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Surgical treatment of meningiomas

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1. ABSTRACT

Meningiomas, though benign histologically, are relatively common tumors that may behave in an aggressive, clinical fashion. Traditionally, treatment for these lesions has been primarily through surgical excision. This may be curative, but it has become clear that the degree of surgical resection achieved is a primary determinant of the rate of tumor recurrence. Often, the size and location of the lesion is a limiting factor during surgery. The following article describes general principles of surgical treatment as well as some of the pitfalls inherent in treating meningiomas in specific intracranial locations.

2. INTRODUCTION

Meningiomas are benign tumors that arise from the arachnoid cap cells of the meninges. Extra-axial in nature, they grow by progressively enlarging and displacing normal tissue and may reach a large size before coming to medical attention. While a detailed review of the epidemiology of these lesions is beyond the scope of this article, meningiomas are generally considered the most common intracranial neoplasm, with a prevalence of approximately 25 percent of brain tumors diagnosed in the United States (1). Both hormonal exposure and radiation have been implicated as contributing risk factors to their

Table 1. Simpson grading system of meningioma resection (56)

Definition	Grade
I	Macroscopically complete removal with excision of dural attachment and abnormal bone (including sinus resection when involved)
II	Macroscopically complete with endothermic coagulation (Bovie or laser) of dural attachment
III	Macroscopically complete without resection or coagulation of dural attachment or of its extradural extension (hyperostotic bone)
IV	Partial removal leaving tumor *in situ*
V	Simple decompression (with or without biopsy)

development, and they are more common in females (2,3,4). Meningiomas may be multiple in up to 8 percent of cases, most frequently in the setting of neurocutaneous disorders, such as neurofibromatosis 2 (5). They may arise throughout the neuroaxis in the intracranial and spinal regions.

Pathological and molecular studies have increased our knowledge of the biology of meningiomas. Relatively speaking, however, meningiomas have received less attention than more malignant tumors. To some degree, this represents a failure to acknowledge that, although these tumors are most often histologically benign, they can be anatomically and surgically complex and have a complicated clinical course. They are largely resistant to medical therapy and are primarily a surgical disease, as will be discussed. The rest of the review will focus on the surgical management of intracranial meningiomas.

3. SURGERY FOR MENINGIOMAS

Though radiation therapy (in particular, stereotactic radiosurgery) has recently received a great deal of attention regarding its application for the treatment of meningiomas and other benign brain tumors (6), surgical excision remains the mainstay of therapy. The degree of surgical resection remains the greatest predictor of long-term tumor control and recurrence, as correlated with the Simpson grading system (7) (Table 1). This is particularly true when the tumor is histologically benign. In cases of a gross total resection (Simpson Grade I), the recurrence rate is approximately 9.5 percent for World Health Organization (WHO) grade I tumors. This rate nearly doubles to 18 percent with a Simpson Grade II resection (8,9). In fact, patients in whom a gross total resection was not achieved had a risk of death 4.2 times greater over 15 years compared with patients in whom a Simpson Grade I resection was possible (10). Resectability depends on many factors, not the least of which is the location of the tumor and its relationship to critical neurovascular structures. In general, the first attempt at surgical resection is considered the best opportunity for achieving a complete resection, given the presence of normal anatomical planes and the absence of scar tissue.

Even histologically benign tumors may behave in an aggressive fashion clinically (11). Aggressive behavior may include local brain or bone invasion and destruction as well as rapid recurrence irrespective of surgical resection (12,13,14). It has been hypothesized that a subset of tumors exist for which the molecular and genetic makeup is more critical in determining recurrence rates than the degree of surgical resection. To date, such subsets have not yet been identified, and surgical excision remains the standard by which other therapeutic interventions must be measured. In atypical or malignant tumors, recurrence rates are substantially higher and surgical resection is less important in determining long-term patient prognosis (11).

While not meant to be comprehensive, the accompanying discussion addresses the major meningioma subtypes most commonly encountered, classified by their anatomic location. It also describes some of the potential pitfalls in their surgical management.

3.1. Anterior fossa meningiomas

Tumors in this region of the cranial vault typically arise from somewhere along the floor of the anterior cranial fossa. Because of the relative lack of eloquent structures in this region, they may reach a massive size before the diagnosis is made. Treatment can be challenging and may be even more complicated if the meningioma invades the frontal fossa floor and extends further into the skull base and sinuses. For tumors that arise along the midline structures, resection is often straightforward, as the sagittal sinus can generally be sacrificed along the anterior one-third of its course without clinical sequelae, if necessary. For this reason, a gross total resection and cure is often readily achievable.

3.2. Olfactory groove meningiomas

Meningiomas commonly arise along the olfactory groove in the midline of the frontal fossa floor (Figures 1A and 1B). These tumors typically arise over the cribriform plate of the ethmoid bone and the area of the suture connecting to the planum sphenoidale, possibly causing anosmia as a presenting symptom. As noted previously, tumors arising in this location may reach a large size prior to diagnosis. The classic presentation is described as the "Foster-Kennedy Syndrome," consisting of anosmia, ipsilateral central scotoma and optic atrophy, and contralateral papilledema (15,16), though unusual presentations have been described (17).

