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Alex Berenstein

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Flow-controlled silicone fluid embolization is a technique that can be useful in situations where selective injection cannot be achieved, but where the proximal part of the feeding vessel must be preserved. It consists of a modified double-lumen balloon catheter and silicone fluid made radiopaque with tantalum powder with a predetermined viscosity and vulcanization time. Flow control by manipulation of the balloon in the proximal artery permits the distribution of emboli to desired sites in distal arteries. A case is described and other details offered about this technique that may be valuable for special situations.

Increased availability of delivery systems and embolic agents have enhanced the physician's capabilities in the treatment of complex hemodynamic lesions [1–4]. Selective catheter placement prior to embolic agent deposition is the ideal situation for the best results and fewest complications. However, situations arise when selective catheterization is impossible due to vessel tortuosity and/or the extent of the lesion. A technique that may be useful in such situations is described in detail.

Technique

Delivery System

The delivery system consists of a modified double-lumen balloon catheter [3] (Meditech Div., Cooper Scientific, Watertown, Mass.) that differs from conventional double-lumen catheters in two ways: (1) the lumen connected to the balloon is oval, following the catheter wall, allowing a larger internal diameter of the injection lumen with no change in overall catheter size, and (2) the distal end of the catheter is not tapered, in order to maintain a constant internal diameter (fig. 1). The larger injection lumen facilitates injection of more viscous embolic agents. An introducer sheath (Cook, Bloomington, Ind.) is used to prevent pericatheter leakage. Continuous heparinized saline is perfused at the puncture site between the introducer sheath and the inner catheter. The catheters are available in different sizes. A 7 French catheter has a 2.34 mm OD at the shaft and 2.88 mm OD over the balloon tip, with a 1.35 mm ID. A 3 French catheter has a 1 mm OD at the shaft and 1.35 mm OD over the balloon tip, with an 0.49 mm ID [3].

Embolic Material

A silicone fluid mixture of 1:2–1:3 of Silastic Elastomer 382 and Silastic Medical Fluid 360 (both Dow Corning Corp., Midland, Mich., I.N.D. required) 20

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[1]Department of Neuroradiology, Bellevue Hospital, and New York University Medical Center, 550 First Ave., New York, NY 10016.

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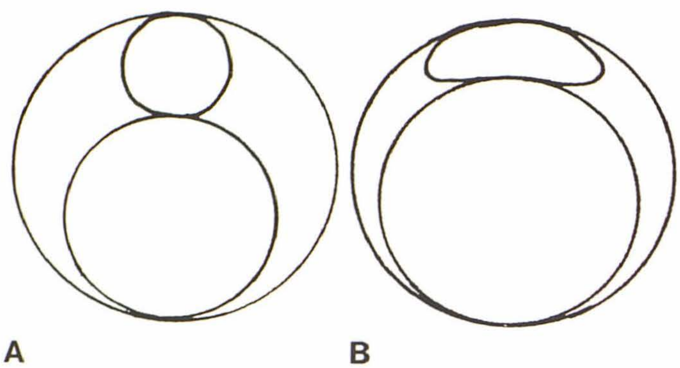


Fig. 1.—A, Cross section of conventional double-lumen balloon catheter with two circular lumens: smaller for balloon, larger or distal lumen for injection. B, Modified double-lumen balloon catheter. Balloon lumen changed to oval, following wall of catheter shaft, which increases injection lumen by 30%. (Reprinted from [3].)

centistokes viscosity is thoroughly mixed with 1–2 μm opacifying tantalum powder (Kena Metal, Latrobe, Pa.) (1 g/ml silicone mixture). A 1 drop/ml mixture of stannous octate (Catalyst M, Dow Corning Corp., I.N.D. required) which will lead to vulcanization in about 20 min is added. If faster vulcanization is desired, the addition of 1 drop/ml of tetra-N-proxysilane [5] will produce vulcanization in 3–4 min, while 1 drop/3 ml will vulcanize the fluid in about 10 min. An in vitro test of vulcanization time is made before injection and adjustments are made as needed.

