Frontal AVMs

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Operative Anatomy

The middle cerebral artery (MCA) tributaries feed the lateral aspect of the frontal lobe, whereas the anterior cerebral artery (ACA) branches supply the medial and basal surfaces of this lobe. These two arterial systems disproportionately supply frontal arteriovenous malformations (AVMs) based on the location of the nidus and its proximity to each of these vascular trees. The contributions of the MCA versus ACA territories to frontal AVMs should be understood preoperatively.

The main trunk of the MCA may branch in three different patterns: 1) bifurcation into superior and inferior trunks, 2) trifurcation into superior, middle, and inferior trunks, or 3) division into multiple trunks. After the M2 and M3 segments exit over the insula, they terminate into cortical branches, including:

1. *Orbitofrontal artery* supplying the inferior frontal gyrus, middle frontal gyrus (anterior part), and pars orbitalis
2. *Prefrontal artery* supplying the pars orbitalis, pars triangularis, pars opercularis, and most of the middle frontal gyrus
3. *Precentral artery* irrigating the pars opercularis, middle frontal gyrus (posterior part), and most of the precentral gyrus
4. *Central artery* feeding the precentral gyrus and postcentral gyrus (inferior part)

The superior part of the lateral frontal surface, including the superior frontal and superior part of the precentral gyri are often fed by the branches of the ACA.

Each ACA has eight branches for the frontal lobe along its passageway within the interhemispheric fissure and around the corpus callosum. Starting from distal to the anterior communicating artery, these branches include: the orbitofrontal artery, frontopolar artery, callosomarginal artery, anterior internal frontal artery, middle internal frontal artery, posterior internal frontal artery, paracentral artery, and pericallosal artery.

The vascular tree of the lateral and medial frontal surfaces drains into the superior sagittal sinus. The basal surface of the frontal lobe drains into the anterior parts of the superior sagittal sinus via the anterior orbitofrontal and frontopolar veins. Therefore, the surgeon should expect multiple parasagittal draining veins for frontal AVMs.

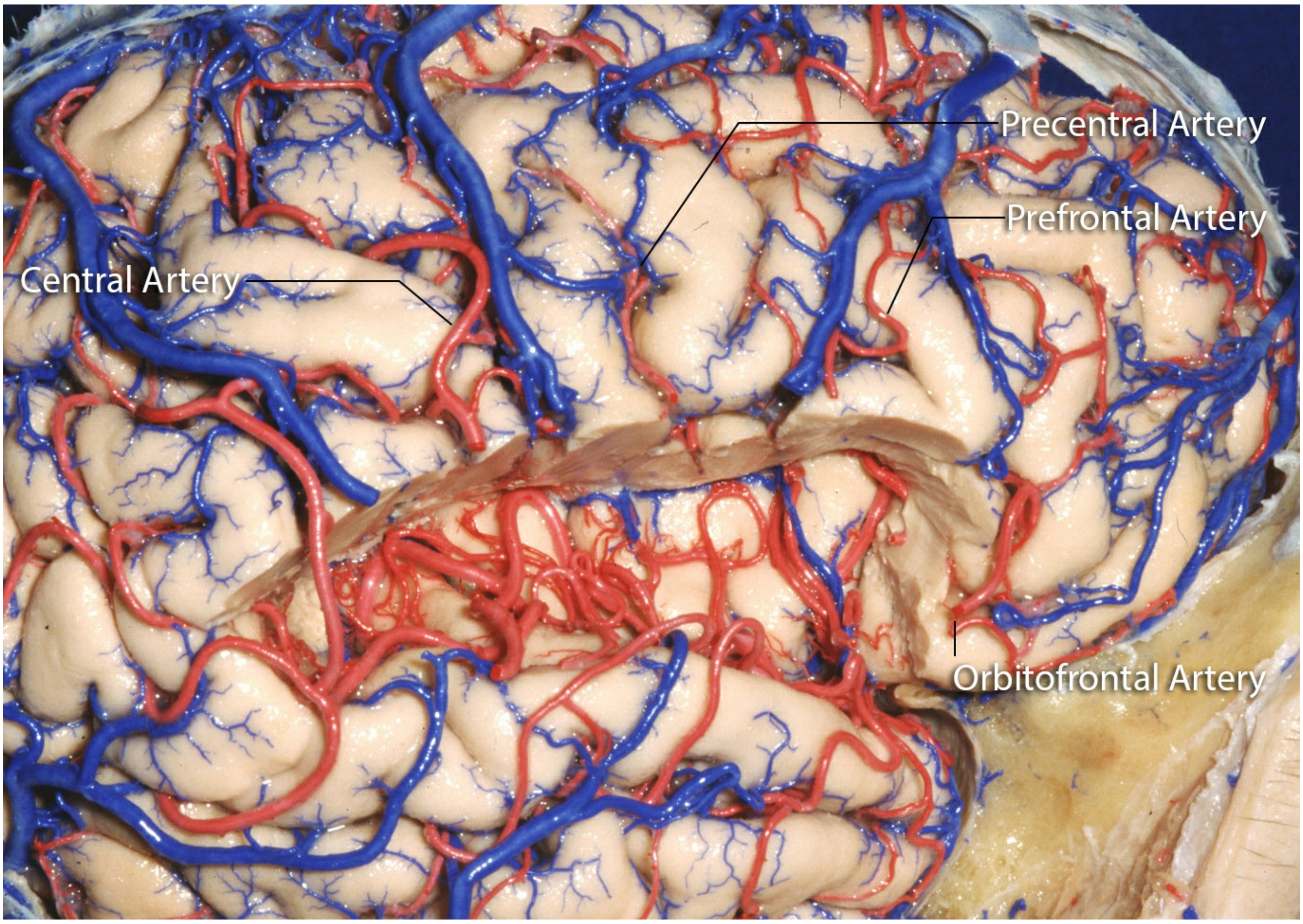


Figure 1: The MCA branches provide the majority of feeding vessels to the lateral frontal AVMs. The enlarged lenticulostriate vessels feeding deep subcortical frontal AVMs can be daunting to control intraoperatively; these very friable white matter feeders are a source of morbidity from the operation (photo courtesy of AL Rhoton, Jr).

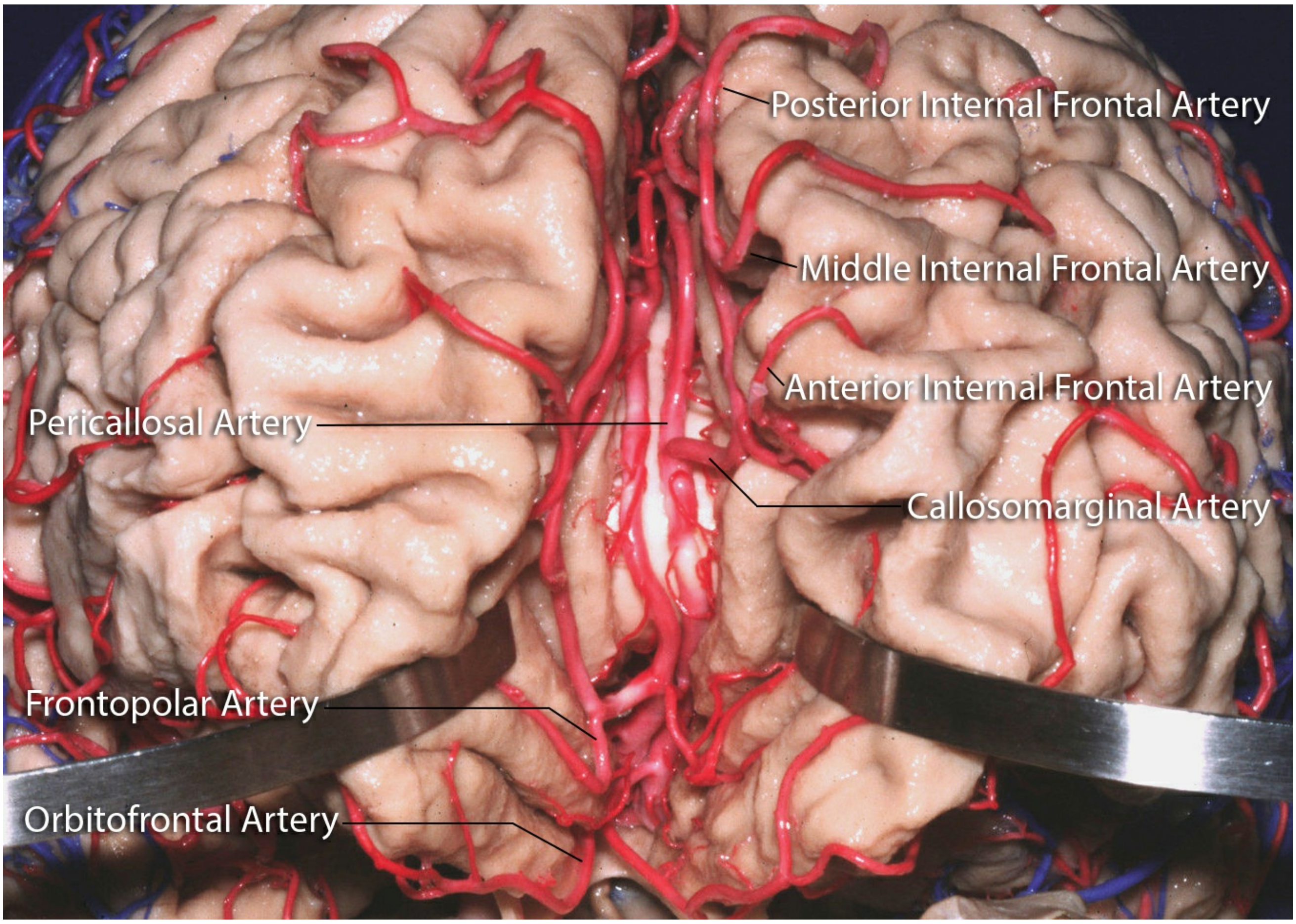
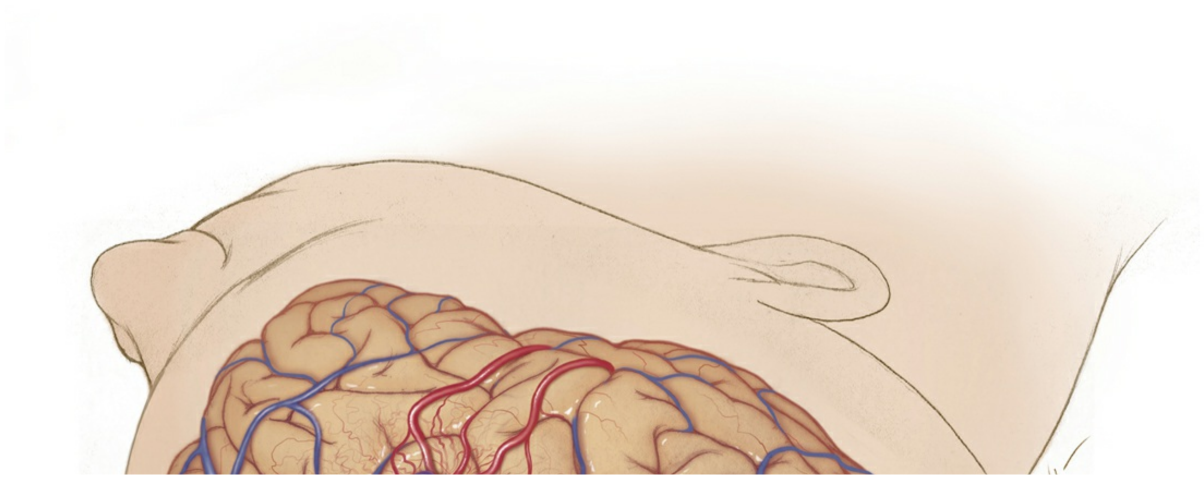


Figure 2: The ACA branches supply most of the medial frontal AVMs. The initial interhemispheric dissection allows timely control of the dominant feeding vessels to these AVMs (photo courtesy of AL Rhoton, Jr).

FRONTAL ARTERIOVENOUS MALFORMATION SUBTYPES

Lateral Frontal AVM

Lateral frontal lesions are cone-shaped AVMs based on frontal convexity, extending toward the lateral ventricle. Their reach to the ventricular chamber depends on the size of the nidus. This subtype is the most common subtype of frontal AVMs.



