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Surgical Technique for Removal of Clinoidal Meningiomas

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Clinoidal meningiomas (CMs) are meningiomas arising from the meningeal covering of the anterior clinoid process (ACP). These tumors have been referred to by various other terms, such as medial or inner sphenoid wing meningiomas. In the literature predating the wide use of magnetic resonance imaging (MRI), which aids in correctly identifying the site of origin in most meningiomas, CM was often reported under the loose category of "suprasellar" meningiomas. In large meningiomas encompassing both the cavernous sinus (CS) and the clinoidal region, the exact site of origin, based on preoperative imaging studies, or at times even after an intraoperative inspection, is often difficult to determine. In these large tumors, the clinoidal origin is assumed in our practice if greater than two thirds of the tumor is extracavernous in location. Those tumors extending to the clinoidal region, but originating from the tuberculum sella, optic canal, orbital roof, planum sphenoidale, or middle or lateral aspects of the sphenoid wing, are not considered as CMs.

◆ General Considerations for Removal of Clinoidal Meningiomas

In 1983, Dolenc introduced an extradural technique of complete removal of the ACP. This technique, described as a component of a more extensive approach, was originally advocated as a critical step necessary to gain safe entry into the CS for direct surgical management of intracavernous vascular lesions. Later, the "Dolenc approach" was utilized for CS tumors, clinoidal segment internal carotid artery (ICA) and upper basilar aneurysms, and giant pituitary adenomas. Subsequently, a few others presented their experience with this technique, with some modifications, applied to surgery of a small number of parasellar/periclinoid region tumors such as craniopharyngiomas and suprasellar meningiomas.

Removal of the ACP provides improved exposure of the optic nerve (ON) and the ICA, enhancing access to the pathology around these structures as well as within the optic canal. Additionally, by opening the optic nerve sheath (ONS) as an extension of the dural incision following anterior clinoidectomy, the ON can be decompressed and visualized early and mobilized safely during surgery, thereby reducing the risk of intraoperative injury to the ON. In cases of large tumors encasing the ON and the ICA, the traditionally recommended surgical technique for removal has been to first identify the distal middle cerebral artery (MCA) branches and follow these vessels proximally toward the ICA with further tumor removal and dissection. However, until the ICA and eventually the intradural ON are located, surgery progresses very slowly. More importantly, the risk of intraoperative neurovascular injury persists during surgery because the exact location of the ON and ICA remains unknown to the surgeon, and the ON remains compressed. During this time, any minor surgical retraction, dissection, or tumor manipulation may add further compression to the ON, especially against the falciform ligament. To circumvent these critical problems, the ON can be exposed and simultaneously decompressed early in the surgery by unroofing the optic canal, followed by anterior clinoidectomy and then opening the ONS. The location of the optic canal, and therefore, the intracanalicular segment of the ON, is fairly constant; only the intradural cisternal segment of the ON varies in location depending on how the tumor causes nerve displacement during its growth. The exposed ON 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 ON. Complete ONS opening, along the length of the nerve within the optic canal to the anulus of Zinn, relieves any focal circumferential pressure on the ON contributed by the falciform ligament. ON decompression, thus achieved, 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 recurs, because the ON is already decompressed from the surrounding falciform ligament and optic canal, the patient's impending visual deterioration may be delayed.

In this chapter, we describe a skull base technique, modified from the original Dolenc approach, consisting of extradural clinoidectomy coupled with optic canal unroofing and ONS opening. We also outline several key advantages provided by the skull base technique, and our current indications for its use. The advantages provided by the skull base technique include (1) early localization and exposure of the ON and the adjacent ICA, (2) complete decompression and mobilization of the ON, (3) expansion of various operative windows, (4) facilitation of access to difficult locations, and (5) facilitation of aggressive removal of tumor, as well as the involved bone and dura.

◆ Patient Selection

Indications for the use of the skull base technique for CMs (and other tumors in the periclinoid region) in our practice include those lesions (1) causing ON or chiasmatic compression based on preoperative ophthalmologic evaluations, (2) encircling or covering the ON and ICA on preoperative MRI studies, (3) extending into the optic canal, subchiasmatic/infraoptic regions, or CS, (4) in patients with limited operative windows (e.g., patients with prefixed chiasm), and (5) causing extensive involvement of the surrounding bone and dura. When tumors are relatively small (3 cm or less) and not causing any significant preoperative visual deficits, surgical resection can be done utilizing standard pterional craniotomy without the added skull base exposure.

For relatively young patients, those with at least 15 years remaining in their life expectancy, we recommend surgery at the time of tumor detection regardless of the size, even in incidental tumors. This immediate intervention is a conscious attempt to provide these patients with total resection and the best possible outcome before these tumors become larger and pose increased surgical risks.

