Olfactory groove meningiomas arise in the midline of the anterior cranial fossa along the dura of the cribriform plate and planum sphenoidale, and comprise approximately 10% of intracranial meningiomas.1,16,30,38 Because of their subfrontal location, many of these tumors are quite large by the time they are diagnosed.16 Hyperostosis of the adjacent underlying bone is common, and further extension into ethmoid sinuses and nasal cavity can occur in 15%–25% of cases.2,9,16,22,34,39 Total Simpson Grade I resection of meningiomas including dural attachment and underlying hyperostotic bone offers the best chance of a Simpson Grade I resection to minimize recurrence. Incomplete removal of involved hyperostotic bone can result in tumor recurrence at the cribriform plate with extension into the paranasal sinuses. Resection has traditionally been performed using a bifrontal or pterional approach, both of which require some degree of brain retraction or manipulation to expose the tumor.

The endoscopic endonasal transcribriform approach offers the most direct and immediate exposure to the tumor without brain retraction and manipulation of neurovascular structures. An endonasal “keyhole craniectomy” is performed in the ventral skull base directly over the basal dural attachment, extending from the posterior wall of the frontal sinus to the planum sphenoidale and tuberculum sellae in the anteroposterior plane, and from one medial orbit to the other in the coronal plane. Excellent panoramic visualization of the keyhole skull base defect can be obtained with a 30° endoscope after performing a modified Lothrop procedure. Because the dural attachment is adjacent to the paranasal sinuses, early devascularization and total Simpson Grade I removal of the tumor including the dural attachment and underlying hyperostotic bone can be achieved in properly selected patients. This approach is also very suitable for meningiomas that have recurred or extended into the paranasal sinuses. Extracapsular, extraarachnoid dissection of the tumor from the frontal lobes and neurovascular structures can be performed using conventional bimanual microsurgical techniques.

In this report, we review the surgical technique and describe our operative nuances for removal of olfactory groove meningiomas, including recurrent tumors with extension into the nasal cavity, using a purely endoscopic endonasal transcribriform approach. In addition, we discuss the advantages, limitations, patient selection, and complications of this approach. We specifically highlight our technique for multilayer reconstruction of large anterior skull base dural defects using fascia lata and acellular dermal allograft supplemented by bilateral vascularized pedicled nasoseptal flaps. Three new cases of endoscopically resected olfactory groove meningiomas are also presented. (DOI: 10.3171/2011.2.FOCUS116)

**Key Words** • endoscopic endonasal approach • transcribriform approach • anterior skull base tumor • olfactory groove meningioma • modified Lothrop procedure • skull base reconstruction
and reported to be as high as 41% at 10 years. The most common sites of recurrence are at the anterior skull base and paranasal sinuses, specifically the cribriform plate and ethmoid sinuses.

The most common surgical approaches for removing olfactory groove meningiomas are the bifrontal transcra- nal and pterional approaches. When using a midline transbasal approach, the surgical corridor is through either an interhemispheric or a bilateral subfrontal route. This requires ligation and division of the superior sagittal sinus, which entails some risk of venous infarction and cerebral edema. When using a pterional approach, the corridor is through a unilateral subfrontal or transsylvian route. Although the contralateral frontal lobe is left undisturbed, the trajectory is oblique with loss of midline orientation, thereby limiting access to the cribriform plate and paranasal sinuses. Additional cranial base techniques with extended osteotomies, such as removal of the supraorbital bar (extended transbasal approach, subcranial approach) or orbital rim (orbitozygomatic approach, supraorbital approach), can be applied as well to increase exposure and minimize brain retraction. Nevertheless, these transcra- nial approaches all require some degree of brain retraction and manipulation of neurovascular structures. Associated complications include frontal lobe edema, venous infarction, hematoma, CSF leak, bone flap infection, and pneumocephalus, with a mortality rate of 5% reported in one series. Because the blood supply to the tumor is at the base of the dural attachment, considerable brain displacement and subsequent debulking is required before the tumor blood supply can be interrupted.

Recently, there has been increased interest in endo- scope endonasal approaches for the removal of anterior skull base meningiomas and this continues to be a topic of debate. The endoscopic endonasal transcra- nial approach offers the most direct and immediate exposure to the tumor without having to apply brain retraction and manipulate neurovascular structures. A panoramic view of the ventral skull base can be obtained from the frontal sinuses to the planum sphenoidale in the anteroposterior view, and from one medial orbital wall to the other in the coronal view (Fig. 1). Because the site of dural attachment is adjacent to the paranasal sinuses, early devascularization of the tumor and subsequent radical resection of the tumor, dural attachment, and involved hyperostotic bone (Simpson Grade I) can be achieved in properly selected patients. This endonasal approach is also very suitable for those meningiomas that have recurred or extended into the paranasal sinuses. Extracapsular, extraarachnoid dis- section of the tumor from the frontal lobes and neuro- vascular structures can be performed using conventional bimanual microsurgical techniques. Reconstruction of large anterior skull base defects and prevention of CSF leakage remains a challenge. However, with the introduction of newer techniques including vascularized flaps, the rate of CSF leakage has dramatically declined.

In this report, we review the surgical technique and describe our operative nuances for removal of olfactory groove meningiomas, including recurrent tumors in the nasal cavity, using a purely endoscopic endonasal transcribriform approach. In addition, we discuss patient sele-

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**Fig. 1.** Case 1. Preoperative sagittal T1-weighted Gd-enhanced MR image demonstrating a large olfactory groove meningioma that extends from the cribriform plate anteriorly to the tuberculum sellae posteriorly. The red arrows indicate the range of exposure that can be obtained with an endoscopic endonasal approach to the entire ventral skull base from the crista galli to the tuberculum sellae.