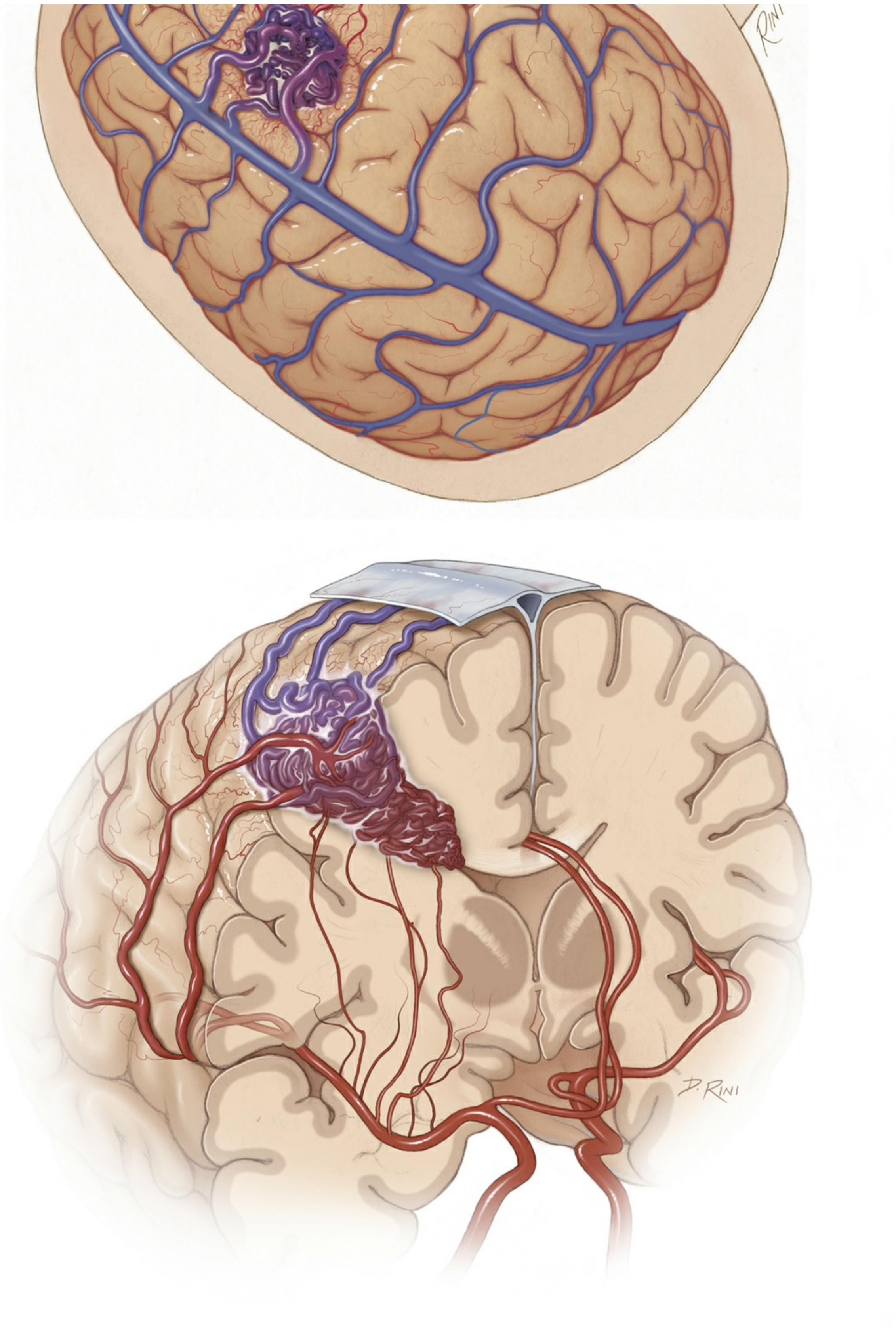


Figure 3: The cortical branches of the superior trunk of the MCA feed most of the lateral frontal AVMs. These branches can be found at the inferior margin of the AVM and are tackled first during circumdissection. Occasionally there may be some feeders arising from the ACA, depending on the complexity of the nidus and its proximity to the midline. Large lesions harbor feeders from the lateral lenticulostriate

branches of the MCA that supply the medial and inferior walls of the AVM. These branches are the most difficult to control and can be secured when the dissection continues within the deep white matter. The venous drainage system is superficial and joins the superior sagittal sinus (mainly) or the superficial Sylvian veins.

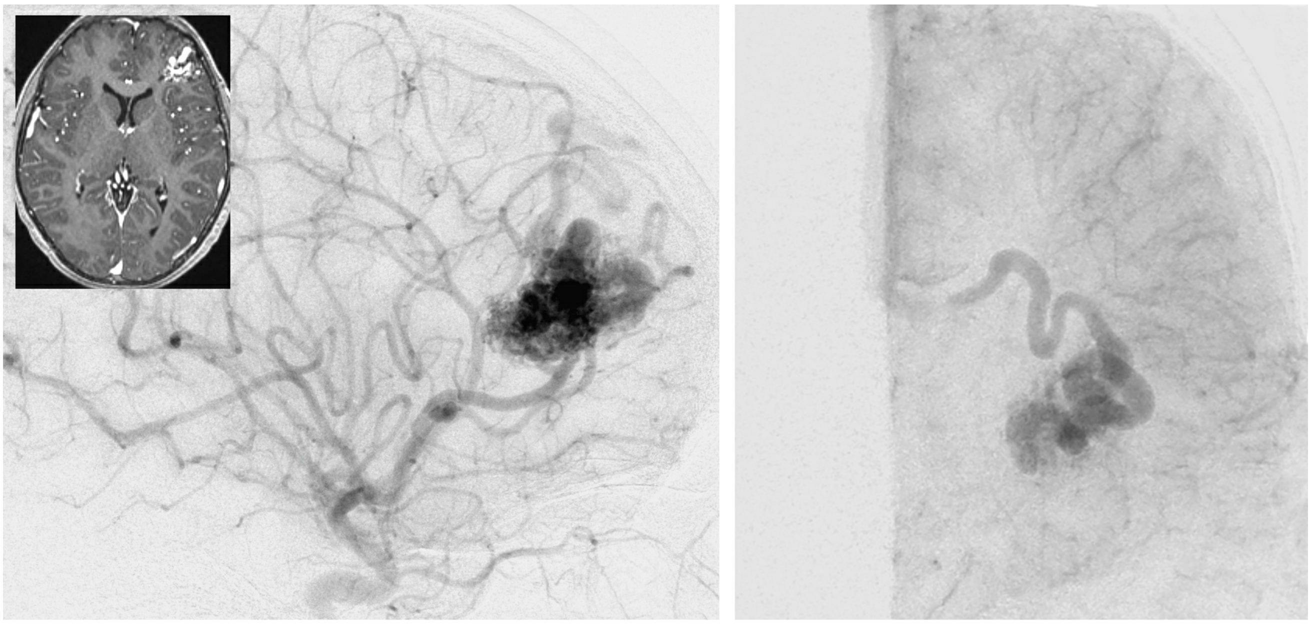


Figure 4: A simple lateral frontal AVM, primarily fed by the MCA branches, is demonstrated (lateral view, ICA angiogram-left image). The primary draining vein joins the superior sagittal sinus (anteroposterior view, ICA angiogram-right image).

The patient is positioned supine and the head rotated so that the axes of the AVM walls become parallel to the viewing angles of the surgeon. In other words, the lateral or cortical aspect of the AVM becomes the highest point on the operative field.

The craniotomy and dural opening should be generous; small dural feeding arteries may supply the AVM and should be carefully coagulated and transected. The draining veins may densely adhere to the dura, be incorporated into dural layers or embed themselves within the inner skull bone. In these situations, the craniotomy should be carefully elevated and the dural opening should accommodate the routs of the veins.

Arachnoid dissection starts through the sulcal planes and follows the vessels in a circumferential manner; the arterial feeders and draining veins are clearly identified. Feeding vessels arising from the superior trunk of the MCA are found after they have left the Sylvian fissure en route to the inferior margin of the AVM, around the superficial nidus; there is no need to dissect the Sylvian fissure.

The overlying normal brain tissue should not be transgressed to create more working space. As the dissection extends toward the apex of the large and deep AVMs, the lateral lenticulostriate branches of the MCA can be the unsettling source of uncontrollable bleeding.

These daunting white matter feeders lack viable walls, retract into the deep white matter, and may even not be amenable to bipolar coagulation and/or clip ligation for a portion of their segment at the level of the nidus. The bleeding feeders should be followed or traced. Their segment that is located a short distance (2-3mm) away from the nidus is typically more “normal” and receptive to coagulation. The operator should persist and follow the flow of blood while dissecting the white matter; packing of the bleeding site will invariably lead to expanding intracerebral hemorrhage and brain swelling.

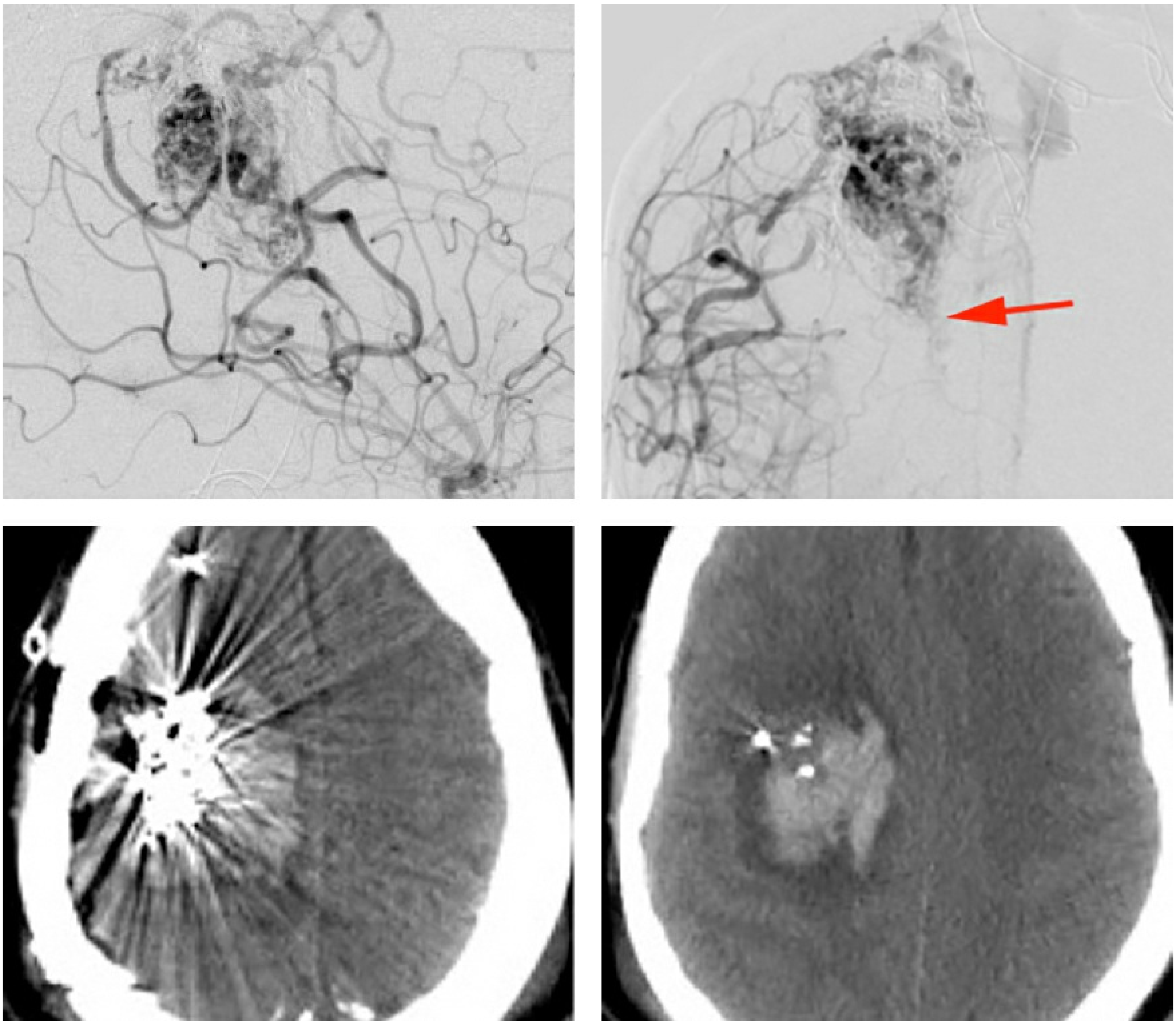
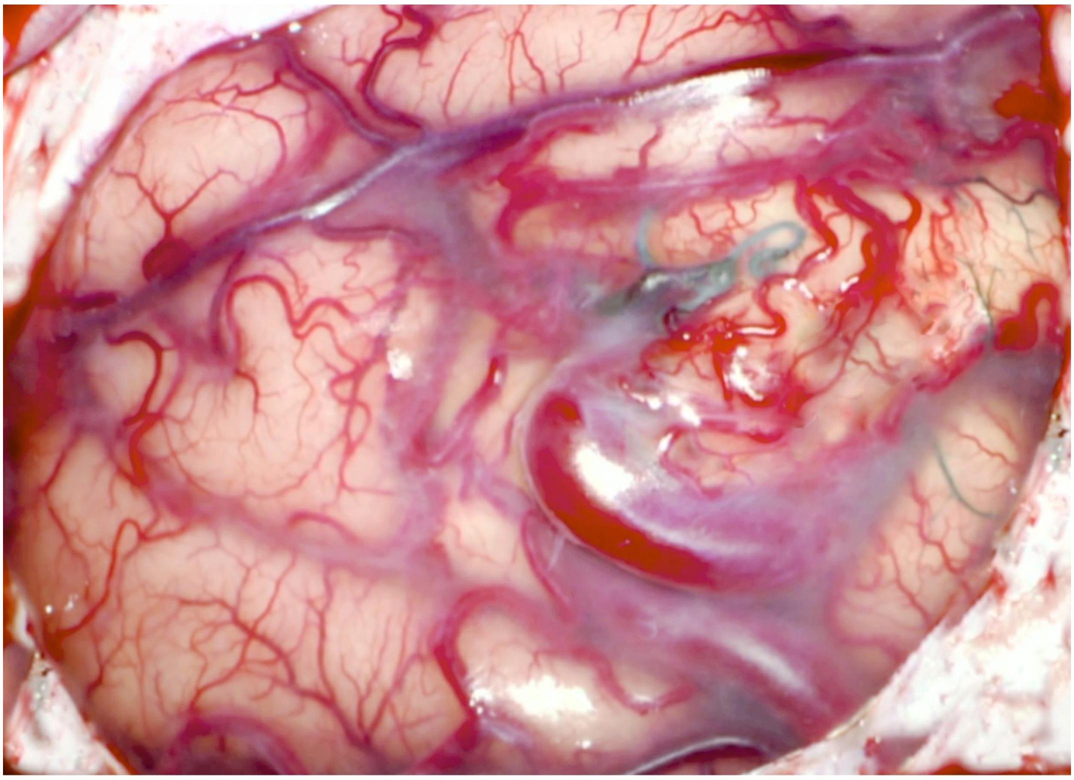


