Surgical nuances for removal of tuberculum sellae meningiomas with optic canal involvement using the endoscopic endonasal extended transsphenoidal transplanum transtuberculum approach

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Tuberculum sellae meningiomas frequently extend into the optic canals. Radical tumor resection including the involved dural attachment, underlying hyperostotic bone, and intracanalicular tumor in the optic canal offers the best chance of a Simpson Grade I resection to minimize recurrence. Decompression of the optic canal with removal of the intracanalicular tumor also improves visual outcome since this portion of the tumor is usually the cause of asymmetrical visual loss.

The purely endoscopic transsphenoidal approach offers a direct midline trajectory and immediate access to tuberculum sellae meningiomas without brain retraction and manipulation of neurovascular structures. Although the endoscopic approach has been previously criticized for its inability to remove tumor within the optic canals, complete Simpson Grade I tumor removal including intracanalicular tumor, dural attachment, and involved hyperostotic bone can be achieved in properly selected patients. Excellent visualization of the suprasellar region and the inferomedial aspects of both optic canals allows for extracapsular, extrarachnoid dissection of the tumor from the critical structures using bimanual microsurgical dissection.

In this report, the authors describe the operative nuances for removal of tuberculum sellae meningiomas with optic canal involvement using a purely endoscopic endonasal extended transsphenoidal (transplanum transtuberculum) approach. They specifically highlight the technique for endonasal bilateral optic nerve decompression and removal of intracanalicular tumor to improve postoperative visual function, as demonstrated in 2 illustrative cases. Special attention is also given to cranial base reconstruction to prevent CSF leakage using the vascularized pedicled nasoseptal flap. (DOI: 10.3171/2011.3.FOCUS115)

Key Words • endoscopic endonasal approach • skull base • extended transsphenoidal approach • transplanum transtuberculum • tuberculum sellae meningioma • optic canal involvement

Abbreviation used in this paper: OCR = opticocarotid recess.
canalicular portion of the tumor. This maneuver has been reported to improve vision in 78%–80% of patients because it provides immediate decompression for rapid relief and alleviation of ischemia to the compromised nerve. Access to the optic canals is critical not only for visual outcome, but also for extent of resection, as undressed residual tumor in the optic canal can be a source of recurrence or failure of visual improvement.

Various transcranial surgical approaches to remove tuberculum sellae meningiomas include unilateral or bilateral subfrontal, bifrontal interhemispheric, supraorbital, eyebrow keyhole supraorbital, frontotemporal/periorbital, orbitopterional, and orbitozygomatic approaches. More recently, there has been interest in endonasal extended transsphenoidal approaches (microscopic, microscopic with endoscopic assistance, and purely endoscopic) to remove tuberculum sellae meningiomas. The purely endoscopic endonasal extended transsphenoidal route via a transplanum transtuberculum corridor offers direct and immediate exposure to the tumor without having to apply brain retraction and manipulation of neurovascular structures. Because the dural origin is adjacent to the paranasal sinuses, early devascularization of the tumor and subsequent radical resection of the involved hyperostotic bone, dural attachment, and optic canal involvement can be achieved. Excellent dynamic close-up and panoramic visualization of the suprasellar area, including the superior hypophyseal perforators to the undersurface of the optic apparatus and the inferomedial aspect of the optic canals, can be achieved without compromise of illumination. Extracapsular, extraarachnoid dissection of the tumor from the surrounding optic apparatus and anterior communicating artery complex using conventional bimanual microsurgical techniques can be performed with preservation of the arachnoid planes. However, the ability to perform optic nerve decompression and remove intracanalicular tumor associated with tuberculum sellae meningiomas using the endoscopic endonasal approach has not been well emphasized in the literature. In addition, several proponents of transcranial approaches have criticized the endonasal approach as being limited by its inability to decompress and remove tumor from the optic canals.

In this report, we review the surgical technique and describe our operative nuances for removal of tuberculum sellae meningiomas with optic canal involvement using a purely endoscopic endonasal extended transsphenoidal (transplanum transtuberculum) approach. We specifically highlight the technique for endonasal optic nerve decompression and removal of intracanalicular tumor to improve postoperative visual function, as demonstrated in 2 illustrative cases. Special attention is also given to cranial base reconstruction to prevent CSF leakage using the vascularized pedicled nasoseptal flap.

### Surgical Technique

#### Patient Positioning

The patient undergoes general anesthesia with the endotracheal tube secured to the patient’s left side so that it is out of the way of the operating surgeon, who stands on the patient’s right side. Although some surgeons may prefer to place a lumbar drain prior to final positioning for postoperative temporary CSF diversion, we no longer use postoperative lumbar drainage because of potential complications arising from intracranial hypotension (see...
Case 1.

