Endovascular treatment of intracerebral arteriovenous malformations: experience in 49 cases

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The authors report the results of treatment in 49 consecutive patients with brain arteriovenous malformations (AVM's) who underwent therapeutic embolization with liquid adhesive agents between 1984 and 1988 at the Toronto Western Hospital. Thirty-three patients had no other treatment and were followed up with angiography at 2 years and clinically from 2 to 6 years. Of the other 16 patients, 10 had adjunctive radiosurgery and six underwent surgical resection following embolization. Seven (14%) of the 49 patients had a morphological cure effected by embolization as evidenced on their 2-year follow-up angiograms; these have remained clinically stable. Twelve patients developed neurological deficits after embolization; eight (16% of the series) were transient and four (8%) were permanent. Two patients (4%) had a delayed hemorrhage after incomplete obliteration of their malformations. Endovascular treatment resulted in clinical improvement in 15 (33%) of the other 46 patients. None of the patients who initially presented with hemorrhage had a rebleed following embolization. It is concluded that endovascular treatment with liquid embolic material can be an integral part of the multidisciplinary treatment protocol for patients with brain AVM's.

KEY WORDS • arteriovenous malformation • embolization • endovascular treatment

The management of brain arteriovenous malformations (AVM's) is a challenging and difficult field. Surgery has proved to be an effective, but not always innocuous, treatment. In addition to radiosurgery, surgical neuroangiography has enlarged the therapeutic armamentarium and indisputably broadened the indications for treatment. The majority of patients at the Toronto Western Hospital were treated by embolization alone and were followed for up to 6 years. This series, analyzed by a neurosurgeon (D.F.), allows us to evaluate the role that embolization may play in the treatment of AVM's.

Clinical Material and Methods

Case Material

Between 1984 and 1988, 108 patients were referred to the Toronto Western Hospital for assessment and possible endovascular treatment of their brain AVM's. In general, patients with AVM's supplied by multiple small vessels were rejected for an endovascular approach. This approach was not proposed for 55 patients and 53 were accepted for treatment. There were 47 patients with AVM's, two with arteriovenous fistulae (one patient with two different fistulae), and four with true AVM's of the vein of Galen. The latter four cases were excluded from this study due to the special problems associated with these malformations. Of the 49 patients treated by embolization, 33 received no other treatment. Six were operated on subsequently and 10 were treated with radiosurgery after embolization.

The mean age of the patients undergoing embolization was 34.3 years (range 18 months to 66 years). There were 27 males (55.1%) and 22 females (44.9%). Seizure was the presenting symptom in 21 cases (42.9%), hemorrhage in 16 (32.6%), and headaches in eight (16.3%). Other presenting symptoms included neurological deficits in three cases; in one case the AVM was an incidental finding. Among the 16 patients who presented with an intracerebral hemorrhage, eight (50%) had bled only once, five (31.2%) had bled twice, and three (18.8%) had bled three times. On clinical examination, 21 patients (42.9%) had normal findings; 12 (24.5%) had an intracranial bruit; and 16 (32.6%) had a neurological deficit. In nine of the latter cases, the deficit followed a hemorrhage. Two cases were discovered during pregnancy, both presenting with bleeding.
Endovascular treatment of AVM's

**Embolization Technique**

Embolization was performed by selective catheterization of the feeding vessels via the femoral route. A No. 6 French or 5 French thin-walled guiding catheter is placed in the cervical portion of either the internal carotid or vertebral artery. Systemic heparinization (5000 to 10,000 U intravenously) is given at the start of the examination and repeated if the procedure lasts more than 2 hours. Protamine is used to reverse the heparin at the end of the study. Up to 1987, a calibrated-leak balloon system and a propulsion chamber were used. The embolic material was a mixture of isobutyl 2-cyanoacrylate (IBCA), Pantopaque, and tantalum powder. The ratio of IBCA to Pantopaque ranged from 40:60 to 65:35. The tantalum powder was added in a concentration of 0.5 gm/ml. Since the advent of variable-stiffness microcatheters such as the Tracker or Mini-Torquer devices, the calibrated-leak balloon system has been used less and less. The microcatheters were used with 0.14 mm guides. Since 1988, we have used N-butyl cyanoacrylate (NBCA) as the embolic material, which proved to be an excellent alternative to IBCA. The patients were given dexamethasone (8 mg three times daily for 3 days) beginning immediately after embolization.

