Treatment of Intracranial Aneurysms with Preservation of the Parent Vessel: Results of Percutaneous Balloon Embolization in 84 Patients

Randall T. Higashida[1]
Van V. Halbach[1]
Stanley L. Barnwell[1]
Christopher Dowd[1]
Bill Dormandy[2]
Julie Bell[2]
Grant B. Hieshima[1]

Treatment of intracranial arterial aneurysms by interventional neurovascular techniques is now being performed in selected cases. From a transfemoral approach, under local anesthesia, a detachable silicone microballoon can be guided through the intracranial circulation, directed into the aneurysm, inflated with a polymerizing agent for solidification, and detached. The goal is to exclude the aneurysm from the circulation and preserve flow through the parent artery. Since 1984, 84 patients have been treated by this technique. The patients ranged in age from 15 to 83 years (mean age, 48) and included 63 females and 21 males. The distribution of aneurysms included 59 in the anterior circulation and 25 in the posterior circulation. The presenting symptom or cause was mass effect in 45 patients (53.6%), subarachnoid hemorrhage in 31 patients (36.9%), carotid–cavernous sinus fistula resulting from rupture of an intracavernous aneurysm in six cases (7.1%), trauma in one case, and transient cerebral ischemia due to emboli in one case. Permanent complications directly related to therapy included 15 deaths and nine cases of stroke. Clinical and radiologic follow-ups were performed 1, 3, and 12 months after treatment; duration of follow-up ranged from 3 to 68 months (mean, 35.5 months). In 65 cases (77.4%) there was evidence of complete aneurysmal occlusion, and in 19 cases 922.6%) there was subtotal occlusion greater than 85%.

Interventional techniques for treatment of intracranial aneurysms may be useful as a therapeutic alternative in those patients not amenable to standard surgical therapy.

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Surgical exploration and clipping remains the treatment of choice for the majority of patients diagnosed with an intracranial aneurysm. However, in certain types of cases, aneurysms may not be accessible by surgery owing to size or anatomic location, or patients may be too unstable medically to undergo general anesthesia. In these instances, treatment with interventional neurovascular techniques has emerged as a therapeutic alternative.

Interventional techniques using detachable balloons were first described by Serbinenko [1] in 1974. Since then, recent advances in high-resolution digital subtraction angiography, road mapping technique, microballoon technology, and solidifying materials have allowed the treatment of selected patients with intracranial aneurysms from an endovascular approach. Under direct fluoroscopic imaging, the balloon can be guided directly into the aneurysm, filled with a polymerizing substance, and detached, thus excluding the aneurysm from the circulation and preserving blood flow through the parent artery [2, 3]. For large and giant aneurysms, more than one balloon may be required for complete occlusion. The transfemoral approach allows access to both the anterior and posterior circulations, and thus far, nearly all types of aneurysms around the circle of Willis have been approached and treated successfully with this method.

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[1] Departments of Radiology and Neurological Surgery, Interventional Neuroradiology Section, L-352, 505 Parnassus Ave., San Francisco, CA 94143-0628. Address repritn requests to R. T. Higashida.

[2] Interventional Therapeutics Corporation, 385 Oyster Point Blvd., Suite 6, South San Francisco, CA 94080.

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Materials and Methods

Patient Population

Since 1984, 84 patients, 63 females and 21 males, have been treated by detachable balloon occlusion of intracranial aneurysms with preservation of the parent artery. The patients ranged in age from 15 to 83 years (mean age, 49 years). Table 1 lists the locations of the various types of aneurysms treated. Fifty-nine patients were treated for an aneurysm in the anterior circulation and 25 were treated for an aneurysm in the posterior circulation. Nineteen patients (22.6%) were treated for a giant aneurysm greater than 2.5 cm in diameter. In 45 cases (53.6%) the presenting symptom was mass effect accompanied by pain, ophthalmoplegia, headaches, and compression of adjacent brain structures causing hydrocephalus, visual loss, or progressive neurologic deficit depending on aneurysm location. in 31 patients (36.9%), subarachnoid hemorrhage (SAH) due to aneurysm rupture was the presenting symptom. Six patients (7.1%) had evidence of a direct carotid-cavernous sinus fistula, which included symptoms of retroorbital bruit, chemosis, ophthalmoplegia, and/or visual decline due to rupture of a preexisting intracavernous aneurysm. One patient presented with a pseudoaneurysm following trauma and one patient presented with symptoms of transient cerebral ischemia from thromboembolic disease presumably originating from the aneurysm.

Indications for Treatment

Our current indications for treatment by detachable balloon embolization therapy include prior surgical exploration of an aneurysm with inability to clip the neck, aneurysms in surgically difficult anatomic regions such as the cavernous segment of the internal carotid artery and midbasilar artery, fusiform aneurysms without a well-defined neck, inability to tolerate general anesthesia owing to an underlying medical condition, and aneurysms in which the risks of surgical clipping are judged to be excessively high owing to their size or location. Therefore, this series favored a very high-risk group of patients in whom standard neurosurgical treatment failed or who were poor candidates for surgery. All patients gave complete informed consent prior to therapy.

