Cavernous sinus meningiomas

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Cavernous sinus meningiomas were once considered unresectable. The development of microsurgical and skull base techniques as well as advances in anesthesia and neuroradiology have allowed safe and systematic treatment of these lesions. Proper evaluation and patient counseling are required. A thorough understanding of the anatomy and surgical approaches are crucial to success, as is knowledge of the possible adverse outcomes including cranial neuropathy and stroke. The authors discuss these issues in the treatment of cavernous sinus meningiomas.

KEY WORDS • cavernous sinus • meningioma • craniobasilar • middle fossa • skull base

Meningiomas appear to be simple lesions. Neurosurgeons have been very successful in treating them because the majority are readily accessible benign lesions for which complete resection achieves long-term cure. Their relative simplicity, however, disappears when they recur, are attached to the major draining sinuses, and are insinuated among critical neural structures. Such is the case in meningiomas involving the cavernous sinus. Within this compact space run the CA and the ocular motor nerves, and the optic nerve and pituitary body lie nearby. While the neurosurgeon pursues the goal of total resection, the risks to vision, ocular function, appearance, and stroke are ever present. Historically, such cavernous sinus meningiomas have been thought to be located in a surgical “no man’s land.” Since the description of effective skull base approaches and techniques in the 1980s, however, experience has continued to accumulate, as has that related to SRS. The treatment of these tumors has evolved to such an extent that the definition of “success” is debated. It is tumor eradication? Lack of neurological deficits? Absence of tumor growth? In this article we outline the techniques used at a surgery-oriented center in the evaluation and treatment of people harboring cavernous sinus meningiomas.

Abbreviations used in this paper: ACP = anterior clinoid process; CA = carotid artery; COZ = craniobasilar; CSF = cerebrospinal fluid; CT = computerized tomography; MR = magnetic resonance; PFS = progression-free survival; SRS = stereotactic radiosurgery.

TREATMENT OF CAVERNOUS SINUS MENINGIOMAS

Presentation and Physical Examination

Meningiomas arise primarily in the cavernous sinus or involve the cavernous sinus secondarily. Not surprisingly, the presenting symptoms are related to the neurovascular structure involved. Patients harboring cavernous sinus tumors most frequently present with ocular motor deficits—ptosis, diplopia, anisocoria, or complete ophthalmoplegia. Trigeminal nerve dysfunction can be present with facial numbness or facial pain. Tumors compressing the optic nerve can result in visual field deficits, and CA compression can cause ischemic deficits. Although involvement of the pituitary body or stalk does not frequently result in the primary presenting symptom, pituitary dysfunction can occur and should be investigated. Any concern about pituitary dysfunction should prompt a complete pituitary laboratory evaluation.

Determining a patient’s medical history is critical in cases in which a cavernous sinus malformation is suspected. Information about any prior treatment including resection (including operative report), pathological study results if available, irradiation, and medical treatment should be obtained. Numerous other tumors can metastasize to the dura and mimic meningioma.^{11,30} Additionally, in women, recent mammography results should be studied, because a potential association between meningiomas and breast carcinoma has been reported²⁸ (although this may represent two tumor types with common risk fac-

tors^{3,10}). Prior cranial irradiation is associated with secondary development of meningiomas.^{9,26} Other manifestations of neurofibromatosis such as café-au-lait spots, hearing loss, cutaneous neurofibromas, or a family history of neurofibromatosis should be determined. In women, history of birth control medications or hormone replacement therapy must be noted, because a hormonal association with meningioma development/growth is suspected.^{1,25,27,29}

Physical examination should include a complete and thorough neurological examination. Third, fourth, and sixth cranial nerve deficits are extremely common as are trigeminal nerve deficits. Visual fields should be examined; suspicion of a field deficit should prompt a complete neuroophthalmological evaluation with visual fields and visual acuity. The remaining cranial nerves must be examined as well. Assessment of motor, sensory, cerebellar function, as well as coordination status will provide insight into the impact of any tumor extension into the posterior fossa.