Olfactory groove meningiomas are supplied by blood from the anterior ethmoidal artery, and interruption of tumor feeders along the base of the tumor should be an early goal of resection. They may be approached unilaterally or through a bilateral subfrontal approach. The latter is preferred in the case of very large lesions, as it minimizes brain retraction and increases visualization of the tumor base bilaterally. Some authors have recently described endoscopic tumor resections through a minimally invasive approach, and small lesions may be amenable to such treatment (18). Alternatively, small lesions may be removed through a small supraorbital craniectomy via an eyebrow incision. Orbital osteotomies may also be used

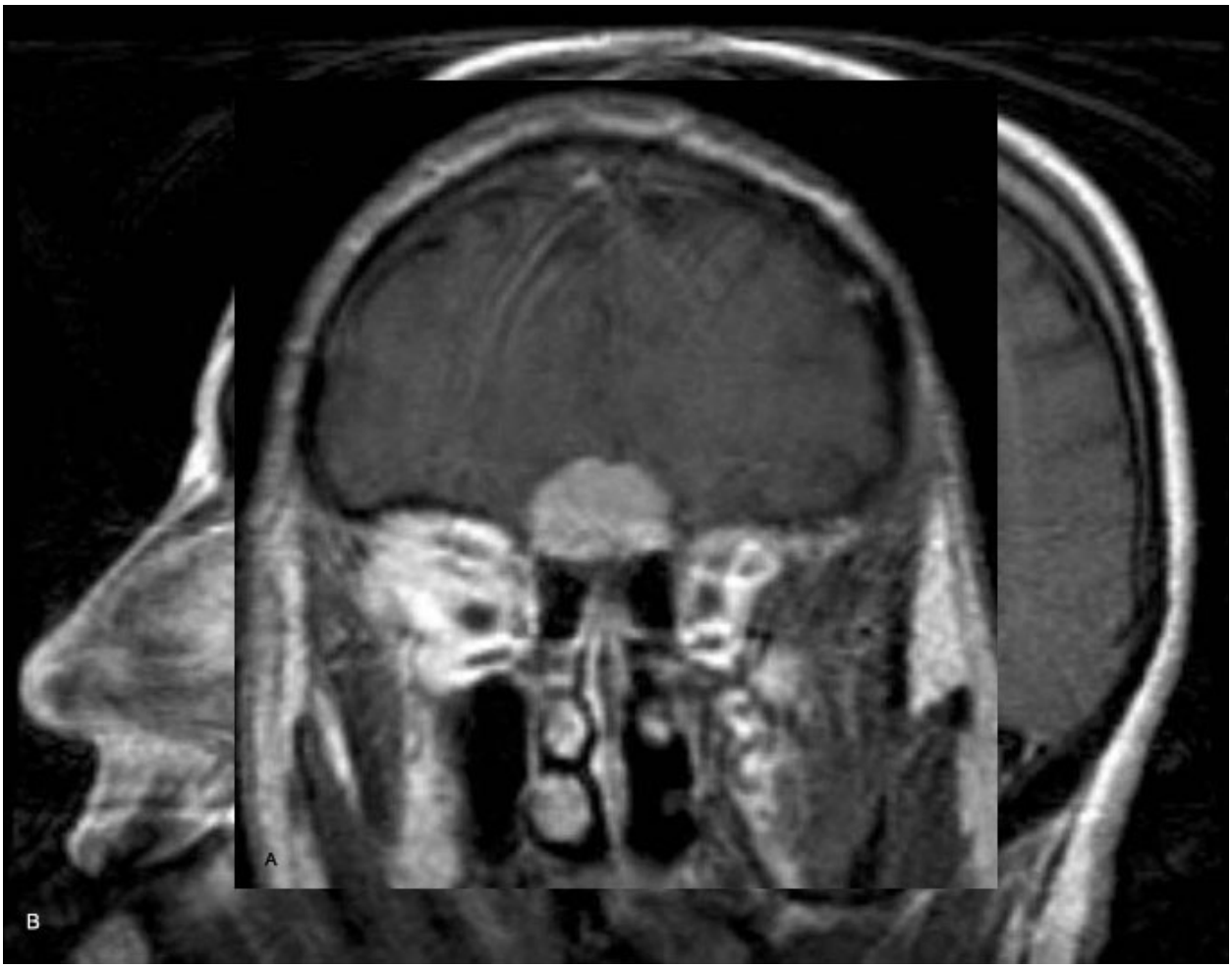

Figure 1. Coronal (A) and Sagittal (B) T1-weighted post contrast images demonstrating a typical olfactory groove meningioma. This patient presented with a generalized tonic clonic seizure.

(19). Tumor devascularization is restricted to the midline to avoid injury to the optic nerve on either side. Midline orientation is maintained by observing the falx position (15).

The importance of acute postoperative anosmia as a potentially disabling complication cannot be overemphasized. For this reason, preservation of at least one olfactory tract should be a priority, and bilateral preservation should be a goal. Other sources of complications include vascular compromise of the anterior cerebral artery branches, particularly along the posterior margin of the tumor where they may be embedded and difficult to identify. This is particularly true if they have been severely stretched and are adherent to the tumor capsule. In cases of frontal sinus violation, care must be taken to properly exenterate the mucosa. Careful packing and the use of vascularized pericranial flaps to avoid postoperative cerebrospinal (CSF) fluid rhinorrhea are important components of a meticulous wound closure (Figures 2A and 2B). If leakage does occur postoperatively, it is treated with endonasal sinus packing and CSF diversion.

3.3. Tuberculum sellae meningiomas

Tuberculum sellae meningiomas are rare, comprising only 5–10 percent of intracranial meningiomas (1,13). As the name indicates, they originate from the tuberculum sellae and its adjacent structures, usually in the midline. These include the chiasmatic sulcus and diaphragma sellae. A “chiasmatic syndrome” consisting of optic atrophy and bitemporal field cuts has been described, and these symptoms may occur anytime the lesion extends superiorly, compressing the optic nerves and tract. The bone along the anterior margin of the sellae may become exostotic in response to tumor invasion. Visual loss may be gradually progressive, though acute changes may occur. These symptoms may be aggravated by pregnancy. Often, visual recovery is significant following surgical decompression. Though endocrinologic abnormalities have been described, they are usually mild and occur later in the course of the disease, aiding in the differentiation of these lesions from primary pituitary tumors. When abnormal laboratory values are seen, they often consist of only a mild elevation in serum prolactin levels.