Figure 5: This posterior lateral frontal AVM was aggressively embolized which may have led to hypertrophy of its deep white matter feeders (upper row, anteroposterior and lateral ICA angiograms-red arrow). The resective operation was performed early in my career. Unfortunately, I did not manage the dominant deep feeders adequately. Intraoperatively, a large white matter feeder retracted into the brain and led to an intracerebral hemorrhage (lower row-postoperative CT) and resultant uncontrollable cerebral tension, mandating a premature abortion of the procedure and closure of the case. Partial devascularization of the AVM led to its significant shrinkage, making it very amenable to radiosurgery. The patient ultimately recovered well but suffered from a permanent minor hemiparesis.

If the AVM reaches close to the ventricle, surgical cure demands exposure of the ventricle and removal of the residual AVM on the ependymal surface. This is especially important for immature AVMs in pediatric patients. When the ventricle in entered, its opening should be covered with a small piece of cottonoid to impede blood from filling the ventricle, preventing hydrocephalus.



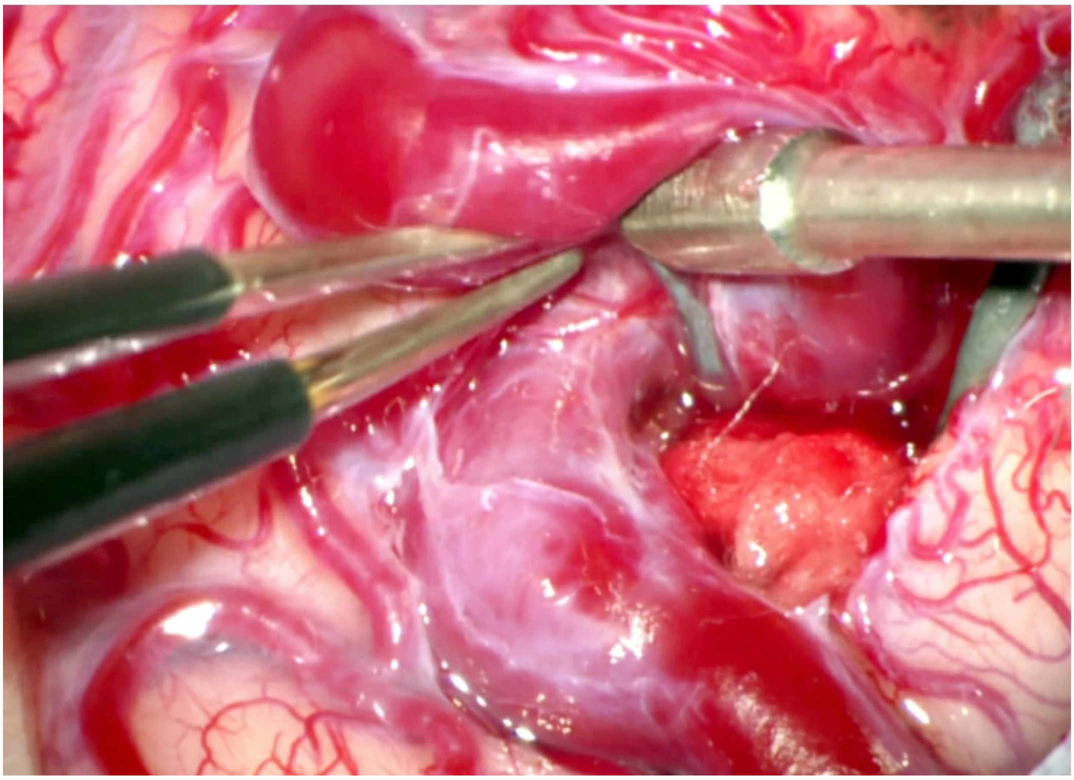


Figure 6: The frontal AVM in Figure 3 is exposed (upper image); there is minimal nidal cortical representation. Note the generous exposure of the surrounding normal cortices. The primary vein was carefully isolated and used as a road map to find the nidus with minimal disruption of the surrounding cortices (lower image). The piece of cotton on the right side

of the vein was used to keep the dissection planes open.

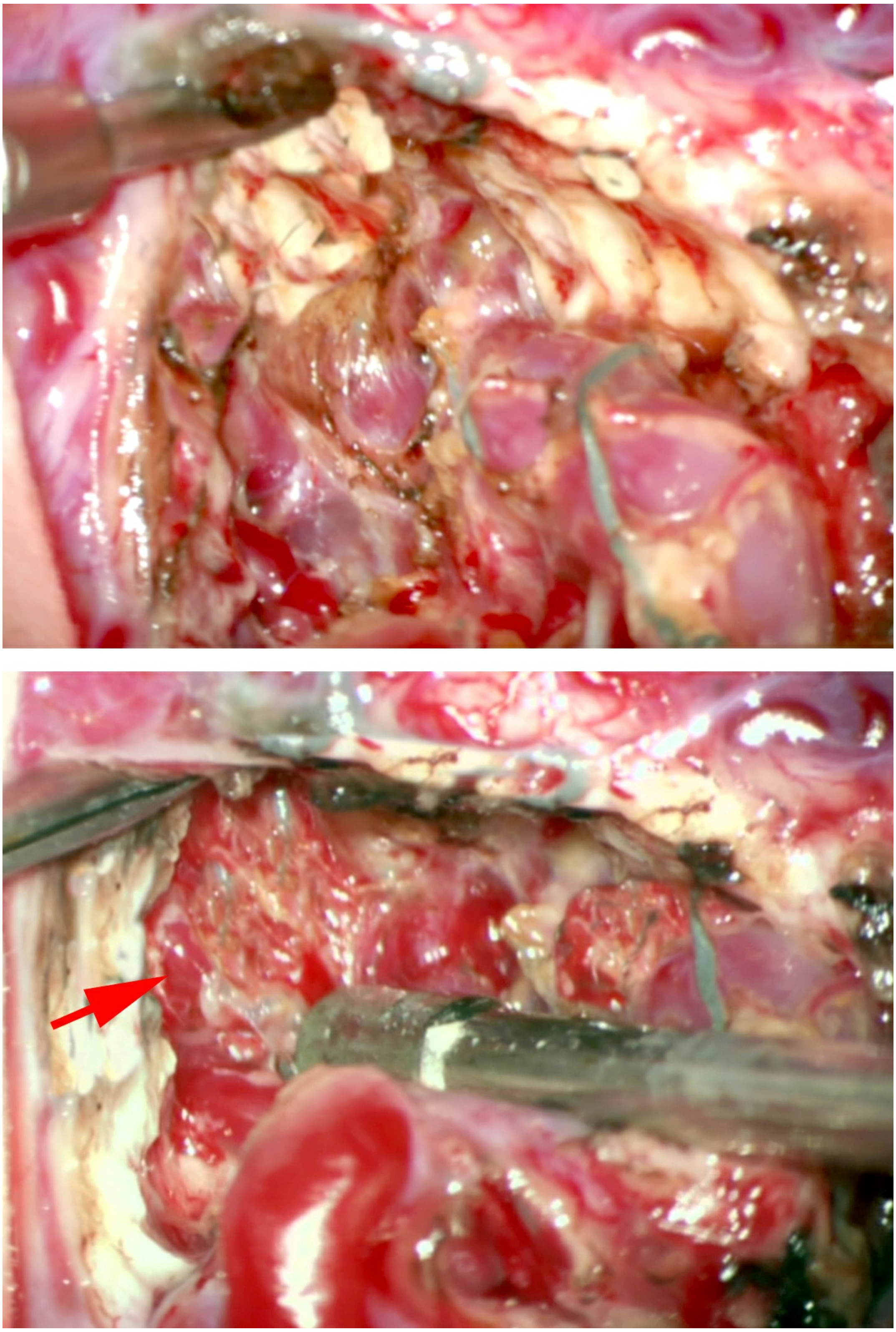


Figure 7: The compact nidus of the AVM allowed me to dissect on the walls of the nidus without significant bleeding (top). The thin-walled white mater perforators at the depth of the dissection cavity are demonstrated (bottom photo-arrow).

Medial Frontal AVM

Medial frontal AVMs are unveiled after opening the interhemispheric fissure. These lesions are within the medial aspect of the superior frontal gyrus and/or in the cingulate gyrus. They are primarily supplied by the distal ACA branches and their drainage system ascends to join the superior sagittal sinus.

The tangential working angle of dissection is toward the surface of the medial frontal AVMs. Resection can be technically challenging and dissection planes at times disorienting to the surgeon.

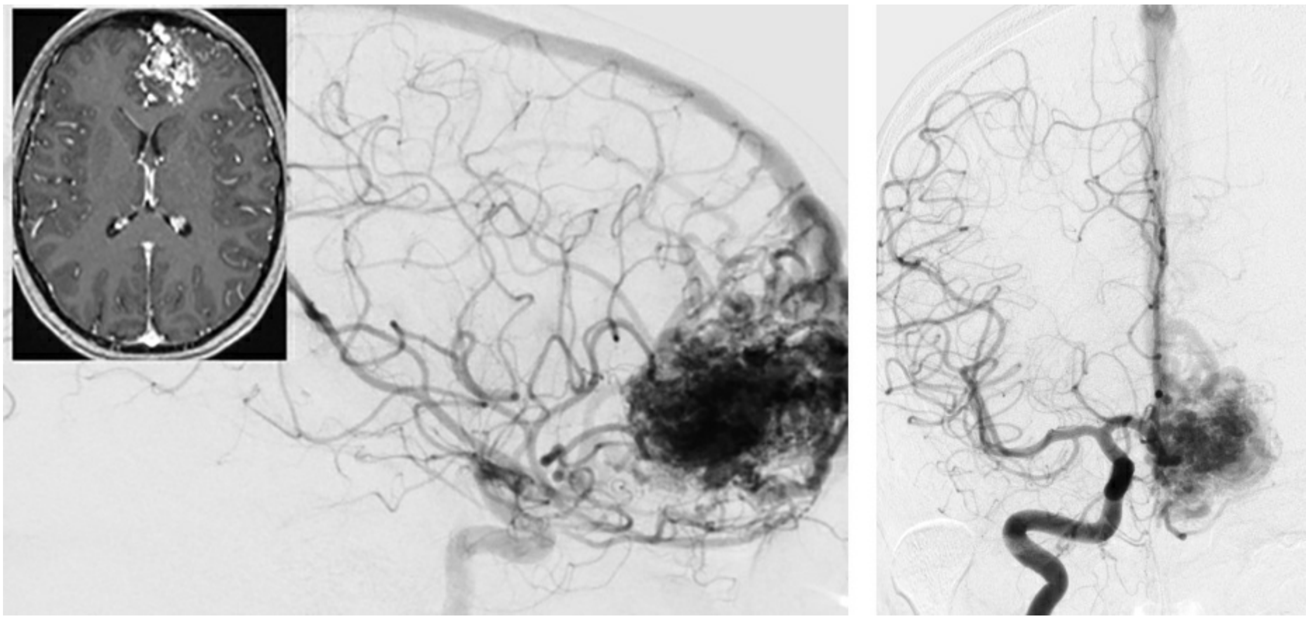


Figure 8: An anterior medial frontal AVM (lateral ICA angiogram-left) is shown with its primary draining vein joining the superior sagittal sinus (anteroposterior ICA angiogram-right). There is minimal or no lateral cortical presentation.

