# Minimally Invasive Approaches to the Anterior Skull Base

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**KEYWORDS**

• Minimally invasive surgery • Endoscopy • Skull base malignancy • Anterior craniofacial

**KEY POINTS**

- The advantages of minimally invasive endoscopic approaches to the skull base are: (1) devascularization of the skull base blood supply before tumor resection, (2) avoidance of brain manipulation and retraction, (3) protecting the vascular supply of the optic apparatus as the tumor is approached from below by maintaining arachnoid planes, and (4) providing a better cosmetic result.
- Limitations of minimally invasive approaches include: (1) instrumentation that may be associated with greater application of force on surrounding structures than when using microinstruments; (2) difficulty accessing large tumors with significant lateral extension; (3) difficulty resecting the entire dural attachment, potentially limiting gross total resections; (4) difficulty with resection of tumor that completely encase vascular structures; and (5) lack of three-dimensional visualization.
- Selection of the appropriate minimally invasive approach depends on identification of the appropriate entry point and surgical corridor.
- Through careful surgical planning to avoid complications and select appropriate patients, minimally invasive techniques can be used to improve the function and prognosis of patients with skull base malignancies.

**Videos of "Exposure of and removal of anterior skull base dura" and "Anterior skull base closure" accompany this article. at http://www.neurosurgery.theclinics.com/**

## INTRODUCTION

Minimally invasive approaches in neurosurgery have been a recent, yet rapidly growing area that is becoming a more accepted and valuable tool in the neurosurgeon's armamentarium. This area continues to rapidly expand because of continual developments in technique and equipment, most specifically endoscopy. As with any new field, these minimally invasive approaches are not always intuitive and require additional training and time to develop the needed skills. Once acquired, however, minimally invasive approaches have been shown to decrease morbidity and speed recovery in patients while providing similar extent of resection.

This article reviews the tenets of the minimally invasive approaches to the anterior skull base in neurosurgery and discusses the history of this technique, advantages and disadvantages, the corridors and pathways of the approaches, the equipment and operating room setup, perioperative care, and complication avoidance.

## HISTORY

Skull base surgery has been founded on the ideals of finding the most direct access to skull based

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lesions with the least amount of risk and brain manipulation. The first attempts at anterior skull based surgery were likely performed by the ancient Egyptians as evidence by intranasal dissection found in their remains.[1] However, not until 1894 was the transphenoidal approach first discussed when David Giordano performed an anatomical study via a transfacial transphenoidal exposure to gain access to the sella turcia.[2] Then in 1907, the first transphenoidal resection of a pituitary tumor was performed by Hermann Schloffer in Austria.[3] Theodor Kocher and Oskar Hirsh further modified the procedure by developing submucosal removal of the septum and an endonasal transseptal transphenoidal procedure that then set the stage for Harvey Cushing to later improve.[3–5] Harvey Cushing, who completed more than 231 pituitary surgeries via a sublabial transphenoidal approach, had an astonishingly low mortality rate of 5.6% during his career.[5] At the same time, the mortality rates of larger open transfrontal surgeries to access the anterior skull base were also decreasing and ultimately equaled that of the more difficult transphenoidal approach. Therefore popularity for these challenging minimally invasive approaches declined until the inventions of the intraoperative radiofluoroscopy and the operating microscope in the 1950's-1960's.[3,6] Jules Hardy, who was responsible for the first use of the operating microscope during the transphenoidal approach, spread the teaching of this approach throughout North America. He was responsible for the development of many of the micro-instruments used in transphenoidal surgery.[3] With continued advancements in technology and technique, the methods that Hardy developed continue to improve and have resulted in minimally invasive procedures of the anterior skull base becoming accepted as an effective and safe procedure.

The first neurosurgical endoscopic surgery was performed in 1910 by Lespinasse. Lespinasse, who practiced urology, performed choroid plexus coagulation via a burr hole in two children with hydrocephalus. In 1923, the neurosurgeons, William Mixter and Walter Dandy, performed the first endoscopic third ventriculoscopy; however, this procedure was severely limited by poor visualization.[7,8] The use of endoscopy in neurosurgery was not well accepted until improvements were made in the endoscopes and additional supportive equipment, as well as in the understanding of the surrounding microanatomy. The return of endoscopy in neurosurgery did not occur until the late twentieth century. Gerard Guiot, in 1963, was likely the first neurosurgeon to apply the endoscope to transsphenoidal surgery. He soon abandoned its use, however, due to poor visualization and light compared with the operative microscope.[8,9] Then in the 1990s, endoscopy increased independently with otorhinolaryngologists operating on the paranasal sinuses for the treatment of inflammatory sinonasal disorders.[10] Then, with the collaboration of these two disciplines, there began a new era in surgical technique with the use of the endoscopy. With the addition of angled lens, surgeons were now able to see areas that were previously unreachable with such small exposure. In 1992, Jankowski and colleagues[11] and, in 1995, Sethi and Pillay[12] (otorhinolaryngologists and neurosurgeons) reported the use of the endonasal endoscopy transsphenoidal technique that relied solely on the use of the endoscope for complete visualization during surgery. With improved lighting, optics, and high-definition imaging, expanded endoscopic techniques have become routine in the management of complex sinonasal and anterior skull base surgery and have also spread to spinal surgery, peripheral nerve surgery, craniosynostosis correction, aneurysm clipping, and accessing of ventricular masses.

Management of anterior skull base lesions endoscopically advanced significantly with the advent of two-surgeon expanded endonasal approaches.[13] In this set up, two surgeons work in tandem to using a four-handed technique to maintain surgical visualization while dissecting with two instruments. At the skull base, an otorhinolaryngologist and neurosurgeon work to dissect tumor from the dura and anterior cranial fossa. Adequate closure of the skull-base defects with the pedicle axial vascularized nasoseptal flap (NSF) has reduced the cerebral spinal fluid (CSF)-leak rate and allowed rapid expansion of endonasal techniques.[14] With advances in minimally invasive techniques continuing to develop, surgeons can customize an approach for each patient and their disease to allow for the safest and most effective treatment.

## *Keyhole Surgery*

The supraorbital craniotomy offers a window to the inferior frontal lobe, to the circle of Willis, and dissection of the sylvian fissure without the need of brain retraction.[15,16] In 1912, McArthur[17] reported trephination following incision over the eyebrow. In 1913, Frazier[18] described the supraorbital approach to treat a pituitary adenoma in the anterior fossa. In 1984, Jane and colleagues[19] used the supraorbital approach to treat orbital tumors, anterior communicating artery aneurysms, pituitary adenomas, craniopharyngiomas, and parasellar or olfactory groove meningiomas. With the advent of neuronavigation and improved microsurgical instrumentation in the 1990s, the supraorbital keyhole approach has become a more accepted approach to anterior communicating artery aneurysms, pituitary tumors, and craniopharyngiomas.[20,21]

## ADVANTAGES OF MINIMALLY INVASIVE APPROACHES

Traditional open approaches to the anterior skull base include bifrontal craniotomies, extended bifrontal craniotomies, pterional craniotomies, as well as complex transfacial operations. These approaches, while adequate, require a large incision, and significant brain exposure and retraction that places critical structures at risk and increases recovery time. This exposure can also cause cosmetic defects in the forehead resulting from the incisional scar, depression of the bone flap, inadequate repair of burr holes, and/or temporal muscle atrophy.[15] With the recent application of concepts from endonasal sinus surgery, neurosurgeons, working with otolaryngologists, can obtain access with a direct anatomic route to the lesion with a minimal opening that limits brain exposure and minimizes iatrogenic trauma. Similar to the larger transcranial approach, minimally invasive approaches obviate brain retraction. Little data are published comparing complications of open verses endoscopic approaches, but the advantages seem intuitive. Proponents argue that, in contrast to the various transcranial approaches, the minimally invasive approaches: (1) devascularize the skull base blood supply before tumor resection,[22] (2) avoid brain manipulation and retraction,[23] (3) allow the intervening arachnoid plane to protect the vascular supply of the optic apparatus because the tumor is approached from below,[24] and (4) provide a better cosmetic result.[25] Typically, these minimally invasive approaches forego skin incisions; instead, the natural apertures in the face are used to gain access. Most tumors in the sinonasal cavity that involve the anterior skull base, and many lesions emanating directly from the anterior skull base, grow in a mediolateral direction, displacing structures laterally, which creates natural corridors that allows resection via an anteromedial approach.