Because of their close relationship with the optic tracts and nerves, these meningiomas often require surgical

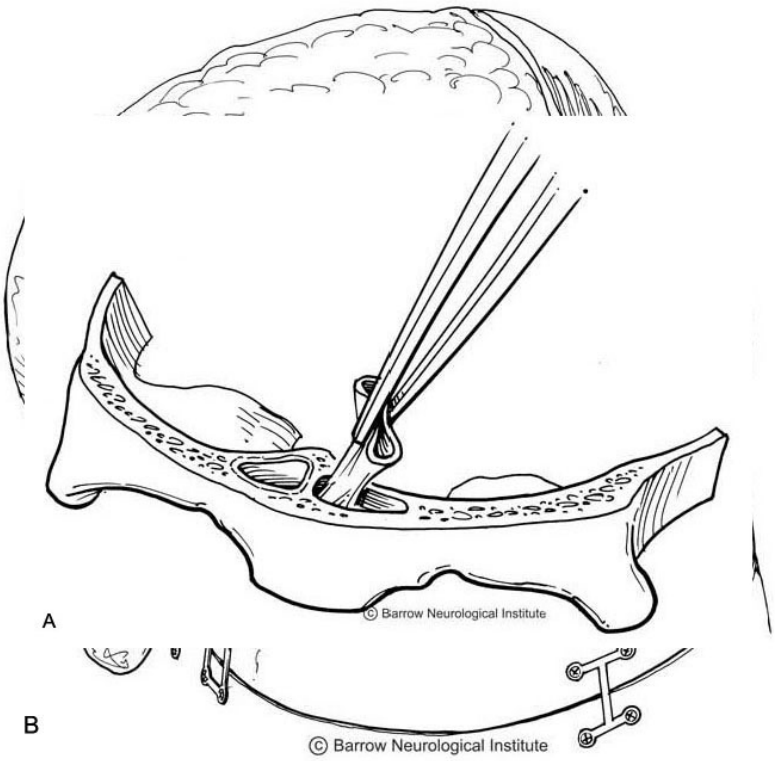

Figure 2. Graphic illustrations of the steps necessary to adequately treat violation of the frontal sinuses during surgical exposure. The sinus mucosa must be exenterated (A) and packed with a combination of muscle, fat, and gelfoam. The defect is then covered with a vascularized pericranial graft (B). Reproduced with permission from Barrow Neurological Institute.

management if symptomatic. The traditional approach has been via a unilateral pterional craniotomy (15). We advocate approaching midline tumors from the side with worse vision to limit manipulation and damage to the better optic nerve, though this is controversial. This approach may be augmented with a selective extradural anterior clinoidectomy to increase visualization while minimizing brain retraction, thereby minimizing additional damage to the optic nerve (20). Endoscopic and transtubercular transnasal approaches have also been increasingly described (6,18). Such approaches are limited by relatively high (though decreasing) incidences of complications, such as CSF rhinorrhea, and the degree of tumor resection achievable through the narrow corridor they offer is greatly dependent on tumor consistency.

3.4. Middle fossa meningiomas

Meningiomas of the middle cranial fossa represent a varied group of tumors. These may include lesions arising from either the medial or lateral wing of the sphenoid bone. When medially positioned, they may invade the cavernous sinus and its anatomical structures. Anterior clinoidal tumors are included in this group. *En plaque* tumors may extend along the entire middle cranial fossa floor and involve the convexities. These tumors may be particularly difficult to manage if they invade the skull base due to potential involvement of the cranial nerves and the carotid artery. Some modification of the orbitozygomatic craniotomy is often helpful in increasing the surgical exposure (Figure 3), and in general, the surgical avenues and techniques used to approach these lesions as a whole are similar. As with meningiomas in other locations, it is ultimately the biological behavior of the tumor that is most decisive in determining the final outcomes, particularly in cases where a complete resection is not possible. Despite similar histopathological patterns, these tumors may vary greatly in their clinical course.

3.5. Lateral sphenoid wing

These tumors arise from the pterion and grow along the Sylvian fissure (15). When large, they may extend along the convexity (Figure 4). Their major blood supply is from the middle meningeal vessels, which can usually be interrupted early in the surgical resection by identifying them at their exit from the foramen spinosum. Alternatively, angiographic embolization is an option. Careful attention to the arachnoid planes is critical during resection. Cases in which tumors are large can involve the Sylvian vessels; their preservation is a key component of a safe resection.

3.6. Medial sphenoid wing

Depending on their point of attachment, medial sphenoid wing tumors may be separable from the optic apparatus and carotid artery. Because their pedicular attachment is usually small, a complete resection can be accomplished even when tumors are very large (Figures 5A, 5B, and 5C). When extending into the cavernous sinus,