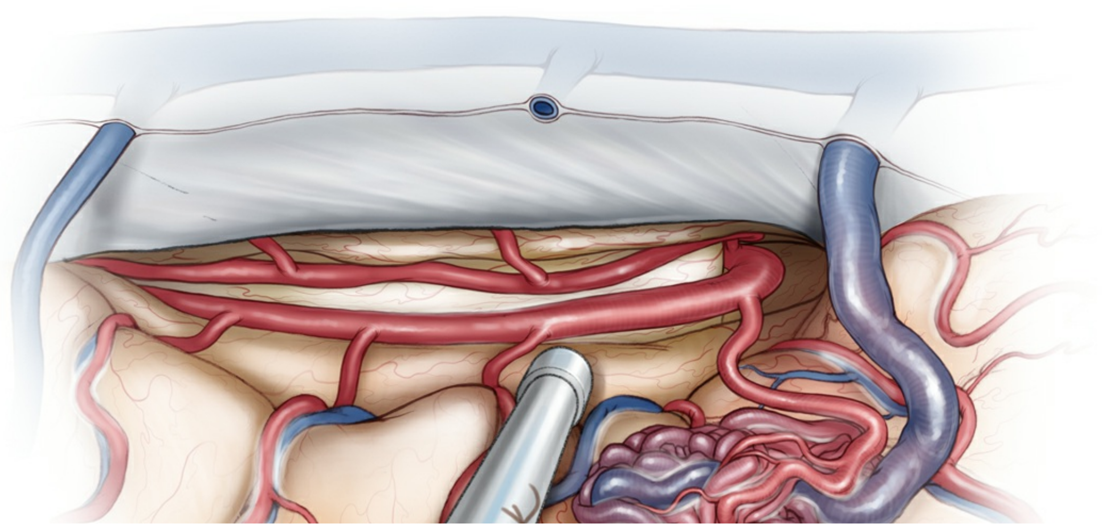
The patient is placed in the supine position with 90-degrees head rotation or in the lateral position to make the midline axis of the head parallel to the floor. This position leaves the AVM on the dependent side of the head and uses gravity in the surgeon's favor to mobilize the affected hemisphere away from the midline.

A frontal craniotomy should expose the width of the superior sagittal sinus. Aggressive dissection of the interhemispheric fissure (please see the chapter on Interhemispheric Craniotomy), extending to the level of the corpus callosum, is necessary to expand the interhemispheric corridor. Generous interhemispheric arachnoidal dissection, beyond the boundaries of the AVM, allows the gravity to have its way with the hemisphere.

The most important anatomic obstacles are the parasagittal draining veins of the AVM that tether the hemisphere to the midline and limit the interhemispheric operative corridor. These veins are prone to rupture, should not be sacrificed during the dural opening, and must be preserved until the end of the procedure. They can be gently released from their encasing parasagittal subdural arachnoid membranes; this maneuver can partially untether the veins and the hemisphere from the midline.

The craniotomy should be large enough to provide enough space for the surgeon to redirect his or her angles of view along the anterior and posterior aspects of the obstructive draining veins. Once generous tangential view of the AVM is secured, the arachnoid and sulcal dissection identifies the feeding arteries in a circumferential manner and distinguishes them from their counterpart *en passage* arteries. The distal ACA branches can be found and the dominant feeding branches to the AVM pursued to the level of the nidus and transected.

After enough circumferential dissection, the lesion becomes mobile and I can work on the inferolateral aspect of the AVM and its corresponding feeders. Next, the AVM is mobilized into the interhemispheric space and additional disconnection along its medial apex is conduced. Since *en passage* vessels can be easily mistaken for AVM feeding arteries, careful inspection of any vessel before its sacrifice is warranted.



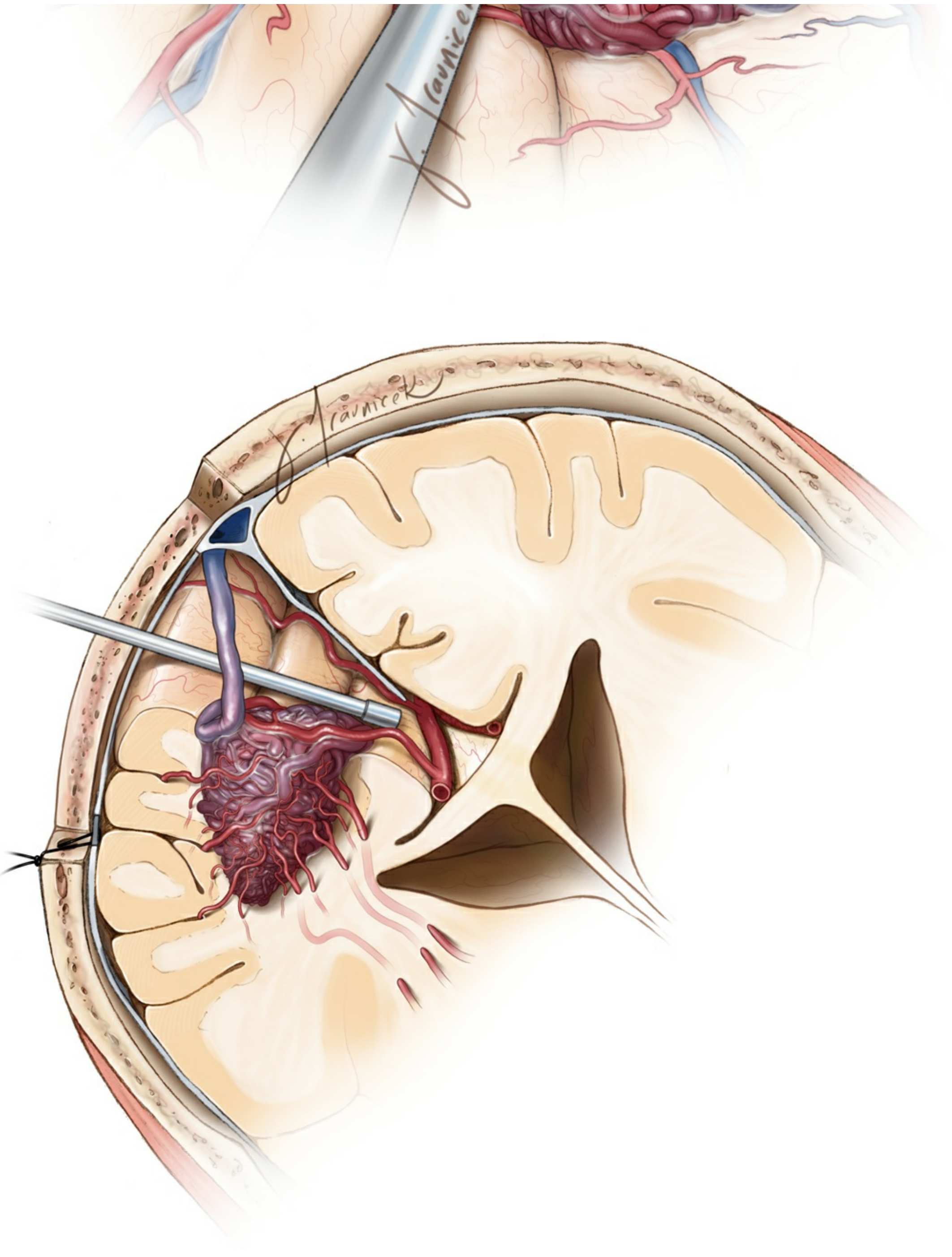


Figure 9: The angioarchitecture of a medial frontal AVM is illustrated. Note the tangential operative working angle toward the surface of the AVM (surgeon's view, top image) and the feeding vessels emerging from the callosomarginal and pericallosal arteries. The bottom sketch emphasizes the location of the inferior deep white matter feeders from the lenticulostriates. These white matter feeders can be especially problematic in large AVMs since they are hiding within the operative blind spot.

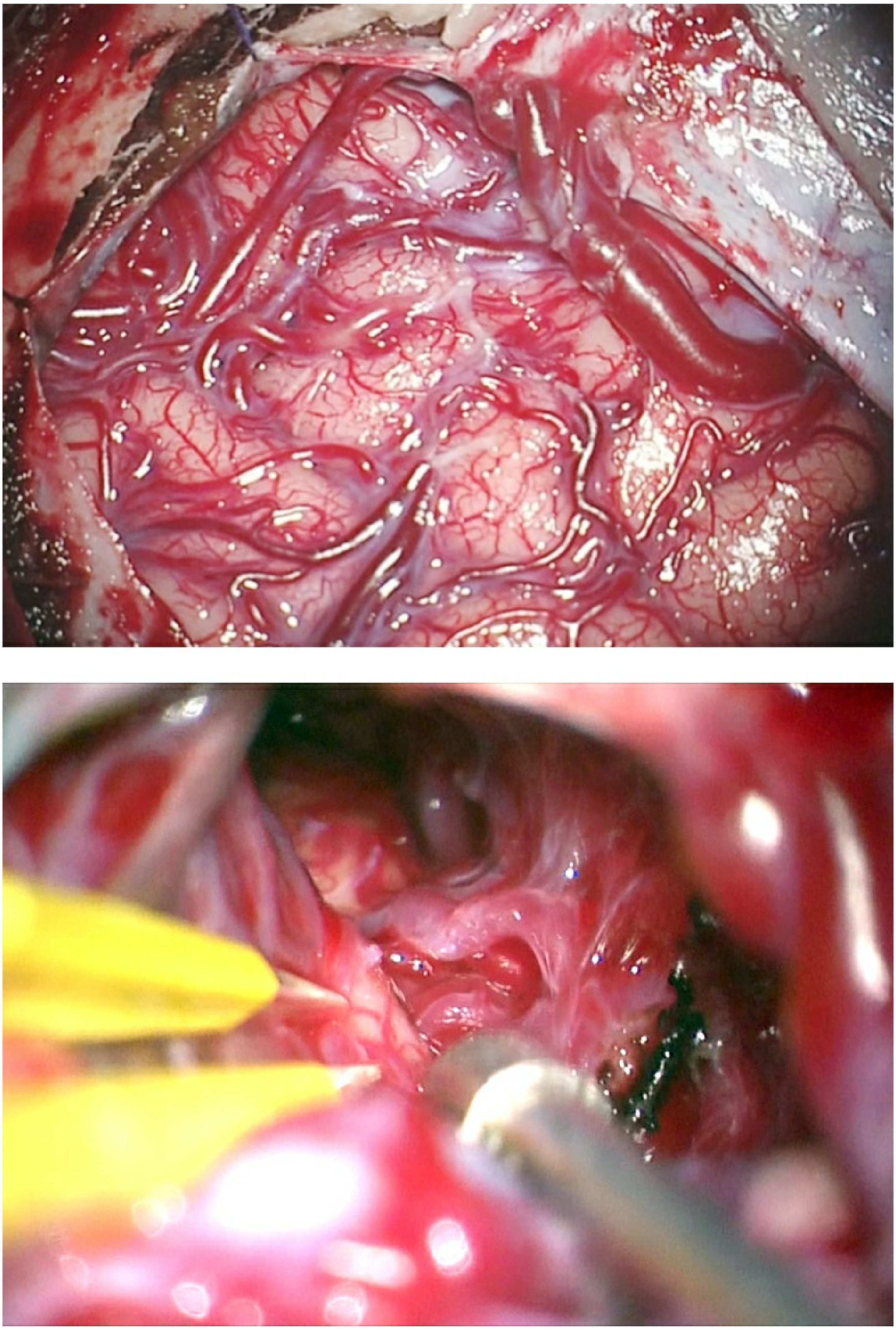


Figure 10: The medial frontal AVM in Figure 8 is exposed. The primary draining vein was released along its path within the subdural space (upper image). The interhemispheric approach isolated the large feeding vessels arising from the A2's.

