Zones of Approach for Craniofacial Resection: Minimizing Facial Incisions for Resection of Anterior Cranial Base and Paranasal Sinus Tumors

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OBJECTIVE: Anterior cranial base tumors are surgically resected with combined craniofacial approaches that frequently involve disfiguring facial incisions and facial osteotomies. The authors outline three operative zones of the anterior cranial base and paranasal sinuses in which tumors can be resected with three standard surgical approaches that minimize transfacial incisions and extensive facial osteotomies.

METHODS: The zones were defined by performing dissections on 10 cadaveric heads and by evaluating radiographic images of patients with anterior cranial base tumors. The three approaches performed on each cadaver were transbasal, transmaxillary, and extended transsphenoidal.

RESULTS: Three zones of approach were defined for accessing tumors of the anterior cranial base, nasal cavity, and paranasal sinuses. Zone 1 is exposed by the transbasal approach, which is limited anteriorly by the supraorbital rim, posteriorly by the optic chiasm and clivus, inferiorly by the palate, and laterally by the medial orbital walls. This approach allows access to the entire anterior cranial base, nasal cavity, and the majority of maxillary sinuses. The limitation imposed by the orbits results in a blind spot in the superolateral extent of the maxillary sinus. Zone 2 is exposed by a sublabial maxillotomy approach and accesses the entire maxillary sinus, including the superolateral blind spot and the ipsilateral anterior cavernous sinus. However, access to the anterior cranial base is limited. Zone 3 is exposed by the transsphenoidal approach. This approach accesses the midline structures but is limited by the lateral nasal walls and intracavernous carotid arteries. An extended transsphenoidal approach allows further exposure to the anterior cranial base, clivus, or cavernous sinuses. The use of the endoscope facilitates tumor resection in the nasal cavity and paranasal sinuses.

CONCLUSION: The operative zones outlined offer minimally invasive craniofacial approaches to accessing lesions of the anterior cranial base and paranasal sinuses, obviating facial incisions and facial osteotomies. Case illustrations demonstrating the approach selection paradigm are presented.

KEY WORDS: Anatomic study, Anterior cranial base, Cranial base surgery, Craniofacial surgery, Minimally invasive, Skull base surgery

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Combined craniofacial approaches have been the standard surgical treatment for resecting lesions that involve the anterior cranial base, nasal cavity, and paranasal sinuses (1, 5, 6, 25, 26, 39, 41). Lesions treated with craniofacial resection commonly include malignant tumors of the sinuses and the anterior cranial base such as squamous cell carcinoma, adenocarcinoma, adenoid cystic carcinoma, chondrosarcoma, and esthesioneuroblastoma. Benign tumors, such as angiofibroma, meningioma, and inverting papilloma, as well as infectious processes, can also be treated with this approach.

Traditionally, this procedure is performed by a team of neurosurgeons and otolaryngologists and involves two steps: 1) a bifrontal craniotomy from above and 2) a transfacial approach from below. The transfacial approach often involves invasive techniques, such as extensive facial incisions, midfacial degloving, and facial disassembly, requiring facial incisions and facial osteotomies (14, 31). Lateral rhinotomy, removal of the frontonasal unit, Le Fort I and II osteotomy, and splitting of the maxilla have been described as means of accessing lesions of the anterior cranial base (13, 15, 25, 34). Janecka et al. (16) described the facial translocation approach, which also involves an extensive facial incision and facial disassembly to access tumors in the anterior cranial base, cavernous sinus, clivus, and infratemporal fossa.

Although these approaches provide wide exposure for complete tumor removal, the cosmetic result may be disfiguring and unsatisfactory. Blacklock et al. (3) reported a series of nine patients who underwent resection of anterior cranial base tumors via a bifrontal craniotomy without use of facial incisions. However, this approach has its limitations in resecting tumors that reside beneath the orbits in the superolateral aspect of the maxillary sinuses. In this study, we used three surgical approaches to define operative zones of exposure that potentially allow access to tumors of the anterior cranial base and paranasal sinuses while avoiding facial incisions or extensive facial osteotomies. Using the zones of exposure, we describe our approach selection paradigm with several case illustrations.

MATERIALS AND METHODS

Surgical dissections were performed on 10 embalmed cadaveric specimens. Three standard approaches were performed on each cadaver: transbasal, transmaxillary, and transsphenoidal. Microsurgical techniques and metric measurements were conducted under a Zeiss OPMI 1 FC microscope (Carl Zeiss, Oberkochen, Germany) and documented with a Nikon Coolpix 990 camera (Nikon, Inc., Melville, NY). A Midas Rex drill (Medtronic Midas Rex, Fort Worth, TX) was used for all bone drilling. The operative zones of access and their limitations were defined for each approach.

Standard Transbasal Approach

The standard transbasal approach, as popularized by Derome (9), is the mainstay of the intracranial component of craniofacial resection and has been well described in the literature (2, 3, 6). In the supine position, the head is elevated 10 to 15 degrees to facilitate venous drainage and extended to minimize frontal lobe retraction. A bicoronal incision is made, and the scalp is reflected forward. Laterally, dissection is immediately superficial to the temporalis fascia, avoiding injury to the frontal branch of the facial nerve as it is reflected with the scalp flap. When reflecting the scalp flap forward toward the orbital ridge, care should be taken to avoid damaging the supraorbital arteries that nourish the scalp and the pericranial flap. Next, a bifrontal bone flap is raised. Bilateral burr holes are made at the keyhole to allow visualization of the floor of the anterior cranial fossa above the orbit. A low cut just above the floor provides maximal exposure with minimal bifrontal lobe retraction. Bilateral burr holes can be placed adjacent to the sagittal sinus to straddle the sinus and separate it from the bone under direct vision to avoid disruption of the sinus by the craniotome. Once the bone flap is removed, dissection proceeds extradurally or intradurally along the floor of the anterior cranial fossa and can be extended posteriorly to the planum sphenoidale.

From this exposure, osteotomies are made through the ethmoid bone unilaterally or bilaterally and across the midline anterior to the cribriform plate and posteriorly across the planum sphenoidale with a high-speed drill, depending on the goals of surgery. The frontal sinus is usually exenterated and cranialized. The nasopharyngeal cavity, sphenoid sinus, and clivus inferiorly will be exposed. The perpendicular plate of the ethmoid bone, nasal septum, and turbinates may be removed to allow access into the maxillary sinuses. At this juncture, an extended transbasal approach can be performed by removing the supraorbital bar and unroofing the orbits and by removing the anterior clinoid processes with a high-speed drill. This option allows for an increased superior to inferior viewing trajectory of the clivus with less frontal lobe retraction. The pericranium is carefully dissected from the galea for subsequent reconstruction of the anterior fossa at the time of closure.

Transmaxillary and Combined Transmaxillary-transsphenoidal Approach

The transmaxillary approach used in this study has been described in previous publications by the senior author (WTC) (8, 33). An initial sublabial incision is made extending from the lateral incisor to the second or third molar. The soft tissue is then dissected superiorly to expose the anterior wall of the maxilla up to the level of the infraorbital nerve and artery and laterally to the anterior tip of the zygomatic arch. With a high-speed drill, an anterior maxillotomy bone flap is created from the level of the infraorbital nerve down to the superior alveolar ridge. The frontal process of the maxilla is carefully removed to allow adequate visualization into the maxillary antrum. The course of the infraorbital nerve (terminal branch of the maxillary branch of the trigeminal nerve) is dissected posteriorly along the roof of the maxillary sinus into the pterygopalatine fossa. The posterior wall of the maxillary sinus is removed to expose the pterygopalatine fossa.

