Arteriovenous malformations

Summary of 100 consecutive supratentorial cases

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One hundred cases of macroscopic supratentorial arteriovenous malformations are studied, along with the significant literature. On the basis of morphology, they are subdivided into straight-line, single-unit, multiple-unit, intra- and extracranial, venous-wall types, and one other of questionable type. The study does not confirm a relationship of pregnancy to bleeding. It does confirm the absence of vasospasm in association with these lesions, the increasing tendency of the lesion to bleed the smaller it is, the equal sex distribution, the peak incidence in the patient's fourth decade, the lack of significance of family history, and the lack of associated vascular lesions. The study stresses the advantages of preoperative three-dimensional angiography, surgical magnification, and intraoperative serial angiography. It is emphasized again that the fistula itself must be removed or obliterated.

KEY WORDS • arteriovenous malformation • classification • age distribution • arterial supply • indications for surgery • surgical results

The demonstration by Harvey\(^1\) of the directional flow through arteries and veins, and then Malpighi's\(^8\) description of capillaries, set the stage for the recognition by Hunter\(^29\) and Steindel\(^11\) of the arteriovenous malformation (AVM). It remained for Holman\(^26\) to discourage attempts to obliterate such a lesion in the extremities by occlusion of entering or leaving vessels; he emphasized the importance of obliterating the fistula. Simultaneous publications by both Dandy\(^12\) and Cushing and Bailey\(^19\) recognized that the solution depended on obliteration or complete isolation of the fistula, yet both cautioned against surgical attack except in a very few selected areas. Olivecrona and his associates,\(^6,11,32\) and Tönnis\(^6\) demonstrated that these lesions could be removed without prohibitive mortality.

In 1958, Anderson and Korbin\(^2\) defined an AVM as "a congenital non-neoplastic vascular abnormality comprised essentially of a coiled mass of arteries and veins partially separated by thin strips of sclerotic nervous tissue, lying in a bed formed by displacement rather than invasion of normal brain tissue," a definition that applies to most of these lesions, but omits the essential feature of them all, which is the fistula or shunt. This feature permits arterial blood to enter the venous system without passing through an arterio-capillary bed and hence, without nourishing tissue or undergoing the resulting pressure reduction of such a bed. A simpler and more descriptive definition would be, "a congenital arteriovenous fistulous malformation." The variation in size, number, course, and configuration of the entering and leaving vessels should not alter the definition. The pathology is the short-circuiting of the arteriocapillary bed. To date, we do not know why this local angioblastic mistake occurs.

Other terms that have been used to describe lesions that may or may not have included true AVM's are: "telangiectases," "varices," "cavernous malformations," and "venous malformations."\(^32,47,66,76,88\) We believe that closer scrutiny of some of these so-called "venous angiomas" or "varices" would show that a fistulous connection, albeit small, actually exists. For instance, Pressig, et al.,\(^9\) reported a frontal lobe
This study is based on 100 cases of macroscopic supratentorial AVM's seen over a 20-year period concluding in 1977. Eleven additional surgically treated AVM's were previously reported in 1957. By "macroscopic," we mean those demonstrable by angiography, thus excluding those AVM's demonstrated by the pathologist's microscope after removal of a bleeding area at surgery for an intracranial clot.

**Summary of Cases**

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**Family History**

Arteriovenous malformations are believed to be congenital, therefore, family histories were examined for possible relevant findings. One patient had a racemose angioma of the left side of the forehead, a younger asymptomatic sibling had an angioma of the forehead, and a paternal grandmother underwent "brain" surgery for some type of "vascular malformation." Two patients in our series had fathers who died of "stroke," one of which was verified cerebral hemorrhage. Two other patients each had one parent with migraine. Our series thus reveals no statistically significant family history.

**Subarachnoid Hemorrhage**

Fifty-three of our patients, 25 males and 28 females, presented with subarachnoid hemorrhage (SAH). This incidence compares with 41% reported by Moody and Poppen, 61% from the Cooperative Study, and the overall average of 52% described by Pia. Ten other patients in our series had a history suggesting previous bleeds, such as "encephalitis." The relationship between the incidence of hemorrhage and age is presented in Figs. 1 and 2. Although our series showed that the left frontal lobe lesions bled nearly twice as often as the right, and the right temporal lobe lesions three and one-half times as often as the left, such discrepancies cannot be statistically significant with such small total numbers (p > 0.05). Our findings would agree with Pia's statement that the smaller lesions have a more vicious bleeding tendency than do the larger ones.