## DISADVANTAGES OF MINIMALLY INVASIVE APPROACHES

Minimally invasive approaches are often deemed difficult because they require increased knowledge of anatomy, particularly anatomy outside the cranial compartment; experience with a different set of instruments that often must be handled further from the site of the pathologic condition; and decreased working room for the surgeon.[26] Although many improvements in techniques and instruments have occurred over the past decades, surgeons must have knowledge about the limitations in using minimally invasive techniques. Attention must be paid to (1) instrumentation that may be associated with greater application of force on surrounding structures than when using microinstruments, (2) difficulty accessing large tumors with significant lateral extension,[24] (3) difficulty resecting of the entire dural attachment, potentially limiting gross total resections (GTRs),[24] (4) resection of tumor that completely encase vascular structures, and (5) lack of three-dimensional visualization.[24] Another drawback of a minimally invasive approach is the inability to quickly adapt to unexpected findings or intraoperative catastrophes through a limited opening. Therefore, complete preoperative imaging, careful patient selection, and thorough surgical planning are of the utmost importance.[15] In addition, high leaks of CSF have been reported with minimally invasive approaches, which, if they persistent, can lead to other complications. It has been suggested that a surgeon should not choose a minimally invasive approach if a tumor typically extends greater than 1 cm beyond the exposure, which could restrict obtaining a GTR.[27] However, surgical classification is currently a moving target as techniques and surgical experience increase. In some cases, intracranial pressure will help express the tumor downwards toward the skull base as the inferior bulk of tumor is resected. This allows for resection of tumors that have extended further intracranially. In these cases, having the option of an open approach or a combined approach may allow a more extensive resection and provide a better patient care. Anatomic constraints, such as encasement of significant vessels or extension beyond the plane of cranial nerve or major vessel, limit endoscopic selection. In general, consent for a possible open approach should be discussed with the patient preoperatively. In particular, lateral spread along the dura should be evaluated on MRI preoperatively. Additional cautions to consider include extent of tumor invasion into the brain, tumor vascularity, patient age and comorbidities, surgeon expertise, and resources.[28]

## EXAMPLES OF MALIGNANT OR POTENTIALLY MALIGNANT ANTERIOR SKULL BASE TUMOR ACCESSIBLE THROUGH A MINIMALLY INVASIVE APPROACH

Most of the malignant lesions located in the anterior skull base consists of rare tumors that present in an aggressive invasive stage. Therefore, much of the literature on skull base malignancies is characterized by single-institution experiences with a variety of tumor locations, histology, and treatment planes, with the rarity of the pathologies making it difficult to draw firm conclusions about prognosis or the role for minimally invasive approaches in the resection.

The most common lesions in the anterior skull base include pituitary adenomas, spontaneous CSF leaks, meningiomas, and craniopharyngiomas.[27] These lesions are benign, yet often require surgical intervention in which minimally invasive approaches are typically used. Less common lesions in the anterior skull base include chordoma, Rathke cleft cysts, and esthesioneuroblastoma. Finally, the very rare lesions found in the skull base include, but are not limited to, pituitary carcinoma, metastasis, hemangiopericytoma, rhabdomyosarcoma, adenoid cystic carcinoma, malignant salivary gland tumor, juvenile angiofibroma, schwannoma, enterogenous cyst, osteoma, papilloma, nasal glioma, lipoma, gout, and rheumatoid pannus.[27] Although meningiomas and craniopharyngiomas are classified as benign tumors, they can be aggressive (particularly craniopharyngioma) due to their invasion and propensity to recur if not fully treated. Meningioma is the most common anterior skull base tumor and can be located at three specific locations of the anterior skull base from anterior to posterior: olfactory groove, planum sphenoidale, and tuberculum sellae. A surgeon must ensure that with minimally invasive techniques they can still achieve the lowest possible Simpson grade.[29] Tumors that have large dural tails, or extend laterally, may be better treated with larger, open approaches. Treatment options include monitoring of small, slow-growing lesions, radiation, or surgical resection. The most common surgical complication is cranial nerve palsies.[30] Craniopharyngiomas, which originate from pituitary embryonic tissue and are lined with squamous epithelium, are typically found in the sellar or suprasellar regions. These tumors occur mostly in children and are less frequent in the adult population. Preoperative and postoperative endocrinologic evaluation is necessary to assess for hypopituitarism, as well as a full evaluation of visual fields. Treatment includes surgical resection and, if residual tumor is noted, potential adjuvant radiation.[31]

Malignant tumors of the anterior skull base can be divided into neuroendocrine sinonasal malignancies and non-neuroendocrine sino-nasopharyngeal tumors. Neuroendocrine sinonasal malignancies originate from epithelium of the paranasal sinuses and can spread to the anterior cranial fossa. These include esthesioneuroblastomas and nonesthesioneuroblastomas (ie, neuroendocrine carcinomas, sinonasal undifferentiated carcinoma [SNUC], and small cell carcinomas). Non-neuroendocrine sino-nasopharyngeal tumors also spread to the anterior cranial fossa and include adenoid cystic carcinomas, squamous cell carcinoma, adenocarcinoma, sarcoma, and melanoma.

## *Neuroendocrine Group of Sinonasal Malignancies*

### *Esthesioneuroblastomas*

Esthesioneuroblastomas, or olfactory neuroblastomas, arise from the olfactory epithelium of the upper nasal cavity and compromise 3% of intracranial tumors. They have a binomial distribution, affect patients in their second and fifth decade of life, and are thought to be a primal neuroectodermal tumor.[32] Esthesioneuroblastomas often invades into the cranial vault and, to assist with prognostic factors, radiographically the tumor is divided into Kadish stages.[33] This radiographic grading scale is as follows[33]:

A—limited to nasal cavity.

B—nasal and paranasal cavity.

C—beyond nasal and paranasal cavity (invades cribriform plate, anterior cranial base or orbit, intracranial, and maxillary sinus).

In a meta-analysis comparing surgery as a unimodal treatment versus surgery plus irradiation there was no significant difference. In patients who underwent surgery alone, instead of surgery plus irradiation, the survival rate at 5 years was 78% versus 75% and, at 10 years, was 67% versus 61%.[34] Further analysis showed that poor prognostic indicators were a Kadish grade of C, more invasive tumor type, and patients greater than 65 years of age.[34] Resection of these tumors is extensive and the goal is negative margins, which can include excision of the cribriform plate and overlying dura (**Figs. 1** and **2**, Video 1). Typically, biopsying the tumor before complete excision is recommended to establish the diagnosis and determine whether there is a role for pre-resection chemotherapy and/or radiation treatment to achieve cytoreduction before definitive resection.[34] Other studies show variable results with 5-year survival rates ranging from 56% to 100%.[35–37]

### *Non-esthesioneuroblastoma neuroendocrine malignancies*

**SNUC** SNUC is an aggressive tumor that originates in the paranasal sinuses. This malignancy is usually present in an aggressive stage with local and distant metastases. No current consensus on the optimal treatment exists owing to the rarity of this disease and poor outcomes; however, a combination of resection, chemotherapy, and radiotherapy has been shown to improve survival rates.[38,39] The University of California San Francisco experience

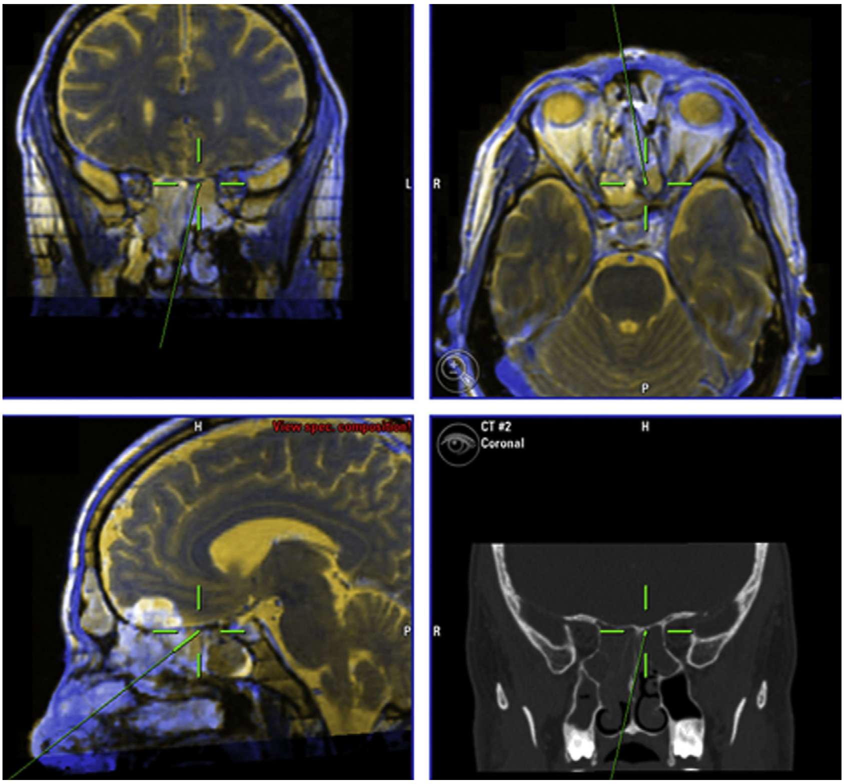


**Fig. 1.** Intraoperative neuronavigation for resection of esthesioneuroblastoma. Preoperative MRI and CT scan fused for intraoperative navigation in a patient diagnosed with an esthesioneuroblastoma. This lesion was resected endoscopically and the patient has been disease-free for 3 years.