Embolization was attempted in the 50 AVM's in 98 sessions. All 49 patients accepted for endovascular treatment underwent embolization. In total, 120 injections of the embolic material were given at sessions varying from one to five per patient. Superselective Amytal (amobarbital) testing (50 mg in 10 cc normal saline) was carried out 27 times and was positive once, preventing embolization of a branch of the anterior cerebral artery group.

**Angiographic Findings**

The 50 AVM's involved the left hemisphere in 26 cases (52%), the right hemisphere in 18 cases (36%), and the midline in six cases (12%). Ten (20%) of the 50 AVM's were frontal, 10 (20%) temporal, eight (16%) occipital, seven (14%) Rolandic, six (12%) parietal, three (6%) thalamic, three (6%) mesencephalic, two (4%) temporo-occipital, and one (2%) cerebellar. The arteriovenous fistulae were frontal in one case and occipital bilaterally in one case.

The number of major arterial groups involved in the supply of each AVM was determined. The major arterial groups included: the middle cerebral, anterior cerebral, posterior cerebral, anterior choroidal, basilar, and vertebral groups. In 29 (61.7%) of 47 AVM's, the blood supply arose from two major arterial groups, in nine cases (19.1%) from a single major arterial group, in seven cases (14.9%) from three major arterial groups, in one case (2%) from four major arterial groups, and in one (2%) from five major arterial groups. There were a total of 10 associated aneurysms, which were all flow-related on feeding pedicles.

According to the classification of Spetzler and Martin, of the 47 AVM's, two (4.3%) were Grade I, 10 (21.3%) were Grade II, 16 (34%) were Grade III, 15 (31.9%) were Grade IV, and three (6.4%) were Grade V. The three fistulae were not included in this classification.

**Results**

**Morphological Obliteration**

A morphological cure was obtained in seven of the 50 AVM's as shown on a 2-year follow-up angiogram. Two of these patients had a total of three arteriovenous fistulae. The AVM's in the other four patients were either Grade I, II, or III according to the classification of Spetzler and Martin and were fed by one or two major arterial groups (Figs. 1 and 2). The eight patients who had 80% to 90% obliteration had AVM's fed by one or two major arterial groups. The percentage of obliteration tended to decrease as the number of major
arterial groups feeding the AVM increased and with higher Spetzler grades.

Modification of the angioarchitecture occurred after embolization. With a postembolization decrease in the flow through the AVM, venous ectasias became smaller and there was less arterial steal. As parts of the nidus are eliminated by embolization, the corresponding venous drainage may also be occluded (Fig. 3). Of the 10 flow-related aneurysms, embolization resulted in disappearance of the aneurysm in five, one decreased in size, and four remained unchanged (Fig. 4).

Complications

Early complications occurred in 24 patients. Four developed focal seizures hours after treatment and these were easily controlled. Perhaps the seizures occurred secondary to ischemia in healthy brain adjacent to the AVM due to blockage of small penetrating arteries or due to venous thrombosis. None of the four with focal seizures had hemorrhage on CT scans. Transient reductions in the level of consciousness occurred in two cases (one with an AVM of the posterior fossa and the other with an AVM of the mesencephalon, each embolized through superior cerebellar arteries). Neither of these two patients showed hemorrhage on their immediate postembolization CT scans. Five patients developed severe headaches which resolved spontaneously. One patient presented with unilateral facial pain after embolization of a middle meningeal artery branch. Two patients transiently developed fear and disorientation after embolization of the anterior choroidal artery. Ten patients suffered new neurological deficits after embolization: in eight of these the deficits were transient (weakness, numbness, or expressive aphasia) and in two the deficits were permanent (superior quadrantanopsia following embolization of an inferior temporal arterial branch of the posterior cerebral artery for an occipital AVM, and hemianesthesia following embolization of the distal pericallosal artery for a left suprasplenic AVM); in both, the deficits resulted in a mild disability and both were able to work. Amytal testing was not carried out in these two cases.