Catheterization and Embolization

A percutaneous technique is preferred for catheter insertion, but in some instances direct arteriotomy may be used. After the balloon catheter has been placed at the desired position, the balloon is inflated and flow stasis is angiographically tested. A drop of the silicone mixture is placed beyond the catheter tip with the balloon deflated; the silicone globule will ascend with the blood flow and will stop and vulcanize at the point where the vessel diameter diminishes sufficiently to arrest its flow. If the silicone fluid is not arrested, as may be the case in large arteriovenous communications, the maneuver is repeated with the balloon inflated. By gradual balloon deflation, the radiopaque silicone will ascend. Under fluoroscopic monitoring, the balloon is reinflated when the embolus has reached the desired position, and the material is allowed to vulcanize before the balloon is deflated. The catheter lumen may be kept patent by pushing the silicone with saline, from the catheter hub to its tip. More than 1 drop may be injected at a time in a large, multiple vessel lesion. Previous experience in animal models is mandatory for proper control of the technique.

Case Report

A 32-year-old man was first seen at age 19 with seizure disorder and a progressive left hemiparesis due to a right frontotemporal arteriovenous malformation that was partially resected at that time. Postoperatively, the patient did well except for continued paresthesia of the left upper and lower extremities; he was able to continue school and then attended college.

At age 26 he was readmitted for progression in his hemiparesis and a bruit in his head. A silicone sphere embolization was performed after surgical exposure of the right external carotid artery in the neck, through which a 4 mm ID catheter was passed into the right internal carotid artery; 50 emboli, 1.5–3 mm in diameter, were introduced. The external carotid artery was ligated at the end of the embolization. Postoperatively, the right eye was blind secondary to an embolus lodging in the ophthalmic artery and ligature of the external carotid artery that decreased collateralization to the right ophthalmic artery. The flow through the malformation was significantly reduced. Neurologically there was no further deterioration; however, there was difficulty in controlling the patient's seizures.

The patient suffered a subarachnoid hemorrhage 3 months before the most recent admission and again 1 month later with an increase in seizure activity. A third episode of subarachnoid hemorrhage occurred 4 days before admission and was documented by a bloody and xanthochromic spinal fluid. The postictal course was characterized by a marked spastic left hemiparesis, inability to walk, and slow mentation.

Admission physical examination showed a 32-year-old man in slight to moderate distress, alert and oriented, but with mild slow mentation; both left upper and lower extremities showed marked muscle wasting in all groups and a left Babinski sign. The patient was blind in the right eye and had 20/20 vision in the left, the remaining cranial nerves were intact. Sensory examination revealed mild hemianesthesia on the left side of the body; pin sensation was present on the right and absent on the left. Left-sided ataxia was noted.

Angiography revealed a large right frontotemporal arteriovenous malformation, supplied by the right anterior cerebral artery (fig. 2A). The right middle cerebral artery filled through leptomeningeal collaterals from the vertebrobasilar circulation and multiple hypertrophied muscular branches of the right vertebral artery supplied the right external carotid trunk from which vessels filled the malformation (figs. 2B and 2C). Left external carotid angiography revealed meningeal and superficial temporal supply (fig. 2D) to the malformation. The left internal carotid circulation did not feed the malformation directly. The left vertebral artery also supplied the malformation in its most posterior and medial aspect via the right posterior cerebral artery with drainage to the internal cerebral vein.

First embolization. The left common carotid artery was entered percutaneously and the left middle meningeal artery was selectively catheterized with a conventional double-lumen balloon catheter and a drop of viscous silicone was injected. This drop of silicone stopped in the distal meningeal vessel, and was well anchored to the vessel bifurcation (fig. 3). The postembolization course was uneventful with the exception of mild tenderness in the left temporal region that completely cleared after 5 days.

