Cavernous Malformations

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Checklist for Cavernous Malformation Surgery

Equipment needed	Procedural steps
Surgical • Surgical microscope, ideally with neuronavigational capability • Neuroendoscope: straight and angled views • Lighted bipolar forceps ± lighted retractor • Long instruments (suction, micro-bipolar, microscissor) • Ultrasound (spine lesions) • Bipolar and unipolar stimulators **Anesthesia** • Mannitol • Arterial line • Coordination with neurophysiology • ETT • $EtCO_2$ monitor • Perioperative antibiotics • Warming prophylaxis • Appropriate padding for pressure points • Central line/precordial Doppler (sitting position) **Neurophysiology** • SSEP • MEP • BAER • CN monitors • ECoG if necessary **Neurosurgeon** • Frameless stereotactic navigation	**Craniotomy** • Adequate exposure based on selected approach • Meticulous hemostasis • Appropriate durotomy—recheck with stereotaxy prior to opening • CSF drainage and cerebral relaxation **Subarachnoid Dissection** • Careful arachnoid dissection focused on maximizing exposure of pial/ependymal surface target entry zone • Mobilize neurovascular structures as necessary; attention to venous angioma • Stimulation to identify eloquent structures • Careful search for any pial discoloration/abnormality • Confirm entry point with neuronavigation **Lesion Resection** • Sharp pial/pseudocapsule entry • Widen exposure of CM with gentle stretching of fibers • *do not* resect gliotic pseudocapsule in brainstem and deep-seated lesions • Judicious use of bipolar for deep/brainstem lesions • Lesion removal with sharp dissection/suction • Gentle tamponade and irrigation to control bleeding • Endoscopic cavity inspection

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Complication Avoidance Flowchart

Complication	Cause	Remedy	Avoidance
New neurologic deficit	Selection of surgical corridor	–	– Study images closely – fMRI/tractography – Use surgical adjuncts (navigation, neuromonitoring, stimulation mapping)
	Surgical technique	–	– Stretch fibers – Minimize bipolar use – Gentle tamponade for bleeding
Incomplete resection	Surgical technique	Consider reoperation if symptomatic	– Endoscope – Lighted instruments
Persistent epilepsy	Inappropriate lesion selection	Consider reoperation	– Consider preoperative invasive monitoring in select cases
	Inadequate resection	Consider reoperation if possible	– Utilize ECoG – Consider cortical/subcortical or awake mapping
Venous infarction	Loss of associated DVA	–	– Select appropriate approach – Respect-associated DVA
Postoperative aspiration	New or worsened postoperative dysphagia	Intubation/trach as needed – Antibiotics – PEG if necessary	– Routine postoperative swallowing interrogation
			– Consider preop PEG/trach
Postoperative hematoma	Violation of DVA poor cavity hemostasis	Consider benefit of reoperation	– Meticulous hemostasis – Consider benefit of lining the cavity with cellulose

Introduction

Cavernous malformations (CM) represent a relatively common vascular lesion occurring in an estimated 1 in 200 people [1]. Although CMs have long been recognized as a pathological entity [2], their occult angiographic nature made them difficult to diagnose preoperatively. More than anything else, it was the introduction of MRI that contributed most to our current understanding of theses peculiar lesions and led to their routine radiographic diagnosis [1, 3].

Complication Statistics

Complications associated with CM management are dependent on only two factors that are predictable: lesion location and method of presentation. Naturally, the approaches to less accessible, or deeper, lesions will be associated with a higher

complication rate while a complete resection with minimal morbidity should be the expectation for a superficial lesion. Similar to other lesions in the family of vascular malformations, a hemorrhagic presentation may frequently increase the accessibility of CMs to surgical resection. In other words the presentation may positively influence the decision for surgical resection. In general, surgery for supratentorial CMs in the post-MRI era can be associated with risks in the range of 3–4% [4, 5].

It is this low morbidity related to the resection of superficial lesions that has resulted in a large proportion of recent neurosurgical literature being focused on brainstem location and the complications that can arise from operating in what we generally refer to as "high-priced real estate." In their series of brainstem cavernous malformations, Abla et al. reported a 36% incidence of new or worsened permanent postoperative neurological deficit and a 28.5% complication rate including three deaths [6]. Garcia et al. reported a 9.6% rate of new permanent neurologic deficit, a 28% complication rate, and one death [7].

Outcomes

For deep-seated and brainstem CMs, operative complications and, in particular, new permanent neurologic deficits tend to be closely related to clinical outcome. This pertains to the relationship between the lesion and eloquent adjacent tissue as well as the unforgiving nature of brainstem injury. In their series of brainstem cavernous malformations treated surgically, Hauck et al. found that the surgical outcome was closely related to the patient's preoperative functional status [8]. Additionally, most authors have found a significant association between improved outcomes and younger patient age [7, 9]. This may relate to superior neuroplasticity in younger patients or the medical comorbidities which accompany advancing age.

The rate of neurologic worsening following surgery for complex CMs is relatively high. However, when patients are carefully selected, surgical treatment remains a much better alternative than the often dismal natural history. Thus, although a new neurologic deficit may be an undesirable outcome, it may not actually represent an "unfavorable" outcome.

Procedural Overview

The surgical resection of challenging CMs is a highly variable endeavor. Here we present four cases which were treated at our institution.