Technique

All procedures are performed in the interventional neuroangiography suite with the use of high-resolution digital subtraction angiography, road-mapping technique, and rapid-sequence filming. From a transfemoral approach, using 1% xylocaine for local anesthesia and IV diazepam and morphine sulfate for mild sedation, a 7.5-French sheath is placed into the femoral artery and an activated clotting time (ACT) is measured. A complete four-vessel cerebral arteriogram is obtained to assess aneurysm size, shape, axis, relationship of the neck to the parent vessel, evidence of intraluminal thrombus, and collateral blood flow. Correlation with prior MR and CT scans is made to determine if recent thrombus is present within the aneurysm [4]. If fresh thrombus of less than 6-weeks duration is evident and the patient is clinically stable, we prefer to postpone therapy because of the increased risk of dislodging clot during balloon manipulation within the aneurysm. Following the diagnostic evaluation, 5000 units of heparin (for a 70-kg patient) are given IV for systemic anticoagulation to prevent thrombus formation on the balloon and microcatheters. A repeat ACT measurement is obtained to ensure adequate anticoagulation.

Balloon selection is determined by aneurysm size and shape. Two different types of balloons, a standard balloon and a collarless balloon, each in several different sizes and three release ranges, are currently available (Table 2). The balloon that we have been using for endovascular aneurysm therapy (Fig. 1) is manufactured as an investigational device by Interventional Therapeutics Corp. (South San Francisco, CA) and is currently undergoing Food and Drug Administration clinical trials [5]. The balloon is attached to a 2.0-French polyethylene catheter or a 2.0-French Tracker catheter (Target Therapeutics Corp., San Jose, CA).

For aneurysms in unfavorable locations relative to the parent vessel, the polyethylene catheter can be steam-formed into different shapes or the Tracker catheter can be used in conjunction with a 0.014-in. (0.035-cm) steerable guidewire to aid in placing the balloon directly into the aneurysm. If the small or medium-sized balloon is used, a 7.3-French nontapered catheter is placed through the femoral artery sheath into the proximal internal carotid or vertebral artery, depending on aneurysm location. For the large balloon, an 8.0-French nontapered catheter is used. Through this guiding catheter, the balloon and microcatheter are then advanced, with continuous perfusion of heparinized saline between the two catheters to avoid thrombus formation. The balloon is filled with metrizamide, at a concentration of 200 mg % iodine, for opacification.

A "road map," which is the subtracted neurovascular architecture superimposed on the real-time fluoroscopic image, is then obtained of the aneurysm and proximal artery. The balloon is flow-directed through the intracranial circulation and carefully guided into the aneurysm. Once within the aneurysm, the balloon is inflated so as to

TABLE 1: Locations of Aneurysms Treated by Detachable Balloon Therapy

Location	No.
Anterior circulation	
High cervical/petrous internal carotid artery	3
Cavernous internal carotid artery	24
Supraclinoid internal carotid artery	24
Middle cerebral artery	6
Anterior cerebral artery	2
Total	59
Posterior circulation	
Distal vertebral/posterior inferior cerebellar artery	2
Mid-basilar artery	3
Distal basilar artery	19
Posterior cerebral artery	1
Total	25

TABLE 2: Characteristics of Silicone Detachable Balloons

Size	Dimension, Uninflated (mm)	Volume, Maximum Unrestricted (ml)	Dimension, Inflated (mm)	Detachment Strengths, All Sizes (g)
Small	0.85 × 4.10	0.10	3.80 × 9.00	20–30
	0.85 × 5.10	0.20	4.20 × 12.0	30–40
	0.85 × 7.10	0.40	4.50 × 16.0	40–55
Medium	1.50 × 4.10	0.20	5.00 × 6.00	20–30
	1.50 × 4.60	0.30	6.50 × 9.50	30–40
	1.50 × 5.10	0.50	7.50 × 13.50	40–55
	1.50 × 7.30	0.90	8.50 × 21.00	
Large	1.80 × 4.10	0.40	6.00 × 10.00	20–30
	1.80 × 5.30	0.70	8.50 × 15.50	30–40
	1.80 × 6.40	1.00	9.00 × 18.00	40–55
	1.80 × 7.60	1.50	10.00 × 23.0	

