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Management Options and Surgical Principles: An Overview

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Management Options

In general, management options for patients with meningiomas include observation, surgery, and radiation alone or as an adjuvant therapy following surgery. To date, no definitively effective chemotherapeutic agent has been identified or developed. As meningiomas are mostly benign and slowly progressive tumors, immediate intervention is usually not required. Final treatment plans must be individualized for each patient based on the age, overall condition of the patient, tumor location and size, neurologic symptoms and deficits caused by the tumor, and the patient's personal wish after a thorough discussion of all available options.

Observation

Surgery is not necessary for every patient with a meningioma. At our institution, we currently evaluate approximately 200 new patients with meningiomas annually, among whom only about 100 undergo surgical intervention. Observation alone, with periodic (usually yearly) follow-up neurologic and magnetic resonance (MR) evaluations, is reasonable for elderly patients, especially if they have minimal or no symptoms caused by the tumor. As people are living healthier and longer lives today, the age at which a person is considered "elderly" is debatable. The patient's absolute age is no longer important in the decision-making process in the management of meningiomas; however, it may be reasonable to consider those with less than 10–15 years of remaining life expectancy (due to various reasons such as other co-morbidities that ultimately determine the overall health status) to be "elderly." In addition, observation may be an appropriate option for the following people regardless of their age: (1) patients with certain skull base meningiomas with minimal or no symptoms (e.g., cavernous sinus or petroclival meningioma causing mild facial tingling or numbness, optic nerve sheath meningioma with minimal or no visual deficit), (2) patients with incidental small tumors with no surrounding edema, and (3) patients who insist on nonintervention after a thorough discussion of all treatment options. However, these patients must be compliant with the necessary radiographic and neurological follow-up evaluations.

As with other brain tumors, the risks of surgery may vary in direct proportion to the tumor size, while the chances of total resection vary inversely proportional to the size of meningioma in most locations. For example, it is quite obvious that removal of parasagittal tumors prior to involvement of the superior sagittal sinus (SSS) would be easier compared to larger tumors intimately involving the SSS. The same may be said of small to medium-sized clinoidal or tuberculum sellae meningiomas before causing optic nerve and internal carotid artery (ICA) involvement or petrous meningiomas prior to reaching a large size that would encase the basilar artery and compress the brainstem and cranial nerves. Therefore, the initial recommendation of observation must be decided upon carefully, especially in younger patients, taking into consideration the increased potential risks posed in the future by further growth in the tumor size and involvement of nearby critical neurovascular structures.

Surgery

General Principles

Surgery is the treatment of choice for most patients with meningiomas. In patients with benign meningiomas, which comprise approximately 92% of all meningiomas,[1] the tumor location largely dictates the extent of resection, which, in turn, determines the tumor recurrence and, ultimately, the patient's survival.[2–4] Primary goals of surgery include: (1) total resection of the tumor and the involved surrounding bone and dura when feasible, thereby possibly providing cure or significantly altering the natural history of the disease process, and (2) reversal or improvement in neurologic deficits/symptoms caused by the tumor. In meningiomas of certain locations, such as the cavernous sinus or petroclival regions where complete resection is not always possible, additional

surgical goals may include confirmation of tissue diagnosis and tumor reduction (to less than 3 cm maximum diameter) in preparation for radiosurgery. Given the benign nature of meningiomas and the established efficacy of adjuvant radiation, the goal of total removal must be balanced by the physician's basic credo to "do no harm." When total removal carries a significant risk of morbidity, a small piece of tumor may be left, with further plans of observation followed by reoperation or radiation when the tumor is noted to be growing or causing new symptoms.

Surgical Technique

Meningiomas of different locations require varying surgical approaches that are primarily dictated by anatomic considerations inherent to each particular location. Surgical procedures of different anatomic regions are discussed in detail in the later chapters of this book. Furthermore, an abundance of excellent descriptions of "standard" techniques and approaches for meningioma surgery is available. This chapter is written not to replace, but to supplement, those previous important writings on the topic. Several key concepts and principles deemed important are reiterated, and new insights and lessons learned by the senior author, based on his personal surgical experience with over 700 meningioma patients, are summarized and presented.

