Embolization of segments of the circle of Willis and adjacent branches for management of certain inoperable cerebral arteriovenous malformations

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Most large cerebral arteriovenous malformations (AVM's) in the territories of the penetrating arteries arising from the circle of Willis, including the proximal anterior, middle, and posterior cerebral arteries, have been considered untreatable. However, the pattern of collateral circulation which accompanies these lesions presents the possibility of completely occluding certain segments of the circle of Willis and adjacent major branches without producing infarction distally in the cerebral hemisphere or in the critical areas occupied by the AVM itself. The ensuing reduction of arterial pressure within the AVM may reduce the likelihood of hemorrhage or progressive enlargement. Four patients in whom this was accomplished in whole or in part by embolization are described. In one patient, infarction did ensue but the potential for collateral circulation had been restricted by the passage of emboli into the pericallosal artery. In the others, angiographic filling of the lesion was considerably reduced without worsening of their neurological deficits. One patient had recovery of neurological loss following the procedure, and another was slightly improved. Over follow-up periods of up to 28 months there have been no recurrent hemorrhages or further progression of neurological deficits. However, final assessment of the efficacy of this procedure will require longer follow-up intervals and additional patients.

KEY WORDS • cerebral arteriovenous malformation • embolization • cerebral hemorrhage • cerebral artery • circle of Willis

In a prior report based upon experience with over 250 cases, it was projected that approximately 50% of all cerebral arteriovenous malformations (AVM's) can be surgically obliterated or resected with a mortality and morbidity less than the natural course. An additional 25% might be managed by an intravascular approach alone or combined with surgery, or, when the AVM's are small and deep, by irradiation alone. For the remaining patients, however, there has been no established treatment or proven effectiveness.

Many of these heretofore untreatable lesions extend through the territories of the penetrating arteries arising from the circle of Willis, including the proximal anterior, middle, and posterior cerebral arteries. They have been classified as Grade IV, lenticulostriate territory, in a recently proposed scheme. Usually, they become symptomatic during or before the second decade of life, with the gradual onset of motor and sensory deficits that may slowly progress to a complete capsular hemiplegia. Spontaneous bleeding is probably more frequent than in the more laterally located AVM's in the cerebral hemispheres. Usually, both anterior cerebral arteries fill from the contralateral internal carotid artery (ICA), as seen angiographically, and the shunting of blood into the deeper portions of the hemisphere is accompanied by extensive development of cortical anastomotic arteries joining the anterior, middle, and posterior cerebral arterial territories. These vascular features create the possibility of occluding the major arterial trunks at certain segments of the circle of Willis, without significantly reducing the distal hemispheric circulation. Our purpose is to present a series of patients demonstrating the feasibility of occluding these arteries, without producing infarction, for the management of these heretofore untreatable AVM's, and to describe the steps we have taken to evolve a surgical technique for accomplishing this.

In three previously reported patients, we had intentionally occluded the middle cerebral trunk to varying degrees by emboli, without evoking a new neurological deficit or increasing a preexisting one. These results encouraged us to gradually extend the...
areas of occlusion in additional patients. These original three patients will be described briefly (Cases 1–3). Four new patients (Cases 4–7) are reported in more detail; in these new patients an attempt was made to occlude more completely segments of the circle of Willis and adjacent arterial trunks as the sole management for their inoperable AVM's.

Technique

Both direct clipping of intracranial arteries and embolization via the cervical internal carotid (ICA) and vertebral arteries were employed. Because the Silastic emboli required were frequently 3.0 mm or larger in diameter, the transfemoral catheter technique was not practical, and direct exposure of the cervical carotid arteries for catheter introduction was necessary. For embolization via the vertebrobasilar system, the catheter was introduced by direct exposure into the subclavian artery and advanced retrograde to the orifice of the vertebral artery. The emboli were spheres of Silastic impregnated with barium and fragments of muscle removed from the adjacent sternocleidomastoid muscle. Frequently, the emboli were tethered with a silk suture for retrieval if necessary or prevention of delayed distal progression. In one patient, electroencephalographic (EEG) monitoring was used during the procedure. General anesthesia was used in all patients.