Endoscopic endonasal removal of tuberculum sellae meningiomas

Endoscopic Endonasal Transsphenoidal Approach

For endoscopic endonasal approaches to the skull base, we use a multidisciplinary team approach comprised of a skull base neurosurgeon (J.K.L.) working simultaneously with an otolaryngologist specializing in endoscopic sinus and skull base surgery (J.A.E.). Using a binostril (binarial) technique without the nasal speculum, both surgeons can work simultaneously with 3–4 instruments in the field at a time (the so-called “3- to 4-handed binostril technique”). The otolaryngologist performs the initial endonasal exposure to the sphenoid sinus using a 4-mm-diameter, 18-cm-long, 30° endoscope (Karl Storz). Although most authors report using a 0° endoscope for the exposure and resection,7,8,15–17,26,37 we prefer to use a 30° endoscope because of its versatility in providing the same degree of surgical exposure as with a 0° endoscope, but with the benefits of additional angled viewing capabilities around corners, without having to repeatedly exchange the 2 endoscopes. After injecting the nasal septum and the tail and anterosuperior attachment of the middle turbinates with 1% lidocaine with epinephrine (1:100,000 dilution), both middle and inferior turbinates are lateralized using a Goldman elevator. If necessary, the right middle turbinate can be removed to accommodate more instruments in the right nostril. After identifying both sphenoid ostia, a wide sphenoidotomy, posterior ethmoidectomy, and posterior septectomy are performed with a microdebrider and rongeurs. This creates an adequate working space for multiple endoscopic instruments to be inserted into both nostrils, which are triangulated at the deep surgical target. In some cases during the posterior ethmoidectomy, one may encounter an Onodi cell, a posterior ethmoid cell that is positioned superolateral to the sphenoid sinus. This is important to recognize because the optic nerve and carotid artery may often course through the lateral aspect of that cell.

We prefer to harvest a pedicled vascularized nasoseptal flap for later skull base dural repair at this juncture so that further exposure of the skull base can be safely performed while preserving the integrity of the vascular pedicle to the flap. The flap is harvested in a similar manner as described by Hadad et al.28 and rotated inferiorly into the nasopharynx. Exposure of the sella, tuberculum sellae, and planum sphenoidale is achieved by maximizing the sphenoidotomy, posterior ethmoidectomy, and posterior septectomy with care to protect the vascular pedicle to the nasoseptal flap. Injury to the pedicle can compromise the integrity and effectiveness of the flap. It is important to ensure that there is no overhang of bone or soft tissue obstructing the line of sight to the planum sphenoidale target or inhibiting the surgical freedom of instrument maneuverability. Approximately 1.5–2 cm of the posterior septum is removed to allow triangulation of surgical instruments through both nostrils so that bimanual microsurgical dissection can be performed.

Transplanum Transtuberculum Exposure (Extended Transplanumoidal)

For the remainder of the operation at this juncture, the neurosurgeon works simultaneously with the otolaryngologist using a 2-surgeon, 3- to 4-handed binostril technique. While the otolaryngologist provides dynamic endoscopic visualization of the surgical target, the neurosurgeon can perform continuous bimanual microsurgical dissection with a suction primarily in the left hand inserted into the right nostril, and a drill, dissector, scissors, bipolar forceps, or tissue aspirator in the right hand inserted into the left nostril. Because the 30° endoscope
provides a direct “looking-up” view toward the tuberculum sellae and planum sphenoidale, we recommend placing the endoscope at the 6 o’clock position with the suction placed in the 12 o’clock position in the right nostril. The neurosurgeon is therefore working “above” the position of the scope while maintaining optimal surgical visualization. Alternatively, if a 0° endoscope is used, the scope is placed at the 12 o’clock position and the suction instrument at the 6 o’clock position.

The endonasal removal of bone at the skull base includes the sella, planum sphenoidale, tuberculum sellae, and both medial OCRs to unroof the optic canals. This is achieved using a high-speed curved endonasal diamond drill (Medtronic Xomed) with copious irrigation. We prefer to use a double-barrel suction-irrigating instrument that allows continuous self-irrigation to keep the surgical field clear of bone dust while cooling the drill tip from overheating near important neurovascular structures. The bone over the sella is initially removed followed by the bone of the planum sphenoidale. In some cases, the planum can be hyperostotic, as is expected with some meningiomas. We prefer to perform a wide opening of the planum so that there is no bony hindrance to the surgical freedom of dissecting instruments during intradural tumor removal. It is important to remove the planum anteriorly to the posterior cribriform so that there is an adequate anterosuperior trajectory to come anterior and superior over the top of the tumor during intradural extracapsular dissection.

