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# Preoperative Embolization of Cerebral Arteriovenous Malformations with Polyvinyl Alcohol Particles: Experience in 51 Adults

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In order to determine possible risk factors and to assess the value of platinum microcoils added to polyvinyl alcohol particles in preoperative embolization of cerebral arteriovenous malformations in adults, we reviewed our experience with this procedure. Between September 1985 and June 1989, we performed embolizations in 54 patients with cerebral arteriovenous malformations. Of these, procedures in 51 adults involved the use of polyvinyl alcohol particles, either alone ( $n = 29$ ) or in combination with platinum microcoils ( $n = 21$ ). A complication during catheterization precluded embolization in another patient. Beginning as flow-directed embolizations via carotid artery catheterizations ( $n = 12$ ), newer catheters allowed progression to superselective intracerebral catheterizations ( $n = 38$ ). Embolization has led to shorter surgical procedures, more clearly defined operative margins, and less bloody operative fields. We have not found recanalization to significantly hinder embolization results with polyvinyl alcohol when resection is undertaken within 1–4 weeks of embolization. Its relative safety and ease of manipulation at surgery argue for its use. We found no significant increase in complications based on patient age, venous drainage of the arteriovenous malformation, or the circulation embolized.

Embolization results in cerebral arteriovenous malformations were improved with superselective catheterization and most improved with the combined use of polyvinyl alcohol for nidus embolization followed by occlusion of the feeding vessel with microcoils.

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Since first reported [1], the number of embolizations of arteriovenous malformations (AVMs) of the brain has increased slowly but steadily. Inhibited at first by the need to develop catheter and embolic materials, the procedure has recently enjoyed more explosive growth [2–12]. Initial catheter development for intracerebral embolization used calibrated-leak balloons [13], necessitating the use of liquid embolic materials. Hence, isobutyl 2-cyanoacrylate (IBCA) has dominated as an embolic material.

With the introduction of polyvinyl alcohol (PVA) [14], a new embolic material became available, and further refinements [15] have enabled the development of an arsenal of prefabricated particles for use, varying from 150  $\mu\text{m}$  to greater than 2 mm in diameter. In about 1987, new variable-stiffness catheters (Tracker-18, Target Therapeutics, Inc., San Jose, CA) became widely available commercially, allowing greater access to the cerebral circulation for delivery of particulate emboli.

In 1988, Hilal et al. [16] introduced a new microcoil device for arterial occlusion and described a series of AVMs embolized with those devices. Though mention was made of their use in combination with PVA, specific information regarding that combination was not included.

Few large series have been reported of patients in whom AVMs were embolized with PVA, alone or in combination with other materials. Scialfa and Scotti [17] reported two cases of AVMs embolized with PVA microemboli. Spetzler et al. [7]

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described 10 patients embolized via a transfemoral approach, which usually consisted of "Ivalon particles and an occasional mix of Gelfoam." Dion et al. [18] reported the use of PVA in combination with microfibrillar collagen and ethanol in 24 brain AVMs. Eskridge and Hartling [19] presented a series of 19 embolizations in 12 patients using a PVA and silk suture combination. We reviewed our experience to determine whether patient age or sex, AVM size or venous drainage, the arterial circulation embolized, or the method of catheterization (proximal artery alone vs superselective intracerebral) influenced either the complication rate or the angiographic outcome of the procedure. We also analyzed the angiographic outcome in cases of superselective catheterization with PVA alone and in combination with platinum microcoils to assess the impact of the addition of the microcoils on angiographic results.

### Materials and Methods

Between September 1985 and June 1989, we performed a total of 73 embolizations in 54 patient with intracerebral AVMs. Because young children have a qualitatively different type of malformation ("vein of Galen" AVM) and because they require general anesthesia, we eliminated three patients from this analysis. Additionally, two procedures were eliminated in which neither PVA nor coils were used. Both of these patients later underwent PVA embolization at other times; those procedures are included in this analysis. Two cases of anterior cerebral artery perforation with the Tracker catheter/guide-wire combination occurred before planned PVA embolization and are included in the totals for complications. Both of these patients underwent emergent surgery and their AVMs were resected without neurologic sequelae. Thus, our series comprises 51 patients who were 14–67 years old at the time of embolization. There were 24 males and 27 females. Twelve patients underwent multiple procedures, for a total of 65 procedures in the 51 patients.

The diameter of each AVM was measured angiographically by one author. Although all malformations had parenchymal components, some were of the mixed dural-pial variety and had some external carotid supply. Territories embolized were recorded as anterior (in-

ternal carotid circulation or both internal and external carotid circulations), external carotid alone, posterior (vertebrobasilar), or both anterior and posterior. Venous drainage from the malformations was recorded as superficial (cortical hemispheric branches draining to the superior sagittal sinus or sphenoparietal sinus), deep (drainage into the galenic system or straight sinus), or both. Two patients had drainage into vermian veins. These were considered deep.

In one patient with a bithalamic AVM and progressive neurologic deterioration, it was believed that resection was too hazardous and embolization was performed as the primary therapeutic procedure. In all others, surgical resection was undertaken subsequent to embolization.

Initially, embolizations were flow-directed via internal carotid catheter placement (Fig. 1). For these, particles were individually fashioned and injected singly, averaging approximately 1–2 mm in diameter. Twelve patients were embolized in this fashion, with up to 370 particles injected in one sitting. One patient underwent surgical exposure of his anterior cerebral artery and direct embolization with PVA in the operating room. All other embolizations were via transfemoral catheterization.

With the introduction of the Tracker system, superselective catheterizations have become routine. Particle sizes have diminished, ranging from a low of 150  $\mu$ m, and they are now injected several at a time in 1-ml syringes. Particles as large as 2–2.5 mm have been injected singly through this system, though particles of this size are difficult to introduce and can result in occlusion of the Tracker catheter.

In one patient whose AVM occupied the majority of one hemisphere (15-cm diameter), one of two embolizations was performed under general anesthesia immediately before transport to the operating room. Otherwise, all procedures were performed in awake, sedated patients.