with 19 patients incorporating radiation therapy and surgery revealed a 74%, 5-year, local control rate if a GTR was achieved compared with only a 24% local control rate for those with subtotal tumor resection.[40]

A recent meta-analysis revealed that survival of patients with SNUC at 23 months was approximately 47%.[39] Recent data in a small series suggest that minimally invasive endoscopic gross-total resection of an SNUC with adjuvant therapy in patients without metastases can allow a disease-free survival rate of 57% at 32 months from diagnosis.[38]

**Sinonasal neuroendocrine carcinoma** Like SNUC, sinonasal neuroendocrine carcinoma (SNEC) is an aggressive tumor, usually presenting in middle age as a nasal mass. Both tumors have the capacity to metastasize locally and distantly, and typically result in poor outcomes. SNEC, which is even rarer than SNUC, has been described in small, single-institution series.[41]

**Small cell carcinoma** Small cell carcinoma typically present aggressively. It is even rarer than SNUC and SNEC, and has been described in small series.[42]

## *Non-Neuroendocrine Sino-Nasopharyngeal Tumors*

### *Nasopharyngeal carcinomas*

**Adenoid cystic carcinoma of the salivary glands** Adenoid cystic carcinoma is also a rare cancer that can occur at multiple sites in the body but most often occurs in the head and neck. At this location this tumor is considered to be a malignant salivary gland tumor. Adenoid cystic carcinoma starts in the maxillary sinus and invades neural foramen. Typically, complete resection is not possible owing to perineural extension, especially into cranial nerves V2 and V3.[32] The goal of surgery is to resect as much as possible without compromising the orbit or cranial nerves. The primary treatment is surgical resection followed by postoperative radiation treatment.[32] Chemotherapy is also used for metastatic disease. In one study of 160 patients, 5-year survival rates were 89% to 90% and 15-year survival rates were 40% to 69%.[43,44] In 22% of the patients, the site of failure was a distant metastasis.[43] Increased mortality and treatment failures were associated with positive lymph nodes, solid histology, and perineural invasion.[43]

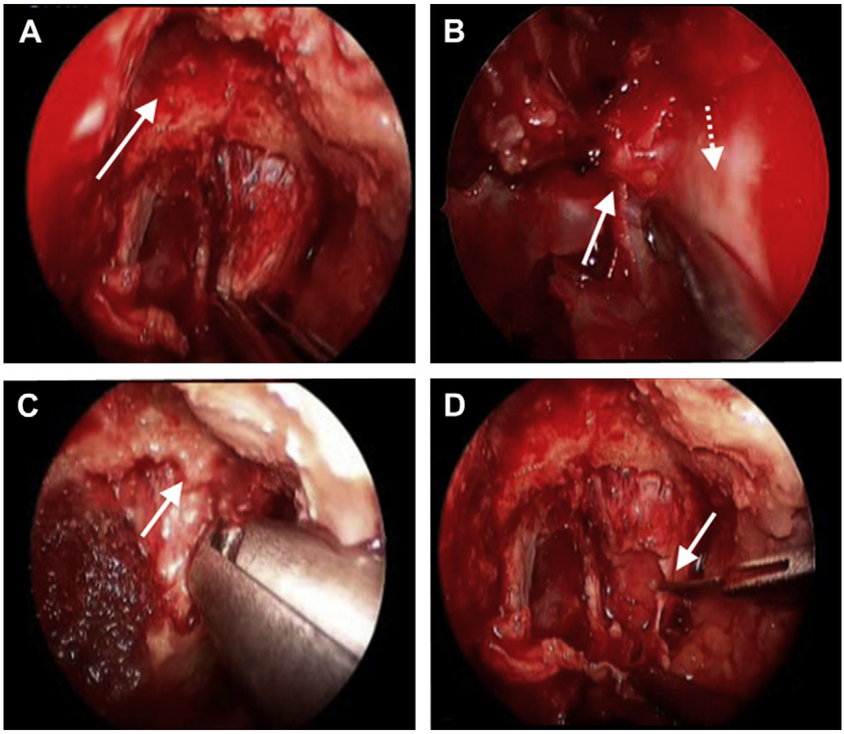


**Fig. 2.** Resection of esthesioneuroblastoma. (*A*) Exposure of posterior wall of frontal sinuses delineates anterior extent of resection (*white arrow*). (*B*) Removal of lamina papyracea exposes the ethmoid artery entering skull base (*white solid arrow*), the periorbita is retracted (*dotted arrow*). (*C*) After drilling down the skull base, the bone (*arrow*) is further resected with a Kerrison rongeur. (*D*) Dural margins are defined and resected with retraction and endoscopic scissors (*arrow*).

**Squamous cell carcinoma** Squamous cell carcinomas are the most common malignancies of the nose and paranasal sinuses and tend to present in men over the age of 50. Treatment plans include surgery, radiation treatment, or both, depending on the grade of the stage of the tumor.[32] In a meta-analysis reviewing 89 patients who underwent resection for squamous cell carcinomas, the 2-year disease-free rate was 64%.[45]

### *Primary sinus (adenocarcinoma, sarcoma) or sinonasal (melanoma) pathology*

**Sinonasal melanoma** Sinonasal melanoma or mucosa melanoma is very rare, accounting for only 1% of all melanomas. Tumors often present in late-stage disease with extension from the sinuses into the skull base. Treatment consists of aggressive surgical resection and subsequent adjuvant radiotherapy.[46] In a study of 53 patients, the 3-year survival was reported as 28% and the recurrence-free survival was 25%.[46]

**Sinus sarcoma** Sarcomas in the head and neck are also very rare and present as a late diagnosis, making their prognosis poor. Low-grade tumors are treated primarily with irradiation, whereas high grade is treated with combination surgery and irradiation, as well as chemotherapy.[32]

## *Other Anterior Skull Base Aggressive Lesions*

Other malignant anterior skull base lesions can include rare more aggressive forms of usually benign intracranial lesions such as atypical or malignant meningioma, or pituitary carcinoma. Finally, there are tumors that are pathologically benign, which can ultimately prove fatal owing to frequent recurrence (eg, suprasellar craniopharyngiomas or infrasellar chordomas). Chordomas are persistent fetal cartilage and notochords involved in skull base development that give rise to their malignant counterparts, chondrosarcomas and chordomas, respectively. Their incidence is 0.8 per 100,000 and they comprise approximately 0.1% of all brain tumors. Chordomas are histologically benign and slow-growing; however, they are considered malignant because of their tendency to engulf and invade neurovascular structures. The origins of these two tumors lead to different locations, with chordomas arising in midline notochord-derived locations (eg, clivus), whereas chondrosarcomas arise from cartilaginous lateral skull base. Their midline location makes chordomas an appealing target for an endonasal endoscopic approach. During resection of these lesions, neuromonitoring is critical, especially due to the medial course cranial nerve VI takes around the clivus. Treatment of these lesions begins with surgical resection, followed with early adjuvant irradiation (either gamma knife or proton beam). In a review of 12 endonasal series, GTR was achieved in 40% to 72%.[47–56] Limitations preventing GTR included tumor volume greater than 20 $cm^3$, tumor location in lower clivus with lateral extension, and previously treated disease.[50] In one study of 60 resected endonasal, endoscopic chordomas, 20% of patients who underwent GTR had recurrence at 15.4 months and 60% of patients who underwent subtotal resection had recurrence at 13.7 months.[50]

## ANTERIOR SKULL BASE CORRIDORS, APPROACHES, AND TARGETS

Minimally invasive anterior skull base approaches have been continually developed by neurosurgeons and otolaryngologists working together over many years and can allow access from the olfactory groove to the odontoid process of C2. The best way to preserve collateral structures is to not expose them. Wide exposure of the brain and vascular structures to the surgical field to nonphysiological conditions for several hours is undesirable. Therefore, the purpose of a minimally invasive approach is to pinpoint where the lesion is and choose a short, direct, targeted approach that eliminates such wide exposures used in the traditional approaches. To find such a selected approach, the surgeon must be familiar and comfortable with three-dimensional skull base anatomy. In addition, the preoperative imaging must be vigilantly reviewed to see where structures are compressed and altered from their original location.

