Title

ENDOVASCULAR TREATMENT OF MIDDLE CEREBRAL ARTERY ANEURYSMS WITH DETACHABLE COILS

Journal
Neurosurgery, 64(5)

ISSN
0148-396X

Authors
Suzuki, Shuichi
Tateshima, Satoshi
Jahan, Reza
et al.

Publication Date
2009-05-01

DOI
10.1227/01.neu.0000343534.05655.37

Endovascular Treatment of Middle Cerebral Artery Aneurysms with Detachable Coils: Angiographic and Clinical Outcomes in 115 Consecutive Patients

Shuichi Suzuki, M.D., Ph.D.
Division of Interventional Neuroradiology, Department of Radiological Sciences, University of California, Los Angeles School of Medicine, Los Angeles, California, and Division of Interventional Neuroradiology, Department of Diagnostic and Interventional Imaging, University of Texas Medical School at Houston, Houston, Texas

Satoshi Tateshima, M.D.
Division of Interventional Neuroradiology, Department of Radiological Sciences, University of California, Los Angeles School of Medicine, Los Angeles, California

Reza Jahan, M.D.
Division of Interventional Neuroradiology, Department of Radiological Sciences, University of California, Los Angeles School of Medicine, Los Angeles, California

Gary R. Duckwiler, M.D.
Division of Interventional Neuroradiology, Department of Radiological Sciences, University of California, Los Angeles School of Medicine, Los Angeles, California

Yuichi Murayama, M.D.
Division of Interventional Neuroradiology, Department of Radiological Sciences, University of California, Los Angeles School of Medicine, Los Angeles, California

Nestor R. Gonzalez, M.D.
Division of Interventional Neuroradiology, Department of Radiological Sciences, University of California, Los Angeles School of Medicine, Los Angeles, California

Fernando Viñuela, M.D.
Division of Interventional Neuroradiology, Department of Radiological Sciences, University of California, Los Angeles School of Medicine, Los Angeles, California

Reprint requests:
Shuichi Suzuki, M.D., Ph.D., Division of Interventional Neuroradiology, Department of Radiological Sciences, UCLA School of Medicine, 10833 LeConte Avenue, Box 951721, Los Angeles, CA 90095-1721.
Email: ssuzuki@mednet.ucla.edu

Received, December 30, 2007.
Accepted, October 10, 2008.

OBJECTIVE: Because of their anatomic configuration, middle cerebral artery (MCA) aneurysms are most often treated with surgical clipping. However, endovascular coil embolization of these aneurysms is an increasingly used alternative. We retrospectively reviewed the anatomic and clinical outcomes of patients with MCA aneurysms who underwent endovascular treatment at our institution.

METHODS: One hundred fifteen MCA aneurysms in 115 patients (mean age, 55.1 years) were treated by an endovascular technique from April 1990 to March 2007. Forty-eight patients (42%) presented with acute subarachnoid hemorrhage, and 67 patients (58%) had unruptured aneurysms. Fifty-three aneurysms (46%) were small with a small neck, 28 (24%) were small with a wide neck, 22 (19%) were large, and 12 (11%) were giant.

RESULTS: Angiographic results immediately after embolization showed complete occlusion in 53 aneurysms (46%), a neck remnant in 51 (44%), and incomplete occlusion in 3 (3%). Because of anatomic difficulties, we could not embolize 8 aneurysms (7%). Thirteen patients underwent combined treatment that included endovascular and extracranial-intracranial bypass surgery. Morbidity and mortality rates were 6.9% (8 patients) and 3% (3 patients), respectively. Procedure-related complications were encountered in 10 patients (9%). Seventy patients had long-term follow-up angiograms. Seven aneurysms (10%) were recanalized; all were large or giant. One partially embolized large aneurysm ruptured 13 months after embolization.

CONCLUSION: In this series, endovascular coil embolization of MCA aneurysms has morbidity and mortality rates comparable to those of conventional surgical clipping. Combined treatment of endovascular and bypass surgery can successfully treat large or giant complex fusiform MCA aneurysms.

KEY WORDS: Bypass surgery, Cerebral aneurysm, Embolization, Endovascular therapy, Fusiform aneurysm, Middle cerebral artery, Subarachnoid hemorrhage

Neurosurgery 64:876–889, 2009 DOI: 10.1227/01.NEU.0000343534.05655.37 www.neurosurgery-online.com

Middle cerebral artery (MCA) aneurysms account for approximately 18% to 22% of all intracranial aneurysms. The MCA is the third most common location for a ruptured aneurysm after the anterior communicating and internal carotid arteries (8, 32, 34). In the International Subarachnoid Aneurysm Trial, the safety and efficacy of endovascular coiling versus neurosurgical clipping were compared in patients with acute aneurysmal subarachnoid hemorrhage (SAH), and a better clinical outcome was observed in patients who underwent endovascular coiling (19). In that study, many patients with MCA aneurysms (14% of all aneurysms) were enrolled and contributed to the data analysis. However, at many institutions, the primary

ABBREVIATIONS: MCA, middle cerebral artery; **mRS**, modified Rankin Scale; **SAH**, subarachnoid hemorrhage; **STA**, superficial temporal artery; **3-D**, 3-dimensional treatment strategy for MCA aneurysms is surgical clipping. The location of MCA aneurysms is relatively close to the brain surface and is accessible with limited brain retraction (10, 23, 37). The anatomic configuration of the aneurysm (i.e., a large dome-neck ratio and incorporation of major branches of the MCA into the aneurysm body and neck) is frequently unfavorable for endovascular coil embolization. There is a paucity of literature regarding endovascular occlusion of MCA aneurysms (2, 16). We report our experience regarding the endovascular management of MCA aneurysms, highlighting the technical complications and the immediate and long-term anatomic and clinical outcomes.

PATIENTS AND METHODS

Patient Demographics

This retrospective analysis includes 115 consecutive patients with MCA aneurysms who underwent an endovascular technique at the University of California, Los Angeles Medical Center from April 1990 to March 2007. Patients were referred to the Division of Interventional Neuroradiology from vascular neurosurgeons practicing at the University of California, Los Angeles Medical Center and from vascular neurosurgeons from the larger community, other states, and foreign countries.

A total of 1292 patients with 1397 aneurysms were treated during that period. One hundred fifteen patients (8.9%; mean age, 55.1 ± 14.2 years; 73 women [64.6%]) had 115 MCA aneurysms. Twelve of these patients (10.6%) were treated for multiple aneurysms.

Patient Clinical Presentations

Forty-eight patients (41.8%) presented with acutely ruptured aneurysms. The Hunt and Hess grades of the aneurysms were as follows: grade I in 14 patients (29.2%), grade II in 10 patients (20.8%), grade III in 13 patients (27.1%), grade IV in 9 patients (18.7%), and grade V in 2 patients (4.2%).

Unruptured MCA aneurysms were seen in 67 patients (58.2%). Mass effect was observed in 5 patients (4.3%), and a transient ischemic attack or focal seizure was reported in 3 patients. In 62 patients (53.9%), MCA aneurysms were incidentally found during the patient evaluations for other neurological symptoms.

The indications for endovascular treatment of the MCA aneurysms included anticipated surgical difficulty (e.g., a partially calcified aneurysm, dysplastic parent vessels, concurrent vasospasm, or any other medical conditions that could potentially limit surgical clipping) in 44 patients (38.2%), failed aneurysm clipping in 9 patients (7.8%), a poor neurological grade or medical condition in 29 patients (25.2%), and refusal of surgical treatment in 33 patients (28.7%).

Aneurysm Location and Configuration

To categorize the aneurysm location, we used the diagram of Rinne et al. (25) to classify aneurysms as proximal, bifurcation, and distal MCA aneurysms. Special attention was given to MCA bifurcation aneurysms. Bifurcation aneurysms were classified in 2 groups: on-bifurcation and off-bifurcation MCA aneurysms. On-bifurcation MCA aneurysms were those arising from the center of the MCA bifurcation. Off-bifurcation MCA aneurysms were those in which the aneurysm arose within 5 mm of either side of the MCA bifurcation. The anatomic configurations of MCA aneurysms were classified into 4 groups: small (≤10 mm) with a small neck (≤4 mm), small with a wide neck (>4 mm), large (11–25 mm), and giant (>25 mm).

Endovascular Coil Embolization and Adjunct Surgical Treatments

The endovascular coil embolizations were performed by teams of 2 interventional neuroradiologists in a neurointerventional angiography suite. All procedures were done with the patient under endotracheal general anesthesia. Most of the aneurysms were embolized with detachable coils until dense packing was achieved. In aneurysms with an artery incorporated in the neck, the aneurysm body and dome were occluded with coils, and a neck remnant was purposefully left to maintain patency of the parent artery. One patient with a wide-neck small aneurysm was treated with a balloon-assisted remodeling technique. None of the patients was treated with a stent-assisted technique.

Systemic heparinization was achieved with an intravenous bolus injection of 3000 to 5000 IU of heparin and then 1000 IU of intravenous injection every hour. For aneurysm protection in patients with acute SAH, heparinization was administered after deploying the first couple of coils. In patients treated longer than 1 week after the SAH and for unruptured aneurysms, heparin was given before the coil embolization. In patients with acute SAH, systemic anticoagulation was routinely reversed with protamine sulfate immediately after the procedure. For the patients in whom there was a potential risk of rebleeding immediately after the surgery, anticoagulation was delayed or not administered.

