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ENDOSCOPIC ENDONASAL RESECTION OF ANTERIOR CRANIAL BASE MENINGIOMAS

OBJECTIVE: The endonasal route may be feasible for the resection of anterior cranial base tumors that abut the paranasal sinuses. There are several case reports and mixed case series discussing this approach. Other than pituitary adenomas, there is a lack of literature describing the outcomes of endonasal approaches for single-tumor types such as meningiomas.

METHODS: In this study, we describe our current endoscopic endonasal technique and demonstrate the feasibility of using it to access anterior cranial base meningiomas from the back wall of the frontal sinus to the sella and laterally to the region of the midorbit. After this discussion, which includes key technical considerations and nuances, we address safety and efficacy by reporting the outcomes of our early experience with endoscopic endonasal resection of 35 anterior cranial base meningiomas.

RESULTS: A total of 35 patients underwent endoscopic endonasal resection of anterior cranial base meningiomas from October 2002 to October 2005. Degree of resection by tumor location was as follows: 10 of the 12 (83%) patients with olfactory groove meningiomas planned for complete resection underwent gross total (seven of 12) or near-total (>95%) (three of 12) resection (67% of all 15 olfactory tumors); 12 of 13 patients (92%) with tuberculum meningiomas underwent gross (11 of 13) or near (>95%) (one of 13) total resection; five patients diagnosed with petroclival meningiomas had successful resection of the parasellar portion of their tumors with relief of visual symptoms (no patients underwent complete resection of their tumors via the endoscopic, endonasal approach); two giant petroclival meningiomas were debulked with 63 and 89% resection, respectively.

All patients experienced resolution or improvement of visual symptoms. No patient experienced permanent worsening of vision after surgery. Only one (3%) patient without preoperative endocrine dysfunction experienced a new, permanent pituitary deficit, diabetes insipidus. One (3%) patient experienced a new neurological deficit after experiencing a hemorrhage 3 weeks after surgery. The postoperative cerebrospinal fluid leak rate was 40% (14 of 35) and varied by tumor location. All leaks were resolved without craniotomy. There were no cases of bacterial meningitis. One patient developed a superinfection of a sterile granuloma from a sinusitis 2 years after surgery. There were two cases of deep venous thrombosis and one pulmonary embolus. There were no operative or perioperative deaths.

CONCLUSION: Cranial base meningiomas can be successfully managed via a purely endoscopic endonasal approach with acceptable morbidity and mortality rates. The extent of resection is guided by patient factors and symptoms, not by approach. This series had a high cerebrospinal fluid leak rate. With the evolution of new reconstruction techniques, these rates have been substantially reduced.

KEY WORDS: Cranial base, Endonasal, Endoscopic, Meningioma, Outcomes, Skull base

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Anterior cranial base meningiomas are a heterogenous group of neoplasms that can involve the crista galli, olfactory

groove, planum sphenoidale, tuberculum sellae, anterior clinoid process, parasellar regions, and petrous ridge. These tumors originate and

derive the majority of their vascular supply from the base of the cranium, deep to critical neurovascular structures. Ideally, approaches to these lesions provide early access to their vascular supply and enough exposure to allow the resection of all involved bone and dura and minimize brain retraction and manipulation of critical neurovascular structures. The frontal lobes, particularly when affected by subpial invasion and venous engorgement, and the optic apparatus, which has had chronic compression with secondary ischemia, are most vulnerable. Even the slightest manipulation can result in compromise of function (1, 6, 12, 14, 33, 45). Approaches such as the anterior transbasal (13, 35) and orbitozygomatic (32) were developed to provide direct access to such tumors while addressing these issues. Although these conventional cranial base approaches have reduced patient morbidity by removing bony structures to limit brain retraction (5), they still require some manipulation by virtue of their lateral-to-medial trajectory (30, 41).

Conceptually, a more direct approach to the ventral cranial base via a midline trajectory that completely obviates any manipulation of critical neurovascular structures would be desirable. Expansion of the transsphenoidal route provides such direct access. For this to be a consideration for anterior cranial base meningiomas, feasibility of access and resection must be demonstrated, followed closely by an evaluation of safety and efficacy. In this report, we present our experience over the course of 4 years to demonstrate the feasibility and evaluate safety and early efficacy of addressing anterior cranial base meningiomas via a fully endoscopic transnasal route, the endoscopic expanded endonasal approach (EEA).

PATIENTS AND METHODS

Patient Characteristics

With approval from the University of Pittsburgh Medical Center Institutional Review Board, a medical record and imaging review of all patients who had undergone endoscopic endonasal resection for a meningioma was performed. Thirty-eight patients fit this criterion from October 2002 to October 2005. Three patients were excluded because they had tumors that were not primarily anterior cranial base: one foramen magnum, one clival, and one cerebellopontine angle with petroclival extension.

Thus, 35 patients who underwent purely endoscopic expanded endonasal resection of anterior cranial base meningiomas at the University of Pittsburgh Medical Center between October 2002 and October 2005 were included in the study (Table 1). Eighty-three percent (29 of 35) were women, and the mean age was 55 years (age range, 39–79 yr).

Tumor locations were as follows: 15 olfactory groove and/or planum sphenoidale, 13 tuberculum, five primary parasellar with secondary petrous involvement, and two primary petroclival tumors with significant secondary parasellar extension. These last two tumors were included in this anterior base series because most of the tumors were parasellar with a chief symptom of vision loss in the patients. Sixty-six percent (23 of 35) of patients presented with evidence of optic nerve, chiasm, or tract compression. Twenty-six percent (nine of 35) of the patients had undergone previous treatment. Seven (20%) individuals had previously undergone surgical resection (six craniotomies, one transsphenoidal resection) and two had undergone empiric radio-

surgery. Three of the craniotomy patients also underwent radiosurgery after their craniotomy. One (3%) additional patient had undergone endonasal surgery for a sinonasal cavity adenoid cystic tumor.

Operative Technique

In this section, we will first describe the general principles of the binarial approach (through both nares) and then discuss the nuances of the extradural and intradural phases of the transplanum/trans-tuberculum module and the transcribriform module. Many of the concepts and techniques have been previously described in more detail by other authors (19, 20, 22, 23).

Patient Positioning and Preparation

Intraoperative, frameless stereotactic image guidance (Stryker, Kalamazoo, MI) was used in all cases. This technology is valuable for confirming critical structures, allowing for wide exposure and targeted resection. Magnetic resonance imaging (MRI) is useful when soft-tissue visualization is paramount. In the case of “expanded” approaches (beyond the sella/tuberculum), however, we prefer fine-cut computed tomographic (CT) angiography because it allows for simultaneous imaging of the osseous, vascular, and soft-tissue anatomy involved in a targeted approach.

The patient is positioned supine with his or her head in a neutral or slightly extended position in a Mayfield head holder. We prefer the patient to be completely immobilized because it prevents the potential for movement during detailed drilling and dissection. Somatosensory evoked potentials are monitored in all cases; brainstem evoked responses and cranial nerve electromyography are performed as appropriate.

Nasal preparation is initiated by packing oxymetazoline-soaked pledgets into both nares to decongest the nasal cavity. The midface is then swabbed with Betadine (Purdue Pharma, Stamford, CT), taking care to avoid the patient’s eyes, and the patient is given a third- or fourth-generation cephalosporin antibiotic for perioperative prophylaxis. The sinuses and mucosa are not sterilized. Depending upon surgeon preference, the nasal mucosa may be injected with a mixture of lidocaine and epinephrine at the beginning of the procedure.

General Exposure of the Sphenoid Sinus

The main goal of the initial exposure is to facilitate bimanual dissection. The ability to use both hands during dissection (one instrument within each nostril) is critical. The initial binarial exposure for an EEA is generally independent of the specific target because almost all cases begin with accessing the sphenoid sinus. A zero-degree endoscope with handheld irrigation or an irrigating sheath is used during the exposure for all expanded approaches. Eventually, the endoscope and suction are placed in the right nostril and a dissecting instrument or drill in the left nostril. Wide bilateral sphenoidotomies are performed, extending to the level of the medial pterygoid plates. The posterior nasal septal artery is coagulated and transected on the side contralateral to the mucosal flap (see section on reconstruction). A small portion (approximately 1 cm) of the posterior edge of the nasal septum is resected, facilitating the bilateral introduction of instruments without continuously pushing the septum into the endoscope and compromising visualization.

Having completed the binarial approach to the sphenoid sinus, exposure of the pituitary fossa can proceed. The principle for this exposure is the creation of a single large, rectangular cavity from the sphenoid sinus, thus allowing for progressive, unhindered endoscope advancement toward the target. This exposure is critical not only for visualization and illumination but also for control in the event of bleed-

TABLE 1. Patients who underwent the endoscopic endonasal approach for anterior base meningiomas, in chronological order of first surgery^a

Patient	Age (yr)/Sex	EEA date	Tumor location	Presentation	Previous treatment	Preoperative volume (cm ³) ^b
1	61/F	10/04/02	Tuberculum	Vision and mental status changes	Craniotomy	7.9
2	79/F	11/26/02	Olfactory groove	Vision loss (Left eye already blind)	Craniotomy	25.7
3	47/F	02/20/03	Olfactory groove	Papilledema/vision loss	None	45.8
4	42/F	04/09/03	Parasellar with petroclival extension	Endocrine dysfunction	Radiosurgery	5.0
5	48/M	04/28/03	Olfactory groove	Papilledema/vision loss	None	16.4
6	41/F	04/28/03	Tuberculum	Vision loss (chiasm/right optic nerve compression)	None	38.3
7	53/F	07/17/03 07/21/03 (2 stage)	Tuberculum	Vision loss (chiasm compression)	None	4.0
8	46/F	09/03/03	Tuberculum	Progressive vision loss (superimposed on congenital monocular blindness)	None	12.0
9	65/F	11/05/03 11/10/03 (2 stage)	Olfactory groove	Headache	None	82.7
10	35/F	11/12/03 11/13/03 (2 stage)	Olfactory groove	Headache, vision change with papilledema	None	64.3
11	47/F	12/19/03	Parasellar with petroclival extension	Headache, vision loss, fatigue	None	19.6
12	72/M	01/19/04	Tuberculum	Vision loss	None	2.2
13	38/F	03/08/04 03/10/04 (2 stage)	Petroclival with parasellar involvement	Headache	None	21.1
14	65/F	03/15/04	Tuberculum	Vision loss	Craniotomy (20 years earlier)	6.7
15	43/M	03/09/04 03/31/04 04/08/04 (3 stage)	Petroclival with parasellar involvement	Headache, bitemporal hemianopsia, right ptosis, right facial numbness/tingling, cranial tumor embolization complicated by right carotid artery occlusion with left hemiparesis Cranial Nerve VI palsy, pituitary dysfunction		90.9
16	55/F	04/26/04	Tuberculum	Decreased vision	None	6.0
17	53/F	05/24/04	Parasellar/petroclival	Vision loss	Radiosurgery	10.8
18	57/F	07/08/04 07/14/04	Olfactory groove	Headache, confusion, incoordination, vision loss	None	7.0
19	72/F	07/30/04	Parasellar/petroclival	Headache, vision loss	Craniotomy; radiosurgery	3.4
20	39/F	09/01/04	Tuberculum	Vision loss	None	8.6
21	44/F	10/04/04	Tuberculum	Vision loss, headache	None	4.1
22	58/F	11/10/04	Tuberculum	Significant residual tumor and CSF leak after previous surgery	Previous TSR with pituitary gland dysfunction and CSF leak	1.4
23	74/F	12/17/04	Olfactory groove	Seizure	None	37.5
24	58/F	01/14/05	Tuberculum	Incidental	None	53.7

TABLE 1. Continued

Patient	Age (yr)/Sex	EEA date	Tumor location	Presentation	Previous treatment	Preoperative volume (cm ³) ^b
25	47/M	02/03/05 02/28/05 (2 stage)	Olfactory groove	Headache	None	109.3
26	53/F	02/04/05	Olfactory groove	Anosmia, sinusitis	Previous endonasal adenoid cystic tumor resection	64.7
27	74/F	03/08/05	Olfactory groove	Headache, dementia, vision loss	None	108.4
28	68/M	04/20/05	Parasellar/petroclival	Ophthalmoplegia with tumor recurrence	Craniotomy × 2; GKRS	34.4
29	65/F	04/28/04 05/02/05 (2 stage)	Olfactory groove	Vision loss	None	52.1
30	55/F	05/12/05	Olfactory groove	Incidental	None	10.5
31	40/F	06/02/05	Tuberculum	Vision loss, fatigue	None	9.4
32	47/F	06/06/05	Tuberculum	Headache, minor vision loss	None	2.1
33	48/M	08/22/05	Recurrent olfactory groove	recurrence/left eye vision loss, L V2 numbness	Craniotomy × 2; GKRS	31.7
34	52/F	09/02/05	Medial orbital apex/lateral olfactory	Incidental	None	3.1
35	70/F	10/14/05	Olfactory groove	Seizure	None	32.5

^a EEA, endoscopic endonasal approach; CSF, cerebrospinal fluid; TSR, transsphenoidal resection; GKRS, gamma knife radiosurgery; LV2, left V2 segment of the vertebral artery. Patients are listed in chronological order of first surgery.