Alternatives to Surgery

Treatment options other than surgery include observation and radiation therapy. Final treatment plans must be individualized for each patient based on age, overall condition, and the patient's personal wish after a thorough discussion of all options. Because people are living longer and healthier lives, there is no specific age limit above which no surgery is recommended. However, given the fact that many meningiomas are slowly progressive, nonoperative options may be considered for patients with less than 10 to 15 years remaining in their life expectancy. Observation alone is reasonable for patients in this group if they have minimal or no symptoms; for those in this age group with significant neurological deficits or with documented radiographic progression, radiation therapy or radiosurgery may be a good option. Radiosurgery can be utilized for lesions less than 2.5 to 3 cm in diameter. However, the tumor's proximity to the optic apparatus must be carefully analyzed to avoid any radiation injury to the optic nerve/chiasm. For those patients with residual tumors following initial resection, adjuvant radiation, either in the form of radiosurgery or radiation therapy (conventional or conformal) depending on the size and proximity to the optic apparatus, may be considered.

◆ Preoperative Management

Symptomatic patients with a significant amount of peritumoral edema seen on preoperative T2-weighted MRI may be started on dexamethasone as an outpatient for 1 to 2 weeks. Anticonvulsants are started preoperatively for patients who present with seizures. Otherwise, a loading dose of phenytoin is given at induction of anesthesia, and then therapeutic levels are maintained postoperatively for 1 to 6 weeks, depending on the tumor size, brain manipulation required during surgery, and extent of pre- and postoperative swelling. All patients undergo detailed neuro-ophthalmologic evaluations pre- and postoperatively.

Routine preoperative angiogram is no longer performed in these patients in our practice. In the past, patients with large clinoidal tumors completely circumscribing the ICA and its branches underwent a test balloon occlusion (TBO) of the ICA. Such information may be helpful because it allows the surgeon to plan the extent of resection around the ICA. For patients passing the TBO, an aggressive tumor resection may be pursued, and in the rare event of intraoperative ICA injury, the surgeon has the options of direct ICA repair, bypass, or ICA sacrifice. However, if the patient does not pass the TBO, tumor resection around the ICA may be more limited to prevent a devastating stroke. Another option is to perform an arterial bypass in preparation for an aggressive tumor resection. Embolization is not possible in these tumors because their main vascular supply is from branches of the ophthalmic artery, ICA, and surrounding small pial vessels.

◆ Operative Procedure

The same basic principles of meningioma surgery apply to CM removal as well, with minor modifications dictated primarily by the unique anatomical considerations inherent to the clinoidal region. These basic surgical principles, applicable to CM, include (1) optimal patient positioning, incision, bone removal; (2) when possible, tumor devascularization; (3) early localization, exposure, and decompression of the ON and ICA; (4) following the ON and ICA into the tumor; (5) internal tumor debulking; (6) extracapsular devascularization and dissection; (7) preservation of the adherent/surrounding neurovasculature; (8) removal of the involved bone and dura; (9) dural reconstruction and closure.

The surgical steps involved in the skull base technique utilized in removal of CMs can be summarized as follows: (1) frontotemporal craniotomy, (2) sphenoid ridge drilling, (3) limited posterior orbitotomy, (4) posterolateral orbital wall removal (to completely decompress the superior orbital fissure), (5) optic canal un-roofing, (6) complete extradural anterior clinoidectomy, and (7) dural opening, with dural incision extending into the falciform ligament and the ONS.

Positioning

After induction of general anesthesia, the patient is placed in the supine position, with the head fixed in a Mayfield three-pin head holder. The head is then rotated 30 degrees to the side contralateral to the tumor. The head of the bed is elevated ~20 degrees.

Incision

A standard curvilinear frontotemporal incision is made following injection of 15 mL of 0.5 % Xylocaine/1:200,000 epinephrine. The incision is initiated just above the palpated zygoma, 1 cm anterior to the tragus, extending superiorly, then curving anteriorly from the superior temporal line to the midline, just to the limit of the hairline. The skin flap and the underlying temporalis fascia/muscle are elevated and reflected anteriorly as separate layers.

Craniotomy

A standard frontotemporal craniotomy is performed. The craniotomy is extended into the anterior frontal region by 1.5 to 2 cm from the "key hole," made parallel to the superior orbital rim to allow for subsequent extradural exposure of the orbital roof and optic canal. The size and shape of the frontal sinus are carefully appreciated from the preoperative MRI, so that if possible, entry into the lateral margin of the frontal sinus is avoided during the frontal extension of the craniotomy. If the frontal sinus is entered, it is repaired with a temporalis muscle graft followed by reinforcement with a pericranial flap.