After coil embolization of unruptured aneurysms, patients were routinely admitted in the neurosurgical monitoring unit for 24 to 48 hours. All patients with an acute SAH were transferred to the neurosurgical intensive care unit, where their clinical status could be continually observed and their hemodynamic status and intracranial pressure could be closely monitored. Nimodipine was routinely administered to all patients. When appropriate, aggressive hypertensive, hypervolemic, and hemodilution therapy was used to treat arterial vasospasm. Endovascular pharmacological/mechanical treatment of symptomatic vasospasm was indicated in patients with severe arterial vasospasm that was unresponsive to hypertensive, hypervolemic, and hemodilution therapy.

Seven patients with an SAH and intracranial mass effect attributable to a hematoma underwent hematoma evacuation after coil embolization of the ruptured aneurysms. Four of the 7 patients had a poor-grade SAH. In these patients, coil embolization with medical stabilization was preceded by surgical evacuation of the hematoma. Three other patients underwent embolization for aneurysm protection and then hematoma evacuation and decompression. In 13 patients with giant aneurysms or fusiform aneurysms, superficial temporal artery (STA)-MCA bypass surgery was done, and then coil embolization was performed as a staged procedure.

Angiographic and Clinical Outcomes

Angiographic and clinical follow-up data were acquired from angiography films, digitized images, medical records from the University of California, Los Angeles Medical Center, referring physicians' reports, and follow-up telephone communications with patients or family members. A modified Rankin Scale (mRS) score was used to evaluate the clinical outcomes. An early clinical outcome was assessed when the patient was discharged or transferred to another medical facility. Midterm and long-term clinical outcomes were assessed by clinical visits or phone communications or during follow-up cerebral angiograms.

The mean length of hospital stay for patients with unruptured MCA aneurysms was 1.8 days (range, 1–3 days). Patients with acute ruptured

TABLE 1. Anatomic configurations in middle cerebral artery aneurysms (n = 115)		
Dome size	**Neck size**	**No. of aneurysms (%)**
Small (<10 mm)	Small (<4 mm)	53 (46.0)
Small (<10 mm)	Wide (>4 mm)	28 (24.4)
Large (11–25 mm)		22 (19.1)
Giant (>25 mm)		12 (10.5)

TABLE 2. Sites of middle cerebral artery aneurysms (n = 115)[a]	
Aneurysm projection, n (%)	**No. of aneurysms (%)**
M1 segment	8 (7.0)
Superior, 4 (3.5)	
Inferior, 4 (3.5)	
Center of MCA bifurcation	75 (65.2)
Superior, 10 (8.7)	
Lateral, 45 (39.1)	
Inferior, 20 (17.4)	
Off-center of MCA bifurcation	28 (24.3)
Arising superior division, 18 (15.6)	
Arising inferior division, 10 (8.7)	
M2/M3 segments	4 (3.5)

[a] MCA, middle cerebral artery.

aneurysms and complicated unruptured aneurysms were hospitalized for a mean of 15.5 days (range, 3–47 days). The mean interval of long-term outcomes was 15.5 months (range, 3–108 months).

Immediate angiographic findings were classified as complete occlusion, aneurysm neck remnant, and aneurysm body filling. Midterm and long-term follow-up angiograms were done between 3 months and 9 years in 70 patients (60.8%) at an average of 16 months. Multiple radiological projections were done to identify aneurysm recanalization. We used the classification system of Roy et al. (27) for the angiographic results. An aneurysm recanalization was defined as opacification of the aneurysm sac or increasing of the size of the residual neck. Data regarding periprocedural complications such as aneurysm rupture, angiographic vasospasm, and thromboembolic complications as well as head computed tomographic findings (Fisher classification) were collected for all patients.

RESULTS

Aneurysm Location and Anatomic Configuration

Fifty-three aneurysms (46.0%) were categorized as small aneurysms with a small neck, 28 (24.4%) as small aneurysms with a wide neck, 22 (19.1%) as large aneurysms, and 12 (10.5%) as giant aneurysms (Tables 1 and 2). Twelve aneurysms were fusiform (10.5%). Seventy-five aneurysms (65.2%) arose from the center of the MCA bifurcation. Twenty aneurysms projected inferiorly, 45 projected laterally, and 10 projected superiorly. Twenty-eight aneurysms (24.3%) were located slightly distal (off-center) to the center of the bifurcation. Eighteen aneurysms (15.6%) were located in the MCA superior division, and 10 (8.7%) were on the MCA inferior division. Four aneurysms (3.5%) arose from the distal M2 or M3 segment. Eight aneurysms (7.6%) were located in the M1 portion of the MCA proximal to its bifurcation. Four aneurysms projected superiorly and 4 projected inferiorly.

Immediate Angiographic Results/Anatomic Results

Complete aneurysm occlusion was achieved in 53 patients (46.1%). A small-neck remnant was observed in 51 aneurysms (44.3%) (Tables 3 and 4). Three aneurysms (2.9%) had incomplete occlusion, with contrast filling in the aneurysm dome and body. Coil embolization was attempted in 8 aneurysms (7.0%); of these, 1 had an incorporated branch arising from the body of the aneurysm. The other 7 of these 8 aneurysms were anatomically unsuitable for coil embolization. Of these 7, 5 aneurysms were subsequently treated with surgical clipping; the other 2 were not medically appropriate for surgical clipping (1 patient had end-stage cancer, and 1 had end-stage liver disease).

Table 3 shows the relation between the immediate anatomic results and the morphological characteristics of the MCA aneurysms. Small aneurysms with a small neck showed significantly higher rates of complete occlusion compared with small aneurysms with a wide neck, large aneurysms, and giant aneurysms ($P < 0.01$, χ^2 test). These results were not observed when evaluating the relation between the MCA aneurysm location and anatomic outcomes (Table 4).

Immediate Technical/Clinical Complications

Intraprocedural technical complications were observed in 10 patients (8.7%) (Table 5). Aneurysm rerupture was observed

TABLE 3. Immediate anatomic results in relation to the middle cerebral artery aneurysm configuration[a]

Aneurysm configuration	No. of aneurysms (%)	Complete (%)	Neck remnant (%)	Incomplete (%)	Failed attempt (%)
S/S	53 (46.1)	34 (29.6)	19 (16.5)	0	0
S/W	28 (24.3)	6 (5.2)	15 (13.0)	2 (1.7)	5 (4.4)
L	22 (19.1)	7 (6.0)	12 (10.4)	0	3 (2.6)
G	12 (10.5)	6 (5.2)	5 (4.4)	1 (0.9)	0
Total	115 (100)	53 (46.1)	51 (44.3)	3 (2.6)	8 (7.0)

[a] S/S, small aneurysm with small neck; S/W, small aneurysm with wide neck; L, large aneurysm; G, giant aneurysm.

TABLE 4. Immediate anatomic results in relation to the middle cerebral artery aneurysm location[a]

Aneurysm location	No. of aneurysms (%)	Complete (%)	Neck remnant (%)	Incomplete (%)	Failed attempt (%)
M1 segment	8 (7.0)	5 (4.4)	3 (2.6)	0	0
Center of MCA bifurcation	75 (65.2)	31 (26.9)	38 (33.0)	1 (0.9)	5 (4.4)
Off-center of MCA bifurcation	28 (24.3)	16 (13.9)	7 (6.1)	2 (1.7)	3 (2.6)
M2/M3 segments	4 (3.5)	1 (0.9)	3 (2.6)	0	0
Total	115 (100)	53 (46.1)	51 (44.3)	3 (2.6)	8 (7.0)

[a] MCA, middle cerebral artery.

TABLE 5. Technical complications of endovascular treatment in middle cerebral artery aneurysms (n = 115)

Technical complication	No. (%)
Total	10 (8.7)
Aneurysm perforation	1 (0.9)
Parent arterial thrombosis	4 (3.5)
Cerebral embolism	4 (3.5)
Coil herniation/migration	0 (0)
Arterial dissection	0 (0)
Femoral arterial thrombosis	1 (0.9)

during embolization of a patient with a Hunt and Hess grade IV SAH. The patient died at a long-term care facility as a result of infectious complications.

Four patients (3.5%) developed a parent artery thrombosis. One patient with Hunt and Hess grade IV SAH developed a clot in the base of the aneurysm at the end of the endovascular procedure. Intra-arterial urokinase 250 000 IU injection was administered, and partial recanalization was achieved without a hemorrhagic complication. Despite receiving intensive medical management, this patient died from severe vasospasm and infectious complications. Two patients with Hunt and Hess grade I SAH developed a parent artery thrombosis. Of these patients, 1 was successfully treated with an intra-arterial urokinase injection, and the other was successfully treated with intra-arterial abciximab (ReoPro; Eli Lilly and Co., Indianapolis, IN). The latter patient developed mild residual weakness with no limitations of his daily activity. One patient with a giant, partially thrombosed, and unruptured MCA aneurysm underwent an STA-MCA bypass and then coil embolization. The endovascular procedure was inadvertently complicated with a thrombus involving the left frontal operculum branch that caused a left frontal infarct. The patient has since recovered to the level of independent daily activity with mild expressive aphasia and trivial residual right hemiparesis.