^b Determined using measurements via Stentor radiology software (Phillips Global PACS, Brisbane, CA).

ing. It is critical in such circumstances that the endoscope and instruments be maneuverable with minimal impingement from superficial peripheral bone and soft tissue.

The first step toward this exposure is to widen the sphenoidotomy even further to include the lateral recess of the sphenoid lateral to the level of the carotid canal. The next step is to extend anteriorly, exposing and removing the posterior ethmoid air cells as needed to define the planum-tuberculum junction. Finally, the sphenoid floor is reduced to the level of the clival recess, with the surgeon removing any residual rostrum or posterior vomer. By reducing the floor of the sphenoid, a more caudal-to-rostral trajectory into the sellar and suprasellar space is created. Any intrasphenoidal septations can then be reduced with caution, as the paramedian septations will inevitably lead to the carotid canals. The sphenoid sinus mucosa is removed and the resultant venous bleeding easily controlled over the course of a few minutes with warm irrigation.

All steps outlined previously culminate to create a single rectangular cavity and allow for the identification of key anatomic landmarks (Fig. 1). Specifically, the medial and lateral opticocarotid recesses (OCR), the carotid protuberance within the parasellar space, the sellar face, clival recess, and strut of tuberculum bone overlying the superior intercavernous sinus (SIS) are important landmarks for any parasellar approach. The key anatomic landmark in this region remains the “medial” OCR (mOCR), which is located on the sphenoid sinus side of the medial termination of the optic strut. This recess corresponds to the pneumatization of the middle/medial clinoid process (7, 37), in the same way that the lateral, or “true,” OCR corresponds to the lateral termination of the optic strut. The lateral OCR represents the pneumatization of the optic strut, which may extend into the anterior clinoid and

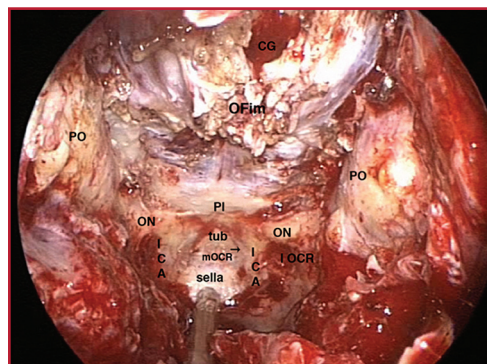


FIGURE 1. Endoscopic view after wide sphenoidotomy, transplanum, and transcribriform approach; a single, anterior base cavity is formed. The planum sphenoidale and cribriform plate have been removed from the lamina papyracea to the lamina papyracea. ICA, parasellar carotid protuberance; mOCR, medial opticocarotid recess; IOCR, lateral opticocarotid recess; ON, optic nerve (bony protuberance); PI, planum sphenoidale; tub, tuberculum sellae; PO, periorbita; OFim, olfactory filaments; CG, residual crista galli.

is generally more prominent than the pneumatization of the middle clinoid. Next, the portion of the tuberculum (which we refer to as the tubercular strut) connecting the two medial clinoids and mOCRs can be

drilled until it is eggshell-thin and then removed along with the medial clinoids. Entry at the level of the mOCR allows for simultaneous access to the carotid canal, optic canal, sella, frontal fossa, and medial cavernous sinus. As such, it is analogous to the “keyhole” used during a pterional craniotomy.

Expanded Approaches: Rostral Extension

Building upon our endoscopic pituitary experience, we proceeded to apply the same principles of exposure and tumor resection to create a series of modular, expanded approaches. Rostral extension provided direct access to the suprasellar cistern without traversing the sella and in the absence of sellar expansion. These transtuberular/transplanum and transcribriform approaches are described herein.

Transtuberulum/Transplanum Extradural Exposure

Once the bilateral approach to the sphenoid is completed, rostral extension is initiated by undertaking wide, bilateral posterior ethmoidectomies. The ethmoid septations are drilled flush with the anterior cranial base and reduced laterally to the level of the lamina papyracea, providing for the widest exposure possible. For a transplanum approach, the anterior margin of the exposure need not extend anterior to the level of the posterior ethmoidal arteries. This, in combination with leaving the most rostral margin of the nasal septum attached to the cranial base and leaving one middle turbinate intact, will minimize the risk of compromising olfaction.

Next, the planum sphenoidale is drilled in an anterior-to-posterior direction. Once the planum is eggshell-thin, it can be fractured inferiorly using a blunt dissector. The most rostral portion of the sella can be opened to expose the SIS. To access the SIS, the overlying bony strut is drilled, or “eggshelled,” and fractured inferiorly. A 1-mm, 45-degree Kerrison can be used to dissect and obtain a controlled fracture. Downward displacement of the SIS will allow for direct access to the supratuberular and retrotuberular portion of the tumor in the suprasellar space. Removal of this segment of bone is adequate to allow this without transecting the SIS. Bleeding can be controlled with “sandwiches” of Avitene microfibrillar collagen hemostat (CR Bard, Inc., Murray Hill, NJ) on a cottonoid patty or morselized Gelfoam (Pfizer Inc., New York, NY). The middle clinoids/mOCRs are drilled with a 3-mm hybrid bit and then removed when thin enough to dissect and control (Fig. 2). Copious irrigation is needed to protect the optic nerves from thermal injury while drilling. It is not uncommon to have venous bleeding from where the SIS inserts laterally into the cavernous sinus directly under this bone (mOCR).

Using a 1-mm Kerrison, the bone overlying the cavernous carotid protuberances, lateral to the sella, can now be removed. This step is most safely performed by using only one-third of the distal tip of the Kerrison, positioned in parallel orientation to the underlying subclinoid/parasellar carotid. This technique of limited, controlled bone work helps prevent inadvertent carotid injury. Removing the remainder of the medial optic strut and middle clinoid process is necessary to access the opticocarotid recess intradurally without having to retract the tumor and risk perforator injury. This point cannot be overemphasized.

It is not uncommon for anterior cranial base meningiomas to have an arterial feeder arising from the distal portion of the carotid at the level of the opticocarotid recess. This feeder should be coagulated to aid in devascularization. Further devascularization can be accomplished by exposing and ligating the posterior ethmoidal arteries. Care should be taken not to allow the proximal stump of the ethmoidal arteries to retract and bleed into the orbit, resulting in a retrobulbar hematoma. At this point, a single anterior base cavity has been created, extending

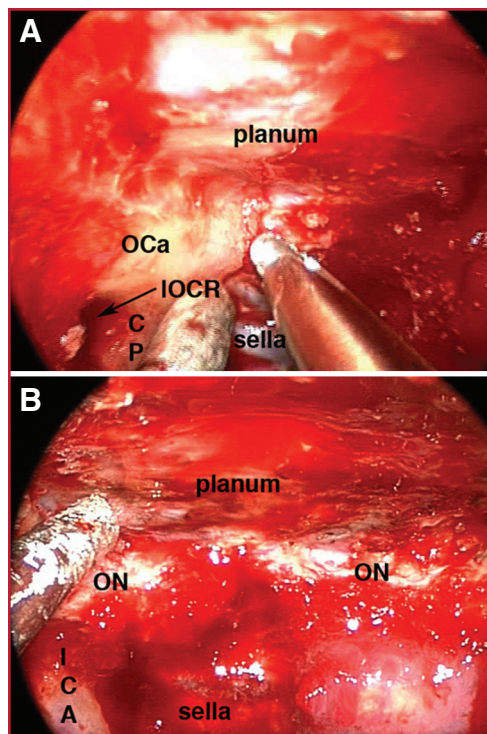


FIGURE 2. Endoscopic endonasal views demonstrating medial optic nerve (sheath/dura) exposure. This exposure allows for opening of the dura overlying the medial optic nerve for resection of tumor if and when necessary. **A**, the bone overlying the optic nerve above and lateral to the sella is carefully removed with a Kerrison rongeur after thinning with a high-speed drill. Copious irrigation is required during drilling to prevent heat transmission to the nerve. OCa, optic canal; IOCR, lateral (opticocarotid recess); CP, carotid protuberance (bone overlying cavernous internal carotid artery). **B**, endoscopic, endonasal view after the removal of all bone overlying the planum, sella, and both optic nerves for exposure before the resection of the tuberculum meningioma. The optic nerve sheaths are completely exposed at this point. The patient's left cavernous internal carotid artery protuberance is obscured by fibrin glue. Planum, planum sphenoidale; ON, optic nerve; ICA, internal carotid artery.

from the planum/cribriform junction to the clival recess and laterally from lamina papyracea to lamina papyracea.

Intradural Dissection

General Principles of Intradural Dissection. The basic principles of microsurgery form the foundation of endoscopic neurosurgery. It is critical that these principles for tumor removal, such as internal debulking followed by capsule mobilization, extracapsular dissection of neurovascular structures, focal coagulation, and capsule removal, not be abandoned. The use of an endoscope or an endonasal route should not alter these basic techniques.

Debulking can be accomplished in several ways, depending upon tumor consistency. Commonly, a slotted suction tip is used in the left or nondominant hand to maintain gentle countertraction, while a dissecting or debulking instrument is used in the right. For debulking of soft lesions, a 6- or 8-French suction tip is adequate. Malleable suction tips allow for distal angulation to improve access, especially when one is working around the endoscope tip. For firmer tumors, an EEA ultrasonic aspirator can be used. Rarely, the tumor contents can be removed using fine, pistol-grip cutting forceps with blunt toes that facilitate dissection. Internal debulking continues until the capsule is mobile and moves freely when countertraction is applied with suction. Limited countertraction should be performed with controlled suction, and not a grasping instrument, to prevent the potentially disastrous complication of tearing extracapsular vessels that can retract and bleed. Extracapsular sharp dissection should be performed whenever possible.

During capsule mobilization and delivery, critical neurovascular structures are identified and protected using small, square Teflon (DuPont, Wilmington, DE) pledgets or cottonoid micropatties. The capsule is coagulated using an appropriately shaped and angled endonasal bipolar. Care should be taken to avoid thermal injury to important neurovascular structures from heat dispersion.

It must be emphasized that the aforementioned endoneurosurgical dissection techniques are consistent with the well-established and proven principles of microneurosurgery, and that the pursuit of such techniques takes precedence over the degree of tumor resection. At no point should tumor be blindly or indiscriminately pulled or retracted. If tumor cannot be removed using these principles, then endoscopic removal is contraindicated.