The remaining tuberculum strut along with both medial OCRs are removed so that bilateral optic nerve decompression is achieved. The medial OCR is a critical landmark in locating the optic nerve canal as it joins the middle clinoid process. From the endonasal perspective, the medial OCR appears as an indentation in the bone that is formed at the medial junction of the parasellar carotid canal and the optic canal. It represents the pneumatization of the middle clinoid process and the lateral aspects of the tuberculum sellae. The lateral OCR represents the pneumatization of the anterior clinoid process and is located at the lateral junction of the parasellar carotid canal and the optic canal. The tuberculum strut along with both medial OCRs are carefully drilled down to eggshell thickness. An up-angled 5-0 curette is then used to remove the remaining egg-shelled tuberculum strut. Removal of the medial OCRs unroofs the medial aspect of the optic canals, and facilitates exposure of the optic nerves and paraclidial carotid arteries in the opticocarotid cistern. Venous bleeding from the cavernous sinus and the superior intercavernous sinus can be readily controlled with Gelfoam or Surgifo (Ethicon, Inc.) followed by gentle pressure with cottonoid pledgets. Drilling can be continued anteriorly to join the medial orbital wall, if necessary. Bony decompression of the extradural optic nerve sheath will provide access to open up the dural sheath into the posterior orbit to remove tumor within the optic canal. This maneuver is analogous to dividing the falciform ligament into the posterior orbit after an anterior clinoidectomy from a transcranial approach to decompress the optic canal. The inferomedial and superomedial aspects of the optic canal can be readily accessed and decompressed using angled endoscopes and angled instrumentation. However, the superior and superolateral portions of the optic canal become more inaccessible from the endonasal approach.

Prior to opening the dura, the extent of skull base bone removal is inspected to ensure that the tumor and both optic canals can be adequately accessed without any obstruction to the line of sight or hindrance to the surgical maneuverability of instruments. The dura over the planum is coagulated with a pistol-grip endoscopic bipolar forceps to devascularize the meningioma. Adequate hemostasis and final confirmation with stereotactic navigation are achieved before proceeding with intradural exposure.

Intradural Exposure and Tumor Resection

We prefer to open the dura in a transdiaphragmatic fashion similar to the technique described by Weiss. Using a No. 15 blade, a cruciate incision is made over the sellar dura followed by a second horizontal incision in the planum dura anterior to the superior intercavernous sinus. The superior intercavernous sinus is then coagulated with a pistol-grip endoscopic bipolar forceps and subsequently divided across the diaphragma sella with scissors to obtain direct access to the supradiaphragmatic suprasellar cistern. Care is taken to preserve the pituitary gland and stalk, so as to avoid traction on the stalk.

Initial intracapsular tumor debulking is performed using an extended tip endonasal ultrasonic aspirator. In fibrous meningiomas that do not respond to ultrasonic aspiration, we prefer to use a Gyrus Diego microdebrider (Olympus) that removes tissue by using rotating blades with integrated suction (Fig. 3). To reach tumor located deeper in the suprasellar space, an angled tip microdebrider can be used. Care is taken to ensure that the microdebrider tip remains intracapsular, so as not to breach the tumor capsule. Once adequate tumor debulking is achieved, collapse of the tumor capsule and extracapsular dissection of the tumor away from the neurovascular structures can be performed using bimanual microsurgical dissection techniques. Care is taken not to prematurely amputate the tumor capsule, so as not to “lose the handle” that serves to provide countertraction for extracapsular dissection.

Although meningiomas are histologically arachnoid-derived tumors, they are anatomically dural-based, and thus, displace the arachnoid ahead of them as they grow. As such, these tumors are extraarachnoid structures with an arachnoid barrier that separates the tumor capsule from the neurovascular structures (anterior communicating artery complex and perforators, optic nerves and chiasm, and pituitary stalk). It is important to identify the double arachnoid layer and to differentiate the tumor arachnoid from the cisternal arachnoid. In larger tumors, this may appear as a single layer of arachnoid. Extracapsular tumor dissection under direct vision is best carried out between the tumor capsule and the tumor arachnoid, not the cisternal arachnoid. Preservation of this arachnoid barrier provides protective coverage over the critical neurovascular structures, and thus, minimizes the risk of vascular injury and ischemia to the optic apparatus that