Follow-Up Results

Two patients had delayed intracerebral hemorrhage. One occurred three hours following embolization and resulted in an expressive aphasia which rapidly resolved.

![Fig. 2. Computerized tomography scan in the same patient as depicted in Fig. 1 showing excellent penetration of the nidus by the embolic material.](image)

![Fig. 3. Right internal carotid angiograms, lateral view. Left: Study before endovascular treatment of an arteriovenous malformation involving the medial aspect of the right frontoparietal cortex. The deep venous drainage into the internal cerebral vein (arrow) is rerouted due to an absence of the straight sinus. Right: Four months after embolization the deep venous drainage (arrow) is no longer present.](image)
Endovascular treatment of AVM's

The second case occurred 1 month following a third procedure of a staged endovascular treatment and resulted in a massive intracerebral hematoma. This required emergency surgical evacuation. The patient eventually died due to severe brain edema and uncontrolled perioperative hemorrhage. Neither of these two patients initially presented with hemorrhage. None of the other patients have bled after initiation of treatment in a 2- to 6-year follow-up period.

Of the 21 patients who presented with seizures, five experienced a significant reduction in the frequency of their attacks and four became more easily controlled on medication. Of the eight patients who presented with headaches, four had a complete cure of their symptoms (two of these after embolization of the dural supply). Subjectively, one patient had significant improvement in mood and behavior as assessed by the family.

Ten patients were treated with radiosurgery after embolization, resulting in three complete obliterations up to 2 years and two failures at 2 years. In five patients the follow-up period is still too short for analysis. All patients underwent a stereotactic technique with the gamma knife. Patients considered suitable for radiosurgery were those with niduses less than 3 cm in diameter. Six patients were surgically treated, five of them successfully. The decision regarding adjunctive surgery was based on the patient's age, history of bleeding, and surgical accessibility. The neurosurgeons involved in removal of these AVM's commented that the newer agent, NBCA, was softer and more pliable within the AVM and adjacent vessels than IBCA. A vessel plugged with NBCA was easy to cut, and control of bleeding in a partially embolized AVM was easier than in a nongeminal AVM.

Discussion

Morphological Obliteration

An angiographic cure of the vascular malformation was achieved in seven of the 50 lesions in this series. Three of these were single-hole arteriovenous fistulae; the other four lesions were classified in Grade I, II, or III. None had more than two major arterial groups involved in the arterial supply of the lesion. One of these morphological cures resulted from delayed thrombosis after initial partial obliteration. Progressive thrombosis of brain AVM's after embolization has been described previously.

Revascularization

Revascularization of brain AVM's after embolization with IBCA is a contentious issue. In eight cases, we observed a newly formed dural blood supply following embolization but most were asymptomatic. The development of a dural supply after embolization may be due to a diminution of pial perfusion with secondary angiogenesis or to subclinical hemorrhage. Two of the patients who complained of headaches several weeks after the treatment developed a dural supply.

Collateral circulation in brain AVM's can be present before treatment or develop after treatment. We observed the development of an extensive collateral circulation supplying the temporo-occipital or the parieto-occipital lobe cortex in six patients after embolization. Revascularization occurred in two cases following almost complete obliteration, both involving occipital AVM's. We therefore caution against a partial embolization in this territory since the occipital lobe appears to be capable of easily developing a collateral supply. Cases of revascularization have been described in the literature. In these cases revascularization occurred following proximal occlusion of the feeding arteries without penetration of the nidus. In two of our cases, the deposition of the embolic material was clearly too proximal and, therefore, in order to avoid revascularization, it is important to have good penetration of the nidus.

Treatment Strategy

For most patients with brain AVM's, treatment is directed at eliminating the risk of hemorrhage. Thus, the
morbidity from any treatment must be carefully weighed against the natural history of brain AVM’s.5,13,29,34 Our treatment decision is based on many factors: symptoms, clinical findings, age, and angioarchitecture.53 Our goal is a morphological cure either by embolization alone or in combination with radiosurgery or surgery. In combination with radiosurgery, embolization may offer an earlier protection from rebleeding in patients who have recently bled and may reduce the size of the AVM, thus making it more amenable to stereotactic radiation. In combination with surgery, we embolize through feeding pedicles which are the least accessible to the surgical approach.