Specific Considerations for Intradural Transplanum Dissections. After the bone removal is complete, the exposed dura from the sella to the anterior portion of the planum is coagulated to provide further devascularization of the overlying tumor. The dura is opened cautiously in a cruciate fashion based inferiorly on the SIS. The dural opening must be precise and generally should not extend beyond the tumor margins initially. Excessive exposure will allow normal brain to herniate through the defect and obscure visualization. Using image guidance, the lesion's anterior margin and the brain-tumor interface is identified, marking the extent of the necessary opening. If additional bone needs to be removed to expose this area, it should be done before opening the dura.

It has been suggested that one significant limitation of the EEA to address meningiomas in this location is the inability to access components of tumor that may have been invaginated through the optic foramen. We have, in fact, found these locations to be much more favorable to endonasal approaches in comparison with conventional transcranial approaches. Specifically, at this stage, we carefully examine the optic canal to ensure adequate bone has been removed. Any residual components of the optic strut are now removed. The optic canal is then decompressed in a retrograde fashion from the lamina papyracea back to the orbital apex 270 degrees around the optic nerve. Specifically, the optic canal adjacent to the carotid artery is completely removed; the bone overlying the more superior and lateral portions of the optic canal is also removed for at least 1 to 2 cm distal to the orbital apex (Fig. 2). This is done bilaterally to untether the nerve completely. In addition, this provides direct access, once the dura is opened, to any residual tumor along the canal without any manipulation of the nerve. It is only after the optic canals are decompressed that the dura is opened and the tumor exposed within the suprasellar space.

With the tumor exposed, it can be internally debulked until the remaining tumor within the capsule is thin and moves easily. Only then can extracapsular dissection begin through the parasellar

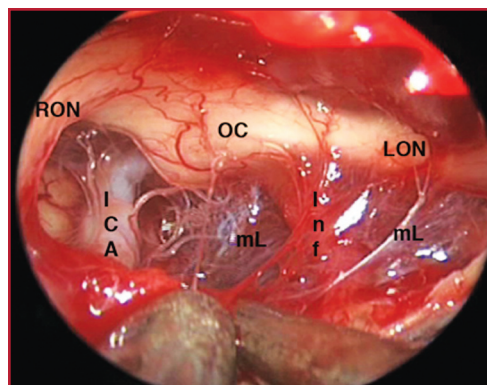


FIGURE 3. Endoscopic view after tumor debulking. LON, left optic nerve; RON, right optic nerve; OC, optic chiasm; ICA, supraclinoid internal carotid artery; Inf, infundibulum; mL, membrane of Lilliequist.

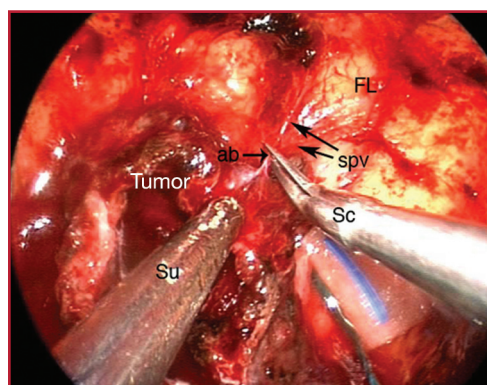


FIGURE 4. Endoscopic view demonstrating countertraction with a slotted suction (Su) tip to facilitate sharp dissection. Sc, scissor; ab, arachnoid band; FL, frontal lobe, spv, subpial vessel.

cisterns. The first anatomic landmark sought should be the parasellar carotid artery because it emerges intradurally at the level of the mOCR. The carotid will lead to the optic nerve located slightly superiorly. The optic nerve in turn can be followed with circumferential extracapsular dissection to the chiasm and then to the contralateral optic nerve and carotid (Fig. 3). Gentle traction with a 4- or 6-French suction will provide the arachnoid bands of the parasellar cisterns to be on enough tension to facilitate sharp dissection (Fig. 4).

Several additional critical structures need to be identified and dissected before capsule coagulation. The infundibulum and superior hypophyseal arteries often adhere to the posterior capsule margin and can be easily damaged during coagulation of the capsule at the tuberculum/sellar junction. Bipolarizing in this space should be avoided until the stalk has been identified and protected. We have learned this through experience, with our only case of hypopituitarism during the resection of a tuberculum meningioma occurring early in the series. In addition, small, subchiasmatic perforators are often draped around the circumference of the tumor (Fig. 5). With adequate debulking and mobilization, they can usually be spared and, if present, any branches directly feeding the tumor coagulated and sectioned. Finally, care

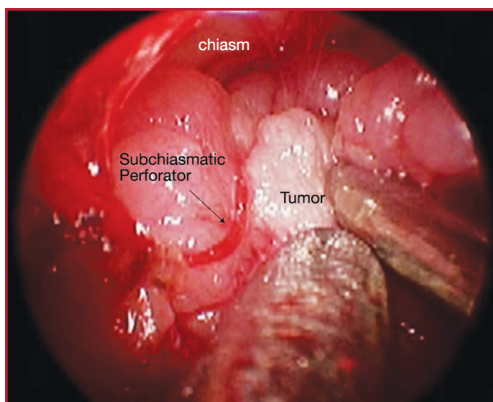


FIGURE 5. Endoscopic view showing subchiasmatic perforators running through the tumor.

should be taken during the perichiasmatic dissection, as the anterior communication artery and, in particular, the recurrent artery of Huebner can be draped over or encased in the tumor's superior surface.

Transcribriform Approach

Extradural Approach. This module allows anterior extension of the previous exposure to the level of the crista galli. If need be, the back wall of the frontal sinus can be approached via an expanded exposure of the frontal recess using a Draf III or modified Lothrop procedure. After bilateral total sphenoidectomies, medial orbital decompressions, and the transplanum module, the transcribriform approach can be initiated by resecting the superior nasal septum, creating a large, rectangular septal window from the frontal sinus to the rostrum of the sphenoid along the cranial base. In such cases, it is likely that olfaction has already been compromised by the target pathology. The frontal recess or posterior table of the frontal sinus is identified, and the cranial base is drilled in an anterior-to-posterior direction. The anterior and posterior ethmoidal arteries are identified and ligated to provide additional tumor devascularization.

To facilitate drilling, the soft tissue overlying the olfactory sulcus on both sides of the crista galli, extending caudally to the planum junction along the cribriform plate, is resected. This tissue consists of small branches of the ethmoidal arteries and the olfactory fimbriae. During removal of the crista galli, it

is important to remember that it is attached to the falx and may require a fair amount of drilling and dissection to remove safely. Removal of the crista galli and cribriform plate in combination with the transplanum approach creates a single cavity along the anterior cranial base (Fig. 1).

Intradural Resection. The exposed dura is coagulated which, in combination with the anterior and posterior ethmoidal artery ligations, provides critical devascularization. This leaves the anterior falcine artery and associated falcine branches as the primary residual feed to the tumor, other than any cortical vessels parasitized from the anterior circulation.

After coagulation, the dura is opened on both sides of the falx. The midline is kept intact, as the falx and tumor in this region are still vascularized. Internal tumor debulking is performed bilaterally, exposing the edge of the falx (Fig. 6). At this point, the feeding vessels arising from the anterior falcine artery as well as the falx itself are coagulated. The falx is now transected to provide a single working cavity (Fig. 6). The tumor is debulked, starting in the center, with the surgeon following the endoneurosurgical principles espoused earlier. The dura anterior to the brain/tumor interface is left intact to prevent downward herniation of the brain, which obscures visualization. During the extracapsular dissection of large tumors, there is often subpial

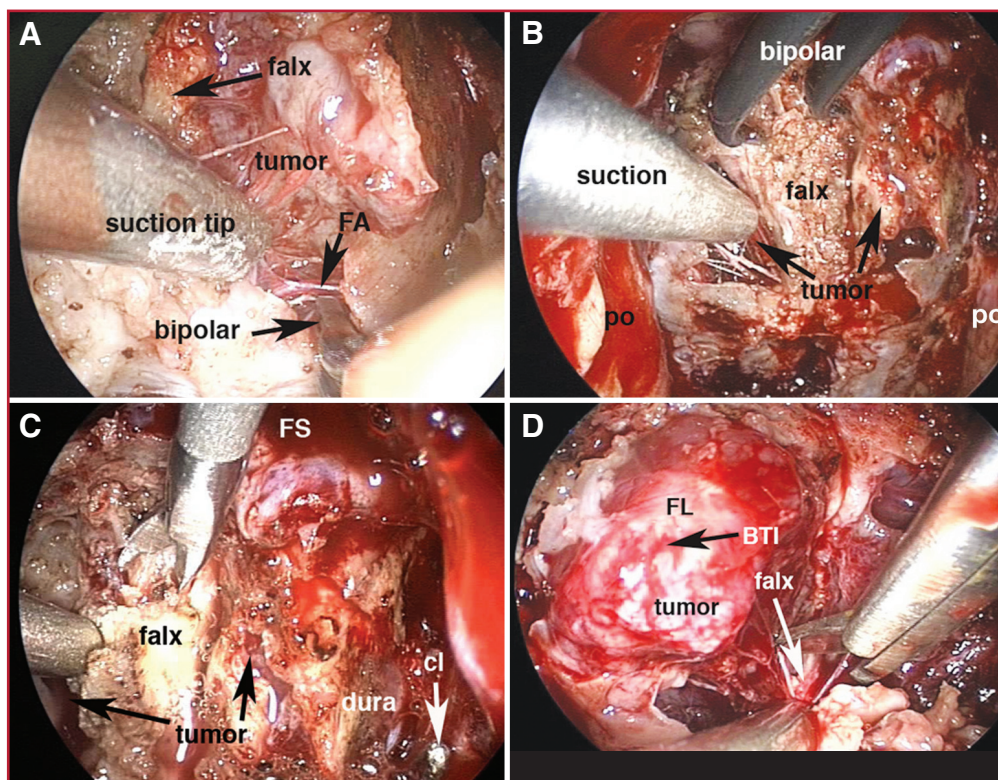


FIGURE 6. Endoscopic endonasal views showing transection of the falx during the resection of an olfactory groove meningioma. **A**, tumor is resected on the (patient's) left side of the falx. During this resection (often performed with suction alone) arterial branches from the falx that supply the tumor are exposed and cauterized, further devascularizing the tumor and thus facilitating resection. FA, falcine arterial branch. **B**, endoscopic endonasal view after tumor resection on both sides of the falx. The falx is cauterized by placing bipolar tips on either side of it prior to transecting it. po, periorbita. **C**, endoscopic endonasal view showing the transection of the falx after cauterization. This releases the tumor and allows further descent and resection. FS, frontal sinus with mucosa intact; dura, lateral dural capsule of tumor; cl, hemoclip on the (patient's) left anterior ethmoidal artery. **D**, endoscopic endonasal view of the final cut along the anterior falx for tumor release. FL, frontal lobe; BTI, brain/tumor interface.