The maxillary nerve as it emerges from the foramen rotundum is then identified. The foramen rotundum is drilled out posteriorly and superomedially to the level of the superior orbital fissure to allow access to the anterior cavernous sinus if desired.

To perform the combined transmaxillary-transsphenoidal approach, after the cranial nerves entering the superior orbital fissure have been safely identified, the lateral and posterior wall and septum of the sphenoid sinus are drilled out. This exposes the sellar and infrasellar region (33). The medial wall of the maxillary sinus may also be removed to enter the nasal cavity to offer a wider region of exposure to the nasopharynx if desired.

Extended Transsphenoidal Approach

The standard sublabial transsphenoidal approach has been well described (7, 23, 27, 42). In the past decade, the sublabial transsphenoidal approach has undergone further modifications. Regions of the cranial base that were once thought to be accessible only transcranially, such as the cavernous sinus and suprasellar cistern, now can be approached by use of extended transsphenoidal approaches (7, 10–12, 18, 19, 22, 29, 33).

Access to the anterior cranial base is facilitated by slight extension of the patient's head and manipulation of the speculum to point more superiorly. The bony resection of the sellar floor is extended superiorly to remove bone of the tuberculum sellae to expose the anterior cranial base. Initially, a small amount of bone over the anterior sellar wall is removed to expose the anterior circular sinus. The bony removal is then extended rostrally with microrongeurs. The circular sinus, which demarcates the anterior extension of the sella, should not be compromised during the bone removal. Once the tuberculum sellae has been removed, the dura anterior and inferior to the circular sinus is opened. The sinus is then coagulated and transected to gain a direct view of the suprasellar cistern while preserving the pituitary in its position.

The extended transsphenoidal approach can also be used to access lesions of the clivus. Exposure is obtained by slightly flexing the patient's head and repositioning the Hardy nasal speculum to point inferiorly toward the upper portion of the clivus. Additional exposure of the mid and lower clivus requires a more inferior trajectory. The posterior wall and floor of the sphenoid sinus are removed with rongeurs and a high-speed drill. During tumor resection, caution is taken to stay in the extradural plane to avoid damage to the basilar artery or disruption of the arachnoid, resulting in cerebrospinal fluid (CSF) leakage.

The bony removal may be extended laterally to expose the cavernous sinus, including the dura overlying the carotid grooves. The lateral extent of the bony removal is delineated by the cavernous cranial nerves. After the bony removal, the dura medial to the internal carotid artery is first incised with a No. 11 blade. The incision is then extended with curved alligator microscissors. Removal of intracavernous tumor is performed with ringed curettes. Any venous bleeding can be controlled by gentle packing with Surgicel (Ethicon, Inc., Somerville, NJ).

RESULTS

Three operative zones for accessing the anterior cranial base and paranasal sinuses were defined in cadaveric heads by use of the above-described approaches (*Fig. 1*). Zone 1 was exposed by the transbasal approach, which allows access to the entire anterior skull base, nasal cavity, ethmoid sinuses, sphenoid sinus, clivus, and the majority of the maxillary sinuses (*Fig. 2*). The average distance from the anterior skull base (at the coronal plane of the orbits, *Fig. 3A*, *Table 1*) to the anterolateral extent of the floor of the maxillary sinus was 71 mm. The average distance from the anterior skull base (at the coronal plane of the sphenoethmoid junction, *Fig. 3B*, *Table 1*) to the posterolateral extent of the floor of the maxillary sinus was 65 mm. The average distance from the anterior skull base (at the coronal plane of the sella, *Fig. 3C*, *Table 1*) to the posterolateral aspect of the floor of the sphenoid sinus was 34 mm. The transbasal approach is limited anteriorly by the nasal bones and supraorbital bar, posteriorly by the optic chiasm and clivus, inferiorly by the palate, and laterally by the medial orbital walls. The limitation imposed by the orbits results in a blind spot in the superolateral extent of the maxillary sinus. An extended transbasal approach allows for an increased superior to inferior viewing trajectory and improved exposure of the upper clivus with minimal frontal lobe retraction.

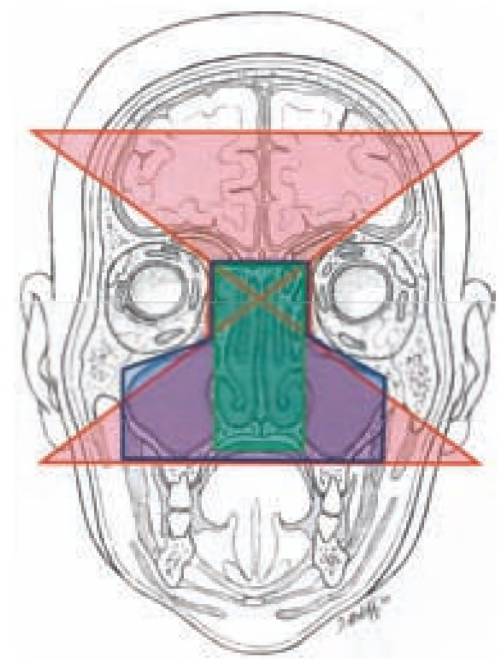

FIGURE 1. *Diagram outlining the three operative zones of exposure for craniofacial resection. Zone 1* (red) *is exposed by the transbasal approach. Zone 2* (blue) *is exposed by the transmaxillary approach. Zone 3* (green) *is exposed by the transsphenoidal approach.*

Zone 2 was exposed by the sublabial transmaxillary approach and accessed the entire maxillary sinus, including the superolateral blind spot and the ipsilateral anterior cavernous sinus (*Fig. 4*). Removal of the posterior wall of the maxillary sinus exposes the pterygopalatine fossa. Removal of the medial wall allows access into the nasal cavity. Further removal of the lateral and posterior wall and septum of the sphenoid sinus further exposes the sellar and infrasellar region, as well as the medial aspect of the contralateral cavernous sinus. In addition, a total ethmoidectomy can be performed through this maxillotomy, especially with the aid of an endoscope. This transmaxillary approach can be performed bilaterally for paranasal sinus disease that extends laterally into both maxillary sinuses. However, access to the intracranial space is limited. Because the transmaxillary approach has an oblique