**Classification of Arteriovenous Malformations**

Beyond the classification of an "abnormal congenital shunt or fistula between the arterial and venous system," there are some obvious anatomical and functional subdivisions of AVM's, as follows:

**Type I: The Multiple-Unit AVM.** The multiple-unit anomaly was the most common type encountered in our series (82%). It consists of multiple cerebral arteries and multiple draining veins connected to a mass of fistulas. In some if not all of these, the single mass contains multiple, clustered, small fistulas; in these cases the surgeon may believe he has removed the entire lesion only to find on postoperative...
angiography a residual unit consisting of artery, fistula, and draining veins (Figs. 3 and 4). It is possible that all of the large malformations involving many arteries and veins are multiple-clustered units, each consisting of a single artery, a single fistula, and a single draining vein (which vein may immediately join another). Does the pathology represent a single error in the angioblastic developmental code or multiple errors, and, if multiple, why do they usually occur in the same region? Rarely have several units been reported in different areas.\textsuperscript{49,61} It is evident that the genetic error is of a different nature or timing than in Type III (the straight-line AVM).

**Type II: The Single-Unit AVM.** In our series, 10% of the AVM’s consisted of a unit including a single artery, a single fistula, and a single draining vein. They were usually small (Figs. 5 and 8).

**Type III: The Straight-Line AVM.** The simplest, yet the most difficult to understand as an angioblastic error, is a “straight-line” or direct arteriovenous shunt, in which one or more major arteries proceed without subdivision or diminution of caliber directly into a venous sinus. These are comparatively rare, and comprised 3% of our series. They are usually seen only in infancy, and the most common is an aneurysm of

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**Fig. 3.** Lateral angiograms showing a Type I multiple-unit fistula in a 22-year-old man. **Upper:** Preoperative film showing two distinct draining veins which should have indicated to the surgeon two lesions. **Lower Left:** Intraoperative angiogram. The bone flap has been wired back in preparation for complete removal. The fourth film of the series, shown here, demonstrates residual fistula filling the uppermost of the two draining veins. The first three of the series resembled the film shown lower right, and, if considered alone, would have falsely indicated a complete removal. **Lower Right:** Subsequent intraoperative angiogram. Film 4 of a complete series of six at 1-second intervals, proved total removal.
FIG. 4. Lateral angiograms of a Type I multiple-unit fistula in a 14-year-old boy with small, weak, right extremities and normal speech. Upper Left: Early arterial phase, left parietal arteriovenous malformation. The fistula phase was not interpreted as multicentric at the time. Upper Right: Venous phase showing multiple venous units. Lower Left: After four seemingly complete removals, each in turn followed by intraoperative angiography, there still remains a separate unit fed by the lenticulostriate artery, visible just below the wire-ring marker. Lower Right: Final intraoperative angiogram demonstrating complete obliteration of all units of this multicentric lesion (extravasation is seen from the pericallosal branch, visible just below the coil of the most anterior opaque thread, placed as landmarks to guide in pursuit of any residual lesion). The patient recovered, with diminution of seizures and improved intellect, but unchanged locomotion.

Type IV: The Combined AVM. In our series, 3% of the AVM's were fistulas fed by both cerebral and extracerebral vessels. In these straight-line fistulas, the cortical veins may be visualized, but only as a retrograde reflux filling, a splash-back, from the sinus and not as afferents from the fistula (Fig. 6).

Type V: The Venous-Wall AVM. The AVM's in 2% of our series consisted of purely extracerebral arteries draining into an intracranial dural sinus.
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Fig. 5. Type II single-unit arteriovenous malformation comprising an artery, fistula, and vein in a 9-year-old girl. Upper Left: Preoperative angiogram, anteroposterior view, of a large midline basifrontal single-unit malformation fed by a single abnormal branch of the left anterior cerebral artery, draining exclusively via a scalp vein. Upper Right: Right carotid injections showing blood flow siphoning into the malformation. Center Left: Photograph showing the dilated draining scalp vein. Center Right: Postoperative film showing complete obliteration. No anterior cerebral components filled from this side (left), both filled from the right side. Lower Right: Eighteen months later, the child returned because of subdural hematoma. Cortical branches can be seen turning away 2 cm proximal from the inner table. This was the first appearance of a “feathery” pattern in the basifrontal region. Venous phase showed sluggish early filling of small cortical veins, which were removed. A normal postoperative angiogram was obtained, but an identical feathery pattern of abnormality recurred three times over a 5-year period. Recurring spontaneous subarachnoid hemorrhages led to each subsequent investigation.