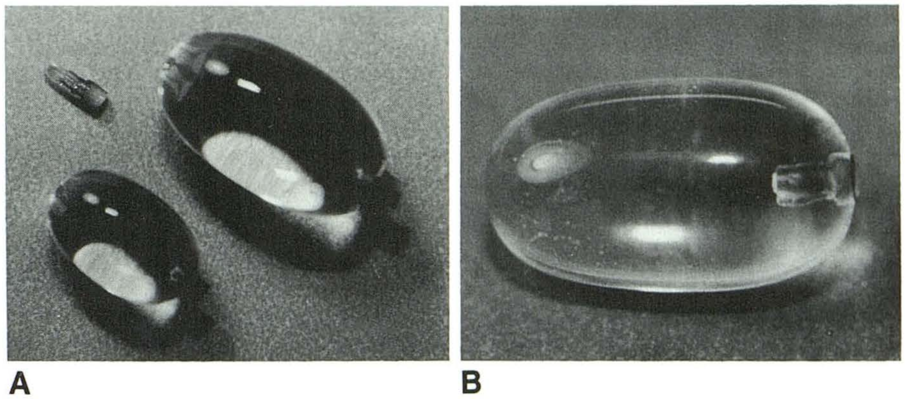


Fig. 1.—*A*. Silicone detachable balloon used for intravascular treatment of intracranial aneurysms. Balloons shown are uninflated, partially inflated, and fully inflated.

***B*, Newer type of silicone balloon currently available shows that self-sealing miter valve is internalized and does not protrude beyond valve base.**

produce complete occlusion of the aneurysm dome, body, and base. The volume required to produce complete occlusion is measured and then the contrast material is aspirated from the balloon and refilled with 2-hydroxyethyl methacrylate (HEMA). HEMA is a liquid monomer, which can be cross-linked and catalyzed to produce polymerization that yields a nonbiodegradable solid substance. This is used as a fill material within the silicone balloon to ensure that a permanent embolic material remains within the aneurysm, should the balloon shell deteriorate or the self-sealing miter valve fail over time [2, 3]. To overcome the dead space of our catheter system, several exchanges with HEMA or the use of a 0.006-inc. (0.015-cm) vent tube are undertaken during this stage of the procedure. Once the HEMA is solidified, confirmed by comparing the HEMA within the balloon with an outside control, the balloon is detached by gentle traction on the 2.0-French catheter. If the neck of the aneurysm is broad-based, a second nondetachable balloon can be temporarily placed across the neck to aid in detachment, and then removed. For giant aneurysms, more than one balloon may be required to completely fill the aneurysm. After the embolization procedure, protamine sulfate is given IV to reverse systemic heparinization (10 mg of protamine will reverse 1000 units of heparin). A final arteriogram is obtained to check for aneurysm occlusion and patency of the parent vessel. Neurologic assessment is also made of the patient's condition.

All patients are observed in the neurosurgical observation unit for 2–4 days after treatment and if stable are discharged. Clinical follow-up is performed in all patients at 1, 3, and 12 months after treatment. Postembolization arteriograms are obtained at 1–3 months and at 3–12 months after treatment. In addition, plain skull radiographs along with CT and/or MR head scans are obtained during these intervals to check balloon placement and aneurysm thrombosis, particularly for large and giant aneurysms.

Representative Case Reports

Supraclinoid Aneurysm with Hemorrhage

A 56-year-old woman presented with a large SAH primarily involving the right side. Cerebral angiography demonstrated a small right middle cerebral artery aneurysm as well as a large supraclinoid carotid artery aneurysm measuring 13 × 16 × 23 mm. In addition, the right anterior cerebral artery was hypoplastic (Figs. 2A and 2B). Surgical exploration of both right-sided aneurysms was performed. The right middle cerebral artery aneurysm was successfully clipped; however, exploration of the right supraclinoid aneurysm showed the neck extending below the clinoid process into the cavernous sinus. Because this patient was still at risk for rehemorrhage she was referred for balloon embolization treatment. Test occlusion of the cervical right internal carotid artery was performed under local anesthesia. The mean arterial pressure of the carotid artery was 93 mm Hg; however, on temporary balloon occlusion the mean arterial pressure dropped to 19 mm Hg, and at 2 min the patient became lethargic, unresponsive to commands, and dysarthric; she also developed a left-sided hemiparesis. The balloon was immediately deflated, and after 15 min the neurologic deficits resolved.

Because the patient did not tolerate temporary occlusion of the carotid artery, it was important to preserve flow of the distal intracranial vessels. Under direct fluoroscopic visualization, two detachable balloons were flow-directed through the intracranial carotid circulation and directed into the large supraclinoid aneurysm. An exchange of HEMA was made into each balloon, allowed to solidify, and then detached. The postembolization angiogram demonstrated obliteration of the aneurysm with preservation of the parent artery. The patient was discharged several days later in stable neurologic condition without any major deficits. A 1-year follow-up angiogram continued to show obliteration of both aneurysms with normal filling of the intracranial circulation (Figs. 2C and 2D); clinically she continued to remain neurologically intact.

Large Intracavernous Aneurysm

A 47-year-old woman presented with retroorbital headaches, nausea, and visual difficulties. A CT head scan followed by cerebral angiography demonstrated a large right-sided intracavernous aneurysm projecting medially and measuring 12 × 15 × 20 mm (Figs. 3A and 3B). Test occlusion of the internal carotid artery demonstrated an arterial back pressure of 18 mm Hg with temporary balloon occlusion. Within 30 sec left-sided hemiparesis and aphasia developed. Thus, the patient was unable to tolerate carotid artery occlusion owing to poor collateral circulation around the circle of Willis and via the external carotid artery.