Distal arterial embolization occurred in 4 patients (3.5%). One of these patients developed left hemiparesis with hemineglect the day after successful complete coil embolization of the aneurysm. A regimen of aspirin and clopidogrel (Plavix; Bristol-Myers Squibb/Sanofi Pharmaceuticals, New York, NY) was initiated, with mild neurological improvement. However, the neurological symptoms recurred because of hemorrhagic transformation of ischemic lesions. An emergent decompressive craniotomy and hematoma evacuation were performed. This patient had a long recovery with a residual mild neurological deficit and independent daily activity. One patient treated with intra-arterial urokinase 500 000 IU for a precentral/central distal branch occlusion had a residual minimal neurological deficit. One patient with a wide-neck small aneurysm required a balloon-assisted coil embolization. This procedure was complicated with a lateral lenticulostriate infarction, which was successfully treated with intra-arterial abciximab. The patient's neurological deficits improved remarkably, and the patient achieved independent daily activity. A clinically silent, distal posterior parietal branch occlusion was seen 1 patient. One patient had a common femoral arterial thrombosis requiring a mechanical thrombectomy.

STA-MCA Bypass and Endovascular Therapy

Combination therapy of STA-MCA bypass surgery followed by aneurysm endovascular embolization was performed in 13 patients (11.3%). Seven aneurysms were giant and fusiform, 4 were large or giant aneurysm with a wide neck, and 2 were M2/M3 junction fusiform mycotic ruptured aneurysms. The mean interval between bypass surgery and coil embolization was 1.4 days (range, 1–3 days). One patient with a Hunt and Hess grade I SAH underwent a partial coil embolization to protect the ruptured giant complex fusiform aneurysm before the bypass surgery. Subsequently, complete aneurysm embolization was achieved as staged procedures with dual bypass of the STA-MCA branches and a bypass of the occipital artery to the MCA branch (Fig. 1). Except for this patient and 2 patients with M2/M3 mycotic fusiform aneurysms, all of the patients had incidentally found unruptured aneurysms. One patient had the complication of a parent artery thrombosis during coil embolization, as described above. Figure 2 illustrates a case of combined treatment of STA-MCA bypass surgery and endovascular coil embolization.

Clinical Outcomes

Three patients died (2.6%). One patient with a Hunt and Hess grade IV SAH died of severe arterial vasospasm. One

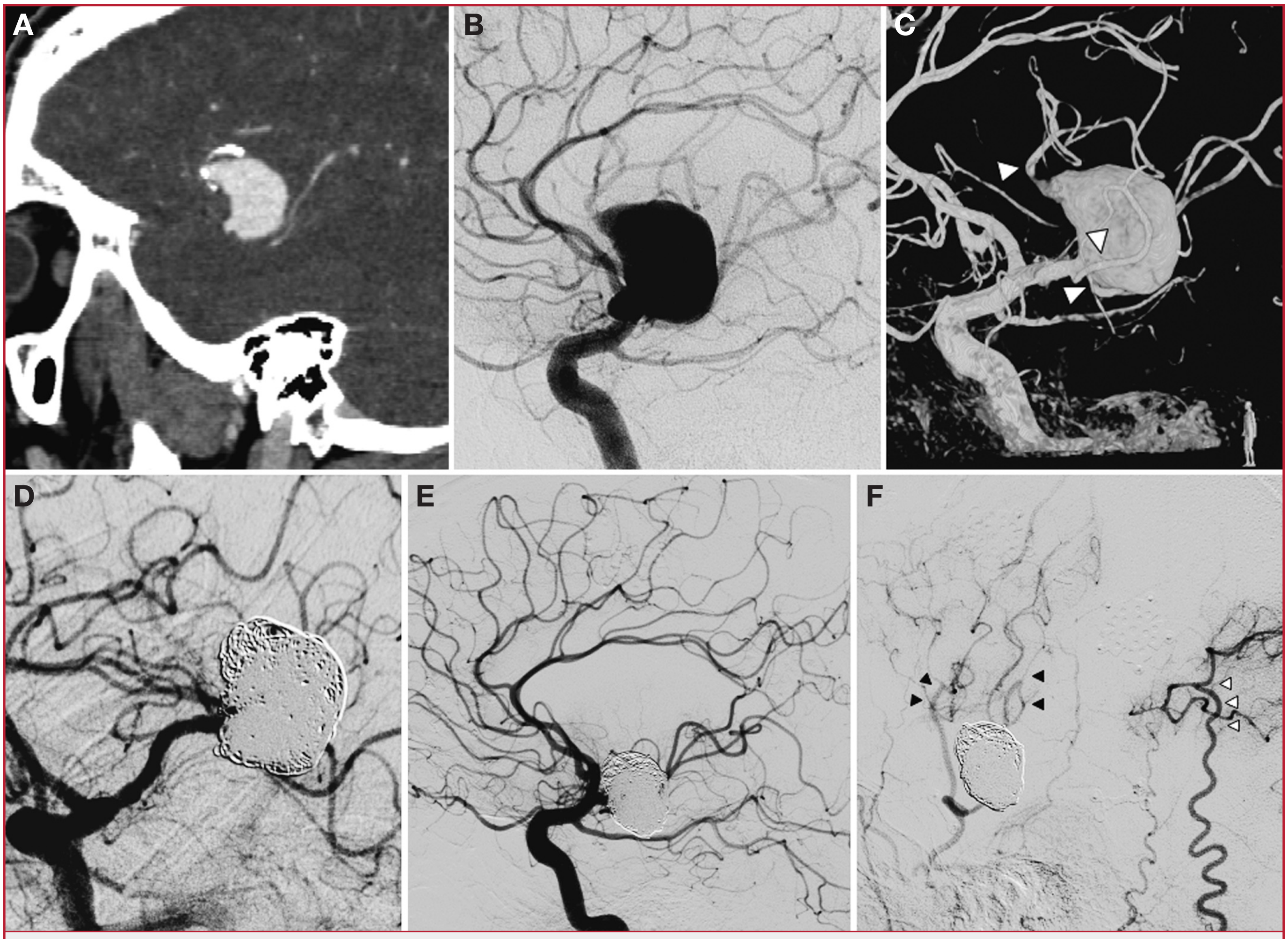

FIGURE 1. A, *computed tomographic angiogram showing a partially calcified and thrombosed giant aneurysm in the left temporal region.* **B**, *left internal carotid artery (ICA) cerebral angiogram (lateral view), showing the complex fusiform giant aneurysm at the M1/M2 junction.* **C**, *3-dimensional (3-D) cerebral angiogram revealing an incorporation of major branches of the middle cerebral artery (MCA) (arrowheads) at the neck and dome of the aneurysm.* **D** *and* **E**, *left ICA cerebral angiograms demonstrating successful staging coil embolization of the aneurysm after bypass operations of the superficial temporal artery (STA) to the MCA and the occipital artery to the MCA. The aneurysm was completely occluded.* **F**, *left external carotid artery angiogram (lateral view), showing patency of dual bypasses of the STA to the MCA branches (black arrowheads) and bypass of the occipital artery to the MCA branch (white arrowheads).*

patient with a Hunt and Hess grade IV SAH died of complicating infections at an outside facility. One patient died of an SAH that occurred as the result of a rupture of a recanalized aneurysm 13 months after embolization (Table 6).

Of 48 patients with acute SAHs, 28 (58.3%) showed no symptoms, no disability, or slight disability (mRS score ≤2, favorable outcome) at discharge. Nineteen patients (39.5% of the patients with an SAH) continued to have moderate or severe disability (mRS score ≥3); these patients had Hunt and Hess grade IV or V SAH.

Long-term clinical follow-up was obtained in 44 of 48 patients with an SAH. Thirty-three patients (68.8%) had a favorable clinical outcome. Three patients with a poor-grade SAH (Hunt and Hess grades IV or V) remained with severe disability or moderately severe disability (mRS score 4 or 5).

Sixty-seven patients had incidental MCA aneurysms. All but 2 patients remained clinically intact. These 2 patients had MCA thrombosis and distal embolic phenomena. At long-term follow-up, both patients demonstrated good functional recovery with an mRS score of 2.

One patient previously embolized for an incidental left MCA aneurysm developed a fatal SAH 13 months after embolization. A 12-month follow-up cerebral angiogram showed aneurysm recanalization with contrast filling of the body of the aneurysm. Unfortunately, the aneurysm ruptured 1 week before the scheduled second embolization.