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can potentially result in postoperative visual worsening.\textsuperscript{12,23,34,43} Small perforators that supply the undersurface of the optic chiasm and nerves reside within the arachnoid and need to be preserved to avoid postoperative visual loss. The use of bipolar cautery in the subchiasmatic region should be minimized or avoided to preserve the blood supply to the optic apparatus. The key to preserving visual function is to minimize direct manipulation or trauma to the optic nerves and to avoid injury to the blood supply of the optic apparatus.\textsuperscript{5,23,27,29,34}

It is important to avoid blind pulling of the tumor capsule, as this may increase the risk of arterial avulsion or optic nerve traction if the tumor has not been adequately dissected free from the critical neurovascular structures. Gentle countertraction of the tumor capsule can be applied with the suction to identify the arachnoid plane to carry out sharp dissection from the critical structures. Once the tumor capsule is completely dissected free from both optic nerves, optic chiasm, and the anterior communicating artery complex, the remaining tumor capsule can be delivered through the nose (Fig. 3). If the tumor is strictly adherent to any critical structure, such as the optic nerves, anterior cerebral artery, internal carotid artery, or perforators, a small remnant should be left behind, so as to avoid a major neurovascular complication. Complete tumor resection should not be achieved at the cost of increased rates of morbidity or mortality.

At this point, both optic canals are inspected with a 30° endoscope. The medial aspect of the optic dural sheath is opened with an angled hook to expose the optic nerve as it traverses the optic canal (Fig. 4). This maneuver is analogous to dividing the falciform ligament and opening the optic dural sheath to decompress the optic nerve in a transcranial approach. Tumor that has extended into the optic canal can be readily removed to optimize visual function and minimize recurrence. Care is taken to identify and preserve the ophthalmic artery when working in the optic canal. Final inspection of the surgical cavity is performed to look for any residual tumor. We often use the suction-irrigator tool to deliver continuous irrigation so that underwater hydroscopy can be performed (so-called endoscopic diving technique), as described by Locatelli et al.\textsuperscript{42} This technique can optimize visualization with a dynamic fluid film lens, wash out any small residual tumor in the suprasellar cistern, and exert hydrodynamic pressure to facilitate hemostasis (Fig. 4).

**Closure and Skull Base Reconstruction**

Successful reconstruction of the skull base dural defect is paramount to preventing a postoperative CSF leak. An autologous fascia lata graft is harvested from the thigh and placed as an inlay graft with the edges of the graft tucked underneath the dural edges. Stamp-size pieces of Surgicel are placed over the bony defect to temporarily hold the fascia graft in place. Although some have described placing a fat graft intradurally in the resection cavity to obliterate dead space,\textsuperscript{37} we prefer not to have any substance in contact with the optic apparatus to avoid potential swelling of the
fat graft and mass effect resulting in postoperative visual loss. The key component to the closure is coverage by the vascularized nasoseptal flap, which is rotated superiorly to cover the dural closure and bony skull base defect. It is important to confirm that the edges of the nasoseptal flap are in contact with demucosalized bone to ensure flap adherence. A thin layer of tissue sealant, Duraseal (Codman) or Tisseel (Baxter Healthcare Corp.) fibrin glue, is administered over the nasoseptal flap followed by Gentamicin-soaked Gelfoam pledges to buttress the flap repair. Sealant should not be placed in between the dural closure and the nasoseptal flap, as this may prevent flap adherence. A Merocel (Medtronic Xomed) nasal pack is then placed in the nasal cavity to bolster the Gelfoam layer and is left in place for about 10 days. The patient is maintained on antibiotics until the packs are removed. Because the patient is already in a CSF hypovolemic state at the end of surgery, we now prefer not to use postoperative lumbar drainage to avoid complications of CSF hypotension (see Case 2 below). Absence of a lumbar drain allows the patient to recover quicker and mobilize sooner, thus minimizing the risk of thromboembolic and pulmonary complications. Since the nasoseptal flap is robust and well-vascularized tissue, we believe that additional lumbar drainage is not necessary as long as meticulous preparation of the flap and reconstruction is performed as described above. We have not experienced any CSF leakage using this protocol in 14 cases of endoscopic endonasal resection of anterior skull base and suprasellar lesions including craniopharyngiomas, meningiomas, giant pituitary adenomas, and sinonasal malignancies.

**Illustrative Cases**

**Case 1**

**History and Examination.** This 62-year-old woman presented with visual loss in the left eye that progressed over the past 12 months. Magnetic resonance imaging demonstrated a 3-cm tuberculum sellae meningioma with mass effect on the optic chiasm and displacement of the anterior communicating artery (Fig. 1). Preoperative visual examination demonstrated visual acuity of 20/20 in the right eye with normal fields, but only finger counting in the left eye via a superior nasal quadrant (Fig. 2).