Paramedian Frontal AVM

Paramedian frontal AVMs are a composite of lateral and medial frontal AVMs. Accordingly, feeders emerge from the superior trunk of the MCA for the lateral AVM's aspect and from the distal ACA branches for its medial and inferior surfaces.

Draining veins may ascend to the superior sagittal sinus, descend to the inferior sagittal sinus or join the superficial Sylvian vein, depending on the size and complexity of the nidus.

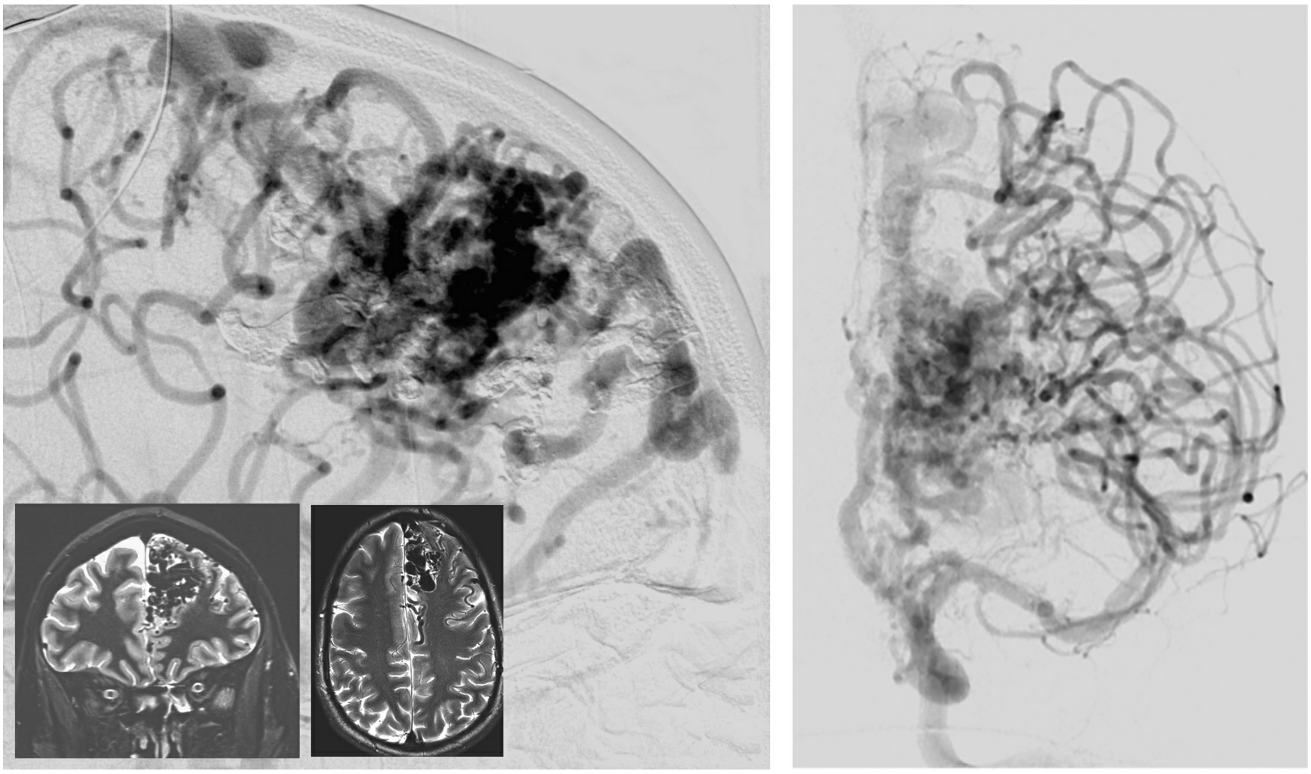
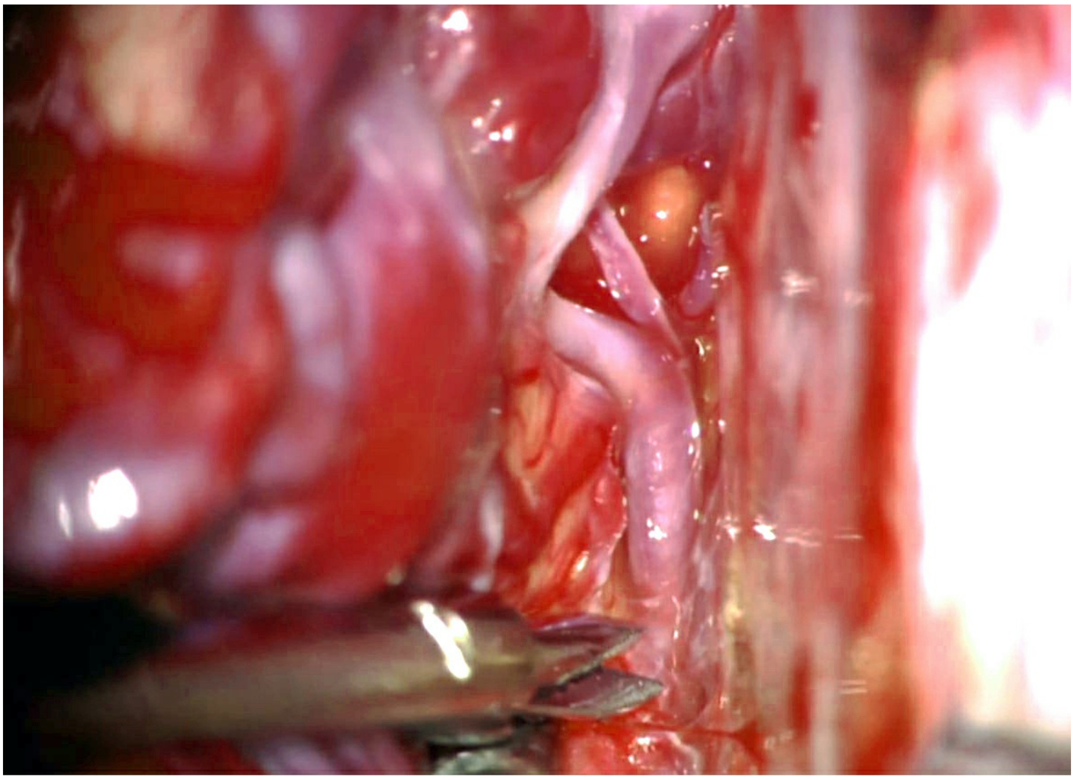


Figure 11: An anterior paramedian frontal AVM, fed by both the MCA and ACA feeders, is demonstrated. Note that there are numerous artery-to-artery connections at the posterior aspect of the nidus. These connections are not considered part of the nidus are should be left intact.

I prefer the patient in the lateral or the supine position with the midline of the head oriented vertically ("nose up") or the sagittal sinus parallel to the surface of the floor, respectively. An appropriate frontal craniotomy should uncover the corresponding segment of the superior sagittal sinus so that it can be gently mobilized via sutures within the superior falx (see the chapter on Interhemispheric Craniotomy for more technical details).

I incise the dura in a curvilinear fashion while protecting the complex parasagittal draining veins and start dissection along the interhemispheric fissure to carefully untether the draining veins and to expand the interhemispheric space. Next, the feeding arteries, usually the prefrontal and callosomarginal feeders, are disconnected precisely at their terminal entry point into the malformation.

The lateral marginal sulci over the convexity are then dissected and the distal MCA feeders are severed. The motor cortex is protected along the posterior margin. Circumferential dissection progresses to mobilize the AVM upward for its deep disconnection from the lenticulostriate feeding arteries and ependymal contributories near the lateral ventricle.



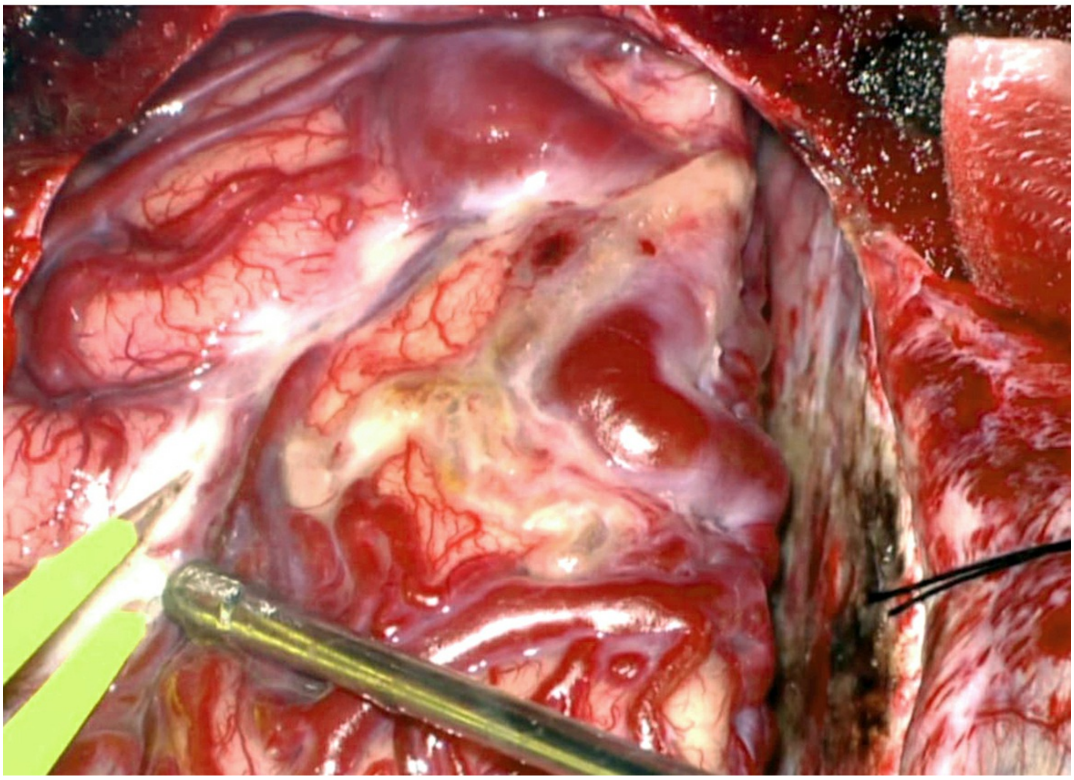
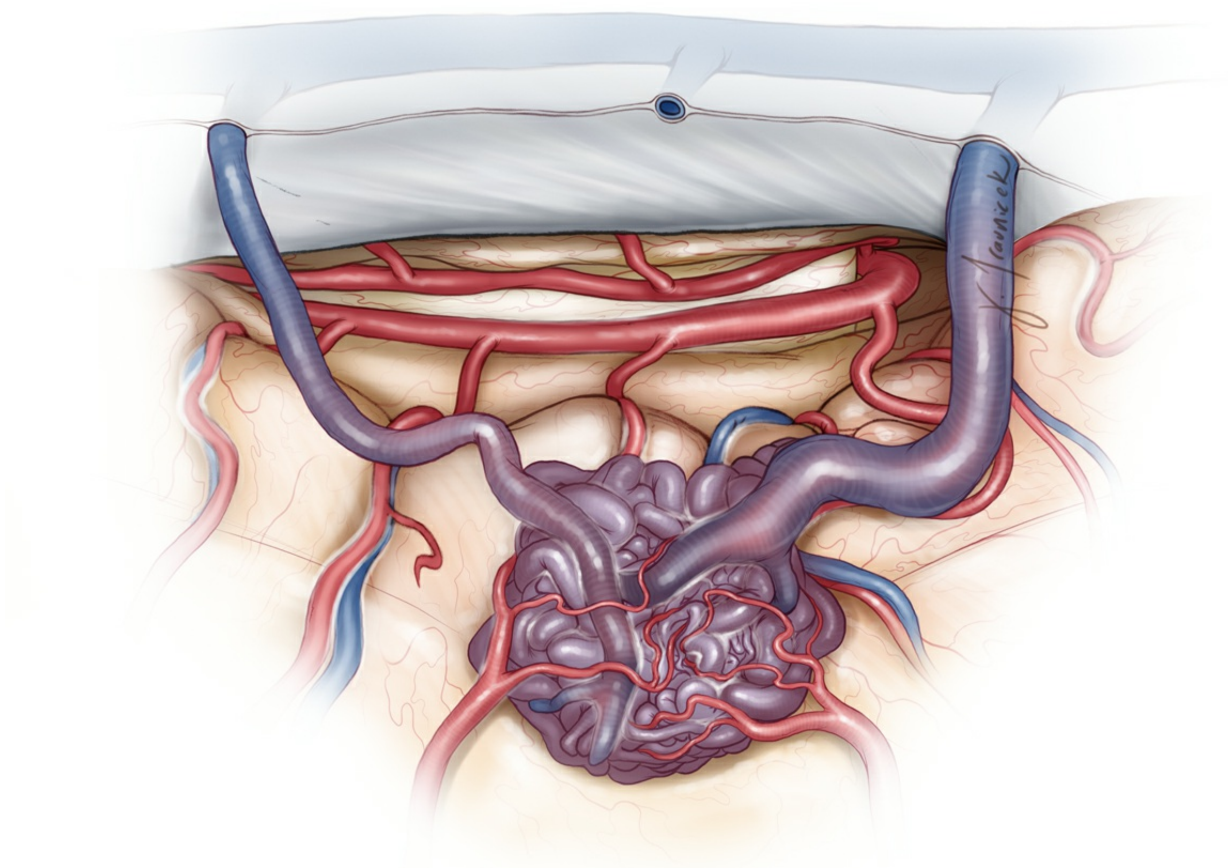
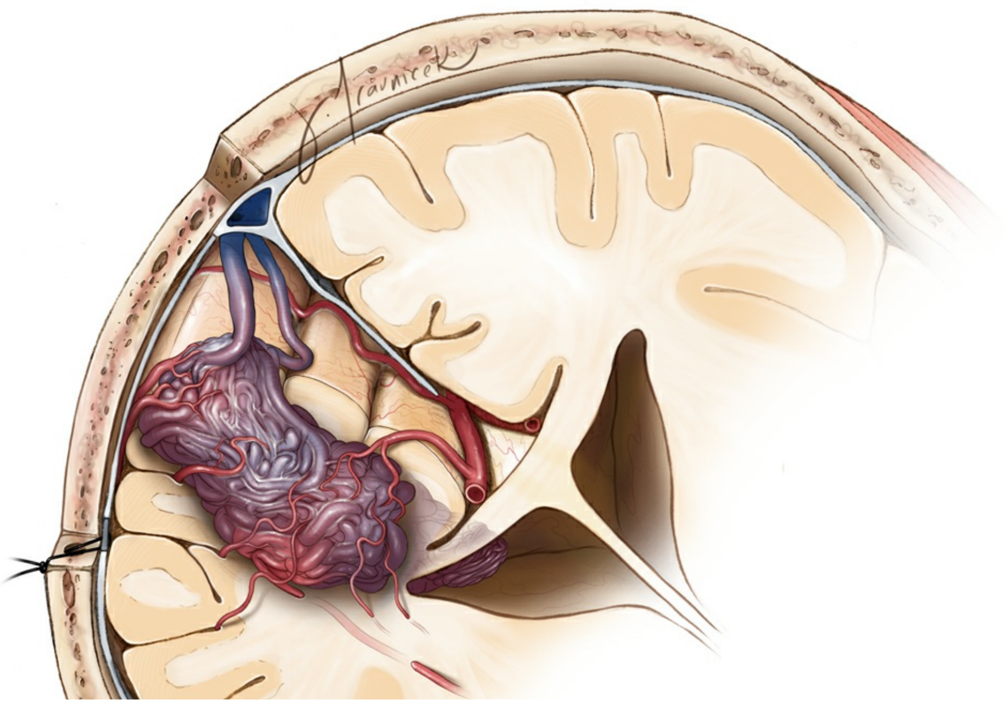