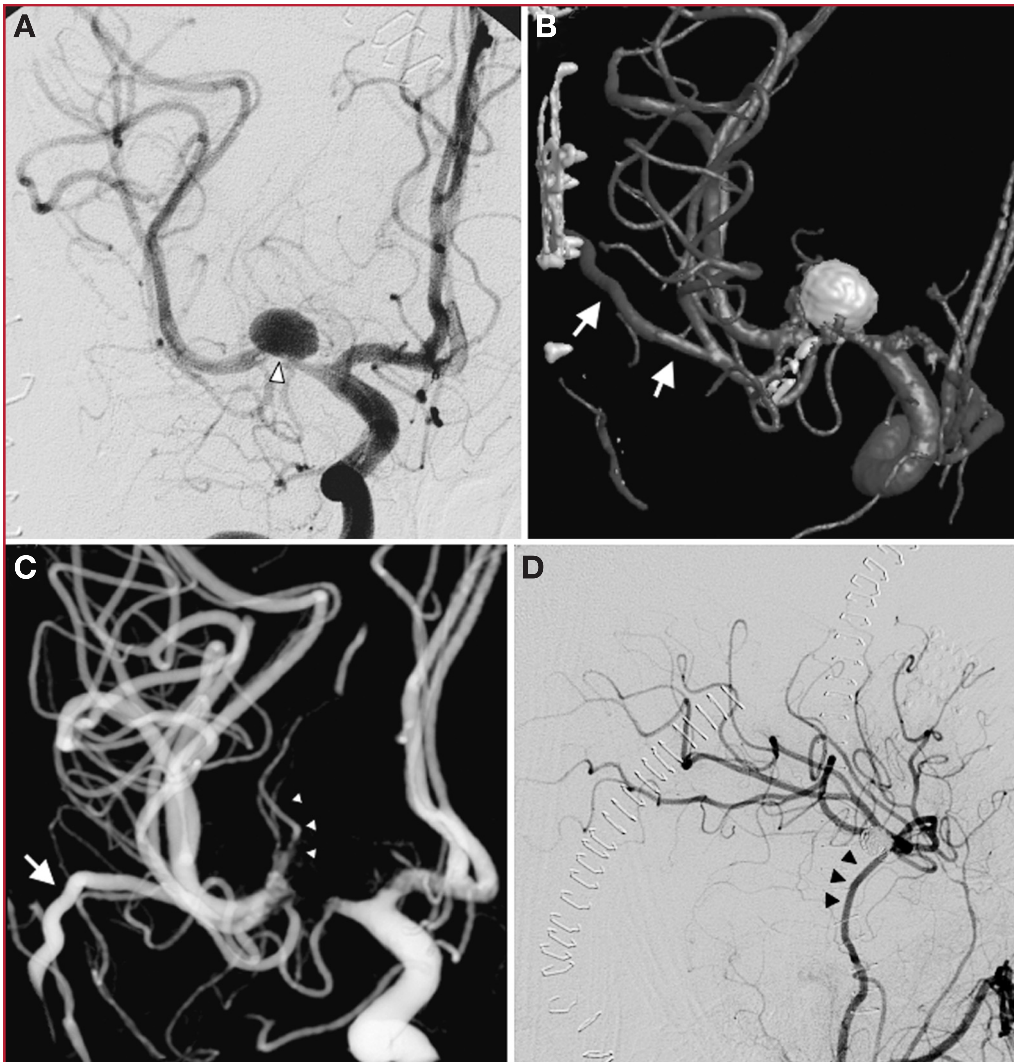

FIGURE 2. A, *right ICA cerebral angiogram (anteroposterior view), showing a previously treated unruptured fusiform aneurysm arising in the right mid-M1 segment. The stenosis is also noted at the base of the aneurysm (arrowhead).* **B**, *3-D angiogram of the right common carotid artery (CCA) injection demonstrating successful complete occlusion of the aneurysm and M1 segment after STA-MCA bypass (arrows).* **C**, *subtraction 3-D angiogram of the right CCA injection demonstrating occlusion of the right M1 segment without sacrificing the lenticular striate branches (arrowheads), and patency of the STA-MCA bypass (arrow).* **D**, *angiogram showing external carotid artery injection and the STA-MCA bypass (arrowheads) supplying the entire MCA branches.*

Late Angiographic Outcomes

Long-term angiographic follow-up was obtained in 70 patients (60.8%) at a mean interval of 16 months. The main reasons that patients were lost to follow-up were the patients' refusal to return and travel distance. Patients with a moderate or severe disability were especially difficult to accommodate for the follow-up angiogram. The follow-up angiograms of 7 patients (10% of the long-term follow-up angiograms) demonstrated recanalization of the treated aneurysm within 24 months of the primary procedure. Four of these 7 recanalizations occurred within 12 months of the primary procedure. Four of these patients underwent successful re-embolization. In 1 patient, there was enlargement of the distal M2 aneurysm with dome contrast filling 6 months after successful initial embolization. This patient's aneurysm was treated by trapping the parent M2 branch during STA-MCA surgery. One patient's angiogram showed an increasing remnant neck on the 3-month follow-up examination, but the subsequent follow-up angiogram showed a stable appearance. Therefore, re-embolization was not a treatment option for this patient. The last patient of these 7 was the patient with the ruptured recanalized aneurysm described above. Three patients (4.3%) demonstrated progressive aneurysm thromboses. In 60 patients (85.7%), the aneurysms remained angiographically unchanged. Of 7 recanalized aneurysms, 2 were ruptured with Hunt and Hess grade I SAH, and the remaining 5 were unruptured and incidentally found. All of the recanalized aneurysms were large or giant.

DISCUSSION

Endovascular coil embolization of intracranial aneurysms was introduced in the early 1990s (5, 6). During its initial use, the technique was primarily used to treat aneurysms in the posterior circulation, where surgical access is particularly technically challenging (35). Currently, the technique is widely accepted as a valid alternative to surgical clipping in the treatment of anterior circulation aneurysms (2, 18, 19, 21, 36).

MCA aneurysms are relatively common and account for approximately 20% of all aneurysms (8, 12, 13, 39). The clinical significance of a rupture of an MCA aneurysm may be greater than that of other aneurysms because of its close location to eloquent cortical arteries (32). Although surgical clipping of MCA aneurysms has been a well-established procedure, patients

TABLE 6. Clinical outcome in patients with middle cerebral artery aneurysms

Modified Rankin Scale score	Ruptured aneurysms (n = 48), n (%)		Unruptured aneurysms (n = 67), n (%)		Overall (n = 115), n (%)	
	Early outcomes	Long-term outcomes	Early outcomes	Long-term outcomes	Early outcomes	Long-term outcomes
Favorable outcomes	28 (58.3)	33 (68.8)	66 (98.5)	62 (92.5)	94 (81.7)	95 (82.6)
0, no symptom	1 (2.1)	5 (10.4)	51 (76.1)	52 (77.6)	52 (45.2)	57 (49.6)
1, no significant disability	5 (10.4)	21 (43.8)	13 (19.4)	8 (11.9)	18 (15.7)	29 (25.2)
2, slight disability	22 (45.8)	7 (14.6)	2 (3.0)	2 (3.0)	24 (20.8)	9 (7.8)
Moderate or severe disability	19 (39.6)	8 (16.7)	1 (1.5)	0 (0.0)	20 (17.4)	8 (6.9)
3, moderate disability	11 (22.9)	5 (10.4)	1 (1.5)	0 (0.0)	12 (10.4)	5 (4.3)
4, moderately severe disability	3 (6.3)	1 (2.1)	0 (0.0)	0 (0.0)	3 (2.6)	1 (0.9)
5, severe disability	5 (10.4)	2 (4.2)	0 (0.0)	0 (0.0)	5 (4.4)	2 (1.8)
Death						
6, death	1 (2.1)	2 (4.2)	0 (0.0)	1 (1.5)	1 (0.9)	3 (2.6)
Unknown	0	4 (8.3)	0	4 (6.0)	0	8 (6.9)

with MCA aneurysms have less-favorable outcomes compared with patients with aneurysms in other locations in the anterior circulation (32). The mortality rates and the frequencies of poor outcome/severe disabilities in patients with surgically treated MCA ruptured aneurysms are 4.2% to 12.9% and 6.5% to 10%, respectively (8, 25, 34). The morbidity and mortality rates for surgical treatment of unruptured MCA aneurysms are 3% and 0%, respectively (23, 38).

There is a paucity of articles regarding the results of endovascular treatment of MCA aneurysms (Table 7) (2, 10, 16, 23). Regli et al. (23) reported the treatment of 30 consecutive patients with 34 unruptured MCA aneurysms. Thirteen patients underwent endovascular embolization, and 21 patients underwent surgical clipping of their aneurysms. Most of the aneurysms (85%) were small; however, 11 of 13 aneurysms (32%) showed an unfavorable configuration for endovascular treatment, and these patients underwent clipping procedures along with the 21 surgically treated patients. Only 2 aneurysms (6%) were successfully treated with endovascular coiling. Two thromboembolic complications were reported in that series: 1 in an endovascularly treated patient and 1 in a surgically treated patient.

In a larger MCA aneurysm series, Iijima et al. (10) reported endovascular embolization in 154 ruptured or unruptured MCA berry aneurysms. The authors successfully occluded 149 of the aneurysms with detachable coils and attempted embolization in 5 aneurysms (3%). The majority of aneurysms were small (7 ± 3 mm), and no giant aneurysm was treated in this series. The authors excluded from their study group patients who required STA-MCA bypass surgery. They used a balloon-assisted technique to treat 66 aneurysms (44%). There were 27 procedure-related complications (18%): 20 patients (13%) had thromboembolic complications, and 7 patients (5%) had an aneurysm perforation, which was found on computed tomography after the procedure. Most of the patients had a good clinical outcome, with an mRS score of 3 or less, except for 3 patients who remained with severe disability. Ten deaths were reported: 9 patients with a ruptured aneurysm and 1 patient with an unruptured aneurysm. In that series, aneurysm recanalization was observed in 20 of 105 available follow-up angiograms (20%) at an average of 15 months after the procedure. One aneurysm reruptured between staging procedures in an acute phase of SAH.

Doerfler et al. (2) presented a series of 38 ruptured and unruptured MCA aneurysms in 36 patients. In 5 aneurysms (13%), coil embolization was not done because the aneurysm had a wide neck or because there was arterial incorporation in the body of the aneurysm, an insecure coil position, or vasospasm. These patients underwent surgical clipping instead. Eighteen percent of the aneurysms were large, most of the aneurysms were small, and no giant aneurysm was treated. Complications occurred in 6 patients (16%), but no aneurysm perforation was reported. The authors noted 3 instances of aneurysm recanalization at the 6-month angiographic follow-up examination.