Embolization results were scored on the basis of a system devised when the first procedure was performed: 1 = a result that is definitely angiographically visible; 2 = a result that is subtle yet still believed to be documented angiographically; 3 means the procedure was discontinued without angiographic change in the AVM. This grading system was followed throughout this series, though we would not now accept as satisfactory some of the results that initially were believed to be good. Specifically, a procedure was rated as 1 even if it did not eliminate a portion of a malformation or its feeders but

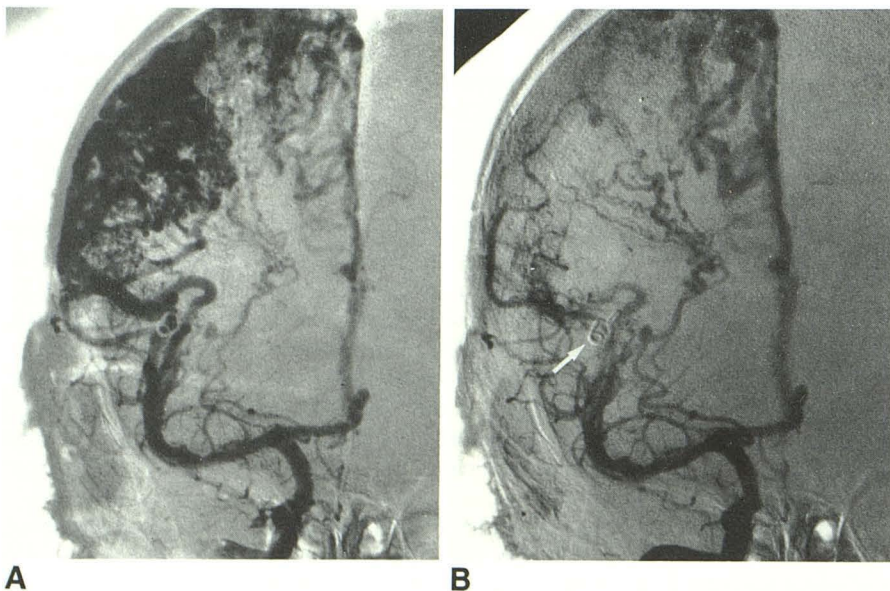


Fig. 1.—A and B, Anteroposterior arteriograms of right internal carotid artery before (A) and after (B) flow-directed embolization with polyvinyl alcohol particles. Catheter was placed in right internal carotid artery and particles were injected from there. The patient tolerated the procedure without complications. Surgical clip (arrow) was placed on aneurysm on branch of middle cerebral artery.



caused definite alteration of flow. An example might be the development of filling of an anterior cerebral artery via a carotid that previously had sufficient shunt into the middle cerebral artery that the anterior cerebral artery did not fill. With superselective catheterization and the use of microcoils in combination with PVA, we now do not have to accept that result.

Neurologic complications were scored as 0 for none, 1 for transient deficits that resolved completely, 2 for deficits that did not resolve completely, and 3 for death as a result of an embolization-related complication. Patients were monitored during the procedures for language function, gross motor function (usually ankle dorsiflexion, finger extension, and facial motor function), and sensation to touch. Specific testing of cranial nerves, visual fields, right-left orientation, dysmetria, calculations, etc., were performed as appropriate for the vascular territories being embolized. More thorough neurologic monitoring was performed postoperatively. Each patient was examined before embolization by two of the authors, at least one of whom was a neurosurgeon.

Development of a neurologic deficit during embolization was one criterion by which procedures were terminated. Originally, contrast load to a hemisphere was monitored and two flow-directed procedures were discontinued when hemispheric dose exceeded 100 ml. No superselective embolizations have been discontinued owing to contrast load. Procedures were otherwise continued until angiographic effect was seen or, in a few early cases, until we terminated embolization after injection of hundreds of particles without angiographic effect. Presumably, rapid shunting into the venous system was taking place. However, none of our patients suffered clinically evident pulmonary decompensation. Since the introduction of superselective techniques and the use of microcoils, we have been able to see angiographic effects in all cases embolized.

Results were analyzed for their effect on complications and on outcome scoring. Comparisons were made between occurrence of complications and AVM size, venous drainage, patient age, circulations embolized, and superselective vs proximal catheterizations. Comparisons were also made between outcome score and the same variables. Of the 38 patients embolized via superselective catheterizations, PVA alone was used in 17, and PVA in combination with platinum microcoils with interwoven fibers (Hilal coils, Cook, Inc., Bloomington, IN) was used in 21; analysis included comparison of outcome scores of superselective catheterizations between these two combinations of materials. Statistical comparisons were made for occurrence of complications and outcome scoring using the two-tailed Fisher's Exact Test or the one-tailed likelihood ratio chi-square test. Results of statistical tests with  $p < .05$  were considered significant.

## Results

AVMs have varied in diameter from 1.7 to 15 cm. The mean in this series was 3.9 cm. The AVMs were located in the frontal lobe (14 patients), temporal lobe (four), basal ganglia (bilateral, two; unilateral, one), parietal lobe (four), parietooccipital area (seven), frontoparietal region (six), frontoparietal and callosal areas (one), occipital lobe (three), frontal lobe and basal ganglia (two), frontoparietal region and basal ganglia (one), cerebellum (four), holohemispheric area (one), and callosal region (one). The territories embolized included the anterior circulation (internal carotid circulation alone or both internal and external carotid circulations, 41 patients), external carotid circulation alone (two), posterior circulation (20), and both anterior and posterior circulations (two). Two procedures

were terminated before embolization owing to perforation of the anterior cerebral artery.

Overall complications are summarized in Table 1. The fixed deficits with selective catheterization included a cerebellar infarct that largely resolved symptomatically after 4 weeks and one case of intraventricular hemorrhage. One patient had a cerebellar hemorrhage 3 days after embolization and died postoperatively owing to brainstem injury incurred at the time

**TABLE 1: Overall Complications in Preoperative Embolizations of Cerebral Arteriovenous Malformations with Polyvinyl Alcohol Particles**

Complication	Type of Catheterization	
	Nonselective (n = 12)	Selective (n = 39)
Transient	4 (33)	3 (8)
Permanent	2 (17)	2 (5)
Death	0	1 (3)
Technical <sup>a</sup>	0	2 (5)

<sup>a</sup> Anterior cerebral artery perforation without focal neurologic deficit.