**Surgical Technique: Endoscopic Endonasal Transcribriform Approach**

**Patient Positioning**

The patient is positioned supine with the bed slightly reflexed so that the head is 15° above the heart to facilitate venous return. After the head is placed in a Mayfield head holder with 3-pin fixation, the neck is slightly extended to enhance the trajectory to the anterior skull base. We pre- fer additional lateral flexion of the head toward the left shoulder with slight rotation of the head toward the right shoulder to facilitate comfortable access to the nose when the surgeon stands on the patient’s right side. The endota- cheal tube is also taped toward the left side of the mouth so that it does not crowd the surgeon’s access to the nose. Frameless stereotactic navigation for image guidance is used to guide the degree of bone removal at the skull base. Navigation using CT angiography is helpful for identifying bony anatomy, anticipating the thickness of the cribriform...
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**Fig. 2.** Illustration demonstrating the endoscopic endonasal transcricriiform approach for resection of an olfactory groove meningioma and subsequent repair of a large osteodural defect. A: Intracapsular debulking of the tumor is performed to facilitate collapse of the tumor capsule for subsequent extraarachnoid extracapsular dissection from the critical structures. B: Following tumor removal, the bilateral frontal lobes and olfactory nerves can be visualized through the large dural defect. A panoramic view of the ventral skull base extending from the posterior wall of the frontal sinus to the planum sphenoidale can be obtained with a 30° endoscope. C: Coronal view demonstrating a recurrent olfactory groove meningioma arising from the cribriform plate and extending into the paranasal sinuses. D: Coronal view demonstrating the technique of AlloDerm graft repair (highlighted in green). A single piece of AlloDerm is positioned intracraniially underneath the edges of the bony defect with the outer margins of the graft extending extracranially to overlay the de-epithelialized margins of the bony defect. The graft is wedged into position using gentamicin-soaked Gelfoam pledgets. The weight of the brain helps buttress the graft to keep it in position. From Eloy JA, Tessema B, Casiano RR: Surgical harvest of an autologous fascia lata graft, which is used during dural reconstruction. Oxymetazoline hydrochloride (Afrin)—soaked pledgets are placed into the nasal cavity. Intravenous antibiotics and 10 mg of dexamethasone are administered at the start of the operation. Anticonvulsants and mannitol are not given for endonasal approaches to olfactory groove meningiomas because the tumor removal is performed in an extraarachnoid fashion without brain retraction or manipulation. We also do not use intraoperative lumbar drainage because there is no need for brain relaxation or brain retraction for this procedure.

General Principles for Endoscopic Skull Base Surgery

In our institution, we use a multidisciplinary team approach when performing endonasal endoscopic skull base surgery. All procedures are performed by a skull base neurosurgeon (J.K.L.) working simultaneously with an otolaryngologist (J.A.E.) specializing in endoscopic sinus and skull base surgery. A so-called “3- to 4-handed bimanual technique” is used, with both surgeons working simultaneously through both nostrils without the use of a nasal speculum. The otolaryngologist performs the initial endonasal exposure of the anterior skull base using a 4-mm-diameter, 18-cm-length, 30° endoscope (Karl Storz) that is aimed superiority. During the transcricriiform skull base drilling and subsequent intradural tumor removal, the neurosurgeon uses traditional bimanual microsurgical dissection techniques with instruments inserted into each nostril. For a right-handed surgeon, the suction is primarily in the left hand inserted into the right nostril, and a dissecting tool (drill, tissue aspirator, microdissector, microscissors, or bipolar cautery) is in the right hand inserted into the left nostril. We prefer not to use the scope holder so that the otolaryngologist can provide dynamic movement of the endoscope to enhance depth perception and continuous visualization of desired surgical targets. The 30° endoscope is aimed superiority toward the skull base so that a direct “looking-up” view of the cribriform plate is obtained. We recommend placing the endoscope at the 6 o’clock position in the right nostril, with suction at the 12 o’clock position, so that the neurosurgeon is working “above” the lens of the scope. We have found that this technique minimizes problems related to our instruments bumping into each other when working in tight spaces.

Although most surgeons report using a 0° endoscope for the exposure and subsequent tumor removal, 7,12 we prefer to use a 30° endoscope as our workhorse. In our experience, the 30° endoscope allows us to achieve the same degree of surgical exposure as a 0° endoscope, and it also has the additional benefit of angled viewing capabilities for looking around corners. Therefore, frequent exchange between the two endoscopes is unnecessary. Our clinical observations are in agreement with the findings in an anatomical study by Batra et al.,3 in which the 30° endoscope provided the best view from the frontal sinus to the planum sphenoidale with the least distortion compared with both 0° and 70° endoscopes.