When planning the surgical approach, the surgeon decides on the target, the corridor, and an entry point.[27] The approach should minimize the need for manipulating any vascular or neural components.[28] At the beginning of the case, the surgeon must already be aware of the closure method that will be needed at the end of the operation. This will dictate the best way to open the mucosal layer to ensure vascular supply is preserved if a nasoseptal flap will be needed.

The decision begins with determining a target. Targets in the anterior skull base include, but are not limited to, the sinonasal cavity, the olfactory groove, the anterior cranial fossa, the sella, the suprasellar cistern, the clivus, the cavernous sinus, the orbital apex, and the inferior frontal lobe.

The tumors at each of these targets typically start in the midline, but can grow more laterally. Understanding how much lateral projection, where the vascular supply is, and where the dural attachment is located are important in planning the next step of selecting an entry point to the skull base to best access this target. Entry points include transfrontal, transcribriform, transclival, transsellar, transtuberculum, and transplanum (**Figs. 3** and **4**). In addition, some lesions of the suprasellar areas or the inferior frontal lobe are best accessed via a supraorbital or supraglabellar approach. After an entry point is selected, a corridor through which the entry point to the skull base will be achieved is chosen. Most of the corridors to the anterior skull base begin transnasally and then extend to either include transsphenoidal and/or transethmoidal corridors (**Fig. 5**). Other corridors that are used less frequently are sublabial and transoral. These assist with gaining access to lesions that are lower in the skull base. Finally, if the lesion extends more laterally and enters the middle fossa, extension of the entry might include transmaxillary and transpterygoid approaches.

### *Corridors*

#### *Transnasal*

Almost all entry points to the anterior skull base begin transnasally because this entry provides largest access to the skull base and is often required for the other corridors. This approach is the least invasive due to minimal soft tissue and bony disruption. The borders include the cribriform

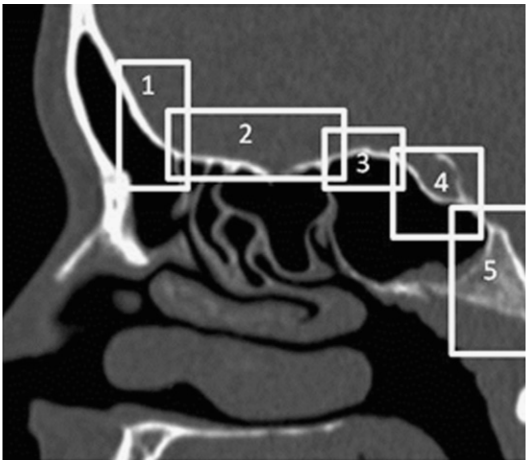


**Fig. 3.** Anterior skull base entry Points. Shown are examples of five anterior skull base entry points: (1) transfrontal, (2) transcribriform, (3) transtuberculum or transplanum, (4) transsellar, and (5) transclival.

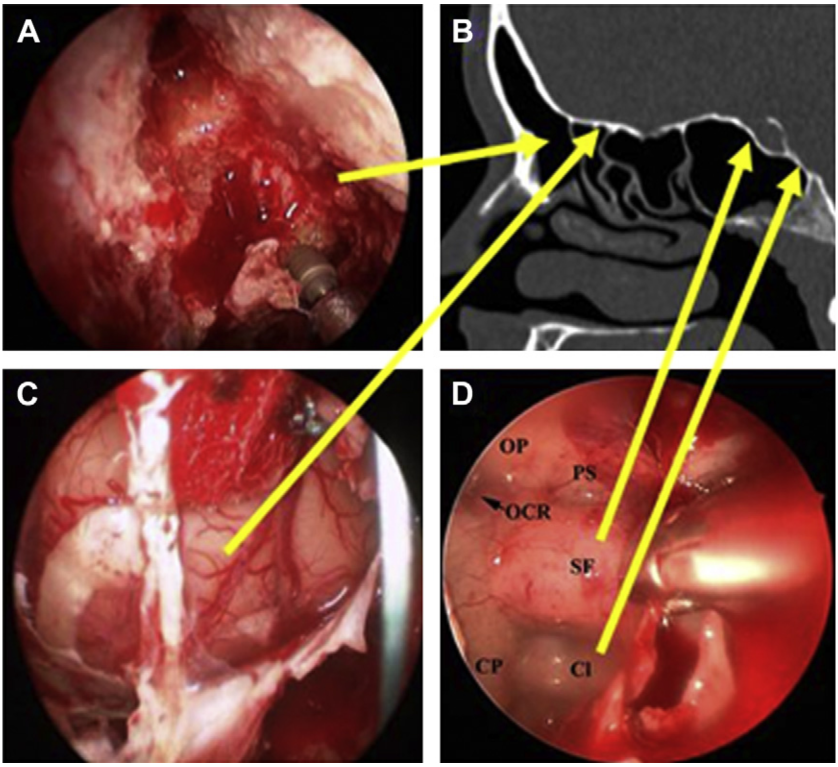


**Fig. 4.** Skull base views. (*A*) Frontal sinus throughout transfrontal entry point. (*B*) Location of views on the skull base (*yellow arrows*). (*C*) Olfactory nerves seen through the transcribriform entry point. (*D*) Planum sphenoidale (PS), sellar fossa (SF), and clivus (Cl) as intersinus septum is being removed via the transsellar entry point. CP, carotid protuberance; OCR, optic-carotid recess; OP, optic- protuberance.

plate superiorly; the septum medially; the superior, medial, and inferior turbinates laterally; and the hard palate inferiorly.[27] Typically, for smaller cases, using one nasal passage is sufficient; however, expansion into both may be necessary for better exposure or to allow more ease of instrument manipulation.

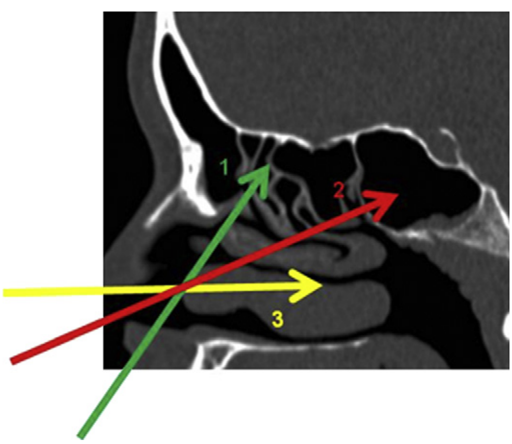


**Fig. 5.** Anterior skull base corridors: (1) transethmoidal (*green arrow*), (2) transsphenoidal (*red arrow*), and (3) transnasal (*yellow arrow*).

With this expansion, the surgeon removes the posterior aspects of the septum. Care must be given to not remove the septum too anteriorly because deformation of the nasal ridge can result. Additionally, removal of the middle turbinate can also decompress the intranasal compartment and allow better working space if needed. Continuing the transnasal opening posteriorly, the surgeon can access the olfactory groove, cribriform plate, and anterior cranial fossa.[27]

### *Transethmoidal*

Once entered via the transnasal corridor, the surgeon can decide the extent of superior lateral access that is required. If needed, extension into transethmoidal area can be performed by advancing lateral to the vertical attachment of the medial turbinate. This allows complete removal of the anterior and posterior ethmoids. Exposure is then gained to the fovea ethmoidalis, frontal fossa, lamina papyracea, and orbital apex.[27] Further extension through a transsellar approach will also allow access to the cavernous sinus.

***Transsphenoidal***

The transsphenoidal corridor is the mainstay for basic cases and is the workhorse for pituitary lesions. After using the transnasal corridor, a large opening into the sphenoid sinus is made. One method is to enlarge the sphenoid ostia bilaterally.[27] As described above, the posterior septum is removed. The mucosal lining of the sinus are stripped, and the septations are removed. At this point, a large opening into the sphenoid sinus is achieved. Access to the sella, tuberculum sellae, planum sphenoidale, cavernous sinus, and upper third of the clivus is achieved.