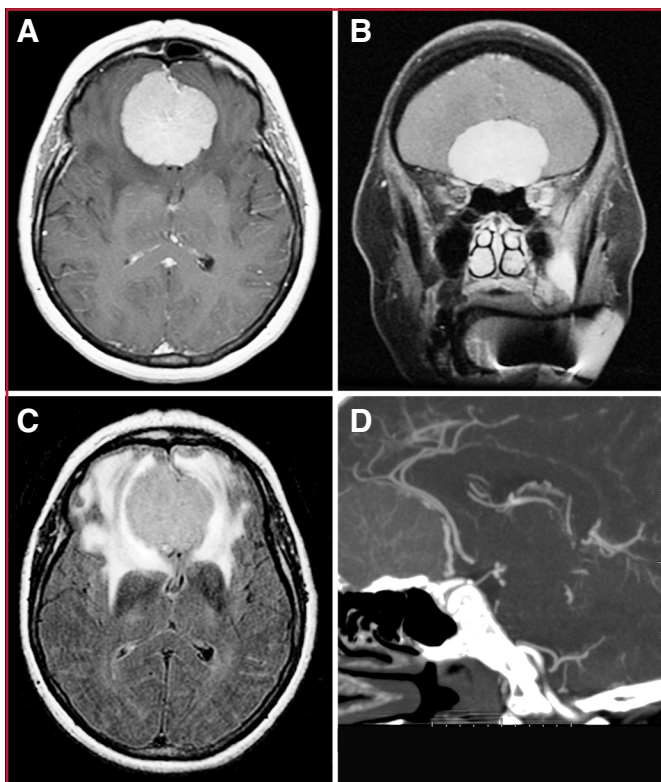


FIGURE 7. Preoperative imaging of an olfactory groove meningioma. **A** and **B**, postcontrast magnetic resonance imaging (MRI) scans showing the extent of the tumor. **C**, fluid attenuation inversion recovery sequence demonstrating the significant surrounding edema, suggestive of subpial invasion. **D**, computed tomographic (CT) angiogram demonstrating the frontopolar branches of the anterior cerebral artery draped over the tumor surface of the tumor.

invasion of the overlying cortex. In such cases, a subpial dissection must be performed using a 4-French suction; fine, pistol-grip scissors; extendable dissectors; and appropriate endoscopic bipolars. This dissection can proceed to the depth of the interhemispheric fissure. Care should be taken as the A2 segments and the frontopolar artery are often draped over the surface (Fig. 7). Very often, during the subpial dissection, small cortical vessels can be identified. With the use of countertraction, the tethering capsular components can be gently dissected and the adhesions sharply transected, preserving the small subpial vessels (Figs. 4 and 5).

Adequate internal debulking is followed by proceeding posteriorly toward the parasellar space. This step will provide access to the parasellar cistern and the identification of key neurovascular landmarks described in "Transtuberculum/Transplanum Extradural Exposure." Identification of the optic nerves and anterior communicating artery greatly facilitates the extracapsular dissection of the A2 segments within the interhemispheric fissure. This also provides proximal control during further vascular dissection along the capsule interface. Visualization with a 45- or 70-degree endoscope may be necessary for the most anterior/rostral tumor dissection. When this is used, the endoscope is placed at the "6-o'clock" position and the suction the "12-o'clock" position, opposite of the positioning used with a 0-degree endoscope.

In some instances, staged tumor removal may be an excellent option, especially for exceptionally large tumors in which circumferential extracapsular dissection is not possible because of growth along the sagittal or coronal planes (i.e., very "tall and wide" tumors). A partial debulking will often allow tumor to collapse inward over time (days to weeks) providing access to the residual. This time frame is variable and depends upon tumor consistency, size, amount resected initially, and patient recovery.

Reconstruction

The techniques used for reconstruction changed over the period of this study, based on high postoperative cerebrospinal fluid (CSF) leak rates early in our experience. Initially, a variety of grafts were used as a dural substitute, augmented by fibrin glues and fat autograft. This technique has evolved over time to the current technique, which uses a Duragen (Integra Life Sciences, Boston, MA) "inlay" (i.e., Duragen placed in the subdural space). This inlay is covered with a vascularized mucosal flap, based on the posterior nasal septal artery (a branch of the superficial palatine artery), which is prepared during the exposure (15). This flap is held in place with a thin, peripheral layer of dural sealant and supported by fat autograft or Gelfoam. Care is used when applying the dural sealant, ensuring that it is not accidentally placed intradurally or applied too generously, thus blocking the nasopharynx. Finally, a Foley catheter balloon is inflated or merocel placed in direct contact with the packing to act as a buttress for the entire reconstruction. This buttress helps prevent graft migration as well as the development of small, persistent channels that are caused by the separation of the flap from the bone as a result of gravity and/or brain pulsations. Care must be taken not to overinflate the balloon, because excessive pressure could be transmitted to the exposed optic nerves.

RESULTS

Extent of Resection

Tumor size and extent of resection were determined by volumetric analysis. With the use of Stentor radiology software (Phillips Global PACS, Brisbane, CA), pre- and postoperative volumes were compared to determine degree of resection. Patient tumor size varied widely, with a range of 2.1 to 109.3 cm³ (mean, 29.5 cm³). Olfactory groove meningiomas ranged from 3.1 to 109.3 cm³ (mean, 47.6 cm³). The average tuberculum sellae meningioma was 7.5 cm³, with a range of 2.1 to 16.4 cm³. Parasellar tumors with petrous extension averaged 9.7 cm³ (range, 3.4–19.6 cm³). The two petroclival meningiomas extended from the tuberculum to the clivus: one had a total volume of 21.1 cm³ and one 90.9 cm³.

Olfactory Groove

The extent of resection varied by tumor location and by surgical goal. Of the 15 olfactory groove meningiomas, 12 were planned for complete resection. Of those, 10 (83%) underwent gross total or near total (>95%) resection (67% of all tumors, regardless of intention). Specifically, seven patients underwent gross total resection (Figs. 7 and 8) and three underwent at least 95% resection (95, 96, and 98%, respectively). Two patients intended to undergo gross total resection underwent unintentional, partial resection. One of these resections was terminated after the surgeon encountered frontopolar artery bleeding,

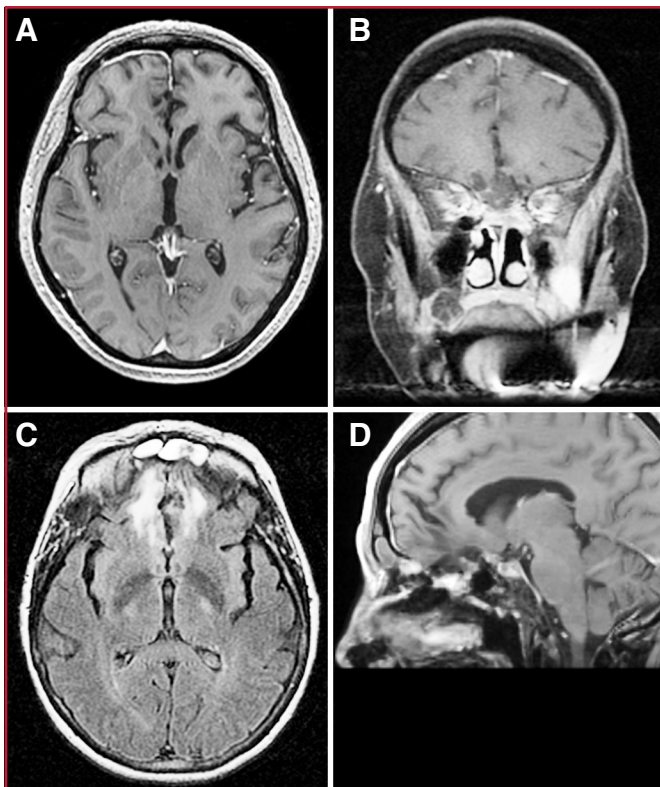


FIGURE 8. Postoperative postcontrast MRI scans of the patient shown in Figure 7, obtained after the expanded endonasal approach (EEA), resulting in complete resection. The small amount of enhancing dura (A) along the right frontal lobe was not seen associated with the tumor pre- or intraoperatively and is not believed to represent residual tumor. B, coronal postcontrast T1-weighted MRI scan. Note the relative lack of frontal encephalomalacia as well as the minimal residual fluid attenuation inversion recovery change (C) observed. D, sagittal postcontrast T1-weighted MRI scan.

which was managed endonasally (as described in detail in “Complications”). The patient had a satisfactory debulking with improvement in vision. Another patient, a morbidly obese man (third olfactory groove tumor in the series), underwent a 30% resection before his case was aborted secondary to poor visualization as the result of venous congestion/bleeding. The patient then underwent an open extended subfrontal approach.

Three patients underwent planned partial resections/debulking. All were at least 65 years of age (65, 74, and 79 yr), and one patient harbored a recurrent tumor. Their tumors were all debulked by more than 60% (Fig. 9). Mass effect and symptoms (vision loss) were relieved. As all of these patients’ symptoms were relieved and preoperative surgical goals were achieved without deficit, no further surgery is planned.

Tuberculum/Parasellar

Twelve of 13 (92%) patients with parasellar meningiomas underwent gross or near (>95%) total resection. Specifically, 11 of 13 patients (85%) underwent complete resection (Simpson Grade 1) (Figs. 10 and 11), and one patient underwent 95%

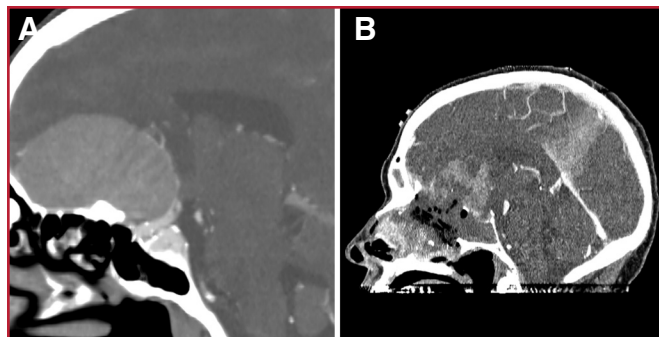


FIGURE 9. CT angiograms obtained before (A) and after (B) surgery in a 74-year-old patient who underwent EEA showing an intentional subtotal resection/debulking. The patient has a pacemaker and was unable to undergo MRI. She had an uneventful postoperative course and demonstrated subsequent improvement in her presumed dementia and resolution of papilledema.

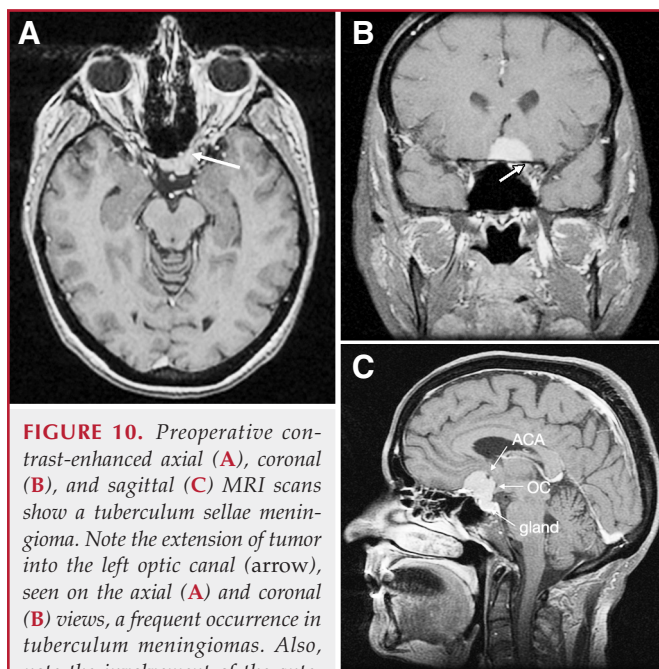


FIGURE 10. Preoperative contrast-enhanced axial (A), coronal (B), and sagittal (C) MRI scans show a tuberculum sellae meningioma. Note the extension of tumor into the left optic canal (arrow), seen on the axial (A) and coronal (B) views, a frequent occurrence in tuberculum meningiomas. Also, note the involvement of the anterior cerebral artery (ACA) and optic chiasm (OC) and association with the gland seen on the sagittal view (C).

resection. The remaining tumor had a 78% resection, based on volumetric analysis. These resections included tumors with extension into the optic canal (Figs. 10 and 11).

