A variety of novel surgical approaches have been developed in recent years to manage disease of the cranial base. Few offer the width and depth of exposure achievable with the extended transbasal approach. This approach combines a bifrontal craniotomy with an orbitonasal or orbitonasoethmoidal osteotomy, and potentially a sphenoethmoidotomy to provide broad access to malignancies of the anterior, middle, and posterior skull base. The approach enables the en bloc resection of tumors within the frontal lobes, orbits, paranasal sinuses, and sphenoclvial corridors without brain retraction and may obviate the need for transfacial access. This can be combined with additional approaches, based on the tumor's epicenter. Reconstruction is accomplished with the use of pericranium, and in some instances, a temporalis muscle pedicle or a gracilis microvascular free flap. Complications include cerebral spinal fluid leakage, pneumocephalus, infection, and cranial neuropathies. However, the morbidity and mortality associated with this approach is low. The extended transbasal approach is a relatively novel exposure that enables the skilled cranial base surgeon to safely excise many malignant lesions previously felt to be unresectable.

Malignancies of the anterior, middle, and posterior skull base including the sphenoclvial corridor represent a unique surgical challenge to the cranial base surgeon. Historically, the approaches utilized to access this region have resulted in incomplete resections, cosmetic deformities, and significant morbidity and mortality.[1-7] Recent technologic advances including sophisticated head and neck imaging, neuronavigational systems, and improved surgical instrumentation have resulted in a better understanding of cranial base anatomy and opened the door to a variety of new approaches to the cranial base.

One such exposure is a variant of the fronto-orbital approach: the extended transbasal approach.[8] Essentially, this is an extension of the subfrontal approach to the cranial base with the addition of an orbitonasal or orbitonasoethmoidal osteotomy.[9] Frazier was the first to describe the orbital osteotomy as a strategy for minimizing brain retraction.[10] This technique contributed to the evolution of the transbasal approach and its modifications, which have been previously described by several authors.[1,10-25] While this approach eliminates much of the morbidity associated with brain retraction, complications may include cerebrospinal fluid (CSF) leakage, infection, and loss of olfaction.[19,20]

**Surgical Indications**

The extended transbasal approach is indicated for exposure of midline lesions of the anterior, middle, and posterior cranial fossa and those extending into the mid-to-low clivus.[23] This approach is often employed when exposure of the orbit, paranasal sinuses, and/or sphenoclvial region is necessary for tumor resection. It can also be tailored to include other indications such as aneurysms, trauma, certain craniofacial anomalies, cerebrosaline leak, and mucocoele repairs.[19,26,27] Additionally, either unilateral or bilateral orbitozygomatic osteotomies, as well as other approaches such as the subtemporal/ infratemporal and frontotemporal transcavernous techniques can be added when dealing with extensive lesions of the infratemporal regions and/or cavernous sinuses, respectively.[5] These additional osteotomies largely obviate the usual brain retraction, which accompanies approaches without this extent of bony removal, thereby decreasing complications.[4]

**Preoperative Evaluation**

All patients undergo extensive imaging studies, including computed tomography (CT) with bone windows, and in some instances, three-dimensional (3D) reconstructions, and magnetic resonance imaging (MRI) of the brain and face to clearly delineate the degree of bony deformity/involvement and degree of tumor growth and softtissue involvement or destruction.[23] The carotid artery anatomy and patency can be established by means of CT angiography, magnetic resonance angiography, and/or conventional cerebral angiography. Additionally, angiography provides valuable insight to the tumors' blood supply, the relationship of major vessels to the tumor, and the extent of collateral vascular channels available.[23] With vascular tumors, partial
embolization can be performed prior to surgical resection. All patients with tumors encroaching on the optic apparatus undergo formal visual field examination. Patients with frontal lobe extension of tumor undergo a standard battery of neuropsychological testing.

**Operative Technique**

The fronto-orbital approach essentially involves three variants. The first is a unilateral frontotemporal craniotomy with a unilateral orbital roof osteotomy. The second variant or so-called “one-and-a-half approach” includes a frontotemporal craniotomy with midline frontal extension, as well as an orbitonasal osteotomy. The third variant is the extended transbasal approach.

Following a standard endotracheal anesthetic technique, the head is positioned neutrally and secured in Mayfield three-point fixation. If appropriate, cranial nerve, somatosensory- evoked responses, and brainstem auditory-evoked responses are monitored. In situations where a significant risk of carotid sacrifice exists, electroencephalography is available. When extensive dural section is anticipated, a cerebrospinal fluid drain should be considered prior to final positioning. Lumbar drains may exacerbate issues with postoperative pneumocephalus and can precipitate neurologic changes if overdrainage occurs. Consequently, such drains should be utilized judiciously. All patients receive broad-spectrum antibiotic prophylaxis. Mannitol and corticosteroids are administered in cases where significant brain infiltration and edema are present.