28, 34, 46, 53, 78, 84, 88 These extracerebral arteries, which may be associated with the scalp, bone, or meninges, undergo normal subdivision to a nearly normal termination, then spill directly into the large dural sinuses without ever involving cortical veins; however, there may be a retrograde splash-back of cortical veins with meningeal, tentorial, and scalp-vessel efferents. Characteristically, these AVM's have resisted multiple surgical efforts, including embolization and surgical isolation of the involved segment of the vein. Our experience leads us to believe that these efforts have failed because the fistulous elements are actually in...
FIG. 6. Type III straight-line arteriovenous malformation in a newborn with congestive heart failure. Left: Lateral angiogram of the straight-line fistula showing fused anterior and middle cerebral artery components entering the sagittal sinus directly. There is no appreciable diminution of caliber between the carotid artery and the sagittal sinus to indicate any significant supply of tissue along the route. There is considerable splash-back, reflux filling into the adjacent normal veins connecting to the sagittal sinus. Right: Postoperative lateral angiogram. The patient died from an undetermined cause.

We encountered one additional case, which we would hesitate to designate as a separate type. A Type II lesion was completely obliterated as demonstrated by follow-up angiogram in a 9-year-old girl. Eighteen months later, she fell from a bicycle; a repeat angiogram at that time demonstrated a subdural hematoma and also a feathery or fern-like branching along a 2-cm segment of an otherwise normal artery, with a sluggish but early filling of an adjacent vein; all these features were in the region of the previous AVM. This segment was removed, and postoperative serial angiography again revealed no evidence of a fistula. One year later, a similar appearance was seen in an adjacent vessel in the same region; this segment was also removed, followed by normal postoperative angiography. One year later, this sequence was repeated in another vessel. Microscopically, the only abnormality the pathologist could see was that the vessels were thin-walled; yet angiographically, this was a different pattern from that of the original fistula, and behaved more like a neoplasm (Fig. 5). It was also unusual in that the single draining vein of the original fistula entered directly into a scalp vessel.

Presentation by Location

Anatomists have been unable to provide us with completely rigid boundaries for the lobes of the brain. Some authors simply localize their lesions by the designations anterior, middle, and posterior. If the feeding arteries and, in particular, the draining veins, are used for localization, some lesions would include an entire hemisphere; whereas the fistula itself is usually, if not always, discretely localized in a single lobe. Throughout our presentation, we use the site of the fistula to localize the AVM, without regard to the extent of the feeding arteries and draining veins.

Some signs and symptoms may be due to effects at a distance from the fistula, such as from vascular steal or the mechanical effect of the large feeding or draining vessels; correlation of signs and symptoms by location of the lesion indicates that the site of the fistula is usually responsible for the resulting neurological deficit. We believe that any sudden headache and/or stiff neck must be the result
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Fig. 7. Type IV combined arteriovenous malformation in a 54-year-old man. Upper Left: Preoperative vertebral angiogram, arterial and fistula phase, showing a moderate-sized fistula fed by the occipital, middle, and anterior cerebral arteries. The posterior cerebral artery contribution is seen. Later films showed the large meningeal vessels contributing as well. The marked meningeal grooving of the calvaria is visible in these pictures. Upper Right: Preoperative angiogram, early venous phase, gives an unrealistic appearance of a much larger malformation, suggesting involvement of the entire posterior hemisphere. Lower: Postoperative angiogram showing complete removal of the multcentric lesion. The angiography series over a period of 12 seconds revealed no filling of the large draining veins, all of which were left in situ.

of hemorrhage, and we have no evidence that hemorrhages occur other than immediately adjacent to or within the site of the fistula. The sudden onset of coma, paresis, and/or aphasia, unless associated with a seizure, must also be due to hemorrhage and, hence, also at the site of the fistula. Table 1 correlates the presenting symptoms with the lobe in which the lesion is located. It is evident that headache of sudden onset is by far the most frequent presenting feature, with seizures and nausea in a virtual tie for second place.