Figure 12: The AVM in Figure 10 is first disconnected along its interhemispheric margin from the ACA feeders (upper image). Next, the MCA supply is disrupted on the lateral convexity using pial incisions guided by intraoperative CTA navigation (lower image). The head is in the anatomically neutral position.





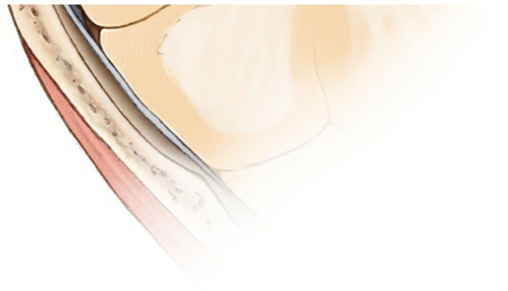


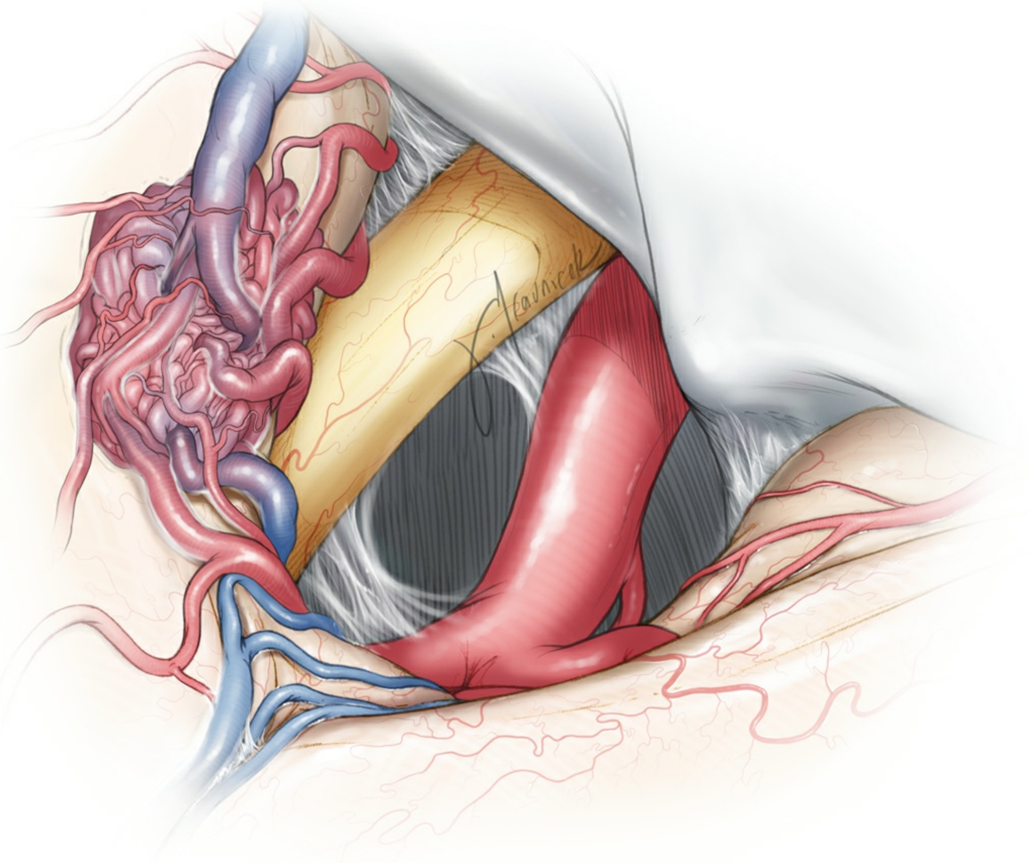
Figure 13: Note the anatomy of a typical paramedian malformation from the surgeon's view (top) and coronal perspective (bottom). The deep white matter and ependymal feeders at the apex of the lesion are the most difficult part of the operation. Adequate and thorough mobilization of the superficial parts of the nidus is required before the deep portions of the AVM are handled so that flexible working angles are available for managing bleeding at the depth of the resection cavity.

Basal Frontal AVM

Basal frontal AVMs reside at the basal surface of the lobe and are bounded medially by the rectus gyrus and olfactory apparatus and laterally by the orbital gyrus. Similar to paramedian AVMs, basal frontal AVMs own feeders from both the MCA and ACA territories.

These feeders originate from 1) the interhemispheric orbitofrontal and frontopolar A2 branches to supply the anteromedial AVM borders, 2) the A1 segment to feed the posterior border, and 3) the orbitofrontal and prefrontal branches of the MCA to irrigate the posterolateral borders.

Logically, the venous drainage usually leads to the superior sagittal sinus and occasionally posteriorly into the basal vein of Rosenthal.



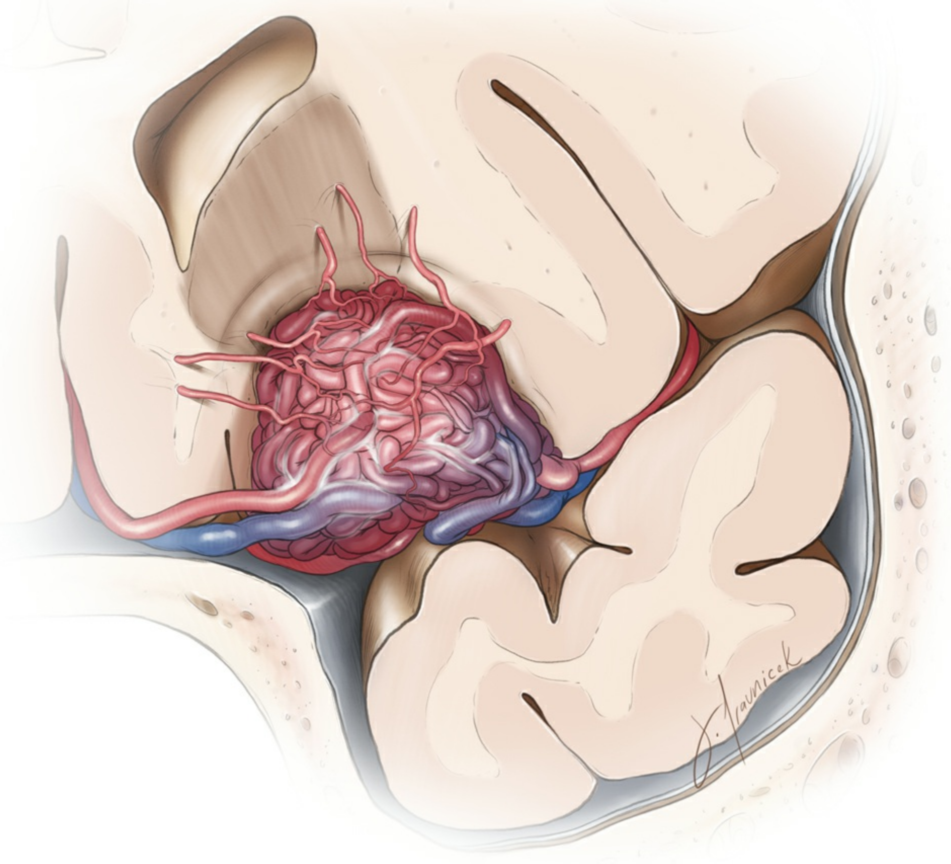


Figure 14: The vascular anatomy of a medial basal frontal AVM is illustrated. The medial ACA feeders can be dominant and potentially difficult to control during the early stages of the operation (surgeon's view, right-sided pterional approach, top sketch). The draining veins can limit the working angles of the surgeon and restrict the mobilization of the nidus after its circumferential disconnection. The primary draining vein should be spared while the secondary ones scarified after most of the nidus is isolated. The deep white matter feeders are within the surgeon's blind spot (coronal view, bottom sketch).

