Neurosurgical Techniques

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Excision of Cerebral Arteriovenous Malformations

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An arteriovenous malformation (AVM), sometimes called an arteriovenous aneurysm or angioma, represents persistence of an embryonic vascular pattern or shunt. With time the vessels of an AVM may become increasingly tortuous, dilated, and numerous, and the lesion more extensive. An AVM usually extends into the brain as a wedge, which means that the surgeon must be wary of its deep as well as superficial blood supply.

An AVM may be the cause of seizures or progressive neurological or intellectual deficits as the result of one or more of the following related developments: 1) circulatory insufficiency, when normal adjacent brain tissue is deprived of an adequate blood supply by the AVM shunt; 2) invasion of intact brain tissue by extension of an AVM; 3) compression by the large vessels of an AVM, including greatly dilated veins at a distance from the lesion; and 4) gliosis secondary to one or more of the above. Some AVMs lead to episodes of subarachnoid hemorrhage or the sudden formation of a massive clot, particularly in children or young adults but less often as a rule in adults over the age of 30. In about 2% of AVMs, a bruit may be heard by the patient or by the physician upon auscultation.

Diagnosis and Indications for Surgery

Clinical manifestations of an AVM may include focal, generalized, or psychomotor seizures, intellectual deterioration, abnormal behavior, or neurological symptoms and signs indicating the location of the lesion.

Work-up includes plain x-rays of the skull that may show abnormal intracranial calcific streaks or dilated venous channels in the calvarium. An electroencephalogram is often, but not always, of localizing value. An ultrasonic echogram may, of course, indicate the presence and laterality of a hematoma. If subarachnoid hemorrhage is suspected, lumbar puncture should be performed for verification. A radioactive scan and arteriography are the two most valuable tests, the latter being essential. Arteriography with high-speed cinematography may be necessary to delineate with certainty the feeding artery or arteries. Contrast studies with air or an inert gas should obviously be avoided, but if they have been made because of a suspected brain tumor they may reveal vascular irregularities in the wall of an involved ventricle, or cerebral atrophy at or around the site of the AVM. If there is any doubt as to which cerebral hemisphere is dominant, as in patients having an AVM in or near the angular gyrus, the preoperative work-up should include an intracarotid amytal test.

Excision of an accessible cerebral arteriovenous malformation is indicated for the relief of seizures that persist despite appropriate medication, for the relief of progressive neurological, behavioral, or intellectual deterioration caused by the AVM, and for the prevention or relief of serious hemorrhage from the AVM, especially in patients who have experienced recurrent episodes of subarachnoid hemorrhage.

AVMs that are usually inoperable include those that directly involve the primary motor or speech cortex, structures deep within the brain, or most or all of an entire hemisphere. However, some AVMs that cannot be safely excised occasionally respond with dramatic benefit to embolic or direct intracranial occlusion of their feeding artery or arteries. Surface coagulation and x-ray therapy are of little or no value. Cerebellar AVMs or intraventricular vascular lesions, although not the specific subjects of this description may be excised according to the surgical principles to be described.

Operative Technique

Intratracheal anesthesia, usually with halothane, is induced after the preliminary intravenous administration of sodium pentothal to facilitate intubation. Hypertonic solu-
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Fig. 1. Exposure of an arteriovenous malformation. A. Outline of bone flap (solid lines) and AVM (dotted line). Medial limb of flap is cut directly over superior longitudinal sinus. B. Localization of motor strip after elevation of dura by electrical stimulation. C. Testing a blood vessel before clips are applied by gently occluding a vessel close to an AVM with bayonet forceps to determine whether it is an artery or a red vein. D. Occlusion of superficial blood supply to AVM. Major superficial arteries supplying the AVM are occluded by clips. The anterior cerebral artery is first exposed along the falx with care to preserve major venous channels such as those draining the motor strip. A branch of this artery supplying the AVM has been clipped as well as surface branches of the middle and posterior cerebral arteries preparatory to their division. (Ang. = Angular gyrus.)
tions such as Mannitol and urea are generally not used unless there is preoperative evidence of increased intracranial pressure. Arfonad-induced hypotension is often helpful during the excision of a large or difficult AVM to reduce the risk of bleeding.

The patient is placed on the operating table so that the head is higher than the chest with the site of the craniotomy uppermost. This position ensures maximal venous drainage, an important aid to AVM surgery.