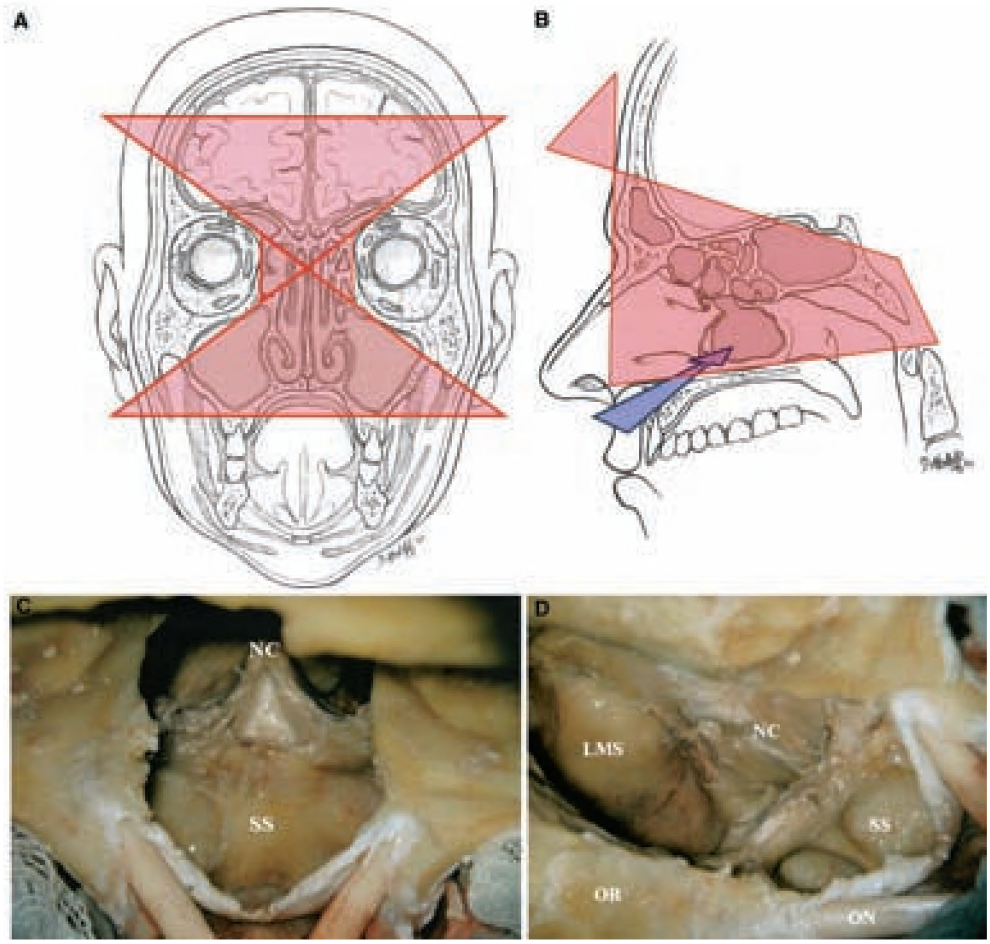

FIGURE 2. A *and* B, *diagrams. Zone 1* (red), *exposed by the transbasal approach, accesses the entire anterior cranial base, the nasal cavity, and the majority of the maxillary sinuses. The blind spots are located in the superolateral recesses of the maxillary sinuses and the most anterior portion of the nasal cavity.* A, *coronal view of Zone 1.* B, *lateral view of Zone 1. The* blue arrow *represents the oblique trajectory of the transmaxillary approach (Zone 2).* C *and* D, *cadaveric dissections.* C, *transbasal exposure in a cadaver head demonstrating visualization of the nasal cavity* (NC) *and sphenoid sinus* (SS). D, *visualization of the left maxillary sinus* (LMS) *can be achieved by pointing the microscope medially to laterally.* OR, *orbital roof;* ON, *optic nerves.*

trajectory, it may be more difficult to access midline structures in the most superior and inferior extent (tuberculum sellae and inferior clivus). However, this can be overcome by incorporating Zone 3 with Zone 2 (combined transmaxillary/extended transsphenoidal approach).

Zone 3 was exposed by the transsphenoidal approach and accessed the midline structures (*Fig. 5A*). The extended transsphenoidal approach allows further exposure to the anterior skull base, suprasellar cistern, clivus, and cavernous sinuses (*Fig. 5B*). The anterior communicating artery complex and the optic nerves can also be visualized superiorly. The standard transsphenoidal approach is limited laterally by the lateral nasal walls, the piriform aperture, and the intracavernous carotid arteries. An extended transsphenoidal approach is limited superiorly by the suprasellar cistern and optic apparatus and inferiorly by the inferior clivus and foramen magnum. This approach is best suited for accessing midline structures but would be limited in removal of tumors that extended laterally into the maxillary sinuses or superolaterally in the intracranial cavity.

Illustrative Cases

Patient 1

A 30-year-old man from Pakistan presented with chronic sinusitis, diplopia, and proptosis of the right eye. Radiographic imaging revealed extensive fungal sinus disease involving the frontal, ethmoid, sphenoid, and maxillary sinuses, with orbital compression and erosion of the anterior cranial base (*Fig. 6*). A combined minimally invasive craniofacial approach was used. First, a bifrontal craniotomy was performed to remove inspissated fungal material within the frontal sinuses and to directly decompress the orbit. Greenish, caseous material was identified and resected. The frontal sinuses were exenterated and cranialized, and the deformed right orbital roof was removed to relieve the proptosis. Then, a bilateral Caldwell-Luc procedure was performed through a sublabial incision. Endoscopically, a total ethmoidectomy, polypectomy, and turbinectomy were performed through the sublabial maxillotomies and endonasal exposure. All the fungal material and polypoid disease were removed, and the involved areas were copiously irrigated. A pericranial flap was fashioned and sutured into the base of the dura along the anterior cranial base. The brain had not been separated from the region of the cribriform plate, and there was no evidence of a CSF leak. The patient achieved an excellent surgical outcome, with complete resolution of proptosis without the use of a facial incision or facial disassembly.

Patient 2

A 74-year-old man presented with nasal obstruction secondary to a recurrent esthesioneuroblastoma involving the nasopharynx and extending up to the anterior cranial base (*Fig. 7*). A magnetic resonance imaging (MRI) scan also revealed a frontal sinus mucocele. The patient underwent a combined craniofacial approach without a facial incision to remove the tumor and mucocele. By use of an endoscopic transnasal approach, the nasopharyngeal mass was removed completely from below. Then, from above, a standard transbasal approach was performed for resection of the mucocele and exenteration and cranialization of the frontal sinuses. The anterior cranial base defect was repaired with a fascia lata graft and pericranial flap.

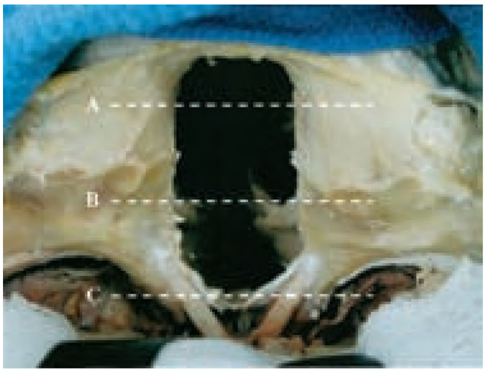

FIGURE 3. *Illustration of locations where measurements of the transbasal exposure were made in the following coronal planes:* A, *orbits;* B, *sphenoethmoid junction; and* C, *sella. Refer to* Table 1 *for measurements.*

Patient 3

A 53-year-old woman presented with left orbital proptosis secondary to a basal-squamous cell carcinoma of the paranasal sinuses involving the anterior cranial base and left medial orbit (*Fig. 8*). A standard transbasal approach was performed to achieve a gross total resection of the anterior cranial base tumor, which had also invaded the dura and the left frontal lobe. The anterior cranial base was drilled out on the left for orbital decompression. The tumor did not invade the medial wall of the left orbit but merely displaced the periorbita. Thus, clean margins were achieved, and orbital exenteration was not indicated. Removal of the tumor from the ethmoid sinus, sphenoid sinus, maxillary sinus, and nasal cavity was achieved entirely from above, obviating a transfacial incision. After the tumor was completely extirpated, the hard and soft palate and the maxillary sinus were clearly visualized. The cranial base defect was repaired with a fascia lata graft and a vascularized pericranial flap.

Patient 4

A 75-year-old man presented with worsening proptosis and periorbital edema of the left eye secondary to a squamous cell carcinoma of the paranasal sinuses. An MRI scan revealed an enhancing lesion, eroding through the left medial orbital wall and extending superiorly into the anterior cranial base and inferiorly into the maxillary sinus (*Fig. 9*). The patient underwent a transbasal approach to remove the tumor extradurally in the anterior cranial fossa. Next, the left orbit was exenterated. Through the orbital defect, a left total ethmoidectomy and a total maxillectomy were performed. Because of tumor invasion into the anterior cavernous sinus, a grossly clear margin was not achieved. The cranio-orbitomaxillary defect was repaired with a pericranial flap supplemented with a free vertical rectus abdominus myocutaneous flap.