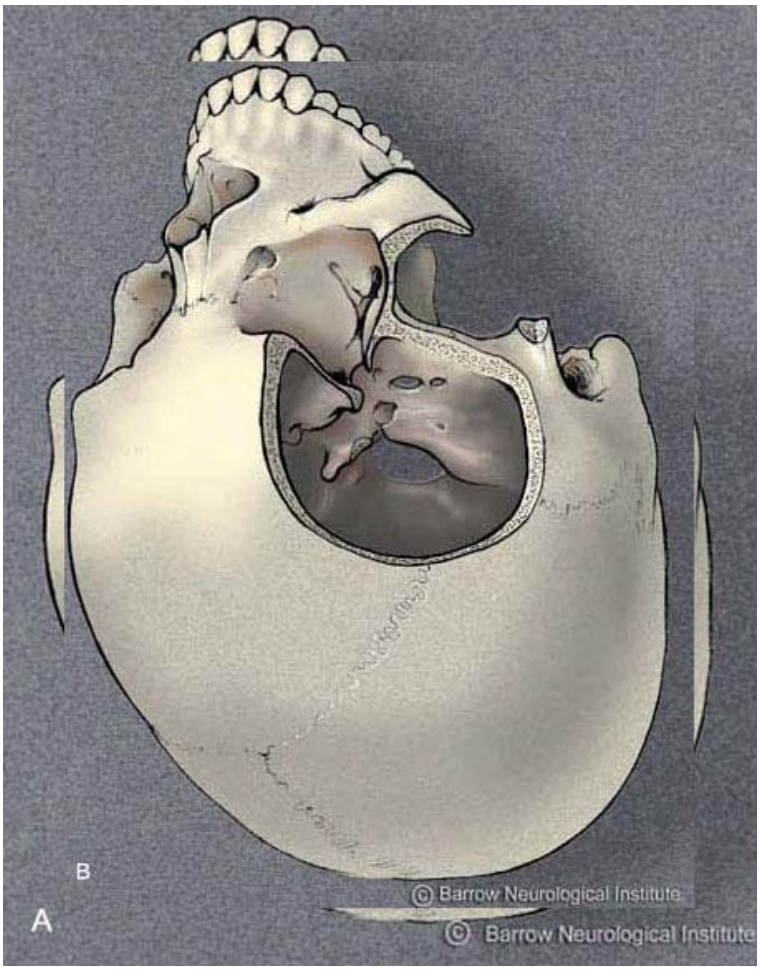

Figure 3. Graphic illustration of the bony exposure provided by a pterional craniotomy without (A) and with incorporation of an orbitozygomatic craniotomy (B). Additional bony removal of the clinoid process along the floor of the middle fossa is shaded in blue. Reproduced with permission from Barrow Neurological Institute.

their management is controversial. If a complete resection can be performed with an acceptable risk of morbidity or if severe cranial nerve deficits already exist, then it provides the greatest chance of a long-term interval of disease-free survival. Radiosurgery has evolved as a viable option for residual tumor, especially if the optic apparatus is not intimately involved or if the tumor can be surgically debulked prior to radiation treatment (12, 21). *En plaque* lesions often cannot be completely removed and are particularly well suited to adjunctive radiosurgical treatment following debulking (22).

Invasion of the middle fossa floor can pose particular difficulties, due to the potential involvement of the carotid artery in its petrous segment (Figures 6A, 6B, and 6C). If the artery is completely encased or involved with tumor and the tumor cannot be dissected away from the vascular adventitia, we favor a subtotal resection to preserve the vessel. Nevertheless, consideration can be given to carotid sacrifice with placement of a short venous bypass graft between the petrous and supraclinoid carotid artery. It must be noted that even in such cases, the time required to perform an adequate bypass often means that it provides limited benefits to those patients who can tolerate the occlusion interval required (15). If carotid sacrifice is planned and preoperative vascularization is anticipated as a requirement, then a preoperative bypass is preferable. This can be done ipsilaterally from the common or external carotid, or contralaterally via a bonnet bypass graft (23).

3.7. Midline cranial vault meningiomas

Tumors arising from the midline cranial vault structures are best characterized by their point of attachment and their proximity to the sagittal sinus. Those that arise from the dura of the convexity adjacent to the sagittal sinus are classified as parasagittal tumors. Tumors attached to the falx cerebri are termed falcine meningiomas. Either type of tumor may grow to involve the sagittal sinus, and falcine meningiomas often displace the pericallosal artery. When large, it may be impossible to distinguish these subtypes, and from a practical standpoint, it makes little difference as their surgical treatment and potential difficulties in management are similar (Figure 7) (15,24,25)

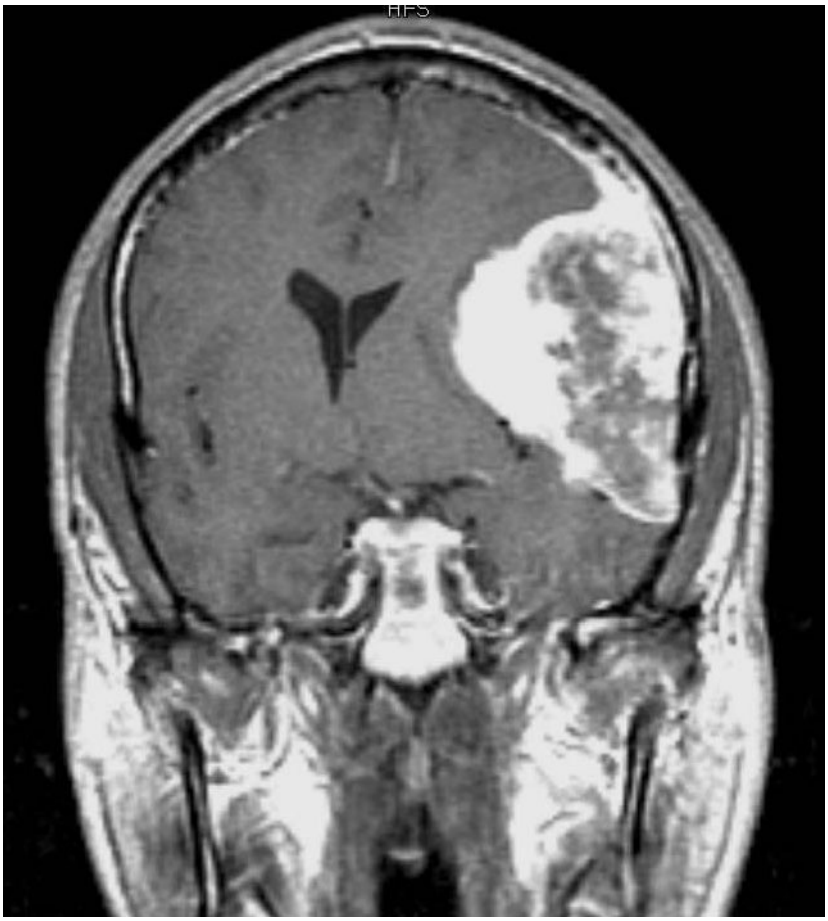

Figure 4. Postcontrast coronal MRI demonstrating a large left lateral sphenoid wing meningioma. The tumor has grown along the cerebral convexity and has produced significant displacement of the normal intracranial anatomy. Central hypointensity is noted following angiographic embolization of the middle meningeal artery supplying the tumor.