From a transfemoral approach, a 1.5-mm medium detachable balloon was guided through the carotid artery and directed into the aneurysm. The balloon was filled with 0.38 ml of HEMA, allowed to solidify, and detached. Her immediate, 4-week, and 4-month follow-up postembolization cerebral arteriograms demonstrated obliteration of the intracavernous aneurysm (Figs. 3C–3E).

Large Basilar Artery Aneurysm

A 74-year-old woman presented with severe throbbing headaches and blurred vision. A CT head scan and cerebral angiogram demonstrated a large distal basilar artery aneurysm measuring 8 × 10 × 13 mm (Figs. 4A and 4B). Two silicone detachable balloons were flow-directed up the posterior circulation, through the basilar artery, and into the aneurysm. After placing HEMA into the balloons for solidification, the balloons were detached, with obliteration of the aneurysm and preservation of the distal posterior cerebral arteries. After the procedure the patient developed a mild visual field deficit, most likely from a small embolus to the posterior cerebral artery from the microcatheter during the procedure. She was discharged several days later in stable neurologic condition without further difficulties.

A follow-up arteriogram at 1 year demonstrated continued occlusion of the aneurysm with normal filling of the distal intracranial vessels (Figs. 4C–4E). At 2 years of clinical follow-up she is still neurologically intact except for a mild visual field deficit.

Results

Since 1984, we have guided a balloon directly into an aneurysm and preserved the parent artery in 84 patients [6, 7]. In 19 cases (22.6%), the patients presented with a giant aneurysm, and often more than one balloon was required to occlude the dome and body of the aneurysm and still preserve the parent vessel.

Complications associated directly with aneurysm treatment included 15 deaths (17.9%). In 10 of these, rupture of the aneurysm occurred as a result of incomplete aneurysm occlusion, resulting in an SAH. Five of these patients had presented previously with an SAH and five with symptoms of mass effect. Six of the 10 patients died from aneurysm rupture within 5 days after treatment; in the other four, rupture was delayed. One death was due to rupture of the balloon and a second death was from valve leakage; both occurred during polymerization of HEMA, resulting in occlusion of the distal intracranial vessels. Two other deaths in this series occurred in patients who developed myocardial infarcts 24 hr after the procedure; a third patient died from a pulmonary embolus 6 days after treatment.

Three other deaths (3.6%) occurred in this series, although not because of the endovascular procedure for aneurysm occlusion. These were caused, respectively, by an intracranial hematoma from a prior surgical craniotomy, severe vasospasm from prior SAH, and hemorrhage from an associated arteriovenous malformation 16 months after successful balloon embolization therapy of a basilar artery aneurysm.

Nine patients (10.7%) developed a stroke as a result of therapy. In five of these patients, the stroke was due to thrombus dislodging either within the aneurysm or on the balloon and catheters during the procedure, despite systemic anticoagulation. in two patients, the balloon narrowed the parent vessel after it was detached, causing occlusion and stroke. In one patient, a stroke developed owing to balloon rupture during HEMA polymerization; in another patient, pre-