Skull Base Technique

The lateral sphenoid ridge is drilled, followed by performing a limited posterior orbitotomy. The sphenoid bone drilling is achieved by using a 6-mm round cutting bur. Orbitotomy and subsequent skull base drilling are then performed using a 4-mm coarse diamond bur. The posterolateral orbital wall is then removed to completely decompress the superior orbital fissure. The roof of the optic canal is then drilled with a diamond bur. During this stage, copious irrigation is critical to prevent potential ON damage by the heat generated from drilling. The bone overlying the optic canal is made paper-thin with the drill, and the remaining bone is then easily removed using a microdissector or a microcuret. While the medial aspect of the optic canal roof is being drilled, entry into the ethmoid or sphenoid sinus must be avoided. If an entry is made, a small temporalis muscle graft is used to cover the opening at the time of closure, further reinforced using a piece of blood-soaked Gelfoam. This extradural dissection and exposure requires some degree of frontal lobe retraction. Rather than using a fixed retraction system, we prefer dynamic retraction utilizing the suction tip held in one hand of the surgeon to gently retract the brain. Although many neurosurgeons advocate using lumbar cerebrospinal fluid (CSF) drainage, in our practice the lumbar drain is not used. We believe that the CSF in the subarachnoid space (including within the ONS) protects the brain and ON from intraoperative injury.

After exposure of the ON within the optic canal is completed, the dura is then circumferentially dissected off the ACP. The ACP is now ready to be removed. In situations of significant hypertrophy of the ACP, the center of the ACP and hypertrophied optic strut is drilled, followed by removal of the remaining ACP by using a small straight-tipped Lempert rongeur. With nonhypertrophic ACP removal can be done by gently manipulating the ACP to fracture the optic strut. During this maneuver, one must be careful not to cause any damage to the adjacent ON, ophthalmic artery, or anterior loop of the ICA. If the fracture technique cannot be performed using minimal force, then the remainder of the ACP can be drilled intradurally under direct visualization. Often, brisk venous bleeding is encountered from the triangular space occupied by the removed ACP. This can be readily controlled by gently packing the extradural triangular space with a small piece of Gelfoam. Aggressive packing should be avoided to minimize compressive injury to the ON or the oculomotor nerve. A brief summary of these extradural steps is as follows: (1) a standard frontotemporal craniotomy, (2) lateral sphenoid wing removal, (3) posterior orbitotomy, (4) complete bone removal surrounding the superior orbital fissure, (5) optic canal unroofing, and (6) anterior clinoidectomy **(Figs. 18–1 through 18–4).**

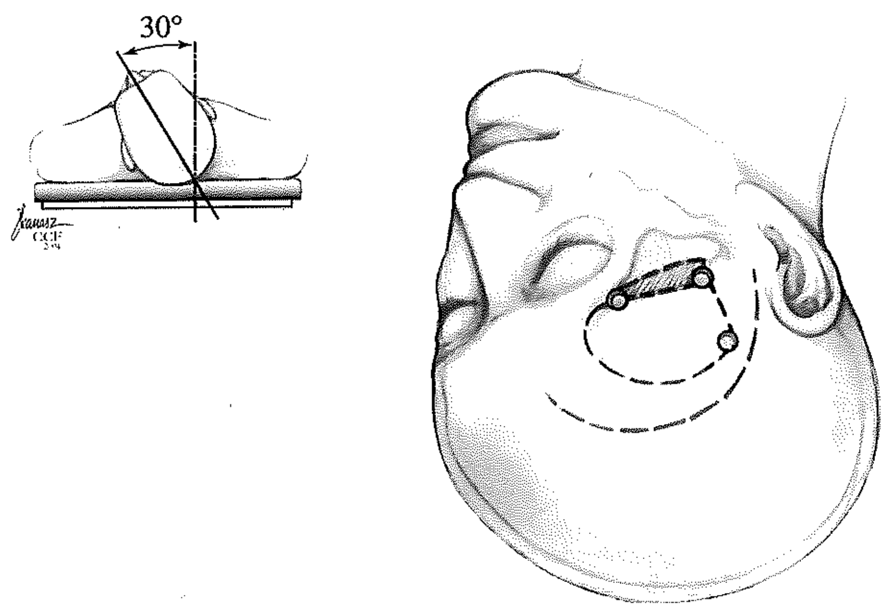


Figure 18–1 Operative position of the patient's head (Mayfield head holder not shown). The head of the bed is raised 15 to 20 degrees and the patient's head is rotated 30 degrees away from the side of surgery (inset). A standard curvilinear incision is made behind the hairline (brown broken line). A frontotemporal craniotomy is turned following placement of three bur holes. The craniotomy flap is depicted by the black broken line, and the shaded area represents the bone drilled from the lateral sphenoid wing after performing the craniotomy.