Patient 5

A 46-year-old woman presented with nasal obstruction. An MRI scan revealed an anterior cranial base mass extending into the paranasal sinuses between the orbits (*Fig. 10*). The tumor also involved the sphenoid sinus and clivus. The patient underwent a transbasal approach for removal of a clear cell chondrosarcoma. The tumor was entirely extradural and had eroded through the anterior cranial base, involving the paranasal sinuses and clivus. Because most of the tumor was in the midline between the orbits, the resection was achieved entirely from above through the transbasal exposure. The anterior cranial base defect was reconstructed with a fascia lata graft and a vascularized pericranial flap. There was no CSF leak after surgery.

Patient 6

A 37-year-old man presented with an enhancing, expansile mass within the sphenoid sinus extending into the posterior ethmoid sinuses and inferiorly into the nasopharynx with osseous erosion of the clivus (*Fig. 11*). There was no evidence of disease extension into the intracranial cavity. The patient underwent an endonasal endoscopic/extended transsphenoidal approach with stereotactic guidance for resection of an adenoid cystic carcinoma of the cranial base. Initially, anterior and posterior ethmoidectomies were performed, revealing tumor in the left posterior ethmoid sinus. Then, a sphenoidotomy was performed, and tumor was removed from the sphenoid sinus and clivus. The tumor had eroded through the sellar floor and was adherent to the sellar dura. The involved dura was removed endoscopically, and a CSF leak was noted. The sella was reconstructed with fascia lata and fat harvested from the thigh, and a lumbar drain was placed after surgery. The drain was removed on the second day after surgery, and there was no subsequent CSF leak. Negative margins for tumor were achieved on frozen sections; however, one of the permanent sections revealed tumor at the superior nasopharyngeal margin. This was subsequently removed endoscopically at a second operation.

Patient 7

A 12-year-old boy presented with a 6-month history of nasal obstruction and epistaxis from a juvenile nasopharyngeal angiofibroma. A computed tomographic scan revealed a large, heterogeneously enhancing nasopharyngeal mass based at the sphenopalatine foramen and extending into the sphenoid sinus, filling the nasopharynx, and extending through the pterygomaxillary fissure and into the pterygopalatine fossa (*Fig. 12*). There was minimal extension into the right inferior orbital fissure, the right foramen rotundum, the right vidian canal, and the right pterygoid plate. There was no evidence of intracranial extension. The

TABLE 1. Measurements of the transbasal exposure

Coronal plane[a]	Distance from roof of orbit to	Average (mm)	Standard deviation
A. Orbits	Anterolateral floor of maxillary sinus	71	6
B. Sphenoethmoid junction	Posterolateral floor of maxillary sinus	65	7
C. Sella	Posterolateral floor of sphenoid sinus	34	7

[a] Refer to Figure 3 to visualize the coronal planes at which measurements were taken.

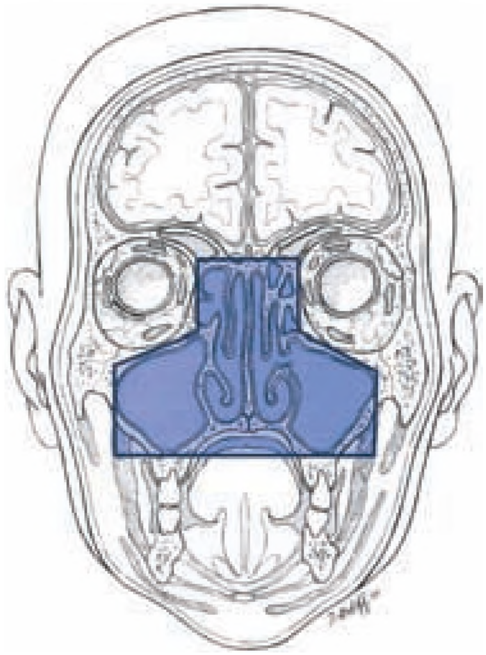

FIGURE 4. *Diagram. Zone 2* (blue), *exposed by the transmaxillary approach, accesses the entire maxillary sinuses, including the superolateral blind spot, the ethmoid sinuses, and the ipsilateral anterior cavernous sinus.*

right sphenopalatine artery was successfully embolized before surgery. Surgical approaches including a lateral rhinotomy, a Le Fort I osteotomy, and an anterior transmaxillary approach were all contemplated. Because of the size and accessibility of this lesion, a decision was made to resect this tumor through a combined transnasal and transmaxillary endoscopic approach with stereotactic guidance. Initially, an anterior ethmoidectomy and a wide maxillary antrostomy were performed to facilitate access to the pterygopalatine fossa. The posterior wall of the right maxillary sinus was removed to expose the tumor in the pterygopalatine fossa. Tumor was removed from the pterygopalatine fossa, nasal cavity, and sphenoid sinus. The remainder of the tumor was pushed down into the nasopharynx and oropharynx and was delivered transorally. The tumor was removed in its entirety endoscopically without a facial incision.

DISCUSSION

Evolution of Craniofacial Resection of Anterior Cranial Base Tumors

Combined craniofacial resection for anterior cranial base tumors has existed for more than 50 years. The first description was provided in 1943 by Ray and McLean (32), who reported a combined transcranial and transfacial resection of a retinoblastoma. This article, which pioneered the era of anterior cranial base surgery, was followed by another in 1954 by Smith et al. (36), who described the combined craniofacial techniques for *en bloc* resections of extensive paranasal sinus cancers. In the 1960s, Ketcham et al. (21) and Van Buren et al. (41) reported good survival rates in their extensive experience of *en bloc* craniofacial resections of advanced malignant tumors of the paranasal sinuses. Since then, many surgeons have made various modifications to the craniofacial approach to achieve the most effective resection (1, 25, 26, 38, 39). Although *en bloc* resection is attainable with craniofacial resection, this procedure has been associated with significant morbidity because of direct contamination of the intracranial space with the paranasal cavity (20). However, reconstruction of the cranial base defect using pericranial, galeal, temporalis, and microvascular free tissue flaps has dramatically reduced the incidence of infection (4, 17, 28, 30).

The goal of craniofacial resection is to provide the best operative exposure to allow a resection (*en bloc* resections with adequate surgical margins with malignant lesions). The surgical approach is usually achieved with a transbasal craniotomy to expose the intracranial portion, accompanied by ei-