Size of Shunt and Patient’s Age

Any discussion of size assumes an exact or at least a uniform method of measurement. The outline of the entire malformation, including the venous cloud, may be used by some. Although it is not clear whether Henderson and Gomez and Raskind and Weiss were talking of the outline of the entire malformation or merely of the portion we would term the fistula, we follow their protocol and classify any AVM’s over 2 cm in diameter as large. In doing so, we are using the outline of the fistula alone.

In our series, 75% of the lesions thus classified as “small” had been diagnosed by the time the patient was 30 years old; 80% of the lesions diagnosed in patients over 30 years old were classified as “large.” The observation by Henderson and Gomez that small malformations are more likely to cause bleeding in children and that fatal hemorrhage from large
lesions does not occur until later life would probably be better explained by the fact that small lesions are more common in children and large lesions are more common in older persons.

**TABLE 1**

*Presenting features and lobe in which the arteriovenous malformation was found*

<table>
<thead>
<tr>
<th>Presenting Feature</th>
<th>Lobe</th>
<th>Frontal (33 cases)</th>
<th>Temporal (27 cases)</th>
<th>Parietal (24 cases)</th>
<th>Occipital (13 cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>headaches</td>
<td></td>
<td>64%</td>
<td>91%</td>
<td>100%</td>
<td>80%</td>
</tr>
<tr>
<td>seizures</td>
<td></td>
<td>57%</td>
<td>80%</td>
<td>80%</td>
<td>50%</td>
</tr>
<tr>
<td>nausea</td>
<td></td>
<td>60%</td>
<td></td>
<td>60%</td>
<td>70%</td>
</tr>
<tr>
<td>hemiparesis</td>
<td></td>
<td>43%</td>
<td>4%</td>
<td>45%</td>
<td></td>
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<tr>
<td>sensory deficit</td>
<td></td>
<td>14%</td>
<td></td>
<td>20%</td>
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<tr>
<td>stiff neck</td>
<td></td>
<td>21%</td>
<td></td>
<td>8%</td>
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<tr>
<td>bruit</td>
<td></td>
<td>18%</td>
<td>18%</td>
<td>2%</td>
<td>4%</td>
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<tr>
<td>aphasia</td>
<td></td>
<td>36%*</td>
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<td>psychosis</td>
<td></td>
<td>14%</td>
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<tr>
<td>retinal hemorrhage</td>
<td></td>
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<td>20%</td>
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<td>10%</td>
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<tr>
<td>papilledema</td>
<td></td>
<td>1 case</td>
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</table>

*Percentage of left-sided lesions only.

**Growth of the Lesion**

Paterson and McKissock suggested that the apparent growth of AVM's was due to repeated, often silent, rupture of vessels, leading to small hemorrhagic infarcts of adjacent brain tissue. The absorption of necrotic material would lead to decreased mechanical support of blood vessel walls and further hemorrhage and enlargement. Hamby pointed out that the malformations are most certainly formed early in the development of the cerebral mantle, and remain separable from normal brain tissue so that lesion growth would be expected to occur between definite boundaries without involvement of originally normal vasculature. Thus, AVM's may have a predetermined ultimate size. This would account for the occasional finding of a very small lesion in an older person.

In two of our cases, operative correction was delayed over a period of from 1 to 2 years, and in both cases there was angiographic evidence of enlargement. On the other hand, one lesion was observed for 7 years, during which time there was no evident growth.

We have managed two cases in which the initial surgery consisted of clipping easily accessible feeding arteries to a deep-seated lesion. In both cases, the immediate postoperative angiogram revealed a marked reduction in fistula size, yet, in both, within less than 2 years the fistula had become larger than its preoperative size and rebled. Slow growth has been suggested as a possible factor to explain the rare...
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presentation in the earlier decades. Svien and McRae observed no growth in their series.

We believe that the low-resistance high-outflow fistula predisposes to enlargement of any feeding arteries or draining veins, and possibly to enlargement of the shunting vessels as well, but the hemodynamics of a fistula do not predispose to the development of fistulous connections. If new connections are proven, they must be neoplastic. As with any short-circuiting connection, once established, flow is invited through the channel of lower resistance, and there would be no mechanism at work eroding new channels of bypass.

**Shunt Resistance**

Shunt resistance and, hence, outflow pressure, is determined by the length and caliber of the connections. These are both independent of the “size,” which refers to the space occupied by the shunting vessels. Thus, some straight-line shunts might be termed “small” because the boundaries of the connecting mechanism are less than 2 cm in diameter, yet the flow rate and the outflow pressure would be great, equal to the carotid arterial systolic pressure, as the caliber of the connection approximates 1 cm.