Primary Parasellar with Secondary Petroclival Extension

Five patients underwent resection for parasellar meningiomas, with petrous/tentorial extension with the specific goal of chiasmal decompression. Four of the five (80%) were recurrent tumors. All five had successful resection of the parasellar portion of their tumors with relief of visual symptoms (Figs. 12 and 13). None underwent complete resections of their tumors

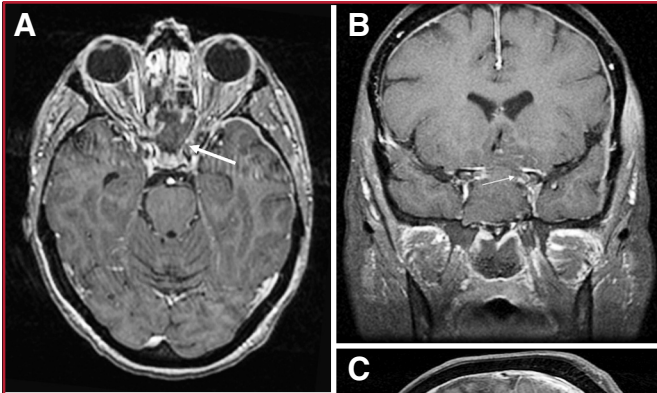


FIGURE 11. Postoperative, enhanced axial (A), coronal (B), and sagittal (C) MRI scans after complete resection of the meningioma shown in Figure 10. The axial (A) and coronal (B) views demonstrate the resection of tumor from the left, medial optic canal (arrow). There is a rim of enhancement representing postoperative change observed lateral to the optic, where there was no tumor on preoperative MRI scans (Fig. 10). On the sagittal view (C), note the preservation of the anterior cerebral arteries (ACAs), gland and stalk in normal position. Also note the enhancement of the vascularized nasal mucosal flap.

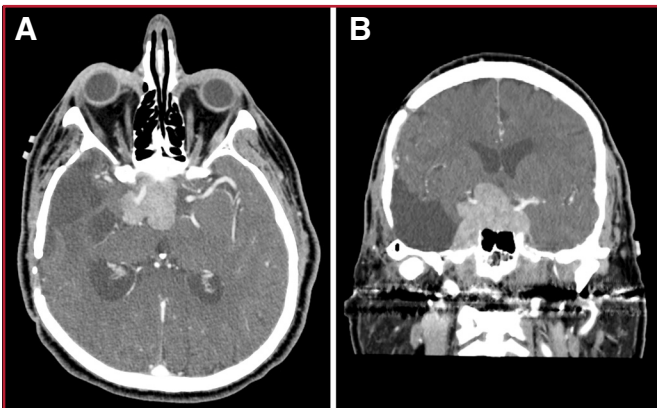


FIGURE 12. Preoperative axial (A) and coronal (B) CT angiogram showing a recurrent petroclival meningioma (two previous craniotomies and radiation) with significant parasellar extension and visual loss.

(mean degree of resection, 67%; range, 38–95%). Residual was either observed (recurrent tumor purely parasellar recurrence/regrowth) or treated with radiosurgery.

Primary Petroclival with Secondary Parasellar Extension

Two patients had giant (21- and 91-cm³ volumes) petroclival meningiomas with secondary parasellar extension and visual compromise. The goal of surgery in these patients was debulk-

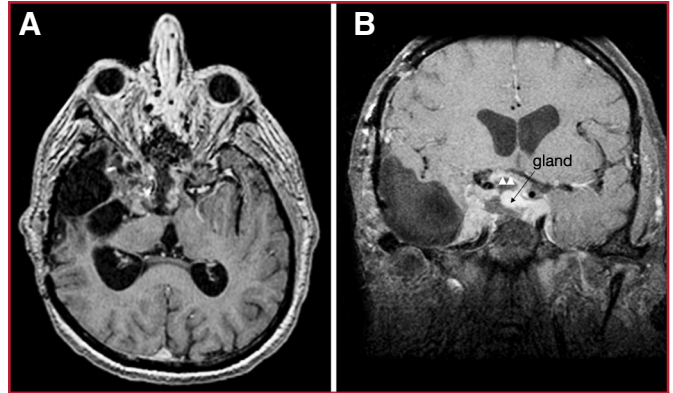


FIGURE 13. Postoperative contrasted axial (A) and coronal (B) MRI scans after debulking of the recurrent parasellar/petroclival meningioma seen in Figure 12. A thin rim of tumor was left adherent to the optic chiasm (arrow) and the pituitary gland was left intact. The patient had relief of progressive visual symptoms and the residual bilateral cavernous sinus tumor was irradiated.

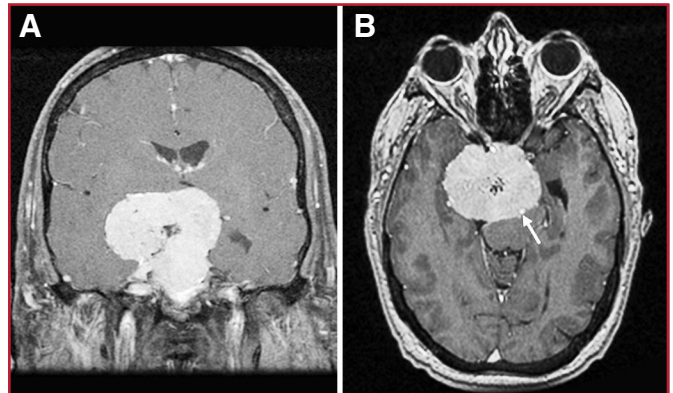


FIGURE 14. Preoperative coronal (A) and axial (B) contrasted MRI scans of a giant petroclival meningioma in a patient with significant vision loss. Note the significant suprasellar extensions and encasement of the basilar artery (arrow).

ing and visual apparatus decompression (Figs. 14 and 15), which was achieved. Degrees of resection were 63 and 89%, respectively. Residual was treated with radiosurgery.

Outcomes

Ophthalmological

As previously noted, 66% of patients presented with visual decline. All patients were objectively evaluated preoperatively and postoperatively. All patients experienced resolution or improvement of visual symptoms. No patient suffered permanent worsening in vision following surgery.

Endocrine

Two patients presented with endocrine dysfunction (one diabetes insipidus [DI], one hyperprolactinemia and hypothy-

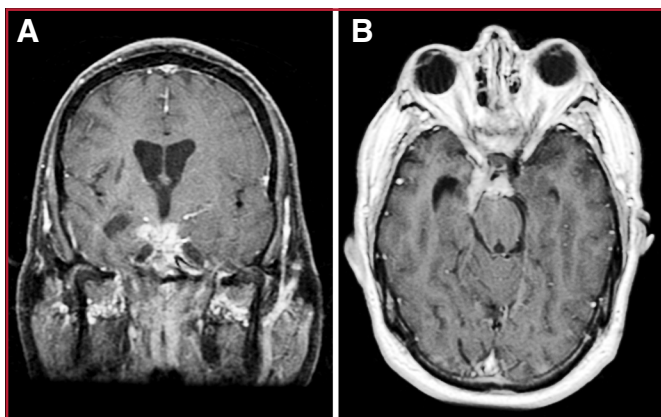


FIGURE 15. Postoperative coronal (A) and axial (B) contrasted MRI scans of the same patient as Figure 14 showing significant debulking.

roidism). Two others had pituitary hypofunction after previous treatment (transsphenoidal resection and radiosurgery).

Only one patient (3%) without preoperative dysfunction experienced a new, permanent deficit, DI. One other patient had panhypopituitarism and DI postoperatively. This patient had incomplete preoperative endocrine records but had hyperprolactinemia and central hypothyroidism on available preoperative testing. Another patient developed transient DI after the resection of a large, parasellar tumor with petroclival extension that presented with pituitary dysfunction and an increased prolactin level, indicative of gland and stalk compression (Figs. 14 and 15). All of these patients had significant sellar and parasellar tumors.

Recurrence

At the time of this review, the follow-up period (12–48 mo) is too short to fully address one of the important measures of the efficacy of this approach, namely, recurrence rate. Obviously, this is closely related to both extent of resection (38) and tumor biological behavior. However, at this point, no patient in our series who underwent a gross or near total resection has experienced a recurrence or regrowth. Much longer follow-up periods are needed to determine recurrence rates.

One patient (Patient 19, Table 1), an elderly woman with a recurrent, primarily suprasellar tumor with secondary petroclival extension who underwent debulking, has required two subsequent debulkings, both via an EEA. This patient had previously failed a craniotomy and radiosurgery. Intent of surgery in each case (EEA) was cytoreduction and relief of mass effect.

Complications

One patient (3%) experienced a new neurological deficit, 3 weeks after surgery. This patient had intraoperative frontopolar artery bleeding, which was controlled endonasally. An immediate postoperative angiogram did not show a pseudoaneurysm. The patient presented 3 weeks later (1 wk before a planned repeat angiogram) with epistaxis and an intracerebral

TABLE 2. Cerebrospinal fluid leak rates and tumor location

Location	Cerebrospinal fluid leak rate (%)
Olfactory groove	4/15 (27)
Parasellar/tuberculum	8/13 (62)
Petroclival extension	0/5 (0)
Other	2/2 (100)

hemorrhage, which was managed via an eyebrow craniotomy. A repeat angiogram showed a pseudoaneurysm that was embolized. The patient was left with a caudate infarct, hemiparesis, and cognitive impairment. There was one patient in the series who experienced a preoperative endovascular complication. This patient underwent preoperative alcohol embolization complicated by a right carotid artery dissection and subsequent occlusion, which resulted in left hemiparesis and a cavernous sinus syndrome. The patient underwent emergent resection of his petroclival meningioma. At the time of the 3-year follow-up evaluation, the patient had improved, with a near resolution of his weakness (Grade 4+/5) but a persistent third cranial nerve palsy. As discussed previously, one patient (3%) experienced new, permanent endocrine dysfunction.

The postoperative CSF leak rate was 40% (14 of 35) and varied by tumor location (Table 2). Increased tumor size did not correlate with leak rate, as evidenced by the highest leak rate (62%) in the smallest tumors, the tuberculum lesions. There is a trend toward a significant difference between the olfactory groove (four of 15) and the tuberculum (eight of 13) meningiomas, with tuberculum having an increased rate of leak ($P = 0.063$). There was also a significant difference between the tuberculum (eight of 13) and parasellar with petroclival extension (0 of five) tumors ($P = 0.036$). Also, the CSF leak rate in those tumors that were smaller than 25 cm³ was seven of 20 (35%). The leak rate in those larger than 25 cm³ was six of 15 (40%) ($P = 0.762$).

Four of the nine (44%) patients who had undergone previous treatment (two after craniotomy, one after gamma knife radiosurgery, one after previous nasal surgery for a different lesion) experienced a postoperative CSF leak, and 10 of 26 patients (38%) who had no previous treatment had CSF leaks. There is no statistically significant difference between these two groups ($P = 0.752$).

All patients were treated initially with lumbar drainage. One resolved with only lumbar drainage. We were reluctant to attempt a full course of lumbar drainage in those patients who did not immediately cease leaking. Despite the high rate of CSF leak, there were no cases of bacterial meningitis. All cases of leak resolved with endonasal reexploration, usually augmented by further lumbar drainage. One patient underwent reexploration, via EEA, for pneumocephalus after the resection of a recurrent olfactory groove meningioma.

As stated previously, there were no patients with new, permanent visual worsening. One patient had progression of pre-existing papilledema after EEA with complete tumor resection.

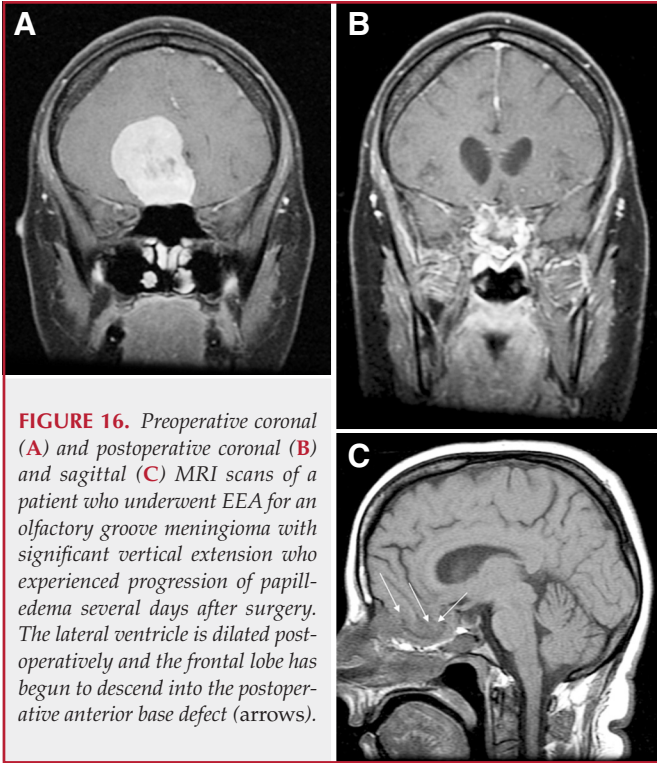


FIGURE 16. Preoperative coronal (A) and postoperative coronal (B) and sagittal (C) MRI scans of a patient who underwent EEA for an olfactory groove meningioma with significant vertical extension who experienced progression of papilledema several days after surgery. The lateral ventricle is dilated postoperatively and the frontal lobe has begun to descend into the postoperative anterior base defect (arrows).