Paranasal Sinus Exposure

After injecting the nasal septum and the tail and anterosuperior attachment of the middle turbinate with 1% lidocaine with epinephrine (1:100,000 dilution), both inferior turbinates are lateralized with a Goldman elevator. Depending on the size of the tumor, the middle turbinates may need to be resected to create more working room. Otherwise, they can be lateralized. If the tumor extends intranasally, as is the case in some recurrent meningiomas, the approach starts with endoscopic endonasal debulking with a 4-mm rotation-suction microdebrider with the objective of identifying the stalk of the tumor. Key elements such as the nasal septum, lateral nasal wall, and posterior nasal choanae are identified. Bilateral maxillary antrostomies are routinely performed to prevent iatrogenic sinusitis and to expose the orbital floor as a major anatomical landmark. A wide bilateral sphenoidotomy is performed to expose the sella turcica, carotid protuberances, bilateral optic canals, tuberculum sellae, and pla-
num sphenoidale. It is important to identify the medial and lateral opticocarotid recesses (OCRs), which are key landmarks in endoscopic skull base surgery. The medial OCR is a pneumatization of the middle clinoid process and represents an indentation in the bone that is formed at the medial junction of the parasellar carotid canal and the optic canal. The lateral OCR is a pneumatization of the anterior clinoid process and is located at the lateral junction of the parasellar carotid canal and the optic canal. The medial OCR is a useful landmark in identifying the optic nerve as it joins the middle clinoid process. The planum sphenoidale and the optic nerves mark the posterior boundary of the anterior skull base exposure.

To expose the entire cribriform plate, particularly for large tumors that extend lateral to the middle turbinates (Fig. 3), bilateral total ethmoidectomies are performed to expose the junction of the lamina papyracea with the fovea ethmoidalis. During the posterior ethmoidectomy, it is important to recognize an Onodi cell, which is a posterior ethmoid cell that is positioned superolateral to the sphenoid sinus. This is an important anatomical variant because the optic nerve and carotid artery often course through the lateral aspect of these Onodi cells.

At this juncture, we prefer to harvest bilateral pedicled vascularized nasoseptal flaps for subsequent skull base reconstruction. The flaps are harvested in a manner similar to that described by Hadad et al., and rotated inferiorly into the posterior nasopharynx. This allows further exposure of the anterior skull base while protecting the vascular pedicle from inadvertent injury that can compromise the integrity and effectiveness of the flaps. Resecting 1.5–2 cm of the posterior aspect of the nasal septum allows triangulation of surgical instruments through both nostrils so that bimanual microsurgical dissection can be performed.

**Endoscopic Modified Lothrop Procedure**

The anterior extent of the exposure is created by performing an extended frontal sinusotomy (modified Lothrop procedure). This portion of the procedure starts with localization of the frontal recess and ostia bilaterally. A superior septectomy is performed anterior to the cribriform plate (anterior to the tumor) and is connected to the already made posterior septectomy. This maneuver allows a panoramic view of the cribriform plate and also facilitates triangulation of bilateral instruments at the surgical target. Up-angled 2-0 and 3-0 bone curettes are then used to create and enlarge one common frontal sinusotomy (Lothrop cavity) by removing the intersinus and intrasinus septations, thereby exposing the posterior frontal sinus wall. The nasofrontal beak is subsequently thinned down using large cutting burs once the posterior wall of the common frontal sinus cavity is visualized. The endoscopic modified Lothrop procedure is a key technical portion in the endoscopic transcryptiform approach because it provides exposure of the posterior table of the frontal sinus, which is an important landmark delineating the anterior border of the bony resection and...
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also acts as a shelf for tucking graft material during skull base reconstruction. This procedure has served as an important adjunct for exposure of the anterior skull base and complex frontal sinus pathology. Widening of the frontal sinuses promotes drainage and minimizes the risk of postoperative frontal stenosis and iatrogenic mucocele formation.

Transcribriform “Keyhole” Craniectomy

Once the endoscopic modified Lothrop procedure, total ethmoidectomy, and wide sphenoidotomy have been performed, a wide panoramic view of the entire ventral skull base from the frontal sinuses to the sphenoid sinuses is achieved. Next, an endonasal “keyhole craniectomy” of the ventral skull base is performed using a high-speed drill with copious irrigation (Fig. 4). The boundaries of the craniectomy extend from the posterior wall of the frontal sinus anteriorly to the planum sphenoidale posteriorly. The lateral boundaries are the lamina papryracea (medial orbital walls) bilaterally. The cribiform plate is carefully drilled away using a self-irrigating high-speed curved endonasal diamond drill (Medtronic Xomed) with copious irrigation. The curve of the drill is directed superiorly to adequately reach the anterior skull base. In addition, we use a double-barrel suction-irrigator that allows continuous self-irrigation and suction to keep the surgical field clear of bone dust while cooling the drill tip to prevent overheating near critical neurovascular structures. Although the extent of bone removal is tailored to the location of the tumor and dural attachment, it is important to perform a wide osteotomy so that there is no residual bone obstructing the surgeon’s line of sight or hindering the maneuverability of instruments. When dealing with tumors that extend more superiorly, more bone is removed anteriorly so that an adequate anterosuperior trajectory over the top of the tumor can be obtained during extracapsular dissection of the tumor. Nevertheless, it is important to leave a bony shelf of the posterior frontal sinus wall, if possible, as this serves as a ledge for tucking inlay grafts at the time of reconstruction. Bone removal starts at the posterior table of the frontal sinus anteriorly and ends at the planum sphenoidale posteriorly. If the tumor extends more posteriorly, removal of the tuberculum sellae and medial OCRs can be performed, if needed. Bony resection of the cribiform plate is carried out laterally to include the fovea ethmoidalis from one lamina papryracea to the other.