Neuroimaging Studies

Magnetic resonance imaging is currently the best neurodiagnostic study for the evaluation of a suspected cavernous sinus meningioma. Meningiomas are typically dural-based masses that are isointense on T₁-weighted and variable on T₂-weighted imaging, densely enhance, and typically have a dural tail (Fig. 1). Calcifications may be seen as hypointense regions within the tumor. Computerized tomography scanning is also an important tool because associated hyperostosis will be demonstrated (Fig. 1). Magnetic resonance angiography generally demonstrates the intracranial circulation without the risks associated with conventional angiography (Fig. 1). Conventional angiography including cross-compression, however, should be considered in cases in which there is any uncertainty about the integrity of the intracranial circulation in general, the ipsilateral CA, or in patients in whom the cavernous sinus has been irradiated. Thorough study is recommended to identify patients in whom the CA is at excess risk. In these cases, assessment of the collateral circulation may be performed by a balloon test occlusion with single-photon emission CT and acetazolamide challenge. Patients in whom poor collateral circulation is identified should undergo a bypass procedure.

Treatment Options and Indications

There are three primary treatment options for patients with cavernous sinus meningiomas: observation, microsurgical resection, and SRS (gamma knife and linear accelerator). Observational treatment is based on the fact that meningiomas can remain quiescent for long periods of time and some grow only very slowly.^{14,22,31} Patients harboring asymptomatic or minimally symptomatic cavernous sinus meningiomas and who exhibit cranial nerve deficit may be candidates for observation.

Cavernous sinus meningiomas that demonstrate growth on serial imaging or become progressively more symptomatic require intervention. These characteristics constitute the primary indications for microsurgical resection. In these patients SRS can be performed as well as in asymptomatic patients. It is also wise to mention alternative medical regimens (such as hydroxyurea, mifepristone, ta-

Fig. 1. Imaging studies obtained in a patient with a tumor originating in the cavernous sinus. *Upper Left:* Axial precontrast T₁-weighted MR image demonstrating an isointense mass in the left cavernous sinus. *Upper Right:* Coronal postcontrast MR image revealing the enhancing mass in the left cavernous sinus. *Center Left:* Axial postcontrast T₁-weighted MR image demonstrating the enhancing mass in the left cavernous sinus, which abuts the left optic nerve and displaces the CA. The mass also appears to have expanded the anterior clinoid process (ACP). *Center Right:* Axial CT scan revealing hyperostosis of the left ACP. *Lower:* An MR angiogram demonstrating displacement and constriction of the left internal CA.

moxifen); however, none has been proven to treat meningiomas unequivocally.^{6,7,12,15,17,19} There are some situations in which surgical resection should be considered over SRS—for instance, tumors with significant extracavernous components in which the lesion has caused neural compression-related symptoms (that is, hydrocephalus due to brainstem compression). Tumors compressing the optic nerves, chiasm, or tracts should be considered candidates for resection to avoid the risk of radiation-induced optic neuropathy.²⁴ A 2-mm space separating the tumor from the optic tract has been mentioned as a safe margin

Cavernous sinus meningiomas

to allow irradiation of the tumor while minimizing the risk of radiation-induced optic neuropathy.²⁰ Finally, tumors greater than 3 to 3.5 cm in diameter are not ideal candidates for SRS.¹⁶

None of these options is without potentially significant risks. Certainly, we have been trained as neurosurgeons, oncologists, and radiation oncologists to discuss treatment options and recommendations, but the medicolegal atmosphere now demands that practitioners present a full and fair accounting of the treatment options, their aims, risks, and benefits. Any requests for second opinions for surgical, SRS, or medical treatments should be readily fulfilled.

Guiding Principles of Cavernous Sinus Meningioma Resection

Skull base approaches provide a wide field of visualization while minimizing neural retraction. Bone is removed to facilitate this wide exposure. Approaches to the cavernous sinus are designed to provide vascular control of the CA. Because meningiomas quite frequently respect arachnoid planes, it is critical to exploit these planes to preserve normal structures. These planes become scarred and obliterated after initial resection or irradiation, making (re)operation much more difficult. Therefore, total removal of the tumor is undertaken at the first operation as the best means of achieving this goal. Carotid artery preservation is sought at this center. Again, there is often an arachnoid plane separating the tumor from the CA and it can be exploited to spare the artery. If necessary, when no plane is encountered, small remnants of adherent tumor are left to avoid sacrificing the artery. The same philosophy is true regarding the cranial nerves. All attempts should be made to remove any affected dura mater, and that which cannot be resected should be electrocoagulated if possible. All involved or hyperostotic underlying bone should be drilled away. If submucosal tumor spread is found within the sinuses, it should be removed. Sphenoid sinus defects must be repaired with extreme care during the reconstruction.