**Exposure of Arteriovenous Malformation.** The bone flap should be planned with three points in mind: adequate exposure to the lesion itself, exposure of remote nutrient arteries, and exposure of the motor strip if this is thought to be near the AVM. Adequate exposure of the lesion requires a flap large enough to provide ample room all around the malformation (Fig. 1 A). Otherwise, it may be difficult to reach adjacent feeding arteries or draining veins that have not been detected by arteriography. The flap should also be large enough to provide access to large nutrient arteries remote from the lesion, such as deep branches of the anterior or posterior cerebral artery along the falx. Finally, the flap should ensure access to the motor strip if the AVM is in its vicinity, so that the strip can be positively identified by electrical stimulation as discussed below.

For a parasagittal exposure, which is required for so many malformations, I always incise the scalp and saw the bone directly in the midline, along and over the superior longitudinal sinus (Fig. 1 A). This avoids troublesome bleeding that may occur if the skull is opened a centimeter or so lateral to the midline, for then arachnoid villi may be torn on passing the saw guide. The bone flap may be free or hinged on muscle. The latter seems preferable because it preserves some blood supply to the bone.

Immediately after reflecting the bone flap, its cut edges are waxed after the dura is covered with cottonoid to reduce any bleeding and the risk of air embolism. Venous and arterial channels of the dura are then cauterized or clipped where necessary, except for openings in large venous channels which are not cauterized lest they be made still larger. Instead, a small muscle stamp is placed over them. I believe this is the best hemostatic agent for this purpose. The muscle is anchored to the dura by a suture passed over it to prevent it from being dislodged by postoperative coughing or straining (Fig. 2). The dura is now tacked up to peristeum and opened so that its base is parallel to the midline. Care should be taken while the dura is being reflected because there may be vascular connections between the lesion and the dura, or adherent vessels of the AVM to the dura. In addition, all possible venous channels in the dura should be spared lest venous drainage of normal cortex become seriously impaired.

**Identification of Motor Strip.** Before attempting any surgical maneuver in the region of the motor cortex, the latter must be identified with certainty by electrical stimulation (Fig. 1 B). The coronal suture is not a reliable index as to the position of the motor strip. However, the position of the motor strip usually can be estimated preoperatively by arteriography.

**Excision of Arteriovenous Malformation.** The key to successful excision of an AVM is, of course, to occlude the arterial supply before sealing the draining veins. Otherwise, the force of arterial blood may rupture the veins, which are usually extremely thin-walled, and lead to tremendous loss of blood. In operating on some malformations, it is occasionally difficult to be certain in a tangle of dilated red vessels which are arteries. This can usually be determined by gently occluding a vessel with the bayonet forceps (Fig. 1 C). Occlusion of a major nutrient artery will change the color of red veins to...
blue and reduce their turgor, whereas occlusion of a vein will not have this effect.

When the nutrient artery or arteries to the AVM have been identified by inspection or temporary occlusion, they are then occluded with clips preparatory to division, as shown for the anterior, posterior, and middle cerebral arteries (Fig. 1 D). Small arterial branches are electrocoagulated and divided. When all surface arteries supplying the AVM have been divided as close to the margin of the lesion as possible, the superficial veins usually become blue or partly blue instead of red, and appear collapsed instead of distended. Such a vein may now be safely divided between ligatures (Fig. 3 A, top center). Careful dissection of the deeper vessels, which are usually present, is then pursued by marking a transcortical incision all around the malformation.

The transcortical incision is usually begun with electrocautery to the depth of 3 to 4 mm (Fig. 3 A, right) and then continued into the substance of the brain by means of a small-caliber suction tip (Fig. 3 A, left). Slow cautious pursuit of the dissection is continued with the aid of retractors (Fig. 3 B) so that deep blood vessels can be identified and clipped or cauterized before they are inadvertently ruptured. Every effort is

![Fig. 3. Excision. A. Preliminary steps for block excision: 1) Division of superficial nutrient arteries between clips; 2) Division of collapsed vein between ligatures (top center); 3) Transcortical incision with electrocautery (at right); and 4) Extension of incision with small suction tip (at left). B. Intermediate steps for block excision. Deep vessels supplying AVM are exposed with the aid of retractors preparatory to their division between clips.](image-url)
made to preserve sizable venous channels until the last, when they too may be safely clipped and divided. The lesion may now be excised as a block (Fig. 3 B), with minimal sacrifice of adjacent brain tissue after clipping and dividing all deep vessels (Fig. 4).

Closure. Perfect hemostasis must always be achieved before closure. Hemostasis is checked by filling the cavity in the brain with saline solution to detect any source of minor bleeding, and corrected by cauterization or other means. Not until the fluid in the cavity remains as clear as spring water (Fig. 4. inset) is the dura closed.