Case Reports

Case 1

This 33-year-old woman* had a 5-year history of a progressive left hemiparesis, seizures, and severe headaches. Angiography revealed a large AVM through the right internal capsule and insula; the distal Sylvian arterial territories were supplied by the anastomotic branches of the ipsilateral anterior and posterior cerebral arteries. She underwent embolization in three stages over 6 months leading to occlusion of at least the distal one-third of the middle cerebral artery (MCA). No increase in her neurological deficit occurred, and her preexisting deficit remained stable over the ensuing 8 years.

Case 2

This 20-year-old woman* had the onset of a right hemiparesis at 6 years of age. This deficit progressed to a complete hemianesthesia, hemianalgesia, and spastic hemiplegia. She had four hemorrhages and was incapacitated by left-sided headaches and a continuous bruit. Angiography showed that the lesion occupied the thalamus, basal ganglia, and internal capsule on the left side. In two stages, over 7 months, the proximal posterior cerebral artery, A1 segment of the anterior cerebral artery, and the entire middle cerebral trunk were occluded with Silastic emboli. This procedure did not provoke any change in her pro-

Case 3

This 32-year-old man* suffered a subarachnoid hemorrhage. Angiography demonstrated an AVM through the anterior temporal lobe on the left side. A 3.5-mm embolus was introduced, completely obstructing the terminus of the middle cerebral trunk. No neurological deficit was provoked. Angiography disclosed that the distal Sylvian territories were supplied by collateral arteries from the anterior cerebral artery. Subsequently, the lesion was totally excised. The arteries branching from the end of the MCA were sacrificed during the surgery. The patient was discharged without deficit.

Case 4

This 23-year-old right-handed woman was admitted to Georgetown University Hospital on February 17, 1978. Four years previously she had experienced the onset of slowly progressive left hemiparesis. Two months prior to admission, she was hospitalized elsewhere after the abrupt onset of a severe headache followed by unconsciousness. Lumbar puncture confirmed the diagnosis of an intracerebral hemorrhage. Angiography demonstrated a large AVM in the territories of the penetrating arteries from the circle of Willis and proximal anterior, middle, and posterior cerebral arteries on the right side (Fig. 1). Both anterior cerebral arteries filled from the contralateral ICA and there was generous development of the collateral arterial circulation over the cerebral hemisphere. She was managed conservatively and improved.

Examination. At admission she was alert and cooperative with adequate recent memory but flat affect. There was a left spastic hemiplegia and hemihypesthesia with no voluntary movements of the hand or ankle. There was a complete left homonymous hemianopsia, a left sixth nerve palsy, and impairment of upward gaze.

Operations. On February 22, 1978, embolization was performed via the right ICA. After a 3.0-mm embolus blocked the terminus of the MCA, as planned, additional emboli measuring 2.5 and 3.0 mm in diameter and multiple fragments of muscle were introduced until the entire MCA trunk was obstructed proximal to the origin of the anterior cerebral artery. When the procedure was nearly completed, a 2.5-mm embolus passed into the anterior cerebral artery and was arrested at the pericallosal artery at the genu of the corpus callosum. Angiography at the termination of the procedure showed a complete obstruction of the ICA proximal to the siphon and no filling of the AVM. Postoperatively, she was temporarily leth-
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FIG. 1. Case 4. Anteroposterior and lateral views of the right carotid angiogram showing an arteriovenous malformation in the right internal capsule and basal ganglia.

argic, but showed no change in her neurological deficit. Angiography via the right ICA showed complete obstruction of the ICA proximal to the siphon and no filling of the AVM. Angiography via the left ICA showed good filling of both hemispheres and only trace filling of the AVM (Fig. 2).

A second operation was performed on March 1, 1978. Embolization was performed via the right vertebral artery. Twelve 2.5-mm emboli were used. These arrested in the proximal posterior cerebral artery and its branches, obstructing additional blood supply for the lesion.