SURGICAL APPROACHES TO THE CAVERNOUS SINUS

Two primary surgical approaches to the cavernous sinus are used by the senior author (O.A.M.): the COZ approach and the extended middle cerebral fossa zygomatic approach. The COZ approach provides wide exposure of the entire cavernous sinus, proximal and distal CAs, and allows minimal cerebral retraction. The extended middle cerebral fossa zygomatic approach is performed to reach tumors present in the posterior cavernous sinus, anterior petrous apex, and medial clival masses. This approach is more limited, does not readily offer distal control, and does not expose the medial or superior cavernous sinus as easily as the COZ approach.

Cranioorbitozygomatic Approach

Extensive setup is required prior to skin preparation (Fig. 2). The endotracheal tube is secured to the side of the mouth contralateral to the approach. A lumbar drain is placed for CSF drainage later. The upper body and head

Fig. 2. Operative setup for the COZ approach. The main illustration demonstrates the head and body positioning, Mayfield pin placement, and lumbar drainage. Inset: The proposed scalp incision and monitoring electrode placement. Reprinted with permission from *Operative Atlas of Meningiomas*, O. Al-Mefty. Lippincott, Williams, and Wilkins, 1998.

are slightly elevated. The head is positioned after application of three-pin skeletal fixation. The frameless stereotactic system is registered, and intraoperative electrophysiological electrodes are applied. Somatosensory evoked potential and fifth and seventh cranial nerve electrodes are placed at this time. The scalp is marked for a coronal flap. An incision is marked over the cervical CA in case more proximal control is required. Incisions are marked on the left lower abdominal quadrant and left lateral thigh for later fat and/or fascia harvest. After preparation, a sterile microphone and electrode are placed in the ipsilateral ear for brainstem auditory evoked response recording.

The anterior superficial temporal artery is carefully located and protected during the coronal incision. This maintains the vascular supply to the flap and provides a donor vessel should extracranial-intracranial bypass become needed in the future. A temporal subfascial dissection is performed to preserve the frontal branches of the facial nerve (Fig. 3 left). The frontal pericranium is maintained as a vascularized flap for the reconstruction and can be raised from beneath the posterior flap (Fig. 4). As the scalp flap is elevated, the temporal fat pad will appear. At this point the superficial and deep temporal fascia are incised. The raising of the cutaneous flap—including the two fascial layers—can now be completed. After dissecting the lateral orbit and zygomatic arch, the zygoma is divided at either end and is displaced inferiorly on its masseteric pedicle (Fig. 3 center). The temporalis muscle is

Fig. 3. Superficial soft-tissue dissection. *Upper Inset:* The elevation of the scalp flap with the superficial temporal artery and the creation of the galeopericranial flap. The main illustration shows the elevation of the galeopericranial flap and the temporal fascia incision. *Inset at Right:* The subfascial dissection to preserve the facial nerve branches to the frontalis muscle. *Center:* Management of the temporalis muscle and zygomatic arch. *Upper Inset:* The use of the air drill to preserve the supraorbital nerve. *Inset at Right:* Osteotomies at either end of the zygoma, which allow the temporalis muscle, shown in the main illustration, to be elevated off the calvarium and retracted inferiorly. *Right:* Creating the cranioorbital flap. Burr holes are placed in the keyhole and posteroinferiorly in the temporal squama. A cut is made across the lateral orbital wall and then up to the keyhole. The keyhole is then connected posteriorly to the posterior burr hole. The cut is then continued up to the frontal bone and through the supraorbital bar. If the frontal sinus is entered, the posterior wall of the sinus must be cut as well. The orbital contents must be protected when drilling the osseous orbit. A V-chisel is then used to cut the orbital roof from the keyhole (*right inset*) to the medial cut behind the supraorbital bar. Reprinted with permission from *Operative Atlas of Meningiomas*, O. Al-Mefty. Lippincott, Williams, and Wilkins, 1998.

elevated off the calvarium in subperiosteal fashion beginning low on the temporal squama and ending by disinserting the muscle at the superior temporal line.