During drilling, it is imperative to identify the anterior and posterior ethmoid arteries. Coagulation and division of these arteries contribute to early devascularization of the meningioma since these vessels provide significant blood supply to the tumor. Care is taken not to let the proximal portion of the vessel retract back into the orbit before adequate coagulation, as this can result in an orbital hematoma and proptosis. The crista galli, which can be hyperostotic in some cases of olfactory groove meningiomas, is carefully drilled down and removed.

Before opening the dura, meticulous hemostasis is obtained and careful inspection of the bony opening with intraoperative navigation is performed to ensure that there is adequate exposure of the basal attachment of the tumor. Any residual bony overhang that is obstructing the line of sight or hindering surgical freedom of instruments is removed. Further tumor devascularization is achieved by coagulating the exposed dura and the anterior falx artery using a pistol-grip endoscopic bipolar forceps (Karl Storz).

Intradural Exposure and Tumor Resection

A No. 15 blade and endoscopic pistol-grip scissors are used to make a rectangular incision around the region of the dural attachment. Anteriorly, the falk is coagulated and divided toward the incisura to un tether the dural attachment. An extended tip endonasal ultrasonic aspirator (Integra LifeSciences) is used for intracapsular tumor debulking. Some meningiomas may be quite fibrous and unresponsive to the ultrasonic aspirator. In these cases, we have used an up-angled rotation-suction microdebrider (Gyrus, Olympus) that effectively debulks fibrous tumors of the anterior skull base (Fig. 4). It is imperative that tumor debulking with the microdebrider or ultrasonic aspirator remain intracapsular, so as not to breach the tumor capsule. Since the tumor’s blood supply has been already devascularized during the extradural approach, the tumor debulking is relatively hypovascular.

After adequate central debulking, extracapsular dissection is performed to collapse the tumor capsule. This allows the tumor capsule to be gathered and brought into

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the cribriform keyhole defect from a lateral to medial direction. Natural pulsations of the brain also facilitate medcialization and delivery of the tumor capsule into the skull base opening. Although the width of the tumor may be larger than the width of the cribriform defect, delivery of large tumors through a relatively smaller bony opening is possible using this keyhole technique, as long as the dural attachment does not extend laterally beyond junction of the lamina papyracea and the fovea ethmoidalis. It is imperative to maintain bimanual microsurgical dissection techniques during extracapsular dissection so as to preserve the arachnoid planes.

Anatomically, meningiomas are dural-based tumors and displace the arachnoid ahead of them as they grow. Therefore they are extraarachnoid structures situated in the subdural space. If possible, it is helpful to identify the “double arachnoid” layer, which is comprised of tumor arachnoid and cisternal arachnoid; in larger tumors, this may appear as a single layer of arachnoid. Nevertheless, extraarachnoid extracapsular dissection is best performed between the tumor capsule and the tumor arachnoid, and not the cisternal arachnoid. Preservation of these arachnoid layers facilitates safer microsurgical dissection of the tumor from critical neurovascular structures, such as the orbitofrontal, frontopolar, or anterior cerebral arteries. In larger tumors with significant edema on preoperative T2-weighted images, one should anticipate the possibility of subpial invasion and recruitment of pial blood supply. Meticulous microsurgical extracapsular dissection can be performed with gentle countertraction on the tumor capsule with the suction instrument in one hand, and the bipolar dissection forceps in the other hand (Fig. 4). It is paramount to avoid premature “pulling” of the tumor capsule before it has been completely dissected free from the surrounding brain and vascular structures, so as to avoid a catastrophic vascular avulsion. If there is tumor tissue adherent to a major vessel or perforator, it is safer to leave a small residual tumor that can be treated later with radiosurgery.

**Closure and Skull Base Reconstruction**

Successful tumor resection is not complete without meticulous multilayer reconstruction of the skull base dural defect to prevent CSF leakage. In a recent anatomical study, the average boundaries of the anterior skull base defect were 33.7 mm (range 29–40 mm) in the anteroposterior direction (posterior wall of frontal sinus to planum sphenoidale), and 23.5 mm (range 20–27 mm) and 19.1 mm (range 17–22 mm) in the transverse direction (orbit to orbit) at the level of the anterior ethmoidal artery and posterior ethmoidal artery, respectively. Although the dimensions of the skull base and dural defect vary among individual patients, these dimensions can be helpful in estimating the size of the grafts to fashion. The dimensions of each graft layer should be larger than the dimensions of the dural and bony defect, when using the following reconstruction technique that we have developed.

For repair of these large anterior skull base defects that extend all the way from the posterior wall of the frontal sinus anteriorly to the planum sphenoidale posteriorly, we use a multilayer reconstruction technique (Fig. 5). An autologous fascia lata graft is placed intradurally as an inlay graft. This initial layer converts a “high-flow leak” to a “low-flow leak.” Several pieces of Surgicel are placed over the bony defect to temporarily hold the graft in place. Next, a layer of thick implantable acellular dermal allograft (AlloDerm, LifeCell Corp.) is tucked at least 1 cm circumferentially between the remaining dural cuff and the edge of the bony defect using gentamicin-soaked Gelfoam pledgets (Figs. 2D and 5C and D). The redundant edges of the acellular dermal graft serve as an overlay while the tucked portions act as an inlay. The previously harvested bilateral pedicled nasoseptal flaps are then rotated over the acellular dermal graft. A thin layer of fibrin matrix (Tisseel, Baxter), or polymerized hydrogel (DuraSeal, Confluent Surgical) is placed over the multilayer closure. Dural sealant should not be placed in between the dural closure and the nasoseptal flap, as this may prevent flap adherence. Several pieces of gentamicin-soaked Gelfoam pledgets are placed over the repair, which is further buttressed by a Merocel nasal tampon (Medtronic Xomed) covered with bacitracin ointment. The patient is maintained on antibiotics until the packs are removed approximately 10 days after surgery. We do not routinely use postoperative lumbar drainage because the patient is already in a CSF hypovolemic state at the end of surgery. Further lumbar drainage can increase the risk of intracranial hypotension or tension pneumocephalus.