**Operation.** A transplanum transtuberculum, endoscopic endonasal extended transsphenoidal approach was used to remove the tumor. Hyperostotic bone at the tuberculum sellae was removed, and bilateral extradural decompression of both optic nerve canals was performed endonasally. The tumor was quite fibrous and required use of a rotation-suction microdebrider to debulk the tumor. Bimanual extracapsular dissection was performed to dissect the tumor from both optic nerves and anterior communicating artery complex (Fig. 3). The optic sheaths were opened bilaterally and intracranial tumor was removed from the left optic canal (Fig. 4). Suprasellar hydroscopy using the endoscopic diverging technique, as described by Locatelli et al., was performed to facilitate hemostasis and inspection of the field (Fig. 4C). Complete Simpson Grade I removal was confirmed after inspection was performed using a 30° endoscope. The anterior skull base dural defect was repaired with an autologous fascia lata inlay graft followed by a vascularized pedicled nasoseptal flap. No lumbar drainage was used after surgery.

**Postoperative Course.** Postoperatively, the patient was neurologically intact with immediate improvement in her vision (20/20 in the right eye, 20/40 in the left eye, improved visual fields with only small superior temporal quadrant defect in the left eye). Postoperative MR imaging demonstrated gross-total resection of the tumor without any evidence of residual tumor (Fig. 1). Three-dimensional reconstruction of the postoperative CT angiogram demonstrated removal of the planum sphenoidale, tuberculum sellae, and middle clinoid processes, as well as bilateral medial optic canal unroofing (Fig. 5). At the 1-month follow-up, her vision returned to 20/20 bilaterally without any visual field deficit. At 3 months’ follow-up, she remained neurologically stable with a well-mucosalized skull base defect. There was no postoperative CSF leakage.

**Case 2**

**History and Examination.** This 38-year-old woman presented with a 3-year history of headaches and progressive visual loss in the right eye. Her visual acuity was 20/20 in the left and 20/400 in the right eye via a small superior nasal field only. Magnetic resonance imaging demonstrated a 2.7-cm enhancing tuberculum sellae meningioma with enhancement in the right intracranial sellar and orbital apex optic nerve sheath consistent with optic canal invasion (Fig. 6).

**Operation.** A transplanum transtuberculum, endoscopic endonasal extended transsphenoidal approach was used to remove the tumor. Hyperostotic bone at the tuberculum sellae was removed. Early extradural decompression of both optic nerve canals was performed endonasally prior to dural opening. After internal debulking of the tumor, bimanual extracapsular dissection was performed to dissect the tumor from both optic nerves and anterior communicating artery complex (Fig. 7). Opening the optic sheaths bilaterally allowed removal of intracranial tumor that had invaded both optic canals (Fig. 7C). Complete Simpson Grade I removal was confirmed after inspection was performed with the aid of a 30° endoscope. The anterior skull base dural defect was repaired with an autologous fascia lata graft followed by a vascularized pedicled nasoseptal flap (Fig. 8). Lumbar drainage at 5 ml per hour was instituted after surgery.

**Postoperative Course.** Postoperatively, the patient was neurologically intact with an improved visual examination. On the 3rd postoperative day, the patient developed increased confusion and transient visual worsening bilaterally, which was attributed to intracranial hypotension and CSF hypovolemia from postoperative lumbar drainage. The postoperative MR image demonstrated gross-total removal of the tumor without any evidence of residual tumor. However, there were radiographic signs of intracranial hypotension including increased enlargement of the pituitary

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Transcranial Approaches for Tuberculum Sellae Meningiomas

The surgical removal of tuberculum sellae meningiomas remains a formidable challenge because of their deep location and intimate involvement with critical neurovascular structures, including the optic apparatus, pituitary stalk, and anterior cerebral artery complex and associated perforators. Total surgical removal, including the tumor, involved dural attachment, and hyperostotic bone, is the most optimal strategy in preventing recurrence.5,9,43

Tuberculum sellae meningiomas have traditionally been approached through a transcranial route. In the microneurosurgical era, numerous reports have been published on using a unilateral or bilateral subfrontal, bifrontal interhemispheric, supraorbital, eyebrow keyhole supraorbital, frontolateral, frontotemporal/pterional, orbitopterional, or orbitozygomatic approach.5,23,27,29,34,46–49,55 In a meta-analysis of modern transcranial microsurgical series by de Divitiis et al.,16 total resection was achieved in 90% with visual improvement in 59% and visual preservation in 30%. The mortality rate was 2.8%. The complication of postoperative visual deterioration has been reported in up to 20% of cases.10,14,23,29,30,55 Other reported craniotomy-related complications have included olfactory nerve damage resulting in anosmia, CSF leak requiring additional transnasal surgery, hemorrhagic infarction resulting in shunt-dependent hydrocephalus, wound infection requiring bone