Dural closure is always watertight (Fig. 5) to prevent subdural hematoma formation from any blood that may ooze from the scalp, or from a mixture of blood with the cerebrospinal fluid that may lead to a stormy postoperative course and possible late development of obstructive hydrocephalus. Another reason for tight dural closure is to reduce the risk of meningitis should infection of the scalp wound occur.

Before the bone flap is replaced, a small hole is drilled through its center so that a suture can be passed through it, attached at one end to the center of the closed dural flap (Fig. 5) and at the other end to the periosteum. This fixation suture serves to hold
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The dura is up against the bone flap and diminish the risk of serious brain compression should an extradural hematoma develop.

The bone flap is anchored by periosteal sutures or wired in place, and then the galea and scalp are each closed with a layer of interrupted sutures. Before the scalp is closed, two split rubber tube drains are inserted, each through a separate small stab wound 1.5 cm outside the scalp incision (Fig. 5). One drain is placed between the dura and the bone, the other between bone and scalp, and both are removed after 24 hours. A subdural drain is never used.

Decadron or a similar steroid preparation is administered intravenously (10 mg) and repeated daily for 6 to 8 days, in tapering doses, to reduce the risk of postoperative cerebral edema.

Aids to Excision

Temporary Carotid Occlusion in the Neck. In planning the attack on an unusually large AVM, or one surrounded by an unusual number of enormously dilated veins that interfere with the exposure of nutrient arteries, I like to expose the internal carotid artery in the neck before the craniotomy is begun. The artery can then be shut off if necessary by a DeBakey clamp. This can be helpful in the event of sudden serious intracranial hemorrhage during surgery, and can materially reduce the distension of large draining veins around an AVM so that dissection of deep feeding arteries is appreciably facilitated. This technique, I feel, requires the use of moderate hypothermia.

Moderate Hypothermia for Temporary Arterial Occlusion. Moderate hypothermia at 28° to 30° C is used only when temporary arterial occlusion is planned, either by carotid occlusion in the neck as stated above, or by intracranial clip or snare occlusion of a major artery supplying the AVM. In my experience, no ill effects have followed the use of moderate hypothermia for excision of an AVM.

Profound Hypothermia for Circulatory Arrest. Profound hypothermia at 10° to 20° C permits total circulatory arrest and therefore a practically bloodless field that greatly facilitates excision of large and otherwise difficult

![Diagram of closure and fixation of dura](image)

**Fig. 5.** Closure and fixation of dura. Water-tight closure of dura; tenting suture from center of dural flap to periosteum through small hole drilled in bone flap; placement of two drains.
vascular malformations. I personally do not favor its use for excision of an AVM, however, because of attendant problems such as extraordinary difficulty in achieving hemostasis on closure, a rather high risk of postoperative hemorrhage, the risk of serious cardiac complications, and the possibility of equipment failure.

Hypotension. The induction of hypotension by Arfonad, by the judicious use of halothane, or by hyperventilation has proved extremely helpful in reducing the turgor of an AVM and adjacent draining veins during exposure and excision. Induced hypotension, however, carries risks that limit its use to the resection of unusually large, deep, or otherwise difficult malformations. Consequently, induced hypotension is not a routine measure. The principle risks are permanent neuronal damage from prolonged hypotension, particularly in older persons, and cardiac arrest from excessive administration of Arfonad or halothane.

Intracranial Hematoma. An intracranial hematoma caused by hemorrhage from an AVM should be promptly evacuated and the AVM excised at the same operation. The diagnosis of massive clot formation is usually indicated by sudden severe headache, followed by progressive lethargy or coma with or without focal neurological signs, depending on the location of the AVM. Occasionally massive bleeding from an AVM leads to immediate loss of consciousness and persisting coma. In addition to clinical evidence suggesting the presence of a clot, plain x-rays may show a pineal shift; echoencephalography, radioactive scanning, or arteriography may demonstrate pertinent shifts or displacements. Excision of the AVM is usually easy in such cases because of the space afforded after evacuation of the clot.

Evacuation of the clot is accomplished by suction through a transcortical incision over the center of the hematoma, which can usually be detected by inspection, palpation, or needle aspiration.

Large Dural Veins. Exceptionally large

![Fig. 6. Incision of dura with large venous channels. The dura is opened away from, instead of toward, the midline to preserve exceptionally large dural-cortical veins over vital areas such as the motor strip.](image)
dural veins are found in some patients with an AVM on reflecting the bone flap. These large venous channels, usually associated with vascular malformations near the midline, may drain blood directly into the superior longitudinal sinus from the AVM itself, or from adjacent cortex such as the motor strip. It is advisable to keep these large channels intact on opening the dura (Fig. 1 D). As indicated earlier, he major veins of an AVM should be preserved until arterial in-flow is first reduced lest an explosive hemorrhage occur in the lesion. Major veins from adjacent cortex, particularly of the motor strip, should be preserved for another reason: namely, the prevention of serious cerebral edema, or more important, retrograde thrombosis which could lead to permanent hemiparesis.