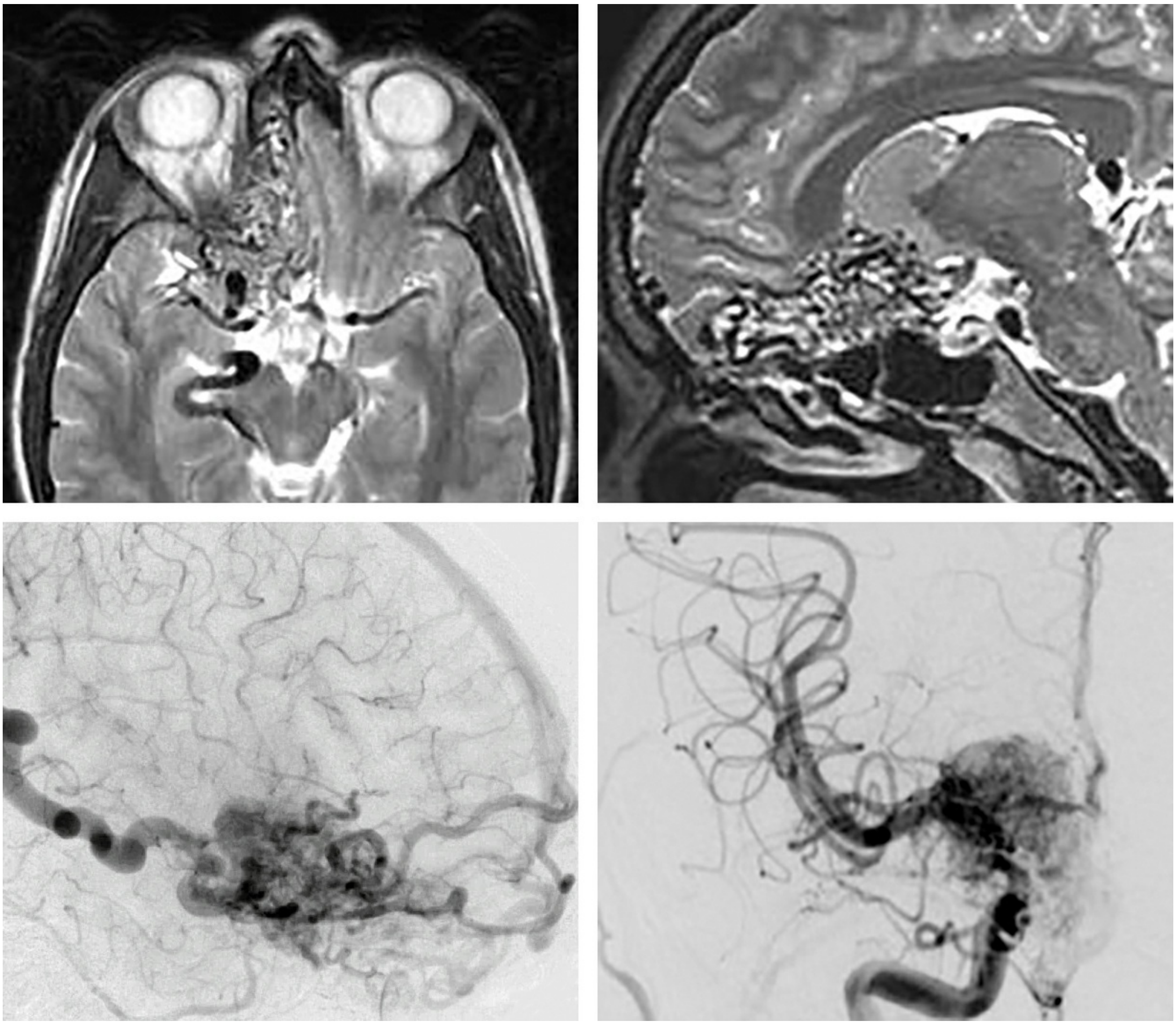


Figure 15: A basal frontal AVM with predominantly deep venous drainage is shown. Note two anterior, secondary draining veins. The supraclinoid ICA perforators may also supply the medial frontal AVMs.

The patient is positioned supine with a 30-degree head rotation contralaterally; the head extension should position the malar eminence the highest point of the operative field. The use of gravity to mobilize the basal frontal lobe away from the anterior skull base is critical to minimize unwanted frontal lobe retraction and to provide reasonable oblique operative trajectories toward the walls of the AVM.

The complexity of the AVM will determine the need for a pterional or modified orbitozygomatic craniotomies (supraorbital osteotomy). The extended pterional craniotomy usually facilitates an adequate subfrontal plane for flexible viewing angles and working space. The roof of the orbit is flattened and the lateral sphenoid wing is resected. If the lesion extends toward the frontal horn, a modified orbitozygomatic craniotomy is needed to provide the necessary acute inferior-to-superior operative trajectory.

The intradural steps begin with subfrontal and anterior (sphenoidal) Sylvian fissure arachnoid dissections for cerebrospinal fluid drainage and frontal lobe mobilization. The sulcal and pial dissection maneuvers identify the draining and feeding vessels at the medial and lateral AVM borders. Next, circumferential interruption of the feeders and white matter dissection mobilizes the nidus inferiorly and provides an oblique trajectory to handle the disconnection of the AVM at its posterior aspect.

If a larger AVM reaches the frontal horn ependyma, an anterior inferior frontal lobe resection despite the use of orbitozygomatic osteotomy may be necessary to provide access to the ependyma of the frontal horn. Dynamic retraction using the hand held suction device provides flexible inferior and superior working angles for circumferential dissection. The posterior deep white matter feeders can be problematic and a more generous posterior resection plane relative to the nidus is prudent in this area.

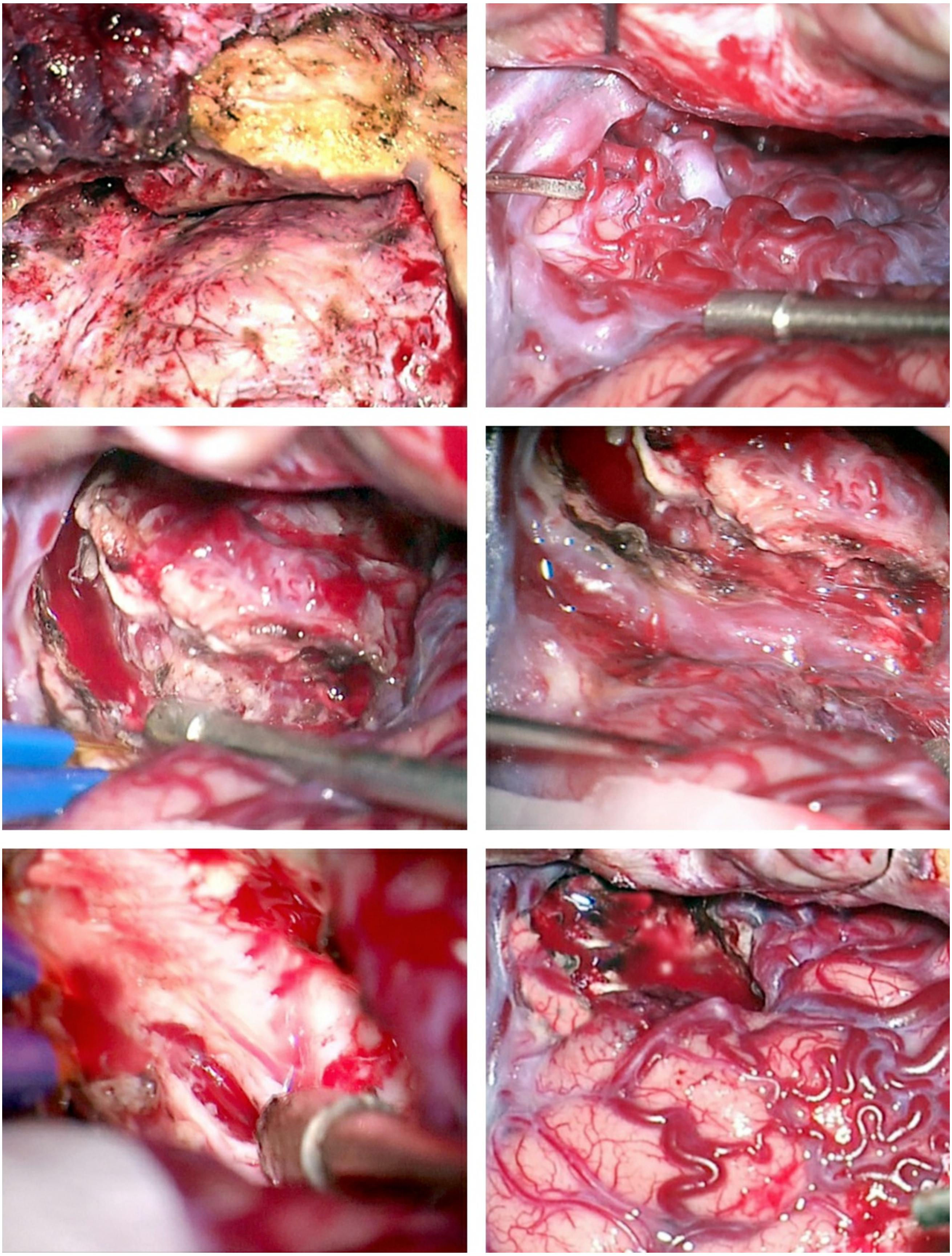


Figure 16: Intraoperative findings for another basal frontal AVM are included. Note the osteotomy over the orbital roof provided an adequate inferior-to-superior operative trajectory without excessive frontal lobe retraction. An orbitozygomatic craniotomy is rarely necessary. Subarachnoid dissection, anterior to the Sylvian fissure, allowed disconnection of predominant AVM feeders from the MCA (upper row).

The nidus was skeletonized and the draining vein was preserved but mobilized to provide access to the deep portions of the AVM (middle row). Next, the deep white matter feeders were found and sacrificed. The AVM was removed and all the cortical veins were noted to turn dark blue (lower row).

Sylvian Frontal AVM

Sylvian frontal AVMs reside on the Sylvian surface of the inferior frontal gyrus, across the temporal lobe. This subtype may or may not involve the Broca's speech area in the dominant hemisphere. If these functional cortices are infiltrated, resection is risky, but is still possible for lesions with compact nidi.

The main arterial feeders for this AVM subtype emerge from the MCA. These feeding arteries are derived from the M3 and M4 segments, especially along the supralateral margin of the malformation. Drainage patterns involve the superficial and/or deep Sylvian veins.