The cranioorbital flap is elevated as a single piece (Fig. 3 right). A burr hole is placed in the keyhole to gain simultaneous entrance into the cranium and orbit. A second burr hole is placed posteriorly on the temporal floor. A cut is made from the medial aspect of the lateral orbital wall to its lateral aspect and is continued to the keyhole. The keyhole is then connected to the posterior burr hole by cutting through the temporal fossa. A cut starting at this burr hole is then brought superiorly to the frontal bone and then anteriorly through the supraorbital rim. The orbital contents must be protected during any cuts in the osseous orbit. With this final cut it must be ensured that the posterior wall of the frontal sinus is cut if it has been entered. A cut is made from the first burr hole through the orbit, taking care to protect the orbital contents. A notched osteotome is used to incise the orbital roof from the second burr hole toward the nasion, taking care to protect the orbital contents during this cut. The bone flap is now elevated. The remaining portions of the orbital roof, lateral orbital wall, and sphenoid wing can be removed using the craniotome for later reconstruction (Fig. 4). With the orbit now exposed, electromyographic electrodes may be directly placed into the superior oblique, superior rectus, and lateral rectus muscles to monitor third, fourth and sixth cranial nerve function.

Proximal control of the CA is the next objective (Fig. 5). The dura of the middle fossa is elevated in a posterior-to-anterior direction. The middle meningeal artery is identified, thoroughly electrocoagulated, and divided. Con-

tinued dural elevation reveals V_3 and foramen ovale. The greater superficial petrosal nerve can be seen emerging from the facial hiatus and is dissected free of the dura. The greater superficial petrosal nerve should not be pulled to avoid transmission force to the geniculate ganglion that can lead to a facial palsy. The apices of the Glasscock tri-

Fig. 4. The remaining portions of the orbital roof, sphenoid wing, and lateral orbital wall can be removed and used during the reconstruction. Reprinted with permission from *Operative Atlas of Meningiomas*, O. Al-Mefty. Lippincott, Williams, and Wilkins, 1998.

Fig. 5. Middle fossa dissection. The anatomy of the floor of the middle fossa. *Inset:* Drilling lateral to V_3 and posterior to the greater superficial petrosal nerve dissection reveals the petrous CA, thereby providing proximal control. Reprinted with permission from *Operative Atlas of Meningiomas*, O. Al-Mefty. Lippincott, Williams, and Wilkins, 1998.

angle are now exposed: the facial hiatus, the anterior aspect of the foramen ovale, and the intersection of the greater superficial petrosal nerve and the lateral aspect of the V_3 . This triangle overlies the CA, and drilling here with the use of a diamond burr and constant irrigation expose the CA. In 63% of cases, bone is absent between the CA and the trigeminal ganglion and continues to be absent up to the lateral edge of the ganglion; in 38% the absence of bone extends lateral to the third division.⁸ This may be sufficient for proximal control of the artery or to allow posterolateral drilling from the known location of the artery. Sufficient exposure allows proximal control, which can be achieved by placement of a temporary clip on the petrous CA. Alternatively, a Fogarty catheter may be inserted into the CA canal. Should vascular control be required, the catheter balloon can be inflated to occlude the CA in the canal.³²

Medial exposure of the cavernous sinus and exposure of the subclinoid CA are obtained by drilling out the remainder of the orbital roof, the superior orbital fissure, the anterior clinoid process, and the optic strut (Fig. 6). In this region a diamond burr is required and copious irrigation must be performed to dissipate the heat of drilling. The optic canal is first opened. The superior orbital fissure is opened by drilling along the lesser sphenoid wing. The anterior clinoid process is cored out by using the drill and then disarticulated by drilling out the optic strut. The clinoid is subperiosteally dissected and resected. This procedure exposes the subclinoid portion of the CA, which is both extradural and extracavernous, and provides distal control of the CA.

Entrance into the cavernous sinus has been described in relation to the intervals among its neurovascular structures. These intervals have been expressed in terms of 10 triangles distributed among the parasellar, middle fossa, and paracaval locations. The chosen approach must be tailored to the anatomy of the lesion in relation to the cav-

Fig. 6. Drilling to obtain medial cavernous sinus exposure. The main figure (*upper image*) demonstrates opening of the optic canal and drilling of the ACP. *Inset:* After resection appearance of the ACP and optic strut. Reprinted with permission from *Operative Atlas of Meningiomas*, O. Al-Mefty. Lippincott, Williams, and Wilkins, 1998.

ernous sinus structures. There are two general approaches to the cavernous sinus: a superior and a lateral approach. The superior approach is particularly suited for those lesions adjacent to the anterior loop of the CA, as well as those superior and/or medial to the cavernous CA. The lateral approach lends itself well to exposure of lesions lateral and/or inferior to the CA and those that are posteriorly located within the cavernous sinus. These approaches can be combined for lesions widely involving the sinus.