A prospective evaluation of 26 endovascularly treated MCA aneurysms was reported by Lubicz et al. (16). The majority of the patients (76%) in that study had unruptured aneurysms, and patients with ruptured aneurysms presented with Hunt and Hess grade I or II SAH. Sixteen patients were treated with balloon-assisted coil embolization, and 2 were treated with a stent alone. Complete occlusion was achieved in 15 patients (57%). An aneurysm perforation and a thromboembolic complication were reported. All patients showed good clinical outcomes (mRS score ≤2). On 6-month follow-up angiograms, 6 recanalizations (24%) were seen, 1 of which required retreatment.

Compared with previous reports, our series includes data representing a greater variety of aneurysm sizes and especially more large and giant aneurysms. The proportion of the aneurysm sizes and anatomic configurations is similar to our reported series of 916 cerebral aneurysms treated with Guglielmi detachable coils (21). The series was conducted over an 11-year period and comprised 39% small aneurysms with a small neck, 29% small aneurysms with a wide neck, 22% large aneurysms, and 9% giant aneurysms. Regarding patients with an acute SAH, we treated more patients with a poor grade of SAH compared with other series (Table 7). The frequency for each grade in the current series is similar to that of the 916 treated cerebral aneurysms in the previous series: 30%, 20%, 27%, 17%, and 6% for grades I, II, III, IV, and V, respectively. These findings indicate that our series of MCA aneurysms were less likely to be biased by anatomic configuration or clinical presentation in grade of SAH during the selection for endovascular treatment.

We found statistically significant differences regarding the success rate of coil embolization when related to aneurysm configuration. However, we did not find such differences with regard to the location of aneurysms. This finding reinforces the concept that successful treatment of an intracranial aneurysm by endovascular coil embolization depends more on the morphology and size of the aneurysm and less on location of the aneurysm and the patient's clinical status (2, 4, 28, 35).

The present availability of 3-dimensional (3-D) rotational angiography and 3-D computed tomographic angiography permits an accurate anatomic assessment of MCA aneurysms. The precise delineation of the body and neck of the aneurysm and its relation with local normal vascular anatomy (such as MCA bifurcation and lenticulostriate arteries) provides a better selection of candidates for endovascular therapy versus surgical clipping along with a reduction in technical and clinical complications (Figs. 1–4). Three-dimensional rotational angiography is a powerful tool providing pivotal information not only to interventional neuroradiologists but to vascular neurosurgeons as well. We have used this technique since April 2003 and have treated 26 of the MCA aneurysms in this series since that time. We retrospectively compared the immediate complication rates of endovascular therapy for intracranial aneurysms between 2 groups: 1) before and 2) after the installation of 3-D rotational angiography (n = 1213). The overall complication rate was 5.9% in the pre–3-D group and 3.0% in the post–3-D group. Three-dimensional rotational angiography improves the safety of the procedure, which may be attributable to improved aneurysm analysis (and thus, patient selection), improved working position selection, or both (15). Advances in imaging techniques and development of new devices and institutional learning curves have contributed to a reduction in the rate of complications. In patients treated with coil embolization, there were 7 complications (12%) in 57 MCA aneurysms between 1990 and 2000, whereas there were 3 complications (5%) in 58 MCA aneurysms between 2000 and 2007.

At our institution, approximately 60% of patients with an MCA aneurysm underwent surgical clipping, and the remainder received endovascular therapy. We consistently used a team approach in making decisions both before and after the introduction of 3-D rotational angiography and other, newer technologies. We are confident that such a systematic approach and the implementation of new technologies at our institution have had a positive effect on the neurosurgical and endovascular management of MCA aneurysms and no negative effect on our surgeons' skills or their ability to treat patients. The overall mortality rate in this series was 3%, including death from severe vasospasm, severe systemic infection, and SAH from recanalized aneurysms. The morbidity rate (frequency of mRS score 3, 4, and 5) was 17.4% at hospital discharge and 6.9% on long-term clinical follow-up (mean, 16 months). On comparative analysis of ruptured versus unruptured aneurysms, the immediate morbidity rates were 39.6% and 1.5%, respectively. Ruptured MCA aneurysms showed a 16.7% long-term morbidity rate compared with a 0% morbidity rate observed in unruptured aneurysms. At discharge, mortality rates were 2.1% in patients with a ruptured aneurysm and 0% in patients with an unruptured aneurysm; on long-term clinical follow-up, these rates were 4.2% and 1.5%, respectively.

Our series shows a similar mortality rate but a higher morbidity rate, especially at discharge, compared with the published data. The inclusion of patients in poor Hunt and Hess grades of acute SAH is the most probable cause of these differences in morbidity. Although the mortality rate was as low as those reported in surgical procedures, many patients with a moderate or severe disability recovered to a more favorable clinical status. This clinical evolution emphasizes the importance of multidisciplinary management in patients with poor-grade SAH (33). In our study, patients with unruptured MCA aneurysms had a morbidity and mortality rate as low as 2%, which is lower than the rates reported in previous studies (3%–6%) of endovascular treatment of MCA aneurysms. The data regarding the surgical treatment of unruptured aneurysms also revealed low rates of morbidity (3%–4%) and mortality (1%) (14, 38).

However, the authors of a large prospective study, the International Study of Unruptured Intracranial Aneurysms (11), reported a combined morbidity and mortality rate 1 year after surgery of 15%, which decreased to 10% when cognitive impairment was excluded. That study included many MCA aneurysms (29%). The changes in cognitive function associated with surgical clipping of unruptured aneurysms might be related to the manipulation of adjacent brain tissue. This technical maneuver is not necessary when endovascular aneurysm coil embolization is used.

Local thromboembolic events related to MCA aneurysm embolization are reported to range from 6% to 28% (1, 2, 10). In our series, 8 patients (6%) developed thromboembolic complications. One patient died, 5 developed a mild neurological deficit, and 2 recovered completely. Cognard et al. (1) reported thromboembolic complications in 28% of the patients in their series. Seven percent of their patients developed permanent neurological deficits, which accounts for 52% of their entire thromboembolic complications. These results led the authors to be highly restrictive in choosing endovascular treatment for MCA aneurysms (1, 2). In our experience, the aneurysm configurations of the 8 patients with a thromboembolic complication included 4 small aneurysms with a small neck, 3 small aneurysms with a wide neck, and 1 giant fusiform aneurysm.

TABLE 7. Summary of endovascular treatment of middle cerebral artery aneurysms[a]

	Series (ref. no.)				
	Regli et al., 1999 (23)	Iijima et al., 2005 (10)	Doerfler et al., 2006 (2)	Lubicz et al., 2006 (16)	Suzuki et al., (present study)
Study period	7/1993–7/1997	2/1998–12/2002	"the last 5 years"	4/2004–4/2005	1990–3/2007
No. of patients (M/F)	30 (23/11)	142 (33/98)	36 (10/26)	25 (18/7)	113 (40/73)
Mean age (y)	45	48	51	53	55
No. of aneurysms	34	159	38	25	115
Size of aneurysms (mm)					
Small (≤10 mm)	29 (85%)	Mean, 7 ± 3	31 (82%)	Unknown	81 (70%)
Large (10–25 mm)	4 (12%)	Range, 2–16	7 (18%)	Unknown	22 (19%)
Giant (>25 mm)	1 (3%)	0	0	Unknown	12 (11%)
Clinical presentation					
Unruptured	34	77	18	19	67
Ruptured (acute SAH), H&H grade	0	72	18	6	48
I		22 (31%)	5 (28%)	4 (67%	14 (29%)
II		24 (33%)	7 (38%)	2 (33%)	10 (21%)
III		17 (24%)	5 (28%)	0 (0%)	13 (27%)
IV		5 (7%)	0 (0%)	0 (0%)	9 (19%
V		4 (6%)	1 (6%)	0 (0%)	2 (4%)
Treatment modality					
EVT	13 (attempted in 11)	149 (attempted in 5)	38 (attempted in 5)	26 (attempted in 1)	115 (attempted in 8)
Surgical clipping	21 + 11	0	5	1	5
STA-MCA bypass + EVT	0	0	0	0	13
Angiographic results					
Complete occlusion	2 (6%)	115 (75%)	25 (66%)	15 (57%)	53 (46%)
Near complete occlusion	0	29 (19%)	8 (21%)	8 (31%)	51 (44%)
Incomplete occlusion	0	5 (3%)	0	2 (8%)	3 (3%)
Attempt failed	11 (32%)	5 (3%)	5 (13%)	1 (4%)	8 (7%)
Overall outcome					
Morbidity	1 (3%)		2 (6%)	2 (8%)	
Ruptured		1 (1%)			8 (16.7%)
Unruptured		2 (3%)			0 (0%)
Mortality	0		0	0	
Ruptured		9 (12%)			2 (4%)
Unruptured		1 (1%)			1 (1%)
Complications of EVT					
Total	1 (3%)	27 (18%)	6 (16%)	2 (8%)	10 (9%)
Thromboembolic	1 (3%)	20 (13%)	5 (13%)	1 (4%)	8 (7%)
Aneurysm perforation	0	7 (5%)	0	1 (4%)	1 (1%)
Coil herniation	0	0	1 (3%)	0	0
Other	0	0	0	0	1 (1%), femoral A thrombosis