**TABLE 2: Comparisons of Occurrence of Complications and Embolization Outcome Across Groups of Patients**

Variable/Group	No. of Patients/Total (%)	
	With Complications (n = 51)	With Definite Results (n = 50) <sup>a</sup>
Size of AVM		
≤3 cm	7/25 (28)	21/24 (87)
>3 cm	7/26 (27)	20/26 (77)
p value	1.00 <sup>b</sup>	.467 <sup>b</sup>
Age		
≤35 years	7/24 (29)	18/23 (78)
>35 years	7/27 (26)	23/27 (85)
p value	1.00 <sup>b</sup>	.715 <sup>b</sup>
Sex		
Female	7/27 (26)	24/27 (89)
Male	7/24 (29)	17/23 (74)
p value	1.00 <sup>b</sup>	.270 <sup>b</sup>
Catheterization		
Selective	8/39 (21)	34/38 (89)
Proximal	6/12 (50)	7/12 (58)
p value	.066 <sup>b</sup>	.027 <sup>b</sup>
Venous drainage		
Superficial	6/22 (27)	15/21 (71)
Deep	4/14 (29)	14/14 (100)
Both	4/15 (27)	12/15 (80)
p value	.993 <sup>c</sup>	.030 <sup>c</sup>
Circulation embolized		
Anterior	8/34 (24)	25/33 (76)
Posterior	5/14 (36)	14/14 (100)
External carotid alone	0/1 (0)	1/1 (100)
Both anterior and posterior	1/2 (50)	1/2 (50)
p value	.610 <sup>c</sup>	.050 <sup>c</sup>
	.480 <sup>d</sup>	.084 <sup>d</sup>

Note.—AVM = arteriovenous malformation.

<sup>a</sup> In one patient, a complication developed during catheterization and actual embolization was not performed.

<sup>b</sup> Fisher Exact Test.

<sup>c</sup> Likelihood ratio chi-square test.

<sup>d</sup> Fisher Exact Test comparing anterior and posterior only.



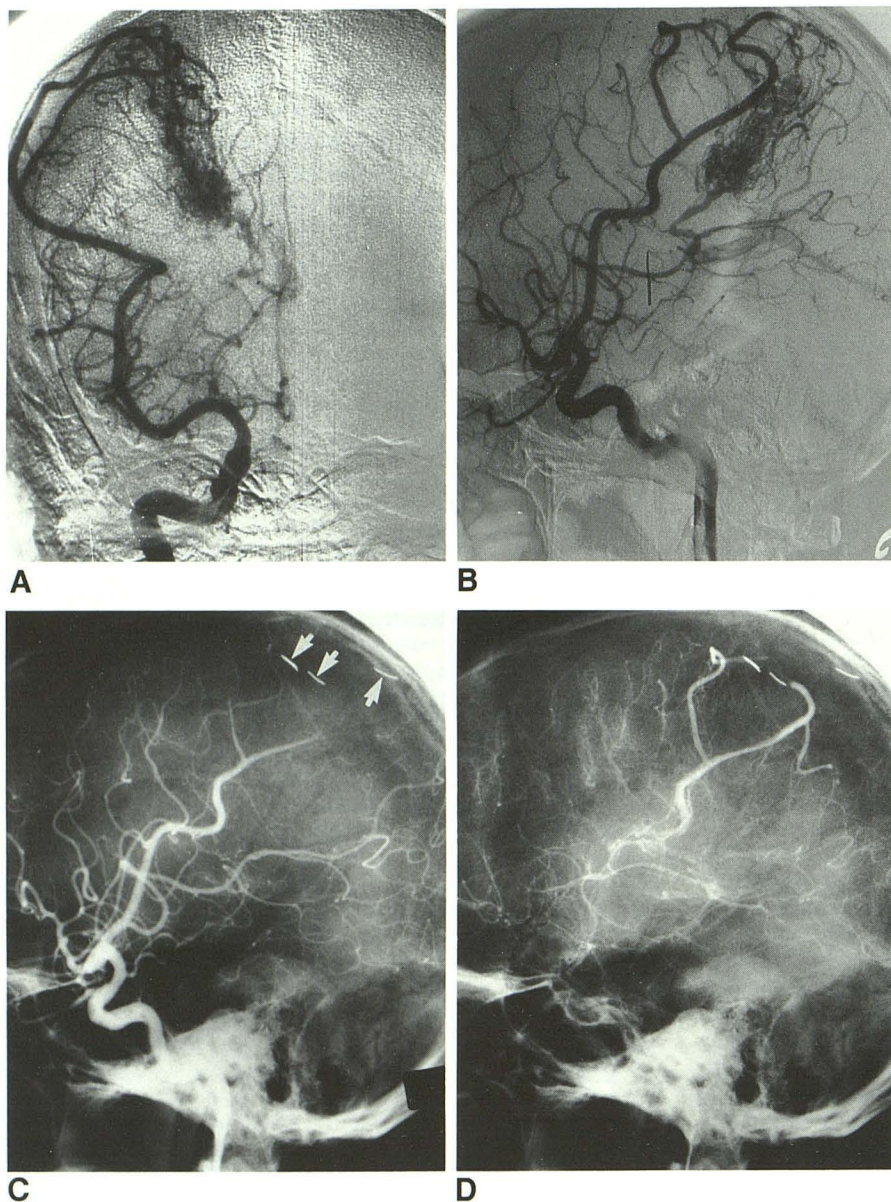


Fig. 2.—A and B, Anteroposterior (A) and lateral (B) arteriograms of right parietal arteriovenous malformation (AVM) before superselective embolization of two middle cerebral artery feeders with polyvinyl alcohol and coils.

C and D, Films obtained early (C) and late (D) during postembolization arteriography show coils in place (arrows) and stasis in embolized middle cerebral artery branches, with no residual filling of AVM. AVM did not fill on vertebral injection, either before or after embolization.

of hemorrhage. Including transient deficits, fixed deficits, and complications occurring during catheterization, the overall complication rate with selective catheterizations was 21% (8/39). The "stroke" rate (fixed deficits or death) was 8% (3/39).

Statistical analysis of complications subdivided into transient vs permanent yielded groups too small to achieve significance. However, when grouped only as "no complication" (score of 0) vs "complication" (score of 1–3), selective catheterization yielded nearly significantly fewer complications (21% vs 50%;  $p = .066$ , Fisher's Exact Test). Results were not significant for comparison of complications with patient age, sex, AVM size, venous drainage, or circulation embolized. Results are summarized in Table 2.

Results of analysis for outcome showed significant improvement for selective catheterization (89% vs 58%;  $p = .027$ , Fisher's Exact Test). AVM size, age, sex, and circulation

embolized yielded no significant differences in outcome. The results are summarized in Table 2.