Follow-up imaging (Fig. 16) revealed ventriculomegaly and secondary frontal lobe descent into the bony defect. The patient underwent a ventriculoperitoneal shunt with subsequent improvement in ventriculomegaly, reversal of frontal lobe herniation (Fig. 17), and resolution of visual symptoms. The patient's visual fields improved significantly compared with before tumor resection. In general, it is our practice to shunt patients with large tumors who present with papilledema early, even before tumor resection. This is our practice independent of the approach (transcranial or EEA).

The same patient developed an unusual, delayed complication. One year after her EEA, she developed an asymptomatic granuloma associated with Teflon, which was intentionally left in the tumor cavity. Teflon "felts" are sometimes used instead of standard cottonoid patties because the tails on the patties can become very cumbersome and even obscure the view in such a small space. This was proven to be a sterile granuloma by stereotactic biopsy. It responded radiographically to steroids. She subsequently developed a superinfection of the granu-



FIGURE 17. Sagittal MRI scan of same patient as Figure 16 after shunting with improvement in ventricular size, reversal of frontal lobe herniation (arrows), and resolution of her papilledema.

loma 2 years after surgery after a sinusitis (Fig. 18). This asymptomatic abscess (noted on follow-up imaging) was stereotactically drained. The remaining Teflon was debrided endonasally without complication. The infection resolved with 8 weeks of antibiotic therapy without sequelae (Fig. 19). At the time of the 3-year follow-up evaluation, the patient had no evidence of recurrence of tumor or abscess.

There were two cases of deep venous thrombosis and one pulmonary embolus. The embolus was discovered on postoperative Day 1 and full anticoagulation was started immediately, without hemorrhagic complication.

The 30-day perioperative mortality rate was 0%. The last patient in the series, a 70-year-old woman, died within 6 months of surgery from multiorgan failure secondary to renal failure and associated complications.

DISCUSSION

Development of the EEA

Anterior cranial base meningiomas are traditionally approached through a frontal or frontolateral approach. Variations incorporating cranial base approaches were developed in an attempt to limit brain retraction when approaching tumors that are often associated with significant surrounding brain edema (5, 36, 43). However, none of these approaches completely eliminates the need for manipulation of neural structures; they only lessen it. In addition, craniotomy for midline anterior base meningiomas carries a well-described risk to the optic apparatus (11–20% in tuberculum meningiomas) (1, 6, 12, 14, 33, 45). This is caused, in part, by the intimate association of these tumors with the optic nerves and chiasm. This may, however, be aggravated by the fact that these approaches, by virtue of their anterolateral-to-medial trajectory, require a certain degree of manipulation of an already compressed optic apparatus.

Expanded endonasal approaches have been developed in an attempt to eliminate brain retraction as well as improve ophthalmological outcomes by approaching the tumors from an



FIGURE 18. Coronal postcontrast MRI scan showing frontal abscess formation after seeding (sinusitis) of an aseptic granuloma.

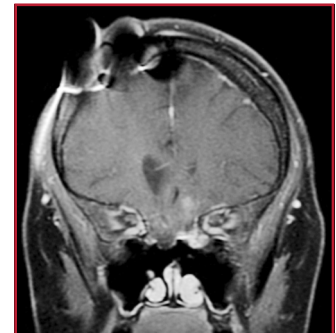


FIGURE 19. Coronal postcontrast MRI scan showing complete resolution of frontal abscess after stereotactic drainage, EEA re-exploration for Teflon debridement, and full course of antibiotics.

anteromedial and inferior trajectory. These approaches have developed slowly and are founded on historical precedent. Harvey Cushing reported two anterior clinoidal meningiomas resected through a transsphenoidal approach (22). Kouri et al. (26), Mason et al. (28), and Weiss (44) augmented the transsphenoidal approach by removing more bone above the sella, thus permitting a supradiaphragmatic view of the contents of the suprasellar cistern. Kaptain et al. (18) reported drilling the bone of the tuberculum sellae and planum sphenoidale to approach anterior cranial base lesions. Other recent series confirm the use of the modified transsphenoidal approach for tumors in the parasellar and clival regions as well as the anterior base (8–11, 17, 25, 27). Advantages include potentially shorter exposure times, avoidance of brain retraction, early tumor devascularization, direct tumor access, and complete, bilateral optic canal decompression. Perhaps the most important advantage is the avoidance of manipulation of an ischemic, compressed optic apparatus. This, combined with early and direct visualization of critical subchiasmatic perforators, has the potential to improve visual outcomes. Current reports demonstrate feasibility, but they are limited by heterogeneity of pathology and sample size. As a result, there is little or no literature available on which to evaluate the efficacy of and outcomes after EEA for anterior base meningiomas (38).

Outcome Measures

Degree of Resection

We did not find degree of resection to be limited by the approach. Vertical tumors may require staging to allow for tumor descent, but this did not prove to be a limitation. The optic nerve and orbital contents prevent resection lateral to midorbit. The anterior limit is the frontal sinus. Inferior limitations do not come into play in this series, as tumors extending to the foramen magnum are not included. However, in our experience, the caudal limit is the odontoid process (21). There was one patient early in our series (Patient 5, *Table 1*) whose surgery was aborted because of our difficulty with visualization and a fibrotic tumor. This patient represents the only case in our experience of any tumor type in any location in which an endoscopic approach was aborted. This occurred early in our experience and before the introduction of the endonasal ultrasonic aspirator (Integra, Boston, MA). This thin, elongated aspirator has greatly improved the ease and efficiency of all tumor resections. We have not had to abort a case since. Indeed, similar tumors have been resected since that time.

One of the main concerns about and criticisms of endonasal approaches to anterior base or parasellar meningiomas is an operator inability to access optic canal extension, a frequent occurrence with these tumors. Meningiomas often extend into the optic canal medial to the optic nerve (*Fig. 10*). We believe the more direct ventral route provided by the EEA has a distinct advantage for resecting disease extending along the inferior and medial portion of the nerve within the optic canal. Accessing this extension requires optic nerve retraction when approached from a lateral approach. Anterior clinoid removal

or release of the falciform ligament may increase the nerve's mobility, but it still must be elevated to access disease inferior or medial to it. When approached via an inferior midline or medial approach, the medial optic canal is easily accessible with little lateral extension (*Figs. 2, 10, and 11*). This access is well illustrated by the optic nerve decompressions typically performed by otolaryngologists for traumatic optic neuropathy (24, 29, 31, 39, 40, 42).

We chose to present degree of resection based upon the goal of surgery, as determined preoperatively. We believe this to be an acceptable method for evaluation of a surgical series and has precedent in the literature (16). This "intent-to-treat" analysis serves to emphasize our surgical philosophy. Ideally, the goal of every resection should be gross total removal and cure. However, this must be tempered with the patient's functional outcome, comorbidities, and age. Meningiomas are nearly always benign, and it is important that patients not be left with significant deficits when resecting such slow-growing tumors. It is our philosophy that resections for such tumors should be performed in a manner that will achieve maximal resection with minimal morbidity while adequately decompressing critical structures (e.g., achieving recovery of vision). This goal was achieved in all but one early case that was aborted. On the basis of this philosophy, we do not believe that the degree of resection would not have been better if a conventional transcranial cranial base approach had been used at our institution. This does, however, raise an important point. We believe that surgeons treating cranial base disease should be equally facile with both open and endonasal approaches. Only then can the patient truly be offered an unbiased opinion as to the best approach for his or her particular tumor.

One advantage to the EEA is that removal of involved bone and dura is usually achieved as a part of the approach, thus facilitating Simpson Grade I resections. In addition, early devascularization of the tumor can be achieved during the approach. Anterior cranial base meningiomas are often fed primarily by the anterior and/or posterior ethmoidal arteries and some branches of the internal maxillary artery. Through the EEA approaches, the blood supply is accessed early, making the tumor avascular and soft. Even the branches from the ophthalmic artery (which traverse the dura to supply the tumor) and falx are devascularized early on. There is often an arachnoid plane which separates the tumor from the optic chiasm and the ventral aspect of the brain. It is the presence or absence of this plane that inevitably determines the safe resectability of the tumor, independent of approach.

Vision Preservation

As with other series, the majority of these patients presented with visual complaints. We believe it is of the utmost importance that vision be improved or preserved, especially when dealing with a benign tumor. Many authors have examined this issue over the years (1, 2, 12). Severity and duration of symptoms have been correlated with visual recovery (6, 12). In addition, it is agreed that ischemia, manipulation of the optic nerve, and thermal injury correlate with deterioration of vision

or lack of recovery. Al-Mefty et al. (1) described the location of the optic nerve in various anterior cranial base tumors. Tumors arising from the anterior leaf of the diaphragma sellae elevate the flattened optic nerve. Tumors arising from the anterior clinoid process primarily involve the ipsilateral optic nerve. Tuberculum sellae tumors push both optic nerves outward and backward. Most of these describe optic nerves that are on or toward the “outside” (dorsal, posterior, or lateral) aspect of the tumor. With the use of standard craniotomy approaches, one has to access many of these tumors (particularly the subchiasmatic component that is buried beneath the chiasm and optic genu) from the “outside,” through the corridor between the optic nerve and the internal carotid artery. There is a risk of trauma to the optic nerve through this corridor. Conventional, open series for the resection of tuberculum sellae meningiomas show visual deterioration in approximately 20% of patients (6, 12, 14, 33, 45). The worsening after surgery does not tend to improve (33).

However, the EEA provides the potential for early and direct visualization of subchiasmatic perforators, which are draped over or enveloped within the dome of the tumor on their way to the optic apparatus. With careful debulking and meticulous, sharp extracapsular dissection under unobscured visualization, the vascular supply to the chiasm is preserved. This, combined with the lack of optic manipulation, holds the potential for improved visual outcomes. Therefore, by approaching tumors that displace the optic apparatus laterally and superiorly from an inferior and medial trajectory, the endonasal approach allows tumor resection and optic decompression without requiring optic nerve manipulation. No patient in our series experienced an immediate or permanent visual deterioration.

Obviously, not all tumors displace the optic apparatus in such a manner. This concept, as well as our resection philosophy, is exemplified by the petroclival tumors. In these cases, although the entire tumor was not resected during the endoscopic EEA, the symptoms and visual deficits caused by the parasellar portion were relieved in all patients. The lateral, tentorial portion of these tumors can be controlled with radiation or transcranial approaches in younger patients and merely observed in the elderly.

Endocrine Function

The endocrine disturbances in anterior cranial base tumors are often mild. Symptoms include decreased libido in men, amenorrhea, and hypothyroidism. Four patients (11%) had some degree of pituitary dysfunction preoperatively, as the result of tumor or of previous treatment.

Overall, there were two patients (6%) with permanent, new dysfunction postoperatively. One of these patients progressed from partial dysfunction preoperatively to panhypopituitarism (including DI) postoperatively. This occurred early in the series and was likely attributable to the use of bipolar coagulation within the posterior or inferior part of the tumor, along the tuberculum, which may have affected the superior hypophyseal artery. This has not occurred since because of the resulting vigilance and avoidance of cautery during this phase.