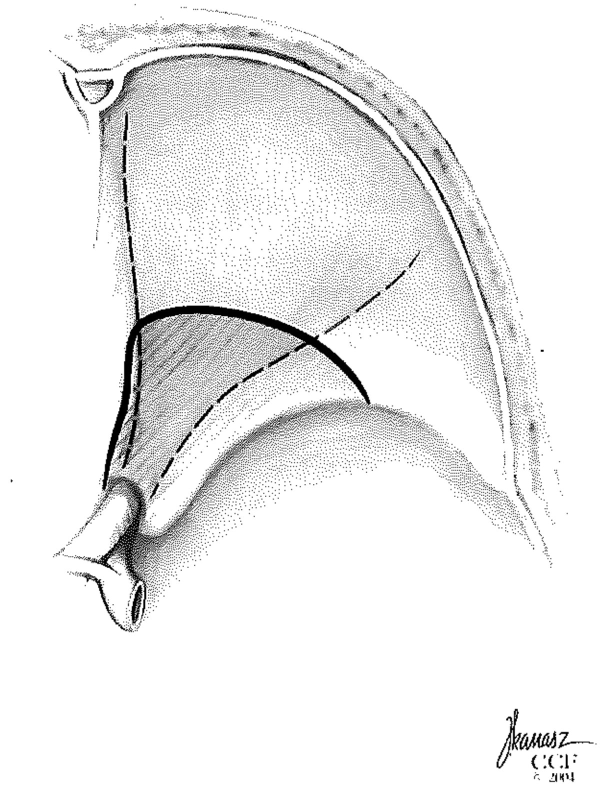
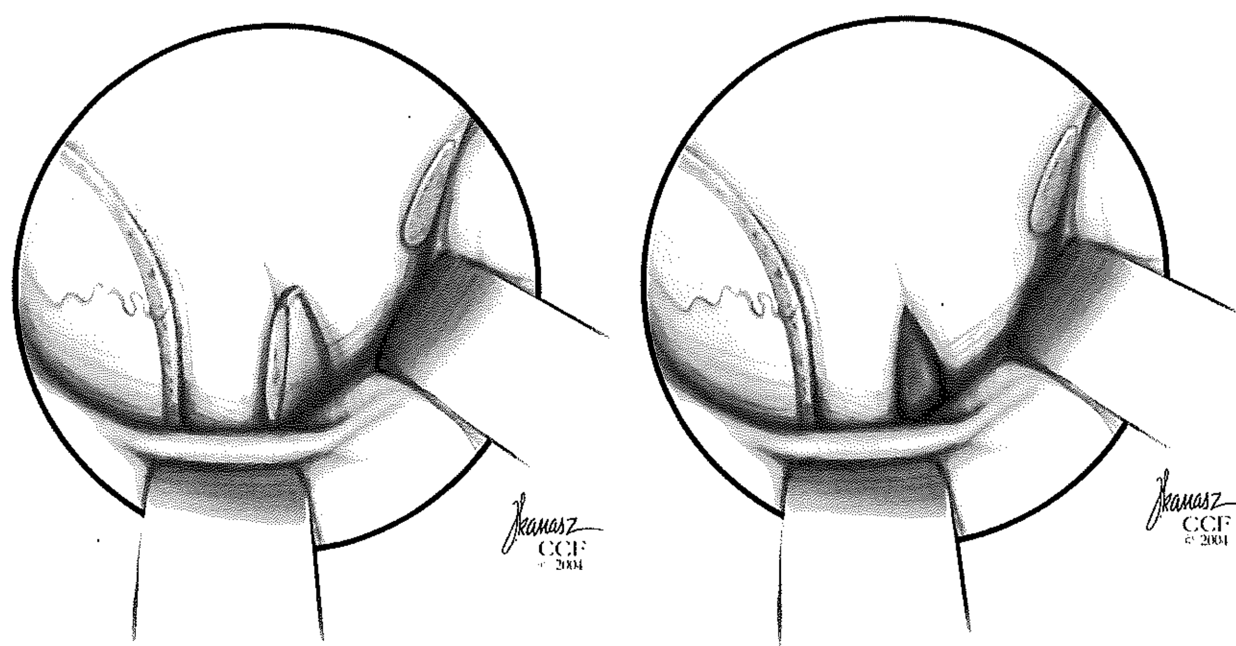


Figure 18–2 The shaded area depicts the bone removed during the skull base technique, including the lateral sphenoid wing, posterolateral orbital wall, posterior orbital roof, optic canal roof, and anterior clinoid process.

Dural Opening

The dura is opened in two steps. First, a frontotemporal curvilinear opening is made centered over the sylvian fissure, followed by a second incision bisecting the dural flap directed toward the falciform ligament. An operating microscope is brought in at this point, and the dural incision is continued from the falciform ligament along the length of the exposed ONS within the optic canal, extending to the anulus of Zinn. Cutting of the falciform ligament, and subsequently the ONS, is best performed by using a right-angle arachnoid knife or a "beaver blade." This completes the full exposure and decompression of the extradural ON, which can then be followed easily toward the tumor with exact knowledge of the ON's location (**Figs. 18–5 through 18–7**). The intradural ICA, located immediately lateral to the prechiasmatic ON, is easily identified by dissecting and removing tumor around the already exposed ON. In comparison, **Fig. 18–7** upper left depicts the conventional intradural exposure, not utilizing the skull base technique and opening of the ONS, in which the tumor is noted to be covering all the critical neurovascular structures.



A B

Figure 18–3 Extradural operative view of the exposed intracanalicular optic nerve and the opened superior orbital fissure (A) before and (B) after complete removal of the anterior clinoid process.