One method of preserving large dural veins entering the superior longitudinal sinus is to reflect the dural flap away from the midline instead of towards it. This can be accomplished by first opening the dura on each side and then extending the incision toward the midline (Fig. 6), being careful to watch for venous channels of the inner as well as outer dural surfaces, so that the dural incision can be made around these channels and thus preserve them. Another reason for using this technique is to facilitate exposure of branches of the anterior cerebral and posterior cerebral arteries along the falx without having to destroy important venous channels. This could be difficult with the conventional type of dural reflection toward the midline.

**Massive Hemorrhage at Operation.** Occasionally serious bleeding may occur during excision of an AVM. In my experience this has only happened when the lesion lay so close to a vital area of the brain, such as the angular gyrus of the dominant hemisphere (Fig. 1 D), that dissection was carried out very close to the margin of the malformation to be certain of preserving cortex concerned with speech. Despite the utmost care during stepwise identification and coagulation of small deep vessels entering the AVM, the cautery may fail to seal one and then another thin-walled artery or vein until presently a chain reaction takes place resulting in profuse bleeding from numerous points. If the cautery fails to control hemorrhage from such a nest of paper thin vessels, pack-

![Fig. 7. Subtemporal exposure. The subtemporal portion of the dilated left posterior cerebral artery supplying the occipito-temporal AVM is exposed for clip occlusion. Large veins entering the tentorium must be divided after cauterization or between clips.](image)
rior frontal AVM supplied by proximal branches of the middle cerebral artery is another example. This type may require a subfrontal and intra-Sylvian approach.

Subtemporal Exposure. The subtemporal portion of the posterior cerebral artery may be approached through a sufficiently low exposure (Fig. 7) so that the midportion of the temporal lobe can be elevated by retractors from the tentorium until the vessel can be identified and then traced as far posteriorly as desirable. This part of the procedure requires careful attention to veins, often large, coursing from the temporal lobe to the tentorium.

Subfrontal and Intra-Sylvian Exposure. The proximal segment of the middle cerebral artery may be easily exposed by a subfrontal approach such that the internal carotid is first identified and traced just beyond its bifurcation to the middle cerebral artery. This permits the application to it of a temporary clip or Hamby snare if necessary. Then, without sacrificing any major vessels, the Sylvian fissure can be opened carefully along its entire proximal extent, to expose and occlude branches of the middle cerebral artery that supply an anterior temporal or low frontal AVM (Fig. 8).

Arterial Occlusion Without Excision. Some malformations are so extensive or so situated that excision is neither safe nor practical. Occasionally, partial occlusion of their major arterial supply intracranially is beneficial for this type of AVM, such as those occupying most of the non-dominant occipito-temporo-parietal lobes. The bone flap should be large enough to provide access to the deep dilated branches of the anterior cerebral artery along the falx, as illustrated in Fig. 1, and also be large enough to expose the subtemporal segment of the posterior cerebral artery by the approach described above. Branches of the middle cere-

Fig. 8. Subfrontal and intra-Sylvian exposure of carotid and middle cerebral arteries. A temporary clip may be applied to the middle cerebral artery as shown, for 6 to 8 minutes provided moderate hypothermia is used. Permanent clips are shown on branches to the AVM. Dotted lines indicate site of subcortical AVM.
bral artery supply to the AVM may of course also be easily occluded by a large craniotomy of this type.

Occasionally, an AVM will be associated with numerous deep and superficial veins that cannot be safely excised. This type of AVM may respond dramatically if it is supplied by a single nutrient artery that can be clipped. If this vessel has been clearly shown by arteriography to lie on the convex surface of the brain, it can be clip-occluded through only a small well-placed craniectomy without the need of a bone flap.

Failure to Locate Subcortical Arteriovenous Malformation. Angiography on the operating table is occasionally necessary to define the precise location of a small subcortical AVM when the course of its nutrient arteries or draining (red) veins is not plainly evident on the surface of the exposed brain.

If the operating room is not equipped with x-ray apparatus for this purpose, a portable x-ray device may be used. For anteroposterior views, an x-ray cassette may be slipped under the head beneath the drapes. For lateral or oblique views, the cassette covered with a thick sterile drape may be propped up against the side of the head outside the usual drapes.

References