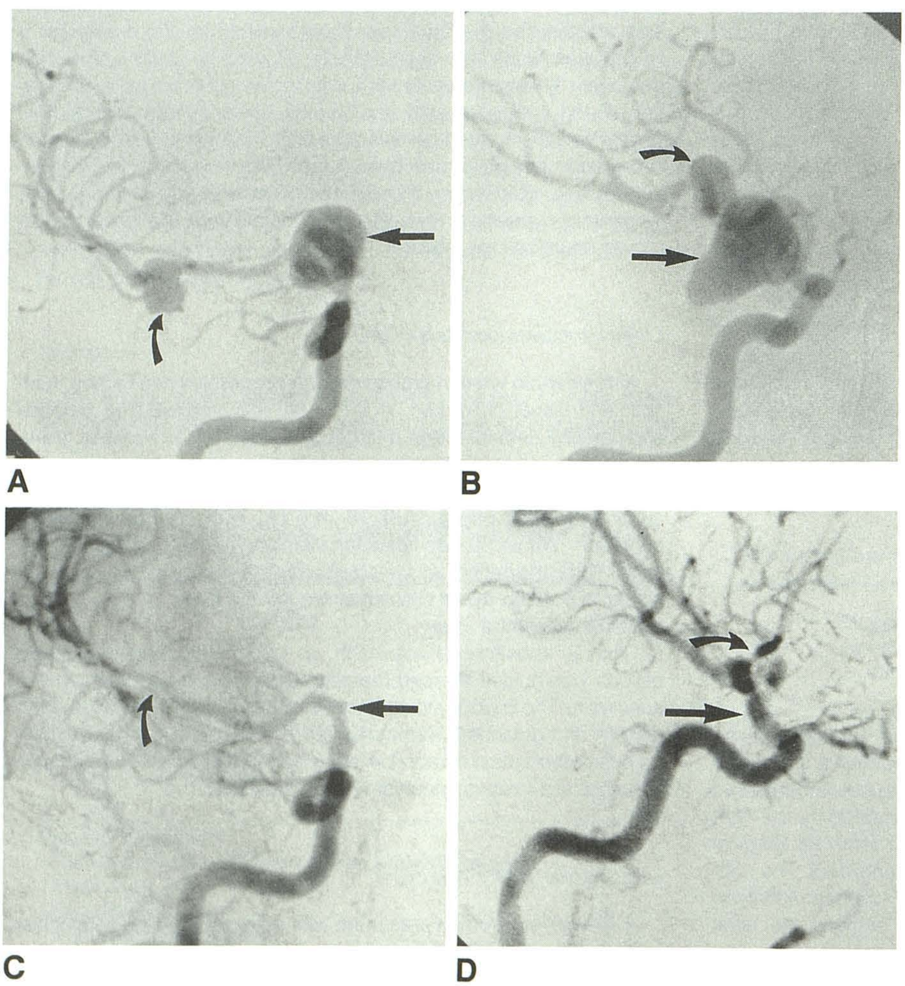
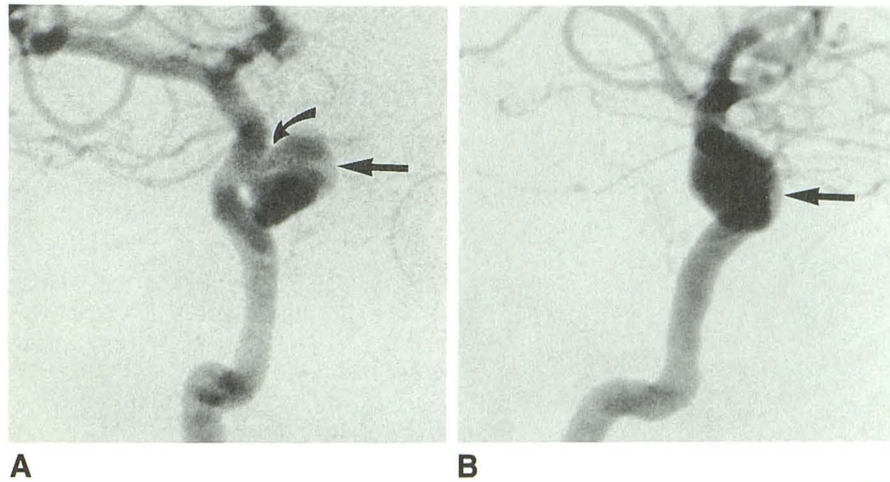


Fig. 2.—Patient presenting with large subarachnoid hemorrhage from aneurysm rupture.

_A_ and _B_, Frontal (_A_) and lateral (_B_) views of right internal carotid arteriogram show small middle cerebral artery aneurysm (_curved arrows_) and large supraclinoid internal carotid artery aneurysm (_straight arrows_). Note that anterior cerebral artery is hypoplastic.

_C_ and _D_, Frontal (_C_) and lateral (_D_) views 1 year after embolization, following placement of two detachable balloons in supraclinoid aneurysm. There is complete and total obliteration of aneurysm by balloons (_straight arrows_) with normal filling of distal intracranial vessels. Small right middle cerebral artery aneurysm has been successfully clipped (_curved arrows_).



