AJNR

MR angiography of saccular aneurysms after treatment with Guglielmi detachable coils: preliminary experience.

C P Derdeyn, V B Graves, P A Turski, A M Masaryk and C M Strother

AJNR Am J Neuroradiol 1997, 18 (2) 279-286
http://www.ajnr.org/content/18/2/279

MR Angiography of Saccular Aneurysms after Treatment with Guglielmi Detachable Coils: Preliminary Experience

Colin P. Derdeyn, Virgil B. Graves, Patrick A. Turski, Anthony M. Masaryk, and Charles M. Strother

PURPOSE: To review our experience using MR angiography to assess the cerebral vasculature after aneurysmal treatment with Guglielmi detachable coils (GDCs). **METHODS:** Forty three-dimensional time-of-flight MR angiographic studies were performed in 23 patients after endovascular aneurysmal therapy with GDCs. Digital subtraction angiographic (DSA) studies were evaluated retrospectively for the following findings: parent artery patency, branch vessel patency, residual flow within the aneurysm, and residual aneurysmal neck. The MR angiographic examinations were inspected for the same findings, as well as for the degree of signal loss surrounding the coil mass. Clinical histories were reviewed to determine the impact of MR angiographic findings on therapy. **RESULTS:** Patency status of the parent artery was correctly identified on 25 of 26 MR angiographic examinations with DSA confirmation. Thirty-four of 37 patent branch vessels were identified by MR angiography. Residual neck was correctly identified in seven studies of six aneurysms, with no false-negative or false-positive results. Intraaneurysmal flow was correctly identified in five of eight studies of six aneurysms with residual flow shown by DSA. Artifact and hemorrhage mimicked residual flow in two of 18 MR angiographic studies of aneurysms with no residual flow shown by DSA. In eight patients, MR angiography provided clinically useful information that affected therapy. **CONCLUSIONS:** MR angiography can identify flow within an aneurysm after treatment with GDCs as well as in the adjacent parent and branch vessels. This technique may be a useful adjunct to DSA in some clinical situations.

Index terms: Aneurysm, magnetic resonance; Interventional instruments, coils; Magnetic resonance angiography

AJNR Am J Neuroradiol 18:279–286, February 1997

The Guglielmi detachable coil (GDC) system (Target Therapeutics, Fremont, Calif) is an accepted method of endovascular treatment in selected patients with intracranial saccular aneurysms (1–5). The goal of this technique is to exclude the aneurysm from the circulation by filling it with platinum microcoils. Preliminary data suggest a durable result when the aneurysm is completely packed with coils (6) (H. C. Nahser, "GDC Treatment of Ruptured Aneurysms," and T. Malisch, "Intracranial Aneurysms Treated with GDC: Midterm Clinical Results in 100 Patients" both presented at the annual meeting of the American Society of Neuroradiology, June 1996).

The long-term occlusion rates of completely packed aneurysms have not yet been established. In some patients the aneurysm may recur, either because of coil compaction or because of regrowth of a residual aneurysmal neck. Moreover, some aneurysms cannot be completely packed with coils, and residual filling within the interstices of the coil mass or a residual aneurysmal neck is left after treatment. Subarachnoid hemorrhage has been observed in patients after subtotal GDC treatment (T. Malisch, paper presented at the annual meeting of the American Society of Neuroradiology, Seattle, Wash, June 1996).

Patients treated with GDCs are routinely studied after therapy with conventional digital subtraction angiography (DSA) in order to assess the durability of the initial treatment and to de-

Received May 8, 1996; accepted after revision August 20.

From the Department of Radiology, University of Wisconsin Hospitals and Clinics, Madison.

Address reprint requests to Colin P. Derdeyn, MD, Neuroradiology Section, Mallinckrodt Institute of Radiology, Washington University School of Medicine, 510 S Kingshighway Blvd, St Louis, MO 63110.

AJNR 18:279–286, Feb 1997 0195-6108/97/1801–0279

termine the need for further therapy. If residual aneurysm or aneurysmal regrowth is identified, retreatment is often considered. Arteriography is the most accurate means of assessing the need for further treatment. Furthermore, additional therapy can be pursued, if necessary, during the same procedure.