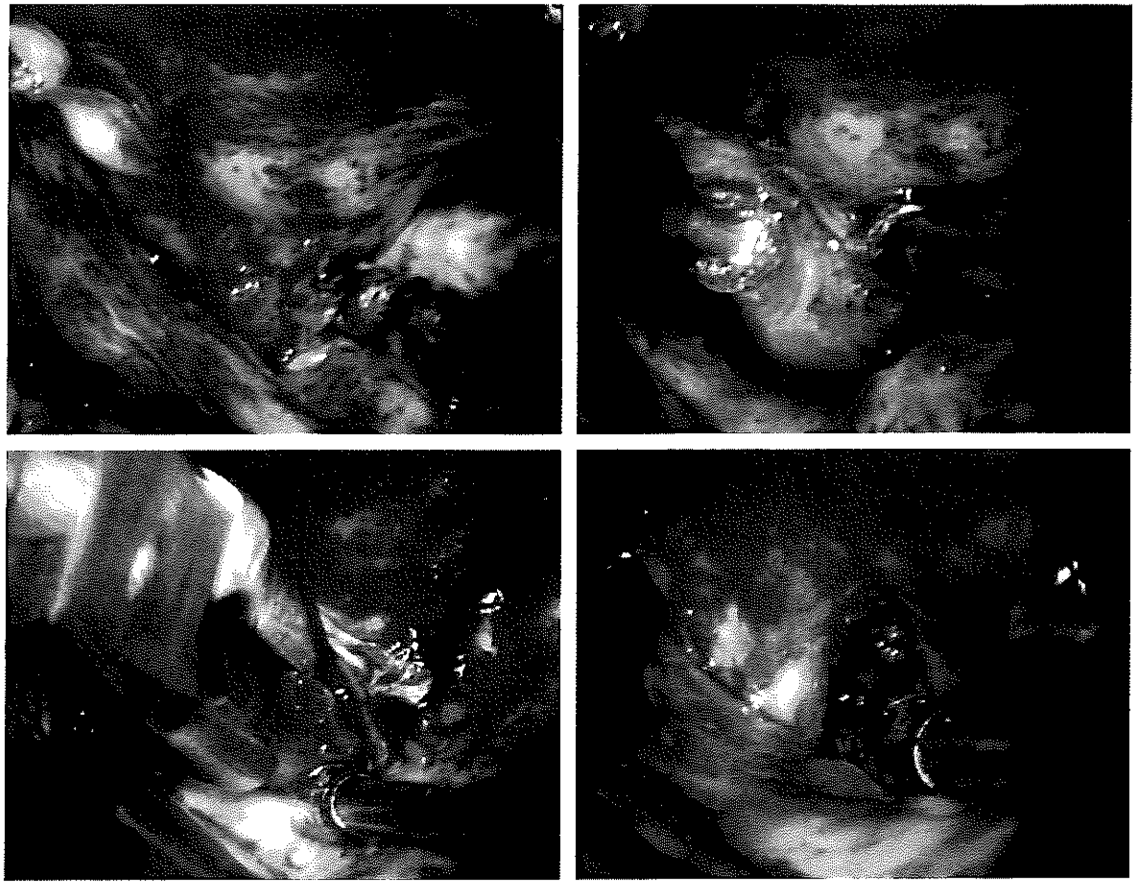


Figure 18–4 Intraoperative photographs of the right-sided extradural skull base technique. Upper left: Posterior orbitotomy is completed, and the superior orbital fissure is completely opened. Upper right: Unroofing of the optic canal is being performed with a 4-mm diamond bur. Lower left: The anterior clinoid process (ACP) is being manipulated to fracture off of the remaining attachment at the optic strut. Lower right: Extradural view of the exposed intracanalicular optic nerve after completion of the skull base technique including extradural removal of the ACP.

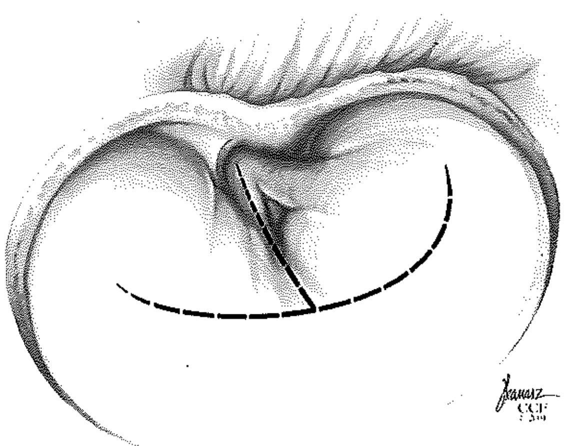


Figure 18–5 Extradural view after completion of the skull base technique, including (1) frontotemporal craniotomy, (2) lateral sphenoid wing removal, (3) posterior orbitotomy, (4) superior orbital fissure decompression, (5) optic canal unroofing, and (6) extradural anterior clinoidectomy. The dural incision (broken line) is made in two steps: First, a frontotemporal curvilinear opening is created, centered on the sylvian fissure, followed by bisection of the dural flap toward the optic sheath and extending across the falciform ligament and to the anulus of Zinn.