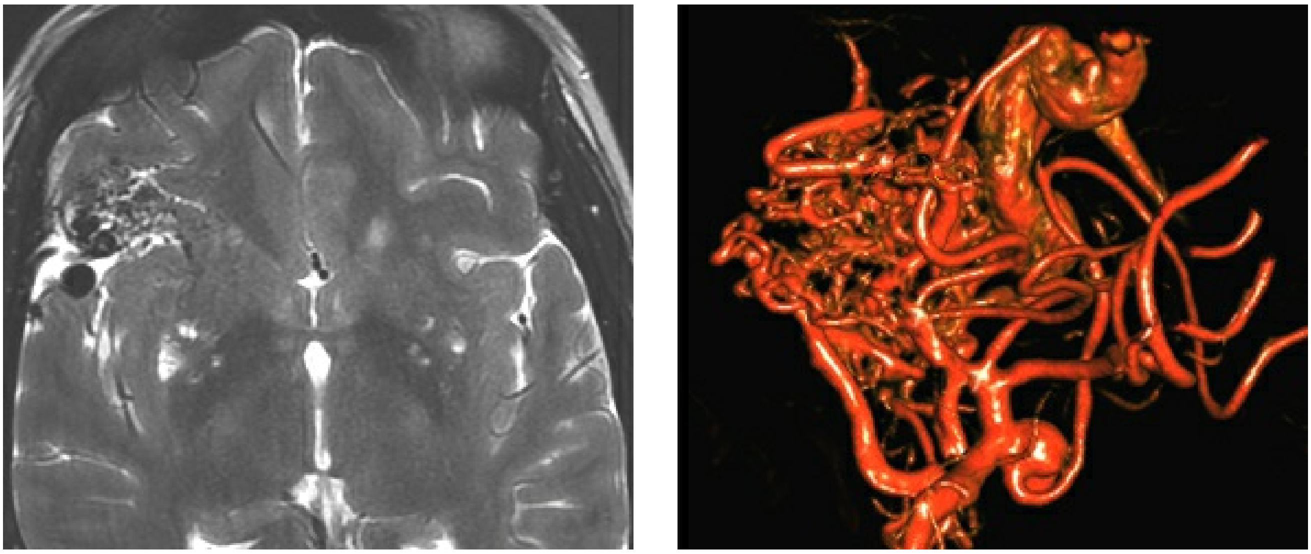


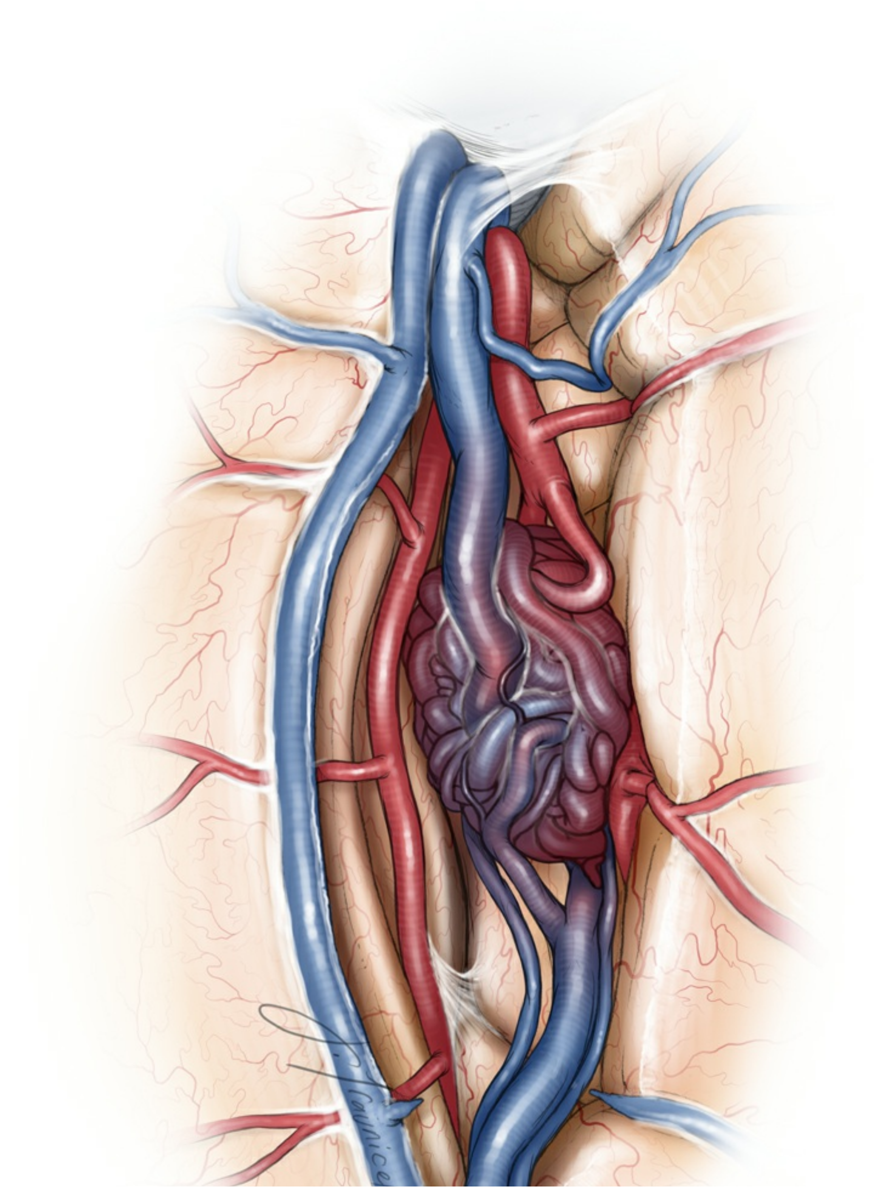
Figure 17: A right-sided Sylvian frontal AVM, primarily supplied by the MCA branches, is shown (left image). An anterior temporal feeding artery aneurysm is also found (right image).

The patient is positioned supine and in the same position as for an MCA aneurysm. A pterional craniotomy and transsylvian trajectory is appropriate.

Sylvian fissure dissection should be carried widely from distal to proximal and deep to the level of the insula; the superficial Sylvian vein is left on the temporal opercula. This arterialized vein is robust and unlikely to rupture easily during the fissure split.

If the patient has a Sylvian frontal AVM, the fissure is a remarkably more crowded area due to hypertrophied MCA branches and other arterialized veins. Meticulous Sylvian fissure splitting should skeletonize the MCA trunk and the adjacent branches. It is critical to clearly identify and differentiate the terminal, transit, and bystander arteries by subarachnoid dissection of the involved vessels and isolating the nidus.

The terminal feeders are carefully dissected, pursued, and identified within the anterior fissure and are finally disconnected near the nidus. Sulcal and parenchymal dissection mobilizes the superior aspect of the AVM.



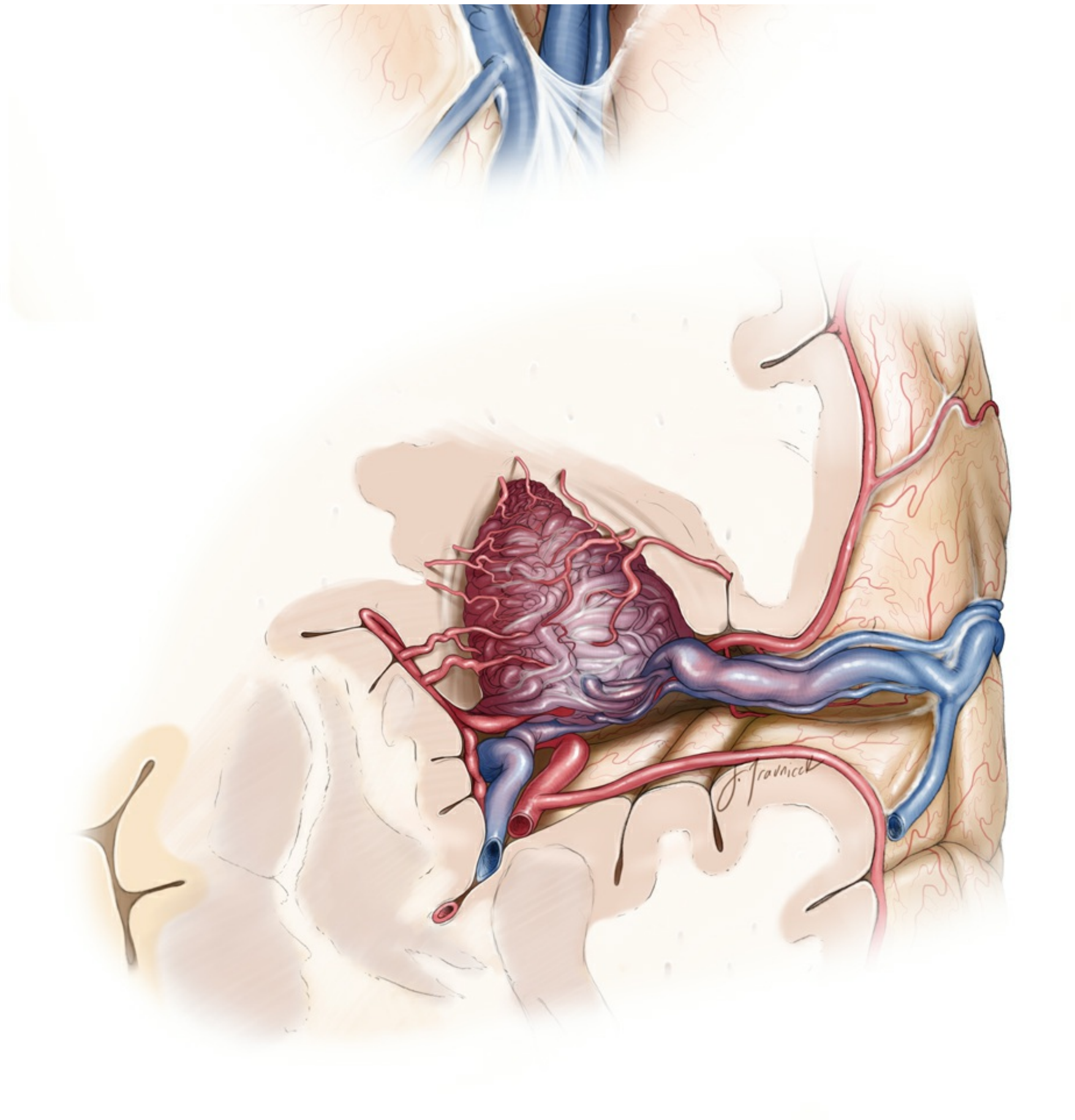


Figure 18: The vascular anatomy of a Sylvian frontal AVM is demonstrated. Please note the relationship of the malformation to the MCA (M2 and M3) branches. Transit or bystander vessels must be recognized from feeding vessels (surgeon's view, top). The superficial Sylvian veins participate in the drainage system of the AVM and are protected during the fissure split. These veins can tether down the the frontal lobe to the temporal lobe and limit the flexibility of the required operative corridors. The anatomy of the malformation is further dissected in a coronal image (bottom illustration).

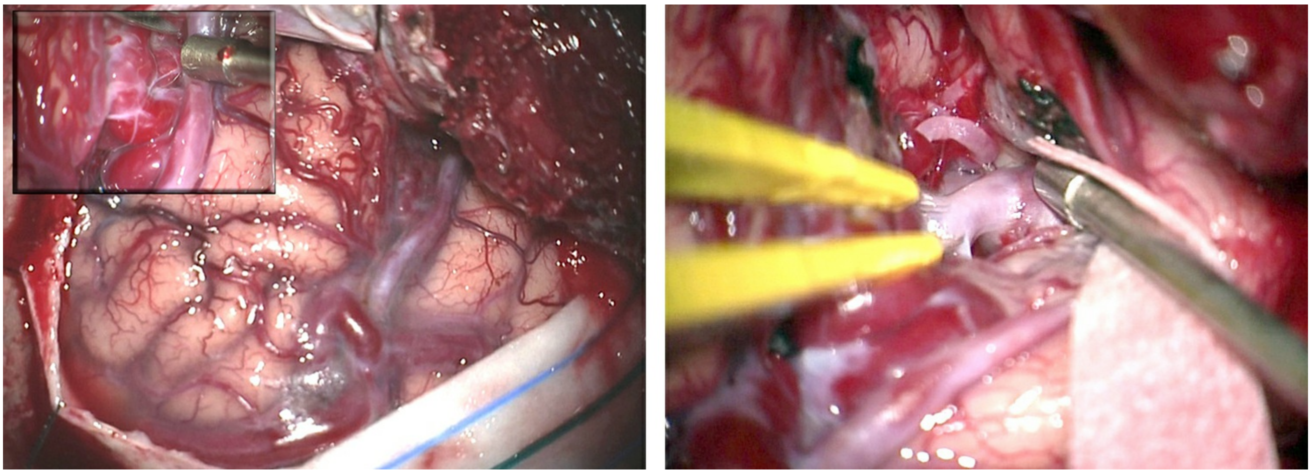


Figure 19: The AVM in Figure 15 is exposed. Note the arterialized superficial Sylvian veins. Additional arterialized veins were found within the crowded fissure (upper image-inset). The enlarged MCA feeding vessels within the fissure are evident.

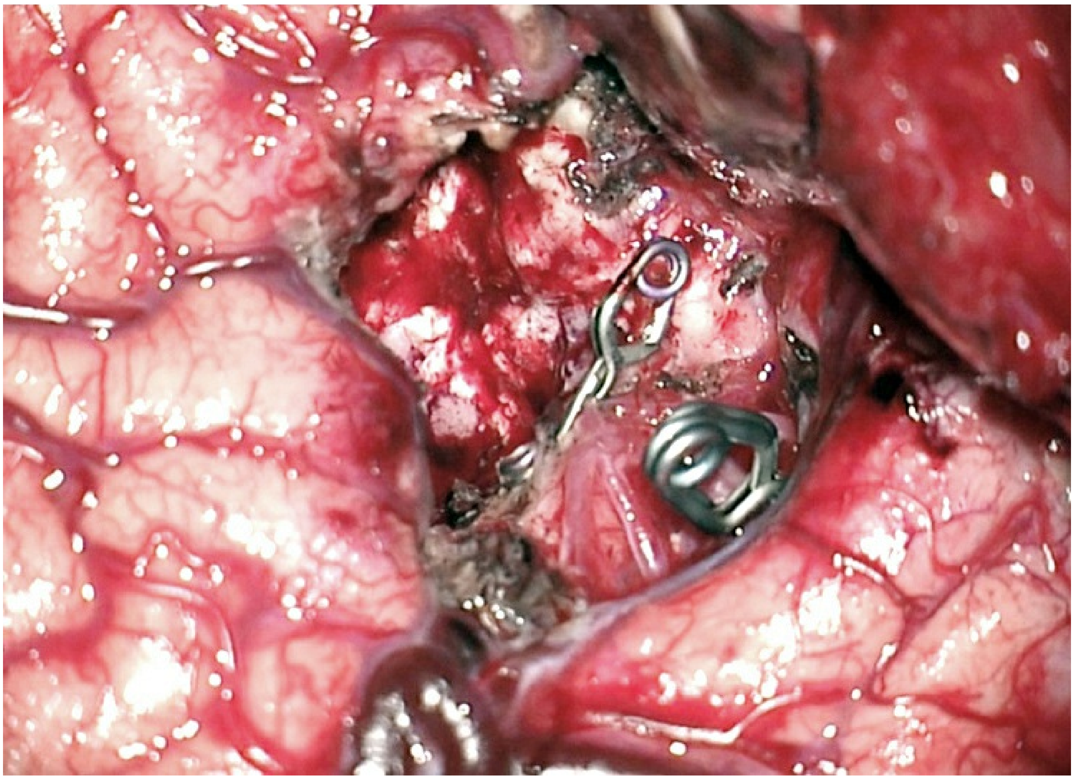


Figure 20: The MCA bifurcation feeding aneurysm was clip ligated (upper image). Next, the feeding MCA terminal branches were first clip ligated using temporary clips, their identity was reliably confirmed via their dissection to the level of the nidus and finally they were sacrificed using permanent clips and the AVM delivered (lower image).

In the dominant hemisphere, the circumferential dissection should be performed as near the nidus as possible to decrease the risk of injury to the eloquent cortex. After enough circumdissection, I mobilize the nidus into the Sylvian fissure to complete the final steps of its detachment within the anterior insula.

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