Similarly, arteriography is often required in acute management after treatment. In a patient with a new neurologic deficit after therapy, arteriography can assess the patency of parent and branch vessels and identify nonocclusive thrombus or vasospasm associated with subarachnoid hemorrhage. Many of these problems may also be treated endovascularly.

However, conventional arteriography is expensive, invasive, and carries some risk to the patient. A noninvasive technique such as magnetic resonance (MR) angiography may find a role as an adjunct to arteriography in some clinical situations, such as the long-term follow-up of treated patients or the initial appraisal of a patient with acute mental status changes in conjunction with an MR examination of the brain. If used for these purposes, MR angiography must be able to accurately define certain clinically important information, such as the patency of parent or branch vessels, the presence of an aneurysmal neck, or residual flow within the aneurysm.

The primary purpose of this study was to evaluate the ability of a standard clinical MR angiographic examination to reliably define the treated aneurysm and the circulation around it. A secondary aim was to review our early experience with MR angiography and to illustrate specific clinical situations in which MR angiography was a useful adjunct to conventional DSA.

Materials and Methods

From September 1993 through April 1996, 23 patients with 24 treated aneurysms had MR angiography in addition to routine arteriography at our institution. A total of 40 MR angiographic examinations were performed in these patients. Sixteen of the 23 patients were treated under the original trial of the GDC system conducted by the Food and Drug Administration (FDA), which required follow-up arteriograms at discharge and at 6 months. Follow-up MR examinations in these patients were obtained for clinical reasons, as were the initial MR examinations in the seven remaining patients not treated under the protocol. An MR angiographic examination was performed in addition to the routine parenchymal MR examination in all patients.

TABLE 1: Timing of 40 MR angiographic examinations relative to DSA studies

Timing of MR Angiography	No. of Studies
Within 10 days of postembolization DSA study	16
Outpatient; findings confirmed by subsequent DSA study (range, 1 day to 6 months between studies)	10
Outpatient follow-up, no subsequent DSA study	14

The timing of the MR angiographic study relative to conventional DSA is shown in Table 1. Sixteen MR angiographic examinations were obtained within 10 days of initial aneurysmal coiling. Ten additional studies were obtained 2 to 18 months after treatment and were confirmed by subsequent arteriography within 6 months. The remaining 14 examinations were done months to years after treatment and were not followed up with conventional arteriography. Only the MR angiographic studies performed within 10 days of DSA or subsequently confirmed by DSA were used in the comparison of the MR angiographic findings with the DSA findings (n = 26). These 26 confirmed MR angiographic studies were acquired for 24 treated aneurysms in 23 patients.

All patients were judged by referring neurosurgeons to be poor or inappropriate candidates for surgery because of their clinical condition or because of the location or anatomy of their aneurysms. Five aneurysms were less than 10 mm in diameter. One of these had been partially clipped. Eighteen were between 11 mm and 24 mm. One was greater than 25 mm in diameter.

Ten aneurysms originated from the posterior circulation: seven at the basilar tip, one at the origin of the superior cerebellar artery, one at the vertebral basilar junction arising at the base of a fenestration of the basilar artery, and one distal posterior cerebral aneurysm. All were greater than 10 mm in diameter, and all had wide necks (>5 mm), with the sole exception of the distal posterior cerebral artery aneurysm. Fourteen aneurysms originated from the anterior circulation: three from the cavernous internal carotid artery, two at the paraophthalmic segment of the internal carotid artery, three at the posterior communicating artery origin, one at the internal carotid artery bifurcation, two from the middle cerebral artery trunk, and three from the anterior cerebral artery.

The aneurysms were treated with coils of various diameters and lengths depending on the clinical situation, the size and anatomy of the aneurysm, and the condition of the parent artery. The FDA's GDC clinical trial protocol, covering 16 of the 23 patients in this study, required diagnostic arteriography at discharge and at 6 months. Similar arteriographic follow-up was obtained in the seven patients not treated under the FDA protocol. Conventional follow-up arteriography was performed via common femoral artery puncture and vertebral or common carotid artery catheterization with a 5F diagnostic catheter. A

1024 × 1024 matrix GE Advantx angiographic unit (General Electric Systems, Milwaukee, Wis) was used for all patients.