In meningioma surgery, approaches may vary, depending on the tumor location and size, as well as the surgeon's personal experience and preference. However, the following basic principles hold for meningioma surgery of most locations:

1. Optimal patient positioning, incision, and exposure
2. Early tumor devascularization
3. Internal decompression and extracapsular dissection
4. Early localization and preservation of adherent or adjacent neurovasculature
5. Removal of involved bone and dura

Positioning, Incision and Exposure

Patient positioning, appropriate incision placement, and selection of the optimal approach for tumor exposure are the critical elements of successful meningioma surgery. The patient is positioned in such a way that his or her safety is maximized. Moreover, the ideal position must allow for an approach that provides complete exposure of the tumor and the involved surrounding bone and dura. At the same time, maximal brain relaxation must be achieved by use of gravity and uncompromised venous drainage. The head should be no lower than the level of the heart, regardless of the position selected, and undue severe neck rotation or flexion must be avoided. In addition, the surgeon's comfort for the duration of surgery must be maintained. The sitting position, preferred by some neurosurgeons for tumors of the pineal and select posterior fossa locations, places the patient at a higher risk of developing air embolism and the surgeon at an increased level of discomfort. When considering the sitting position for the aforementioned lesions, preoperative sagittal MRI should be reviewed carefully to appreciate the relative size of the posterior fossa and the steepness of the tentorial angle. Patients with a small posterior fossa usually have a low-lying posterior tentorial attachment because of the inferior location of the torcular and inion. This anatomic variation leads to a very steep, nearly vertical tentorial angle, making the infratentorial/supracerebellar approach with the patient seated extremely difficult. Other approaches to be considered in this situation include the transoccipital/transtentorial approach with the patient in the prone position or the infratentorial/supracerebellar approach with the patient in the modified park-bench (the "Concorde") position.

For superficial tumors (e.g., convexity or parasagittal), the planned scalp flap should contain the tumor in the center, and the patient is positioned so that the tumor is at the highest point. Importantly, the incision must be planned to avoid any visible cosmetic defect or significant compromise to the scalp vascular supply. If a horseshoe-shaped incision is planned, the depth must not exceed the width of the flap. Again, for superficial tumors, the size of the scalp and bone flaps must be sufficiently large so as to allow for maximal exposure of the tumor, the involved bone and dura, as well as the limits of the dural tail as noted on preoperative MRI scans. With the availability of frameless stereotactic image-guidance systems, the exact extent of the tumor and the dural tail may be fully delineated before surgery. This aids in optimal positioning and placement of incision and craniotomy.

An optimal approach should provide the shortest and most direct route to the tumor without "sacrificing" any normal brain tissue or creating undue brain damage by retraction. The need for retraction is minimized by taking advantage of gravity. For example, for surgery of an olfactory groove meningioma the head can be slightly hyperextended, and for a cerebellopontine-angle lesion the patient may be placed in the lateral position. For large, deep, falcine tumors, the patient's head may be placed with the side of the tumor down and the direction of the sagittal sinus parallel to the operating room floor. In all of these examples, the brain falls away from the tumor and its attachment. In deep-seated tumors, brain retraction may be minimized by use of cerebrospinal fluid (CSF) drainage via either a ventricular drain (in patients with obstructive hydrocephalus) or a lumbar drain. Furthermore, many of the skull base approaches developed over the last two decades, which convert the deep basal meningiomas to more superficial "convexity" lesions by reducing the working distance to the tumor, may minimize or obviate the need for brain retraction.

An optimal surgical approach also facilitates surgery by maximizing exposure of the tumor and surrounding structures, thereby minimizing risks of injury to the adjacent neurovasculature. For example, in surgery of large clinoidal or tuberculum sellae meningiomas, complete removal of the anterior clinoid process (ACP) provides improved access and exposure of the regions surrounding the optic nerve, optic

chiasm, ICA, and sella turcica.[5-7] Additionally, by opening the optic sheath as an extension of the dural incision following anterior clinoidectomy, the optic nerve can be decompressed and visualized early and mobilized safely during surgery, thereby reducing the risk of intraoperative injury to the nerve.[8] This maneuver also expands operative windows, particularly the optico-carotid triangle, facilitating access to tumors in the suprasellar and subchiasmatic regions.

In most situations, there exist a number of options for selecting the patient's position, surgical approach, and exposure. The final selection must be based on what is best for the patient and the surgeon, based on the surgeon's knowledge, past experience, and preference.