Second embolization. Three weeks later, the right external carotid artery (previously ligated 6 years earlier) was surgically exposed in the neck and our modified 7 French double-lumen balloon catheter was selectively placed in the right middle meningeal artery (fig. 4A). Using flow control, emboli were successfully injected to produce distal occlusion of more than 90% of the supply from the right external carotid artery (figs. 4B and 4C). The postembolization course, apart from mild right temporal pain, was uneventful. The pain subsided in about 2 weeks. The neurologic status seemed improved; the left lower extremity spasticity was considerably decreased. The patient regained control of movement in the left lower extremity and was able to move his toes and ankle. A radionuclide flow study, after the partial embolization of the left external carotid

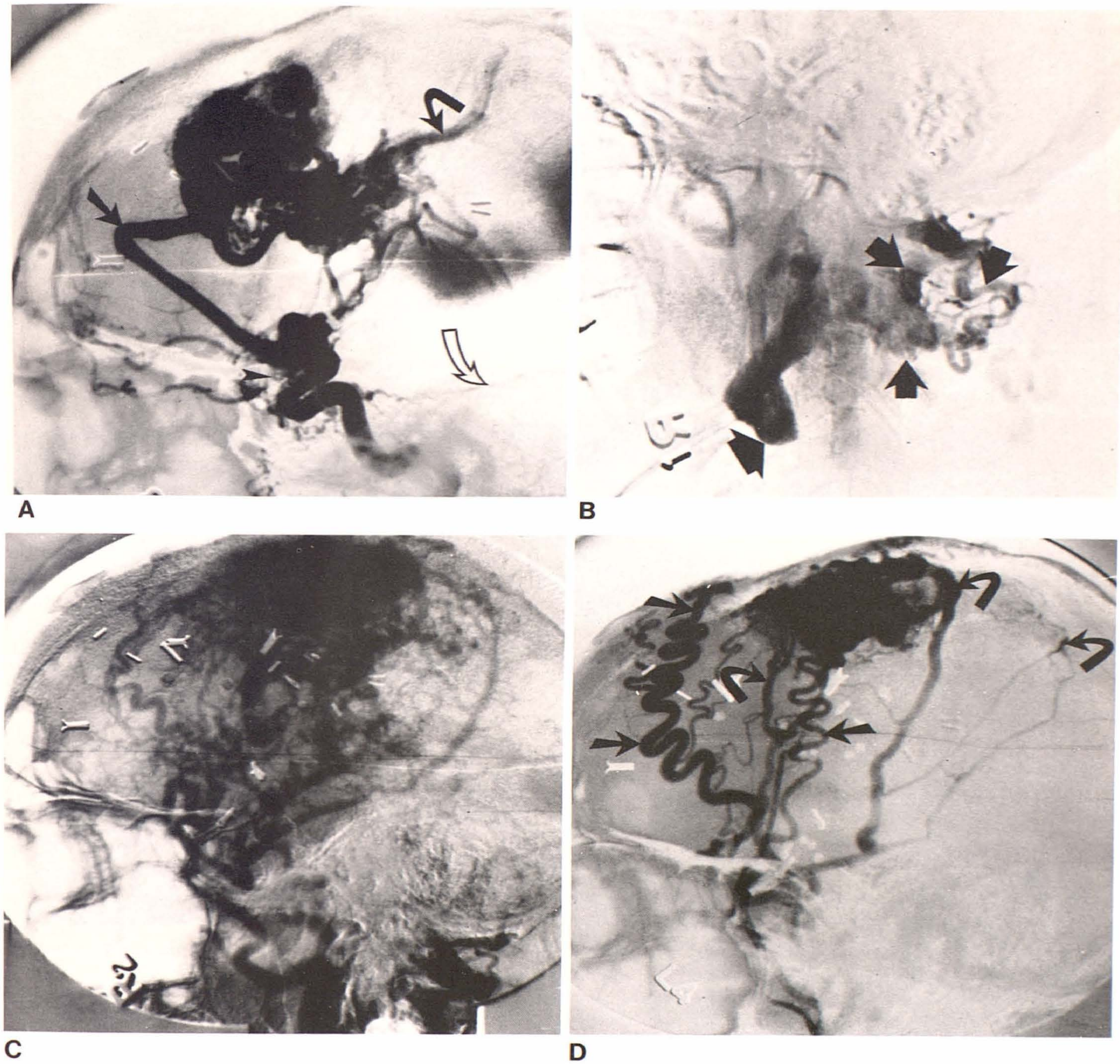
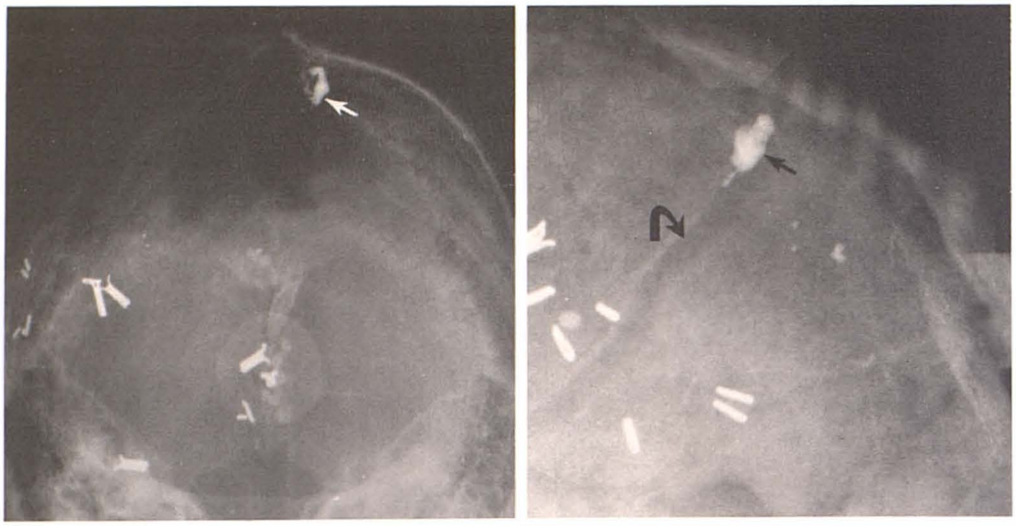
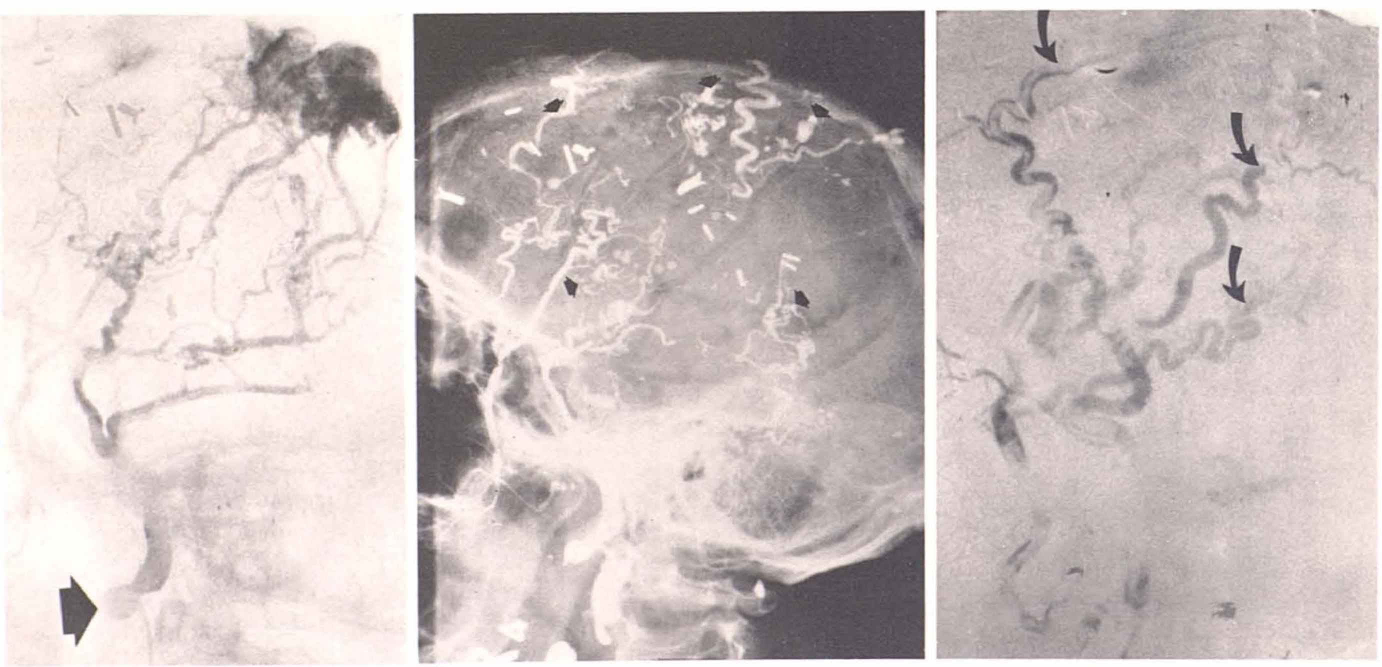