All MR angiographic examinations were done with a 1.5-T unit. Standard MR head imaging was performed with sagittal T1-weighted (500–600/13–20/1 [repetition time/echo time/excitations]) and axial proton density– and T2-weighted fast spin-echo (2500/30,90) sequences. The vascular MR imaging was performed with the Multisequence Vascular Package (GE Medical Systems) using three-dimensional time-of-flight (TOF) and two-dimensional phase-contrast angiography. Three patients had contrast-enhanced MR angiography.

The volume for 3-D TOF angiography was localized with a sagittal 2-D phase-contrast scout image with 30 cm/s maximum velocity encoding. A 3-D TOF spoiled gradient-recalled sequence was used. The 3-D TOF imaging was performed with parameters of 40–48/5.3–5.7/1, a 192 × 512 pixel matrix, a flip angle of 30°, and a 22 × 16-cm field of view. Approximately 40 axial images were generated. The entire volume was processed using a maximum-intensity-projection (MIP) technique. Subvolumes corresponding to each cerebral hemisphere and to the circle of Willis were also selected and rotated for display. Source images were filmed for review. Sagittal phase-contrast images were also generated.

All DSA studies were reviewed retrospectively by two neuroradiologists. The studies were evaluated for parent and branch vessel patency, residual flow within the interstices of the coil mass, and residual or recurrent aneurysmal neck. The presence or absence of these findings was determined by consensus of the reviewers and subsequently recorded. Patency of branch vessels was only assessed in those aneurysms whose origin involved or was in proximity to the origin of major branch vessels. For example, the patency of both superior cerebellar and posterior cerebral arteries was assessed for treated basilar tip aneurysms. Similarly, branch vessel patency was evaluated for aneurysms of the internal carotid artery bifurcation (two branches), the middle cerebral artery trifurcation (three branches), the anterior communicating artery (two branches), and the posterior communicating artery (one branch).

All MR angiographic examinations were evaluated by a neuroradiologist blind to the results of the posttreatment DSA examinations. Only the filmed MR angiographic examination was reviewed; the original MR angiographic data were not retrieved and reprocessed. The pretreatment DSA study was first reviewed for the location of the aneurysm and its relationship to branch vessels. The patency of branch and parent arteries was assessed using both the axial 3-D TOF source images and the MIP reconstructions and comparing these directly with the pretreatment DSA examination. The parent vessels were considered patent if some continuity of high signal was observed, even if contour irregularity or signal loss was present. Branch vessels with signal loss at the origin were considered patent if high signal was visible distal to the origin.

Residual flow within the aneurysm and the presence of an aneurysmal neck were assessed in a similar manner. Focal high signal within the coil mass or at the neck of the aneurysm beyond the expected confines of the parent vessel on axial source and MIP images was assumed to represent flow.

The degree of signal loss beyond the margins of the coil mass due to artifacts was judged subjectively by comparing the axial MR angiographic source images with the axial fast spin-echo T2-weighted images through the aneurysm. The fast spin-echo T2-weighted sequence was chosen for comparison because it should be least affected by susceptibility artifacts. These data were recorded and then compared with the DSA results.

The case histories of all patients were analyzed retrospectively. Situations were identified in which MR angiography was performed to answer a specific clinical question or in which the MR angiographic findings altered therapy. All 40 MR angiographic examinations of the 24 aneurysms in 23 patients were included in this portion of the study.

Results

Comparison of MR Angiographic Findings with DSA Findings

The data are summarized in Table 2. The parent artery was patent at DSA in 25 of the 26 paired DSA and MR angiographic examinations. One aneurysm of the petrous carotid artery required parent artery occlusion, which was accomplished with GDCs. MR angiography correctly identified the patency status of 24 of the 25 patent parent arteries. The one incorrect finding occurred with an aneurysm of the posterior cerebral artery arising in the region of the quadrigeminal plate. No definite distal flow was identified by MR angiography. This small artery was patent on the DSA examinations. MR angiography correctly detected no flow in the one aneurysm treated by parent artery occlusion.