Critical in the surgical treatment of these tumors is the management of the sagittal sinus. Preoperative magnetic resonance venography or conventional angiography is helpful in assessing the patency of the sagittal sinus as well as defining the anatomy of cortical venous drainage. The anterior one-third of the sinus, extending from the floor of the frontal fossa to the coronal suture, may be sacrificed, if necessary. If the sinus is occluded, radical resection with preservation of venous drainage is preferable to subtotal resection (Figure 7). The patency of the sinus and its surrounding cortical venous drainage pattern is critical to avoiding venous infarction and postoperative neurological deficit. In a nonocclusive pattern, we favor subtotal resection with adjuvant stereotactic radiosurgical treatment, if necessary. In a retrospective review of 328 patients, Caroli and colleagues describe a recurrence rate of approximately 9 percent when following such a treatment paradigm (12). Venous grafting has a low patency rate but may be considered an option in select cases (15).

3.8. Posterior fossa meningiomas

Tumors arising in the posterior fossa pose unique challenges for surgeons because of the compact neurovascular structures that comprise the anatomy in this intracranial region. The cranial nerves in particular must be studied thoroughly in their anatomical course during the preoperative planning phase of surgical resection. Devastating complications can result from a hastily made surgical plan that does not take normal anatomic structures into consideration. Even uneventful resections can result in significant morbidity due to the fragile nature of the cranial nerves, particularly the seventh cranial nerve. Meticulous surgical technique and frequent use of intraoperative monitoring and stereotactic guidance are crucial adjuncts in complication avoidance.

It is important to visualize the lesion and surrounding eloquent structures adequately in such a way that resection can be safely undertaken. This must be weighed against the potential complications associated with each type of approach. The skull base of the posterior fossa can be exposed through multiple directions broadly classified as posterior or lateral approaches when considered in the axial plane (Figure 1A). In the sagittal plane, the options include supratentorial or infratentorial directions (Figure 1B). The simple midline suboccipital route is often sufficient for midline tumors, while lesions in the cerebellopontine angle can be adequately approached

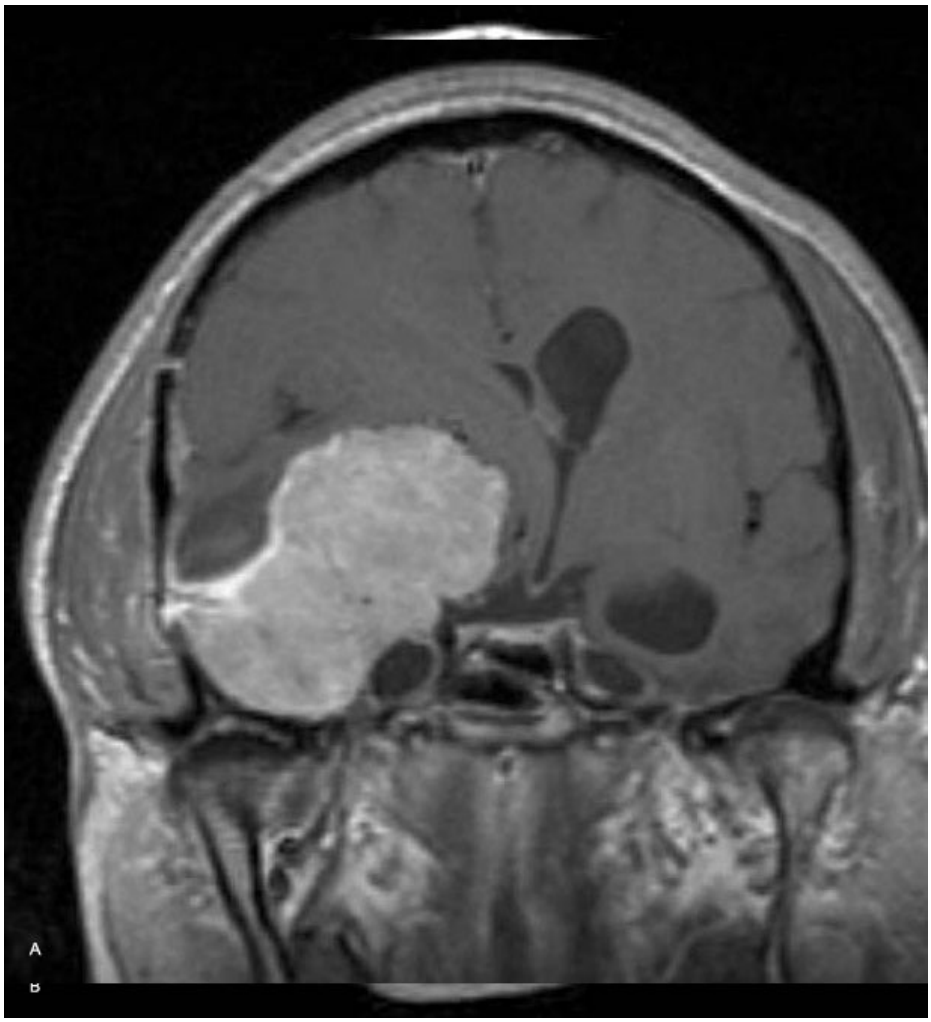

Figure 5. Large medial sphenoid wing meningioma seen on postcontrast MRI in the coronal (A) and axial (B) views. Because of its pedicular attachment lateral to the cavernous sinus and lack of bony involvement of the petrous apex, a complete resection was readily accomplished (C).

using a retrosigmoid craniotomy. In other cases, particularly when tumors are large and extensive with a supratentorial component, combinations of these approaches may allow the greatest degree of exposure. This strategy maximizes the potential for safe surgical resection of the pathology in question while limiting potential risks to the patient.

When a combined approach is utilized, some degree of petrosectomy is usually required (26). Such an extensive amount of bony removal allows maximal surgical exposure while minimizing brain retraction. This typically requires the talents of both a neurosurgeon and a neuro-otologic skull base surgeon. Combination approaches using an anterior petrosectomy and subtemporal craniotomy (Kawase's approach) (27) allow excellent exposure of the middle cranial fossa. If required, a combination of the posterior petrosectomy with a far-lateral or subtemporal approach can be performed, providing an unimpeded view of the entire cranial base from the sphenoid sinus to the foramen magnum. Likewise, a posterior petrosectomy can be combined with a far-lateral approach, subtemporal approach, or both to provide an unimpeded view of the entire cranial base from the foramen magnum to the clivus to the sphenoid sinus (26,28,29). This combined approach allows exposure of cranial nerves III through XII, the anterolateral brain stem, and the posterior fossa vasculature from the vertebral artery to the basilar apex (30).