![Fig. 5. Case 1. Postoperative 3D reconstructed CT angiograms demonstrating multiple views of the anterior skull base defect (SBD) and surrounding vasculature after a transplanum transtuberculum approach with bilateral optic canal decompression. A: View looking from above showing removal of the planum sphenoidale, tuberculum sellae, and both medial optic canals (OC). B: A midline endonasal view demonstrating the anterior communicating artery complex in the suprasellar space. The left internal carotid artery (IC) and ophthalmic artery are also visualized. C and D: Side-angled views mimicking the view from a 30° endoscope looking toward the right optic canal (C) and left optic canal (D). Note that both optic canals have been unroofed medially. ACP = anterior clinoid process; A1 = A1 segment of anterior cerebral artery; CP = cribriform plate; ES = ethmoid sinus; M1 = M1 segment of middle cerebral artery; MS = maxillary sinus; OR = orbital roof; Or = orbit.](image-url)
flap removal, cerebral edema, and venous infarction. In general, transcranial approaches usually require some degree of brain retraction and manipulation of neurovascular structures to obtain complete removal. Benjamin and Russell noted that one disadvantage of the pterional approach was that it was difficult to remove tumors located under the ipsilateral optic nerve without some manipulation. Intracanalicular tumor extension is also on the inferomedial side of the optic canal, which is difficult to visualize from an ipsilateral anterolateral approach.

The supraorbital approach, as originally described by Jane et al., is essentially a supraorbital unilateral frontal craniotomy that incorporates the orbital rim as a 1-piece bone flap that is performed through a coronal incision. Removal of the supraorbital rim provides a more basal approach to the tumor, thereby minimizing brain retraction. The working corridor is primarily through an anterior subfrontal route, and access to the suprasellar and parahippocampal structures can be achieved. Al-Mefty and colleagues advocated the advantages of unroofing both optic canals and drilling hyperostotic bone at the tuberculum sellae and planum sphenoidale. This is likely attributed to a more anterior subfrontal trajectory rather than a lateral transsylvian trajectory. Others have described a minimally invasive “keyhole” supraorbital approach that utilizes a smaller supraorbital craniotomy without orbital rim resection through a smaller eyebrow skin incision. In a recent report by a group performing endonasal and keyhole supraorbital approaches for tuberculum sellae meningiomas, the keyhole supraorbital approach was recommended for larger tumors (> 3.0–3.5 cm), those extending lateral to the suprachiasmatic structures, or those with vascular encasement. Endonasal approaches were generally reserved for smaller, less invasive tumors. However, some have questioned the ability to adequately decompress the optic canals and to drill involved basal bone through a more limited keyhole opening. This may be due to the potential for limited instrument maneuverability because of a smaller working corridor. In addition, the size of the pericranial flap for reconstruction is also smaller due to a smaller eyebrow incision, and the cosmetic result is debatable since the incision can still be visible on the face in contrast to an incision behind the hairline. In general, supraorbital approaches lack the lateral angle of attack that a transsylvian exposure affords, and are limited in accessing suprasellar lesions that extend lateral to the ipsilateral oculomotor nerve. An orbitozygomatic approach can, therefore, combine the advantages of both supraorbital and lateral transsylvian routes.

Evolution of Endoscopic Endonasal Approaches

The endoscopic endonasal extended transsphenoidal (transplanum transtuberculum) route provides a direct midline approach to the suprasellar region without any brain retraction or neurovascular manipulation. This approach has several advantages over transcranial approaches including early extradural optic nerve decompression bilaterally, early devascularization of the tumor resulting in a relatively bloodless tumor debulking, immediate and safe internal decompression of the tumor, excellent visualization of the infrachiasmatic perforators and inferomedial aspect of the optic nerve and optical chiasm in case of large suprasellar meningiomas, and minimally invasive endonasal approaches that require smaller incisions and flaps.

