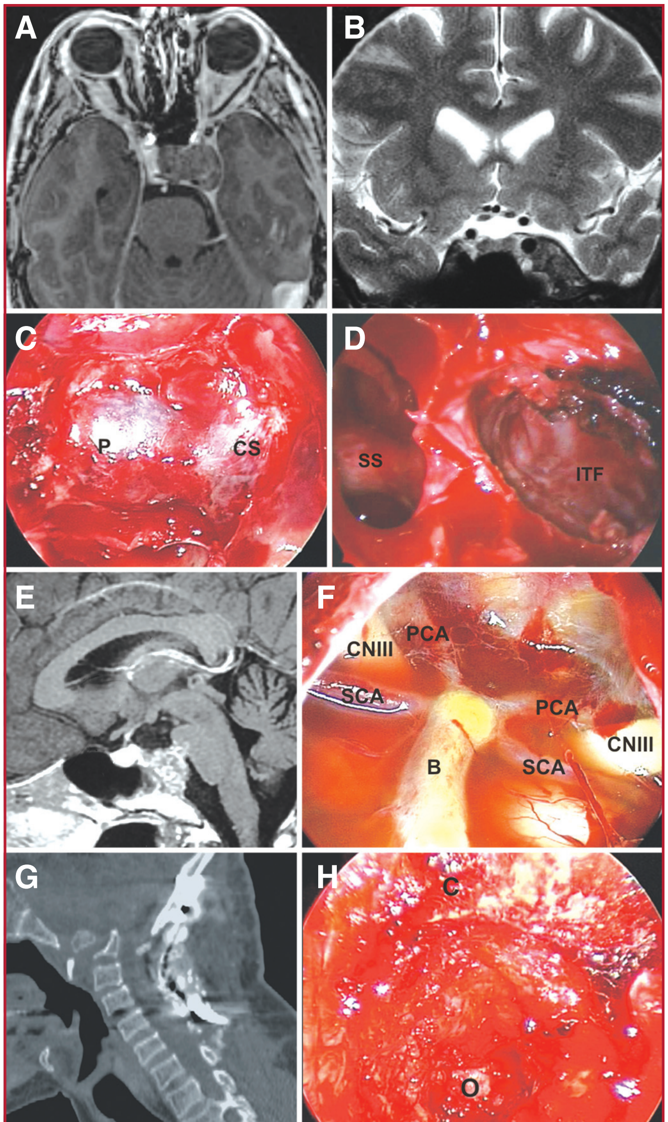


FIGURE 10. **A**, *axial T1-weighted gadolinium-enhanced MRI scan showing cavernous hemangioma.* **B**, *coronal T2-weighted MRI scan demonstrating a nasal glioma of Meckel's cave and infratemporal fossa.* **C**, *the transethmoidal corridor to the transsphenoidal approach to the cavernous sinus* (CS) *exposes dura more lateral to the pituitary (P) than if the ethmoid sinuses are not opened.* **D**, *the transmaxillary corridor to the transpterygoid approach exposes the lateral sphenoid sinus* (SS) *and infratemporal fossa* (ITF). **E**, *sagittal T1-weighted gadolinium-enhanced MRI scan showing a clival chordoma.* **F**, *the transnasal and transsphenoidal corridors to the clivus expose the basilar artery* (B), *superior cerebellar arteries* (SCA), *posterior cerebral arteries* (PCA), *and third cranial nerve* (CNIII). **G**, *sagittal computed tomographic scan showing basilar invagination.* **H**, *the transnasal corridor to the transodontoid approach passes below the clivus* (C) *to expose the odontoid* (O), *which has been removed, and the craniovertebral junction.*

posterior wall of the sphenoid sinus. The approach begins with a bilateral transsphenoidal opening and removal of the posterior third of the septum. The front wall of the sphenoid sinus must be opened as low as possible, flush with the floor of the sinus. The lateral margins of the floor of the sphenoid sinus are marked by the course of the vidian nerve, which runs posteriorly along the floor into the vertical segment of the carotid artery. The bone of the clivus can be opened from carotid to carotid artery with a microdrill, and the venous plexus can be controlled with hemostatic agents. The amount of drilling required will depend on the aeration of the sinus. The sella must also be opened to mobilize the pituitary gland laterally or rostrally, because the clivus extends up behind pituitary gland, forming the posterior wall of the sella. With this maneuver, the posterior clinoid processes can be thinned with a microdrill and removed with a Kerrison rongeur. The inferior intercavernous sinus is cauterized and transected. The dura is then opened to expose the basilar tip, superior cerebellar and posterior cerebral arteries, and third cranial nerve (*Fig. 10*). The sixth cranial nerve runs at the lateral edge of the exposure as it enters Dorello's canal.

To reach the inferior two-thirds of the clivus, the bilateral transnasal corridor is used to reach the nasopharynx. This is often combined with a transsphenoidal corridor, and the floor of the sphenoid sinus is removed after the vomer is drilled flush with the floor of the sinus. The nasopharyngeal mucosa and fascia are dissected free from the clivus and cauterized and cut laterally to create a U-shaped flap, which can be flapped downward. The lateral limits of the nasopharyngeal flap are the vidian nerves superiorly and the eustachian tubes laterally, which mark the location of the carotid arteries. The bone of the clivus is drilled through the cancellous part to a thin layer of cortical bone, which is removed with a Kerrison rongeur. Extensive venous bleeding from the basilar plexus can be controlled with careful cautery, hemostatic agents, and gentle pressure. Opening the dura will expose the basilar trunk, anteroinferior cerebellar and vertebral arteries, and ventral pons. These approaches are most useful for chordomas and chondrosarcomas as well as intradural pathology, such as dermoid, epidermoid, and enterogenous cysts and midline petroclival meningiomas.

Transodontoid Approach

The transodontoid approach is the inferior extent of the transclival approach. A bilateral transnasal corridor is used, with removal of the most inferior part of the vomer. The approach passes parallel to the palate, and an angled scope is used to view inferiorly. The mucosal flap should be reflected, starting at the base of the sphenoid sinus and limited laterally by the eustachian tubes, which will expose the lower third of the clivus. The bone of the base of the clivus is removed from occipital condyle to occipital condyle. Below this, the atlanto-occipital membrane, longus capitis, and longus colli muscles as well as the anterior aspects of C1 and C2 are exposed. The anterior arch of C1 can be removed to expose the dens, which can be removed after separating it from the apical and alar ligaments. This approach is useful for removing pathology of the dens, such as rheumatoid pannus, metastases, or basilar invagination, and can be extended intradurally to approach ventral foramen magnum meningiomas for cervical fixation (*Fig. 10*).