A bicoronal incision is performed from tragus to tragus (and potentially lower if a zygomatic osteotomy is anticipated). In order to avoid inadvertent laceration to the superficial temporal artery or branches of the facial nerve, the incision begins about a centimeter anterior to the tragus. In general, the incision is placed behind the hairline or approximately 12 cm posterior to the glabella. This generally allows for sufficient frontal lobe exposure and the development of an adequate pericranial flap for purposes of reconstruction at the end of the case. The length of the pericranial flap can be increased with the use of traction posteriorly at the time of skin incision. The scalp flap is mobilized forward with the pericranium and swept above the temporalis fascia bilaterally to expose the frontozygomatic processes laterally and the superior orbital rim and nasion medially. The supraorbital nerves and vessels complex can reside in a notch or a complete supraorbital foramen. When the latter occurs, a fine osteotome or Kerrison punch is used to create a window through which the nerves can be mobilized forward with the scalp flap. The periorbita is dissected superiorly from the orbital roof to a depth of approximately 2 to 2.5 cm, laterally to the point of the inferior orbital fissure and medially to the anterior ethmoidal foramina. Such dissection should be done with minimal pressure on the globe to avoid autonomic discharges and significant intraoperative fluctuation in blood pressure and heart rate. Again, the craniotomy is tailored to accommodate one of the three frontal-orbital approaches described. In the extended transbasal approach, a series of burr holes are placed adjacent to the sagittal sinus anteriorly and posteriorly just adjacent to the coronal suture. The bifrontal bone flap should extend from the coronal suture to as far frontal as can be achieved. In some instances, the frontal sinus may be deep, necessitating osteotomes or a Gigli saw to take down its posterior wall. With the bone flap removed, the next step is to perform an orbitonasal or orbitonasoethmoidal osteotomy and, potentially, a sphenoethmoidotomy. The choice of osteotomy depends on the tumor's epicenter, as described below.
Orbitonasal and Orbitonasoethmoidal Osteotomy

Resection of tumors with epicenters within the anterior cranial fossa, including the orbitonasal and perinasal sinuses, is enhanced with the addition of an orbitonasal osteotomy. After dissection of the peri-orbita, the frontal dura is elevated from the orbital roof working laterally toward the midline (Figure 1). In the midline, the dura will be tethered to the crista galli and cribriform plate (Figure 2A). The crista galli can be removed with a narrow bone rongeur and the dura incised along the base of the cribriform plate with mandatory transection of anterior and posterior ethmoidal arteries and olfactory fibers. The preservation of olfactory fibers has been described[25,31-33]; in our series, however, we found this maneuver to hinder the approach and could not preserve meaningful olfaction.

The dissection is carried posteriorly to expose the planum sphenoidale and tuberculum sella (Figure 2B). Working laterally, the dura overlying the optic foramina is exposed. The incised midline dura is primarily repaired in a meticulous fashion to minimize the possibility of CSF leakage. A reciprocating saw is then used to perform strategic cuts on the exposed orbitonasal bar. The first cuts are performed across the supraorbital rim and orbital roof just medially to the supraorbital foramina. The supraorbital rim is often thicker than the orbital roof, which requires that only the tip of the saw blade be used to cut the orbital roof once the cut has been completed across the orbital rim. Approximately 2.5 cm of the orbital roof should be included in this cut so as to minimize the possibility of a postoperative enophthalmos. For more broad-based tumors, these cuts may be expanded to include the frontal zygomatic process, and for lesions extending laterally into the infratemporal fossa, a tailored zygomatic osteotomy may be considered.[34]

The last cut is across the superior aspect of the nasion just adjacent to the frontonasal suture in an anterio-to-posterior direction. The saw is angled superiorly, entering the anterior cranial fossa just in front of the crista galli. An osteotome completes the removal of the bone flap. For tumors involving the ethmoid sinus, a sphenoidethmoidotomy is performed.