Tumor Devascularization

Many meningiomas can be quite vascular. In addition to utilization of preoperative embolization when appropriate, early operative devascularization of the tumor reduces blood loss and makes surgery easier. In superficial tumors, upon dural exposure prior to opening the dura, extra time should be expended to coagulate all the dural feeding vessels—most commonly the branches or the main trunk of the middle meningeal artery. In olfactory groove meningiomas, bifrontal craniotomy, preferred by many surgeons, provides early access to the main tumor feeders, i.e., ethmoidal arteries, as they enter the medial anterior fossa floor. In large sphenoid wing meningiomas, which receive siginificant transdural blood supply, utilizing the extradural skull base technique of orbitosphenoid bone removal obliterates many dural feeders prior to dural opening. Similarly, in petroclival meningiomas, the transpetrosal approach allows the exposed petrous dura and tentorium to be aggressively coagulated, and may significantly devascularize the tumor. In falcine or tentorial meningiomas, wide exposure and coagulation of the surrounding falx and tentorium reduce tumor vascularity. Yasargil advocates initial transtumoral devascularization of basal meningiomas by working through a small "window" created in the tumor to reach the blood supply coming through the base.[9] However, this technique may not be suitable for an inexperienced surgeon as there may be a significant risk of injury to unexposed neurovascular structures that may be located on the other side of the tumor.

Internal Decompression and Extracapsular Dissection

Although small meningiomas may be removed "en bloc," internal decompression is a key initial step in actual tumor removal for most meningiomas following adequate exposure and initial devascularization. Internal debulking is carried out until a thin rim of exposed portion of the tumor is remaining. This internal debulking minimizes brain retraction and facilitates extracapsular dissection. Following initial internal decompression, extracapsular dissection is initiated by identifying a layer of arachnoid (maintained in most meningiomas) at the brain–tumor interface. As surgery progresses, rather than increasing brain retraction to expose more of the tumor hidden under the brain, the thinned capsule is pulled towards the center of decompression. Cottonoid patties are placed in the brain–tumor interface as the capsule is being pulled away from the brain, while maintaining the arachnoidal layer intact between the brain and the tumor. As patties are being placed sequentially around the tumor, they are used to gently strip the arachnoid from the tumor capsule, simultaneously covering the brain and arachnoid together, thereby protecting the brain from surgical trauma. As the remaining tumor capsule is brought into the surgeon's view, any adjacent neurovascular structures are carefully dissected, and exposed blood vessels on the capsule surface are thoroughly inspected. Only tumor-feeding vessels are obliterated, preserving and dissecting free those transit vessels that are either passing through the depth of tumor or adherent to the tumor surface. Portions of tumor capsule thus devascularized and completely dissected from the surrounding neurovasculature are further removed in segments. These alternating sequential steps of internal decompression, extracapsular dissection, and removal of devascularized capsule are repeated until the entire tumor is removed.

For meningiomas in the clival, petroclival, or cerebellopontine-angle regions, the surgeon must analyze the preoperative MRI scan carefully. First, evidence of surrounding edema in the brainstem noted on T2-weighted scan must be appreciated prior to surgery as this indicates disruption of the arachnoidal layer and the blood-brain barrier.[10] This implies that the surgical plane between the brainstem and tumor may have been obliterated and, therefore, aggressive resection off the brainstem should be avoided. Second, the basilar artery location in relation to the tumor and brainstem must be noted. Although rare, if the tumor is located between the brainstem and basilar artery or completely encases the artery, this indicates that all the perforating branches of the basilar artery are stretched and course through the tumor. In this situation, an attempt at aggressive tumor removal is likely to result in a brainstem infarct. When the basilar artery is abutting directly on the brainstem, aggressive tumor removal off the brainstem is possible.

During extracapsular dissection, as a rule, no artery or arterial branch is sacrificed except when the vessel is definitely confirmed to be a tumor feeder. Commonly, loops of vessels may be encased by the tumor or may course onto the capsule surface and become adherent. In these situations, the surgeon may initially misinterpret these vessels as tumor feeders. Before concluding that a vessel is a tumor feeder and therefore amenable to obliteration, the afferent and efferent course of the vessel must be fully appreciated. It is very rare for meningiomas to have feeders directly from main intracranial arterial trunks. Therefore, no vessels coming directly off the ICA (in tuberculum sellae or clinoidal tumors), basilar artery (in petroclival- and cerebellopontine-angle tumors), or vertebral artery (in foramen magnum meningiomas) should be coagulated. If any appreciable vasospasm occurs while dissecting tumor off

arteries, small pieces of gelfoam soaked in papaverine applied directly onto the vessel readily reverse the spasm.