**Fig. 5. Case 1.** A–C: Intraoperative photographs demonstrating multilayer reconstruction of the skull base dural defect. A: View of the dural defect (outlined by dashed lines). Bilateral frontal lobes (FL) are visualized through the dural defect. B: An initial layer of autologous fascia lata (FL) is tucked underneath the edges of the dura as inlay graft to convert a “high-flow” defect to a “low-flow” defect. C: A single piece of acellular dermal allograft (ADA) is positioned intracranially underneath the edges of the bony defect with the outer margins of the graft extending extracranially to overlay the de-epithelialized margins of the bony defect. The graft is wedged into position using gentamicin-soaked Gelfoam pledgets (G). D: Drawing (sagittal view) demonstrating the multilayer reconstruction with the acellular dermal allograft tucked underneath the bony defect. The reconstruction is completed with rotation of bilateral vascularized pedicled nasoseptal flaps (not shown) to cover the AlloDerm repair followed by application of DuraSeal. ESC = expanded sphenoid cavity; LC = Lothrop cavity.
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feel that our reconstruction technique is also somewhat dependent on restoration of CSF pressures to allow the brain to buttress the inlay grafts against the skull base. Without lumbar drainage, patients are able to mobilize earlier with less risk of low-pressure headaches and thromboembolic complications.

Illustrative Cases

Case 1

This 43-year-old woman with a known 1.5-cm olfactory groove meningioma detected 3 years prior presented with progressive headaches and absence of olfaction. A follow-up MR imaging study demonstrated an enlarging 4-cm olfactory groove meningioma with an associated tumor cyst resulting in cerebral edema with mass effect on the frontal lobes (Figs. 3–6). Hyperostosis at the cribriform plate was also seen on preoperative CT (Fig. 6). The patient underwent an endoscopic endonasal transcribriform approach for resection of the tumor. The tuberculum sellae was removed because the tumor extended posteriorly in this region. A microdebrider was used to debulk the tumor because the tumor was very fibrous and unresponsive to an ultrasonic aspirator (Fig. 4B). Extracapsular dissection of the tumor from the surrounding critical structures was performed without brain retraction or neurovascular manipulation. A Simpson Grade I tumor resection was performed including removal of the dural attachment and underlying hyperostotic bone (Fig. 4). Multilayer reconstruction was performed using autologous fascia lata, AlloDerm, and vascularized nasoseptal flaps (Fig. 5). No lumbar drainage was used. Postoperative MR imaging demonstrated gross total resection of the tumor. The patient was neurologically intact after surgery without any CSF leakage. At 3 months’ follow-up, nasal endoscopy demonstrated excellent re-epithelialization of the ventral skull base repair that was noted on the follow-up MR imaging (Fig. 3).

Case 2

This 40-year-old woman presented with a 3-month history of nasal congestion and frontal headaches. Three years previously, she had undergone a bifrontal craniotomy for treatment of an olfactory groove meningioma at another institution. Magnetic resonance imaging demonstrated recurrent meningioma arising from the cribriform plate and planum sphenoidale with extension into the paranasal sinuses (Fig. 7). Significant hyperostosis of the anterior skull base extending from the crista galli to the planum sphenoidale was seen on preoperative CT (Fig. 8). An endoscopic endonasal transcribriform approach was performed. A modified Lothrop procedure facilitated exposure of the ventral skull base from the posterior wall of the frontal sinus to the planum sphenoidale. A Simpson Grade I total resection was achieved by excising all of the hyperostotic bone and dural attachment at the cribriform plate with tumor-free margins (Fig. 9). The anterior skull base defect was reconstructed with an autologous fascia lata inlay graft and an AlloDerm inlay/outerlay graft, followed by bilateral vascularized nasoseptal flaps. No lumbar drainage was used. The patient remained neurologically intact without CSF leakage in the immediate postoperative period and at 6 weeks’ follow-up. Nasal endoscopy also demonstrated excellent re-epithelialization of the ventral skull base repair.

Fig. 6. Case 1. A and B: Preoperative sagittal (A) and coronal (B) contrast-enhanced CT reconstructions demonstrating a large olfactory groove meningioma with hyperostosis of the cribriform plate. D and E: Postoperative sagittal (D) and coronal (E) contrast-enhanced CT reconstructions demonstrating the extent of bone resection extending from the back of the frontal bone to the sella turcica in the sagittal view, and from medial orbit to medial orbit in the coronal view. Note that the patient did not have a frontal sinus. C and F: Postoperative 3D reconstructed CT angiograms demonstrating multiple views of the anterior skull base defect and surrounding vasculature after a transcribriform approach. C: View looking from above demonstrating a large anterior skull base defect. F: View looking up from below mimicking the endonasal endoscopic view of the ventral anterior skull base defect with the anterior cerebral arteries in the distance.
Case 3