The AVM’s in this series were divided into three groups on the basis of their hemodynamic resistance as follows: 51% were classed as low-resistance, with essentially simultaneous venous filling; 30% as intermediate, with venous filling within 2 seconds of arterial filling; and 9% as high-resistance, with venous filling more than 2 seconds after arterial filling. With such small subgroups, statistical inference is unwarranted, but the percentage of bleeding was greater in the small high-resistance group.

**Associated Findings**

**Bruit.** Bruit was noted in all four straight-line lesions, and in all those with extracranial components, but only in three of the remaining purely intracranial lesions. This supports our original contention that bruit is dependent on an abrupt change of caliber or direction of blood flow, which is not a common occurrence in these congenital fistulas.

**Vascular Lesions.** One patient had a racemose angioma of the left side of the forehead, a vascular anomaly of the proximal portions of the major branches of the left internal carotid artery, and a small vascular malformation on the dorsum of the right hand. One other patient had an AVM of the spinal cord in addition to a temporal lobe AVM, each of which bled on separate occasions. Cardiomegaly with congestive heart failure was noted in all four of the infants with the straight-line lesions. Many observers have noted that these AVM’s in infancy are large enough to cause heart failure. One adult with a large-flow lesion had preoperative cardiomegaly that had resolved at the time of discharge.

**Saccular Aneurysms.** Saccular aneurysms coexisted with the principal AVM in three cases. Two others had false saccular aneurysms associated with their malformations.

**Neoplasms.** Neoplasms were seen in two patients. In one, meningioma of the tentorium was diagnosed at the same time as the AVM, and the other developed a Grade IV astrocytoma 2 years postoperatively in the opposite hemisphere.

**Migraine.** Migraine, with a classic pattern, was seen in only two of our patients.

**Pregnancy.** One patient presented with hemorrhage while pregnant. Nine patients, including this one, had previously gone through one or more normal pregnancies. Our series would thus contradict the impression of others of a high incidence of bleeding from these lesions during pregnancy.

**Patients’ Age and Sex**

There was an exactly equal sex distribution in our series, the same ratio as reported by Mackenzie and in the Cooperative Study. The fourth decade was the median age of incidence, with a rapid decline thereafter. When corrected for the population age distribution, this finding becomes even more dramatic (Figs. 1 and 2).

**Arterial Supply**

Moody and Poppen found that the anterior cerebral artery supplied 36% of their AVM’s. Gould, et al., reported that the posterior cerebral artery was the most active feeder, contributing in 66% of cases. Kunc noted that 51% of his AVM’s had more than one of the three supratentorial arteries contributing, whereas in our series only 34% were supplied by more than one artery.

The parent arterial trunk feeding these malformations is usually a normally placed but enlarged channel. In the embryo 20 to 40 mm in length, which is probably the determinant stage of these lesions, the terminal branches of the main arteries are virtually continuous on the medial and pallial walls of the embryonic hemisphere. Thus, it is not surprising that two or three main trunks participate in many of these fistulas. In our series, approximately 55% were supplied exclusively or in combination by the middle cerebral artery, 48% by the anterior cerebral artery, and 38% by the posterior cerebral artery (Fig. 9). These figures probably represent the percentage of their cerebral supply as much as any chance distribution.

**Venous Drainage**

Venous drainage is predictable from the site of the lesion in most instances, and the percentages reflect a total area of normal drainage as much as any other
FIG. 9. Diagram of arterial participation in the arteriovenous malformations in this series. Any deviation from a 50:50 right:left distribution was not statistically significant ($p > 0.05$). The middle cerebral artery (M.C.) participates the most, either singly or in combination with others, as is to be expected since it has the largest area of primary supply. Circle: frontal lobe; square: parietal; triangle: temporal; diamond: occipital.

M.H. = meningohypophyseal artery; Ch. = anterior choroidal artery, M.M. = middle meningeal artery; A.C. = anterior cerebral artery, P.C. = posterior cerebral artery, Occ. = occipital artery.

feature. We saw no instance of a lesion bypassing the most adjacent venous sinus to drain into a more distant one. The superior sagittal sinus participated in draining 42% of AVM's, the vein of Galen 12%, the parasellar plexus 6%, and the petrosal sinus 3%. We can see nothing of inherent significance in the arterial or venous components other than the site and extent of the chance interposition of the angioblastic error resulting in a fistula; thus, the arterial and venous components can be explained by the site of the fistula.