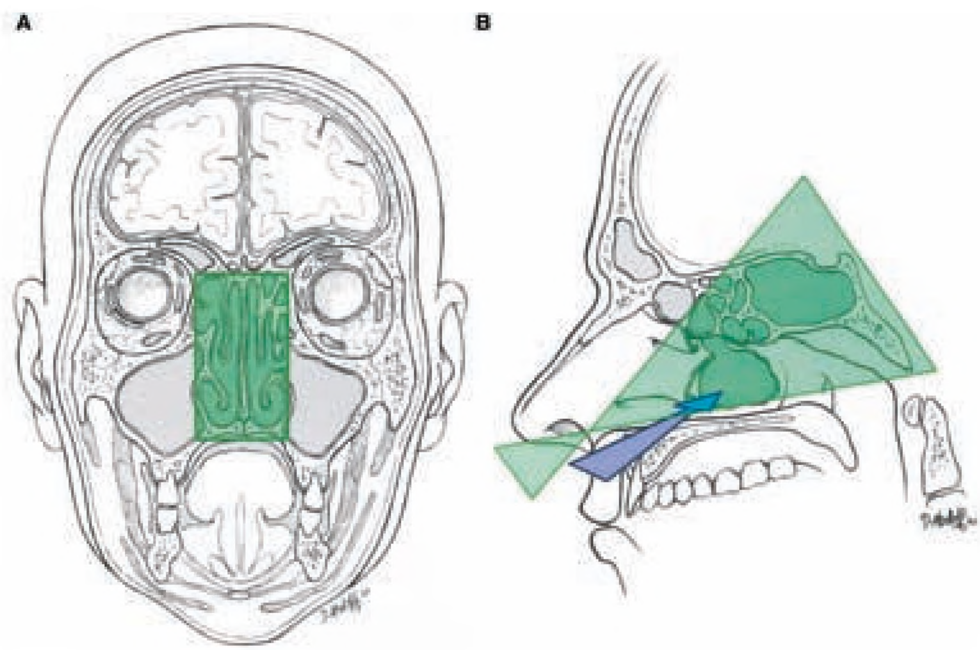

FIGURE 5. *Diagrams. Zone 3* (green), *exposed by the transsphenoidal approach, accesses the midline structures. This approach is limited by the lateral nasal walls and the intracavernous carotid arteries. A, coronal view of Zone 3. B, lateral view of Zone 3, demonstrating the areas of exposure of the extended transsphenoidal approach* (green). *The* blue arrow *represents the oblique trajectory of the transmaxillary approach (Zone 2).*

ther a lateral rhinotomy or a midfacial degloving to provide facial access to the paranasal sinuses. The most common transfacial surgical approach involves the Weber-Fergusson incision, which is invasive and may not produce a satisfactory cosmetic result. The facial soft tissues are dissected off the anterior wall of the maxilla, and the infraorbital nerve is often transected. This combined approach allows the surgeon to achieve an *en bloc* tumor resection. The initial experience by Tessier (40) in the correction of congenital craniofacial anomalies led to the development of "exposure osteotomies." His concept of facial disassembly was that facial bones could be stripped of periosteum, osteotomized, translocated, and reconstructed with good tissue survival. This concept of facial disassembly has been adopted by cranial base surgeons to improve visualization of anterior cranial base tumors (13, 25, 34, 35, 37).

Lawton et al. (24) described six transfacial approaches that used either a transfacial incision or a midfacial degloving for exposure, followed by disassembly of the facial bones to expose tumors of the anterior cranial base and clivus. Some of these facial disassemblies included removal of the frontonasal unit, removal of the frontal naso-orbital unit, a Le Fort I osteotomy with splitting of the maxilla, and a Le Fort II osteotomy with splitting of the nasomaxillary unit. Janecka et al. (16) described a facial translocation approach to the cranial base that allows exposure of the clivus, cavernous sinus, nasopharynx, and infratemporal and middle cranial fossae. This approach also involves a Weber-Fergusson facial incision and extensive bony facial disassembly.

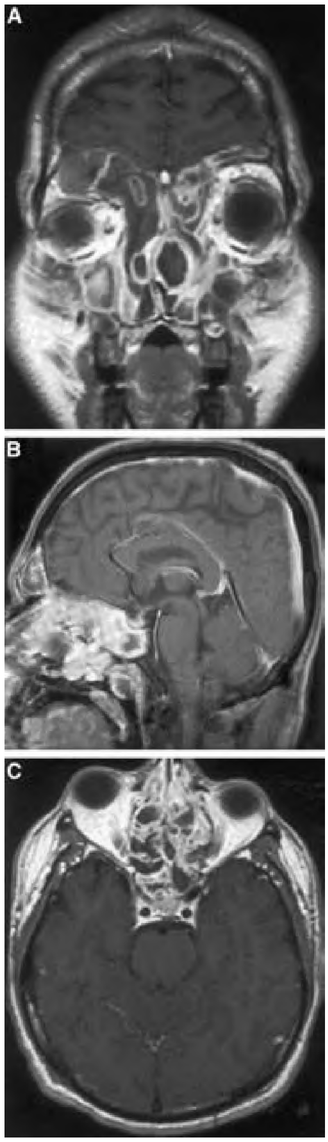

FIGURE 6. *Patient 1. T1-weighted MRI scans with gadolinium. A, coronal view; B, sagittal view; C, axial view. Allergic fungal pansinusitis with intracranial extension and right proptosis. Removal of intracranial disease and orbital decompression were performed via the transbasal approach (Zone 1). The remaining sinus disease was addressed with endoscopic resection via the endonasal route and bilateral Caldwell-Luc maxillotomies (Zone 2).*

The craniofacial approaches currently used permit excision of most anterior cranial base tumors and allow access to the anterior sphenoid, cavernous sinus, orbital apex, contiguous middle cranial fossa, and infratemporal fossa. However, the cosmetic result is often unsatisfactory. Avoidance of facial scarring and unnecessary disfiguring facial osteotomies is a desirable goal in this present era of minimally invasive surgery (31). A facial incision may not necessarily enhance the surgeon's ability to achieve complete resection of tumors of the anterior cranial base and paranasal sinuses.

Zones of Exposure: Approach Selection Paradigm

In this article, we outline three operative zones that are defined by three well-described surgical approaches: transbasal, transmaxillary, and transsphenoidal (*Fig. 1*). We also describe our approach selection paradigm with several illustrative cases. These approaches can be used alone or in combination to achieve a complete resection while avoiding extensive osteotomies of the facial bones or external facial incisions, thus resulting in a better cosmetic outcome. In some cases, the endoscope can provide additional surgical visualization of structures that may be obscured from the microscopic view, thus enhancing tumor resection without using facial incisions or osteotomies.

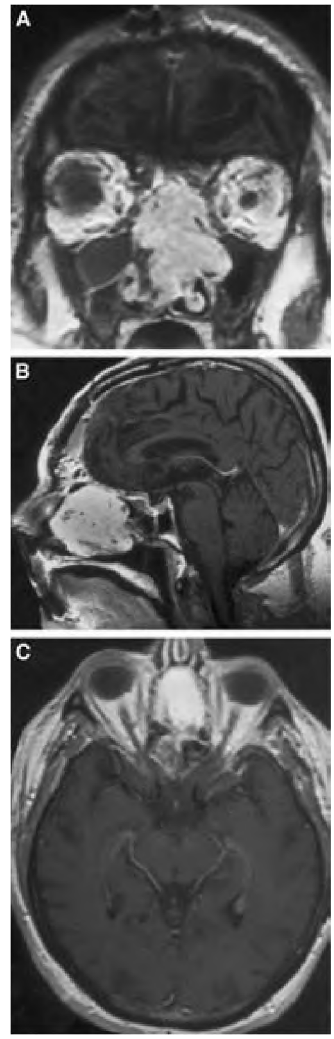

FIGURE 7. *Patient 2. T1-weighted MRI scans with gadolinium. A, coronal view; B, sagittal view; C, axial view. Recurrent esthesioneuroblastoma involving the nasopharynx. The tumor was removed via an endoscopic transnasal approach (Zone 3).*

If the location of the tumor is primarily intracranial or involves the superior orbital region, a transbasal approach is recommended. This approach has the advantage of accessing tumors involving the frontal sinus anteriorly, the optic chiasm posteriorly, and as far as the clivus inferiorly (*Fig. 2*). Decompression of the orbital roofs can be achieved from the transbasal approach, as demonstrated in Patient 1 (*Fig. 6*). Even when the intracranial tumor has extended inferiorly into the nasal cavity and laterally into the maxillary sinus, a complete resection can be achieved solely from above, as illustrated in Patients 3 and 5 (*Figs. 8* and *10*). An extended transbasal approach, which involves additional removal of the supraorbital rim, reduces frontal lobe retraction for exposure of clival lesions.