This 53-year-old woman, who had undergone 2 previous bifrontal craniotomies for resection of an olfactory groove meningioma at another institution, presented with progressive growth of recurrence at the skull base with extension into the paranasal sinuses. Magnetic resonance imaging also demonstrated enhancement extending laterally over both orbital roofs suggestive of tumor (Fig. 10). An endoscopic endonasal approach alone was felt to be inadequate to resect the laterally extending tumor. Therefore, a combined bifrontal transbasal and endoscopic endonasal approach was performed to resect the anterior skull base and paranasal sinus tumor. From the transcranial exposure, the tumor was resected from the orbital roofs, anterior clinoid process, and along the lesser wing of the sphenoid. The cribriform plate was drilled out from above, and resection of paranasal sinus tumor was carried out. Endonasal endoscopic inspection from below identified more tumor that was not visualized from above, which was removed with a rotation-suction microdebrider. A near-total resection was achieved because microscopic residual tumor was observed infiltrating the left optic nerve. A safe plane of dissection could not be identified.

Multilayer reconstruction was performed with a watertight closure using an autologous temporalis fascia graft that was sewn primarily to the dural defect from above. An AlloDerm graft was tacked down in 4 corners to cover the fascial closure from above. Since there was no pericranial flap available (used in previous surgery),

Fig. 7. Case 2. A–C: Preoperative sagittal (A), coronal (B), and axial (C) T1-weighted Gd-enhanced MR images demonstrating a recurrent olfactory meningioma arising from the cribriform plate and planum sphenoidale with extension into the paranasal sinuses. D–F: Postoperative sagittal (D), coronal (E), and axial (F) T1-weighted Gd-enhanced MR images showing gross total resection of the tumor using an endoscopic endonasal approach. Enhancement at the ventral skull base represents the vascularized nasoseptal flap with some postoperative changes.

Fig. 8. Case 2. A and B: Preoperative sagittal (A) and coronal (B) CT reconstructions showing recurrence with extensive hyperostosis at the ventral skull base (white arrows). Note the previous bifrontal craniotomy defect at the frontal sinus. C and D: Postoperative sagittal (C) and coronal (D) CT reconstructions (after an endoscopic endonasal approach) demonstrating a maximal ventral skull base defect extending from the posterior table of the frontal sinus to the anterior sella in the sagittal view, and from medial orbit to medial orbit in the coronal view.
the closure was supplemented by a vascularized nasoseptal flap from below. No lumbar drainage was used after surgery. The patient remained neurologically intact with normal vision (20/25 visual acuity, normal visual fields) in the immediate postoperative period and at the 1-year follow-up examination. There was no postoperative CSF leakage, and follow-up nasal endoscopy at 9 months after surgery demonstrated excellent re-epithelialization of the ventral skull base reconstruction.

**Discussion**

*Endoscopic Endonasal “Keyhole” Removal of Olfactory Groove Meningiomas*

The endoscopic endonasal transcribriform approach offers several surgical advantages for removal of olfactory groove meningiomas. Because these tumors originate at the cribriform plate, the endonasal route provides a natural corridor of access to the tumor and allows the most direct approach, without any brain retraction or manipulation of neurovascular structures to obtain adequate exposure (Fig. 1). In cases of convexity meningiomas, a craniotomy is made directly over the dural attachment of the tumor. Similarly, in treating olfactory groove meningiomas, the endonasal “keyhole craniectomy” is made in the cranial base directly over the basal dural attachment, allowing for early devascularization of the tumor (Figs. 4A and 6C and 6F). The anatomical limits of the endonasal keyhole exposure are the posterior table of the frontal sinuses anteriorly, the medial orbits laterally, and the planum sphenoidale posteriorly. Further removal of the planum sphenoidale and tuberculum sellae can be performed, if necessary, for treatment of tumors that have more posterior extension (as in Case 1, Figs. 3–6). The endoscopic view, particularly with a 30° endoscope aimed superiorly, provides an unparalleled panoramic view of the entire ventral skull base (Figs. 4 and 5).

In many cases, the greatest diameter of the tumor in the coronal view is often wider than the width of the endoscopic corridor (from medial orbit to medial orbit). To deliver larger tumors through a relatively smaller keyhole opening, aggressive intratumoral debulking is required to promote collapse of the tumor capsule, thereby making the tumor smaller. The natural pulsations of the brain and any preexisting intracranial pressure both facilitate medialization of capsular walls into the cranial base keyhole opening as the brain gradually reexpands during sequential tumor debulking and extracapsular dissection from surrounding structures. For this reason, we do not use intraoperative mannitol or lumbar drainage. Because these tumors are anatomically subdural extraarachnoid structures with an arachnoid barrier that separates the tumor capsule from the neurovascular structures, extra-
capsular dissection with preservation of the arachnoid planes minimizes the risk of neurovascular injury. We emphasize maintaining the plane of dissection between the tumor capsule and the tumor arachnoid, not the cisternal arachnoid, whenever possible. It is important to recognize that larger tumors may recruit pial blood supply and may even exhibit subpial invasion. It is paramount to perform meticulous dissection of these vessels from the tumor capsule and to ensure that the tumor is completely dissected free from the surrounding brain before any attempt to deliver the tumor capsule, so as to avoid avulsion injury of vascular structures (Fig. 4C and D).