Case 1 (Fig. 17.1)

A 25-year-old female with a history of two hemorrhagic events. Preoperatively, she had left ptosis and a left CN VI and VII palsy which were both slowly improving. She also had decreased sensation over her left face and right hemibody. Her strength

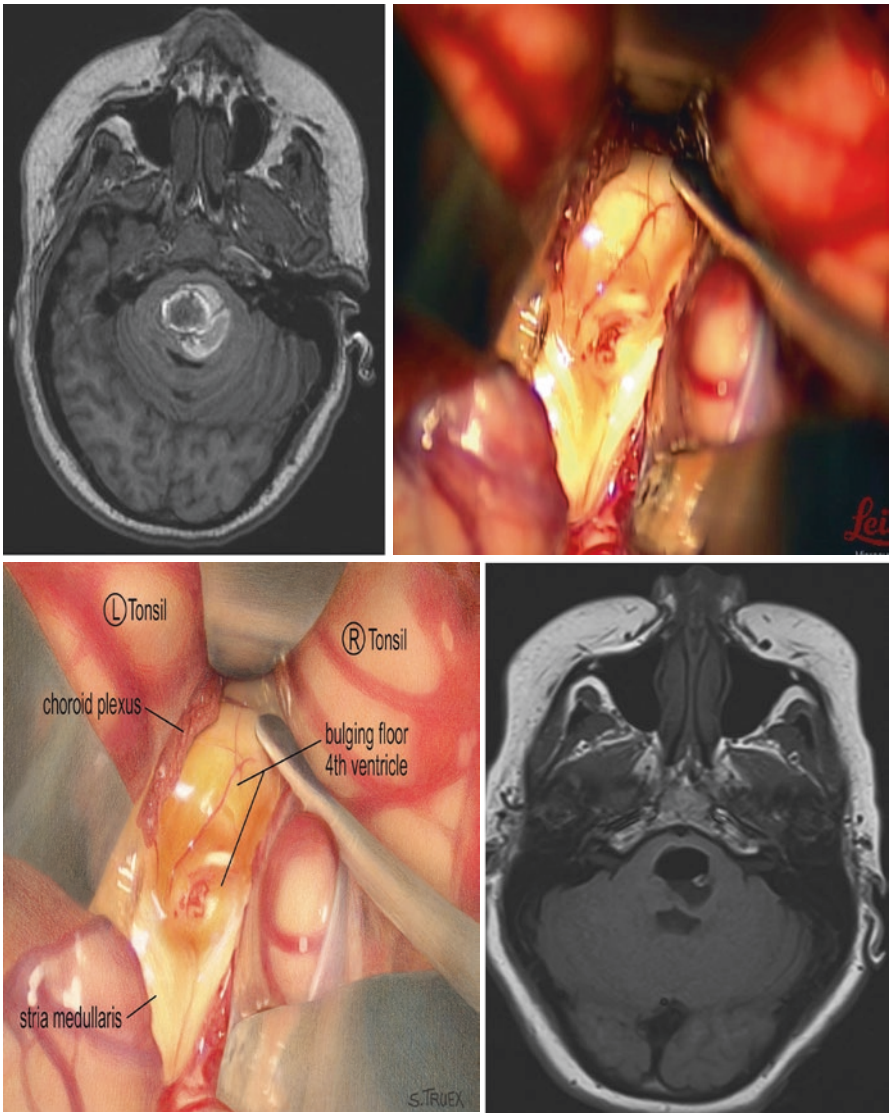

Fig. 17.1 (Case 1) Images clockwise from *top left*: (1) preoperative MRI, (2) intraoperative microscopic view, (3) postoperative MRI, and (4) cartoon of operative view 4

was normal in all four limbs. Her examination was otherwise pertinent for right-sided upper extremity dysmetria. This examination correlated with the radiological diagnosis of a CM effacing the fourth ventricular floor from the posterior pons.

A midline suboccipital craniectomy using frameless stereotactic localization with the patient in the prone position was planned. Subarachnoid dissection was performed through a telovelar approach. Neuromonitoring included SSEPs, MEPs, and bilateral CNVII monitoring.

The cerebellar tonsils were separated and the floor of the fourth ventricle identified.

A facial nerve stimulator was used to find the facial colliculi. Using a stereotactically registered probe placed through a shortened ventricular catheter, the most superficial point of entry of the CM was identified on the ventricular floor. The catheter was then gently inserted into the center of the lesion. The probe was removed, and fluid indicative of chronic hemorrhage spontaneously flowed out of the catheter. The catheter was then removed, and the entry point was gently dilated open with the tips of the bipolar. A combination of sharp dissection and suction was then used to evacuate the cavity through this opening.

Postoperatively her neurological deficits were unchanged. She did benefit from postoperative rehabilitation.

Three months following surgery, she was fully independent and had returned to work. Her left CN VI palsy had completely resolved, and her face was only slightly asymmetric when active but appeared normal at rest. She noted significant improvement in her left face and right hemibody sensation. Her right-sided ataxia had significantly improved.

Case 2 (Fig. 17.2)

A 25-year-old female awoke with headache and progressive blurring of her vision. On examination she was found to have a left homonymous hemianopsia. She had no motor or sensory deficits. This examination correlated with a mass lesion that superiorly displaced the left optic nerve and was most consistent with a CM.

With the patient positioned supine and the head rotated to the left, a modified orbitozygomatic craniotomy was used in which a standard pterional craniotomy was performed, followed by removal of the superolateral orbital wall.