Flow-related arterial aneurysms, due to high flow toward the AVM, represent one of the factors contributing to the risk of hemorrhage.2,17,35 Our series contained 10 such aneurysms of these, five disappeared following embolization, one decreased in size, and four remained unchanged. We encourage treatment of the AVM itself and not the flow-related aneurysm since these may regress after treatment of the malformation. If multiple feeders are present, the pedicle containing the flow-related aneurysm should be embolized first.

The choice of embolic material (NBNA or IBCA) reflects the authors’ strong belief that other embolic materials (such as particles, coils, balloons, or cocktails) result in revascularization of the AVM in the long term. Therefore, if these alternative embolic materials are used, the chance of a cure by embolization alone is not available. In addition, the result of embolization with these alternative embolic materials followed by radiosurgery have yet to be fully analyzed.

Morbidity

Compared to the literature,8,23 our 8% morbidity (two new permanent neurological deficits and aggravation of existing neurological deficits in two) is favorable. Our two patients with new permanent deficits both suffered only a mild disability. In our experience, embolization of brain AVM’s in eloquent brain areas carries a similar morbidity to that in noneloquent areas. In our series, three AVM’s involved the midbrain, three the thalamus, seven the sensorimotor cortex, nine the primary visual area, and seven the language area. This represents 29 patients or 58% of our series. Of these patients, four experienced a transient neurological deficit and one developed a permanent neurological deficit, thus accounting for less than 50% of the deficits observed. In a series of 10 patients with AVM’s in eloquent territories, Viñuela, et al.,30 reported two permanent deficits after embolization through a transfemoral approach. Laine, et al.,18 did not record any language impairment in a series of 16 patients with dominant hemisphere AVM’s who underwent surgery. In another surgical series, Hubschmann and Krieger16 reported no new deficits in 11 patients with AVM’s in eloquent areas who presented with mild or no deficit.

We do not know yet if there is a role for partial embolization of brain AVM’s in decreasing the risk of hemorrhage. Among those who bled (16 patients), none had a rebleed after embolization and a follow-up period ranging from 2 to 6 years. Two of our patients treated by embolization alone who had never bled developed delayed hemorrhage, and one of these died after emergency surgery. In our 5-year study period this bleeding rate is similar to the natural history of AVM’s.6,13,34

Thirty-three patients continue to be evaluated after complete or partial embolization. A long-term follow-up study will permit us to more accurately assess the outcome of partially treated lesions.

Conclusions

A complete cure of AVM’s by embolization alone is uncommon and is confined to Spetzler Grade I, II, or III lesions. Grade IV and V AVM’s can be treated initially by embolization to facilitate surgery or make them amenable to radiosurgery. When the arterial supply involves more than two major arterial groups, the chances of more than 60% obliteration are minimal. An embolization made too proximal clearly compromises the results and may lead to revascularization, particularly in lesions involving the occipital lobe. The risk of a permanent neurological deficit was 8% in our series. In a 2- to 6-year follow-up period, the bleeding rate in patients with embolization was similar to the natural history of AVM’s. None of the patients who presented with a hemorrhage have rebled after treatment. The role of partial embolization in reducing the risk of hemorrhage is unknown; however, theoretically when total obliteration of an AVM is impossible by any means, partial embolization with liquid tissue adhesive may have a role in stabilizing an AVM that has become symptomatic. Embolization may reduce both the flow and the size of AVM’s. Favorable modifications of the angioarchitecture can occur with embolization such as the disappearance of flow-related aneurysms and the shrinkage of venous ectasias. Long-term follow-up monitoring of patients treated by embolization is mandatory and, for this purpose, all outpatients are followed in a multidisciplinary brain vascular malformation clinic at the University of Toronto, facilitating review of clinical results and treatment strategy.

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Endovascular treatment of AVM's

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