Tumor Removal

Although the tumor may completely cover, circumscribe, and/or displace the intradural ON and the ICA, with the ON now exposed and decompressed, and with the intradural ICA localized, subsequent tumor removal can progress with ease. Moreover, because the ON is no longer compressed by the falciform ligament following complete opening of the ONS, the ON can now be safely manipulated and gently retracted to enlarge the interoptic and opticocarotid spaces during subsequent tumor removal. The undersurface of the ON and chiasm is also readily and safely explored. In most cases, as the arachnoid around the ON and ICA is maintained, careful dissection of the tumor off of these critical neurovascular structures is possible. Tumor extension into the optic canal is also removed, with care exercised to prevent any damage to the ophthalmic artery. The tumor is removed, in large part, using suction and bipolar coagulation. In firm tumors, an ultrasonic aspirator or careful use of microscissors facilitates piecemeal removal. Central tumor debulking facilitates dissection of the tumor off of the surrounding critical neurovascular structures.

After initial debulking of the anterior aspect of the tumor, having established the exact intradural locations of the ON

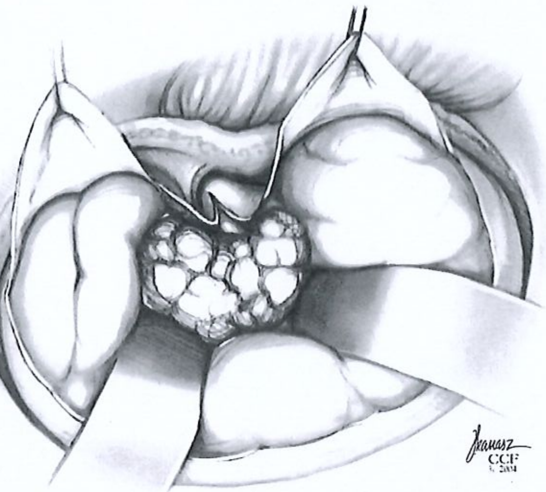


Figure 18–6 View of a clinoidal meningioma following completion of the skull base technique and extending the dural incision into the optic sheath. The optic nerve is readily identified in the exposed optic canal and completely decompressed at the onset of tumor removal. Tumor resection progressed by following the optic nerve proximally. The combination of early identification and decompression leads to prevention of intraoperative optic nerve injury.

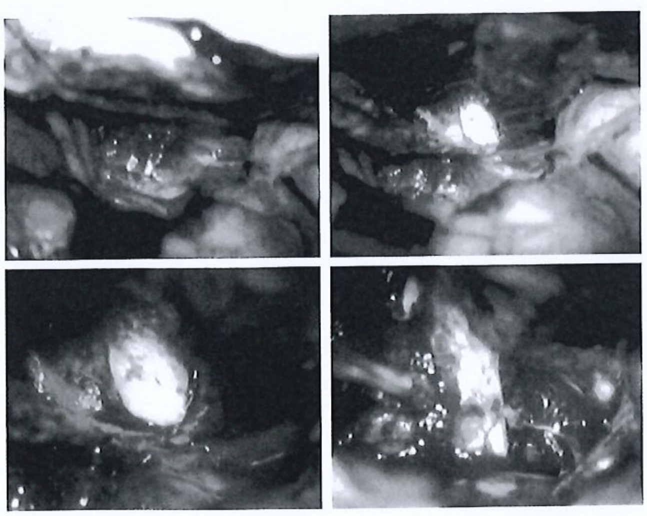


Figure 18–7 Intraoperative photographs of tumor and optic nerve exposure. Upper left: View of the clinoidal meningioma following a conventional technique of tumor exposure, not utilizing the skull base technique. Note that the tumor covers the optic nerve and internal carotid artery (ICA). Upper right: Following completion of the skull base technique, the optic nerve within the canal is readily localized. The initial dural flap has been bisected with microscissors. The optic sheath has not been opened. Lower left: The same view as the Upper right under higher magnification. Lower right: The optic nerve is completely exposed and decompressed by opening the optic sheath. A linear contusion is seen where the falciform ligament was compressing on the nerve. The optic nerve is further exposed proximally as tumor removal progresses. The ICA (not shown) can be readily located just lateral to the exposed intradural optic nerve.

and ICA, attention may be directed at exposure and removal of the remainder of the tumor. The sylvian fissure is opened, and both the frontal and temporal lobes gently retracted. Particular attention is paid to preserve branches of the ICA and MCA. In large tumors, several arterial branches are often seen coursing into the tumor or around the capsule. Until their final course can be determined, confirming that these are indeed arterial branches feeding the tumor, the vessels should not be sacrificed. When dissecting the tumor off of the ON or the chiasm, fine vessels coursing on the undersurface (which provide main blood supply) to the optic apparatus must be preserved. In dissecting the tumor extending into the suprasellar region, the pituitary stalk, which is usually displaced posteriorly and medially, must be recognized and preserved. Other neurovascular structures of critical importance include the oculomotor nerve, posterior communicating artery, anterior choroidal artery, and their branches, which are encountered during dissection of the inferior pole, and the A1 and M1 main trunks and their branches, which are encountered during dissection/removal of the posterior segment.