Superior Approach. After exposing the superior surface of the cavernous sinus, the dura overlying the optic nerve is divided over the length of the optic canal to free the optic nerve. The distal carotid ring is now divided. The dura is then incised toward the oculomotor nerve, which provides initial entry into the cavernous sinus (Fig. 7). The exposure can be increased by dissecting along the length of the CA. Further exposure can be obtained by subperiosteal dissection of the posterior clinoid process and drilling off the process, the dorsum sellae, and the superior clinus. These maneuvers allow increased exposure of the posterior fossa.

For tumors with medial extension, the jugum sphenoidale can be drilled away. This exposes the sphenoid sinus. Dissection and incision of the diaphragma sellae provides visualization of the pituitary gland. During the closure, great care must be taken to obliterate any communication between the cavernous sinus and the sphenoid sinus to prevent CSF leakage.

Lateral Approach. Lateral entry into the cavernous sinus can be intra- or extradural.

Extradural entry begins by incising the dura propria overlying the V_3 . By applying superiorly directed traction, the dura propria is peeled away from the trigeminal

Fig. 7. Superior entry into the cavernous sinus. *Inset:* Incision of the optic nerve and cavernous sinus dura. The main illustration demonstrates the superior exposure obtained. Reprinted with permission from *Operative Atlas of Meningiomas*, O. Al-Mefty. Lippincott, Williams, and Wilkins, 1998.

branches and ganglion. This will initially expose the V_3 and lateral ganglion followed by the V_2 and the majority of the remaining ganglion. In cases involving anterior extension from the region of the Meckel cave, bone around the foramina rotundum and ovale can be drilled away to allow exposure of the sphenoid sinus and infratemporal fossa. This will also free the trigeminal branches; in turn, the branches and the ganglion become more mobile. A mass beginning to enter the posterior fossa can be further exposed by drilling the petrous apex, which also allows greater exposure around and under the trigeminal ganglion.

For lesions requiring intradural exposure, intradural entry into the cavernous sinus is achieved via the Parkinson triangle²³ (Fig. 8). The third and fourth cranial nerves are identified over the tentorial edge. An incision is made beneath the anticipated position of the fourth cranial nerve and extended approximately 8 mm anteriorly and 8 mm inferiorly. The external dural layer is peeled away from the thin inner dural layer in which the third through fifth cranial nerves are found. The dural flap can be further dissected from the trigeminal ganglion to expose the Meckel cave. Exposure can be increased posteriorly and into the posterior fossa by drilling petrous apex. The trigeminal nerve can be mobilized by drilling the foramina rotundum and ovale.

The inner dural layer between the fourth nerve and the ophthalmic division can be incised to expose the lateral space of the cavernous sinus, the posterior bend and horizontal segment of the intracavernous CA, and the lateral cavernous and the meningohypophysial arteries. The abducent nerve is the only cranial nerve coursing inside the cavernous sinus proper, and it should be carefully sought and protected. Not uncommonly, the nerve is found as two to five fascicles that must be protected.^{8,18}

Fig. 8. Intradural lateral entry into the cavernous sinus via the Parkinson triangle. Reprinted with permission from *Operative Atlas of Meningiomas*, O. Al-Mefty. Lippincott, Williams, and Wilkins, 1998.

Reconstruction after the COZ approach begins with preventing the possibility of CSF leakage: any feature of the dissection that can result in a CSF leak should be obliterated. Any entrance into the paranasal sinuses or the Eustachian tube should be obliterated by placing fat and fascia. Tenuous or incomplete dural closures should be reinforced with tissue—preferable autologous—such as fascia, muscle, or fat. For further reinforcement, fibrin glue can be applied. The galeopericranial flap can now be brought down under the frontal lobe, over the orbit, and over any sinus entries in the middle fossa or petrous apex. The orbital roof is reconstructed to prevent late development of enophthalmos. Dural tackup sutures are placed circumferentially, including in the subtemporal region, to obliterate dead space and prevent postoperative development of epidural hematomas. If the frontal sinus has been entered, the mucosa should be exenterated and the cavity packed with fat or tissue to prevent mucocoele formation and CSF leakage. The cranioorbital flap is secured in place with titanium miniplates. Bone defects can be reinforced using titanium plates or mesh, or numerous cranio-plastic materials such as hydroxyapatite cement. The temporalis muscle is sutured to the superior temporal line. The zygoma is secured into position by application of titanium miniplates. The scalp is closed in layers, and a craniotomy headwrap is applied to decrease postoperative fluid collection beneath the flap.