In removing the tumor from cranial nerves, especially the optic nerve, fine vessels feeding the nerves must be preserved. The optic chiasm and intradural optic nerve have main feeders on the inferior surface, and therefore removal of large tumors involving the subchiasmatic and suboptic space must be done carefully so as to preserve these fine vessels. Again, the preserved arachnoid around the cranial nerves facilitates tumor removal and reduces risks of intraoperative neurovascular injury.

Early Localization and Preservation of Adjacent Neurovasculature

Whenever possible, any adjacent or nearby normal neurovasculature (e.g., a cranial nerve or a vessel) should be identified and dissection carried out following this structure into the tumor. For example, in large clinoidal tumors encasing the optic nerve and the ICA, the conventional technique for removal has been first to identify the distal middle cerebral artery branches and follow these vessels proximally toward the ICA with subsequent tumor removal and dissection. However, until the ICA and eventually the intradural optic nerve are located, surgery progresses slowly. More importantly, the risk of intraoperative neurovascular injury persists during surgery as the exact location of the optic nerve and ICA remains unknown to the surgeon, and the optic nerve remains compressed. During this time, any minor surgical trauma caused by retraction, dissection, or tumor manipulation may exacerbate compression of the optic nerve, especially against the falciform ligament. To circumvent these critical problems, the optic nerve can be exposed and simultaneously decompressed early in the surgery by unroofing the optic canal, followed by anterior clinoidectomy and opening of the optic sheath. The location of the optic canal, and therefore the intracanalicular segment of the optic nerve, is fairly constant; only the intradural cisternal segment of the optic nerve varies in location, depending on how the tumor causes nerve displacement during its growth. The exposed optic nerve can then be followed from the optic canal proximally, toward the tumor in the intradural location. As tumor resection progresses further, the ICA can be readily found adjacent to the exposed distal intradural segment of the optic nerve. Complete optic sheath opening, along the length of the nerve within the optic canal to the anulus of Zinn, relieves any focal circumferential pressure on the optic nerve contributed by the falciform ligament. Optic nerve decompression thus achieved also leads to reduced intraoperative injury to the nerve, because the force of retraction is then dispersed over a much larger surface area. Moreover, if the tumor eventually recurs, the patient's impending visual deterioration may be delayed as the optic nerve is already decompressed from the surrounding falciform ligament and optic canal. In the senior author's personal experience utilizing the described technique in over 50 patients with presenting clinoidal meningiomas, 73% experienced significant improvement in their vision postoperatively.

Whenever possible, no cortical vein or dural sinus is "sacrificed." Although the anterior third of the sagittal sinus is traditionally said to be amenable to obliteration without any significant sequelae, there is a risk of developing significant venous infarcts. Therefore, even in large olfactory groove or planum sphenoidale tumors, rather than routine anterior sagittal sinus obliteration following a bifrontal craniotomy, either a unilateral pterional or a bilateral interhemispheric approach with preservation of sagittal sinus is used whenever possible in the senior author's practice. In parasagittal meningiomas, the tumor is removed aggressively, along with the involved segment of sagittal sinus, only when the sinus is completely occluded by the tumor. Otherwise, every effort is made to preserve the sagittal sinus integrity and patency while removing as much tumor as possible. Nearby prominent cortical veins, especially in the posterior two thirds along the sinus, are preserved as well.

Removal of the Involved Bone and Dura

Following complete tumor removal, the site of tumor origin is carefully inspected. If possible, the involved dura and bone are removed. In tumors of basal locations, the involved bone is drilled using a diamond burr, which is also quite effective in achieving hemostasis from tumor feeders arising directly from the base of the skull. Involved bone adjacent to paranasal sinuses is aggressively drilled, short of entering the sinus space. Inadvertent opening into paranasal sinuses or mastoid air cells must be recognized and appropriately sealed with muscle or fat graft and/or bone wax.

In 1983, Dolenc introduced an extensive extradural skull base technique to gain safe entry into the cavernous sinus.[11] The critical steps of this technique, following a routine frontotemporal craniotomy and drilling of the lateral sphenoid wing, include complete bone removal around the superior orbital fissure (SOF), posterior orbitotomy, optic canal unroofing, extradural removal of the ACP, and removal of bone around the foramen rotundum and ovale. Meningiomas of the posterior orbital roof, cavernous sinus (CS), sphenoid wing, or orbitosphenoid regions frequently cause hyperostosis of the orbital roof, and the greater and lesser sphenoid wing, including the ACP. For these tumors, the Dolenc approach, with modifications tailored to removal of only the involved bone, is an ideal technique.