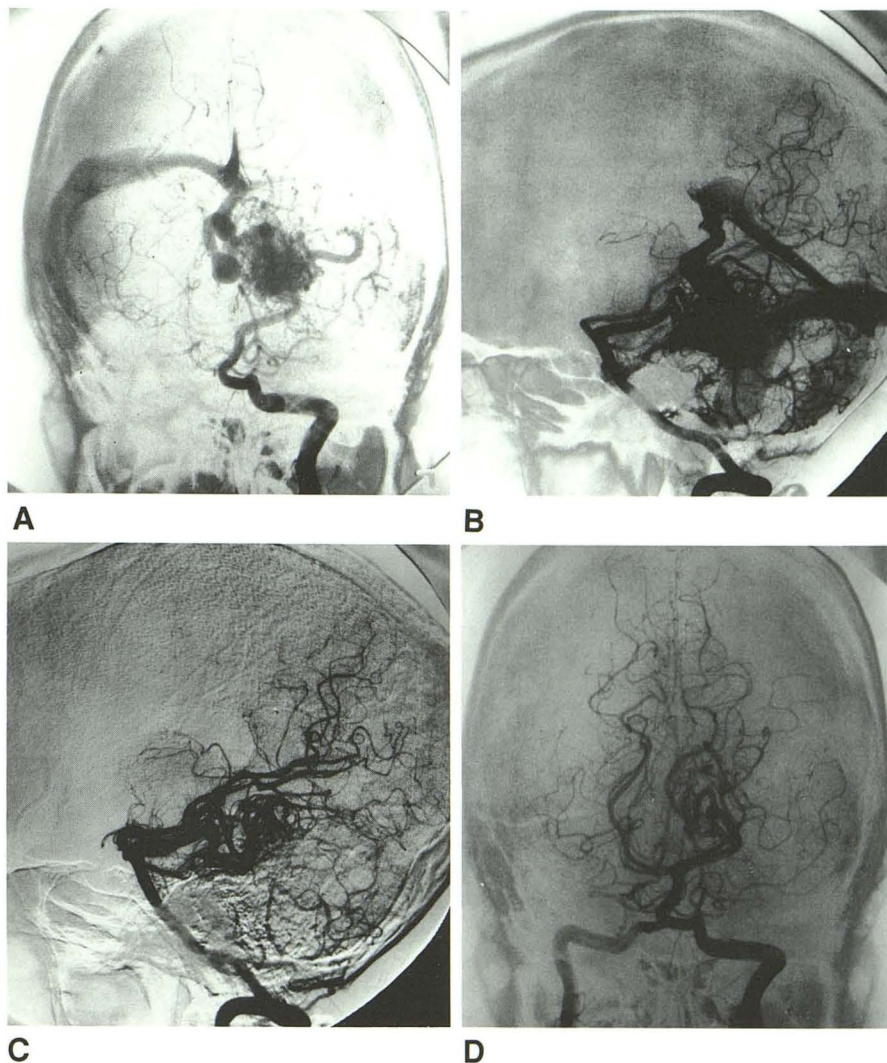
Among patients who underwent selective catheterization, definitely visible result from embolization were observed in all 21 patients with PVA plus coils as opposed to 13 (76%) of 17 patients with PVA alone ( $p = .032$ , Fisher's Exact Test). We attribute this improvement in embolization outcome to the ability of these coils to reliably occlude major feeders and to obliterate shunts.

Significant improvement in embolization outcome was observed also among patients with deep venous drainage (100%) vs superficial or both (71% and 80%, respectively;  $p = .030$ , likelihood ratio chi-square test). The difference in embolization outcome between anterior and posterior circulation approached significance ( $p = .084$ , Fisher's Exact Test). We believe these phenomena to be largely reflective of the



Fig. 3.—A and B, Anteroposterior (A) and lateral (B) left vertebral arteriograms show cerebellar arteriovenous malformation (AVM) before catheterization and embolization of superior cerebellar artery supplying it.

C and D, Lateral view (C) after embolization is compromised by overlapping vessels, but anteroposterior view (D) shows no residual AVM. At surgery, AVM was thrombosed and drainage was no longer arterialized. Malformation was resected without development of neurologic deficit.



effect of the addition of microcoils to PVA, since larger percentages of selective catheterization patients with posterior circulation (64% vs 50% for anterior) and deep venous drainage (57% vs 23% for superficial and 53% for both) have been embolized with PVA plus coils.

## Discussion

The role of embolization in the treatment of AVMs remains controversial. Though angiographic elimination of the malformation at the time of embolization is possible (seen in three of our patients) (Figs. 2 and 3), it is uncommon [12]. Subsequent recanalization or collateral development is known to occur [20]. Therefore, it should be reserved for palliation in an inoperable lesion or in order to assist surgical extirpation. In one patient embolized successfully, we saw little recanalization 1 month after embolization with only small particles of PVA (Fig. 4).

As palliative therapy, the value of embolization is unproved. Reduction of seizures has never been documented with em-

bolization. Although it seems reasonable that reduction of an AVM mass might potentially reduce the risk of hemorrhage, it is known [21] that embolization produces a progressive increase in pressures in arterial feeders. It also may produce partial or complete thrombosis of venous drainage, as we saw at surgery in a patient who had a hemorrhage 5 days after embolization of a posterior inferior cerebellar artery feeder to a cerebellar AVM. An anterior inferior cerebellar artery feeder had not been embolized. Although the AVM was subsequently resected and that feeder clipped, the hemorrhage caused irreversible brainstem injury.

Arrest or improvement in a progressive deficit has been shown following embolization [11], although in most cases progressive deficit would be considered an indication for surgery. Therefore, the lesion should be unresectable or its resection should carry unacceptable risk if primary embolotherapy is contemplated. In that setting, we used embolotherapy on one occasion.