3.9. Petroclival region meningiomas

Petroclival meningiomas represent a particularly challenging neurosurgical problem. Their deep location and proximity to eloquent neurovascular structures greatly increases the risks of surgical treatment. This remains the case, despite advances in skull base surgery that have increased the surgical safety margin associated with procedures in this region. Successful resections of even large tumors with acceptable rates of morbidity and mortality have been reported in related literature (31,32,33,34,35,36). A variety of approaches have been

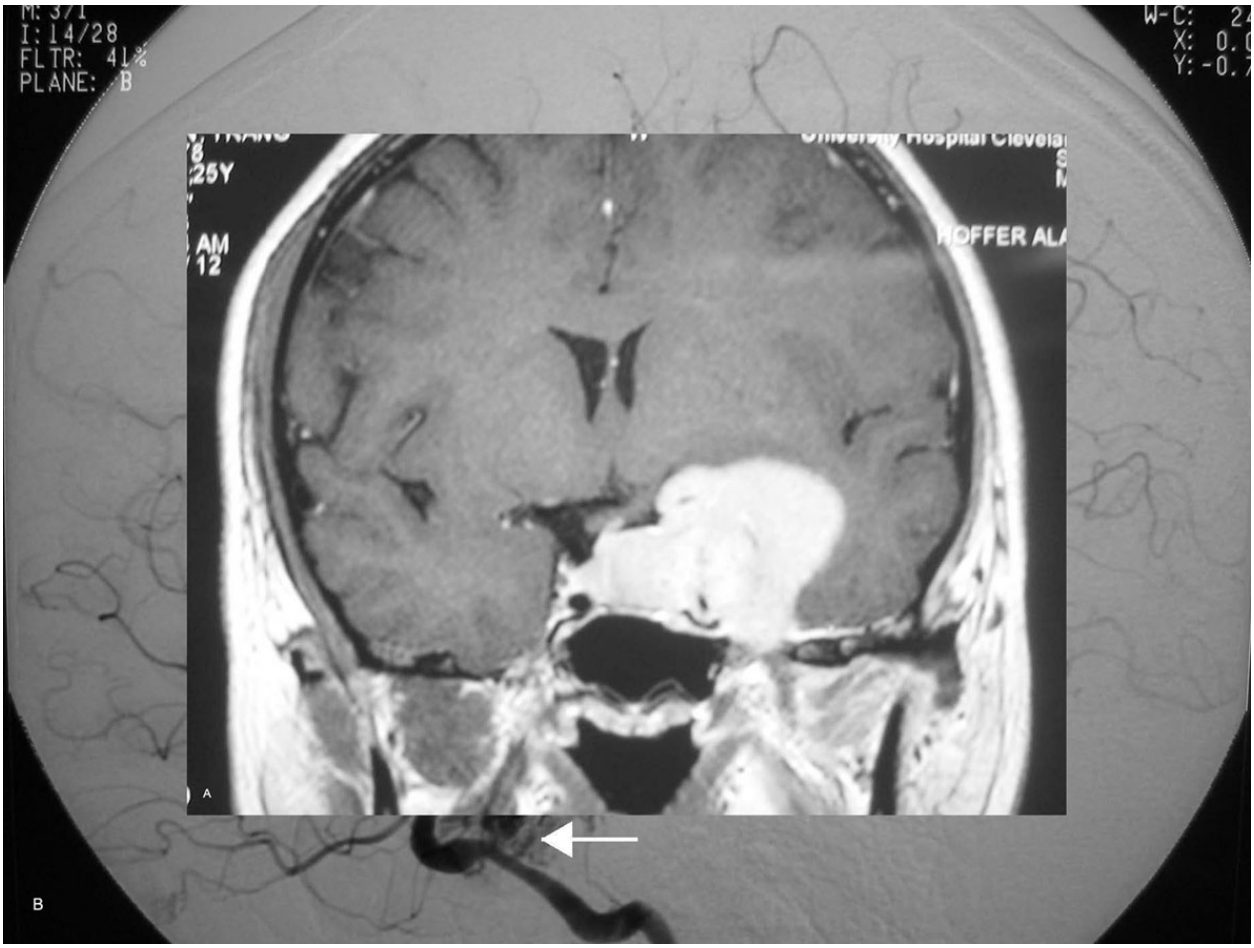

Figure 6. Medial sphenoid wing meningioma visualized on coronal postcontrast MRI (A). Note the involvement of the cavernous sinus in this young patient who presented with a partial third cranial nerve paresis and visual deficits. Angiography demonstrating significant tumor feeders arising directly off the petrous carotid artery (B, arrow). These were obliterated with preoperative embolization, which allowed for a subtotal resection of the tumor (C). Residual tumor is visualized deep in the cavernous sinus.

developed to provide adequate surgical exposure for these lesions. These types of exposures often involve the use of partial or total petrosal bone resection as a way of minimizing brain retraction without sacrificing exposure. The optimal treatment of these lesions is controversial given their generally slow growth and protracted course (32,37). Recent advances in the application of stereotactic radiosurgery have provided an alternative to open surgical resection in selected cases (12,23,38). This option has had an effect on the shape of modern treatment algorithms.

Erkmen and colleagues reviewed the treatment of 97 patients with petroclival tumors (39) Their recommended approach depends on the location of the tumor along the clivus and in relation to the internal auditory meatus (IAM). The use of a posterior transtentorial approach is deemed appropriate for lesions arising lateral to the IAM. The orbitozygomatic approach is recommended to resect tumors located medially to the IAM in the absence of posterior fossa involvement. The transcochlear approach is reserved for use in patients with no serviceable preoperative hearing. In fact, the preservation of hearing has been emphasized in recent surgical reports. In a review by Shen and colleagues, 94 percent of 71 tumors were completely removed (40). While reporting an overall use of aggressive, combined surgical approaches in 47 percent of cases, they describe a reduction in their use of the combined approach over the course of the study. This was done as an attempt to preserve facial nerve function and hearing. Kaylie and colleagues preserved hearing in 8 of 10 patients who underwent a transcrusal approach to the petroclival region (41). When a partial labyrinthectomy is added to a standard presigmoid petrosal approach in an effort to preserve hearing, it is successful in more than 80 percent of cases (42).