When dealing with a large tumor (>5 or 6 cm), the senior author (JHL) prefers to approach the tumor by subdividing the tumor into several segments or poles: (1) the anterior segment, located directly above the anterior prechiasmatic ON and the proximal ICA (proximal to the posterior communicating artery). This is the anterior pole of the tumor first encountered upon following the intracanalicular ON proximally; (2) the lateral segment, located lateral to the ICA main trunk, dorsal to the ICA branches (posterior communicating and anterior choroidal arteries) and the oculomotor nerve, and includes the portion of the tumor extending into the middle fossa floor; (3) the medial segment, located medial to the ICA main trunk, surrounding or displacing the posterior prechiasmatic ON and optic chiasm; (4) the posterior segment, located posterior to the ICA bifurcation, sometimes circumscribing the MCA, anterior cerebral artery (ACA), and their branches; (5) the inferior segment, located inferior to the optic chiasm and the ICA trunk and its branches, at times extending ventral to the oculomotor nerve. In this manner, the surgeon is, in principle, removing five small manageable tumors, rather than one large formidable tumor.

Not infrequently, a CM extends into the CS by following the oculomotor nerve through the porous oculomotoris or via transdural penetration. The dural fold forming the porous oculomotoris is opened completely to allow decompression of the oculomotor nerve, and the CS may be explored if the tumor is soft and amenable to further removal. If the CS involvement is extensive and the tumor is fibrous, surgery is stopped after confirmation of the following: (1) gross-total resection of the intradural extracavernous portion of the tumor and removal of any accessible tumor-involved dura and bone, (2) decompression of the ON, and (3) decompression of the oculomotor nerve. Any involved dura not possible to remove is aggressively coagulated. Occasionally, the distal carotid dural ring may be involved by the tumor, which should also be removed down to the base. Any further bony hyperostosis is drilled using a 2- or 4-mm diamond bur, with care taken not to enter the surrounding sphenoid or ethmoid sinuses.

Closure

The dura is reapproximated with multiple interrupted sutures. The dural defect along the skull base is covered with commercially available collagen dural substitute. No attempt is made for a watertight closure because this is neither necessary nor possible following extensive resection of the dura involved by tumor at the skull base. The bone flap is replaced and secured with titanium miniplates and screws. Closure of the temporalis muscle/fascia and the scalp is then performed in a routine fashion.

◆ Postoperative Management

Because of the proximity of the ON to the ACP, patients with CM most commonly present with monocular visual deterioration, which is often unrecognized by patients until visual loss is severe and the tumor has reached a significant size. These tumors are often formidable to resect completely and safely, especially when their size becomes large enough to encircle, compress, and/or displace the adjacent ON, the ICA and its branches, and the oculomotor nerve. In the past, common morbidity associated with CM surgery included injury to the optic and oculomotor nerves, the ICA, and its branches. Total resection was possible in only a minority of cases, leading to early tumor recurrence and further deterioration of the patient. Many neurosurgeons, even today, recognizing the relatively high incidence of poor postoperative outcome for patients with these tumors, recommend conservative subtotal resection with or without postoperative radiation therapy. Others advocate an even more conservative approach, using radiation as the sole treatment. Additionally, most asymptomatic patients with CM are often observed with serial MRI scans.