Continues

TABLE 7. Continued

	Series (ref. no.)				
	Regli et al., 1999 (23)	Iijima et al., 2005 (10)	Doerfler et al., 2006 (2)	Lubicz et al., 2006 (16)	Suzuki et al., (present study)
Clinical outcome (interval from EVT)	At unknown interval	At 3 mo	At 6 mo	At 1 mo 25 (100%)	At 16 mo
Good (mRS 0, 1, 2; GOS 5)				0	
Ruptured		Unknown	12 (71%)		33 (69%)
Unruptured	27 (90%)	Unknown	16 (94%)		62 (93%)
Moderate disability (mRS 3; GOS 4)				0	
Ruptured		Unknown	4 (24%)		5 (10%)
Unruptured	2 (7%)	Unknown	1 (6%)		0
Severe disability (mRS 4, 5; GOS 2, 3)				0	
Ruptured		1 (1%)	0		3 (6%)
Unruptured	1 (3%)	2 (3%)	0		0
Death (mRS 6; GOS 1)				0	
Ruptured		9 (12%)	1 (6%)		2 (4%)
Unruptured	0 (0)	1 (2%)	0		1 (2%)
Follow-up angiogram					
No. of aneurysms (%)	Unknown	105 (71%)	27	23 (92%)	70 (61%)
Mean interval (mo)	Unknown	15	6	6	16
Recanalization	Unknown	21 (20%)	3 (9%)	6 (24%)	7 (10%)
Reembolization	Unknown	12	0	1	3
Rebleeding	0	1 (5 d after EVT)	0	0	1 (13 mo after EVT)

[a] SAH, subarachnoid hemorrhage; H&H, Hunt and Hess; EVT, endovascular treatment; STA, superficial temporal artery; MCA, middle cerebral artery; mRS, modified Rankin Scale score; GOS, Glasgow Outcome Scale score.

Five of these were located in the center of the bifurcation, and the remaining 3 were off-center from the MCA bifurcation. Even a small and anatomically favorable MCA aneurysm for endovascular treatment could be a source of thromboembolism.

The use of 3-D rotational digital angiography has had a positive impact in decreasing any iatrogenic effects related to endovascular occlusion of MCA aneurysms. The majority of thromboembolic complications are mechanical in nature and are related to poor visualization of the location of the aneurysm in the MCA bifurcation and the incorporation of an MCA arterial branch in the neck or the body of the aneurysm. Mechanical impingement by coils in arteries as small as 2 mm in diameter can elicit a local thrombosis with distal cerebral embolization.

In a practical sense, appropriate routine, systemic heparinization and the improved coating of modern catheters/wires have decreased the damage to the endothelium produced during intravascular navigation. Premedication with an antiplatelet agent has been proposed for selected unruptured aneurysms (22, 26), but this is not routinely done for MCA aneurysms. Intra-arterial or intravenous injections of urokinase, recombinant tissue plasminogen activator, and, recently, abciximab have been judiciously used for intraprocedural thromboembolic complications (26).

The goal of aneurysm treatment should be permanent exclusion of the aneurysm from the circulatory system to prevent rupture or rerupture. Aneurysm recanalization must be acknowledged as a failure to achieve this goal, and aneurysm reembolization or surgical clipping should be done. We observed 6 cases of aneurysm recanalization on follow-up angiograms obtained at an average of 16 months after embolization. One of these ruptured before a second embolization could be attempted, causing the patient's death. All of the recanalized aneurysms were large or giant, and an aneurysm remnant was seen in all recanalized cases after the first embolization. Therefore, sequential follow-up angiograms are mandatory in those aneurysms showing incomplete coil occlusion (35). Because any additional procedure can cause complications, particular attention must be given to follow-up angiograms and retreatment of previously embolized aneurysms. In our MCA aneurysm series, no adverse events were shown on follow-up angiograms or occurred during retreatment with detachable

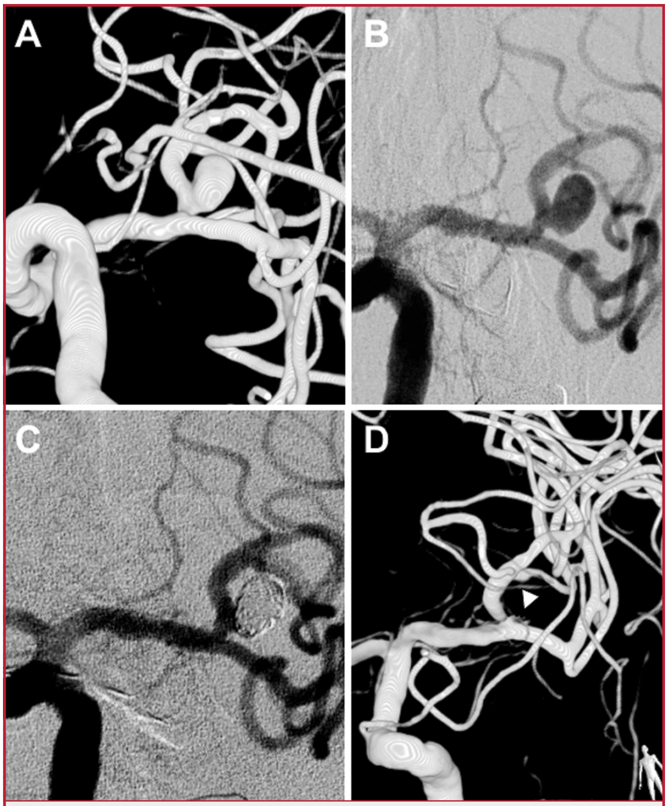

FIGURE 3. A, *left ICA 3-D cerebral angiogram providing a precise anatomic configuration of a small-neck MCA aneurysm and its relation with local vascular anatomy.* **B**, *optimal working projection obtained from the 3-D angiogram for the coil embolization of the MCA aneurysm.* **C**, *complete occlusion of the aneurysm dome and neck.* **D**, *left ICA subtraction 3-D cerebral angiogram demonstrating successful coil embolization with no apparent residual neck (arrowhead).*

coils. Recently, Renowden et al. (24) and Henkes et al. (7) reported complication rates of 2% to 3% in their large series of retreatment of previously embolized aneurysms. Follow-up procedures can be done safely, and the risk from retreatment with detachable coils does not negate the advantages of initial use of coil embolization.

Iijima et al. (10) statistically analyzed factors influencing MCA aneurysm recurrences after endovascular treatments. The statistically significant factors included large-size aneurysms, incomplete aneurysm occlusion after first embolization, and mode of clinical presentation with acute SAH. Our results support their conclusions.

In some cases, an unfavorable geometric configuration of the aneurysm precludes a successful embolization or even surgical clipping. We reported 8 cases of attempted coil embolization (6.9%). Successful surgical clipping was subsequently achieved in 5 of these aneurysms. All of these MCA aneurysms had a wide neck. Five were small, 2 were large, and 1 was giant. All were treated before the availability of the balloon-assisted neck remodeling technique (17, 20). Currently, the balloon-assisted remodeling technique and use of intracranial self-expandable stents have increased the number of wide-neck MCA aneurysms that can be safely treated with endovascular coil embolization (29). In our series, 1 patient with a wide-neck aneurysm was treated with a balloon remodeling technique. As part of a team approach to treating MCA aneurysms at our institution, when an MCA aneurysm has an unfavorable anatomic configuration and attempts at coil embolization fail, we consider clipping. If concomitant medical conditions prohibit a craniotomy, then a stent-assisted technique and/or a balloon remodeling technique is considered. We prioritized patients' safety when comparing endovascular coil embolization versus surgical clipping. At our institution, the vascular neurosurgery team has consistently performed surgical clipping of MCA aneurysms with low rates of morbidity and high rates of clinical success. We think that the stent- and balloon-assisted techniques are highly suitable for specific patients and represent viable options for difficult MCA aneurysms. However, during this study period, none of our patients was a candidate for the stent-assisted technique. Along with these sophisticated techniques, the latest, highly conformable, 3-D 360-degree coils as well as bioactive coils can be used to enhance the safety and effectiveness of endovascular treatment of complex MCA aneurysms.

FIGURE 4. *Right ICA cerebral angiogram of an unruptured aneurysm in a patient with polycystic disease. Three-dimensional image showing a wide-neck aneurysm harboring an MCA branch at its dome. Surgical clipping was considered for this aneurysm.*

We successfully treated 12 MCA giant aneurysms. Seven of these were fusiform aneurysms. All of the giant fusiform aneurysms were treated with a combined approach of STA-MCA bypass followed by endovascular embolization (details described above). The natural history of giant fusiform aneurysms shows an 80% morbidity and mortality rate on 5-year clinical follow-up. The therapeutic management of MCA giant aneurysms is challenging and requires a combined surgical-neurointerventional approach in most patients (31).

Drake and Peerless (3) reported their surgical treatment experience in 120 patients with giant fusiform aneurysms. The authors treated 13 giant fusiform MCA aneurysms with various techniques, including wrapping, arterial reconstruction, proximal occlusion, trapping, and excision with and without STA-MCA bypass. They reported a combined morbidity and mortality rate of 23% and excellent clinical outcomes in 62% of their patients.

Sekhar et al. (30) recently reported surgical vascular reconstruction of complex MCA aneurysms with excellent outcomes. These authors combined new techniques in the bypass graft procedure with advances in microsurgery, neuroprotection, and thrombosis control. Combined surgical and endovascular techniques to treat fusiform aneurysms have been reported as an alternative treatment strategy. Weill et al. (37) and Hoh et al. (9) reported successful treatment of MCA aneurysms using a combination of extracranial-intracranial bypass followed by proximal parent vessel occlusion with endovascular coiling. The advantages of this approach are that it alters the aneurysm hemodynamic flow and prevents aneurysm growth without sacrificing vital perforators and blood supply to the eloquent regions.