As an alternative to more extensive skull base approaches, the standard retrosigmoid approach has been promoted as an easy and straightforward alternative by which excellent results may be obtained with minimal morbidity (32,33,43,44). Anatomical studies in cadavers have compared the working area provided to the petroclival surface between the retrosigmoid and combined petrosal approaches (45). Siwanuwatn and colleagues found no

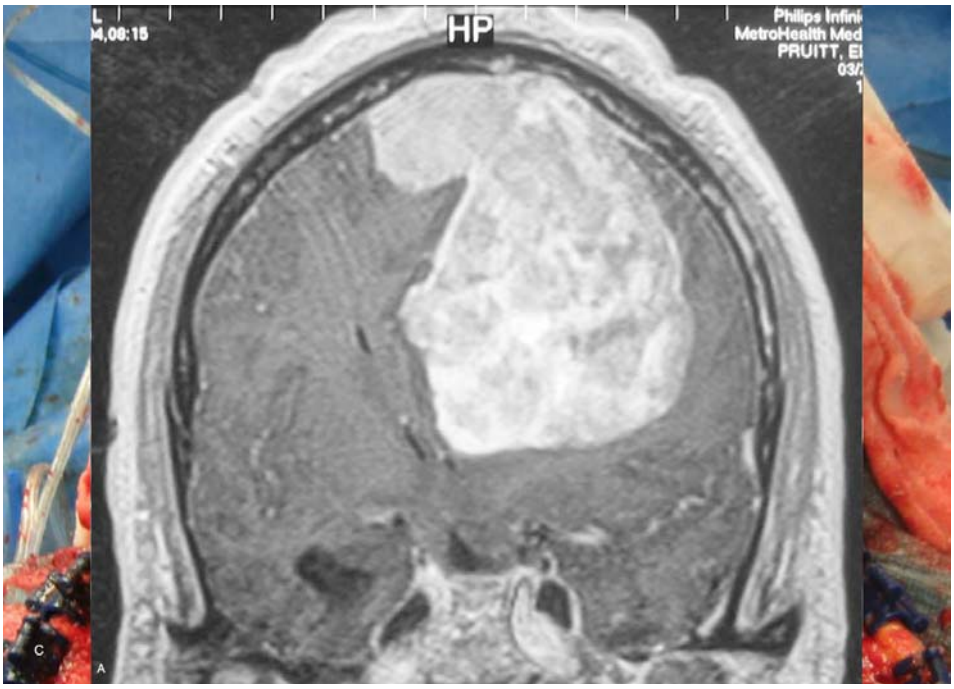

Figure 7. Massive midline cranial vault meningioma involving the sagittal sinus (A and B). Following cranial degloving exposing the entire skull from the coronal to lambdoid sutures (C), an aggressive resection was performed with complete resection of tumor in the sinus (D).

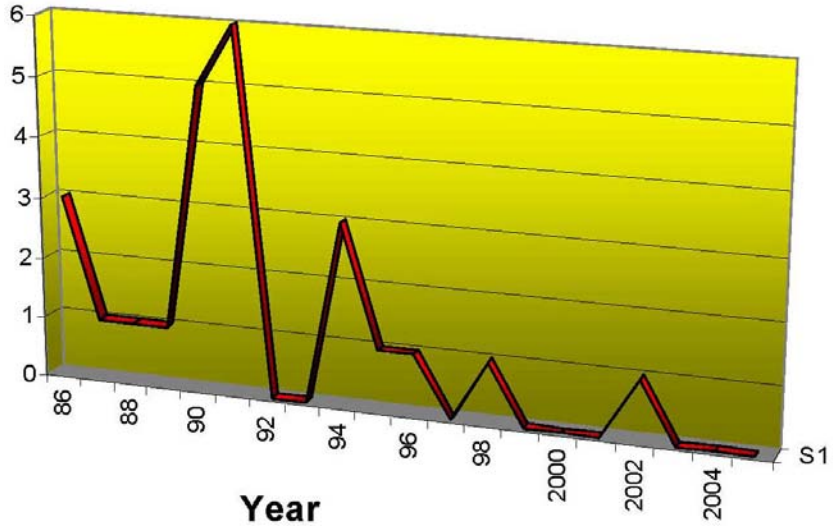

Figure 8. Graphic demonstration of combined petrosal and transcochlear procedures performed at our institution over the past 20 years in the treatment of petroclival meningiomas. A majority of these complex approaches were performed prior to 1996 (48). Reproduced with permission from Wolters Kluwer Health.

significant difference in either working area or angle of attack to the petroclival surface without the inclusion of a complete transcochlear exposure (46). The axis of approach via the retrosigmoid approach is from a dorsal aspect along the plane of the petrous bone. They, therefore, suggested that the increase in bony removal afforded by the combined approaches, in the absence of a complete petrosectomy, is not extensive enough to increase the working area significantly. In a recent *in vitro,* cadaveric investigation, we quantitatively assessed, via the retrosigmoid approach, the working areas, angles of attack, and brain shift associated with inflating a balloon between the upper cranial nerves and upper clivus to mimic the effects of tumor compression (Figure 11). This simulation of a tumor mass in the posterior fossa and cerebellopontine angle significantly shifted neurovascular tissue and opened a surgical corridor to the petroclival region (unpublished data).