Extended Middle Fossa Approach

The scalp incision, temporalis dissection, zygomatic osteotomies are performed as previously described (Figs. 2, and 3 *left and right*). Four burr holes are placed: 1) in the keyhole; 2) low and anterior in the middle fossa; 3) low and posterior in the middle fossa; and 4) along the superior temporal line. These four burr holes are connected with a craniotome. Residual bone along the sphenoid wing or

the temporal squama can also be removed using the craniotome. Dissection along the middle fossa floor (dural elevation, MMA division, greater superficial petrosal nerve dissection, and acquisition of proximal CA control) is performed as previously described. The dissection now continues to expose the pathological entity of interest. Further dural elevation will expose the confines of the petrous apex: the lateral aspect of V₃, the greater superficial petrosal nerve dissection, and the facial hiatus. If the petroclival area requires exposure, then the petrous apex is drilled down. The procedure for gaining lateral entrance is similar to that for the extradural lateral cavernous sinus as previously described. The dura propria overlying V₃ is incised and peeled away from the trigeminal branches and ganglion. Further dissection of the dura propria will reveal V₁ and the fourth cranial nerve. If the lesion extends anteriorly from the Meckel cave, exposure is gained by drilling bone around the foramina rotundum and ovale to reveal the sphenoid sinus and infratemporal fossa. If the surgeon discovers intradural extension of the lesion, such as invasion into the temporal lobe and the cisterns anterior to the brainstem, then intradural exposure can be easily obtained using this approach. The aforementioned lateral intradural entrance can also be used in this approach, although distal control of the CA cannot be obtained.

Closure after this approach requires meticulous attention to preventing CSF leakage, as described. A strip of the posterior temporalis muscle is placed along the petrous apex to prevent leakage. The remainder of the closure process is similar to that after the COZ approach.

Dissection Within the Cavernous Sinus

Dissection within the cavernous sinus is performed using microdissectors and microscissors. Sharp dissection is performed when possible to prevent placing traction force on intracavernous cranial nerves and arteries. Coagulation, when necessary, should be bipolar. As stated, once the cavernous sinus is entered, the abducent nerve should be sought and preserved. Venous bleeding can be controlled by elevating the patient's head and packing the sinus judiciously with hemostatic agents. Any frankly severed cranial nerve should be directly repaired. If a tension-free direct repair is not possible, an interposition graft should be placed. Injury to the CA can be addressed in several ways: placement of a temporary clip and direct

repair of tears by using No. 8-0 suture. More severe CA injury can be treated by performing vein graft repair.

SURGICAL RESULTS

The resections of tumors within the cavernous sinus are not the prohibitive procedures they once were. Many refinements in skull base surgical approaches, neuroanesthesia, neuroimaging, and nerve monitoring have rendered surgery in the cavernous sinus a more manageable problem. Gross-total resection has been possible in a wide range of published cases (20%–76%)^{2,4,5,13,21} (Table 1). In the senior author's experience, total resection has been achieved in 44% of cases (71 of 163 patients) (Fig. 9). Recurrences in these cases have ranged from 5 to 13%. In cases of total resection recurrence has occurred in 7%, and in cases of residual tumor, it has occurred in 57% at our institution. De Jesus and colleagues⁴ have reported 87% PFS at 3 years and 62% at 5 years. Therefore, reasonable rates of gross-total resection and PFS have been reported by centers working routinely with patients harboring cavernous sinus meningiomas. Stroke secondary to CA injury has been a significant concern when working in the cavernous sinus. Ischemic stroke has not been a frequent complication associated with cavernous sinus meningioma surgery.^{5,13,21} At our institution, one goal is CA preservation, even if it means leaving a remnant of tumor adherent to the artery (Fig. 10). Of 163 cases, seven patients (4%) sustained an ischemic stroke at this institution. Cusimano, et al.,² reported four disabling strokes in 89 patients, and De Jesus, et al.,⁴ reported six (5%); however, the surgery-related philosophy espoused by the latter group includes bypass and resection of an invaded CA.