The limitation of this study is the variability of angiographic follow-up. Only 61% of the patients returned for follow-up, at an average of 16 months. The main reasons patients were lost to follow-up were their refusal to return and travel distance. Some patients had been referred to us from overseas, and others had been referred from other states. Further clinical and angiographic follow-up data for MCA aneurysms are needed for both endovascular coil embolization and surgical clipping.

CONCLUSIONS

Compared with conventional surgical clipping, endovascular therapy for MCA aneurysms is feasible and safe with comparable incidences of morbidity and mortality. Small aneurysms with small necks are favored for complete aneurysm occlusion. Wide-neck small aneurysms and large and giant aneurysms are challenging; however, 3-D coils, balloon-assisted technology, and stent placement improve anatomic and clinical outcomes.

MCA aneurysms vary in location and anatomic configuration. Three-dimensional rotational angiography provides pivotal anatomic data regarding aneurysm morphology and its relation with the MCA bifurcation and lenticulostriate arteries. This new technique allows for more precise aneurysm selection for surgical or endovascular approaches and therefore decreases iatrogenic complications. Combined extracranial-intracranial bypass surgery and endovascular aneurysm occlusion is a viable approach for treating giant and/or complex fusiform MCA aneurysms.

Thromboembolic events remain the most common complication in MCA aneurysm endovascular occlusion. With better selection of patients and the use of antiplatelet therapy before and after the procedure, this complication could be decreased.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

1. Cognard C, Weill A, Castaings L, Rey A, Moret J: Intracranial berry aneurysms: Angiographic and clinical results after endovascular treatment. **Radiology** 206:499–510, 1998.
2. Doerfler A, Wanke I, Goericke SL, Wiedemayer H, Engelhorn T, Gizewski ER, Stolke D, Forsting M: Endovascular treatment of middle cerebral artery aneurysms with electrolytically detachable coils. **AJNR Am J Neuroradiol** 27:513–520, 2006.
3. Drake CG, Peerless SJ: Giant fusiform intracranial aneurysms: Review of 120 patients treated surgically from 1965 to 1992. **J Neurosurg** 87:141–162, 1997.
4. Fernandez Zubillaga A, Guglielmi G, Viñuela F, Duckwiler GR: Endovascular occlusion of intracranial aneurysms with electrically detachable coils: Correlation of aneurysm neck size and treatment results. **AJNR Am J Neuroradiol** 15:815–820, 1994.
5. Guglielmi G, Viñuela F, Dion J, Duckwiler G: Electrothrombosis of saccular aneurysms via endovascular approach. Part 2: Preliminary clinical experience. **J Neurosurg** 75:8–14, 1991.
6. Guglielmi G, Viñuela F, Sepetka I, Macellari V: Electrothrombosis of saccular aneurysms via endovascular approach. Part 1: Electrochemical basis, technique, and experimental results. **J Neurosurg** 75:1–7, 1991.
7. Henkes H, Fischer S, Liebig T, Weber W, Reinartz J, Miloslavski E, Kühne D: Repeated endovascular coil occlusion in 350 of 2759 intracranial aneurysms: Safety and effectiveness aspects. **Neurosurgery** 58:224–232, 2006.
8. Heros RC, Fritsch MJ: Surgical management of middle cerebral artery aneurysms. **Neurosurgery** 48:780–786, 2001.
9. Hoh BL, Putman CM, Budzik RF, Carter BS, Ogilvy CS: Combined surgical and endovascular techniques of flow alteration to treat fusiform and complex wide-necked intracranial aneurysms that are unsuitable for clipping or coil embolization. **J Neurosurg** 95:24–35, 2001.
10. Iijima A, Piotin M, Mounayer C, Spelle L, Weill A, Moret J: Endovascular treatment with coils of 149 middle cerebral artery berry aneurysms. **Radiology** 237:611–619, 2005.
11. International Study of Unruptured Intracranial Aneurysms Investigators: Unruptured intracranial aneurysms—Risk of rupture and risks of surgical intervention. **N Engl J Med** 339:1725–1733, 1998.
12. Kassell NF, Torner JC, Haley EC Jr, Jane JA, Adams HP, Kongable GL: The International Cooperative Study on the Timing of Aneurysm Surgery. Part 1: Overall management results. **J Neurosurg** 73:18–36, 1990.
13. Kassell NF, Torner JC, Jane JA, Haley EC Jr, Adams HP: The International Cooperative Study on the Timing of Aneurysm Surgery. Part 2: Surgical results. **J Neurosurg** 73:37–47, 1990.
14. King JT Jr, Berlin JA, Flamm ES: Morbidity and mortality from elective surgery for asymptomatic, unruptured, intracranial aneurysms: A meta-analysis. **J Neurosurg** 81:837–842, 1994.
15. Loh Y, McArthur DL, Tateshima S, Jahan R, Duckwiler GR, Viñuela F: Safety of intracranial endovascular aneurysm therapy using 3-dimensional rotational angiography: A single-center experience. **Surg Neurol** 69:158–163, 2008.
16. Lubicz B, Graca J, Levivier M, Lefranc F, Dewitte O, Pirotte B, Brotchi J, Balériaux D: Endovascular treatment of middle cerebral artery aneurysms. **Neurocrit Care** 5:93–101, 2006.
17. Malek AM, Halbach VV, Phatouros CC, Lempert TE, Meyers PM, Dowd CF, Higashida RT: Balloon-assist technique for endovascular coil embolization of geometrically difficult intracranial aneurysms. **Neurosurgery** 46:1397–1407, 2000.
18. Malisch TW, Guglielmi G, Viñuela F, Duckwiler G, Gobin YP, Martin NA, Frazee JG: Intracranial aneurysms treated with the Guglielmi detachable coil: Midterm clinical results in a consecutive series of 100 patients. **J Neurosurg** 87:176–183, 1997.
19. Molyneux A, Kerr R, Stratton I, Sandercock P, Clarke M, Shrimpton J, Holman R: International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: A randomised trial. **Lancet** 360:1267–1274, 2002.
20. Moret J, Cognard C, Weill A, Castaings L, Rey A: Reconstruction technic in the treatment of wide-neck intracranial aneurysms. Long-term angiographic and clinical results. Apropos of 56 cases [in French]. **J Neuroradiol** 24:30–44, 1997.
21. Murayama Y, Nien YL, Duckwiler G, Gobin YP, Jahan R, Frazee J, Martin N, Viñuela F: Guglielmi detachable coil embolization of cerebral aneurysms: 11 years' experience. **J Neurosurg** 98:959–966, 2003.
22. Qureshi AI, Luft AR, Sharma M, Guterman LR, Hopkins LN: Prevention and treatment of thromboembolic and ischemic complications associated with endovascular procedures: Part II—Clinical aspects and recommendations. **Neurosurgery** 46:1360–1376, 2000.

23. Regli L, Uske A, de Tribolet N: Endovascular coil placement compared with surgical clipping for the treatment of unruptured middle cerebral artery aneurysms: A consecutive series. **J Neurosurg** 90:1025–1030, 1999.
24. Renowden SA, Koumellis P, Benes V, Mukonoweshuro W, Molyneux AJ, McConachie NS: Retreatment of previously embolized cerebral aneurysms: The risk of further coil embolization does not negate the advantage of the initial embolization. **AJNR Am J Neuroradiol** 29:1401–1404, 2008.
25. Rinne J, Hernesniemi J, Niskanen M, Vapalahti M: Analysis of 561 patients with 690 middle cerebral artery aneurysms: Anatomic and clinical features as correlated to management outcome. **Neurosurgery** 38:2–11, 1996.
26. Ross IB, Dhillon GS: Complications of endovascular treatment of cerebral aneurysms. **Surg Neurol** 64:12–19, 2005.
27. Roy D, Milot G, Raymond J: Endovascular treatment of unruptured aneurysms. **Stroke** 32:1998–2004, 2001.
28. Rüfenacht DA, Mandai S, Levrier O: Endovascular treatment of intracranial aneurysms. **AJNR Am J Neuroradiol** 17:1658–1660, 1996.
29. Sani S, Lopes DK: Treatment of a middle cerebral artery bifurcation aneurysm using a double Neuroform stent "Y" configuration and coil embolization: Technical case report. **Neurosurgery** 57:E209, 2005.
30. Sekhar LN, Stimac D, Bakir A, Rak R: Reconstruction options for complex middle cerebral artery aneurysms. **Neurosurgery** 56 [Suppl 1]:66–74, 2005.
31. Steinberg GK, Drake CG, Peerless SJ: Deliberate basilar or vertebral artery occlusion in the treatment of intracranial aneurysms. Immediate results and long-term outcome in 201 patients. **J Neurosurg** 79:161–173, 1993.
32. Stoodley MA, Macdonald RL, Weir BK: Surgical treatment of middle cerebral artery aneurysms. **Neurosurg Clin N Am** 9:823–834, 1998.
33. Suzuki S, Jahan R, Duckwiler GR, Frazee J, Martin N, Viñuela F: Contribution of endovascular therapy to the management of poor-grade aneurysmal subarachnoid hemorrhage: Clinical and angiographic outcomes. **J Neurosurg** 105:664–670, 2006.
34. Suzuki J, Yoshimoto T, Kayama T: Surgical treatment of middle cerebral artery aneurysms. **J Neurosurg** 61:17–23, 1984.
35. Tateshima S, Murayama Y, Gobin YP, Duckwiler GR, Guglielmi G, Viñuela F: Endovascular treatment of basilar tip aneurysms using Guglielmi detachable coils: Anatomic and clinical outcomes in 73 patients from a single institution. **Neurosurgery** 47:1332–1342, 2000.
36. Viñuela F, Duckwiler G, Mawad M: Guglielmi detachable coil embolization of acute intracranial aneurysm: Perioperative anatomical and clinical outcome in 403 patients. **J Neurosurg** 86:475–482, 1997.
37. Weill A, Cognard C, Levy D, Robert G, Moret J: Giant aneurysms of the middle cerebral artery trifurcation treated with extracranial-intracranial arterial bypass and endovascular occlusion. Report of two cases. **J Neurosurg** 89:474–478, 1998.
38. Yasui N, Nishimura H: Surgical treatment of unruptured intracranial aneurysms over the past 22 years. **Neurol Med Chir (Tokyo)** 44:155–163, 2004.
39. Zouaoui A, Sahel M, Marro B, Clemenceau S, Dargent N, Bitar A, Faillot T, Capelle L, Marsault C: Three-dimensional computed tomographic angiography in detection of cerebral aneurysms in acute subarachnoid hemorrhage. **Neurosurgery** 41:125–130, 1997.