DISCUSSION

The field of endoscopic cranial base surgery has made significant advances in the past few years. However, the principles of endoscopic endonasal approaches to the cranial base find their roots in the evolution of transsphenoidal pituitary surgery and minimally invasive sinus surgery. In the early 1900s, Hirsch (27) and Cushing (18) described the transnasal transsphenoidal approach to the sella. Over the years, this approach has been expanded to remove lesions above and below the sella; however, the use of a microscope and retractors limited its versatility and applicability (17, 40, 63). Simultaneously, the field of functional endoscopic sinus surgery evolved, and it became clear that straight and angled endoscopes could provide full visualization of the entire midline cranial base as well as aspects of the lateral cranial base through an endonasal approach (45, 57). As a result, several groups have recently pushed the evolution of endoscopic cranial base surgery with cadaveric dissections and small case series (1–4, 7, 13–15, 19, 29–31, 34, 36–39, 44, 50, 51, 55). Nevertheless, minimally invasive endoscopic approaches to the cranial base are not yet widely accepted as preferable to conventional microscope-based transcranial, transfacial, and transsphenoidal approaches. Certainly, outcome studies that would directly compare the results, with respect to extent of resection, time to recurrence, morbidity, length of stay, and cost, are lacking. However, one reason for the slow proliferation of these newer minimal access techniques is the ambiguity in the classification of the various approaches. For this reason, we have documented our experience with endoscopic cranial base surgery and present a clear method for categorizing the surgery on the basis of nasal corridors, cranial base targets, and approaches.

The first principle in both understanding and successfully achieving the desired results using the endoscopic endonasal approaches is that the surgery is best performed as collaborative surgery between otolaryngology and neurosurgery, preferably by an otolaryngologist with experience performing functional endoscopic sinus surgery and a neurosurgeon with experience performing transsphenoidal pituitary and transcranial cranial base surgery. Both surgeons should be involved in all aspects of the case, including operative planning as well as the approach, resection, and closure. Our categorization of the endoscopic cranial base approaches derives precisely from this collaboration. Although the nasal corridors are most familiar to the otolaryngologist, the targets are most familiar to the neurosurgeon. The approaches derive from the union of these two perspectives (*Table 2*). In addition, the surgical technique itself and the understanding of how straight and angled endoscopes can be applied to improve visualization arise from the meeting of these two unique perspectives, which evolves over time during the course of the collaboration. The second principle for successful endoscopic cranial base surgery—and critical in deriving adequate approaches and exposure—is the role of stereotactic navigation, which we use in all cases. One now has the option of using either rigid fixation or a cranial pin to fix the reference frame as well as electromagnetic or infrared tracking systems. Although fluoroscopy has been the primary method of navigation during transsphenoidal surgery, the ease and accuracy of modern frameless stereotactic systems has made implementation of more extensive endoscopic approaches safe and feasible. Although the corridor(s), approach(es), and target(s) are chosen before each procedure, as the operation progresses, we often use intraoperative stereotactic navigation to modify, improve, update, and streamline our approach.

Previous groups have categorized the endoscopic endonasal approaches in a variety of ways. de Divitiis et al. (19) described four extended transsphenoidal approaches: 1) transethmoid–transsphenoidal, 2) transplanum, 3) transclival, and 4) transethmoidal transsphenoidal with removal of the superior turbinate to reach the lateral cavernous sinus. They also described a contralateral transsphenoidal transcavernous approach to reach the medial contralateral cavernous sinus, which can be extended with additional entry into the maxillary sinus with removal of the medial pterygoid process. In addition, two approaches to the cribriform plate were described: 1) a medial to middle turbinate approach to the olfactory groove, and 2) a lateral to middle turbinate approach to the ethmoid cribriform plate. These authors prefer a unilateral approach and reserve the bilateral approach for pediatric cases or for times when an additional hand is necessary. Jho and Ha (29–31) used cadaveric dissection to define three approaches to the anterior fossa, cavernous sinus, and clivus: 1) the paraseptal approach with bilateral ethmoidectomies, 2) the middle meatal approach, performed lateral to the turbinate with a unilateral ethmoidectomy, and 3) the middle turbinectomy approach, in which removal of the middle turbinate is followed by bilateral ethmoidectomies. All approaches were unilateral and provided exposure to the cribriform plate, planum sphenoidale, tuberculum sellae, cavernous sinus, clivus, posterior fossa, and petrous apex. Alfieri et al. (3) extended these three approaches to reach the craniovertebral junction and odontoid and described three new approaches to reach the pterygopalatine fossa and cavernous sinus (1, 2): 1) the middle meatal transpalatine, 2) the middle meatal transantral, and 3) inferior turbinectomy transantral approach.

Endoscopic endonasal approaches to the midline cranial base were further classified by Cavallo et al. (14) in cadaveric studies. The basis of these approaches was a large bilateral sphenoidotomy with removal of the right middle turbinate and the posterior septum. The following approaches were described: 1) planum sphenoidale and tuberculum sellae removal to expose corridors above and below the optic chiasm; 2) removal of the ethmoid air cells, cribriform plate, and lamina papyracea bilaterally and the medial nasal septum to expose the olfactory groove and basal frontal lobe; 3) removal of the clivus through the sphenoid sinus and nasopharyngeal mucosa to expose the ventral brainstem; and 4) removal of the lower third of the clivus and the odontoid and ring of C1 to reach the foramen magnum. Lateral approaches to the cavernous sinus and pterygopalatine fossa were defined separately (13, 15). The cavernous sinus was approached either through a direct transethmoidal transsphenoidal approach or a contralateral route to the medial cavernous sinus (13), as described previously by de

Diviitis (19). The pterygopalatine fossa approach involved removal of the middle turbinate, the posterior wall of the maxillary sinus, and the palatine bone and pterygoid bones (15). Further cadaveric studies by Magro et al. (44) and Solari et al. (55) provided additional information about the lateral approach to the pterygopalatine fossa, demonstrating the use of this approach in reaching the lateral sphenoid sinus.

Kassam et al. (34, 36, 37) divide the endonasal cranial base approaches into two planes. The first plane, the midline sagittal plane, has six modules: 1) the sellar module, 2) the transtuberculum-transplanum module, 3) the transcribriform module, 4) the superior clival module, and the middle third of the clivus, which has two midline sagittal modules, 5) a superior module, and 6) an inferior module divided by the floor of the sphenoid sinus. The middle third of the clivus then has five modules or zones in the coronal plane; two of these zones are infrapetrous: 1) the medial petrous apex module and 2) the petroclival module; and three of these zones are suprapetrous: 3) the quadrangular space module, 4) the superior cavernous module, and 5) the transpterygoid-infratemporal module. In addition, an approach to the odontoid has been described (35). In a separate article from the same group, Snyderman et al. (54) revised the modules to include six modules in the sagittal plane: 1) transfrontal, 2) transcribriform, 3) transplanum, 4) transsphenoidal, 5) transclival (which in turn has three submodules: A) posteroclinoid, B) midclivus, and C) foramen magnum), and 6) transodontoid. In the coronal plane, seven modules were described: 1) transorbital, 2) petrous apex, 3) lateral cavernous, 4) transpterygoid, 5) transpetrous (which in turn has two submodules: A) superior and B) inferior), 6) transcondylar, and 7) the parapharyngeal space.