A total of 37 branch vessels arising in proximity to the treated aneurysm were evaluated on the 26 MR angiographic examinations. None was occluded after GDC treatment. MR angiography correctly identified branch vessel patency in 34 of the 37 vessels. The most proximal portion of some of these vessels was not visible on the MR angiographic study, but distal flow could be identified. A patent posterior communicating artery was missed in one patient after treatment of an aneurysm of that vessel. The other two missed branch vessels were small superior cerebellar arteries associated with treated basilar tip aneurysms.

Residual flow within the interstices of the coil

TABLE 2: MR angiographic performance (26 DSA-confirmed MR angiographic studies in 24 treated aneurysms)

Finding	n	DSA		MR Angiography				Sensitivity, %*	Specificity, %*
		Present	Absent	TP	FP	TN	FN		
Parent artery flow	26	25	1	24	0	1	1	96 (7.5)	. . .
Branch artery flow	37	37	0	34	0	0	3	92 (8.7)	. . .
Residual flow in coils	26	8	18	5	2	16	2	71 (31.4)	89 (14.5)
Residual neck	26	7	19	7	0	19	0	100 (42.9)†	100 (15.8)†

Note.—TP indicates true positive; FP, false positive; TN, true negative; and FN, false negative.

* 95% confidence limits are shown in parentheses.

† 95% confidence limits for zero numerator values calculated by using the method of Hanley and Lippman-Hand (7).

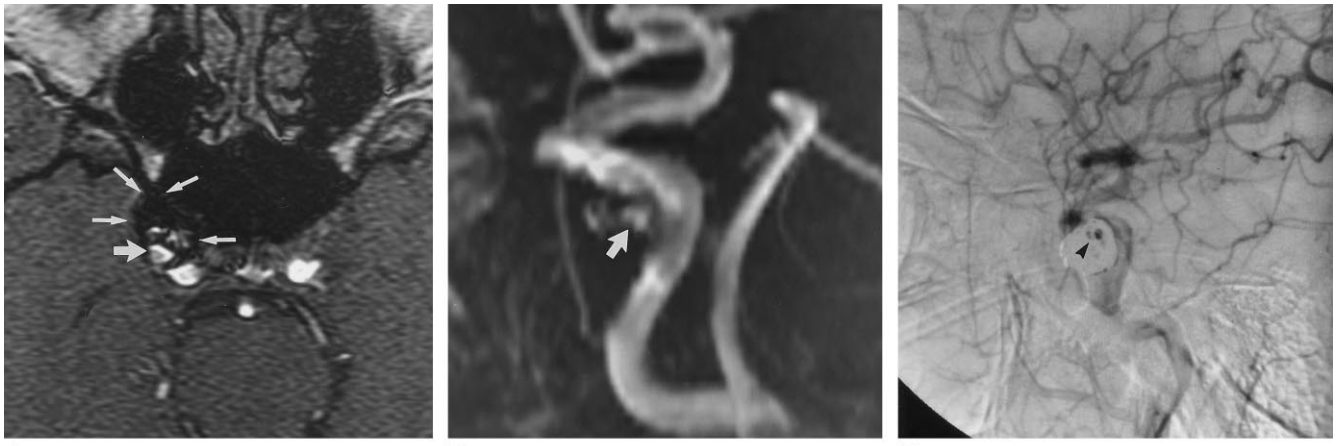

Fig 1. Persistent flow within the interstices of an intracavernous internal carotid artery aneurysm.

A and *B*, Axial 3-D TOF source MR angiogram (48/5.3/1) and targeted lateral MIP image, respectively, obtained 7 months after treatment. *Small arrows* in *A* indicate the edges of the coil mass. These images show high signal in the region of the treated aneurysm (*large arrows*) within the cavernous sinus and anterior to the internal carotid artery. This high signal was interpreted as flow within the aneurysm and correlated with DSA studies demonstrating persistent filling.