The Sylvian fissure was opened sharply under high magnification. Once the optic apparatus was identified, sharp subarachnoid dissection was used to widen the opticocarotid window. Brain relaxation was gained though patient CSF removal. Next, the exophytic portion of the cavernous malformation was resected and used to create a pathway for internally debulking the lesion. The walls of the cavity were carefully inspected for any residual lesion and the gliotic pseudocapsule was left in place to avoid any unnecessary manipulation of the left optic nerve.

She was discharged home on postoperative day 6. She did well and returned to full time employment. Her left homonymous hemianopsia improved significantly but remained at a 2-year follow-up visit.

Case 3 (Fig. 17.3)

A 26-year-old male originally presented with sudden onset of occipital headaches, nausea, and vomiting accompanied by left face and arm weakness. He suffered two more episodes over the next few months before eventually being referred to our cerebrovascular center. At the time of presentation, his only deficit was numbness in

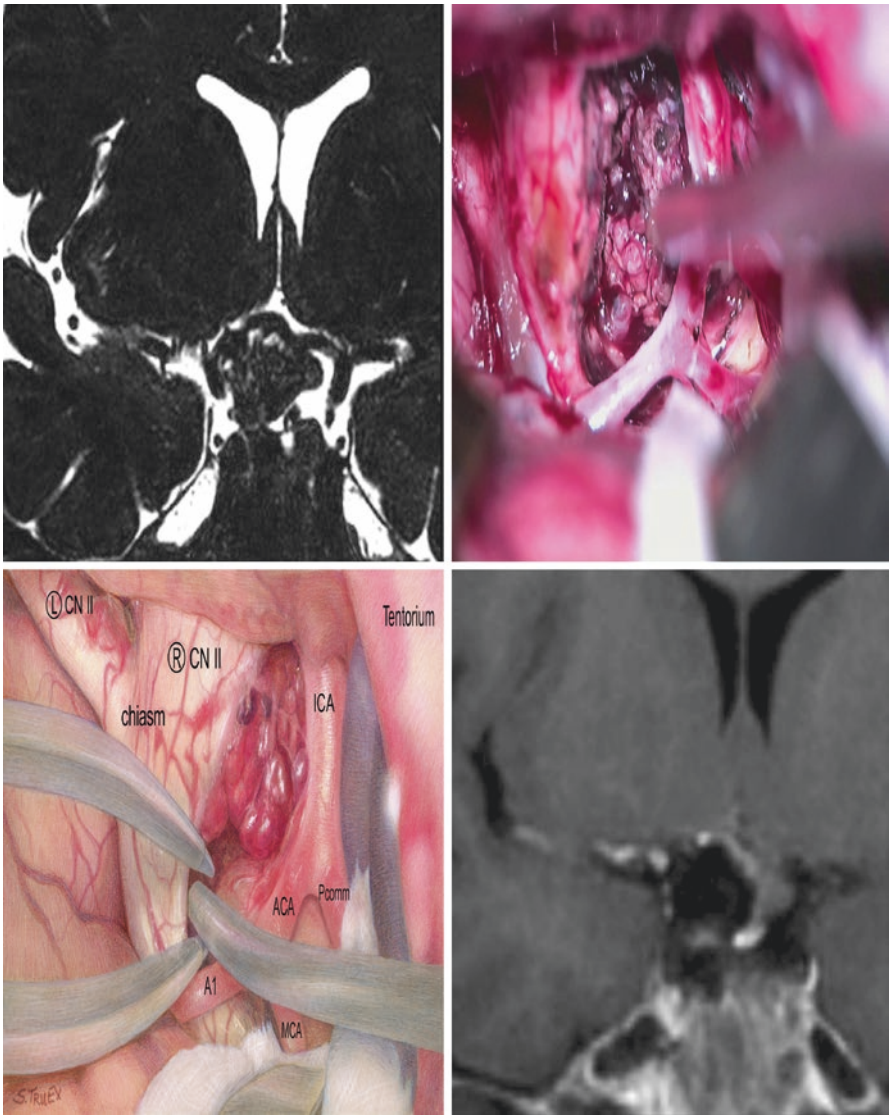

Fig. 17.2 (Case 2) Images clockwise from *top left*: (1) preoperative coronal MRI, (2) intraoperative microscopic view, (3) postoperative coronal MRI, and (4) cartoon of operative view

his left foot. He was hyperreflexic on the left side. His presentation was appropriate for the exophytic pontine cavernoma that was identified on his MRI. A suboccipital far-lateral approach with frameless stereotactic assistance in the lateral position was planned for resection. Neuromonitoring included SSEPs, MEPs, and bilateral CN VII and VIII monitoring.

A generous right far-lateral craniotomy was performed with drilling of the occipital condyle. It was not necessary to mobilize the ipsilateral vertebral artery.