## *Expanded Endonasal Surgical Technique*

The procedure can be tailored to the lesion at hand but, in general, starts with creation of a surgical corridor to allow passage of the endoscope and at least two surgical instruments. The procedure is often initiated by the otolaryngology team. The nasal cavity is decongested preoperatively with intranasal packing of 1:1000 epinephrine or 4 mL of 4% cocaine on pledgets. Obstructing sinonasal tumors are often debrided through various means such as blunt or sharp dissection or electrocautery, which can lead to bleeding. The tumor is packed off with hemostatic agent and pledgets soaked with decongestant. A wide maxillary antrostomy and total ethmoidectomy is typically performed on the right side (unless a unilateral left dissection is being performed). Next, if planned for use, a nasal septal flap is harvested and stored in the maxillary antrum or nasopharynx. The posterior 1.5 cm is removed to provide access to lesions of the sphenoid planum and pituitary. For lesions involving the anterior cranial fossa, the entire septum may need to be removed preserving the anterior nasal L strut (approximately 1.5 cm of the anterior nasal septum) to prevent a saddle nose deformity. Variations of nasal septectomy can be tailored on a case-by-case basis, but should not obstruct surgical access. A wide sphenoidotomy is performed from orbital lamina to orbital lamina to correctly identify the plane of the orbit. Anteriorly, the frontal sinus is identified by complete removal of the anterior ethmoid cells. The authors prefer to enter the frontal sinuses in the midline using a high-speed coarse diamond burr, drilling out the nasal septum where it enters the floor of the frontal sinus. The remainder of the frontal sinus floor is removed with 70 angled Kerrison rongeur. The anterior ethmoid artery is identified traversing from the orbit to midline at the junction of the anterior skull base with the posterior wall of the frontal sinus. The posterior ethmoid artery traverses the skull base just anterior to the anterior sphenoid sinus wall. Importantly, the ethmoids often travel within the bone of the skull base, and we prefer to identify them in the orbit. The orbit lamina bone can then be removed, preserving the periorbita to prevent herniation of orbital fat into the surgical field. The vessels are identified and ligated. The skull base bone, if intact, can then be eggshelled with a high speed burr. The crista galli is identified dividing the left and right anterior skull base, and can be drilled out from nasal cavity using a diamond burr. After the tumor is devascularized and debulked to the dura, the neurosurgical team typically joins for a meticulous tandem dissection of the intracranial disease. Typically, a clean dural margin can be identified by its pearly white appearance and using extended microdissection or microscissors, the dura is entered in a disease-free zone. The dura is dissected off the brain circumferentially around the disease. At this point, it is often appreciated that intracranial tumor can descend into the nasal cavity, facilitating dissection. If dictated for control of malignant disease, the tumor is dissected off the brain with a clean margin. After the tumor is resected, we typically close the wound with a fitted piece of DuraGen (Integra Life Sciences, Plainsboro, NJ, USA) soaked in saline, then cover the wound with the septal flap. In some cases, a fat graft can be used to supplement the closure. In some cases, if the flap is too small for the defect, we place the fat graft on the DuraGen, then vascularize the fat with the septal flap. In other cases, we have supplemented the edges of the septal flap with a fat bolster. The nasal septum is covered with Silastic splints if there is exposed cartilage. The cavity is then packed with 10 cm Merocel sponges (Medtronic Xomed, Jacksonville, FL, USA) and a Foley balloon catheter filled with saline under direct observation.

## *Entry Points*

***Transcribriform or transfrontal***

The transcribriform entry point is accessed through the transnasal corridor by projecting medially and superiorly. This access allows visualization from the olfactory groove and crista galli, along the floor of the anterior fossa to the anterior planum sphenoidale.[28] More superiorly, the frontal sinus can be entered if tumor extension is present and this entry point would be transfrontal.[28] Because of the high angle of entry, a 30° endoscopic is very useful for examining beyond the floor of the anterior fossa. Typical tumor types at this location include esthesioneuroblastoma, SNUC, adenoid cystic carcinoma, olfactory groove meningiomas, and squamous cell carcinoma. If the tumor extends more laterally off midline, this approach can be expanded to include transfovea ethmoidalis approach; however, careful attention and possible transaction of the ethmoidal arteries is needed.[27] In addition, the supraorbital approach or supraglabellar approach may be better suited for tumors depending on the amount of bony involvement and location. Damage to the olfactory structures as they enter the cribriform plate bilaterally will result in anosmia; therefore, this risk should be addressed with the patient preoperatively.

#### Transsellar

The transsellar entry point is accessed via the transsphenoidal corridor and allows exposure to the sellar and suprasellar structures. Laterally the exposure is limited by the cavernous segment of the internal carotid artery. Most of the lesions (Rathke cleft cyst and pituitary gland) originating in sella are benign; however, the approach is needed to address inferior extension of suprasellar pathologic tumor (craniopharyngiomas) or superior extension of infrasellar pathologic tumor (chordomas). The pituitary gland can be transposed, if needed, to gain further access to superior intradural aspect of a superiorly growing chordoma. Care must be given to the location of the hypophyseal arteries; the superior artery must be preserved and, if needed, the inferior artery can be sacrificed. In addition, evaluation and removal of tumor that invades into the medial cavernous sinus can be approached with this method.[27] Finally, tumor that extends superiorly and laterally may need removal of the opticocarotid recess. This can be removed by carefully drilling until the bone is eggshell thin and then slowly elevating the bone with a rongeur such as a Cloward. Removal of tumor from surrounding the optic nerve not only allows decompression of the nerve but also a safer target for radiosurgery in the postoperative treatment.

#### Transtuberculum or transplanum

The transtuberculum and transplanum approaches typically involve an extension of the transsellar entry point anteriorly or the transcribriform entry point posteriorly. With this additional exposure, better visualization of the suprasellar cistern is achieved, especially when tumors are more anteriorly and superiorly projecting. The planum sphenoidale or the tuberculum are thinned out to eggshell thinness, then removed carefully with an up-biting Hardy punch. Typically, the anterior and superior wall of the sella is also removed. Through a midline dural opening, access to the optic nerves, anterior communicating artery, interhemispheric cistern, and distally third ventricle can be achieved.[27] Special attention to the superior intercavernous sinus must be made, and ligation can be performed if it cannot be displaced. Representative pathologic conditions in this location are meningiomas, craniopharyngiomas, or large pituitary lesions with significant superior extension.[28]

#### Transclival

The transclival entry point is accessed via the transnasal and/or transsphenoidal corridor and allows visualization of the clivus. The clivus can then be accessed from the level of the posterior clinoids to the foramen magnum.[28] When entering the sphenoid sinus, removal of the inferior aspect of the anterior wall down to the floor of the sphenoid sinus, close to the nasopharynx, is needed to allow a more downward trajectory. Identification of the petrosal segment of the internal carotid artery in the posterior wall of the sphenoid sinus is imperative and will limit the lateral extension of resection. This bone can be drilled carefully to expose the surrounding venous plexus and carotid artery. Micro-Doppler can be used if the carotid is encased with tumor for localization. Because the clivus also extends superiorly and posteriorly to the pituitary gland, a transsellar entry point may also be needed for mobilization of the pituitary gland.[27] The tumor will likely erode a large part of the clivus, but the remaining portion can be drilled down to allow full exposure of the tumor. Again, to allow a wider corridor, resection of one or both of the middle turbinates may be needed on entry to allow access to all involved structures. If the tumor erodes into the dura, opening the dura at the midline at or below the vertebral basilar junction will allow careful preservation of cranial nerve VI as it runs laterally into Dorello canal.[49] The lateral limitation of this exposure include the vidian nerve running along the lateral border of the inferior aspect of sphenoid sinus; the carotid arteries; and, inferiorly, the eustachian tubes in the lateral nasopharynx mucosa.[27] Typical pathologic tumors at this location include chordoma, chondrosarcomas, and lymphoma.

### Supraorbital Approach

The supraorbital and supraglabellar approaches offer a window to the inferior frontal lobe and the circle of Willis, and dissection of the sylvian fissure without the need of brain retraction.[15,16,57] This approach does not disturb the temporalis muscle, branches of the facial nerve, or the superficial temporal artery, which decreases operative exposure time when compared with a typical bifrontal craniotomy or pterional craniotomy.[15,21,26] An eyebrow incision eliminates the need for a hair shave and is easily hidden by the eyebrow, which decreases the psychological impact of surgery. If additional exposure is needed, the craniotomy can be expanded with an orbital rim osteotomy, medial supraorbital craniotomy, or conversion to a standard pterional craniotomy. Complications associated with the supraorbital approach include transient anesthesia over the frontal part of the scalp or transient frontalis muscle palsy.[15,16,21,26] Less common are CSF leaks and sinus fistula.[21] Avoiding the frontalis nerve is important for good cosmetic results. The course of the frontalis nerve can be plotted on the skin as a line starting from a point 0.5 cm below the tragus and passing 1.5 cm above the lateral extremity of the eyebrow.[58] Positioning is in the supine position with the head slightly rotated and extended to orient the surgical corridor vertically toward the lesion. This allows the frontal lobe to fall away from the floor of the anterior cranial fossa. An eyebrow incision can be made in the superior aspect of the eyebrow from the supraorbital notch to the lateral eyebrow. The pericranium is incised and raised as a separate flap, exposing the orbital rim and keyhole. A burr hole is then made in the keyhole, the underlying dura dissected free, and a craniotomy flap opened just lateral to the superior temporal line. The inner table of the frontal bone is then drilled flush with the orbital roof to flatten the exposure. Careful attention to the preoperative bony anatomy should be made and, if possible, avoiding the frontal sinus is recommended. The dura can then be opened as a flap based inferiorly. Intracranially, one priority is to open the arachnoid of the sylvian fissure and the olfactory and suprasellar cisterns for CSF drainage to create enough room for brain retraction and surgical manipulation.