Although frequently not reported, postoperative pituitary dysfunction in transcranial series ranges from 0 (12) to 12.9% (3). Pituitary function is a critical outcome measure after resection of any parasellar tumor. As further literature develops evaluating this measure, we believe the EEA will provide promising results with respect to this measure for the same reasons elucidated in “Vision Preservation.”

Complications

The most frequent complication was CSF leak, which occurred in 40% of patients. Nearly all of these patients underwent reexploration for leak repair, which is partly the result of aggressive management of these leaks. We were reluctant to attempt a full course (5 d) of lumbar drainage if the leak did not resolve quickly. All leaks were resolved without requiring a craniotomy or permanent CSF diversion. There were no cases of bacterial meningitis.

It is our hypothesis that arachnoid violation, especially overlying a basal or suprasellar cistern, greatly increases the risk of leak as well as of difficulty in achieving its resolution. This is supported by the observation that tumor size does not correlate with leak rates, but seem to correlate with tumor location and type. Indeed, tuberculum tumors, which tend to have significant suprasellar and prepontine cistern involvement, had the greatest rate of leak. Olfactory groove meningiomas, which usually have more frontal lobe and less suprasellar cistern involvement, show a trend toward significantly decreased leak rate when compared with tuberculum tumors. Interestingly, parasellar/petroclival tumors which only underwent a parasellar debulking had the lowest rate of leak of all (0 of 5). This may be a reflection of the fact that these tumors were debulked and not thoroughly dissected from an arachnoid cistern.

Although not significant with respect to CSF leak rate in this series, recurrent tumors can be more difficult to seal. Two of the three patients who required multiple reexplorations had recurrent tumors, a factor that (in our opinion) greatly increases the difficulty of successful reconstruction, despite the fact that this did not prove to be statistically significant in this report. This result may be attributable to the small sample size. One contribution to this difficulty is the encephalomalacia, which occurs after a previous subfrontal approach (Fig. 20). This creates a large arachnoid space from which to dissect the tumor, without a frontal lobe buttress for an inlay graft.

In our experience, the leaks tend to involve only a small portion of the graft, which



FIGURE 20. Sagittal noncontrast MRI scan showing a recurrent olfactory groove meningioma whose resection was complicated by cerebrospinal fluid leak. Note the extensive encephalomalacia, which resulted from a previous subfrontal craniotomy (arrows), in comparison with Figure 7 after EEA.

has not successfully adhered to the bony edge. We believe this was caused by graft migration and CSF fistula formation associated with delayed vascularization of allograft tissue. This was managed with an additional small onlay graft and repacking of the sphenoid sinus with additional fat graft. The reconstruction technique used early in the series was derived from techniques used to seal posttraumatic or spontaneous CSF leaks (4).

However, high leak rates have led to changes in our technique. The latest addition has been a vascularized posterior nasal septal mucosal flap (15). This mucosal flap remains pedicled on the posterior nasal artery and can be rotated to cover virtually any cranial base defect after EEA (34). Because it maintains its blood supply, this flap heals within 5 to 7 days, thereby quickly forming a seal. This addition has provided what will hopefully be the final step in the long evolution of reconstruction after endoscopic EEA. This is analogous to the development and application of the pericranial flap as an integral part of the reconstruction after conventional craniofacial resections. We believe this vascularized, nasal septal flap will become a similar “workhorse” for EEA reconstruction. This current series precedes the use of this vascularized flap. During the past year, with the use of the nasoseptal flap, the overall CSF leak rate after EEAs has been reduced to 5.4%.

As stated, CSF leak has been a manageable complication. As the result of vigilance and rapid reoperation when necessary, there were no cases of bacterial meningitis. In addition, all leaks were repaired endonasally. Therefore, despite a high incidence, the long-term sequelae have been minimal or absent, although we do not minimize the potential morbidity to the patient.

By comparison, the most serious complication with the greatest long-term sequelae was a vascular event. This was rare, with one patient of 35 (3%) experiencing such an event. This was a delayed frontal hemorrhage after a pseudoaneurysm secondary to bleeding from a frontopolar artery. The cases in this report involve complex tumors that were large (mean volume, 29.5 cm³), often recurrent (26%), and in difficult locations around the Circle of Willis. On the basis of these factors, we believe this to be an acceptable rate. We also believe that it is necessary that the surgical team be able to manage such events endonasally, as the time required to convert to a transcranial approach may be prohibitive. This case demonstrates the ability to manage intracranial arterial bleeding endonasally. However, it must be emphasized that experience is paramount. This event occurred 7 years into our endonasal experience. Lesions with potential for such bleeding should probably be managed only after significant experience has been gained with other pathology and approaches.

Long-term Outcomes and Tumor Recurrence

The “gold standard” of any procedure in oncological management is tumor recurrence. This is often correlated to complete excision of the lesion. There are those who believe it is not possible to achieve an adequate dural resection via a transsphenoidal approach. However, it is our belief that the added visualization and exposure afforded by the endoscope allows us dural resection through this approach that is comparable to

transcranial approaches in selected cases. There is always the question of residual tumor attached to the neural or vascular structures. This is especially true in the case of optic canal extension. We have demonstrated the access to the optic canal provided by EEA (Figs. 2, 10, and 11) and believe this to be more direct than via a transcranial route. However, as previously stated, the presence or absence of an arachnoid plane ultimately determines the feasibility of gross total resection particularly with respect to the optic apparatus. Neither the endoscope nor the microscope can recover this plane once the tumor has transgressed it. However, we believe the endoscope provides at least equivalent, if not superior, views compared with the microscope when trying to dissect this plane. The structures of interest are on the other side of the tumor, unlike the transcranial approaches, where the carotid or optic nerve may be draped over the surface of the tumor, thereby inhibiting access.

We do not yet have long-term follow-up data on our patients, but we are optimistic based on these early results. As stated previously, one advantage to EEA may be the early removal of involved bone and dura as part of the approach. This may lead to a greater number of Simpson Grade I resections, thereby potentially resulting in lower recurrence rates.

Furthermore, by eliminating even minimal brain retraction, this approach may provide the best potential neuropsychological outcomes, particularly if there is compromised function preoperatively (Fig. 20). We are currently studying this sometimes subtle but critical determinant of quality of life.

CONCLUSION

This case series adds to the growing experience with endoscopic endonasal cranial base surgery. We do not think the endoscope is the answer to all the problems of anterior cranial base surgery. It is a versatile instrument which, when used judiciously and with experience, will continue to expand horizons. There have been several important criticisms that have been cited as limitations of the EEA for anterior base meningiomas. These include accessibility of optic canal extension, lesion size, tumor consistency, vascular encasement, and CSF leak.

Each of these is an important concern and needs to be addressed specifically as the approaches evolve. We believe that the technique, case illustrations, and outcome data in this report demonstrate that once adequate experience has been acquired, these factors can be addressed safely. There are still issues to be dealt with, such as better instrumentation, optimal repair of the dural opening to prevent CSF leaks, and, of course, long-term outcomes. However, in our opinion, EEA represents a viable alternative for the resection of anterior cranial base tumors, providing it is pursued after adequate experience with less complex pathology.

A learning curve is associated with endoscopic endonasal work; it is encompassed in this series. Again, it is important that surgeons managing these tumors be skilled in approaching them via traditional open approaches, as well as endonasal approaches. Anterior base meningiomas come in a wide variety

of origins and extensions, making their surgical treatment challenging. The more options available to a surgeon, the less bias he or she will have toward any one, and the greater potential for improved outcomes. In fact, we believe that certain tumors are best managed with combined medial (EEA) and lateral (open transcranial) corridors. A great example of this concept is petroclival tumors, which lend themselves well to medial, transclival approaches, often followed by a posterior lateral, retromastoid craniotomy.

We hope this series helps to demonstrate safety and efficacy of the technique once adequate experience is achieved. The work describes a 9-year EEA learning curve. It is our belief that given equivalent training and experience, the EEA has potential to provide improved results. Surgeons must provide their patients with the best result that they can, regardless of approach. Therefore, the best approach for the patient is the approach that works best in his or her individual surgeon's hands. Surgery is only minimally invasive if it is minimally invasive to the patient's way of life.

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COMMENTS

The Pittsburgh group is the leader in the field of endoscopic endonasal cranial base surgery, and in the present article they report their experience with endoscopic endonasal resection of anterior cranial base meningiomas. I believe that it is an important contribution to this topic for many reasons: 1) it adds the largest series available up to now to the scarce literature describing the outcome of endonasal approaches for such types of meningiomas; 2) the technique is well described; 3) the critical points of the technique, such as accessibility of the optic canal extension, lesion size, tumour consistency, vascular encasement, and cerebrospinal fluid (CSF) leak are discussed; and 4) results and complications are reported.

There are two points that are not convincing for me: 1) Should petroclival meningiomas really be included with anterior cranial base meningiomas, if the majority of the tumors were parasellar with a chief symptom of vision loss? 2) The entity of tumor removal must be independent from the intent to treat. The latter concept may explain why, in some patients, the effective resection was inferior to the expected result.

Giorgio Frank
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The expanded endonasal approach for cranial base tumors as a minimal access alternative to open cranial base approaches has engendered much discussion in the neurosurgical literature. The most controversial application of this approach is undoubtedly removal of meningiomas. Critics argue that it is impossible to get a Simpson Grade I removal without a wide exposure of the dural tail, that the optic canal cannot be adequately visualized, that surgeons must “pull” on the tumor to remove it from the nasal cavity, and that the risk of CSF leak is too high. As this report and our own personal experience have shown (2, 5), these criticisms are generally fallacious, often proposed by surgeons with little experience in endonasal surgery. The endonasal approach provides the most direct route to the tumor, permits early devascularization, facilitates removal of dural and bone infiltration, and optimally exposes the medial aspect of the optic canal. Early internal decompression of the tumor allows the surgeon to mobilize the capsule away from the brain and dissect adherent vascular structures. As instrumentation and techniques for closure advance, the rate of CSF leak in most centers is now well under 10%, and these leaks can often be managed with a few days of lumbar drainage, thus causing no long-

term morbidity (2, 3). In addition, the lack of stereoscopic vision provided by the endoscope is easily overcome with experience by integration of tactile and visuospatial cues, which may soon be a moot point with the advent of a new generation of three-dimensional stereoscopic endoscopes (1).

However, endonasal enthusiasts must not be overly fervent in the application of ventral midline approaches for tumors with significant lateral extension. The key to the success of the expanded endonasal approach is careful patient selection. Although the medial optic canal may be best visualized through a medial approach, the lateral optic canal is best visualized through a lateral approach. Likewise, the lateral extent of a tumor often creates a corridor for open cranial base approaches to reach the midline cranial base without using significant brain retraction. Nevertheless, in general, we agree with Gardner et al. that the expanded endonasal approach has a significant role in the treatment of midline meningiomas. As endonasal techniques proliferate, the literature will soon confirm what is already apparent to current practitioners (1). For tuberculum and planum meningiomas, it is easier to preserve and improve vision with a ventral midline approach compared with a lateral approach, which requires manipulation of tenuously thin optic nerves. For olfactory groove meningiomas, the ability to remove the tumor without any frontal lobe retraction will reduce the 30% morbidity rate reported in the literature from open approaches (4). For petroclival meningiomas, a two-stage approach, in which tumor ventral to the brainstem is removed with an endonasal approach and tumor lateral to the brainstem is removed with an open approach, may provide the lowest morbidity. Finally, expanded endonasal approaches may be increasingly important, given the paradigm shift in the role of radiosurgery for cranial base tumors. Previously, surgeons would remove as much tumor as possible and then radiate the residual tumor. Given the efficacy of radiosurgery, it may be more prudent to conceive of the goals of surgery with a priori knowledge that radiosurgery will be implemented for control of the portion of the tumor most dangerous to remove surgically. Hence, the objective of surgery may evolve to be decompression of the optic nerves and the creation of an optimal target for radiosurgery.