C, Lateral carotid projection of a late anterior phase DSA study obtained 1 month later shows the slow flow within the coil mass (*arrowhead*).

mass was present on DSA studies of six aneurysms. Eight MR angiographic examinations confirmed by DSA were performed in these six aneurysms. MR angiography correctly identified the residual flow in five examinations of five aneurysms (Fig 1). Two of these five aneurysms were studied twice. In both, the initial postprocedural MR angiographic examination missed the residual flow, while a subsequent MR angiographic study showed flow. In the sixth aneurysm, the initial MR angiographic study showed no residual flow, although the immediate posttreatment arteriogram as well as subsequent MR angiographic studies, not confirmed by DSA, showed flow within the interstices of the coil mass.

Of the 18 MR angiographic examinations performed in 18 aneurysms with angiographic evidence of complete occlusion, the blinded reviewer diagnosed persistent flow on MR angiograms in two. In these two examinations, artifact and hematoma, respectively, caused the high signal within the treated aneurysm that was mistaken for residual flow (Fig 2).

A residual neck was shown by DSA in six aneurysms. Identification of the residual neck by MR angiography was accomplished in all seven studies of the six aneurysms. One aneurysm was studied twice by MR angiography. In two of these aneurysms, the MR angiogram and the DSA study had identical appearances; however, it was not clear on either whether there was actually a residual neck. One patient with a history of cocaine use had caliber abnormalities of the parent artery on either side of the aneurysmal neck (Fig 3). The second patient had a complex middle cerebral artery aneurysm in which it was difficult to distinguish origins of branch vessels from possible residual aneurysm.

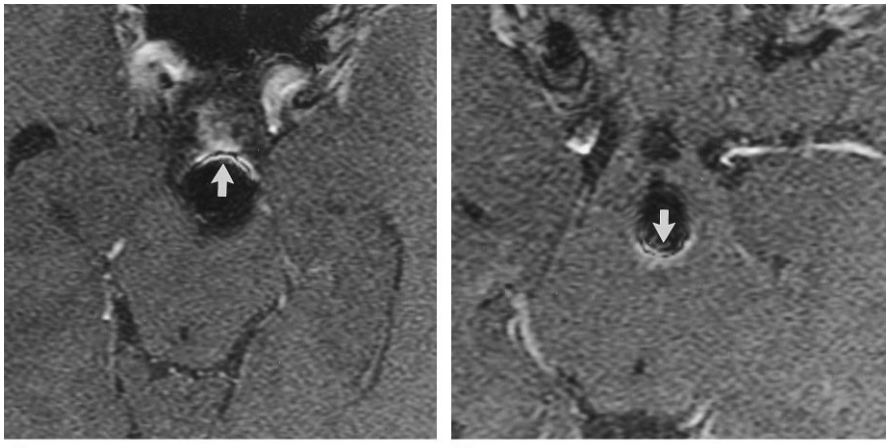

Fig 2. High-signal artifact displaced over coil mass.

A and *B*, Axial source images from a 3-D TOF MR angiogram (40/5.7/1) after complete packing of a basilar tip aneurysm. *A* is at the level of the interpeduncular cistern. A high-signal rim anterior to the coil mass is present (*arrow*) as well as high signal from the marrow in the clivus. *B* is several millimeters more cephalad than *A*. It shows the high-signal rim posterior to the treated aneurysm (*arrow*).