As stated in our introduction, a variety of materials have been used for primary embolization therapy or for preoperative embolization. Many centers use acrylic glues. Though we



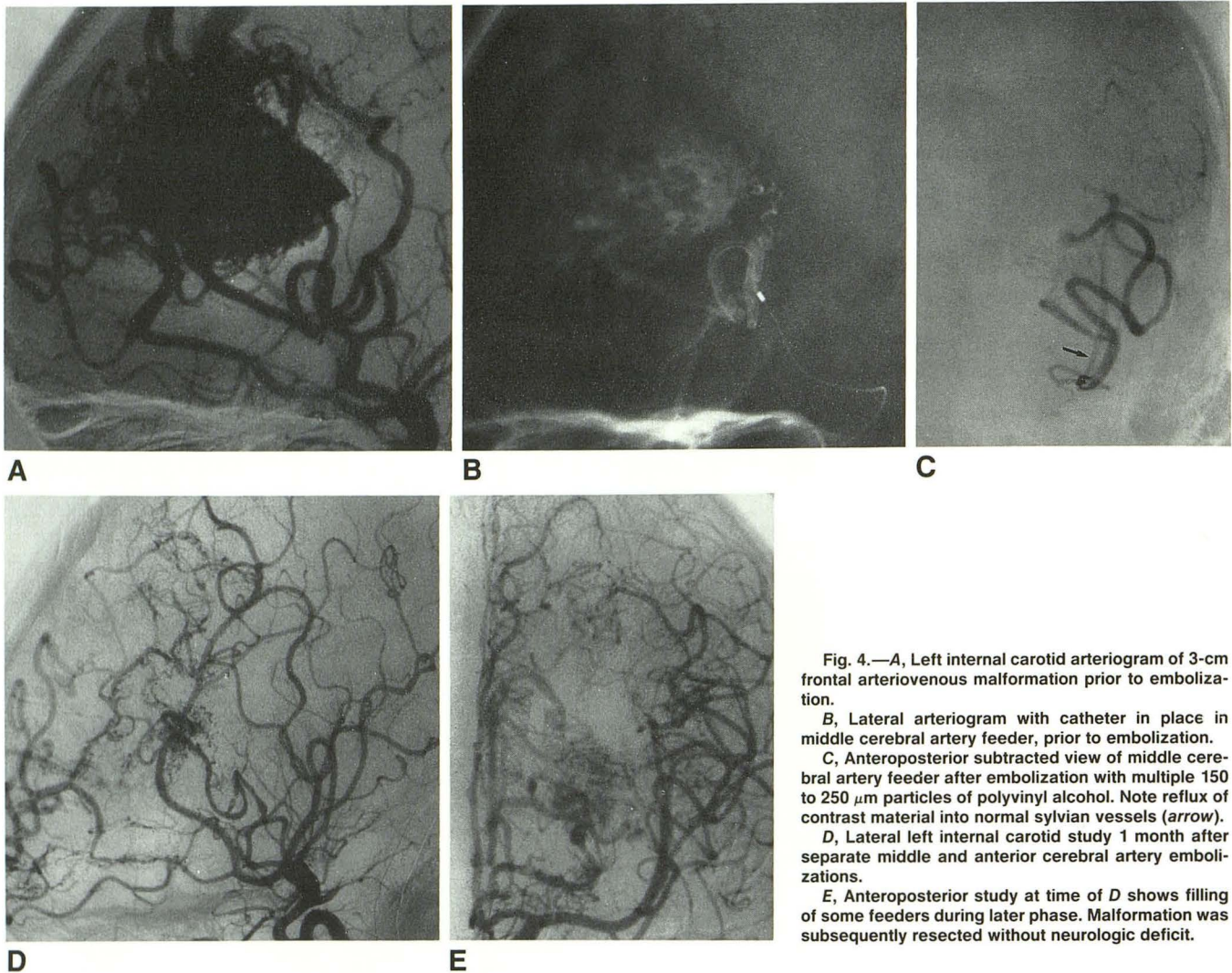


Fig. 4.—A, Left internal carotid arteriogram of 3-cm frontal arteriovenous malformation prior to embolization.

B, Lateral arteriogram with catheter in place in middle cerebral artery feeder, prior to embolization.

C, Anteroposterior subtracted view of middle cerebral artery feeder after embolization with multiple 150 to 250  $\mu$ m particles of polyvinyl alcohol. Note reflux of contrast material into normal sylvian vessels (arrow).

D, Lateral left internal carotid study 1 month after separate middle and anterior cerebral artery embolizations.

E, Anteroposterior study at time of D shows filling of some feeders during later phase. Malformation was subsequently resected without neurologic deficit.

had some early experience with IBCA [4], we have no recent experience with it. Clearly, glues can be used to devascularize AVMs. We believe the use of IBCA in a preoperative setting to be less ideal than PVA because of the difficulty in cutting vessels and retracting brain that it imposes. As with any compounds, both IBCA and *n*-butyl 2-cyanoacrylate (NBCA) have been shown to recanalize [20, 22].

There are times when different strategies apply in preoperative embolization than apply in primary embolotherapy. Although the ideal would be angiographic cure in all cases, some vessels are more easily accessed surgically and some more easily accessed via a transarterial approach. In most lesions, we embolize as completely as we believe is safe before proceeding with surgery. However, in evaluating a malformation and planning its treatment, we discuss the anticipated surgical approach prior to embolization. In some cases, we opt for a surgical approach to vessels that would be technically feasible to embolize. In occipital lesions fed by both the middle and posterior cerebral arteries, for instance, our first priority is embolization of the posterior cerebral artery,

since the middle cerebral artery can be easily accessed at surgery, if necessary. If the middle cerebral artery feeders are large and easily accessed embolically, we would embolize them as well. However, there are occasions where feeders from one arterial territory are largely via distal collaterals that cannot be catheterized. In those situations, embolization more proximally would expose the patient to greater risk of untoward injury than a surgical resection carried out along the margin of the malformation. Thus, if a malformation is fed by a large feeder and by a collection of more peripheral, smaller vessels, we often think that the more peripheral vessels are better approached surgically at the margin of the AVM rather than more proximally embolically (Fig. 5). At other times, the AVM resection is not technically as challenging as its location. In one case, a relatively small AVM was located in the dominant, left temporal lobe, either involving or adjacent to Wernicke's area (Fig. 6). In that case, the embolization was carried out as much for the purpose of Amytal testing of the feeders along its superior margin as for the purpose of preoperative devascularization. When the patient tolerated Amytal injection