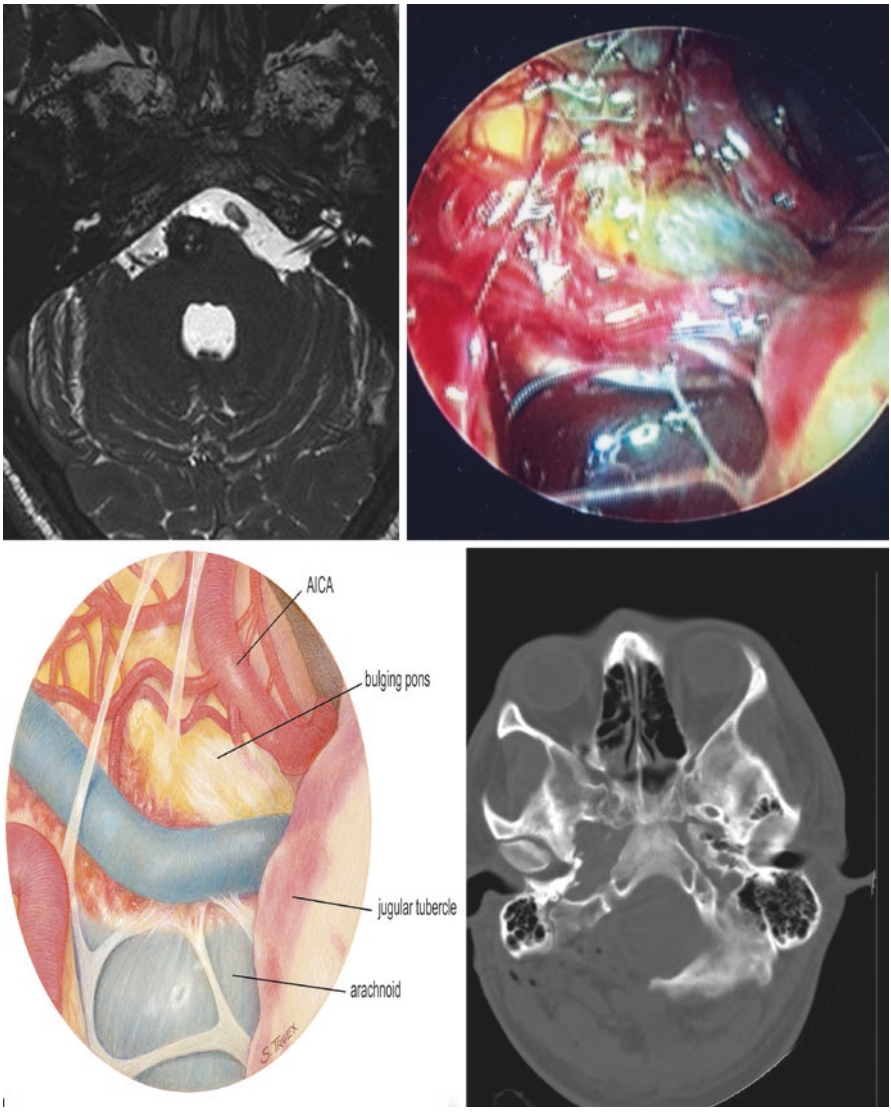

Fig. 17.3 (Case 3) Images clockwise from *top left*: (1) axial MRI demonstrating large exophytic lesion of the left pons, (2) intraoperative endoscopic view of pontine surface with CM visualized as discolored swelling of the pons, (3) postoperative CT demonstrating bony removal for operative approach, and (4) cartoon of intraoperative view

The bony opening was extended to include a retrosigmoid component. The dura was opened in a curvilinear fashion and bisected to allow for maximal lateral exposure. The arachnoid of the cerebellopontine angle was dissected sharply followed by patient CSF drainage to provide relaxation of the cerebellum. The arachnoid dissection then continued medially in order to mobilize the trigeminal nerve and SCA

artery. Venous sacrifice was minimized. The CM was visible on the surface of the pons as a tan protuberance. The capsule was cauterized and entered. Its contents were internally debulked using suction and gentle bipolar cautery. The capsule was left intact, and the cavity was inspected with a 30° endoscope to confirm complete resection.

The patient awoke from surgery with mild left-sided weakness which improved. He failed a postoperative swallow study and required a gastrostomy tube. He was eventually discharged home and had the gastrostomy tube removed 1 month following the surgery. He is neurologically normal and has returned to full-time employment with 5 years of follow-up.

Case 4 (Fig. 17.4)

A 51-year-old female originally presented with severe headaches. She had three episodes of acute decline over the following 4 years with symptoms including blurred vision, right hemibody sensory deficits, and right hemiparesis. She was transferred to our institution from out of state. At the time of presentation, she was no longer ambulatory and somewhat cognitively slowed. Imaging demonstrated mild hydrocephalus in addition to a large CM in the posterior aspect of the thalamus. A supracerebellar infratentorial approach to this region was planned in the sitting position with frameless stereotactic guidance.

With a right frontal external ventricular drain in place, the patient was positioned with careful attention to blood pressure control during her head elevation. Precordial Doppler and a right-sided internal jugular central line were in place for the management of potential air embolism. Neuromonitoring including SSEPs and MEPs was established.

A midline incision extending from above the inion down to C2 with self-retaining retractors was used to expose the suboccipital and posterior occipital bones. A craniotomy was fashioned around the torcular extending above the transverse sinuses and centered to the patient's left side. A persistent occipital sinus was sacrificed during the suboccipital exposure. The dura was opened and retracted toward the transverse sinus and torcular. Two small supracerebellar veins were sacrificed to permit gravity assisted retraction of the cerebellar hemispheres. Following deep subarachnoid dissection, the left pulvinar nucleus of the thalamus was identified and confirmed using stereotaxy. There was a discolored area on the lateral aspect. This region was cauterized and incised with microscissors. Blood of various ages was encountered and evacuated with suction and gentle bipolar cautery. Following this, a 30 ° neuroendoscope was used to fully inspect the walls of the cavity for any residual cavernoma tissue. The cavity was irrigated, and cellulose strips were used to gently tamponade any points of venous oozing from the cavity walls.