Cranial nerve morbidity is a critical issue attendant on the resection of cavernous sinus meningiomas. Table 1 provides a summary reported incidences of cranial nerve deficits developing after resection of cavernous sinus meningioma. In general, existing preoperative cranial nerve deficits infrequently improve following resection, and the majority of new postoperative deficits resolve. DeMonte and colleagues⁵ reported improvements in 14% of preoperatively affected cranial nerves, whereas there was no change in 80%. They reported 10 new neuropathies in seven patients (18%). These data represent their early experience at their center. Despite continued experience, these percentages remain the same. This finding has sug-

TABLE 1
Summary of reported cases treated with resection*

Authors & Year	No. of Cases	Mean Follow Up (Range)	GTR (%)	Tumor Recurrence	PFS	New Cranial Nerve Deficits	No. of Deaths
DeMonte, et al., 1994	33	43 mos (2 mos–10 yrs)	31 (76)	13		10 (13% of patients)	6 (18%)
Cusimano, et al., 1993	39	23 mos	39 (66)	7			3 (6%)
De Jesus, et al., 1996	119	33.3 mos	73 (61)	10	87 @ 3 yrs, 62 @ 5 yrs		
Katzip, et al., 1996	29	(3 mos–7 yrs)	6 (21)			12 (41% of patients)	3 (10%)
O'Sullivan, et al., 1997	39	24 mos (6 mos–3.3 yrs)	3 (20)	3		23 (12% of 192 cranial nerves at risk)	

* GTR = gross-total resection.

† Patients died of tumor progression or as a result of surgery.

Fig. 9. Magnetic resonance images demonstrating complete resection of a cavernous sinus tumor. *Left:* Preoperative coronal postcontrast image demonstrating a large mass involving the right cavernous sinus. *Right:* Postoperative coronal postcontrast image revealing complete resection of the mass.

gested that these rates are more a function of the responses of the cavernous sinus cranial nerves to manipulation than surgeons' increasing experience. O'Sullivan, et al.,²¹ reported that preoperative optic nerve deficits improved in four (24%) of 17 patients while one of 17 patients with normal preoperative vision suffered a new visual field deficit. Five (21%) of 24 preoperative extraocular nerve deficits improved, whereas 14 (18%) of 78 patients with preoperatively normal cranial nerves at risk suffered a new deficit. They reported an overall 12% risk of new cranial nerve morbidity. Knosp, et al.,¹³ noted improvement in 43% of impaired oculomotor deficits, 50% of sixth cranial nerve deficits, and 33 and 28% of V_2 and V_3 deficits, respectively. Preoperative fourth and V_1 nerve deficits rarely improved (0 and 7%, respectively). In their experience no patient with intact cranial nerve function experienced any postoperative deficits. There was no new third nerve palsy; there was one case of new sixth nerve palsy and V_1 palsy, two new cases of fourth nerve palsy, three new cases of V_2 palsy, and five new cases of V_3 palsy.

CONCLUSIONS

Cavernous sinus meningiomas can be very difficult to treat. A thorough understanding of the patient's history must be combined with rigorous, physical, radiographic, and other (visual field, pituitary function) evaluations. It is also critical that these patients understand the natural history, management options, and risks associated with every treatment. Further, it is critical to understand the patient's goals of treatment. Skull base techniques have rendered the resection of cavernous sinus meningiomas a viable option. Currently, microsurgical resection of cavernous sinus meningioma stands alone as the only treatment associated with total tumor removal. No other treatment can achieve total removal or disappearance consistently. Critics of this surgery warn of dire consequences in traversing this region. The main problem of total resection is cranial neu-

Fig. 10. Magnetic resonance images demonstrating subtotal resection of a cavernous sinus meningioma in which a remnant was left adherent to the CA and middle cerebral artery. *Left:* Preoperative axial postcontrast image demonstrating a large cavernous sinus meningioma that had extended superiorly. *Right:* Postoperative axial postcontrast image revealing a remnant left in place to preserve the CA.

ropathy. The majority of neuropathies in these patients exist at presentation, whereas a minority develop permanently after surgery, and many of those that occur affect sensory function or can be treated with strabismus surgery. Optic nerve deficits are infrequently encountered. These morbidities are tractable. The balanced presentation of options, includes surgical resection. Multiple surgical centers across the US and worldwide have extensive expertise at treating such tumors, and techniques and outcomes continue to evolve.

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Cavernous sinus meningiomas

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