An ethmoidopterygosphenoidal approach to the cavernous sinus and lateral sphenoid sinus has also described by Frank et al. (25), Pasquini et al. (47), and Castelnuovo et al. (10). The transclival approach to the posterior fossa has been further explored by Stamm et al. (56). In addition, Kassam et al. (38) and Locatelli et al. (43) have shown that most of these approaches are also applicable to the pediatric population.

Although these previously existing methods of categorizing the endonasal endoscopic cranial base approaches are comprehensive and well illustrated, the variety of individual reports gives a fractured view of the field. Our goal is to try to present a simple, comprehensive compendium of the endonasal endoscopic cranial base approaches to aid in the proliferation of these techniques to other centers that can then reproduce and validate the use, indications, and complications associated with these approaches. Additionally, we want to present an alternative perspective arising from our unique experience. Hence, the method of considering nasal corridors, intracranial targets, and then the resulting approaches became the most logical system for conceiving these endonasal endoscopic cranial base approaches.

Exclusion and Inclusion Criteria

Although the approaches we describe are adequate to remove a variety of pathologies in several different locations, not all tumors and locations are amenable to these minimal access approaches. Clearly, this article does not describe the cases that we thought were not suitable for an endoscopic approach. To minimize complications, an understanding of the exclusion criteria is almost as important as the ability to perform the approaches. In general, we do not use an endoscopic endonasal approach if the lateral extent of the tumor passes more than 1 cm beyond the lateral limits of our exposure, beyond which even angled scopes and instruments provide limited visualization and reach. In addition, the epicenter of the tumor must lie within the midline exposure. Another way to consider the limitations of the midline approaches is to decide whether the lateral limit of the tumor would be more easily reached through a craniotomy that would involve minimal brain retraction. If so, then one must consider whether the medial extent of the tumor can be more easily reached through this transcranial approach once the more lateral aspects of the tumor have been removed. If not, one can consider using a combined approach, using an endonasal endoscopic approach to remove the midline component of the tumor, and a transcranial approach to remove the lateral component of the tumor. Finally, significant tumor within the frontal sinus is generally easier to remove through a bifrontal craniotomy, and inferior extension below the body of C2 is difficult to visualize endonasally.

Several other factors must be examined in deciding on the suitability of an endonasal approach. Tumors that appear to be encasing blood vessels are not an absolute contraindication. With current endoscopic equipment and practice, it is possible to dissect small arteries off the back of tumors, if adequate internal decompression is performed. However, the lack of stereoscopic vision and pistol grip versus bayoneted instruments make this maneuver more difficult than with a microscope, so surgeons must have a realistic idea of their surgical abilities. Brain edema is also not a contraindication. Tumors that breach the pia can be dissected off the brain, but one must be facile with endoscopic methods for attaining hemostasis either using pistol grip or conventional bayoneted bipolars, which can often fit through large nostrils. Meningiomas with long dural tails may be inappropriate if the goal of surgery is a Simpson Grade 1 removal. However, tuberculum sellae meningiomas that extend into the optic canal can be completely removed as long as the optic canals are opened from within the sphenoid and ethmoid sinuses. In addition, it must be realized that leaving small amounts of residual, benign, slow-growing tumor is not necessarily a poor surgical plan, particularly in elderly patients or if the tumor is densely adherent to critical neurovascular structures. Stereotactic radiosurgery and/or observation are acceptable and, in some cases, may be preferable to attempting radical surgery in all patients. Finally, certain esthesioneuroblastomas may be unsuitable for these approaches. Orbital exenteration cannot currently be performed endonasally. Hence, an esthesioneuroblastoma with clear intraorbital extension is an inappropriate case if radical single-stage surgery is the goal.

CONCLUSIONS

Endoscopic cranial base surgery is a minimal access but maximally invasive alternative to traditional transsphenoidal, transcranial, or transfacial approaches to the cranial base. In this article, we provide a comprehensive compendium of endonasal, endoscopic cranial base approaches based on nasal corridors and intracranial targets to assist in the proliferation of this technique. A discussion of inclusion and exclusion criteria is provided to help facilitate an understanding of the limitations and applicability of these procedures.