In cases in which the tumor extends beyond the line of sight into the superolateral recesses of the maxillary sinus, these "blind spots" make it more difficult to achieve a satisfactory resection. The blind spots, which are difficult to access from a transbasal approach, are located in the superolateral recesses of the maxillary sinuses and the most anterior portion of the nasal cavity (*Fig. 2*). These blind spots can be easily accessed from below by the transmaxillary and transnasal approaches. When blind spots are accessed from above, angled endoscopes (30, 45, or 70 degrees) can also be used to visualize corners that are hidden from the microscopic view, while providing excellent magnification and illumination.

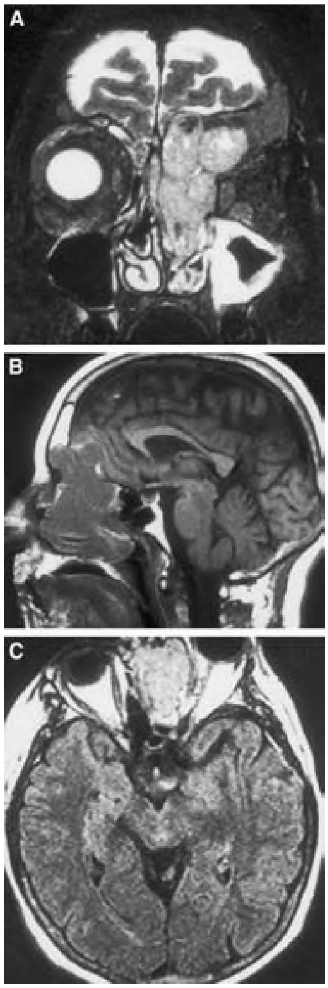

FIGURE 8. *Patient 3.* A, *T2-weighted MRI scan, coronal view.* B, *T1-weighted MRI scan, sagittal view.* C, *T2 fluid-attenuated inversion recovery (FLAIR) scan, axial view. Basal-squamous cell carcinoma of the paranasal sinuses involving the anterior cranial base and displacing the left orbit. The pericranium of the left orbit was not invaded. A transbasal approach (Zone 1) alone was performed to achieve a gross total resection.*

In cases in which an orbital exenteration is indicated, a disfiguring cosmetic outcome is unavoidable. However, the removal of the globe also allows wide surgical access to the ipsilateral maxillary sinus, and further facial incisions may be avoided, as in Patient 4 (*Fig. 9*). When tumor ablation leaves a large cranio-orbitomaxillary defect, reconstruction with a vascularized flap (free flap or pedicled myocutaneous flap) is mandatory to prevent a CSF fistula.

In cases in which the disease involves primarily the paranasal sinuses with minimal or no intracranial extension, an approach from below, either with a transmaxillary approach and/or an extended transsphenoidal approach, can be used (*Figs. 4, 5B, 11,* and *12*). Because these approaches are initiated through a sublabial incision or via an endonasal corridor, facial scars and facial osteotomies are avoided. These approaches also offer the advantage of accessing the anterior cavernous sinus without using a craniotomy.

If the tumor remains in the midline sphenoethmoid region, a midline transnasal transsphenoidal approach from below is usually adequate. In Patient 2, the esthesioneuroblastoma was midline in the paranasal sinuses and confined between the orbits (*Fig. 7*). Thus, tumor resection was achieved solely from a transnasal endoscopic approach. In Patient 6, the adenoid cystic carcinoma was also in the midline and remained entirely extracranial (*Fig. 11*). This was removed entirely via a transnasal transsphenoidal approach.

However, if paranasal sinus disease has a significant intracranial component with lateral extension across the orbits, a transbasal approach from above should be added to complete the resection. This approach is useful in cases in which superior orbital decompression is indicated, as in Patient 1 (*Fig. 6*).

For paranasal sinus disease that is more laterally situated, a transmaxillary approach can readily be used. This approach was useful in addressing the allergic fungal sinusitis from bilateral maxillary sinuses in Patient 1 (*Fig. 6*). A transnasal route can be used in conjunction with a wide maxillary antrostomy to gain access to the posterior maxillary wall and pterygopalatine fossa. This is best illustrated in Patient 7 (*Fig. 12*), in whom a juvenile nasopharyngeal angiofibroma was removed from the pterygopalatine fossa. In our experience, we have performed the majority of our transnasal/transmaxillary approaches endoscopically with stereotactic guidance (Patients 6 and 7; *Figs. 11* and *12*). This adjunct has allowed our multidisciplinary cranial base surgery team to perform resections of large tumors without using an external facial incision or degloving procedure.

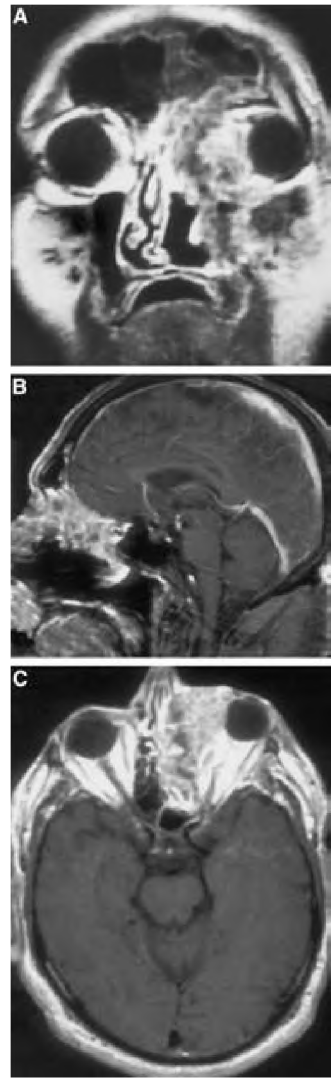

FIGURE 9. *Patient 4. T1-weighted MRI scans with gadolinium.* A, *coronal view;* B, *sagittal view;* C, *axial view. Carcinoma of the paranasal sinuses involving the anterior cranial base, left maxillary sinus, and left medial orbital wall. The tumor was resected via a transbasal approach (Zone 1) with a left orbital exenteration. Through the orbital defect, a left total ethmoidectomy and total maxillectomy were performed.*

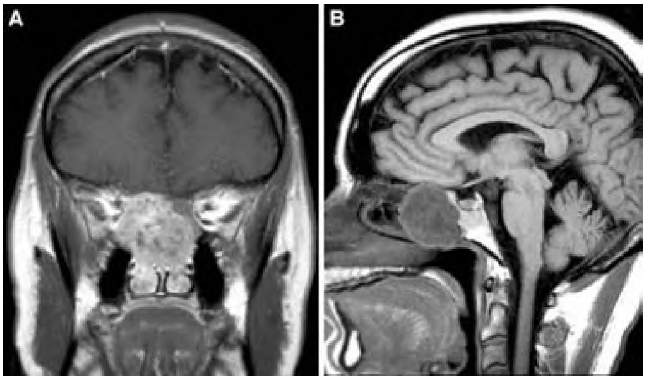

FIGURE 10. *Patient 5. T1-weighted MRI scans.* A, *coronal view;* B, *sagittal view. Clear cell chondrosarcoma of the anterior cranial base involving the ethmoid and sphenoid sinuses, clivus, and nasopharynx. The tumor was removed via a transbasal approach (Zone 1).*