Fig. 2.—**A**, Lateral subtraction angiogram of right internal carotid artery in midarterial phase. Filling of pericallosal artery (*straight arrow*) supplying malformation with early venous filling (*curved black arrow*). Second angiomatous complex in supraclinoid area (*arrowhead*) supplied by tentorial artery (*open arrow*). **B**, Lateral angiogram of hypertrophied right vertebral artery, early phase, with prominent muscular branches (*arrows*) and filling of right external carotid artery via right occipital artery. Ligated external carotid artery (*arrowhead*). **C**, All vessels filled from right external carotid artery supply malformation on right side. **D**, Lateral subtraction angiogram of left external carotid artery reveals supply to malformation through middle meningeal branches (*curved arrows*) and branches of superficial temporal artery (*straight arrows*).



A B

Fig. 3.—Flow-controlled silicone emboli in left middle meningeal artery. **A**, Frontal view. Emboli (*arrow*). **B**, Lateral view, close-up. Anchored emboli (*straight arrow*). Prominent vascular groove (*curved arrow*).



A B C

Fig. 4.—**A**, Lateral subtraction angiogram of right middle meningeal artery. Modified double-lumen balloon catheter. Balloon (*arrow*) in proximal part of middle meningeal pedicle. Multiple feeding vessels. (Reprinted from [2].) **B**, Lateral skull radiograph. Numerous radiopaque silicone emboli (*arrows*) after injection with balloon flow control (Reprinted from [2].) **C**, Lateral subtraction angiogram of right external carotid artery after embolization. Contrast material fills vessels until site of emboli (*arrows*); no filling of malformation. (Cf. fig. 2C.)

supply (first embolization) and the second embolization of the right external carotid supply, showed a marked decrease in the flow of the right side and no gross change on the left (fig. 5).

Third embolization. Percutaneous catheterization of the left external carotid artery via the femoral route was performed. A control angiogram showed the previously embolized meningeal vessel to be occluded. On the left side two other feeders were embolized by the same technique with good results of 80% occlusion of the left external carotid supply (fig. 6). The procedure was stopped because some of the fluid silicone passed into the lungs; there were no clinical manifestation from the pulmonary emboli.

Fourth embolization. The right internal carotid artery was catheterized through the femoral route; repeated attempts to flow-guide a microballoon catheter to the right anterior cerebral artery were unsuccessful due to vessel tortuosity, and silicone spheres were flow directed to the malformation. A total of 25 1 mm spheres and 65 1.5 mm spheres was injected with a reduction of about 40% in the flow, as documented by isotopic flow studies and angiography