REFERENCES

1. Alfieri A, Jho HD: Endonasal endoscopic approaches to the cavernous sinus: An anatomic study. **Neurosurgery** 48:827–837, 2001.
2. Alfieri A, Jho HD, Schettino R, Tschabitscher M: Endoscopic endonasal approach to the pterygopalatine fossa: Anatomic study. **Neurosurgery** 52:374–380, 2003.
3. Alfieri A, Jho HD, Tschabitscher M: Endoscopic endonasal approach to the ventral cranio-cervical junction: Anatomic study. **Acta Neurochir (Wien)** 144:219– 225, 2002.
4. Anand VK, Schwartz TH: *Practical Endoscopic Skull Base Surgery*. San Diego, Plural Publishing, 2007.
5. Anand VK, Schwartz TH: The endoscopic, transsphenoidal, transplanum, transtuberculum approach to the suprasellar cistern, in Anand VK, Schwartz TH (eds): *Practical Endoscopic Skull Base Surgery*. San Diego, Plural Publishing, 2007, pp 105–122.
6. Black PM, Zervas NT, Candia GL: Incidence and management of complications of transsphenoidal operation for pituitary adenomas. **Neurosurgery** 20:920–924, 1987.
7. Brown SM, Anand VK, Schwartz TH: The endoscopic, transethmoidal, transorbital approach to the orbital apex, in Anand VK, Schwartz TH (eds): *Practical Endoscopic Skull Base Surgery*. San Diego, Plural Publishing, 2007, pp 123–134.
8. Cappabianca P, Cavallo LM, Colao A, de Divitiis E: Surgical complications associated with the endoscopic endonasal transsphenoidal approach for pituitary adenomas. **J Neurosurg** 97:293–298, 2002.
9. Cappabianca P, Cavallo LM, Colao A, Del Basso De Caro M, Esposito F, Cirillo S, Lombardi G, de Divitiis E: Endoscopic endonasal transsphenoidal approach: Outcome analysis of 100 consecutive procedures. **Minim Invasive Neurosurg** 45:193–200, 2002.
10. Castelnuovo P, Dallan I, Pistochini A, Battaglia P, Locatelli D, Bignami M: Endonasal endoscopic repair of Sternberg's canal cerebrospinal fluid leaks. **Laryngoscope** 117:345–349, 2007.
11. Castelnuovo PG, Delù G, Sberze F, Pistochini A, Cambria C, Battaglia P, Bignami M: Esthesioneuroblastoma: Endonasal, endoscopic treatment. **Skull Base** 16:25–30, 2006.
12. Cavallo LM, Briganti F, Cappabianca P, Maiuri F, Valente V, Tortora F, Volpe A, Messina A, Elefante A, de Divitiis E: Hemorrhagic vascular complications of endoscopic transsphenoidal surgery. **Minim Invasive Neurosurg** 47:145–150, 2004.
13. Cavallo LM, Cappabianca P, Galzio R, Iaconetta G, de Divitiis E, Tschabitscher M: Endoscopic transnasal approach to the cavernous sinus versus transcranial route: Anatomic study. **Neurosurgery** 56 [Suppl 2]:379–389, 2005.
14. Cavallo LM, Messina A, Cappabianca P, Esposito F, de Divitiis E, Tschabitscher M: Endoscopic endonasal surgery of the midline skull base: Anatomical study and clinical considerations. **Neurosurg Focus** 19:E2, 2005.
15. Cavallo LM, Messina A, Gardner P, Esposito F, Kassam AB, Cappabianca P, de Diviitis E, Tschabitscher M: Extended endoscopic endonasal approach to the pterygopalatine fossa: Anatomical study and clinical considerations. **Neurosurg Focus** 19:E5, 2005.
16. Ciric I, Ragin A, Baumgartner C, Pierce D: Complications of transsphenoidal surgery: Results of a national survey, review of the literature, and personal experience. **Neurosurgery** 40:225–237, 1997.
17. Couldwell WT, Weiss MH, Rabb C, Liu JK, Apfelbaum RI, Fukushima T: Variations on the standard transsphenoidal approach to the sellar region, with emphasis on the extended approaches and parasellar approaches: Surgical experience in 105 cases. **Neurosurgery** 55:539–550, 2004.
18. Cushing H: The Weir Mitchell Lecture: Surgical experiences with pituitary disorders. **Jour A M A** 63:1515–1525, 1914.
19. de Divitiis E, Cappabianca P, Cavallo LM: Endoscopic transsphenoidal approach: Adaptability of the procedure to different sellar lesions. **Neurosurgery** 51:699–707, 2002.
20. de Divitiis E, Cavallo LM, Cappabianca P, Esposito F: Extended endoscopic endonasal transsphenoidal approach for the removal of suprasellar tumors: Part 2. **Neurosurgery** 60:46–59, 2007.
21. Deschler DG, Gutin PH, Mamelak AN, McDermott MW, Kaplan MJ: Complications of anterior skull base surgery. **Skull Base Surg** 6:113–118, 1996.
22. Dusick JR, Esposito F, Kelly DF, Cohan P, DeSalles A, Becker DP, Martin NA: The extended direct endonasal transsphenoidal approach for nonadenomatous suprasellar tumors. **J Neurosurg** 102:832–841, 2005.
23. Frank G, Pasquini E: Endoscopic endonasal cavernous sinus surgery, with special reference to pituitary adenomas. **Front Horm Res** 34:64–82, 2006.
24. Frank G, Pasquini E, Doglietto F, Mazzatenta D, Sciarretta V, Farneti G, Calbucci F: The endoscopic extended transsphenoidal approach for craniopharyngiomas. **Neurosurgery** 59 [Suppl 1]:ONS75–83, 2006.
25. Frank G, Pasquini E, Mazzatenta D: Extended transsphenoidal approach. **J Neurosurg** 95:917–918, 2001.
26. Hadad G, Bassagasteguy L, Carrau RL, Mataza JC, Kassam A, Snyderman CH, Mintz A: A novel reconstructive technique after endoscopic expanded endonasal approaches: Vascular pedicle nasoseptal flap. **Laryngoscope** 116:1882–1886, 2006.
27. Hirsch O: Endonasal method of removal of hypophyseal tumors: With a report of two successful cases. **JAMA** 55:772 –774, 1910.
28. Jho HD: Endoscopic transsphenoidal surgery. **J Neurooncol** 54:187–195, 2001.
29. Jho HD, Ha HG: Endoscopic endonasal skull base surgery: Part 1—The midline anterior fossa skull base. **Minim Invasive Neurosurg** 47:1–8, 2004.
30. Jho HD, Ha HG: Endoscopic endonasal skull base surgery: Part 2—The cavernous sinus. **Minim Invasive Neurosurg** 47:9–15, 2004.
31. Jho HD, Ha HG: Endoscopic endonasal skull base surgery: Part 3—The clivus and posterior fossa. **Minim Invasive Neurosurg** 47:16–23, 2004.
32. Kaptain GJ, Vincent DA, Sheehan JP, Laws ER Jr: Transsphenoidal approaches for the extracapsular resection of midline suprasellar and anterior cranial base lesions. **Neurosurgery** 49:94–101, 2001.
33. Kassam A, Carrau RL, Snyderman CH, Gardner P, Mintz A: Evolution of reconstructive techniques following endoscopic expanded endonasal approaches. **Neurosurg Focus** 19:E8, 2005.
34. 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.
35. Kassam AB, Snyderman C, Gardner P, Carrau R, Spiro R: The expanded endonasal approach: A fully endoscopic transnasal approach and resection of the odontoid process—Technical case report. **Neurosurgery** 57 [Suppl]:E213, 2005.
36. Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL: Expanded endonasal approach: The rostrocaudal axis—Part I: Crista galli to the sella turcica. **Neurosurg Focus** 19:E3, 2005.
37. Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL: Expanded endonasal approach: The rostrocaudal axis—Part II: Posterior clinoids to the foramen magnum. **Neurosurg Focus** 19:E4, 2005.
38. Kassam A, Thomas AJ, Snyderman C, Carrau R, Gardner P, Mintz A, Kanaan H, Horowitz M, Pollack IF: Fully endoscopic expanded endonasal approach treating skull base lesions in pediatric patients. **J Neurosurg** 106[Suppl 2]:77–86, 2007.
39. Laufer I, Anand VK, Schwartz TH: Endoscopic endonasal extended transsphenoidal, transplanum transtuberculum approach for resection of suprasellar lesions. **J Neurosurg** 106:400–406, 2007.
40. Laws ER Jr: Transphenoidal removal of craniopharyngioma. **Pediatr Neurosurg** 21:57–63, 1994.