In properly selected patients, radical Simpson Grade I tumor removal can be achieved with the endoscopic endonasal transcribriform approach because the nature of the approach incorporates removal of the underlying hyperostotic bone and dural attachment to access the tumor. The endonasal approach is also very suitable for resecting meningiomas that have recurred or invaded into the paranasal sinuses, as demonstrated in Cases 2 and 3 (Figs. 7–10). Careful examination of preoperative neuroimages is critical for selecting patients for endoscopic resection. If the dural attachment is confined between the medial walls of the orbit, then the endonasal approach may be considered. On the other hand, if the dural attachment extends laterally over the orbital roofs and along the lesser wing of the sphenoid (as in Case 3), complete removal of the tumor, including the dural attachment, may not be possible. In these cases, we would consider a transcranial approach, preferably a bifrontal transbasal interhemispheric approach, if radical resection were the goal. Some authors have reported intentionally performing subtotal debulking via an endoscopic endonasal approach with the goal of relieving mass effect in patients with advanced age and medical comorbidities.12

In some instances, a combined transcranial and endonasal endoscopic approach can be considered for some tumors with lateral extension and paranasal sinus invasion.5,10,24,35,42,43 The patient in our Case 3 (Fig. 10) was treated with such a combined approach because she presented with a recurrence in the paranasal sinuses and skull base with dural enhancement extending laterally over the orbital roofs. Although an endonasal approach alone is able to address the sinonasal tumor and cribiform plate involvement, addition of a bifrontal craniotomy allows for wider access and control of laterally extending tumor over the orbital roofs. Conversely, a transcranial approach alone could have addressed the tumor in Case 3, but the patient had previously undergone surgery performed by a different surgeon, and the pericranial flap had already been used. Addition of the endoscopic approach allowed us to harvest a vascularized nasoseptal flap for reconstruction from below when the pericranial flap from above was not available. The superior visualization afforded by the endoscope also allowed us to detect intranasal tumor that was hidden from the microscopic view from above.
It is also important to recognize the presence of any tumor encasement of major vessels, such as the anterior cerebral arteries, on preoperative imaging, as this may preclude total tumor removal, whether the lesion is approached endonasally or transcranially. In situations where tumor is adherent to important vessels, it is safer to leave a remnant than risk a catastrophic vascular injury. In the event of a neurovascular injury, the reality of quickly gaining adequate vascular control, applying aneurysm clips, and performing direct suture repair or bypass is more feasible with a transcranial approach than with an endonasal approach. Therefore, in cases with major vessel encasement on preoperative images, we would strongly consider a transcranial approach, particularly if a gross- to near-total resection is the desired goal.

Reconstruction of Large Anterior Skull Base Defects

One of the major criticisms of endoscopic endonasal skull base surgery is the relatively higher rate of postoperative CSF leakage. In patients with olfactory groove meningiomas, the anterior skull base osteodural defect is much larger than in patients with tuberculum sellae meningiomas (Figs. 6 and 8). These defects usually extend from the posterior wall of the frontal sinus to the planum sphenoidale. Successful reconstruction of these large defects to prevent CSF leakage remains a challenge.

A summary of results of 3 experienced endoscopic teams removing olfactory groove meningiomas endonasally revealed an overall postoperative CSF leak rate of 24% (6 of 25 patients).12,14 In the largest series reported to date (15 patients), Gardner et al.15 cited 4 cases of CSF leak (26.7%), which were all successfully treated with endonasal reexploration followed by further lumbar drainage. No subsequent craniotomies or permanent CSF diversion procedures were required. De Divitiis et al.7 reported 1 CSF leak in a series of 4 cases (25%); it was successfully treated with endonasal reexploration. In another recent report, Greenfield et al.14 reported 1 CSF leak in a series of 6 cases (16.7%), with an additional craniotomy being required to repair the leak. The authors stated that a craniotomy was chosen rather than repeat endonasal surgery because the defect was large and the leak site was just posterior to the frontal sinus and difficult to reach endonasally. It appears that the majority of these reported cases were performed prior to the application of vascularized nasoseptal flaps, as described by Hadad et al.13 This mucosal flap remains pedicled on the posterior nasal artery and can be rotated to cover a variety of cranial base defects. Because this tissue is vascularized, the flap heals within 5–7 days, thereby quickly forming a mucosalized seal.12 This technique is analogous to the pericranial flap technique that is frequently used in transbasal and craniofacial approaches from above to repair anterior skull base defects.23,24 There are emerging reports that demonstrate significant reduction in CSF leakage (down to 5.4%) when reconstruction is performed with vascularized mucosal flaps.12,20