Angiography

While magnification, subtraction views, tomography, and, in some instances, computerized tomography, may be helpful in diagnosis, we have found no substitute for stereoscopic three-dimensional simultaneous serial angiography. The angiogram should be tailored to the individual case. We have found that the cassette changer should be started the instant the injection starts, and exposures should be taken at the rate of five to six per second in order to capture the all-important final feeding arteries and fistula phase. With careful adjustment of the timing and volume of the contrast medium, an arterial phase, a fistula phase, and a venous phase may be obtained with minimal overlap, providing accurate delineation of the fistula itself along with the final feeding arteries. The most dramatic, but the least helpful, films are those showing the explosion of contrast medium billowing out into the draining veins (Fig. 7 upper right). Frequently, a smaller volume of contrast medium (5 to 6 cc) provides more information by avoiding the obscuration of the details by this explosion into the venous drainage. Simultaneous anteroposterior and lateral films are often of help in that the surgeon knows the leading edge of contrast material is at the same point in both projections. Usually, the stereoscopic lateral views provide all the information necessary as to the exact relationship to the final feeding artery. The angiogram should provide the surgeon with a three-dimensional relationship of a lesion to the final feeding artery or arteries and to the arteries beyond it. Thus, if there are two deep adjacent parallel arteries, both of which are final feeding arteries, the surgeon can safely clip either
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or both with the use of digital palpatlone alone, without viewing them. However, if one of them is going past to feed the motor cortex, the surgeon must identify each before clipping the final feeding artery.

**Vasospasm**

Vasospasm was seen once in this series. The patient was a 64-year-old obese, hypertensive lady, who died 24 hours after a massive hemorrhage from an AVM that bled into the head of the caudate nucleus, into the ventricular system, and out into the subarachnoid space. Although there are reports of occasional vasospasm with AVM, our findings agree with those of most investigators that arterial spasm is virtually unknown in association with AVM's, contrary to its common appearance in association with bleeding from saccular aneurysms. On the basis of this and other observations, we wonder whether there is some unrecognized factor present in some individuals with saccular aneurysms that predisposes to spasm, a factor rarely present in the rest of the population.

**Indications for Surgery**

Pool and Potts listed the advantages of excising AVM's, including the relief of seizures not alleviated by medication, the relief of progressive neurological behavioral or intellectual deterioration, and the prevention and relief of serious hemorrhage, especially if it is recurrent. In general, we have recommended surgery in all cases. These lesions can be removed without interfering with the normal circulation, and, in fact, their excision can improve the normal circulation without sacrifice of any significant amount of brain tissue. Of course, we recognize the compromise imposed by varying degrees of accessibility and the neurological responsibility of the area involved.

**Surgical Considerations**

The surgeon's skill, ingenuity, manual dexterity, patience, stamina, and past experience, along with the experience of the entire operating room team, are major factors in the success of surgery. In addition, we have found the following considerations helpful.

**Feeding and Draining Vessels.** The surgeon must recognize and rely on the basic principle that a final feeding artery supplies nothing but the fistula, and that interrupting it can only improve the general circulation and function; whereas, interrupting the parent artery either proximal or distal to the departure of a final feeding artery can only worsen function. He must also recognize that pursuing a feeding artery or a draining vein beyond its connection to the fistula serves no purpose and can only cause unnecessary damage. Removing the fistula corrects the pathology. However, we agree with Malis that starting excision at the venous end and using the sectioned draining vein as a "handle" can be a very effective surgical procedure in many cases.

**Exposure and Magnification.** A very considerable exposure is usually available down a widened sulcus or fissure presenting at the point of departure of a major draining vein. Through such a widened sulcus, with gentle suction and retraction, the shunt is first developed along the surface known to provide most immediate access to the final feeding arteries. These last arteries withstand a normal amount of manipulation, whereas the vessels comprising the shunt may be exceedingly friable. The undersurface of the lesion is often demarcated by the natural barrier of a ventricular wall. A hemorrhage may have provided another free surface of separation on one or more boundaries. The additional space from removal of any clot may allow the surgeon to compress the lesion between his fingers for control.

If multiple bleeding sites become troublesome in one area, it is wise to pack that area and start work on another side, returning later to the original area, by which time it may be dry. Every feeding vessel that is interrupted decreases the total bleeding.