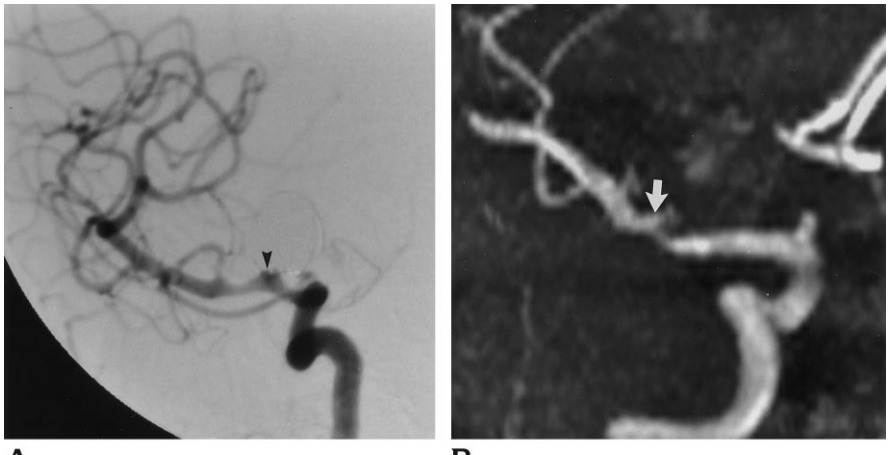

Fig 3. A 33-year-old man with a ruptured aneurysm of the middle cerebral artery. MR angiograms and DSA studies obtained 6 months after GDC treatment show nearly identical changes in caliber of the middle cerebral artery trunk and a possible residual neck.

A, Contralateral oblique anteroposterior projection of a right common carotid DSA study. The subtracted coil mass is visible, as is a small aneurysmal neck (*arrowhead*) and changes in caliber of the middle cerebral artery both proximally and distally.

B, 3-D TOF MR angiogram (40/5.3/1) targeted MIP reconstruction rotated to a similar degree as *A*. Similar findings of residual neck (*arrow*) and caliber changes in the parent artery are visible. These caliber changes may be related to the patient's prior drug use.

Signal Loss and Artifacts

No signal loss was subjectively identified beyond the expected margins of the treated aneurysm (Fig 4B). The ability of MR angiography to show flow in the parent and branch vessels and even within the aneurysm itself also demonstrates the relative lack of susceptibility effects of coils.

A thin rim of high-signal artifact was often encountered in the frequency-encoding direction, both anterior and posterior to the outer margins of the aneurysm (Fig 2). This only caused confusion as to residual aneurysmal flow in one MR angiographic examination.

Useful Clinical Information

MR angiography was used in two patients to answer specific clinical questions. One patient had mental status changes 48 hours after treatment of an unruptured aneurysm of the anterior communicating artery. An MR angiogram and MR image were quickly obtained and effectively excluded distal anterior cerebral artery ischemia or vascular occlusion (Fig 4). An MR angiogram was obtained in another patient to confirm parent vessel occlusion.

Two patients had relative contraindications to DSA owing to complicated migraine headaches induced by arteriography. One had become hemiparetic during a migraine attack subsequent to a prior study. In both patients, findings on MR angiograms 6 months after treatment were similar to those of the DSA study at 6 months. In both cases, MR angiography was used instead of DSA for the 1-year follow-up examinations. In two other patients with large complex basilar tip aneurysms requiring more

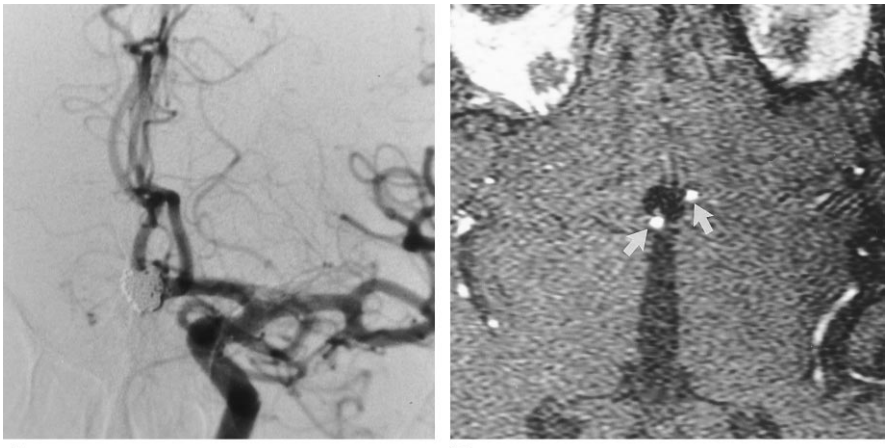

Fig 4. A 59-year-old man after treatment of an unruptured aneurysm of the anterior communicating artery.