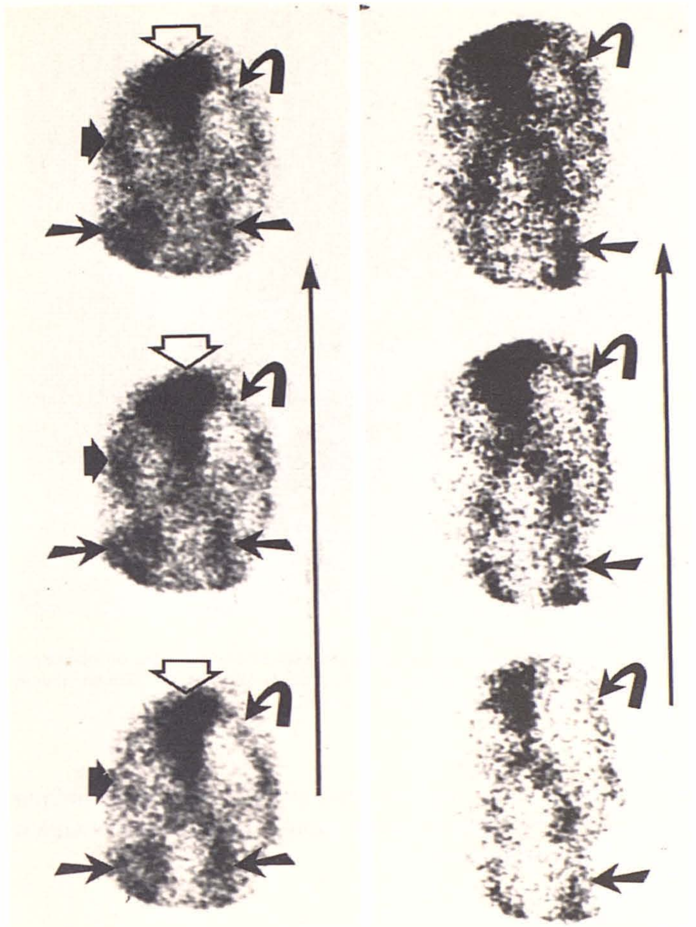


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Fig. 5.—**A**, Preembolization radionuclide flow study. Increased activity in neck area bilaterally (*longer solid arrows*) represents collateral supply between vertebral artery and external carotid systems. Left side supply (*curved arrows*), right side supply (*short solid arrows*), and activity in brain (*open arrows*). *Single long arrow* demonstrates flow sequence. **B**, After embolization of right side and partial embolization in left. Decreased activity in neck on left side (*straight arrows*) and no activity on right side of neck or in right convexity, but no gross change in left convexity area (*curved arrows*).

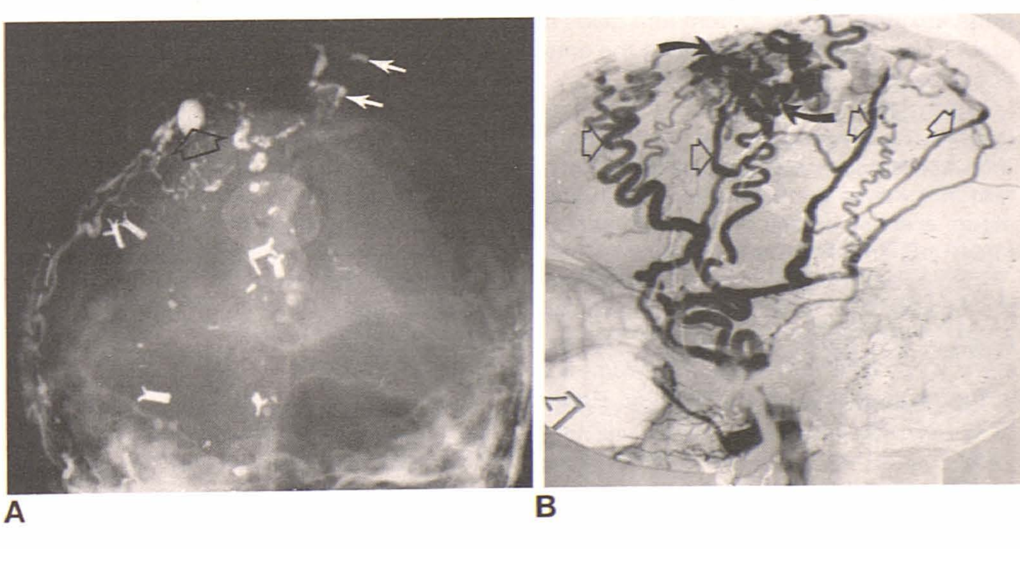
(figs. 7 and 8). The patient was discharged 7 days after embolization. Plain films of the skull show the radiopaque emboli to be unchanged. Neurologic status was markedly improved, to the point of the patient walking out of the hospital assisted only by a short brace on the left lower extremity and a cane. The patient's clinical status was stable 1½ years later. He could walk unassisted and without the brace or cane. He was seizure-free (on the same medication), and no subarachnoid hemorrhage had recurred.