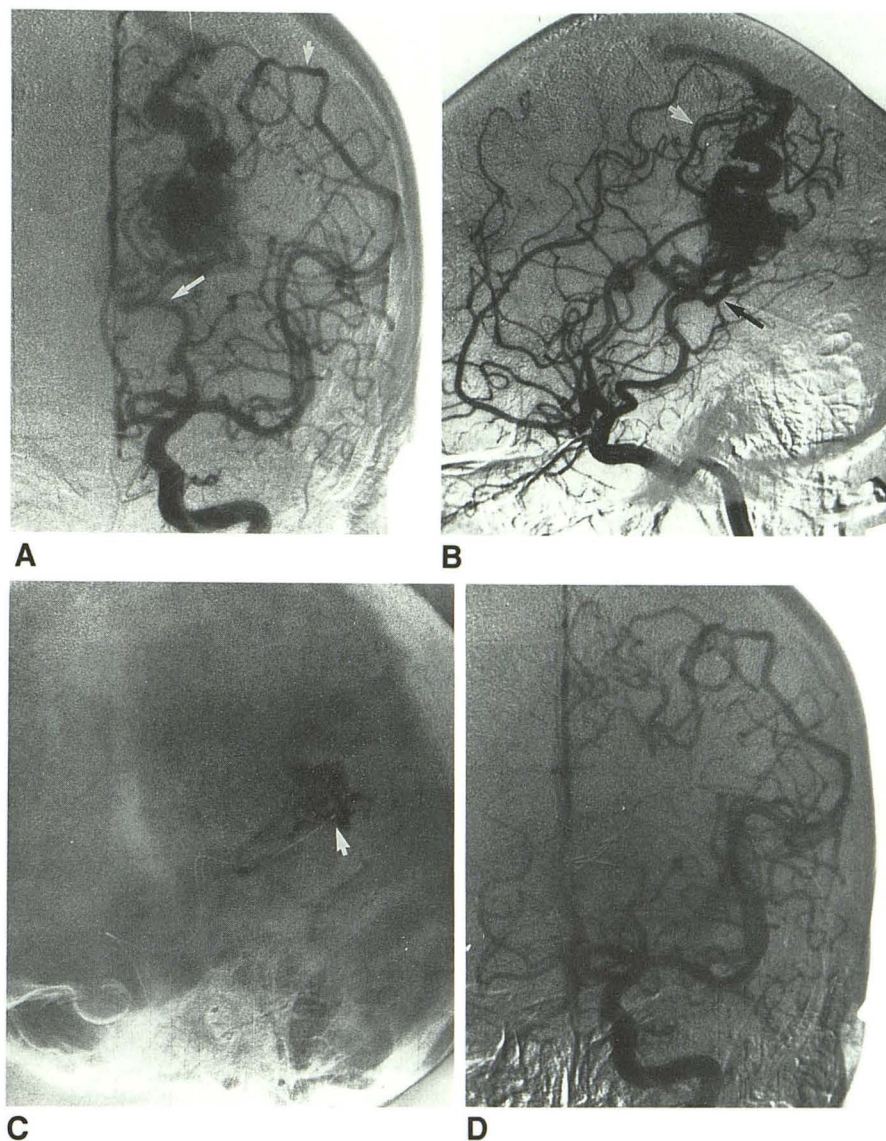


Fig. 5.—Anterior occipital arteriovenous malformation (AVM).

A and B, Anteroposterior (A) and lateral (B) views before embolization show both posterior (long arrows) and middle (short arrows) cerebral artery feeders.

C, Catheter placement in posterior cerebral artery feeder, at nidus. Catheter tip (arrow).

D, After embolization with polyvinyl alcohol and coils, posterior cerebral artery supply is eliminated; slower, distal supply to AVM is still provided by middle cerebral artery branch. No deficits developed.



into those branches, they were then embolized. However, an inferior branch that could have been catheterized and embolized was left. It is arguable that we should have embolized that vessel. The goal, however, is ultimately the cure of the AVM without neurologic morbidity. We believed that vessel was easily identifiable and could be clipped at the beginning of the resection, and the embolization had defined the margin of the resection along the most eloquent cortex. The AVM was subsequently resected completely and the patient awoke without neurologic deficit. The interdependent team approach to AVM therapy is advantageous to both the patient and physicians to maximize the benefit of the skills of each team member.

Assessment of the value of embolotherapy to the surgical procedure is difficult, in view of the lack of comparable non-embolized controls. As interventional techniques have evolved, there has been concurrent development of surgical and anesthetic techniques. In our judgment, operations are

more efficient when they follow an aggressive, successful embolization than when no embolization is performed. This shortens anesthesia time, allows cleaner margins for resection, and decreases transfusion volumes. Additionally, the ability to stress the patient's cerebral vasculature with partial obliteration prior to resection may help to decrease hyperemic complications. More investigation is needed of hyperemic phenomena that accompany treatment of some AVMs [23] and the relationship of those phenomena to the timing of surgery after embolization.

When an embolization has been successful, there is often some swelling of the surrounding brain. Though hyperemia due to redistribution of previously shunted blood may play a role, we also believe there is occasionally infarction of non-functioning tissue within the malformation. When swelling is present, we have found that it often detracts from the benefit of embolization if surgery is performed early. We use MR imaging to help assess the degree of edema (Fig. 7), and