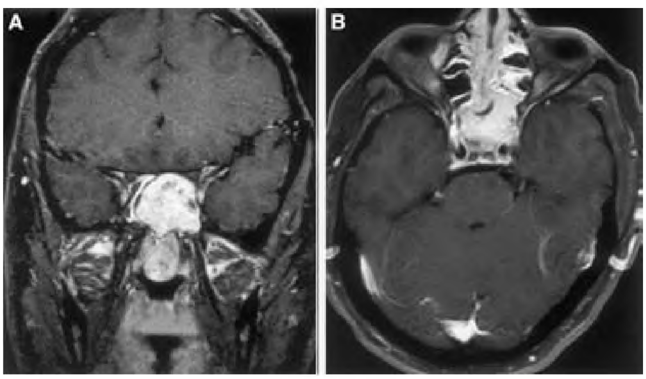

FIGURE 11. *Patient 6. T1-weighted MRI scans with gadolinium.* A, *coronal view;* B, *axial view. Adenoid cystic carcinoma of the posterior ethmoid and sphenoid sinuses. The tumor was removed entirely through a direct endoscopic transnasal transsphenoidal approach (Zone 3).*

Alternatively to the combined transmaxillary/extended transsphenoidal approach, a Le Fort I osteotomy approach can be used for midline tumors of the anterior and middle cranial base such as sinonasal malignancies and clival chordomas. This approach involves a sublabial incision with a facial degloving by elevating the mucosa and muscles from the maxillary surface superiorly. After the piriform aperture is exposed, the maxilla is osteotomized, downfractured, and disarticulated from the pterygomaxillary fissures bilaterally. The osteotomy can be readily secured with fixation plates and screws. As measured in our cranial base laboratory, the greatest width of the maxillary sinuses measured on average approximately 30 mm, and the greatest width of the piriform aperture measured on average approximately 35 mm. The Le Fort I osteotomy thus offers a wide panoramic visualization from one maxillary sinus to the other laterally and from the sphenoid sinus and sella turcica superiorly down to the lower clivus inferiorly. The combined transmaxillary/extended transsphenoidal approach (Zone 2; *Fig. 4*) (8, 33) is performed via bilateral Caldwell-Luc maxillotomies through a sublabial incision, combined with the transnasal portal.

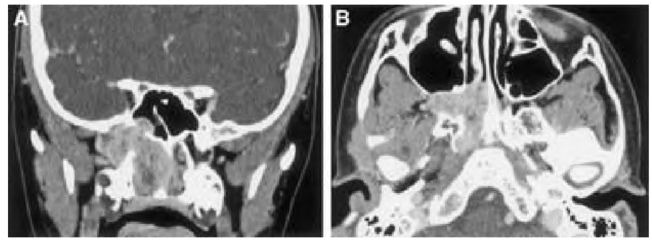

FIGURE 12. *Patient 7. Computed tomographic scans with contrast.* A, *coronal view;* B, *axial view. Juvenile nasopharyngeal angiofibroma involving the nasal cavity, pterygopalatine fossa, and sphenoid sinus. This was resected through an endoscopic transnasal and transmaxillary approach. A medial maxillary antrostomy was performed to access the pterygopalatine fossa (Zones 2 and 3).*

The sellar region, clivus, bilateral maxillary sinuses, and ipsilateral and contralateral anterior cavernous sinuses can be readily accessed. Although the visualization is clearly not as panoramic as in the Le Fort I approach, the combined transmaxillary/extended transsphenoidal approach obviates a facial osteotomy.

Endoscopic Cranial Base Surgery

The use of the endoscope has facilitated the evolution of minimally invasive surgery. Since the 1990s, endoscopic sinus surgery has virtually replaced the conventional open techniques used by otolaryngologists in treating sinonasal disorders. The excellent visualization and surgical results offered by the endoscope have expanded its use in cranial base surgery. Through the wide-angle ("fish-eye") or side-angle visualization of the endoscope, extended viewing angles allow the surgeon to "look around the corners" to examine vital structures hidden from the view of the microscope. In tumors that invade the anterior cranial base, the endoscope may serve as an adjunct to the standard bifrontal craniotomy by allowing visualization of paranasal extension into the sphenoid, ethmoid, frontal, and maxillary sinuses. From the nasal or maxillary portals described here, the endoscope allows visualization of all of the paranasal sinuses. Use of the endoscope as a supplement to the surgical approaches described can alleviate the need for any additional and unnecessary facial incisions by allowing the surgeon to observe areas hidden from the field of view of the microscope. The increased use of endoscopic guidance has limited facial incisions for tumors of the anterior cranial base with paranasal sinus extension. As the technology of endoscope optics and video systems improves, the role of endoscopic cranial base surgery will augment and supplement current microsurgical techniques.

CONCLUSION

The operative zones defined offer minimally invasive craniofacial approaches to access lesions of the anterior cranial base and paranasal sinuses, obviating facial incisions and extensive facial osteotomies.

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COMMENTS

Liu et al. describe three sectors in the anterior cranial base, each of which is reached by one of three well established surgical corridors: the transbasal, sublabial transmaxillary, and transnasal-transsphenoidal. Depending on whether the tumor is engaging one or more sectors, it may be removed by use of one or a combination of these approaches. The authors' point is that the combination of these three approaches offers access to neoplasms in the anterior cranial base, obviating facial incisions and osteotomies that may give cosmetically unsatisfactory results.

The present article is helpful in that, through cadaveric dissections and illustrative case reports, it demonstrates systematically the anatomic area that can be exposed and the blind corners of each of the three approaches. This represents a step toward standardization of the surgical corridors in this area.

When selecting an approach or a combination of approaches, we usually depend on our personal experience, which, however useful and important, represents a somewhat unsystematized and undocumented mass of information. In this context, a more detailed morphometric analysis of the approaches is useful. For instance, when speaking of the transbasal approach, it is helpful to know the exact coordinates of the blind spot of the superolateral maxillary sinus.

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On the basis of anatomic studies and supported by clinical cases, Liu et al. thoroughly analyze the exposure and the limitations of three surgical approaches: the transbasal, maxillotomy, and extended transsphenoidal. They convincingly describe the applications of these approaches in dealing with lesions located at the anterior cranial base and clivus in three different zones. The thrust of these studies is that these approaches can effectively provide access to these tumors, alleviating the need for a disfiguring facial incision or a more extensive craniofacial disassembly. This study is thorough and clear. Not only is a disfiguring facial scar avoided, but additional complications may be avoided as well.

However, the issue remains of an *en bloc* resection of a highly malignant mass, such as squamous cell carcinoma of the paranasal sinuses. The craniofacial operation is based on the principle of oncological *en bloc* removal with a margin, without touching the cancer itself, to avoid implantation or seeding. Although the authors use these approaches, they indicate that one can achieve gross removal, but it is usually associated with piecemeal removal. Highly malignant tumors usually will require adjuvant radiation. The question is whether a pure *en bloc* removal is superior, in disease control and outcome, to gross removal that involves entering the tumor. Future long-term follow-up of cases with these malignancies will provide the answer.

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Liu et al. have identified three zones in the anterior craniofacial area that can be exposed by selected modifications of the transbasal, transsphenoidal, and transmaxillary approaches. They were able to use these approaches singly or in combination to remove lesions strictly confined to the three zones in their illustrative cases. The transmaxillary approach they describe is a relatively simple one that involves opening the anterior and medial walls of one maxillary sinus. It should be noted that some lesions require more extensive osteotomies of the maxilla. An anterior wall opening is suitable for removing a tumor in the maxillary sinus and can be done through a degloving incision.

On the other hand, a number of lesions that involve this area are not strictly confined to the maxilla and paranasal sinuses but extend to the infratemporal and pterygopalatine fossae; these lesions require a wider mobilization of the maxilla than is obtained by the exposure the authors describe. Mobilizing the lower maxilla, with the adjacent hard palate, and folding the lower maxillotomy unit down into the floor of the mouth for later reconstruction provides wide access to the infratemporal and pterygopalatine fossae as well as the adjacent part of the nasal cavity, the ethmoid and sphenoid sinuses, and the clivus. The unilateral lower maxillotomy approach can be used with a degloving incision. We have described the microsurgical anatomy of this approach elsewhere (1).