Discussion

Sano et al. [6] reported the use of viscous silicone (6,500 centistokes viscosity) for the embolization of intracerebral arteriovenous malformations. We modified his technique by varying the silicone viscosity from 6,500–25,000 centistokes, depending on the vessel to be occluded, by making the silicone radiopaque with tantalum powder, and using balloon catheters to control the flow. Due to the multiple vessel involvement in our case, it became apparent that the proximal part of the scalp vessels should be preserved to prevent unwanted skin necrosis. The first embolization demonstrated this could be accomplished, and, encouraged by this result, we undertook some animal experimentation with this technique before attempting further embolization. At the same time, we had been working on the development of a modified double-lumen balloon catheter for coaxial embolization [3] and noted that the injection of more viscous mixture was facilitated by the increased diameter of the injection lumen.

These modifications permit the operator to vary the viscosity of the silicone mixture for the size of the vessel to be occluded; less viscous material is used for smaller vessels and higher viscosity for larger vessels. Long vulcanization time is desired to allow multiple emboli to be introduced before the catheter lumen becomes obstructed. The use of introducer sheaths at the puncture site permits multiple catheter change without the need of guide wires, which cannot be inserted if the catheter is blocked by the vulcanized silicone.

The addition of tantalum powder to embolic fluid makes



A B

Fig. 6.—**A**, Frontal skull view after third embolization. Two new feeders from left side occluded (*white arrows*). Radiopaque silicone also seen in right occipital artery (from second embolization). (Cf. fig. 4B.) Drop of radiopaque silicone in venous side (*open arrow*). (Cf. fig. 3A.) **B**, Lateral subtraction angiogram after embolization of left external carotid artery. Preservation of proximal vessels (*open arrows*), with only minimal filling of malformation (*curved arrows*). (Cf. fig. 2D.)

Fig. 7.—**A**, Radionuclide flow scan after fourth embolization. (Cf. fig. 5A.)

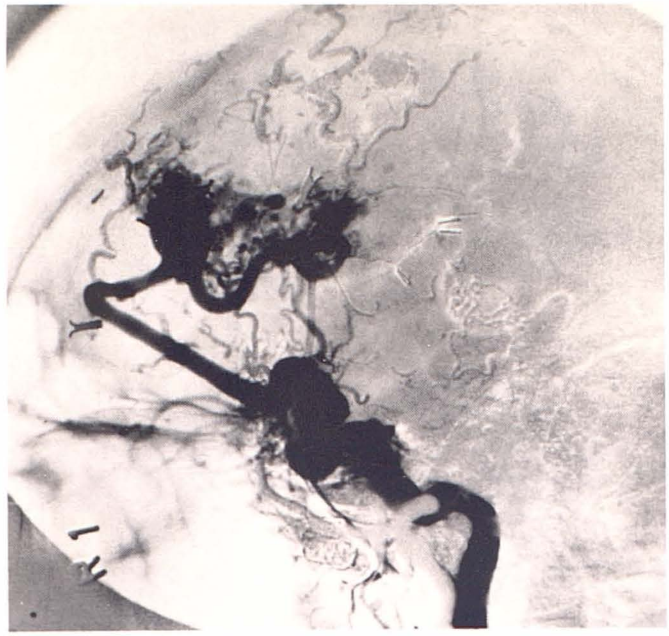


Fig. 8.—Lateral subtraction angiogram after silicone sphere embolization of right internal carotid supply with reduction of about 40%. Slower flow in lesion (fig. 2 comparable in time sequence).

the mixture radiopaque, allowing fluoroscopic monitoring of its final position. Graduated control of the flow by the balloon adds flexibility to the system and gives better control of the emboli final position, decreasing the amount of material that will pass to the venous side.

In our case, only branches of the external carotid circulation were embolized with this technique. We have used this technique in the cerebral circulation on one occasion and in a spinal hemangioma. The indications for this technique are existence of a significant hemodynamic sump effect and linearity toward the lesion.

At present, curing complex arteriovenous malformations by intravascular embolization is still not possible in most patients with inoperable lesions. However, palliative treatment is possible with some improvement or at least an arrest in the progression of the disease. Repeated embolizations may be necessary, and the greater versatility in technique will enhance the possibilities in patients previously unsuited for this therapeutic method.

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