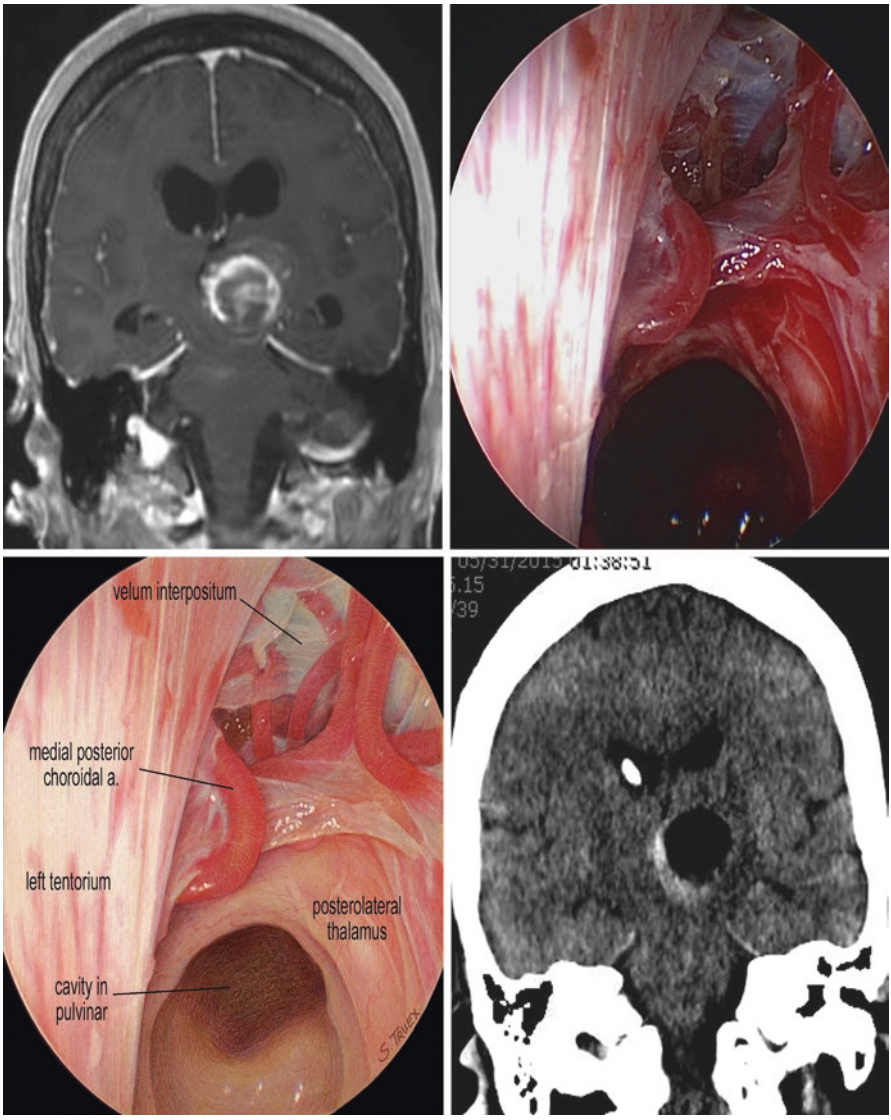

Fig. 17.4 (Case 4) Images clockwise from *top left*: (1) preoperative coronal MRI, (2) intraoperative endoscopic view, (4) postoperative coronal CT, and (5) cartoon of endoscopic view

She was left intubated for 24 h and then extubated. Her right hemiplegia was somewhat worsened postoperatively; however, this improved back to her preoperative baseline left-sided weakness. She was eventually transferred to an out-of-state rehabilitation facility 2 weeks after surgery.

Complication Avoidance

General Considerations

Imaging

The single biggest factor in avoiding complications and mitigating risk when treating patients with CMs lies in patient selection. The majority (70–80%) of CMs are asymptomatic, and thus surgery and its attendant risks are not indicated. The decision to offer surgical treatment should be individualized based on patient factors including mode of presentation, hemorrhage frequency, residual deficit, and lesion location. Any treatment plan should be created to approximate the quality of life that the patient expects using the best information available. In general, without more than one event and presentation to a pial (or ependymal) surface, surgery should be approached with extreme caution or not at all. Once a surgical discussion is held, it is reasonable to discuss temporary postoperative worsening of the patient's deficits. For brainstem lesions the chances of requiring temporary nutritional or ventilator support must be discussed in advance.

The surgical approach to any CM must be tailored to the lesion such that it traverses the least amount of eloquent tissue. Deep-seated and brainstem lesions require more thoughtful consideration. Preoperative permanent neurological deficits should be carefully considered as the approach can be tailored to take advantage of pre-existing deficits and the surgical corridors they may afford. The two-point method, where a straight line connects one point in the center of the lesion and the second point is placed on the pial or ependymal surface closest to the lesion, can be utilized as a guide [6]. The surgeon should be comfortable with the approach and confident that it will ensure adequate exposure of the target (see discussion below).

Usual operative strategies to maximize brain relaxation including intraoperative control of the $PaCO_2$ and the administration of Mannitol remain essential to the approach of CMs. A discussion with the neuroanesthesiology team the day before the case provides an excellent opportunity to anticipate and preemptively address logistical and technical considerations. This discourse should include the use of paralytics such as rocuronium and higher doses of inhalational anesthetics (e.g., sevoflurane) as this may interfere with neuromonitoring during the procedure.