41. Laws ER Jr: Vascular complications of transsphenoidal surgery. **Pituitary** 2:63–70, 1999.
42. Locatelli D, Rampa F, Acchiardi I, Bignami M, De Bernardi F, Castelnuovo P: Endoscopic endonasal approaches for repair of cerebrospinal fluid leaks: Nine-year experience. **Neurosurgery** 58 [Suppl 2]:ONS-246–ONS-257, 2006.
43. Locatelli D, Rampa F, Acchiardi I, Bignami M, Pistochini A, Castelnuovo P: Endoscopic endonasal approaches to anterior skull base defects in pediatric patients. **Childs Nerv Syst** 22:1411–1418, 2006.
44. Magro F, Solari D, Cavallo LM, Samii A, Cappabianca P, Paternò V, Lüdemann WO, de Divitiis E, Samii M: The endoscopic endonasal approach to the lateral recess of the sphenoid sinus via the pterygopalatine fossa: Comparison of endoscopic and radiological landmarks. **Neurosurgery** 59 [Suppl 2]:ONS237–ONS243, 2006.
45. Messerklinger W: Background and evolution of endoscopic sinus surgery. **Ear Nose Throat J** 73:449–450, 1994.
46. Origitano TC, Petruzzelli GJ, Leonetti JP, Vandevender D: Combined anterior and anterolateral approaches to the cranial base: Complication analysis, avoidance, and management. **Neurosurgery** 58 [Suppl 2]:ONS327–ONS337, 2006.
47. Pasquini E, Sciarretta V, Farneti G, Mazzatenta D, Modugno GC, Frank G: Endoscopic treatment of encephaloceles of the lateral wall of the sphenoid sinus. **Minim Invasive Neurosurg** 47:209–213, 2004.
48. Pasquini E, Sciarretta V, Frank G, Cantaroni C, Modugno GC, Mazzatenta D, Farneti G: Endoscopic treatment of benign tumors of the nose and paranasal sinuses. **Otolaryngol Head Neck Surg** 131:180–186, 2004.
49. Patel SG, Singh B, Polluri A, Bridger PG, Cantu G, Cheesman AD, deSa GM, Donald P, Fliss D, Gullane P, Janecka I, Kamata SE, Kowalski LP, Kraus DH, Levine PA, dos Santos LR, Pradhan S, Schramm V, Snyderman C, Wei WI, Shah JP: Craniofacial surgery for malignant skull base tumors: Report of an international collaborative study. **Cancer** 98:1179–1187, 2003.
50. Schwartz TH, Anand VK: The endoscopic, endonasal transsphenoidal approach to the sella, in Anand VK, Schwartz TH (eds): *Practical Endoscopic Skull Base Surgery.* San Diego, Plural Publishing, 2007, pp 89–104.
51. Schwartz TH, Anand VK: The endoscopic, transethmoidal, transcribriform approach to the anterior cranial fossa, in Anand VK, Schwartz TH (eds): *Practical Endoscopic Skull Base Surgery.* San Diego, Plural Publishing, 2007, pp 135–154.
52. Sekhar LN, Nanda A, Sen CN, Snyderman CN, Janecka IP: The extended frontal approach to tumors of the anterior, middle, and posterior skull base. **J Neurosurg** 76:198–206, 1992.
53. Sen CN, Sekhar LN: An extreme lateral approach to intradural lesions of the cervical spine and foramen magnum. **Neurosurgery** 27:197–204, 1990.
54. Snyderman C, Kassam A, Carrau R, Mintz A, Gardner P, Prevedello DM: Acquisition of surgical skills for endonasal skull base surgery: A training program. **Laryngoscope** 117:699–705, 2007.
55. Solari D, Magro F, Cappabianca P, Cavallo LM, Samii A, Esposito F, Paternò V, De Divitiis E, Samii M: Anatomical study of the pterygopalatine fossa using an endoscopic endonasal approach: Spatial relations and distances between surgical landmarks. **J Neurosurg** 106:157–163, 2007.
56. Stamm AC, Pignatari SS, Vellutini E: Transnasal endoscopic surgical approaches to the clivus. **Otolaryngol Clin North Am** 39:639–656, 2006.
57. Stammberger H: The evolution of functional endoscopic sinus surgery. **Ear Nose Throat J** 73:454–455, 1994.
58. Tabaee A, Anand VK, Brown SM, Lin JW, Schwartz TH: Algorithm for reconstruction after endoscopic pituitary skull base surgery. **Laryngoscope** 117:1133–1137, 2007.
59. Tabaee A, Plakantonakis D, Schwartz TH, Anand VK: Reconstruction after endoscopic skull base surgery, in Anand VK, Schwartz TH (eds): *Practical Endoscopic Skull Base Surgery.* San Diego, Plural Publishing, 2007, pp 191–202.
60. Unger F, Haselsberger K, Walch C, Stammberger H, Papaefthymiou G: Combined endoscopic surgery and radiosurgery as treatment modality for olfactory neuroblastoma (esthesioneuroblastoma). **Acta Neurochir (Wien)** 147:595–602, 2005.
61. van Aken MO, de Marie S, van der Lely AJ, Singh R, van den Berge JH, Poublon RM, Fokkens WJ, Lamberts SW, de Herder WW: Risk factors for meningitis after transsphenoidal surgery. **Clin Infect Dis** 25:852–856, 1997.
62. Weinberger DG, Anand VK, Al-Rawi M, Cheng HJ, Messina AV: Surgical anatomy and variations of the Onodi cell. **Am J Rhinol** 10:365–370, 1996.
63. Weiss MH: Transnasal transsphenoidal approach, in Apuzzo MLJ (ed): *Surgery of the Third Ventricle.* Baltimore, Williams & Wilkins, 1987, pp 476–494.

COMMENTS

This article shows the cooperation between Ted Schwartz, a young brilliant neurosurgeon dedicated to the transsphenoidal approach and cranial base surgery, and Vijay Anand, an otorhinolaryngologist with a long-standing background in sinonasal pathological conditions via the endoscopic approach which has determined the growth of an endoscopic cranial base center in New York. Their book, *Practical Endoscopic Skull Base Surgery,* with multiple cooperative efforts, focused more on the technical aspects of the different possible approaches and has been recently published. This article deals with the concepts behind the approaches and the preliminary results, which look quite interesting.