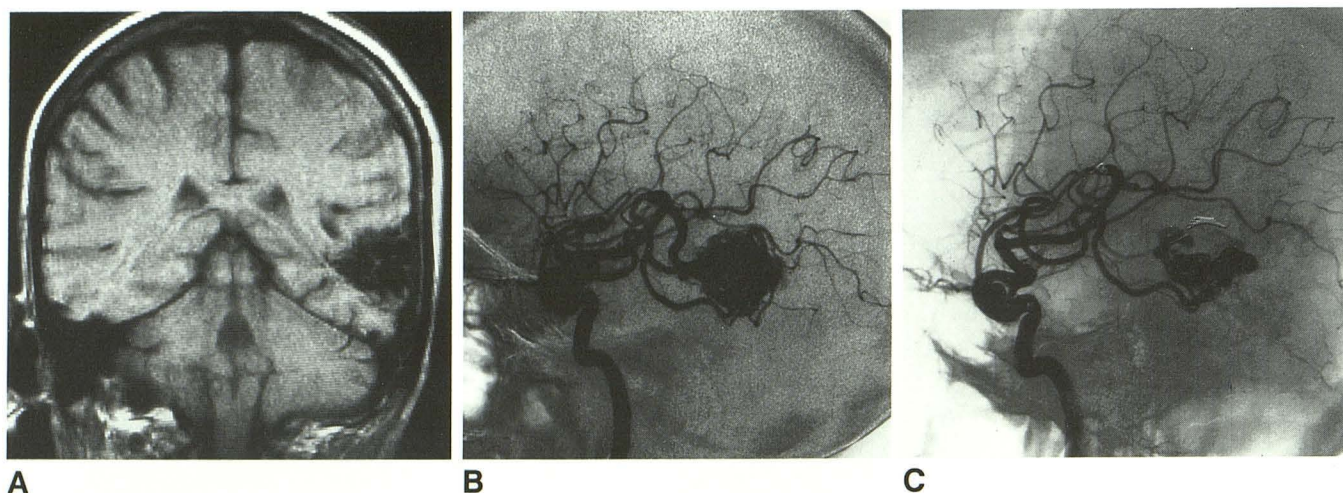


Fig. 6.—Patient with 1.5- to 2-cm arteriovenous malformation near Wernicke's area. Intracarotid Amytal testing had shown this hemisphere to be dominant for language.

A, Coronal MR image shows lesion to be adjacent to or involving superior temporal gyrus.

B and C, Left carotid arteriograms before (B) and after (C) selective catheterization, Amytal testing, and embolization of two superior feeding branches of middle cerebral artery. Inferior branch was not embolized. (See text.)

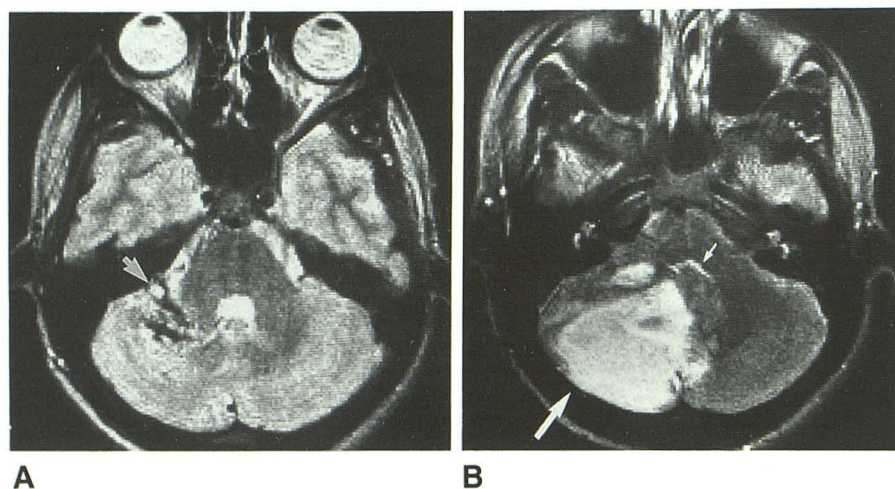


Fig. 7.—MR images, 2500/80 (TR/TE), through posterior fossa in patient with right cerebellar arteriovenous malformation.

A, Before embolization. Malformation (arrow).

B, 4 days after embolization of only large feeding vessel, right superior cerebellar artery. Note large amount of edema (area of high signal shown by large arrow) with associated compression and shift of fourth ventricle (small arrow). T1-weighted images showed this to be nonhemorrhagic. The patient required ventriculostomy to control hydrocephalus, but all swelling resolved and there was only mild dysmetria of her right hand at the time of surgery 5 weeks later.

often delay surgery 3–6 weeks to allow edema to resolve after aggressive embolization. If no edema is present, we will generally operate within 3 weeks following completion of embolization.

One of the most important developments in the evolution of our techniques has been the introduction of microcoils. Since we started using them, there have been no cases in which we were unable to occlude a feeding vessel once it was catheterized. We now use coils to obliterate shunts refractory to PVA, then place PVA behind them. It is now our practice to being an embolization with small particles of PVA, then continue with larger particles, then coils. Some variation occurs depending on the flow dynamics and anatomy encountered from one malformation to the next; if smaller particles do not produce a fluoroscopic change in flow or staining of the malformation after a few milliliters of injectate, we switch to larger particles under the assumption that significant

shunting is occurring. When significant slowing of flow is seen, we return to smaller particles. In general, we believe the most significant impact is achieved with the smallest particles, since they lodge further into the nidus. If no change in flow is achieved even with large particles, we assume large shunts to be present and use coils to slow flow. We often then return to smaller particles to obliterate more of the nidus behind the coils, and repeat the cycle, ultimately occluding the feeder with coils prior to catheter withdrawal. More recently (cases subsequent to this series) we have used 33% ethanol and microfibrillar collagen as described by Dion et al. [18] in situations where marked shunting occurs in order to stimulate thrombosis and decrease shunting. This appears to be a valuable adjunct, though our experience with it is still limited and it is not the subject of this report.

Though initially advocated for use alone in embolization [16], we believe that the resistance of coils to coagulation