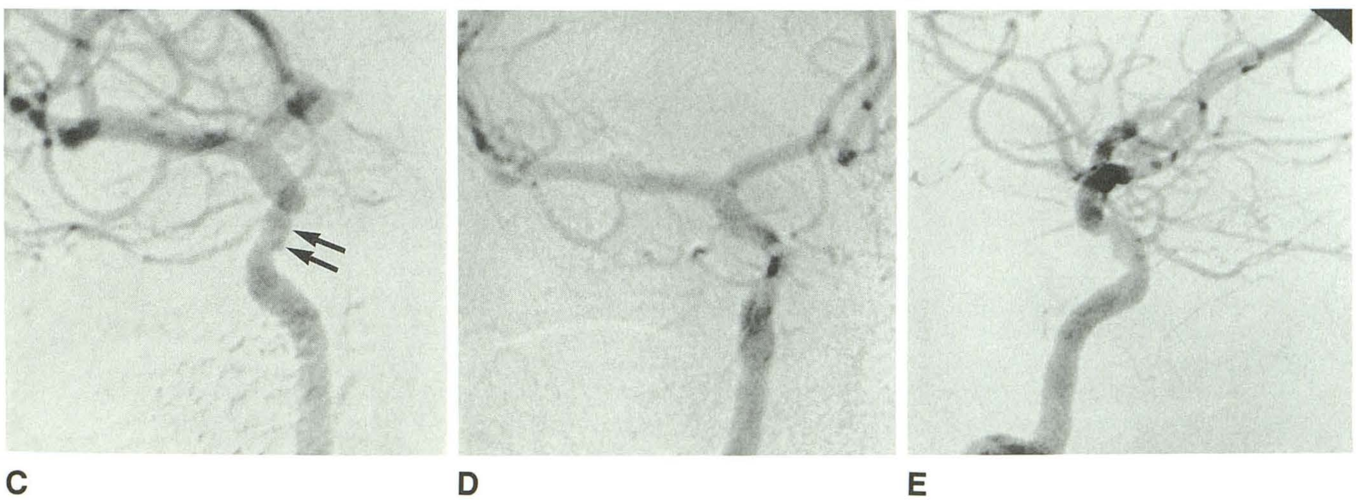


Fig. 3.—*A* and *B*, Selective right internal carotid arteriograms, frontal (*A*) and lateral (*B*) views, show large intracavernous aneurysm measuring 12 × 15 × 20 mm (*straight arrows*). Aneurysm projects medially; neck is seen well angiographically (*curved arrow*).

C–E, After placement of a single detachable balloon into aneurysm (*arrows*), 4-month follow-up arteriogram shows obliteration of aneurysm with preservation of intracranial vessels. This is demonstrated best on left anterior oblique projection (*C*), but is seen also on frontal (*D*) and lateral (*E*) views.

mature balloon detachment resulted in an embolus to the middle cerebral artery. Long-term follow-up demonstrated improvement in neurologic function in seven of these nine patients: three had only mild to moderate expressive aphasia, two had a visual field deficit, one was recovering from a frontal lobe stroke, and one had a mild hemiparesis. One patient required surgical repair of the right and left femoral artery due to pseudoaneurysms that developed after treatment from the femoral artery puncture for therapy of intracranial aneurysms; this patient had no other difficulty.

Follow-up has ranged from 3 to 68 months (mean, 35.5 months). Radiologic follow-up has demonstrated complete aneurysm occlusion in 65 cases (77.4%), with good clinical recovery of the presenting symptoms. In the other 19 patients (22.6%), subtotal occlusion of the aneurysm was observed with greater than 85% occlusion of the dome and body. Two patients had evidence of the balloon shifting and occluding the parent vessel on follow-up studies. Ten patients (11.8%) required more than one balloon embolization treatment owing to shift of the balloon(s) or enlargement of the aneurysm on follow-up studies. These patients with subtotal occlusion tended to have large and giant aneurysms, often requiring placement of multiple balloons, and evidence of intraluminal thrombus within the aneurysm prior to therapy. These patients continue to have follow-up clinical and radiologic studies to ensure that no further change occurs in the size of the residual neck.

Discussion

Intravascular detachable balloon embolization therapy for treatment of intracranial aneurysms has been reported from several different centers. The earliest report was by Serbinenko [1] in 1974, who described successful occlusion of aneurysms involving the internal carotid artery using latex balloons. In 1981, Debrun et al. [8] and in 1984, Berenstein et al. [9,10] described a small number of patients who underwent carotid occlusion for treatment of giant unclippable aneurysms in the anterior circulation with only one permanent complication. In 1987, Fox et al. [11] described the use of detachable balloons for treating 68 patients with aneurysms by parent vessel occlusion therapy. They reported a 13.8% complication rate, consisting of delayed cerebral events and no permanent morbidity. These researchers have demonstrated that proximal occlusion of the parent artery can be performed with acceptable morbidity and mortality to alleviate symptoms from an intracranial aneurysm.

The largest report on intravascular occlusion of intracerebral aneurysms using detachable balloons has been from Romodanov and Shcheglov [12] at the Kiev Research Insti-