Midline tumors of the middle and posterior skull base require a bilateral orbitonasal osteotomy. The technique is similar to that described above, but the final bone cut includes the upper aspect of the ethmoidal bone. The saw blade is angled parallel to the plane of the cribriform plate and is directed toward the anterior ethmoidal foramina bilaterally. A narrow osteotome is then used to perform a linear cut across the floor of the anterior cranial fossa inclusive of the midline cribriform plate. This same osteotome can then be used to gently displace the orbitonasal bar. Once complete, tumor within the frontal lobes, orbits, midline nasal cavity, and, potentially, the maxillary sinus are completely accessible (Figure 2C).
Sphenoethmoidotomy
For lesions based more posteriorly and medially within the sphenoclival region, the addition of a sphenoethmoidectomy should be considered. On completion of the orbital nasal osteotomy, a microscope is brought into the field and a high-speed air drill with a 3-mm cutting burr is used to drill through the planum sphenoidale medially to expose the sphenoid sinus and then more laterally to enter the ethmoid sinuses. Sinus trabeculations and mucosa are removed with a narrow pituitary rongeur. The optic nerves can then be unroofed utilizing a 2- to 3-mm diamond burr and microdissectors. Continuous irrigation is critical to minimize a thermal optic nerve injury (Figure 3A). At this point, the orbital apex contents are completely exposed. With further drilling through the posterior wall of the sphenoid cavity, sella dura is revealed. Working more caudally, the cancellous bone of the clivus can be progressively removed to expose clival dura from approximately 5 to 10 mm inferior to the posterior clinoids to the foramen magnum. In the depths of this exposure, the hypoglossal nerves may be skeletonized as they course through the hypoglossal canal of the foramen magnum and occipital condyle (Figure 3B).

Resection and Reconstruction
Dural defects are closed primarily, or if necessary, a pericranial or fascia lata graft may be employed to ensure a watertight closure. Other materials such as bovine pericardium and cadaveric dura
remain an option; however, autologous tissue is preferred when accessible. Exposed mucosa from the frontal, ethmoidal, and sphenoid sinus should be extirpated. Small portions of fat, typically harvested from the abdomen, are then packed into the above-mentioned sinus cavities. Fat has a lower metabolic rate than muscle; hence, fat is preferred over muscle when packing the sinus.[6]

A generous pericranial flap is then harvested and insinuated into the depths of the exposure as far caudal as the margins of the bone resection. This flap serves as a barrier between the sinus cavities and the brain, minimizing the risk of postoperative infection or spinal fluid leakage. Care should be taken to preserve blood supply of the flap, which typically arises from the supraorbital vessel complex. The empty space is then filled with fat and fibrin glue or equivalent. More substantial defects, which cannot be adequately covered with pericranium due to prior operations or poor tissue quality, may require a temporalis, a muscle rotational flap, or a vascularized free flap. We have had success utilizing gracilis and rectus abdominus muscle for this purpose.[35] The orbitonasal bone flap may then be secured with titanium plates followed by replacement of the bifrontal craniotomy. If a bony defect greater than 3 cm remains after tumor resection, bony reconstruction should be considered to minimize potential frontal lobe herniation. Central dural tack-ups are helpful in minimizing postoperative pneumocephalus and epidural hematomas. A subgaleal drain to gravity is left in place for 48 hours.

**Case Study**

A 16-year-old male presented with severe headaches, progressive right visual loss, a palpable right facial mass, and airway obstruction (Figure 4). He underwent a transnasal biopsy of the intranasal portion of his tumor, which confirmed a diagnosis of esthesioneuroblastoma. Given the apparent encasement of both carotid arteries and the extremely vascular appearance of the lesion on MRI, an angiogram and embolization procedure were performed. An extended transbasal approach with the addition of an orbitozygomatic osteotomy and temporal craniotomy was utilized to achieve a gross total resection of this lesion (Figures 5 and 6).

Subsequent to the operation, the patient received radiation and chemo-therapy. Four weeks following the surgery, he experienced a superficial wound infection, which responded to intravenous antibiotics. Twelve months postoperatively, he developed a recurrence. He died 18 months after his initial operation.
**Complications**

Cerebrospinal fluid leaks are the most commonly reported complication of the extended transbasal approach to cranial base tumors. They occur most often in situations where intradural tumor necessitates primary dural repair or grafting.[36] Postoperative spinal fluid leaks can usually be controlled with 4 to 5 days of controlled lumbar drainage.[28] As mentioned earlier, lumbar drains can result in additional complications and must be monitored closely. Persistent CSF leaks may require ventricular peritoneal shunting.

Despite broad-spectrum antibiotic prophylaxis, wound infections may occur. The incidence of significant infections with this approach, however, is remarkably low.[20,27,36-38] They usually occur in the setting of larger tumors requiring longer operative times. Superficial wound infections can be effectively treated with local wound care and intravenous antibiotics. Deeper infections such as epidural abscesses require surgical evacuation, irrigation, and debridement. The bone flaps, both craniotomy and osteotomy, can often be left in place, and patients treated with a 4- to 6-week course of appropriate IV and oral antibiotic therapy. When cerebritis or brain abscess is suspected, a 6- to 8-week course of IV antibiotics with frequent surveillance brain images is required.