Fig. 6. Case 2. A–C: Preoperative T1-weighted post-Gd sagittal (A), coronal (B), and axial (C) MR images demonstrating a tuberculum sellae meningioma with suprasellar extension. Hyperostosis of the tuberculum sellae is seen on the sagittal view (A). Complete Simpson Grade I resection including underlying hyperostotic bone was performed using the endoscopic endonasal extended transsphenoidal approach. D–F: Postoperative T1-weighted post-Gd sagittal (D), coronal (E), and axial (F) MR images showing gross-total resection of the tumor. The patient experienced transient neurological worsening from lumbar drain–induced intracranial hypotension. Note the interval enlargement of the pituitary gland (D), venous engorgement of the bilateral cavernous sinuses (E), and the pachymeningeal enhancement and thickening of the retroclival dura that is characteristic of intracranial hypotension. The patient returned to her neurological baseline after clamping and removal of the lumbar drain.
Endoscopic endonasal removal of tuberculum sellae meningiomas

The feasibility and success of the endoscopic endonasal approach are based on earlier work described in microsurgical extended transtorial series. Since the advent of the extended transtorial approach, described initially in 1987 by Weiss, and later by Mason et al. in 1997, there has been increased interest in transtorial transtorial access to suprasellar lesions beyond the confines of the sella turcica, such as tuberculum sellae meningiomas and supradiaphragmatic cranioopharyngiomas. This was initially described using a speculum-based sublabial submucosal transsseptal approach, with drilling of the transeptal transplanum corridor for transdiaphragmatic exposure of the suprasellar region. Others have implemented an endonasal submucosal, and also a direct endonasal microsurgical route with successful removal of tuberculum sellae meningiomas. Coulswell et al. reported gross-total removal in 7 of 11 tuberculum sellae meningiomas with one complication of monocular blindness. Fatemi et al. reported complete removal in 7 (50%) of 14 patients and near-total removal in 3 patients (21%), with visual improvement in 82% and visual worsening in 7%.

However, illumination becomes compromised at very high magnifications of the microscope. In addition, the operative corridor and field of view of the surgical target are limited by the aperture of the distal end of the speculum. The line of sight and surgical freedom of instrument maneuverability are also restricted by the blades of the nasal speculum. An additional relaxing nasal alar incision is sometimes made to accommodate for the nasal speculum.

The endoscope offers superior illumination with a wide panoramic view of the surgical target from the planum sphenoidale to the clival recess, and from one medial OCR to the other. Unlike the microscope, the endoscope also allows high magnification of the surgical target without compromise of illumination by bringing the light source and lens directly up to the target. The purely endoscopic endonasal approach allows a direct view of the infrachiasmatic aspect of the optic nerves and optic canals bilaterally as well as the infrachiasmatic perforators. This advantage facilitates safe, extracapsular dissection of the tumor off of the visual apparatus with preservation of the pituitary stalk and vascular structures. The use of angled endoscopes and angled instruments also allows for removal of intracanicular extension of tumor. Since the pattern of tumor extension is most often through the infrachiasmatic aspect of the optic canal, an endoscopic approach from below is very favorable for visualizing this region. Although some have reported the use of the endoscope for “looking around” and assessing the degree of resection after a speculum-based microsurgical approach (endoscope-assisted microsurgical resection), tumor removal is still performed under microscopic and not endoscopic visualization. Thus, the advantages of the endoscope are not fully capitalized.
nasal approach simultaneously combines the benefits of an extracranial transnasal route to the skull base and the superior visualization of the endoscope. This advantage allows for tumor removal and dissection of the critical structures under direct and continuous endoscopic visualization with increased range of instrument maneuverability that was previously encumbered by the nasal speculum.

Gardner et al. reported complete Simpson Grade I resection in 11 (85%) of 13 tuberculum sellae meningiomas with extension into the optic canals by using a purely endoscopic endonasal approach. There were no instances of postoperative visual deterioration. This was attributed to an inferior and medial approach to the tumor to allow early decompression of the optic nerves and careful meticulous dissection of the tumor without manipulation of already compromised and ischemic optic nerves. Preservation of the infrachiasmatic perforators was also critical for visual improvement or preservation. In a report by de Divitiis et al., complete removal was achieved in 6 of 7 patients. Visual improvement was observed in 5 patients, and none had postoperative visual worsening.

**Optic Canal Involvement in Tuberculum Sellae Meningiomas**

Tuberculum sellae meningiomas can frequently extend into one or both optic canals, with reports as high as 67%–77% of cases. Mahmoud et al. reported unilateral involvement in 28% and bilateral in 40% of cases. Optic canal involvement appears to correlate with preoperative visual dysfunction. Visual loss usually starts in one eye and can subsequently progress to involve the contralateral eye, if left untreated. The presence of asymmetrical visual findings is highly indicative of optic canal involvement, as seen in both patients described in this report. Unaddressed residual tumors left within the optic canal after surgery could result in persistent visual loss, visual deterioration, and future tumor recurrence. This has led to several authors in recommending early optic nerve decompression. Visual improvement has been reported as high as 78%–91% in some series.