Postoperative Course. The patient exhibited no immediate change in neurological status. Thereafter, she showed gradual improvement in both motor and sensory function of the left arm and some opening of her left visual field. Within 3 weeks, she could walk with a foreleg brace, and recovered voluntary flexion and extension of the fingers of her left hand. Eight months following the surgery, she was able to walk rapidly with a cane and had isolated movements of the wrist and fingers of the left hand which she could use for grasping and assisting. Position sense and touch localization of the left arm were still impaired but were improved from her preoperative status. She has been followed for 28 months. She has subsequently married. There has been no recurrent bleeding or seizures.

Case 5

This 25-year-old woman was admitted to Georgetown University Hospital on October 10, 1977. She had been well until 6 years prior to admission when she had an intracerebral hemorrhage.

Examination. Angiography demonstrated a large AVM in the territory of the penetrating arteries around the circle of Willis on the right side (Fig. 3). A left hemiparesis followed the hemorrhage, but she recovered from this with only a minor increase in her hemiparesis. However, the headaches became more severe. Her neurological examination revealed a moderately severe left spastic hemiparesis equally involving the arm and leg. Cortical sensation was well preserved, and the visual fields were full.

Operations. On October 12, 1977, she underwent embolization via the right ICA. Two 3.0-mm emboli obstructed the proximal portion of the right MCA. Intraoperative angiography demonstrated that the middle cerebral trunk on the right was unusually short,

FIG. 2. Case 4. Left carotid angiogram after embolization via the right internal carotid artery. Collateral circulation via the anterior cerebral artery supplies the right cerebral hemisphere with slight residual filling of the arteriovenous malformation.
terminating after a few millimeters into multiple small penetrating arteries that supplied the lesion. It was judged that 3.0-mm emboli would be too large to pass into the anterior cerebral artery. Therefore, three additional emboli were introduced. They were temporarily arrested in the ICA, as planned, but then passed through the A1 segment and stopped distally in the callosomarginal artery. The procedure was therefore terminated. The patient's neurological status was unchanged, and her postoperative course was uneventful. Her headaches persisted as before, and angiography continued to show generous filling of the lesion from arteries arising from the terminus of the ICA.

She was readmitted on April 2, 1978. Her neurological examination had not changed in the interval. At a second operation, on April 7, 1978, she underwent embolization via the right ICA. A 3.5-mm embolus was introduced, followed by two large muscle fragments. Intraoperative angiography showed complete occlusion of the terminus of the right MCA. Her neurological status was unchanged. However, 3 days following this procedure, angiography again showed renewed patency of the MCA and limited filling of the lesion. Collateral supply to the hemisphere was considered adequate despite emboli in the callosomarginal artery.

A third operation was performed on April 12, 1978. Via the right ICA, nine 3.5-mm emboli and five large muscle fragments were introduced, leading to complete obstruction of the MCA and the ICA back to the siphon. One embolus passed into the posterior communicating artery (Fig. 4).

Postoperatively, the patient had a dense left hemiplegia and left homonymous hemianopsia. A computerized tomography (CT) scan confirmed the presence of an extensive area of infarction through the midportions of the right hemisphere. Over the ensuing

![Fig 3. Case 5. Anteroposterior (left) and lateral (right) angiograms. Upper: Right carotid angiography showing a large arteriovenous malformation (AVM) in the internal capsule, basal ganglia, and thalamus. Lower: Vertebral angiography demonstrating the contribution of the posterior circulation to the AVM.](image-url)
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week, she regained proximal movements of the arm and leg, and became ambulatory with a foreleg brace.

Sixteen months after the last procedure, her headaches began to recur. Angiography elsewhere demonstrated extensive refilling of the lesion with recanalization of the ICA. She was readmitted on January 6, 1980. Her neurological examination was unchanged. Although she could walk, she had not recovered any voluntary use of the left hand.

A fourth operation was performed on January 7, 1980. Embolization via the right ICA was repeated. Intraoperative angiography confirmed complete patency of the ICA. The Silastic emboli were incorporated in the wall of the artery with flow around them. Two large muscle emboli were introduced and the proximal ICA was ligated and divided.

Postoperative Course. During the immediate postoperative period, the patient remained drowsy and confused, but thereafter steadily recovered. She had a complete third nerve palsy on the right and increased facial weakness on the left. At the time of discharge, 2 weeks following the procedure, she was recovering rapidly, and her headaches had completely subsided. Over the ensuing 5 months, there has been no recurrence of her headaches.