### *Supraglabellar Approach*

The supraglabellar approach is very similar to the supraorbital approach but allows a midline exposure to the base of the frontal fossa. The skin incision is made through a forehead skin crease, between supraorbital foramina laterally.[57] The craniotomy is performed with a craniotome between supraorbital foramina laterally, which then removes the frontal bone.[57] When accessing the frontal sinus with either the supraglabellar or the supraorbital approach, care must be given to prevent a posterior sinus tract or CSF leak. This is prevented by stripping the mucosa layer from the sinus and then filling it with fat or muscle at the end of the surgery. Once the dura is opened, the falx cerebri and the anterior tip of the superior sagittal sinus can be ligated.[57]

The visualization that each of the corridors and approaches described above can be achieved with an operating microscope; however, it can be much further increased by the use of straight and angled endoscopes. These will provide a panoramic view of the deeper structures. With the use of straight and angled lenses, visualization around nerves, vascular structures, and bony structures becomes possible and significantly better than a traditional microscope. Surgeries with only the use of an endoscopy are possible, especially with gradual learning and experience.

## EQUIPMENT

To gain access and manipulate the tumor a special set of instruments for minimally invasive surgery should be accessible and prepared before surgery. A set of long and narrow instruments have been made for specific endonasal use and include irrigation devices, suction devices, drills, ultrasonic debriders, osteotomes, rongeurs, scissors, and cautery devices. The bipolar devices should have a range of angled tips to allow for easier coagulation through small narrow channels.[28] Likewise, the suction devices should also have a range of lengths, diameters, and angled tips to allow for access and evacuation of tumor. Neuronavigation and, possibly, intraoperative fluoroscopy should be available before starting each case. For surgical visualization, an operating microscope and/or endoscope setup should also be accessible. Two or more video screens in the room are also needed so that the remainder of the operating room team has an accurate knowledge of the surgical course.

### *Endoscopic Equipment*

The rigid endoscope rod lens telescopes developed in the 1950s by Harold Hopkins, a professor of applied optical physics, improved the picture quality considerably.[7] This was then complimented by the fiberoptic cold-light light source by Karl Storz.[59] Current endoscopes are available through several companies come with varying sizes and lengths of shafts and lens angles. The angles range from 0° to 30°, 70°, and even 110°, and allow the surgeon to view all angles from the tip of the endoscope. Typically, the entire procedure is performed with a 0° endoscope. A bright xenon white light source and high-definition image system is necessary for adequate visualization. Endoscopes are reusable and provide excellent visual quality; however, owing to their rigidity and size, they often are difficult to maneuver. The physical positioning of the instruments and the two surgeons' four hands requires training and cannot be underestimated as an essential part of the case. Typically, the operating surgeon will need a cosurgeon to control the endoscope and prevent obstructing dissection instruments while maintaining adequate visualization (**Fig. 6**). Another method is to use a device to immobilize the endoscope, which allows the surgeons' hands to be freed for other instruments. However, for anterior skull base lesions and transplanum approaches, this is not preferred because dynamic control is needed for vascular control in bloody fields. For the two-surgeon technique, a binostril approach is used with one surgeon on each side of the patient or on one side of the patient (**Fig. 7**). Endoscopes and relevant instruments can be registered to a frameless neuronavigation system, which allows identification of the tip of the instrument in virtual space. To prevent the endoscope lens from becoming obscured by blood, a sheath over the endoscope that provides intermittent irrigation and cleaning is used. A 4 mm endoscope is used in adults, which allows passage of two to three more instruments for dissection or cauterization. Cautery must be available. The authors have had limited success with currently available, specially designed endoscopic pistol-grip bipolars and, typically, we use extended standard bayonet bipolars with straight or angled tips to reach the skull base. The typical instruments available for passage include various dissectors, suction freers, forceps, scissors, balloon dilation catheters, extended monopolar and bipolar cautery, CUSA debrider, microdebrider, and a CO2 laser handpiece.

**Fig. 6.** Single-surgeon endoscope manipulation. A single surgeon working on the patient's right can hold the endoscope in the left hand atop the right naris and the surgical instrument in the right hand at the base of the right naris.

## PREOPERATIVE CONSIDERATIONS

Any patient with a skull base lesion will need preoperative imaging. This consists of MRI of the brain and skull base. For lesions of the sella, high-quality pituitary or sellar protocol MRI is also performed. The internal carotid arteries, cavernous sinus, and anterior cerebral arteries should be evaluated for tumor encasement. Extension of tumor along the dura should be evaluated. The position of tumor in relation to cranial nerves should be evaluated because tumors that extend beyond functional cranial nerves, typically, should not be crossed with an endoscopic approach.[28] In some patients, fusing preoperative CT and MRI scans can allow better understanding of the correlation of the bony skull base and soft tissues. Also, special attention to the anatomy of the sinuses, especially in respect to septations, bony curvatures, and prior surgical openings, are helpful in identifying midline structures during surgery. Aeration of the posterior ethmoid cells above the sphenoid sinus, called Onodi cells, can lead to unrecognized exposure and injury of the optic nerve. A history of use, radiation therapy, or nasal-septal surgery may limit the use of the nasal septal flap and require an alternate flap (ie, turbinate or pericranial).

In all cases, provisions need to be made for the possibility of conversion of the minimally invasive approach to an open approach. Sometimes this will play a role into the positioning and prepping of the patient.

Some patients with anterior skull base lesions may be complicated with other underlying symptoms. Specifically, patients with endocrine abnormalities—typically, pituitary lesions or craniopharyngiomas—must be carefully evaluated for pituitary hypofunction and will need hormone replacement before surgery. Stress-dose steroids are most critically needed for patients whose tumors may cause adrenal insufficiency from damage to the pituitary gland. Patients with tumors whose resection requires work around the suprasellar cistern or pituitary gland are also at risk for perioperative diabetes insipidus and, therefore, must undergo postoperative monitoring for large volumes of dilute urine. Finally, preoperative testing should include evaluation of electrolytes and glucose.

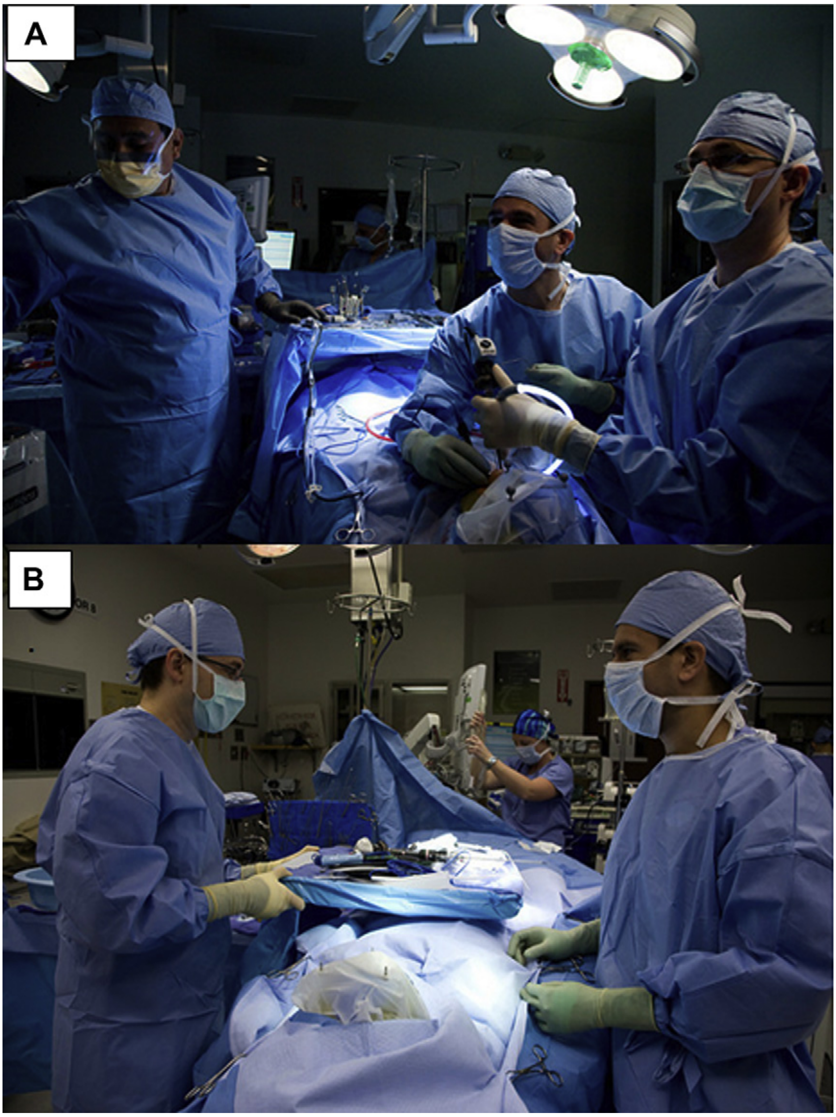


**Fig. 7.** Binostril approach with two surgeons. Endoscopic endonasal surgery can be performed with two surgeons working together: (*A*) with one surgeon on each side and the scope-holding surgeon on the right or (*B*) with both surgeons on the patient's right and the scope-holding surgeon up top.