Stereotactic image guidance is essential for all subcortical, deep-seated, and brainstem lesions. Most modern microscopes can be configured such that the focal point of the microscope becomes the stereotactic probe. This can be tremendously helpful for deep-seated and brainstem lesions as the "brain shift" expected during arachnoid dissection and CSF drainage is less, relative to more peripheral structures.

Neurophysiological monitoring is a useful adjunct that increases the safety profile of what is often a relatively high-risk procedure. Brainstem auditory-evoked responses, specific cranial (or spinal) nerve monitoring, somatosensory-evoked potentials, and motor-evoked potentials, along with cortical and deep white matter stimulation and mapping, can all be tailored depending on the location of the lesion

and the specific approach selected. Baseline recordings for noninvasive monitoring techniques should be established before positioning the patient.

Lesions at the end of narrow operative corridors can pose a challenge for the operating microscope, especially when inspecting the walls of the resection cavity. Lighted micro-instruments (suction and bipolar) are commercially available to help illuminate deep cavities. Endoscopes can also be used to augment illumination and visualization in such situations. The availability of multiple angled options can help to look around otherwise obscured corners to evaluate the completeness of any CM resection.

Intraoperative ultrasound can be a useful addition to cranial lesions for identifying subcortical lesions in real time. Such an adjunct can prove very helpful where shift has affected the accuracy of the frameless stereotactic system. As this is an older technology, many of the ultrasound probes are cumbersome, and image acquisition and interpretation are highly user dependent. Intraoperative consultation with a radiologist may be useful. For localizing spinal lesions following a posterior approach, we have found ultrasound to be very useful in planning both the durotomy and localizing lesions which do not obviously present directly to a pial surface.

Specific Considerations

Lobar Cavernous Malformations

Symptomatic lobar CMs are generally safe to resect, but certain principles should be kept in mind especially when dealing with lesions in, or adjacent to, eloquent cortex. The goals of surgery must be clear. Mitigation of hemorrhagic risk necessitates complete lesion resection while the surgical treatment of CM-associated epilepsy may also involve the resection of surrounding brain. Factors that may increase the chances of seizure freedom, particularly in difficult cases, should be evaluated in order to maximize the chances of seizure control but minimize neurological deficit. Many studies report better outcomes when the surrounding gliosis and hemosiderin fringe are removed [10, 11] while some authors have failed to find this relationship [12, 13]. When seizure freedom is a principle goal of surgery, we generally promote extra-lesional resection to include the surrounding gliotic and hemosiderin-stained tissue as dictated by the functional eloquence of the surrounding brain. Surgical adjuncts may include electrocorticography as well as sensory, motor, awake language, and deep white matter tract mapping.

From their review of existing literature encompassing 1226 patients, Englot et al. found that factors associated with seizure freedom following surgery were a duration of seizures less than 1 year, gross total resection, smaller lesion size (<1.5 cm), solitary CMs, and focal seizures without secondary generalization [14]. Hence, surgery for patients with generalized seizures and those with multiple lesions will have a lower chance of seizure freedom. In this meta-analysis, 75% of patients achieved seizure freedom following microsurgical lesion removal.

For those with multiple CMs (familial disease), the correct epileptogenic CM must be resected. Concordance between seizure semiology, EEG, long-term video EEG, and neuropsychological testing can help elucidate the correct seizure generator.

In those with discordant investigations, the chances of postoperative seizure freedom are substantially lower. Consideration should be given to invasive monitoring in order to further delineate the epileptic focus when there is uncertainty. Given that timing is important to achieving a seizure free status with surgery, it may be acceptable to determine a failure of antiepileptic treatment medication sooner than with other forms of epilepsy whose definitions are often more rigorous.

In patients with mesiotemporal CMs and those with concomitant mesial temporal sclerosis, consideration should be given toward resection of the mesial temporal structures (amygdala and hippocampus) in addition to CM resection. On the dominant side, this necessitates interrogation of the functional status of the hippocampus [15].

For supratentorial lesions in non-eloquent regions, the gliotic pseudocapsule can be used as a dissection plane to obtain a complete resection. Often gentle bipolar cautery can shrink the lesion thereby facilitating resection. For resection of CMs in language regions, functional MRI can help plan an appropriate surgical approach to the lesion. Strong consideration should be given to awake craniotomy with mapping of language to help guide resection of the CM (Fig. 17.5).

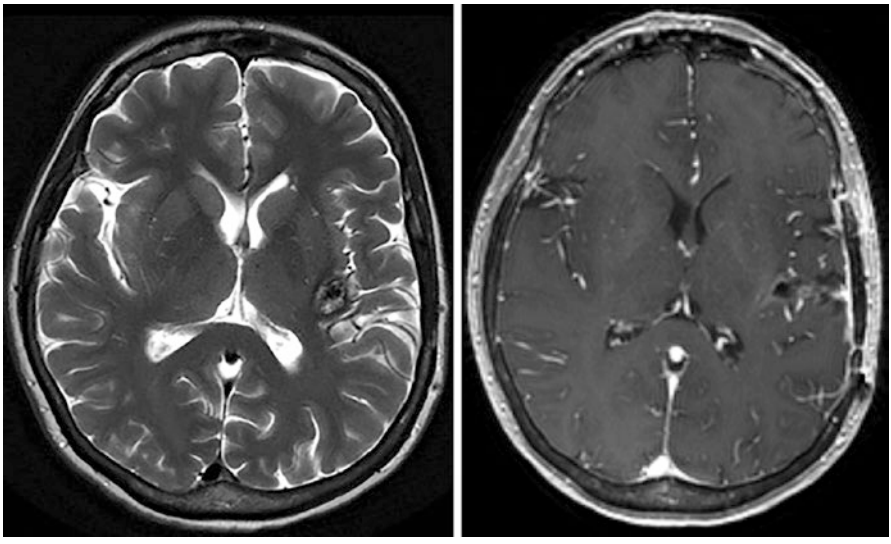

Fig. 17.5 Left pre- and right postoperative MRI of a 37-year-old female with poorly controlled seizures who underwent awake craniotomy with language mapping for resection of this left insular cavernous malformation. Postoperatively she had no language deficits. Her seizures are now well controlled on a single agent