Case 6

This 43-year-old man was admitted to Georgetown Hospital on July 10, 1978. Two months before admission, he had two episodes of loss of consciousness within 1 hour. After the second, he complained of severe headache, difficulty in using his right arm, and impaired verbal expression. For 1 year before admission, he had shown personality changes and impairment of recent memory. Also, he had left frontoparietal headaches and had exhibited less initiative at work.

Examination. Angiography before admission demonstrated an AVM in the territory of the left MCA through the basal ganglia, thalamus, and internal capsule. Neurological examination was normal except for a very slight truncal ataxia with a tendency to deviate to the right. Angiography confirmed the presence of the AVM through the territory of the penetrating arteries of the MCA. Both anterior cerebral arteries filled from the right side, and there was extensive development of collateral circulation between the left anterior cerebral and ascending Sylvian arteries on the left (Fig. 5).

FIG. 4. Case 5. Plain film showing final disposition of the Silastic emboli. One embolus is seen in the posterior communicating artery and three emboli in the callosomarginal artery and its branches.

FIG. 5. Case 6. Anteroposterior (left) and lateral (center) views of the left internal carotid angiography showing an arteriovenous malformation (AVM) in the internal capsule and basal ganglia. Right: Vertebral angiography demonstrating filling of the AVM (arrow) via the posterior communicating artery.
Operations. On July 17, 1978, the patient underwent embolization via the left ICA. A single 4.0-mm embolus was introduced and arrested at the orifice of the middle cerebral trunk (Fig. 6). Intraoperative angiography showed markedly reduced filling of the lesion and filling of the anterior cerebral artery from the left ICA injection. The distal territory of the MCA was completely taken over by collateral circulation from the anterior cerebral artery (Fig. 7).

After surgery, the patient showed no neurological deficit and was discharged 6 days later. Over the ensuing months, he continued to have recurrent seizures, but the effectiveness of anticonvulsant medications was uncertain because of mild alcoholism. Eighteen months after the procedure, a CT scan indicated reestablishment of the AVM. He was readmitted on February 4, 1980. Neurological examination indicated slight paresis of the right upper extremity, and slight alteration of cutaneous sensation over the forearm. The patellar reflex on the right was hyperactive. Plain films of the skull showed that the embolus, originally arrested at the orifice of the right MCA, had migrated distally into a Sylvian artery. Angiography showed a complete reestablishment of the AVM (Fig. 8 left).

At a second operation, on February 7, 1980, a single 3.5-mm embolus was introduced, and this was arrested in a Sylvian artery along the insula. Then a 4-mm embolus tethered with a silk suture was introduced, and this was held in position at the origin of the MCA. Another tethered 4.0-mm embolus was introduced, and this rested adjacent to it at the orifice of the A1 segment. Final angiography demonstrated very
slight filling of the lesion from the arterial branches arising more proximally from the ICA (Fig. 8 right).

The patient's postoperative course was uneventful. There was no change in his neurological examination, and he was discharged on the 7th postoperative day.

Eleven months after his second operation, the patient had an intracerebral hemorrhage. This was managed by ventricular drainage, and he ultimately made a satisfactory recovery with no change in his neurological deficit.

Case 7

This 15-year-old boy was admitted to Georgetown University Hospital on April 10, 1978. Since early childhood, he had noted a tendency for his right hand to shake during skilled acts. He learned to write with his left hand. Six years before admission, he began to experience increasing incoordination of the right hand and the onset of brief episodes of loss of consciousness, occasionally preceded by "déjà vu" phenomena. Cerebral angiography elsewhere had demonstrated an AVM in the left hemisphere. Over the following years, he was managed with anticonvulsant medication. For 2 years before admission, incoordination of the right arm and leg progressed. Six weeks before admission, he had a brief period during which the right side of his body felt numb.

Examination. He had a mild hemiparetic gait. There was hypesthesia and hypalgesia throughout the entire right side including the face. The deep tendon reflexes were increased on the right. There was moderate loss of skilled movements of the right hand, with dysmetria and dysdiadochokinesia.