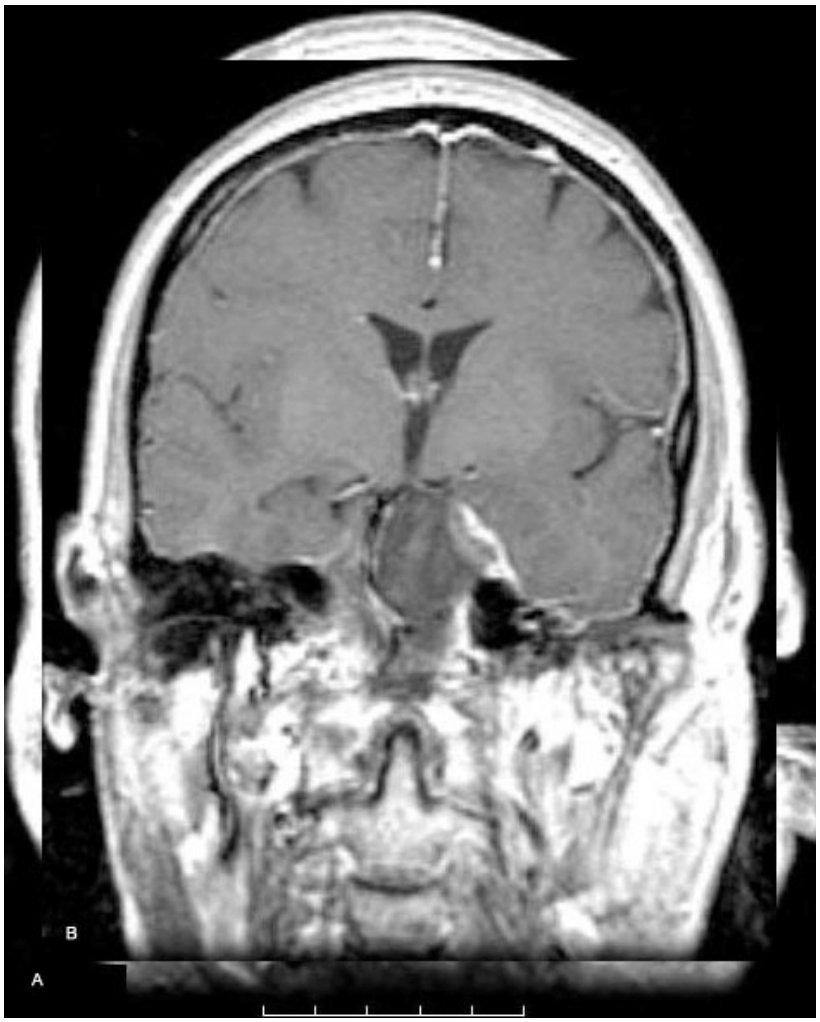

Figure 9. Coronal postcontrast MRI showing a large petroclival meningioma (A). A near complete resection was performed using a combined supratentorial and infratentorial approach via the orbitozygomatic and retrosigmoid craniotomies in a staged manner. Residual tumor (B) was treated with stereotactic radiosurgery.

Critical to the completion of an adequate resection achieved at minimal risk is the consistency of the lesion as well as its involvement of major neurovascular structures. Bricolo and colleagues emphasized this point in their use of the retrosigmoid approach alone to treat 65 percent of 110 skull base tumors (32). Of 84 cases treated by Goel and Mazumdar over 11 years, 28 were treated with the retrosigmoid approach (33) with a gross total resection rate of 75 percent. These results were reported for moderately sized (mean diameter of 4 cm) tumors. Five patients (18 percent) developed new facial nerve deficits. Regardless of the surgical approach used, the major determinants of the ability to achieve excellent resection associated with low morbidity are the presence of an arachnoid plane around the tumor, the consistency of the tumor, and the degree of its involvement with critical neurovascular structures. In a review of 137 patients, Little and colleagues demonstrated that independent factors associated with postoperative neurological morbidity included a history of prior resection and the presence of tumors described as adherent or fibrous (47). Over time, these authors have altered their surgical approach in favor of decreasing morbidity at the expense of achieving a gross total resection.

While initially very aggressive in using combined approaches to treat a variety of skull base tumors and vascular lesions, (28,48), our management strategy has changed significantly over time. In a recent retrospective analysis of 64 patients with petroclival tumors treated at our institution over the past 20 years, the use of combined petrosal approaches has led to increased rates of gross total resection. This increase has been at the cost of higher complication rates and has led to a decrease in the use of combined petrosal approaches in an effort to limit patient morbidity (Figure 8). At the limits of our brief follow-up, progression-free survival remains excellent in all groups we followed. Detailed follow-up information regarding tumor progression was available for 45 patients. Of these, two patients developed tumor progression 5 and 10 years after surgery, respectively. No patients developed tumor

recurrence after gross total resection. The rate of progression-free survival in patients treated with either a retrosigmoid or orbitozygomatic approach was 96 percent at 36 months and 87 percent at 48 months. In cases in which supratentorial extension is significant, we now favor the use of the orbitozygomatic craniotomy, in combination with a retrosigmoid craniotomy, and have found this method to be adequate in achieving an excellent resection, even of very large tumors (Figure 9). An inability to obtain a gross total resection is increasingly acceptable if a small enough residual tumor mass that can be easily treated with stereotactic radiosurgery is retained. No patient in our series developed progression following stereotactic radiosurgery. In our opinion, the best approach provides the greatest degree of exposure to maximize surgical resection while minimizing the risk of surgical morbidity. The choice of exposure must be tailored to the ability and experience of the treating surgical team.

4. CONCLUSIONS

While an increasing amount is known about the biology of meningiomas, the mainstay of treatment remains total surgical excision. Radiation therapy has proved an important adjunct as remnants and tumors of smaller size have proven controllable with acceptable doses of stereotactically applied radiation. Ultimately, however, the meningioma remains in the domain of the surgeon who must work with the anatomy of the tumor on a regional basis to provide the best possible resection and, failing that, to control the tumor as best possible. Tumors of a high grade have a behavior more in line with cancers. For these tumors, new treatments are needed, as no specific treatments exist. Hence, much remains for the clinical scientists of the 21st century to do to improve the outcome in this common disease.

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Abbreviations: CSF: cerebrospinal fluid, IAM: internal auditory meatus, WHO: World Health Organization

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