Deep-Seated and Brainstem Cavernous Malformations

Cavernous malformations of the basal ganglia, thalamus, and brainstem represent a surgical challenge. Because the surgical risks in these regions are much higher and the potential for morbidity is greater, careful patient selection is of the utmost importance for these lesions. Relative to supratentorial lesions, the only surgical goal in these deeper lesions is complete resection of the lesion in order to prevent future hemorrhage. The probability of reversing a long-standing neurological deficit is very low, and they do not present with seizures.

The resection of deep-seated and brainstem CMs begins with the localization. Few feelings are worse in neurosurgery than the presumed inaccuracy of frameless stereotaxy during localization of a brainstem CM. Careful attention to image acquisition and merging cannot be overemphasized. Unlike supratentorial lesions, the resection of this category of CM must not include the gliotic pseudocapsule and hemosiderin-stained tissue surrounding the lesion. Bipolar cautery should be used sparingly and only within the gliotic capsule. Excessive bleeding when attempting resection of a deep or brainstem CM should be managed with gentle tamponade.

Most, if not all, deep-seated and brainstem CMs have an associated DVA even if not identified on imaging. Deliberate or inadvertent sacrifice of the associated DVA will increase the risk of venous infarction and elevate procedural morbidity.

Postoperative Management

Long cases involving brainstem CMs in patients who are already at risk for, or already have, respiratory and swallowing difficulty are best kept intubated for 24–48 h in an intensive care setting. Patients who are successfully extubated should all undergo formal swallowing studies before any oral feeding is permitted.

The postoperative blood pressure should be judiciously controlled to protect the resection cavity. We prefer to keep the systolic blood pressure less than 150 mmHg through a combination of titrated short-acting sedatives (dexmetetomodine or diprivan), non-sedating pain medication (such as fentanyl), and short-acting antihypertensive medications (nicardipine, verapamil).

All patients receive perioperative steroids as well as a short postoperative taper to minimize edema and (theoretically) protect neural tissue from damage associated with manipulation.

Postoperative imaging is somewhat variable among practices. Immediate postoperative/intraoperative MRI serves to alert the surgeon to residual CM in the cavity [16]. Many do not take this approach and only image based on clinical changes. Our preference is routine 3-month postoperative imaging with initial close clinical follow-up.

Special Considerations

Spinal cord CMs are rare lesions often grouped together with those of the brainstem. Because of their rarity, the natural history of CMs of the spinal cord is less well defined. They often present with new onset of sensory and/or motor deficits.

A larger percentage of patients in this group (up to 34%) also have associated pain. Any patient with a spinal lesion should be screened with cranial MRI to exclude cerebral lesions which can be found in up to 40% of patients [17].

Presentation to a pial surface, though strongly desired, is a less stringent requirement for spinal lesions. The standard approach for deep spinal lesions is through a posterior midline myelotomy if the lesion does not present to a pial surface. Anterior approaches have also been described and can be utilized when necessary [18].

Neurophysiologic monitoring with SSEPs and MEPs is essential. Signal loss should prompt an immediate cessation of activity. Resection can be restarted at a different location once the signal recovers. Similar to brainstem lesions, the surrounding hemosiderin-stained tissue and gliotic pseudocapsule should not be disturbed.

Outcomes following resection of spinal cord lesions in the literature come from small, single center series. The rate of improvement following resection is variable. Ardeshiri et al. reported a 20% improvement at follow-up while 80% of patients were no worse following resection [19]. Zhang et al. found that 3.4% of patients had a deterioration following surgery while 14.8% of patients in a conservatively managed cohort deteriorated over time [20].

Stereotactic Radiosurgery (SRS)

This treatment modality remains controversial. The utility of SRS is currently unclear and should only be considered for surgically inaccessible, aggressive CMs. Because SRS does not result in radiographic obliteration of CMs, most studies have attempted to demonstrate a decrease in the rate of hemorrhage following SRS [21]. In their series of 103 patients with symptomatic CMs, Lunsford et al. reported a 14% complication rate. The hemorrhage rate was 10.8% per year for the first 2 years and then decreased to 1.1% [22]. Given the known hemorrhage patterns of temporal clustering, the concrete benefits of SRS relative to the natural history of CMs remain uncertain while the adverse events secondary to radiation are clear.

Laser Ablation Treatment

Recently, MR thermography-guided stereotactic laser ablation (SLA) techniques for the treatment of CMs have been proposed based on previous success of this technique for other disease processes. To date, only limited case series and individual case reports have been published [23, 24]. The idea of a minimally invasive stereotactic guided technique for the treatment of CMs is attractive, especially for deep-seated lesions. However, currently there is not enough experience with this technique to advocate for SLA for either the treatment of epilepsy or neurologic symptoms outside of a clinical trial.

Complication Management

From the prior discussion, it should be clear that the best means of avoiding the most common (and most serious) complications associated with CM resection requires a careful approach to the patient before setting foot in the operating room.