An arteriogram showed an AVM in the territory of the penetrating arteries of the left middle cerebral trunk, posterior communicating artery, and proximal posterior cerebral artery. There was extensive collateral circulation to the left hemisphere (Fig. 9). Because he was attending school and the deficits did not seriously interfere with his activities, he elected to defer surgical treatment.

He was readmitted on July 8, 1978, for further evaluation because of progression of the hemiparesis. His neurological examination was essentially unchanged, although his intention tremor appeared to be of a slightly wider amplitude.

Operations. On July 12, 1978, as a preliminary to embolization to restrict passage of emboli to the MCA, he underwent a left frontal craniotomy with clipping of the posterior communicating artery and the midportion of the A1 segment on the left side. He made a satisfactory recovery, with no change in his neurological deficit.

He was readmitted on December 3, 1978. Since his last admission there had been only a slight increase in his intention tremor, but he was having frequent rightsided focal seizures, despite medication. Angiography confirmed the occlusions of the left posterior communicating and anterior cerebral arteries as intended in the first operation (Fig. 10).

At a second operation on December 6, 1978, he underwent embolization of the left ICA, under EEG
monitoring. A trial period of 10 minutes of complete occlusion of the ICA showed no evidence of EEG slowing.

A 4.5-mm embolus tethered with a 4-0 silk ligature was introduced, and this was arrested at the terminus of the MCA. A total of 10 2.0-mm and 10 1.5-mm emboli were then introduced. These completed the occlusion of the middle cerebral trunk. Three were arrested in penetrating arteries distal to the middle cerebral trunk, and eight passed through the lesion into the pulmonary circulation (Figs. 11 and 12).

Postoperative Course. Immediately after surgery, there was no obvious change in the patient's neurological deficit, but 4 days later he was more proficient in the use of his right hand and his intention tremor was less pronounced. For the first time in many years he was able to deal cards from a deck without difficulty. He has been followed for 18 months with no change in his neurological deficit.

Discussion

For consideration of an intravascular approach, the AVM's described here must be contrasted with the more common, laterally placed, hemispheric AVM's which are mostly in the terminal territories of tertiary cortical arteries. For management of these, the feed-
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FIG. 10. Case 7. Internal carotid artery angiography, anteroposterior (left) and lateral (right) views, after direct clipping of the posterior communicating artery and proximal A1 segment.

ing tertiary arteries are occluded immediately proximal to the lesion or in the lesion itself by multiple particulate emboli or rapidly polymerizing plastics. The goal, although practically never achieved, is total occlusion of the lesion. In contrast, for AVM's in the lenticulostriate territories, extensive widespread occlusions with thrombosis are not desirable because residual circulation is always necessary for the critical neural pathways and nuclei in the interstices of the abnormal vasculature. Therefore, little hope of absolute cure can be offered, and the method described here may be the only rational approach at present.

The major source of complications is passage of the emboli into the anterior cerebral artery with obstruction of the collateral circulation, as occurred in Case 5. Subsequently, this was prevented by the use of tethered emboli and preembolization direct clipping of the A1 segment. Inflatable, detachable balloon-tipped catheters may have a use here. However, there may be a disadvantage of late deflation or delayed passage distally if the balloon is not secured.

Only in one patient (Case 7) was an attempt made to obstruct the penetrating arteries distal to the major arterial trunks with multiple small emboli. However, most of the emboli 1.5 and 2.0 mm in diameter passed directly through the lesion, further confirming that blockage of the major arterial trunks may be the only certain method for effective management.

In general, these cases demonstrate that occlusion of the major arteries around the circle of Willis is possible without producing a significant infarction, and angiographic demonstration of a generous collateral reserve for the distal portion of the hemisphere is possible.
probably a reliable guide. The technique allows an adequate residual circulation for the basal ganglia, internal capsule, and thalamus. The goal of reduction of intravascular pressure to delay progression and reduce the likelihood of hemorrhage may be achieved temporarily. However, the overall benefit that may accrue requires further clinical observation with longer follow-up periods.

References

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