In this report, we introduce our technique for repairing large anterior skull base defects that extend all the way from the posterior wall of the frontal sinus anteriorly to the planum sphenoidale posteriorly (Figs. 2D and 5). We use a multilayer reconstruction technique that has its foundations based on a technique previously reported by Germani et al.13 The autologous fascia lata inlay graft is the initial layer that serves to convert a “high-flow” defect into a “low-flow” defect. The next layer, using acellular dermal allograft (AlloDerm) is the most critical layer; it completely occludes the dural defect and thereby functions as our primary workhorse for repair of large (> 2 cm) anterior skull base defects. We use the technique of Germani et al.13 whereby a single piece of AlloDerm is positioned intracranially underneath the edges of the bony defect, with the outer margins of the graft extending extracranially to overlay the de-epithelialized margins of the bony defect. The graft is wedged into position using gentamicin-soaked Gelfoam pledges (Fig. 5C and D). We rely on the weight of the brain to buttress and hold the intracranial portion of the graft in position and prevent migration. We do not routinely use postoperative lumbar drainage, as this may theoretically defeat the purpose of this repair technique by promoting lowered intracranial pressures. Absence of a lumbar drain also promotes quicker mobilization and shorter hospital stays,15,16 as well as avoiding the risks of lumbar drain-induced intracranial hypotension and progressive pneumocephalus. Germani et al.13 reported a CSF leak rate of 3% when using AlloDerm as the sole graft material without any additional vascularized mucosal flaps. In our modified technique, we incorporate bilateral vascularized pedicled nasoseptal flaps on top of the AlloDerm repair as an additional layer of coverage. The length of the nasoseptal flaps may not always reach anteriorly to adequately seal the posterior wall of the frontal sinus. Therefore, we rely on the AlloDerm layer, rather than the nasoseptal flaps, as the primary layer of coverage. The nasoseptal flaps in this technique act as a supplemental layer to promote rapid ingrowth of granulation, vascularization, and re-epithelialization by sinonasal mucosa. Although some have reported difficulty in reaching the posterior wall of the frontal sinus endoscopically to repair dural defects,14 we have found that this region can be readily accessed and visualized by performing a modified Lothrop procedure with 30° and 70° endoscopes.3 With this technique, large skull base defects that extend anteriorly to the posterior wall of the frontal sinus can be successfully repaired without occlusion of the nasofrontal recess. Therefore, the risk of a delayed mucocle is not a concern with this method of repair. Additional craniotomy may not be necessary to repair these anteriorly based dural defects. Although our preliminary results appear favorable, longer follow-up and a larger number of patients are warranted to further assess the efficacy of this technique.

The risk of CSF leak after transcranial removal of olfactory groove meningiomas is not insignificant either, particularly if the hyperostotic cribriform plate is removed to access tumor extension into the parasellar sinuses. Obeid and Al-Mefty30 reported a CSF leak rate of 20% (3 of 15 patients) after radical excision that included removal of hyperostotic bone and tumor extending into parasellar sinuses. One of these patients required an additional operative repair, whereas the other 2 cases resolved with lumbar drainage. In a report of 80 patients by Specter et al.,10 10 patients (12.5%) had postoperative CSF...
leakage and 4 patients (5%) had meningitis, resulting in 1 postoperative death. This reemphasizes the importance of meticulous multilayer reconstruction of the cranial base, whether the operative approach is endonasal or transcranial.

**Hyperostosis and Invasion Into Paranasal Sinuses**

Olfactory groove meningiomas tend to have a rather high rate of recurrence (30% at 5 years and 41% at 10 years), which is often attributable to incomplete resection, particularly of the involved underlying bone at the cranial base. Radical Simpson Grade I removal including the dural attachment and involved bone, when safely possible, remains the best option for minimizing recurrence. Interestingly in Simpson’s original report, Grade I resection was possible only in 1 of 14 patients with olfactory groove meningiomas because of tumor involvement of the cranial base. This stems from the thinking that violation of the cranial base and entrance into the paranasal sinuses increases the risk of CSF leakage and meningitis. Thus, most surgeons have taken a more conservative approach, usually a Simpson Grade II resection, without aggressive resection of the involved bone at the cranial base. However, mere cauterization of the dural attachment or even dural resection alone without removal of bone involvement may not be sufficient to minimize recurrence.

It is not uncommon for olfactory groove meningiomas to exhibit hyperostosis of the anterior skull base because they frequently involve the underlying bone (Fig. 8). This rate of hyperostosis has been reported to be as high as 86%, and it appears to be a result of tumor invasion rather than a reactive association to the tumor. Because olfactory groove meningiomas arise from the region of the cribriform plate and planum sphenoidale, they can invade the adjacent ethmoid and sphenoid sinuses. Drome and Guiot reported that 15% of olfactory groove meningiomas extended into the paranasal sinuses. In a more contemporary series of 80 patients, Spektor et al. found 26.3% of cases with paranasal sinus invasion. As such, the ethmoid sinuses and cribiform plate are frequent sites for tumor recurrence, with extension into the paranasal sinuses and nasal cavity in patients who have undergone conservative Simpson Grade II resections. In our report, all 3 patients exhibited hyperostosis at the cribiform plate, which was the likely source of tumor recurrence into the paranasal sinuses in 2 patients. In a study by Obeid and Al-Mefty, all 6 patients who presented with recurrent olfactory groove meningiomas had hyperostotic bone involvement at the cranial base.

Therefore, to minimize recurrence, a Simpson Grade I removal should be performed that includes the dural attachment or even dural resection alone without removal of bone involvement may not be sufficient to minimize recurrence.

Conclusions

The purely endoscopic endonasal transcribriform approach offers a direct midline trajectory and immediate access for removal of olfactory groove meningiomas without brain retraction and manipulation of neurovascular structures. Extracapsular dissection with preservation of the arachnoid planes can be achieved using bimanual microsurgical techniques through a keyhole cranietomy directed at the ventral skull base. In carefully selected patients, complete Simpson Grade I tumor removal including the dural attachment and involved hyperostotic bone can be achieved. Excellent panoramic visualization of the entire ventral skull base extending from the posterior wall of the frontal sinus to the planum sphenoidale can be obtained with a 30° endoscope after performing a modified Lothrop procedure. Successful cranial base reconstruction can be performed using a multilayer fascia lata and AlloDerm technique supplemented by bilateral vascularized nasoseptal flaps. In experienced hands, this approach can be considered a viable alternative for a select group of patients.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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