In addition, the extensive sphenoid bone removal of the Dolenc approach, when coupled with the extradural exposure of the CS, facilitates removal of the involved dura, especially the portion of temporal dura covering the medial greater sphenoid wing, which simultaneously forms the outer lateral wall of CS. Following extradural bone removal as summarized above, the dural fold at the superolateral aspect of the SOF is sharply cut with microscissors tangential to the temporal dura. The temporal dura forming the outer lateral CS wall is

then "peeled" off the underlying inner CS lateral wall. This process of separating the two-layered CS lateral wall is continued laterally and posteriorly until all three divisions of the trigeminal nerve and the gasserian ganglion are exposed. In this manner, the lateral aspect of the CS is exposed entirely extradurally, freeing up the dura of medial temporal pole for removal as necessary, which would not have been possible to resect otherwise. This maneuver is particularly helpful in orbitosphenoid, CS, and sphenoid wing meningiomas, which frequently involve the temporal polar dura.

Postoperative Management

Follow-up evaluations consist of careful neurologic examination and MRI scans with and without gadolinium. For patients with preoperative diplopia and changes in vision, detailed neuro-ophthalmologic evaluations are a critical part of follow-up management. Similarly, patients with posterior fossa meningiomas presenting with hearing loss, or those patients whose surgery involved dissection of the cranial nerve complex VII–VIII, should have thorough audiologic evaluations as part of their postoperative management. Following resection of all meningiomas, a postoperative baseline MRI scan is obtained on day 1 or 2 after surgery. For benign tumors, following confirmation of total removal on postoperative MRI, further follow-up evaluation with imaging studies is performed every 1–3 years, depending on whether Simpson grade I or II removal was achieved. Following a subtotal removal, subsequent follow-up with MRI is done every year, with plans of adjuvant radiation if and when there is clinical or radiographic progression of the residual tumor. If the tumor is noted to be clinically and radiographically stable for a few years after initial surgery, the frequency of follow-up may be decreased to every 2–3 years. For atypical meningiomas, after initial postoperative MRI following either subtotal or total removal, subsequent evaluations with MRI are performed every 6 months for the first 2 years. As with benign tumors, radiation is considered in the presence of documented clinical or radiographic progression of the residual tumor. With malignant meningiomas, adjuvant radiation is administered shortly after surgery regardless of the extent of resection. However, if there is any reversible postoperative neurologic deficit from brain swelling or cranial nerve manipulation, the timing of radiation therapy should be delayed to allow for adequate recovery. Depending on the extent of resection, follow-up MRI scans are performed every 3–6 months.

References

1. Lee JH, Sade B, Choi E, et al. Meningothelioma as the predominant histological subtype of midline skull base and spinal meningioma. J Neurosurg 2006;105:60–4.
2. De Monte F, Al Mefty O. Meningiomas. In: Kaye AH, Laws ER Jr, eds. Brain Tumors. New York: Churchill Livingstone, 1995:675–704.
3. Mirimanoff RO, Dosoretz DE, Linggood RM, et al. Meningioma: analysis of recurrence and progression following neurosurgical resection. J Neurosurg 1985;62:18–24.
4. Simpson D. The recurrence of intracranial meningiomas after surgical treatment. J Neurol Neurosurg Psychiatry 1957;20:22–39.
5. Evans JJ, Hwang YS, Lee JH. Pre- versus post-anterior clinoidectomy measurements of the optic nerve, internal carotid artery, and opticocarotid triangle: a cadaveric morphometric study. Neurosurgery 2000;46:1018–23.
6. Sade B, Kweon CY, Evans JJ, et al. Enhanced exposure of the carotico-oculomotor triangle following extradural anterior clinoidectomy: a comparative anatomical study. Skull Base 2005;15:157–62.
7. Yonekawa Y, Ogata N, Imhof HG, et al. Selective extradural anterior clinoidectomy for supra- and parasellar processes. Technical note. J Neurosurg 1997;87:636–42.
8. Lee JH, Jeun SS, Evans J, et al. Surgical management of clinoidal meningiomas. Neurosurgery 2001;48:1012–21.
9. Yasargil MG. Meningiomas. In: Yasargil MG, ed. Microneurosurgery, Vol 4B. New York: Thieme, 1996:134–85.
10. Carvalho GA, Mathies C, Tatagiba M, et al. Impact of computed tomographic and magnetic resonance imaging findings on surgical outcome in petroclival meningiomas. Neurosurgery 2000;47:1287–95.
11. Dolenc V. Direct microsurgical repair of intracavernous vascular lesions. J Neurosurg 1983;58:824–31.