Loupe magnification is often adequate and frequently better than operating microscope magnification because of the need to constantly change the field. The superb illumination at the depth of a small opening provided by the operating microscope is advantageous at times. The much higher power magnification provided by the microscope is not usually necessary, and sometimes even slows the procedure.

**Timing of Surgery.** The timing of the surgery is of less significance than with saccular aneurysms, as vasospasm is not a consideration in delaying the surgery. Patients in Hunt and Hess' Grade III and Grade IV are more likely to recover from AVM's, as their coma is frequently due to intraventricular or intracerebral clots easily removed at surgery. Also, successful AVM surgery always improves the circulation, and postoperative spasm is not a problem as with saccular aneurysms.

**Intraoperative Serial Angiography.** Intraoperative serial angiography affords the operating surgeon instantaneous information as to whether the lesion has been completely removed and, if not, the exact location of any residuum. It thus avoids the not infrequent incidence of closure and later discovery that some fistulous remnants persist. Although single-film angiography has been reported as adequate in our experience it can lead to false conclusions regarding total removal (Figs. 3 and 4). Incomplete removal of the lesion invites devastating postoperative hemorrhages.

**Adjuncts.** We have used neither hypothermia nor hypotensive drugs, and have rarely found hypertonic solutions necessary with these lesions.

**Risk Factors.** The nature and location of the lesion are both considerations in determining risk, along with the obvious factors such as age and physical condition. In our experience, the more diffuse lesions give more troublesome bleeding than discrete lesions, even
thorough they might be considerably larger. The total number of arterial sources is not in itself a factor.

Perret reports 27% inoperable AVM's, usually in young patients. Inoperability is often determined after the event. Possibly, some of ours should have been considered inoperable, particularly those with a fatal outcome, but we believe that, with increasing experience, a vast majority of these lesions are removable. As surgeons develop greater skills and angiography provides more information, the morbidity and mortality from these lesions will progressively decrease. We have no experience with blind clipping, using stereotaxic guidance, nor with coagulation by freezing. In our hands, embolization has never completely obliterated the fistula.

Results

Of our 100 patients, 90 were operated on. There were 10 surgical deaths; three due to postoperative intracerebral hematomas. One of these patients was an infant with a straight-line fistula that was obliterated were 10 surgical deaths; three due to postoperative in-

Of the four survivors without surgery, two are asymptomatic. A third, who was followed for 16 years, has had recurrent hemorrhages but also has a large saccular aneurysm. The fourth is demented. Review of our series clearly points out that a poor outcome is the result of poor technique. We believe that, with better technique, all AVM's with an accessible surface will become removable without deficit.

Summary

1. In agreement with previous studies, the majority of the patients in our series presented by the age of 40 years.
2. Males and females were equally affected.
3. Sudden headache was the commonest presenting symptom, followed by seizures. Psychosis as a presenting symptom was of considerably lower incidence than that recorded in the literature.
4. Bruit was very rare.
5. Arteriovenous malformations diagnosed in older patients tended to be larger than those diagnosed in young patients.
6. Lesions with higher hemodynamic resistance had a greater incidence of bleeding.
7. Pregnancy and family history were not significant factors in the incidence of AVM's, and their coexistence was purely coincidental.
8. The middle cerebral artery gave rise to final feeding arteries more often than did other cerebral arteries, probably in proportion to the size and distribution of this artery.
9. The majority of malformations drained into the sagittal sinus, the straight sinus, or the transverse sinus.
10. Vasospasm was rarely noted in subarachnoid hemorrhage from AVM's, either pre- or postoperatively.
11. Surgical excision can result in very minimal morbidity, but patients suffering seizures before surgery are very likely to continue to suffer from them after surgery.
12. Since our first cases, advances in simultaneous anteroposterior and lateral stereoscopic angiography and the more recent advent of intraoperative serial angiography have improved our handling of these cases immensely.
13. The operating microscope was of great help, particularly for the illumination it affords with deep-seated lesions. Many AVM's are better operated on with the aid of Loupe magnification because the surgeon is constantly going back and forth from one area to another.
14. An experienced assistant using intelligent retraction and suction is probably the greatest help in successful surgery.
15. Grade III and IV patients are more likely to recover if they are treated surgically, as coma is frequently due to intraventricular or intracerebral clot which can be removed at surgery. Successful surgery
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always improves the circulation with AVM’s, whereas occasionally it transiently worsens the circulation with saccular aneurysms.

16. Our failures were due to technical inadequacies.

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