The technique for early optic nerve decompression and release is generally performed using a frontotemporal pterional, supraorbital, or orbitozygomatic approach that includes a posterior orbitotomy, extradural anterior clinoidectomy, optic canal unroofing, and division of the falciform ligament. Once the optic nerve is released, the site of constriction is often discolored where the nerve meets the falciform ligament and bony entrance of the optic canal. Further division of the dura propria along the longitudinal axis of the optic nerve sheath and division of the distal dural ring allows further mobilization of the internal carotid artery to optimize optic nerve decompression and exposure of the optic nerve within the optic canal to facilitate intracanalicular tumor removal.
Endoscopic endonasal removal of tuberculum sellae meningiomas

Limitations of the Endoscopic Endonasal Approach

One of the major criticisms of endoscopic endonasal surgery for tuberculum sellae meningiomas and other intradural tumors is the higher rate of CSF leak when compared with transcranial results. In the microsurgical transsphenoidal series, the CSF leak rate has been reported to be as high as 21%. In the endoscopic endonasal series, the CSF leak rate has ranged from 10% to 28%. However, these results did not incorporate the use of a vascularized nasoseptal flap for reconstruction. The latter technique is an important innovation in endoscopic endonasal skull base surgery, which offers robust, vascularized tissue for coverage of skull base defects to optimize tissue healing and prevention of CSF leaks. This tissue is analogous to the pericranial flap that is used in reconstruction after transbasal and craniofacial approaches. Emerging reports have demonstrated a significantly reduced CSF leak rate to 5.4% when reconstruction is performed with a pedicled nasoseptal flap.

The extent of optic canal decompression and removal of intracanalicular tumor from the endonasal approach is also limited to the superomedial and inferomedial aspects of the optic nerve. The superior aspect of the optic canal becomes more difficult to decompress, and the superolateral and lateral aspects of the optic canal become rather inaccessible from below. Although tumor along the medial aspect of the optic nerves can be readily removed endonasally, tumor involvement along the lateral compartments of the optic canal cannot be safely accessed. The exposure and ability to perform safe resection during the endoscopic endonasal approach also becomes limited when the dural attachment of the tumor extends laterally past the optic canals and along the orbital roof and anterior clinoid process. In these instances, complete Simpson Grade I removal cannot be reasonably obtained. Therefore, in cases with larger, widely based meningiomas exhibiting lateral extension over the optic canals and orbital roofs, we prefer to choose a transcranial approach, such as a pterional or orbitozygomatic approach. The presence of vascular encasement on preoperative imaging may preclude total removal and may not be an optimal approach for the endonasal route because of the difficulty in gaining adequate control and repair in the event of neurovascular injury. In these instances, a transcranial approach is probably more prudent. Nevertheless, it is important to recognize that vascular encasement can also preclude total removal during a transcranial approach as well.

Another criticism of the endoscopic approach is the lack of stereoscopic vision that is afforded by the microscope. However, with increased experience, knowledge of the endoscopic anatomy, dynamic mobilization of the endoscope, and integration of tactile and visuospatial cues, a sense of depth perception can be acquired. The advent of 3D endoscopes (Visionsense, Ltd.) has now greatly enhanced the subjective depth perception for the operating surgeon. These endoscopes are able to render a single 3D view similar to the human eye by using dual channel technology that incorporates information from 2 distinct perspectives. We have used 3D endoscopes for endonasal removal of craniofaryngiomas, pituitary tumors, and sinonasal tumors. This new technology is an important addition to the armamentarium of endoscopic skull base surgery and complements current high-definition 2D endoscopes.

Conclusions

The purely endoscopic endonasal extended transsphenoidal approach offers a direct midline trajectory and immediate access to tuberculum sellae meningiomas without brain retraction and manipulation of neurovascular structures. In carefully selected patients, complete tumor removal including intracanalicular tumor, dural attachment, and involved hyperostotic bone can be achieved. Excellent visualization of the suprasellar region and the inferomedial aspects of both optic canals allows for extracapsular, extraarachnoid dissection of the tumor from the critical structures using bimanual microsurgical dissection. This approach can be considered a viable approach for properly selected patients in experienced hands.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Liu, Eloy. Acquisition of data: Liu, Christiano, Patel, Eloy. Analysis and interpretation of data: Liu, Christiano, Patel. Drafting the article: Liu, Christiano, Patel, Tubbs. Critically revising the article: all authors. Approved the final version of the paper on behalf of all authors: Liu. Administrative/technical/material support: Liu, Christiano, Patel. Study supervision: Liu.

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Manuscript submitted January 16, 2011. Accepted March 15, 2011.
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