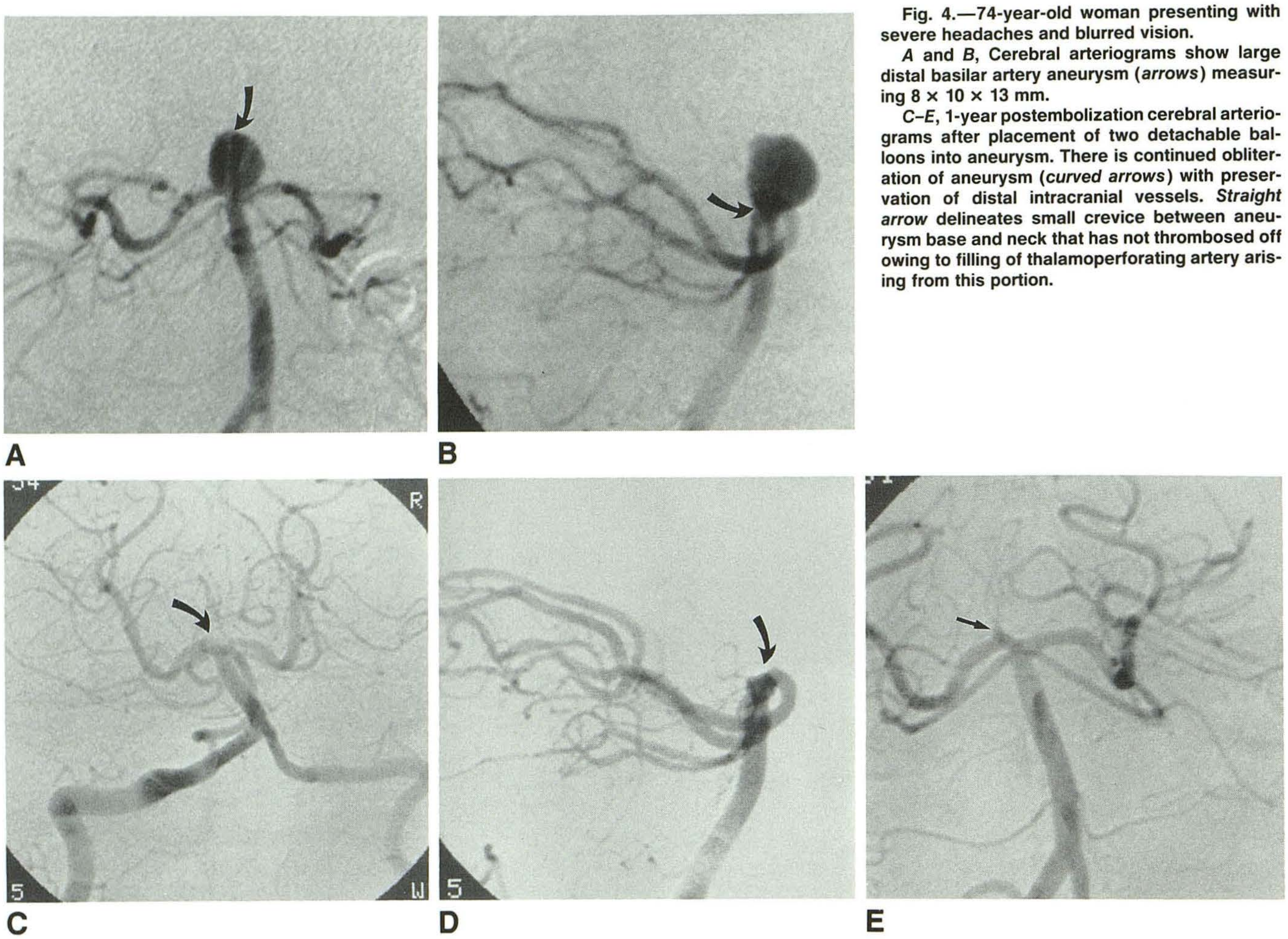


Fig. 4.—74-year-old woman presenting with severe headaches and blurred vision.

A and *B*, Cerebral arteriograms show large distal basilar artery aneurysm (*arrows*) measuring 8 × 10 × 13 mm.

C–E, 1-year postembolization cerebral arteriograms after placement of two detachable balloons into aneurysm. There is continued obliteration of aneurysm (*curved arrows*) with preservation of distal intracranial vessels. *Straight arrow* delineates small crevice between aneurysm base and neck that has not thrombosed off owing to filling of thalamoperforating artery arising from this portion.

tute of Neurosurgery. In 1982, they reported 119 cases, including 118 cases involving the anterior circulation and one patient treated for a posterior inferior cerebellar artery aneurysm. In 93 cases (78.2%), they were able to occlude the aneurysm and preserve patency of the parent artery. Fifteen patients (12.6%) required parent artery vessel occlusion and in 11 cases (9.2%) the aneurysm could not be occluded. In 89 (96.7%) of 92 patients treated with preservation of the parent artery, Romodoanov and Shcheglov reported good to excellent results with complete aneurysm occlusion. In 1989, Shcheglov updated the series and described 617 patients treated by intravascular detachable balloon therapy. (Shcheglov VI. Endovascular occlusion of saccular intracranial aneurysms: results in 617 patients. Presented at the annual meeting of the American Society of Neuroradiology, Orlando, FL, March 1989.) The aneurysm was successfully occluded and the parent artery preserved in 91% of cases. The reported mortality rate was 1.7% in 338 patients who were in fair condition when treated and 22% in 71 patients who were in poor condition. Currently, Shcheglov proposes that patients with an intracranial aneurysm first undergo detachable balloon embolization therapy, and only if that technique fails should they be treated by surgical clipping.

The experience of our group differs from that of Shcheglov in several important aspects. Since we consider this technique to be somewhat developmental, our criteria for patient selection are more limited. Patients are included only if standard surgical exploration for clipping aneurysms in surgically difficult anatomic locations has failed or if patients cannot tolerate general anesthesia [5]. We also tend to treat patients who have an acute SAH shortly after presentation, because of the increased risk of recurrent hemorrhage within the first 4–6 weeks [13–15]. Shcheglov prefers waiting at least 2–4 weeks after the initial hemorrhage; we believe that during this time patients may rehemorrhage or develop severe vasospasm. Our patient population therefore favors a higher-risk group of patients to undergo this form of therapy. Our complication rate compares favorably with neurosurgical results for large and giant aneurysms in difficult anatomic locations. The overall reported operative morbidity and mortality statistics range from 16% to over 50% for complex aneurysms, such as those involving the posterior circulation, from several large neurosurgical centers [16–23].