Both our group and the Pittsburgh group of Kassam have artificially divided the endoscopic endonasal cranial base approaches in three main steps: exposure of the lesion, management, and reconstruction. Concerning the first step, they try to simplify the whole strategy with reference to targets and corridors, which is clear and easy to understand. I would add to their indications the need to use the micro-Doppler probe to check the position of the carotid artery, as suggested by Kelly's team (2), in addition to neuronavigation. With regard to the second phase, I would underline the importance of adequate instruments and the need for new, more dedicated tools to reach and manage properly all of the different pathological entities. Regarding the third step, i.e., the reconstruction, this is still an evolving field and the solutions reported by the authors (e.g., multilayer reconstruction, gasket seal closure, and nasoseptal vascularized flap) represent up-to-date resources to minimize complications related to reconstruction. We do not use lumbar drainage as much as they do, and this use could be explained by the high number of cerebrospinal fluid (CSF) leaks among their 150 case series (n = 21 or 14%) and their diagnostic use of fluorescein. We reserve the use of lumbar drainage only for minor postoperative leaks or for instances in which reconstruction does not seem to be really watertight. For postoperative CSF leaks, we prefer to reseal the approach under local anesthesia either with reinforcing the defect just where it leaks or under general anesthesia.

Another difference between our experience and their report concerns the subgroups among the respective series: starting in 1997 we first performed more than 400 standard endoscopic transsphenoidal approaches mostly for pituitary adenomas before performing, in the last 3 years, more than 40 extended approaches to the cranial base. We like to stress the importance of starting with easier procedures (i.e., pituitary adenomas for neurosurgeons and CSF leaks for ear, nose, and throat surgeons) and then moving to more complex procedures, according to defined criteria (1, 3).

In summary, all this work of the pioneers and contributors in both the United States and in Europe should move the neurosurgical community to further accept the modernity and the efficacy of such approaches and cooperative efforts, without any preconceptions on the final judgement regarding which way, transcranial or transnasal, is better. At present, new solutions are increasingly used in selected centers for selected indications, and we must be able to understand which of them is optimal for each individual patient.

Paolo Cappabianca
Naples, Italy

1. Cavallo LM, Dal Fabbro M, Jalalod'din H, Messina A, Esposito I, Esposito F, de Divitiis E, Cappabianca P: Endoscopic endonasal transsphenoidal surgery. Before scrubbing in: Tips and tricks. **Surg Neurol** 67:342–347, 2007.
2. Dusick JR, Esposito F, Malkasian D, Kelly DF: Avoidance of carotid artery injuries in transsphenoidal surgery with the Doppler probe and micro-hook blades. **Neurosurgery** 60 [Suppl 2]:322–329, 2007.
3. Snyderman C, Kassam A, Carrau R, Mintz A, Gardner P, Prevedello DM: Acquisition of surgical skills for endonasal skull base surgery: A training program. **Laryngoscope** 117:699–705, 2007.

In this article, the authors retrospectively reviewed their institutional experience of endoscopic cranial base surgery. They present an interesting and well illustrated compendium of several operative nuances in performing endoscopic approaches to the cranial base and report a personal series of 150 consecutive cases. Their experience over a 3-year period is remarkable, their techniques are elegant, and their results are effective, particularly in case of craniopharyngiomas, for which they achieve 100% total removal.

Although several studies have addressed this topic, this one has the largest series and comes from an institution with early experience in this kind of surgery. On the basis of the authors' suggestions, there are several issues that deserve further discussion. Regarding the new classification of surgical approaches, which is the major goal of the study, they propose a methodology for clarifying the approaches, suggesting consideration of four nasal corridors, nine cranial base approaches, and 12 intracranial targets. Their reason is that, in their opinion, there has been low proliferation of these minimal access techniques owing to the ambiguity in the previous classifications. It is, however, difficult to follow the reason behind their statement, because, despite such "ambiguity," on one hand reports of new cases increase day by day and, on the other hand, this new classification perspective does not seem to clarify the existing ones but, rather, may increase confusion among new practitioners.

There are some reservations with regard to their policy about intended subtotal resection. Although we understand the general principles the authors propose, we think that many procedures should be performed differently.

Regarding pituitary adenomas involving the lateral compartment of the cavernous sinus, they advise against dealing with such types of tumor owing to the risk of increasing functional disturbances and, despite the fact that they nicely describe the technique to approach the lateral compartment of the cavernous sinus, prefer to leave the residual tumor as appropriate for radiotherapy. The modern endonasal extended techniques (such as the transpterygoid route described by the authors) usually allow adequate exposure of both the compartments of the cavernous sinus with a reduction of surgical morbidity and a high rate of gross total removal. Only when that is not feasible is tumor debulking an important factor for the efficacy of the radiation therapy.

Regarding tuberculum sellae meningiomas, there are several issues that arise. Because these tumors are lesions with different extensions, it is clear that the relevance is in identifying the subgroup that may have the potential to be resected via the endonasal approach. Meningiomas extending into the optic canal(s) and/or with extension into the cavernous sinus, with a large attachment and main vessel encasement, are a more complex tumor subtype and represent a very difficult task for any neurosurgical approach. In our experience, the rigorous selection of the patient suitable for the endonasal approach is still the crucial point at present. Thus, a transsphenoidal approach should be used selectively in patients who are thought to have a lesion 1) of small or medium size, 2) without lateral extension, 3) with limited dural attachment, 4) without vascular encasement, and 5) without calcifications, as a basis of their symptoms. In this way, the tumor can be exposed consistently to assure that the lesion is easily identified and removed. In the ongoing debate concerning open surgery versus endoscopic surgery, the issue of safe and radical removal is important; it is well known that the grade of resection is correlated with the recurrence rate. Again, there is no convincing evidence that two-stage approaches (low route before and high route after) represent the best way to manage these tumors.

In our opinion, an honest and rigorous evaluation of the results made by both endoscopic and open surgeons would certainly be a great first step to clarify the algorithm for treatment.

In conclusion, the authors have presented a somewhat controversial but stimulating report; their data provide a valuable source for potential discussion.

Felice Esposito
Enrico de Divitiis
Naples, Italy

In this article, Schwartz et al. present their scheme of classification of endoscopic approaches to the cranial base. Other than being a system of classification, it is very difficult to evaluate their work, because no results or complications are presented for each set of operations. Endoscopic surgery for pituitary tumors has now become commonplace; however, for all other types of tumors, the approaches and results are under evaluation. There have been very few reports of the extent of tumor resection and the long-term results and no detailed reports about complications.

Since the early days of cranial base surgery (as in some of the articles quoted by the authors), the results have improved dramatically and complications have decreased for cranial base approaches to intracranial tumors (and vascular lesions), but perhaps this information not been adequately publicized. Endoscopic approaches have the advantages of no craniotomy and no brain retraction. However, the monocular vision provided, the obscuration of the field in the event of significant bleeding, the need to dissect critical neurovascular structures at a distance, and the inability to respond quickly to vascular complications can be limiting. CSF leakage remains a problem and in some patients can become very difficult to resolve. Total tumor removal is more difficult than with cranial approaches, and the surgeon thus will have to rely on adjuvant radiotherapy or observation in several patients. Nevertheless, this is an expanding field of neurosurgery. The leaders in this field need to provide us with an honest assessment of the technical difficulties, immediate results, complications, and long-term results.