New Neurologic Deficit

The key to managing complications lies within the realm of prevention. The following text considers those factors which we feel are associated with a lower likelihood of new postoperative deficits. Patient selection, lesion selection, surgical approach selection, and timing of surgery are all essential to safely resecting the offending lesion while minimizing damage to adjacent tissue. Likewise, functional imaging, accurate integrated neuronavigation tools, and neurophysiologic monitoring can all help to decrease the chances of inadvertently damaging critical structures.

Specific intraoperative pearls include the judicious use of bipolar cautery within the capsule of the lesion. Foci of bleeding should be addressed with patience, irrigation, and gentle tamponade. For brainstem or deep-seated CMs, avoid resecting the gliotic pseudocapsule.

Incomplete Resection

Occasionally, based upon a surgical judgment of risk vs. benefit or changes in neuro-monitoring, part of the CM is purposely left behind. However, inadvertent residual CM tissue is a not infrequent complication associated with long, dark operative corridors combined with a low tolerance for manipulation of eloquent tissue. This can result in an inability to inspect part(s) of the resection cavity appropriately. Once again, preoperative planning, especially with respect to the surgical approach, is essential.

Technical nuances that may assist with visualization include the use of lighted instruments such as bipolar cautery and/or retractors. Some authors have utilized intraoperative (or immediate postoperative) MRI to help define any residual cavernoma tissue. We have found the use of endoscopes to be very beneficial for their superior lighting and visualization of deep and dark cavities and around corners.

Postoperative Hematoma

Blood within the resection cavity is not uncommon following CM surgery. This is not completely unexpected for deep-seated and brainstem lesions given the desire to avoid excessive bipolar cautery and tissue manipulation. The vast majority of the time, this finding can be followed radiographically with close clinical monitoring of the patient in the neurological intensive care unit. Occasionally, the hematoma may be large enough to produce mass effect and clinical change. In equivocal cases this can be a difficult dilemma as new (usually temporary) neurological deficits or worsening is also common following CM resection. Deciding when a patient should return for hematoma evacuation to relieve suspected mass effect on surrounding tissue may be challenging, but erring on the side of hematoma evacuation is probably the best approach. If in doubt, take it out.

Avoiding this complication requires patience, which can be challenging at the end of a long case. Gentle tamponade and carefully placed pledgets of Surgicel or Nu-Knit (Ethicon, Somerville, NJ) are advised. Again, neuroendoscopes may assist with improved visualization of dark corners of the resection cavity.

Persistent Epilepsy

There is always some risk that the seizures are not relieved or even improved following surgical resection of an identified CM. The degree to which this constitutes a true complication is somewhat debatable. Nonetheless, it represents not only an important surgical indication but obviously is also a significant patient expectation. This is a complication that will generally only be discovered postoperatively during the intermediate clinical follow-up period. Avoiding this outcome is heavily dependent on the preoperative workup. Patient and lesion selection can be challenging in those with multiple lesions (see the above discussion regarding discordant seizure investigations).

Certainly, when possible the gliotic pseudocapsule and surrounding hemosiderin stained tissue should be resected. Although evidence is lacking, it would seem reasonable to assume that a more aggressive surgical resection would offer a better chance at seizure freedom, at the cost of increased neurological deficits. To that end cortical and subcortical mapping to direct resection may spare important cortical regions and white matter tracts. Additionally, electrocorticography can be used to focus the resection toward an epileptogenic focus while awake craniotomy can be used to tailor the resection away from critical functions in nearby regions.

Excessive Bleeding During Resection

While operating on deep-seated and brainstem lesions, there are times when the approach, subarachnoid dissection and resection of the CM itself, may prove more difficult than expected. When excessive bleeding occurs, the surgeon should question whether a vascular structure other than the CM was violated (DVA, nearby artery/vein). Although there is always room for persistence in cerebrovascular neurosurgery, knowing when to back away can be just as important. When such bleeding impairs visualization and limits a controlled resection, strong consideration should be given to aborting the procedure. It can often be tackled at a later date when evolution of the lesion may change its consistency and propensity to bleed.

Venous Infarction

Venous infarction following cavernoma resection can have disastrous consequences. As discussed above, DVAs are frequently associated with CMs, and by definition they drain normal regional tissue in a fashion that tends to preclude sufficient venous

collateral pathways from draining the area in the event of their loss. Preservation of an associated DVA is the most direct means of preventing venous infarction and should be taken into consideration at every step of the procedure from planning the surgical approach to resecting the lesion itself.

Postoperative Aspiration

For posterior fossa lesions, a high index of suspicion should be maintained for dysphagia. At our institution, all posterior fossa cases are formally tested by a speech-language pathologist as part of their routine postoperative care prior to any oral intake. Consideration for up-front tracheostomy and/or gastrostomy should be considered in patients with preoperative deficits. This consideration is of added importance when prone positioning is considered best for the resection.

Conclusion

These fascinating lesions run the gamut from benign incidental pathology on neuroimaging to life or quality-of-life threatening. Likewise, surgical resection of CMs extends from routine craniotomies in non-eloquent regions to a complex orchestration of neurosurgical, anesthetic, and electrophysiologic modalities. Complications cannot be entirely avoided in any surgical endeavor; however, they can be minimized and appropriately managed. The vast majority of complications related to CMs can be avoided through careful patient selection, thoughtful planning with attention to detail, appropriate use of surgical adjuncts, and meticulous surgical technique.

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