We have also developed a different detachable balloon catheter system for aneurysm therapy. Our group has developed a silicone, rather than latex, balloon system for several different reasons. Silicone is much more stable than latex, is biocompatible, and will not degrade within the intravascular system [24, 25]. In order to ensure that the aneurysm remains occluded, HEMA has been developed as a fill material for the silicone balloon, which may not be compatible with latex balloons [5]. Shcheglov and his group fill their latex balloons with silicone; however, this is a very viscous material and is not water soluble. Therefore, the dead space of the attached catheter must be overcome to ensure the balloon is completely filled. For aneurysms involving the anterior circulation, the Kiev group uses direct puncture of the cervical carotid artery. For posterior circulation aneurysms, other approaches are required. We perform all our procedures from a transfemoral arterial approach, thus permitting access to both the anterior and posterior circulation.

Complications associated with endovascular therapy are different from those of conventional surgery. Since balloons and catheters are being manipulated within the blood vessel lumen, thrombus may form on these materials. To avoid this, we place our patients on systemic anticoagulation by administering IV heparin prior to the balloon procedure and rechecking an activated clotting time. Despite this precaution, embolic episodes related to the procedure still occurred in five of our patients. Also in patients with a recently ruptured aneurysm, systemic anticoagulation may increase the prevalence of another severe hemorrhage during the procedure. Dislodgment of thrombus within an aneurysm by the balloon is also possible during the procedure, and we suspect that in two of our pateints this occurred, resulting in transient cerebral ischemia. The most critical phase with the use of HEMA is during the polymerization phase, lasting 20–60 min after mixing with the catalyst. If the balloon were to rupture or the valve leak during this interval, HEMA could leak out into the distal intracranial vasculature as a semisolid embolic agent, resulting in a stroke.

Other complications include premature detachment of the balloon, resulting in parent vessel occlusion or distal embolization, aneurysm rupture during balloon inflation, and delayed thromboembolic events in an incompletely treated aneurysm. The majority of deaths in our series were due to incomplete aneurysm occlusion with recurrent hemorrhage, occurring in 10 of 12 patients. Unless the aneurysm is completely occluded at the base by the balloon, there is the potential for aneurysm regrowth at its base or shift of the balloon within a thrombus already present within the aneurysm. This may result in persistent filling of the aneurysm and the potential for further hemorrhage or increase in mass effect. This is particularly important in giant aneurysms, in which more than one balloon may be required for complete occlusion. In 22.6% of our patients, only subtotal occlusion was apparent on follow-up studies; these patients are being closely followed for any change in residual size at the aneurysm base. Ten patients in our series required more than one procedure for aneurysm treatment owing to balloon shift within thrombus or regrowth of the aneurysm on follow-up studies.

The advantage of this procedure is that it is performed under local anesthesia from a transfemoral arterial approach; therefore, neurologic monitoring of the patient can be continuous. The suppleness of the catheter and balloon system aids in making placement of the balloon directly into the aneurysm possible for almost all types of aneurysms around the circle of Willis. For smaller aneurysms, a vent tube can be used during the exchange for HEMA to allow an adequate volume for permanent solidification of the entire contents of the balloon. Some of the disadvantages associated with this procedure include the need for a high degree of experience with detachable balloon systems, polymerizing materials, and high-resolution fluoroscopic equipment with road-mapping capability.

Long-term follow-up is still required to assess the clinical outcome and efficacy in patients with subtotal occlusion. In our experience, after an aneurysm is occluded by detachable balloons, any remaining small crevice still filling between multiple balloons placed within the aneurysm and at the aneurysm base will thrombose in the majority of patients. However, in those patients in whom persistent filling is seen on studies after 1–3 months, we have observed late hemorrhage and regrowth of the aneurysm. As with incomplete surgical clipping, these patients need to be assessed continuously to check further change in residual filling and to see if retreatment is necessary [26]. Preliminary animal studies of experimentally created aneurysms treated by endovascular placement of detachable silicone balloons into the aneurysm have indicated that thrombosis with reendothelialization does occur at the aneurysm base, with patency of the parent vessel. (Negoro M. Endovascular treatment of cerebral aneurysm, clinical and experimental aspects. Presented at the International Workshop on Intracranial Aneurysms, Nagoya, Japan, April 1989.) Further studies need to be carried out to assess changes with subtotal occlusion and hemodynamic changes that occur within the aneurysm lumen, particularly with giant aneurysms that require multiple balloons.

For now it is believed that intravascular detachable balloon embolization therapy is a viable alternative for treating patients with intracranial aneurysms. This technique allows occlusion of the aneurysm with preservation of the parent vessel, which may be the only alternative in patients in whom surgical clipping has failed and who cannot tolerate parent vessel occlusion therapy. As continued improvements in this technique evolve, the indications for therapy may broaden also.

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The reader's attention is directed to the commentary on this article, which appears on the following pages.