Laligam N. Sekhar
Seattle, Washington

Over the past decade, there has been significant interest in the development of expanded endoscopic endonasal approaches to treat a variety of lesions affecting the cranial base. One fundamental reason behind this initiative was the need for more direct routes to the cranial base in hopes of minimizing morbidity and optimizing surgical outcomes. We believe that this goal represents the guiding principle for the development of these techniques. The endonasal corridor complements those provided by open techniques, thus allowing complete access to 360 degrees of the ventral skull base. Therefore, the endonasal corridor can either be an alternative or an adjunct to other skull base approaches, depending on the extension and nature of the lesion. This continuously evolving paradigm shift, to develop, standardize, and popularize the expanded endonasal endoscopic approaches, has been made possible by the confluence of enabling technology with an improved understanding (and reinterpretation) of the regional anatomy (as defined by Professor Rhoton and others) and with the adoption of the concept of team surgery. A multinational effort comprising a decade's worth of work based on hundreds of cases from around the world, spearheaded this evolution (12). Schwartz et al. have undertaken this challenging surgical evolution and emphasize the importance of the joint efforts of neurosurgeons and otolaryngologists. However, we are compelled to discuss several issues presented by the authors.

Schwartz et al. provide us with a manuscript that aspires to "create a comprehensive classification system of various endoscopic cranial base approaches and describe their indications" so that "clear understanding of the possible approaches . . . will facilitate the propagation of . . . endoscopic cranial base techniques." Indeed, a classification scheme is necessary to facilitate preoperative planning, allow comparison of reported surgical series, promote effective teaching of surgical techniques, and lead to further refinement of surgical techniques. Therefore, an ideal classification system would be simple, intuitive, anatomically based and reproducible and would yield consistent results. Although not directly used as part of the classification, outcomes are part of the foundation for any such system.

The authors' initial premise is that the published literature is confusing, and, therefore, they propose a classification system based on three factors: target, corridor, and surgical approach. In an effort to do so, they define 12 possible targets, four corridors, and nine approaches. The guiding principle, in the authors' opinion, is the surgical target, and they suggest that there are 12 possible targets in the cranial base that establish the use of a corresponding corridor. In our opinion, one could describe innumerable ventral cranial base targets, and each of these would be associated with multiple subdivisions. Therefore, creating separate subdivisions based on targets, often millimeters apart, does not simplify our understanding of these techniques and seemingly adds to the confusion. We find multiple practical issues with the application of this system, principally from the anatomic standpoint. For example, considering the authors' classification for the anterior cranial base, they segregate the olfactory groove, cribriform plate, and the rest of the anterior cranial fossa, placing them into two different targets. We do not appreciate the advantage of separating the anterior fossa approaches into medial and lateral components. We recognize that the transcribriform approach (requiring wide exposure of the median anterior cranial base) can be unilateral in select patients. However, the separation of the area into a medial and lateral component is a moot point because the need to access the medial region of the anterior fossa in isolation is rare; thus, such a division just adds complexity and confusion. In addition, some areas described as a target by the authors are best considered as a corridor. The pterygopalatine fossa, for instance, may be considered a target; however, from the cranial base surgeon's standpoint it is more useful to consider its importance as a corridor to the paramedian cranial base. Conversely, this classification fails to include several important "targets," such as Meckel's cave, the intra- and extraconal orbital anatomy, occipital condyle, and jugular fossa, among others. Naming each of these targets in the manner proposed by the authors would make this classification system unmanageable. This is somewhat reflected in the figures, which, although aesthetically pleasing, fail to clarify the classification.

We also identify various conceptual problems with the proposed corridors. A transnasal corridor is a common denominator to all endoscopic endonasal techniques; thus, to use the term "transnasal" as a modifier for other approaches seems redundant. Conversely, a pure "nasal corridor" is rarely adequate to surgically expose the anterior cranial base, which often requires the removal of the ethmoid sinuses. Even more, a wide exposure of this region often requires frontal and/or sphenoid sinusotomies. Suggesting the addition of corridor subtypes to further classify the approaches further increases the complexity of the classification system. The authors use the terms transnasal approach and transnasal corridor interchangeably throughout the manuscript, adding to the confusion. Using the proposed classification, a sellar pituitary adenoma would now be operated on via an endoscopic transnasal corridor plus a transsphenoidal corridor with a transsellar approach. This problem increases as we apply the proposed corridors to patients with neoplasms requiring a transplanum/transtubercular approach. This would now be referred to as endoscopic transnasal, transsphenoidal, and transethmoidal corridors, with a transplanum/transtubercular approach as opposed to an endoscopic endonasal transplanum approach (6).

It is apparent that this article is not an outcomes analysis and should not be used to evaluate the effectiveness or morbidity of endonasal cranial base surgery. As such, the authors do not provide information regarding demographics or symptomatology. A pathology distribution is presented but the proportion of pituitary adenomas subtypes (functional versus nonfunctional) is not provided. Their data regarding patients with meningiomas does not take into account the location of the tumors. The degree of tumor resection is presented in general terms without volumetric analyses, and there is no information regarding complications, recurrences, or endocrine or visual outcomes. This information should be the minimum for future publications intending to address outcomes.