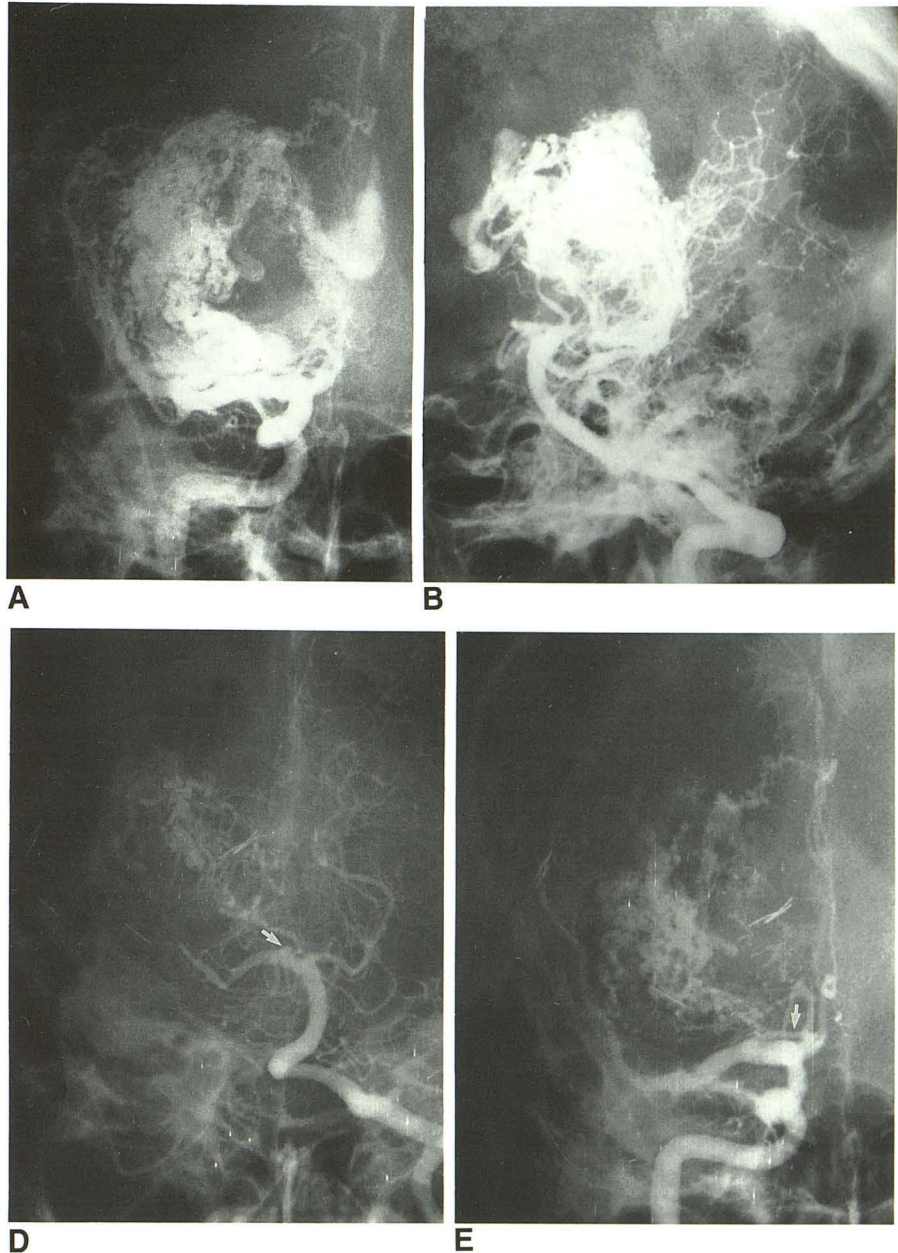


Fig. 8.—A and B, Anteroposterior right internal carotid (A) and lateral left vertebral (B) views before embolization in patient with large arteriovenous malformation (AVM) located primarily in right basal ganglia. The patient presented with a dense left hemiparesis and hemianopia.

C, After four embolization procedures, lateral left vertebral arteriogram shows significant diminution in flow to AVM.

D, Basilar tip perforator seen on this anteroposterior view (arrow) could not be catheterized owing to its sharp angulation at its origin.

E, Anteroposterior right internal carotid arteriogram also shows significant decrease in flow. Recurrent perforator arising from anterior cerebral artery (arrow) could not be catheterized. No new deficits occurred during embolization. The AVM was subsequently resected successfully.



and cutting is a disadvantage at surgery when compared with PVA, and they are best used in conjunction with PVA in a preoperative setting. Surgical silk has been advocated as another embolic material for shunt obliteration or feeder occlusion [19]. We have used it on a few occasions (cases subsequent to this series) and believe it has a place along the spectrum of embolic materials between larger particles of PVA and coils. Though it cuts more easily, silk has the disadvantage that it lacks radiopacity and could pass through shunts unnoticed. In situations with high-flow shunts, the final placement of coils is not in doubt under fluoroscopic observation.

Jungreis et al. [21] have described their experience with intraarterial pressure monitoring in guiding embolization of

AVM feeders. This technique addresses the need for objective criteria to signal when it is time to discontinue embolization. We recognize that need, and have performed intraarterial measurements in several of our patients. We agree that as the pressure in the feeder approaches that in the more proximal arterial tree, the goal of distal occlusion is reached soon thereafter. We have found that that point also correlates well with the point at which proximal reflux of contrast material is seen on test injection through the catheter. Because our PVA is injected with a contrast material/saline mixture that renders it radiopaque, cumbersome and time-consuming pressure monitoring is obviated. In routine cases, we embolize with PVA until reflux is seen, then occlude the feeder with coils at the point of catheter placement.



Another dilemma is the situation in which an aneurysm exists on a feeding vessel proximal to an AVM. We have treated this situation both with clipping of the aneurysm before embolization and with embolization of the AVM without prior treatment of the aneurysm. Though the situation creates discomfort, our current belief is that if the aneurysm is unruptured, the feeder distal to the aneurysm probably can be embolized safely. If we encountered an aneurysm that appeared particularly irregular or that had a bulbous aneurysmal component with a very narrow neck, we might be inclined to clip the aneurysm first. We have not encountered that particular situation as yet, though.

Embolization of basal ganglia AVMs presents a particular challenge (Fig. 8). We have treated six cases embolically, five of which were subsequently resected. In general, we treat these malformations no differently from cortical ones (i.e., superselective catheterizations, Amytal testing, embolization with PVA and coils). However, the feeders are frequently numerous and small and difficult to catheterize. Their origins at sharp angles near the basilar tip create many technical obstacles, and patient tolerance for prolonged procedures becomes a factor. We encountered one complication in this group of patients, in the patient with a bithalamic AVM who did not undergo resection. In that case, a few hours after his only procedure, the patient's level of consciousness deteriorated acutely. CT showed acute hydrocephalus. Ventriculostomy was placed, and ultimately the patient underwent permanent shunting. Though his course was somewhat stormy, the patient improved from his baseline progressive quadriplegia to become more ambulatory and was able to resume employment. Lower extremity spasticity was substantially diminished. We believe the hydrocephalus resulted from edema around the aqueduct of Sylvius. None of our other patients suffered a neurologic complication from embolization, though most had baseline deficits.

The goal of treatment of an AVM should be to cure the lesion without creating significant neurologic morbidity. Angiographic elimination of an AVM via embolization is uncommon, and the presence of recanalization with all embolic materials calls into question the use of the term "cure" under any circumstances in that setting. The most definitive, established current treatment for these lesions is surgical resection. The adjunctive use of embolization creates relatively bloodless margins that allow the more rapid and safe resection of those margins that are less accessible via catheterization and more accessible via surgical exposure. We believe the collaborative approach to this lesion results in the transformation of some "unresectable" lesions into "resectable" ones and in safer treatment of any lesions in which embolization is successful.

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