A, Ipsilateral oblique anteroposterior projection after left common carotid artery injection. Both A2 segments fill normally and the aneurysm does not fill. The right A1 segment was hypoplastic. The patient became suddenly disoriented and confused 2 days after treatment. His neurologic examination was nonfocal. No signal abnormalities suggestive of ischemia were identified on proton density– or T2-weighted MR images. An MR angiogram showed good flow in both anterior cerebral arteries as well as flow across the preserved anterior communicating artery.

B, Three-dimensional TOF MR angiographic axial source image (40/5.3/1), acquired just above the level of the anterior communicating artery, shows flow in both A2 arteries (*arrows*) as well as signal loss within the treated aneurysm. The patient recovered quickly with no neurologic deficit.

than one treatment procedure, MR angiography was used for long-term follow-up beyond the first year.

MR angiography detected new recurrent aneurysm in two patients. In the first patient, MR angiography 24 months after treatment showed new filling at the base of a complex basilar tip aneurysm. Complete occlusion had been identified on DSA at 1-year follow-up. This information led to conventional arteriography and subsequent complete obliteration of the aneurysm (Fig 5). In the second patient, MR angiography 26 months after treatment detected new aneurysmal filling. Further intervention in this patient was attempted but was not feasible because of arterial access problems.

In two other patients treated early in our experience with GDCs, a small amount of residual filling was left at the base of two large basilar tip aneurysms. Follow-up MR angiography showed larger residual aneurysms. In both patients, the aneurysms were completely occluded with further coiling.

Neither of the two false-positive MR angiographic studies judged by the blinded reader as showing residual flow led to unnecessary intervention. The reader only had access to pretreatment DSA images and to the MR angiographic examination. When the scans were initially acquired and interpreted, knowledge of the complete MR examination and the postembolization DSA study showing complete occlusion of the aneurysm prevented this mistake (Fig 3).

Discussion

The treatment of intracranial saccular aneurysms with GDCs is still in its infancy. Much more knowledge regarding the durability of this therapy as well as the clinical importance of residual aneurysmal neck and flow within the interstices of the coil mass has yet to be gained (4, 5). As this information is accumulated, we will achieve a better understanding of the need for patients to undergo follow-up arteriography and retreatment.

DSA is the procedure of choice for the follow up of patients treated with GDCs for intracranial aneurysms. DSA clearly provides superior resolution of the vascular anatomy surrounding a treated aneurysm. In addition, further endovascular therapy can be pursued at the same time, if required.

A noninvasive technique such as MR angiography may find a role as an adjunct to DSA in some clinical situations. MR angiography may be able to identify flow within a treated aneurysm and within large surrounding branch vessels. The brain parenchyma can be imaged and assessed at the same time. Unlike surgical aneurysmal clips, the detachable platinum coils