## PERIOPERATIVE CONSIDERATIONS

All patients undergoing anterior skull base procedure are under general anesthesia, which allows for strict control of blood pressure and intracranial pressure. During the surgery many of the structures of the anterior skull base are highly vascularized and, therefore, a lower or normal systolic blood pressure is recommended. Pretreatment with vasoconstricting agent to the mucosal layers can also help reduce bleeding in the corridors; however, monitoring the blood pressure during this application is imperative because of the potential for a systemic response. Finally, reducing the positive end-expiratory pressure can help reduce venous pressure and bleeding. Leaving the head slightly elevated during surgery can reduce venous pressure and bleeding intraoperatively. At the completion of the surgical case, the field should be inspected again for bleeding. After the dural closing, a Valsalva maneuver is used to increase intrathoracic pressures, which would elicit a CSF leak if present.

Preoperative antibiotics are chosen to cover sinus bacteria and prevent meningeal bacteria. Ceftriaxone or cefepime is recommended.[60] Vancomycin and aztreonam can be administered to β-lactam–allergic patients.[60] If sinusitis is identified preoperatively, an intradural approach should not be undertaken until the infection has cleared.[61] If CSF is noticed during surgery and postoperative packing is used, postoperative antibiotics continue until the packing is removed.[60] Anticonvulsants are typically not dosed. A lumbar drain is typically placed when a CSF leaks is planned or identified. At the conclusion of surgery, mask ventilation is avoided to prevent tension pneumocephalus.

## PATIENT POSITIONING AND ROOM SETUP

For the procedures associated with the approaches listed above, the patient is lying in the supine position with the head slightly extended and the neck slightly flexed. The head is immobilized in a rigid Mayfield or a semirigid gel doughnut. Horizontal alignment is critical to ensure the correct trajectory throughout the case. For fully endoscopic procedures, the room setup will include multiple pieces of equipment, including the endoscope, the video screens, Mayfield clamps, arms to secure the endoscope, neuroimaging devices, and irrigation equipment. The positioning of the surgeon, scrub technologist, and the neuroanesthesiologist becomes critical. One recommended setup is shown in **Fig. 8**. A thorough check before prepping the patient should be completed because the neuroanesthesiologist may have limited access to the patient, especially their face and airway, during the case. Typically, arterial lines and large-bore intravenous catheters are indicated for these intracranial procedures. The surgeon may also consider a central venous line if there is concern of a possible air embolus, for instance if the cavernous sinus is likely to be explored. Reinforced endotracheal intubation tubes can be used to prevent kinking.

## TUMOR RESECTION

Once the tumor is visualized, before resection, attention must be paid to the blood supply. Coagulation of the arterial supply can be followed by tumor debulking. Debulking allows for collapse of the tumor and easier manipulation and dissection. One method for tumor resection is using a two-suction technique in which gentle countertraction facilitates sharp extracapsular dissection. This prevents tearing and minimizes vascular injury because no grasping forceps is used.[49] This method is alternated with intratumor debulking. Tumor removal en bloc versus in layers was not shown to have a significant difference in outcome, in one series.[62] This series concluded that tumors with minimal dural involvement and minimal local invasion can be treated effectively with minimally invasive transnasal approaches.[63] In all malignant skull base tumors, it is recommend to remove as much tumor as possible, to remove a dural margin, and to remove all of the intracranial extension to achieve negative margins.

## SKULL BASE RECONSTRUCTION

One of the greatest challenges of minimally invasive anterior cranial base surgery is to consistently provide closure of dural defects to prevent postoperative CSF leaks, pneumocephalus, and infection. There are several types of closures available, but these are limited owing to the availability of localized vascularized flaps. Other options for

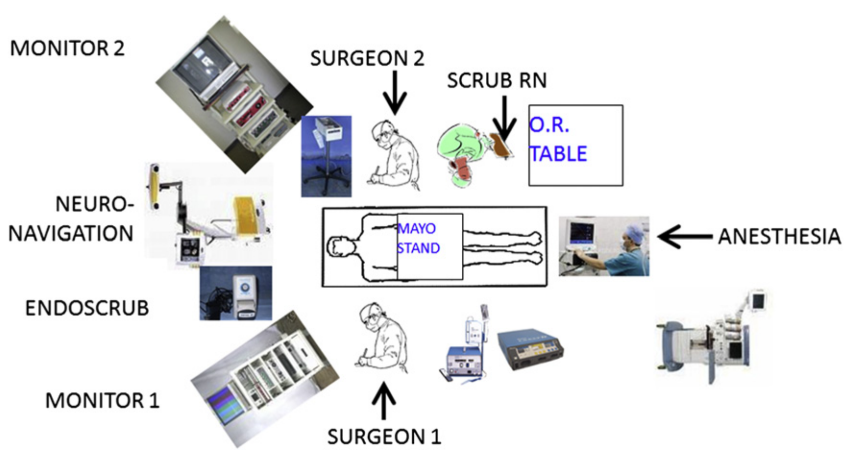


**Fig. 8.** Endoscopic room setup. The operating room for an endoscopic endonasal skull base surgery can be setup with the patient's head positioned away from anesthesia using an extended endotracheal tube. At the head of the patient, neuronavigation can be positioned in between two monitors, which allow the two surgeons to view the operation while working across from each other.

repair include microvascular free flap, pericranial scalp flap, synthetic dural substitute, suturable dural substitute, fat graft packing of the sphenoid sinus, and nasal packing with balloon catheters. For instance, at the authors' institution, openings for routine pituitary gland tumor resection are closed with devascularized tissue (free tissue fat graft and/or DuraGen).

Initially, in one large series of 800 cases closed using a variety of methods, the documented rate of postoperative CSF leak after endonasal endoscopic endonasal skull base surgery was 15.9%.[64] Other investigators report postoperative CSF leaks in up to 30% to 58% of their patients.[22,31,65,66] The current advantage of large craniofacial open techniques is the use of vascular pedicle flaps and suturing techniques that can provide a watertight seal and result in a postoperative CSF leak rate of less than 2%.[63] With minimally invasive approaches, the use of an NSF has been reported to significantly decrease postoperative CSF leak rates from 20% to less than 5% in multiple series,[64,67,68] results closer to those achieved with open approaches. The NSF has been based on a large posterior pedicle, which includes the nasoseptal artery, a branch of the posterior septal artery.[67] The addition of the pedicle originating near the sphenopalatine foramen clearly defines the arterial supply, allows harvest of large flaps composed of nearly the entire septal mucosa, and allows rotation of the flap in the posterior, superior, inferior, or lateral plane.[28] If prepared carefully during the opening of the procedure, this flap will be large enough to cover large dural defects from the frontal sinus to the sella. In a series at the authors' institution, 28 patients had 32 NSFs (either unilateral or bilateral) raised over 14 months; no cases of CSF leak or meningitis were noted with an average follow-up time of 8 months.[67] In select cases in which an NSF is unavailable, a middle or inferior turbinate flap can be used. In some cases, a bicoronal approach with pericranial flap is used and passed through a hole created in the nasal dorsum.

## NSF PREPARATION

Several studies give evidence that the NSF decreases CSF leak rates postoperatively; therefore, the authors recommend NSFs for all large dural defects. At the beginning of the operation, an NSF is harvested as a mucoperichondrial flap based on the posterior nasoseptal artery, with incisions as described in a previous report.[67] After the mucosa is dissected off the sphenoid wall, a pedicle of mucosa from the sphenoid ostia to choanae and taken back to the level of the sphenopalatine foramen.[67] At the end of the case, once hemostasis is achieved, the exposed brain is covered with a synthetic dural substitute, such as DuraGen, and the edges are tucked intradurally.[61] Fat grafts can sometimes be used to cover the fascia and are in contact with the surrounding bone. The surface of the fat graft is covered with a cellulose material, Surgicel (Ethicon, Inc, Somerville, NJ, USA), to form an adherent crust.[61] The fat is then held in place with a fibrin sealant (Confluent Surgical, Inc, Waltham, MA, USA). Then the NSF is laid over it and secured with DuraSeal (Confluent Surgical Inc, Waltham, MA, USA). Careful attention should be made to ensure the NSF is oriented properly; the periosteal surface of flap must contact denuded walls of sinonasal tract (Video 2). Septal splints are placed over denuded septal cartilage and bone and left in place for 3 to 4 weeks.[67] Finally, gel foam (Pharmacia & Upjohn, Kalamazoo, MI, USA) covers the wound and a Foley balloon catheter (F12–14) crosses the nasopharynx posterior to the nasal septum before inflation with saline.[61] Two Merocel sponges are often used underneath the balloon.[67] A lumbar drain may be left in place for 3 to 5 days draining 10 to 20 cc/h, depending on the size and nature of the dural defect. The balloon is removed at 3 to 5 days and the Merocel sponges, when present, are removed at 10 days.[67] Also, the authors recommend no positive pressure ventilation for 3 days if there was no intraoperative CSF leak and for 1 month if there was an intraoperative CSF leak.