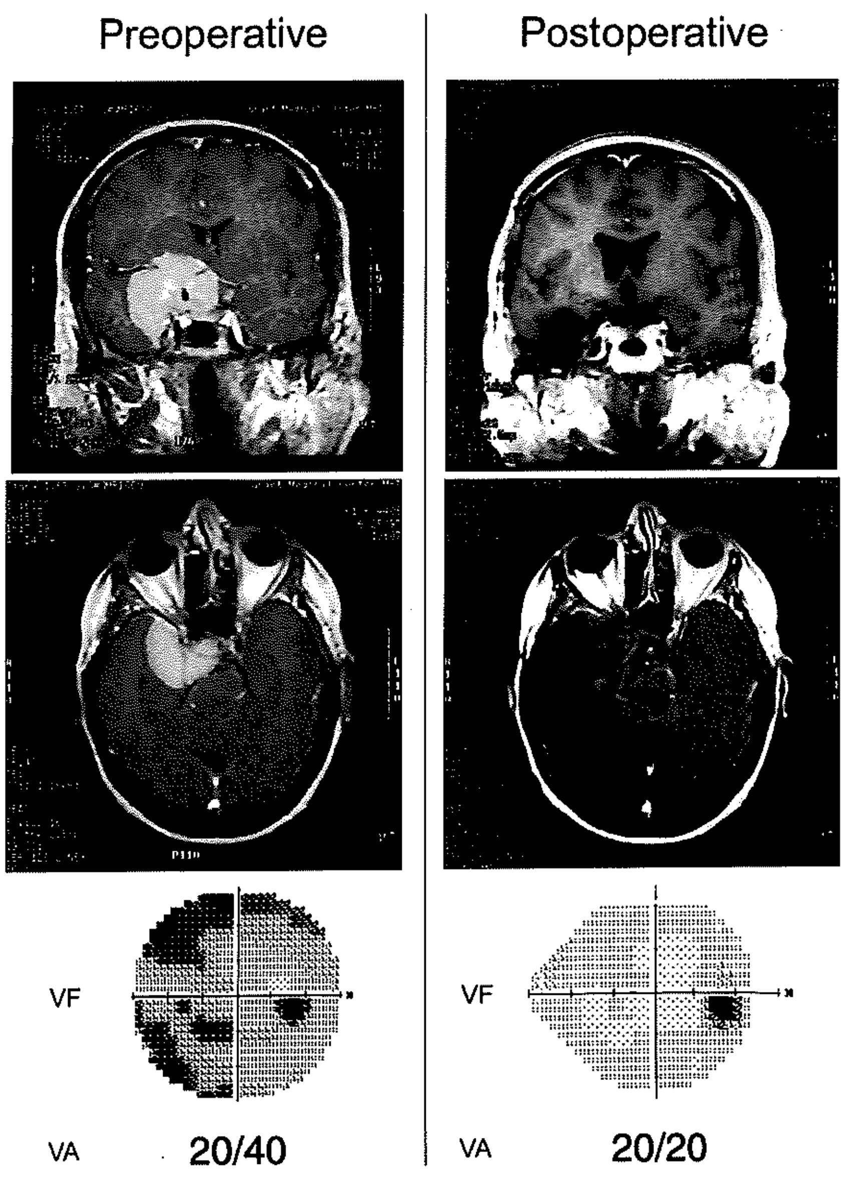


Figure 18–8 Upper and Middle Left: Preoperative coronal (upper) and axial (middle) contrast-enhanced T1-weighted magnetic resonance imaging (MRI) obtained in a 61-year-old woman. A 5-cm right clinoidal meningioma is present, encasing both the right internal carotid artery and optic nerve. Lower Left: She presented with decreased visual acuity (20/40) and visual field deficit as depicted on her Humphrey's perimetry. Upper and Middle Right: Postoperative contrast-enhanced MRI reveals complete resection of the tumor. Lower Right: Her visual acuity returned to 20/20 and her preoperative visual field deficit completely resolved.

During the past few decades, the primary goal of surgical management for patients with CM focused on maximizing the extent of resection and reducing the operative morbidity/mortality without any particular attention paid to enhancing visual outcome. In fact, reporting has been very limited regarding the patients' visual status. Moreover, the past views regarding postoperative visual recovery in patients with CM have been quite pessimistic. Poor visual outcome was previously attributed to an ischemic mechanism of preoperative visual loss, and visual deficits were considered mostly irreversible. At best, only a fraction of the patients with preoperative visual deterioration experienced visual improvement after removal of their CM (up to 30 to 40%), and many even noted visual worsening. There is a clear need for further efforts directed at improving the overall, and particularly, the visual outcome in patients with CM. Today, with advances in neuroimaging, which allows the detection of small tumors at the onset of symptoms, in addition to improved microsurgical techniques, skull base exposures, and neuroanesthesia, CM surgery can be far less risky. We propose that by utilizing the surgical technique delineated in this chapter, it is possible to attain gross total removal with minimal morbidity, and more importantly, to achieve postoperative visual improvement in the majority of patients with CM.

◆ Summary

The surgical steps involved in the skull base technique utilized in removal of CMs can be summarized as follows: (1) frontotemporal craniotomy, (2) sphenoid ridge drilling, (3) limited posterior orbitotomy, (4) posterolateral orbital wall removal (to decompress the superior orbital fissure), (5) optic canal unroofing, (6) complete extradural anterior clinoidectomy, and (7) dural opening, with dural incision extending into the falciform ligament and the ONS.

The described skull base technique provides several critical advantages, which result in improved extent of resection and outcome. These include (1) early localization and exposure of the ON and ICA; (2) complete mobilization and decompression of the ON and ICA, which prevent or minimize intraoperative neurovascular injury; (3) expansion of various operative windows, particularly the opticocarotid triangle; (4) facilitation of access to difficult locations, especially in dealing with tumor extension into the orbit, sella, optic canal, CS, orbital apex, or the infraoptic and subchiasmatic regions; and (5) facilitation of aggressive removal of tumor as well as the involved bone and dura. The main goals of surgery are to achieve aggressive tumor removal with avoidance of intraoperative morbidity and, ultimately for those with preoperative compromised vision, to provide improvement in their visual function following surgery **(Fig. 18–8)**.