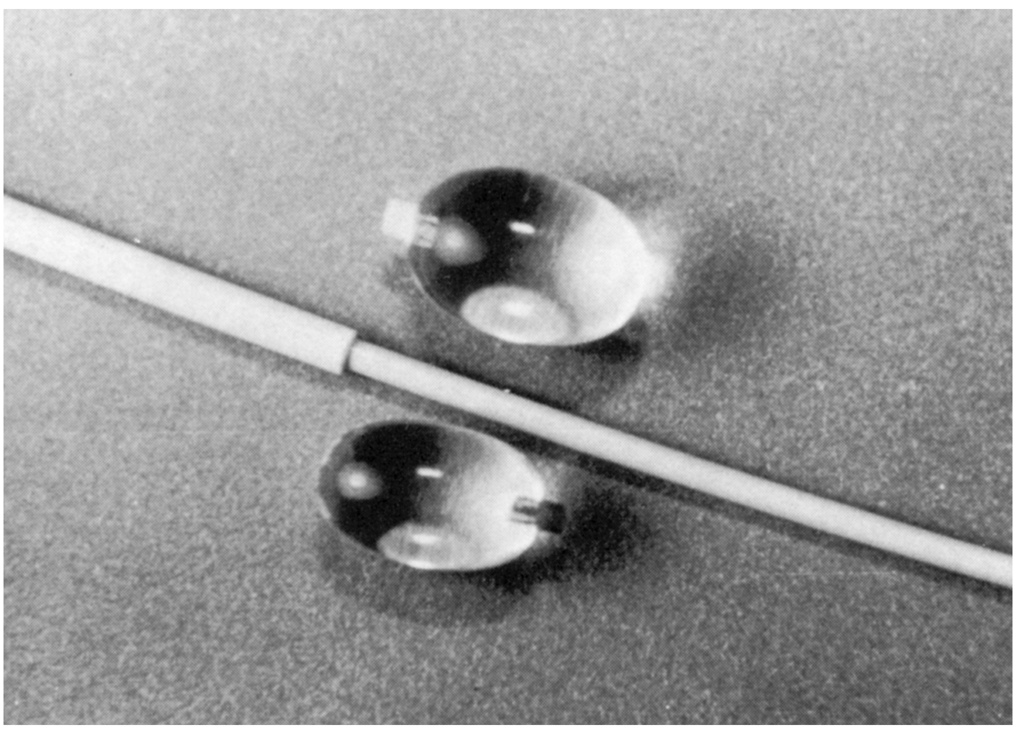
In their discussion of various surgical approaches, the authors redescribe well documented anatomical concepts and surgical techniques that have been published by multiple authors (1–10). Although this review may be of some value for the reader, there is a disturbing lack of direct citations within the actual text wherein these approaches are described. Their reference list is extensive; however, the absence of citations linked directly to the text fails to properly recognize those individuals who have painstakingly mapped out the anatomical landmarks that are the basis for the proposed "corridors" or those surgical pioneers whose innovation facilitated the adoption of these techniques. Instead, this manner of reporting implies that this is new information provided by the authors. Furthermore, it does not provide guidance to those readers who may want to acquire a detailed description of the techniques from the original references.

Furthermore, some of the anatomic and technical considerations offered by the authors are not consistent with our experience using expanded endonasal approaches to treat more than 900 patients over the last decade. It is our experience that most transplanum/transtubercular approaches do not require a superior intercavernous sinus ligation as suggested by the authors. In the majority of these approaches, removal of the bone overlying the anteroinferior sella turcica allows caudal displacement of the sinus, obviating the need for direct transection and thus minimizing bleeding. In their discussion of the transplanum/transtubercular approach, the authors state that the "dissection is then carried out through Liliequist's membrane, either above the optic nerves or toward the anterior communicating artery." We find this statement to be inaccurate both anatomically and in practical application, as Liliequist's membrane is a retrosellar structure and has no surgical relationship to the region of the anterior cerebral arteries (11).

The authors' classification system is based on data that included 150 lesions, of which 97 were in the parasellar area (pituitary tumors, Rathke's cleft cysts, and craniopharyngiomas) and 21 were CSF leaks presumed to have arisen in various areas, thus leaving us with 32 lesions to distribute as targets around the rest of the cranial base. This experience of extrasellar tumors is offered as the foundation of a proposed "comprehensive classification system of various endoscopic cranial base approaches . . . will facilitate the propagation of . . . endoscopic cranial base techniques." We believe that this has not been accomplished by the reported experience. It would seem intuitive that if the goal is to develop a comprehensive classification, then more extensive experience with both endoscopic and external cranial base surgery would be critical. Furthermore, we believe endoscopic techniques augment existing cranial base approaches, which are enduring, creating 360-degree access to this complex area, thus, completing the armamentarium of the contemporary cranial base surgeon.

Carl H. Snyderman
Ricardo L. Carrau
Daniel M. Prevedello
Paul A. Gardner
Amin B. Kassam
Pittsburgh, Pennsylvania

1. Cappabianca P, Frank G, Pasquini E, de Divitiis E, Calbucci F: Extended endoscopic endonasal transsphenoidal approaches to the suprasellar region, planum sphenoidale and clivus, in de Divitiis E, Cappabianca P (eds): *Endoscopic Endonasal Transsphenoidal Surgery.* New York, Springer-Verlag, 2003, pp 176–187.
2. Cavallo LM, Messina A, Gardner P, Esposito F, Kassam AB, Cappabianca P, de Divitiis E, Tschabitscher M: Extended endoscopic endonasal approach to the pterygopalatine fossa: Anatomical study and clinical considerations. **Neurosurg Focus** 19:E5, 2005.
3. Frank G, Pasquini E: Endoscopic endonasal cavernous sinus surgery, with special reference to pituitary adenomas. **Front Horm Res** 34:64–82, 2006.
4. Frank G, Pasquini E, Doglietto F, Mazzatenta D, Sciarretta V, Farneti G, Calbucci F: The endoscopic extended transsphenoidal approach for craniopharyngiomas. **Neurosurgery** 59 [Suppl 1]:ONS75–ONS83, 2006.
5. Frank G, Pasquini E, Mazzatenta D: Extended transsphenoidal approach. **J Neurosurg** 95:917–918, 2001.
6. Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL: Expanded endonasal approach: The rostrocaudal axis. Part I. Crista galli to the sella turcica. **Neurosurg Focus** 19:E3, 2005.
7. Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL: Expanded endonasal approach: The rostrocaudal axis. Part II. Posterior clinoids to the foramen magnum. **Neurosurg Focus** 19:E4, 2005.
8. 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.
9. Kassam AB, Mintz AH, Gardner PA, Horowitz MB, Carrau RL, Snyderman CH: The expanded endonasal approach for an endoscopic transnasal clipping and aneurysmorrhaphy of a large vertebral artery aneurysm: Technical case report. **Neurosurgery** 59 [Suppl 1]:ONSE162–ONSE165, 2006.
10. Kassam AB, Snyderman C, Gardner P, Carrau R, Spiro R: The expanded endonasal approach: A fully endoscopic transnasal approach and resection of the odontoid process: Technical case report. **Neurosurgery** 57 [Suppl 1]:E213, 2005.
11. Lü J, Zhu XI: Microsurgical anatomy of Liliequist's membrane. **Minim Invasive Neurosurg** 46:149–154, 2003.
12. Prevedello DM, Doglietto F, Jane JA Jr, Jagannathan J, Han J, Laws ER Jr: History of endoscopic skull base surgery: Its evolution and current reality. **J Neurosurg** 107:206–213, 2007.



Silicone detachable balloon technology (1990), for treatment of intracranial aneurysms. From, Rumbaugh CL, Wang A, Tsai FY: *Cerebrovascular Disease, Imaging and Interventional Treatment Options*. New York, IGAKU-SHOIN Medical Publishers, Inc., 1995.