A special population of patients, characteristically obese, middle-aged women with elevated CSF pressures following repair, have an increased risk of postoperative CSF leak.[61] Patients who suffer from coughing or gagging during emergence from anesthesia, obstructive sleep apnea, morbid obesity, or excessive nose blowing cause elevated CSF pressure that also increases the risk of CSF leak.[61] Despite initial success, such patients remain at risk for recurrent CSF leaks months to years following repair. One helpful adjunct in patients who are at risk for CSF leak is to place a subarachnoid lumbar drain to allow CSF diversion, lower intracranial pressures, and allow healing of the nasal flap.[61] Overdrainage should be avoided because this creates a negative intracranial pressure (ie, suction effect) that may result in pneumocephalus and promote bacterial contamination of the CSF with resultant meningitis.[69]

## POSTOPERATIVE CARE

Following surgery, patients with intracranial extension of tumor may benefit from a brief intensive care unit stay. Strict blood pressure control and neurologic examinations are carefully monitored.

A clinician should be aware of the possibility of postoperative diabetes insipidus occurring. Daily sodium levels and in-outs should be monitored. A postoperative MRI should be obtained before 48 hours. This will serve as a baseline MRI and assist the team in determining if further adjuvant radiation or chemotherapy is needed and where. Adjuvant therapy is specific for tumor type, histology, and quantity of residual tumor remaining.

Postoperatively, a clinician must also follow the patient closely and evaluate for CSF leak. Diagnosis of CSF leak in the postoperative patient can be challenging. The clinician should start by examining the patient for a CSF leak by asking them to lean forward for a period of time to elicit a leak. However, this is difficult if the nasal packing is in place. A postoperative CSF leak can confirmed with a beta-2 transferrin test. However, if nasal leakage is uncertain to be CSF, the presence of CSF in the nasal cavity at the time of surgery may confuse interpretation of this test. Subsequently, identifying where the leak is coming from is needed to plan the repair. Starting with a thorough endoscopic examination of the nasal cavity may reveal the site of the leak.[69] In addition, a high resolution CT scan of the sinuses with contrast may prove useful.[69] If a sizable defect is noted, a follow-up MRI may be indicated to investigate a possible meningocele or encephalocele. The T2 imaging on MRI can often identify the presence of a leak. If the concern is high or findings inconclusive, intrathecal injection of contrast materials in combination of high-resolution bone coronal CT scan and/or radioactive tracers can confirm a CSF leak and identify the site of origin.[69] Typically, CSF leak from an apparent defect in the primary closure should be repaired in the operating room.

## SURGICAL OUTCOMES

Malignant pathologic lesions located in the anterior skull base consist of rare tumors that often present in an aggressive invasive stage. Therefore, much of the literature on skull base malignancies, whether resection occurs via a minimally invasive approach or a larger craniofacial approach, is characterized by single-institution experiences with pooled results from a variety of tumor locations, histology, and treatment plans. Comparing treatment plans, tumor response, recurrence rate, and survival rates between studies to arrive at standard protocols can be challenging.

Several reviews attempt this comparison, although many have significant differences between the two patient cohorts, which make their results uncertain. In one review, multiple tumor types were evaluated and compared with open and minimal invasive approaches.[70] The results were notable for craniopharyngiomas, clival chordomas, esthesioneuroblastomas, and giant pituitary adenomas endonasal endoscopic approach resulting in higher rate of GTR for endoscopic approaches.[70] Open cranial procedures had a higher GTR for meningiomas.[70] CSF leaks, however, were higher in patients recovering from endoscopic surgery.[70] Interestingly, one study reviewing skull base meningiomas notes that the use of the endoscope allowed further visualization of tumor that a microscope could not see in 65% of patients.[30] GTR was noted in 76% cases and near total resection in the remaining 24%.[30] Another study in which minimally invasive technique was used for craniopharyngiomas reports 91% of patient received gross total or near total resection.[31] For chordomas GTR was reported in 66.7% in a series of 60 patients; however, this rate improved to 88.9% in the later years of the study, giving evidence the importance of experience with minimally invasive approaches.[50]

A literature review comparing only open transcranial versus transsphenoidal craniopharyngiomas showed that the endoscopic study had greater rate of total resection and improved postoperative visual outcome.[71] However the rate of CSF leak was higher in the endoscopic group (18%) versus in the transcranial group (3%).[71] Two smaller studies retrospectively reviewed the experience with endoscopic approaches to the suprasellar tumors through transtuberculum and transplanum sphenoidale approaches.[72,73] In these studies, the incidence of postoperative CSF rhinorrhea was 15% to 25%. This rate was decreased with the use of vascular flaps instead of mucosal free grafts. The rate of GTR was greater than 80%.

Another meta-analysis that reviewed 379 patients with esthesioneuroblastoma resulted in a Kaplan-Meier analysis that showed improved survival with endoscopic resection compared with open craniofacial resection (hazard ratio, 3.56; 95% CI, 1.61–7.91), with similar follow-up in the endoscopic and open groups (54.5 vs 51.0 months).[74]

Finally, in a review of over 800 endoscopic endonasal cases, the mortality rate was 0.9% and the rate of permanent neurologic deficit was 1.8%.[64] In total, these studies, although well short of Level 1 evidence, support the notion that minimally invasive approaches performed by experienced surgeons are safe and provide benefit with the correct patient selection.

## PREVENTION OF COMPLICATIONS

In addition to CSF leak, another challenging complication during minimally invasive anterior skull based surgery is hemostasis.[28] One possibility to improve control in vascular tumors is to obtain an angiogram with embolization preoperatively. During surgery, attempting to ligate the tumor from the dural attachment quickly and ligate feeding ethmoidal arteries decreases heavy bleeding.[28] Hemostasis can also be eased by reducing high venous pressure by changing the patient's position and the ventilator settings. Another recommendation is to use a diamond drill tip, which acts with more hemostatic effect when removing bone.[28] If major vascular injury does occur during surgery, packing or clipping is typically used to bridge the patient to the neurovascular suite for angiogram and possible interventional repair. Using a micro-Doppler to identify vasculature structures—specifically, the position of the carotid—helps with navigation intraoperatively.

Postoperative infections, including bacterial meningitis, tend to have a low incidence of 1% to 2%.[60,61,64] This has been attributed to the use of perioperative antibiotics, frequent irrigation intraoperatively, careful reconstruction with vascularized flaps, and no need for nonbiodegradable materials left at the completion of the surgery.[61] Risk factors for infection include male sex, complex tumors, presence of an external ventricular drain or shunt, and postoperative CSF leak.[60]

### *Difficult Patients*

Pediatric patients have smaller nares and allow less room for instrumentation. However, children over the age of 4 typically have enough room for these procedures.[61] Also patients with decreased sinus pneumatization, including pediatric patients, have more difficult anatomy to navigate intraoperatively. Neuronavigation is of the utmost importance for cases like these.[61]

## SUMMARY

Application of instruments from endoscopic sinus surgery to skull base tumors has allowed neurosurgeons and otolaryngologist to perform minimally invasive resection of malignant tumors in the anterior skull base for the past decade. Minimally invasive approaches reduce the need for more extensive surgical approaches, which allows less soft tissue manipulation and brain tissue exposure, shorter recovery times, and offers a better cosmetic result. Surgical planning includes determining the target, entry point, and corridor with the least amount of vascular and neural manipulation. Not all tumors, given their size, invasion, and locations are amenable to these minimally invasive approaches; therefore, patient selection is critical. The use of minimally invasive approaches, especially when coupled with endoscopy, is best when both neurosurgeon and otolaryngologist work and learn together while understanding their limitations. Minimally invasive anterior skull base approaches continue to gain acceptance as a safe and effective approach to remove malignant lesions. Further randomized, controlled studies are needed to investigate and confirm the many benefits this approach has to offer.

## SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.nec.2012.08.001.

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