The authors accurately point out that the superolateral margin of the maxillary sinuses cannot be reached by the transbasal approach. It should be noted that the lower lateral part of the orbit, located adjacent to the roof of the maxillary sinus, is another relative blind spot in the approach. The discussion suggests that one may not need to consider such approaches as the facial translocation approach, in which the upper maxilla is mobilized, or the LeFort osteotomies. However, there are lesions involving the floor of the orbit and roof of the maxillary sinus and extending through the paper-thin walls of the maxillary sinus into the pterygopalatine and infratemporal fossae that require more extensive approaches than those described in this article.

One should not gain the impression from this report that all lesions involving the anterior cranial base and paranasal sinuses can be treated by these three approaches. Selection of these procedures should be made only after a very careful evaluation of the extent of the pathology because multiple lesions may require a combination of other approaches. The extended transsphenoidal approach may not be suitable for lesions that extend out of the clivus into the temporal bone. The maxillotomy approach described may not be suitable for many lesions located predominantly in the maxilla that break into the adjacent floor of the orbit and the infratemporal and pterygopalatine fossae. Also, in applying the maxillotomy, there are numerous variants that may provide a more optimal exposure than the maxillotomy approach described here. These three approaches may be suitable for lesions that are strictly localized to the zones outlined, although even for some of the lesions described here, the exposures would not be great enough to gain tumor-free margins around the outer extent of the lesions.

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1. Hitotsumatsu T, Rhoton AL: Unilateral upper and lower subtotal maxillectomy approaches to the cranial base: Microsurgical anatomy. **Neurosurgery** 46:1416–1453, 2000.

Liu et al. present their approach selection paradigm for anterior cranial base and paranasal sinus lesions. I have to admit a bias in my review: a portion of my training in cranial base surgery derived from the two senior authors of this article. Therefore, it will come as no surprise that the approach selection paradigm is essentially what I use in my own practice with regard to these anatomic locations.

In my practice, I have found few instances when facial incisions have been useful or necessary. These situations arise especially in the case of tumors that spread to involve the superficial nasal structures. In such situations, it may be difficult or impossible to obtain a complete removal without a more proximate skin incision, which, unfortunately, sometimes must be located in a visible area on the face. Such situations have been the case in the few times when a facial incision has been necessary. Otherwise, as is well illustrated in this article, virtually any tumor of the anterior cranial base and paranasal sinus region may be adequately exposed via this paradigm. Recently, I have been impressed with the ability of my head and neck surgery colleagues to perform the essential elements of dissection at the lower pole of tumors in the paranasal sinus region through a purely endoscopic intranasal approach. When this method is combined with the transbasal approach, even very large and extensive tumors can be delivered through the anterior fossa defect created by the transbasal approach. This general strategy to approach selection will result in adequate surgical exposure in essentially every case of anterior cranial base and paranasal sinus tumor, with obvious additional cosmetic advantages.

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Liu et al. analyzed commonly performed craniofacial approaches in cadavers in an effort to evaluate the limits of visualization and dissection. They divided the surgical approaches into the three zones: Zone 1, transbasal; Zone 2, maxillary; Zone 3, a transsphenoidal approach. They describe the limitations of these approaches, particularly for more laterally situated tumors. Because many lesions are near the midline, they obviate the need for facial incisions and major facial ostectomies. Knowing the details of this approach and its limitations before surgery is clearly very important, and therefore this is a worthwhile study. This article's major strengths are in clarifying the technical details and optimizing the visualization of each of these approaches, along with clarifying how far this approach will take the surgeon. Because greater familiarity is gained with these approaches, the time of surgery is likely reduced, enhancing efficacy. These approaches, because they are less involved technically, are likely to be used for even routine tumor treatment, likely yielding greater safety as well as enhanced efficiency.

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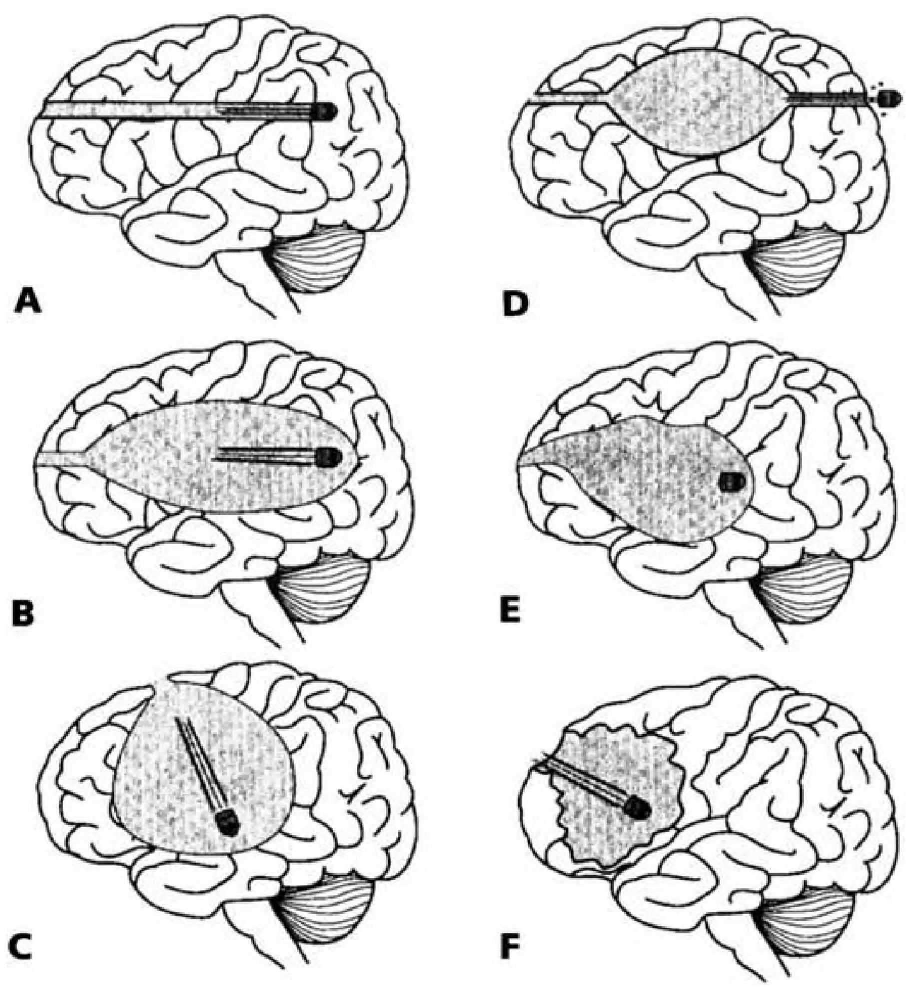

Representations of the effect of various bullet velocities on cerebral tissue. A, *low-velocity projectile, with minimal cavitation and entrance site.* B, *higher-velocity projectile, with associated cavitation. The magnitude of acceleration of tissue is outward from the cavitation.* C, *very-high-velocity projectile causing extensive cavitation associated with a small entrance site. Additionally, the exit site could be small.* D, *tissue cavitation deep within the parenchyma associated with small entrance and exit sites.* E, *asymmetric cavitation associated with deformation and tumbling of a bullet after impact.* F, *damage predicted by a very-high-velocity, small-caliber projectile with no exit wound.* (From, *Swan KG, Swan RC: Wound ballistics for the civilian surgeon.* ***Surg Ann*** *17:163–187, 1985.*)