Cranial nerve injuries may occur with this operation. All patients undergoing a true transbasal approach will experience loss of olfaction. However, in a vast majority of cases, olfaction has been lost preoperatively. Those without preoperative loss should be counseled appropriately. The literature contains scattered reports of injury to the optic oculomotor, trochlear, and abducen nerves.[4,23]

**Discussion**

Malignancies along the sphenoclival corridor and associated nasal sinuses represent a unique surgical challenge. Oftentimes, these tumors may extend into the brain or brainstem. Standard anterior approaches, including the transfacial, transmaxillary, transsphenoidal, and transoral, may achieve a cosmetically acceptable result but fail to yield enough exposure to achieve gross total resection.[39] The concept of gaining better access to these lesions through removal of the orbital rims was introduced initially by Frazier in 1913.[40] In 1972, Derome described the transbasal approach for removal of sphenoid ethmoidal tumors.[15] Since that time, there have been several
reports detailing the addition of osteotomies to gain better access to tumors and fractures of the cranial base.[1,3,6,9,10,16,19,20,23,25,41,42] In particular, Raveh et al described an anterior subcranial approach for skull base tumors and fractures without the addition of a bifrontal craniotomy.[19,20] Sekhar was the first to introduce the concept of a bifrontal craniotomy with the addition of orbitonasal osteotomy and sphenoethmoidectomy.[23] All of these techniques are relatively similar and must be tailored to the epicenter of the lesion and the surgeon's experience. The ultimate goal in cranial base surgery for malignant disease is appropriate access to achieve gross total resection with minimal damage to neurovascular structures. In rare instances, this may require the addition of a transfacial or subtemporal infratemporal approach to the described extended transbasal exposure, as detailed in this report.[13,22,41]

Until more recently, aggressive approaches to anterior cranial base lesions were treated primarily with transfacial and transmaxillary approaches, which while providing for reasonable surgical access, may be associated with a high incidence of postoperative infection, CSF leakage, cosmetic deformity, and unacceptable mortality.[2,4,13,14] The extended transbasal approach is specifically well suited for lesions with epicenters in the sphenoclival region extending into the frontal lobe paranasal sinus and/or orbits. It is a cosmetically sound approach yielding excellent visualization of the anterior cranial fossa contents without brain retraction and creates an excellent window for primary dural repair or reconstruction if warranted.[42]

Malignancies in the nasal and paranasal sinuses can be accessed through this approach; however, lesions confined to these sinuses may be more appropriately treated by transmaxillary or transfacial approaches. Similarly, lesions confined to the sphenoid sinus or clivus may be better accessed through a transsphenoidal or transoral route.[1-3,14,24,39] When appropriate, the wide exposure offered by the extended transbasal approach affords the safest opportunity for preservation of the carotid arteries as well as the optic and abducens nerves.

Limitations
Bilateral loss of olfaction is a mandatory consequence of this approach. Patients must be carefully counseled preoperatively, as loss of olfaction is often associated with transient disturbances in taste and can, in fact, significantly affect the patient's lifestyle. In two patients, we attempted to preserve olfaction as described by Spetzler et al[25,31]; however, the patients reported anosmia postoperatively. The majority of patients with lesions amenable to this particular approach have lost all or a substantial part of olfaction prior to surgery.

Important anatomic limits exist with this approach. In general, the lateral extent of the approach is limited by the optic nerves, cavernous sinuses, carotid arteries, petrous apaxes, and hypoglossal canals.[9,23,25] The rostral extent of the exposure along the clivus is just inferior to the base of the posterior clinoid process (Figure 1). Thus, tumors extending superior to the posterior clinoid involving the petrous apexes or cavernous sinus may require the addition of a more lateral approach, such as a petrosal craniotomy or subtemporal-infratemporal technique.[13,22] Additionally, orbitozygomatic osteotomies can be tailored to significantly improve exposure.[34]

Conclusions
The extended transbasal approach lends itself to a wide variety of applications and obviates the need for many of the traditional more aggressive and potentially disfiguring anterior cranial base exposures. Clear knowledge of cranial base anatomy is paramount for success with this relatively novel approach. Many of these operations are quite long, and the risk of complication (eg, infection) is significant. The importance of watertight dural closure or dural repair with grafting cannot be overemphasized. Further, extreme caution must be exercised in maneuvering around the optic nerves, carotid arteries, and abducens nerves. Our experience has suggested that this approach can be utilized alone to treat the vast majority of sphenoclival malignancies, with minimal complications and good immediate results. Further data on long-term results are needed.

Disclosures:
The authors have no significant financial interest or other relationship with the manufacturers of any products or providers of any service mentioned in this article.

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