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This is an excellent article that summarizes the results from previous, shorter reports from the same group in a systematic manner, as a valuable “guideline for the transnasal management of anterior cranial base and perisellar meningiomas.” Gardner et al. nicely describe the anatomic and technical features of the procedure and provide a careful evaluation of the results. The quite low rate of serious complications (and especially no optic nerve injuries) makes this “expanded endonasal approach” a valuable, if not superior, alternative to transcra-

nial approaches at least for those with adequate experience in transnasal endoscopy and cranial base microanatomy/microsurgery. This value would be increased, if in further follow-up, the risk of CSF leak is really minimized to approximately 5% by the vascularized nasal mucosa flap technique. As Gardner et al. demonstrate, an interdisciplinary approach at least for larger meningiomas in the area of the expanded endonasal approach is recommended by neurosurgeons and ear, nose, and throat surgeons with significant experience in both endonasal endoscopy and anatomy. Because this wide endonasal exposure may lead to nasal complaints/disturbances of nasal airflow or even to ozena as we know from larger microsurgical transnasal exposures (e.g., midface degloving), the expanded endonasal approach seems preferable with larger meningiomas, for which the risks of cerebral and optical damage by transcranial retraction are more important than disturbances in nasal airflow. However, with smaller frontobasal (olfactory groove to anterior tubercular) meningiomas, for which the risk of functional central nervous system damage (especially of optic nerves) is not a significant surgical factor, a transcranial approach (eyebrow or subfrontal, possibly endoscopy assisted) may still be preferable. Growing experience in further reports with adequate evaluation may establish a differential indication between transnasal and transcranial (and combined) approaches.

Michael R. Gaab
Hannover, Germany

This is a landmark article describing the largest series of meningiomas removed via an endonasal approach to date. This is a technique in evolution that was once considered impossible with an excessively high complication rate and now has very acceptable morbidity and is reproducible. The technique is innovative and simple. Although the learning curve is steep, once it is mastered, as this series shows, almost any anterior cranial base lesion may be approached via the nose. The section on surgical technique is excellent and offers a practical guide to meningioma resection. My only criticism is that the authors could have possibly recognized that the technique may have some limitations when it comes to complete and curative resection. Granted, if you grade success on "intent to treat," then the results appear relatively good. However, using this excuse for the somewhat disappointing complete resection rate is a little glib. With minimally invasive transcranial techniques and contemporary surgical series for meningiomas showing high cure rates with low morbidity, it would have been more insightful to have acknowledged the shortcomings of this approach. The first step to improving the endonasal technique is to recognize its limitations. The authors clearly did this with their CSF leak rate and have subsequently improved this to a level comparable to that with transcranial approaches. The authors of this article have reputations for being excellent technical surgeons. I cannot help but wonder whether they would have been as happy with similar resection rates for an open, transcranial surgical series of meningiomas. I concede that one should temper surgical aggression with morbidity. If the incomplete resection rate was high but the complication rate was low in a population of geriatric patients with petroclival meningiomas I would applaud such a series. However, some of the patients with incomplete resections were relatively young and had very resectable olfactory groove tumors. The intent-to-treat argument does not really hold here. I am hoping this is the first of many more articles on this subject that will show more pleasing results with the development of better instruments, refinement of technique, and more experience.

Charles Teo
Queen's Park, Australia

This is a very exciting article showing that it is possible to resect meningiomas of the anterior cranial base through the most logical approach, i.e., the extracranial one from below reaching primarily the insertion and the vascular supply. The large series of 35 patients demonstrates that the approach is not an anecdotal adventure but a repetitive, well-organized technique. There was no mortality, no permanent worsening in vision, and only one new pituitary deficit. We must accept that fact that this new way of approaching the cranial base is safe. However, closure of the dura is still a persisting problem. In this series ending in 2005, the rate of CSF leak was very high (40%). Since then consistent progress has been made to greatly decrease the rate of this complication with the use of new mucosal flaps. I am really convinced that endoscopy is an efficient technique we should learn as I am sure it is going to have a large role in cranial base neurosurgery. It is not easy procedure for a microsurgeon who is not used to working with two-dimensional views through a deep and very narrow space. Training is, therefore, very important. In addition, the instrumentation should also be improved to make these endoscopic techniques still safer for the patient and more comfortable for the surgeon.

Bernard George
Paris, France

This is an excellent article concerning the removal of a variety of cranial base meningiomas by means of an endoscopic endonasal approach and, as a matter of fact, it could be considered as another important contribution from Kassam's group in Pittsburgh. The following are required for this technique: 1) excellent knowledge of the anatomy of the cranial base, from both its surfaces (intra- and extracranial), 2) precise knowledge of the disease, 3) skill in endoscopy, 4) adequate operative setup, i.e., neuronavigation, micro-Doppler probe, and last-generation endoscopic equipment; and 5) a team approach.

The Pittsburgh team achieved such integrated know-how and, following them, other groups around the world, including ours, have been starting to apply the technique in the same way. Our contribution, as that of many other groups, comes from the expansion of the pituitary endonasal transsphenoidal experience to the areas around the sella. Credit should be given to Dr. Kassam's team for their innovation in application of the systematic approach to the entire ventral cranial base through the endoscopic endonasal passage.

We should address whether this route, which is generally considered minimally invasive but, actually, often requires extensive removal of the bone structures of the nasal cavities and of the ventral cranial base, is appropriate for every type of meningioma. The answer comes from the fact that the minimal invasiveness of this approach relates to the lesion itself and the removal technique. Hence, in the endoscopic endonasal approach, lesion removal starts with its dural attachment and continues with gentle dissection of the tumor from brain tissue and the surrounding neurovascular structures. That is exactly the opposite of what often happens during a transcranial cranial base approach. It is obvious that we cannot manage every single meningioma of the midline cranial base through the endoscopic endonasal approach. Furthermore, at the moment we cannot yet ultimately define what shape, dimension, and position of midline cranial base meningiomas are more likely to be treated through such an approach. Nevertheless, it should be pointed out that there are currently some contraindications to use of the technique, i.e., encasement of the main vessels. Time and experience of selected groups with dedicated experience with such tumors will define the wise use of such approaches for the neurosurgical community.

The endonasal route has a higher rate of postoperative CSF leaks, which represents a challenge with use of the approach. In fact, tech-

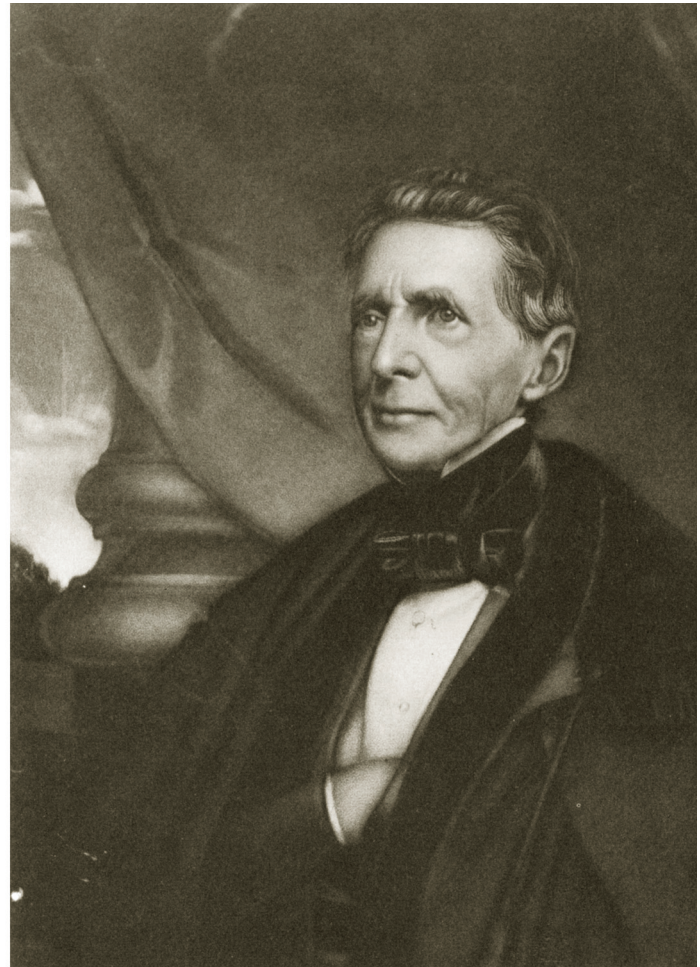
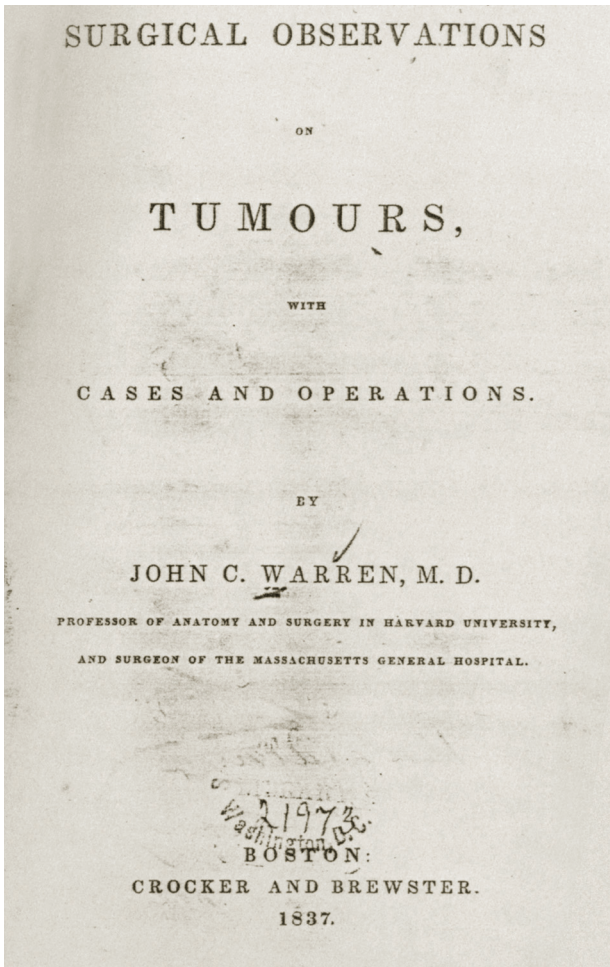
niques and materials for the reconstruction are continuously evolving and, therefore, the numbers of CSF leak rates reported in the literature are decreasing. The fact that we are dealing with cranial base surgery and not with transsphenoidal surgery of the sellar area should not be underestimated. Also, for tuberculum sellae meningiomas and olfactory groove meningiomas operated on via the transcranial route, a visual worsening rate up to 30% (1) and a CSF leak rate of 12.5% (2) have been reported. Such rates do not seem much different from those reported in the endonasal series, and, furthermore, with the extended endonasal approach the rate of visual worsening seems to be lower.

Younger neurosurgeons could easily be fascinated by this type of surgery, which is developing rapidly with expansion of its boundaries to new frontiers, considered insurmountable only few years ago. Nevertheless, it is crucial to emphasize the fact that modern microsurgical transcranial approaches, tailored for treatment of different cranial

base meningiomas, are here to stay and that the use of the endonasal route for the removal of such lesions requires perfect knowledge of each of them.

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Pioneers of Cancer Treatment: Oncology in the United States. In 1837, *Surgical Observations on Tumours with Cases and Operations*, by John Collins Warren, was the first monograph dealing with tumors published in the United States. Warren (1778-1856) was the founder of the Massachusetts General Hospital and of the *Boston Medical and Surgical Journal*, now the *New England Journal of Medicine*. He helped establish the discipline of anesthesia when he removed a vascular tumor from the neck of a patient put to sleep with ether. From Shimkin MB: *Contrary to Nature: Being an Illustrated Commentary on Some Persons and Events of Historical Importance in the Development of Knowledge Concerning Cancer*. Washington D.C., U.S. Department of Health, Education, and Welfare, 1977.