COMMENTS

Suzuki et al. document a fairly large series of endovascularly treated middle cerebral artery (MCA) aneurysms. The patients were treated over a 17-year period between April 1990 and March 2007. During this period of time, there was a significant evolution in embolization technique, equipment, pharmaceuticals, and surgical/endovascular decision-making. Moreover, during this time span, surgical planning was affected by advances in medical care, some of which have improved the periprocedural care and rehabilitation of patients treated with aneurysm clipping. The success and complication rates described by the authors are admirable, and, overall, this is useful information that should be of value to all physicians treating cerebral aneurysms. Unfortunately, reports such as this one often raise more questions than they answer. One must wonder whether the authors are attempting to pat themselves on the back for doing such good work or if they believe that they are providing genuinely useful information and just fail to realize how short of that mark they fall.

When it comes to treating cerebral aneurysms, especially unruptured cerebral aneurysms, the extent of what we do not know can be frightening. The patient with an asymptomatic, incidentally discovered aneurysm would like to know the risks. As physicians familiar with cerebral aneurysms, we may be able to give the patient a general answer regarding the risk of rupture or of symptomatic mass effect based on the size and location of the aneurysm, but there are often significant confounding variables. For example, how, exactly, is the risk of rupture affected by the orientation of the aneurysm relative to the parent vessel, by the presence of lobulations or "daughter" aneurysms, by the size of the neck of the aneurysm or its length or fundal diameter (or some combination of these), or by the patient's own medical comorbidities? We raise these questions because the authors fail to provide any information that might help to answer them. The authors emphasize that, at their institution, they use a team approach in deciding how to treat cerebral aneurysms, yet they provide almost no indication of how the team arrives at its decision. Even relative to the 115 MCA aneurysms treated with endovascular techniques, they provide almost no details of the treatments that would help other operators faced with similar patients. In addition, the authors state that, at their institution, "approximately 60% of patients with an MCA aneurysm underwent surgical clipping," but they provide us with no insight as to how the decision of whether (or not) to operate was made.

In the introduction to the article, the authors make a casual reference to the International Subarachnoid Aneurysm Trial (ISAT) (2), stating that "a better clinical outcome was observed in patients who underwent endovascular coiling." However, they fail to describe how this somewhat misleading reference to ISAT was relevant to their own patient population. For example, ISAT's primary inclusion criterion was patients with ruptured aneurysms who were determined to be equally suited for either endovascular coiling or neurosurgical clipping. Most of the patients evaluated during the ISAT were not determined to be equally suitable for both treatment options and, therefore, they were not randomized. Also, most of the patients randomized into the trial had what would be considered good-grade, small, anterior circulation aneurysms. The ISAT did find that, in patients equally suited for both treatment options, those patients who underwent endovascular coiling did do significantly better than those who underwent surgical clipping at 12 months (additional follow-up indicated that the improved outcomes persisted at least 7 years) (1, 2). The authors of the current article do not describe any subset of their own patients that would have met the ISAT inclusion criterion. They also fail to provide any data to indicate that the outcomes noted in their patients would extend the treatment indications suggested by the ISAT outcomes.

It is not unique to this article that the question of the need for long-term follow-up of patients treated with endovascular coiling is not addressed in a meaningful way. The authors state that "sequential follow-up angiograms are mandatory in those aneurysms showing incomplete coil occlusion," yet their "long-term" follow-up averaged only 16 months. Campi et al. (1) reported on the extended follow-up of some patients treated in the ISAT and noted that late retreatment was much more likely in the patients treated with endovascular coiling. What constitutes adequate follow-up of a coiled aneurysm remains unclear.

In the final paragraph of the Conclusions, the authors contend that, with "better selection of patients and the use of antiplatelet therapy before and after the procedure," the risk of thromboembolic events during aneurysm coiling "could be decreased," without providing any data or references to indicate that this is true. Some readers could interpret this statement as an endorsement of the use of antiplatelet agents during all aneurysm coiling procedures. In fact, without the benefit of additional study, it might be equally accurate to say that the use of periprocedural antiplatelet therapy could worsen outcomes by resulting in an increased incidence of hemorrhage.

The above comments are not meant to be criticisms of the authors or of their work. Rather, they are meant to highlight some of the limitations of our understanding of cerebral aneurysms and how carelessly worded statements could potentially be misinterpreted.

Charles A. Guidot
L. Nelson Hopkins
Buffalo, New York

1. Campi A, Ramzi N, Molyneux AJ, Summers PE, Kerr RS, Sneade M, Yarnold JA, Rischmiller J, Byrne JV: Retreatment of ruptured cerebral aneurysms in patients randomized by coiling or clipping in the International Subarachnoid Aneurysm Trial (ISAT). **Stroke** 38:1538–1544, 2007.
2. Molyneux A, Kerr R, Stratton I, Sandercock P, Clarke M, Shrimpton J, Holman R: International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: A randomised trial. **Lancet** 360:1267–1274, 2002.

The authors report on 115 MCA aneurysms in 115 patients. Certainly, this study reinforces current thinking regarding this lesion, in particular that the majority of these aneurysms should be treated microsurgically, because the current endovascular technology is not quite "there" yet.

As would be expected on the basis of other publications, the best results were in small aneurysms with small necks, and the authors did treat a fair number in this category. However, this is what is problematic in their report: I think reinforces the fact that, particularly in young patients, microsurgical management should be undertaken. Fifty-three aneurysms, or 46%, were small and small-necked. That said, complete occlusion could be achieved in only 46% of the aneurysms; there was a neck remnant in 44% and incomplete occlusion in 3%. The authors had a 7% crossover rate in patients whom they attempted to treat by endovascular means but who required microsurgical repair. Certainly, in patients who present in poor neurological grade, or who have extreme medical comorbidities precluding a transcranial procedure, this is an option. However, in younger patients and in good-grade patients, the incomplete occlusion achieved by this group, which has a tremendous amount of experience, highlights the fact that, in most centers, microsurgery should be strongly considered for aneurysms on the middle cerebral tree.

Newer technology and newer stent technology certainly will increase the number of lesions that can be tackled endovascularly and will increase the degree of complete occlusion. The authors have provided an honest and comprehensive review of their experience.

Robert H. Rosenwasser
Philadelphia, Pennsylvania

This experienced endovascular group describes their large series of MCA aneurysms that were addressed through coil embolization. This study reinforces the argument that these aneurysms can be addressed safely through endovascular means. Nonetheless, these aneurysms often require adjunctive techniques such as balloon remodeling and stent-supported embolization. In complex cases that are not amenable to clip ligation, such techniques are often warranted. The relatively low rate of complications documented in this study further reinforces the option of endovascular treatment of MCA aneurysms.

Felipe C. Albuquerque
Phoenix, Arizona

At many centers where both ruptured and unruptured cerebral aneurysms are managed, aneurysms of the MCA are treated with microneurosurgical clipping. Aneurysms of the MCA often involve bifurcating/branching vessels and have wide necks. This complex anatomy lends itself to surgical clip reconstruction. The authors present 115 consecutive patients who underwent endovascular treatment of their MCA aneurysms because they had poor–Hunt and Hess grade subarachnoid hemorrhages, were deemed poor surgical candidates (because of aneurysm morphology or medical condition), failed clipping, or requested endovascular treatment. Unfortunately, only 60.8% of the patients had angiographic follow-up, which limits what can be extrapolated from this cohort.

The patients that had follow-up studies, including those with large and giant aneurysms, demonstrated good outcomes. Additionally, 7 patients presented with hematomas and underwent coil "stabilization" followed by surgical evacuation of the hematoma. This has been a topic of discussion among endovascular surgeons and cerebrovascular surgeons, and it is an area that requires further investigation. The current techniques of coil embolization using both balloon remodeling and stent assistance may ultimately be an acceptable method of managing patients with aneurysms in this location, but as with aneurysms in other locations, the outcomes for endovascular treatment must approach what can be achieved by open microsurgical clipping before this technique can be considered a primary treatment strategy. As with all aneurysms, there are often multiple treatment options that can be considered, depending on the clinical situation. The best strategy remains to evaluate aneurysms on an individual basis and to discuss treatment alternatives, including combined surgical and endovascular options, with the patients and their families.

Howard A. Riina
New York, New York