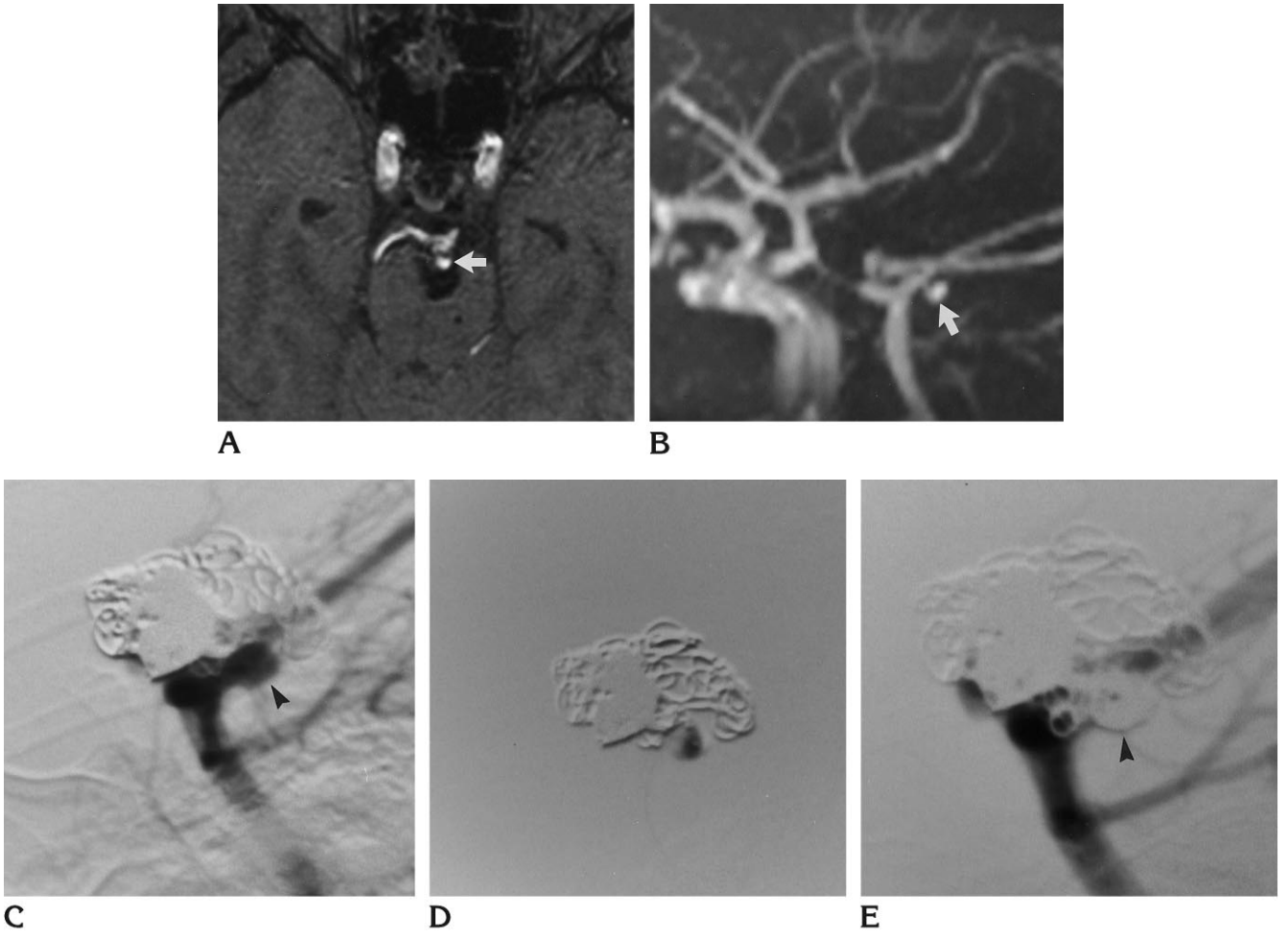

Fig 5. Complex basilar tip aneurysm, partially treated initially with a detachable balloon and fibered coils. More definitive treatment with GDCs was performed subsequently.

A and *B*, Axial 3-D TOF source MR angiogram (40/5.7/1) and targeted lateral MIP image, respectively, obtained 24 months later show new residual flow (*arrows*) at the base of the aneurysm posteriorly.

C–E, Conventional DSA study shows contrast material posterior and inferior to the coil mass (*arrowhead* in *C*) only on a lateral projection on the vertebral artery injection. The aneurysm was catheterized, and intraaneurysmal injection (*D*) confirmed the presence of this cavity, which was immediately packed with one 5-mm × 15-cm, two 3-mm × 15-cm, and one 2-mm × 8-cm Tracker-10 coils (*arrowhead* in *E*).

cause very little signal loss of the surrounding tissue.

Our early experience demonstrates that MR angiography can identify patency of parent and large branch vessels in nearly all studies. High signal seen on MR angiograms within the parent or branch vessel almost always represents flow. The signal loss due to the coil mass did not often obscure flow in adjacent vessels (Fig 4). Flow in smaller vessels, however, may sometimes be obscured. Three patent branch vessels and one patent parent vessel were thought to be occluded by MR angiography. All were relatively small vessels (two superior cerebellar arteries, one distal posterior cerebral artery, and one posterior communicating artery). MR angiography also provided an accurate map of the arterial anatomy, with good correlation between DSA and MR angiography on all seven studies showing a residual aneurysmal neck (Fig 3A and B).

High signal within the aneurysm is suggestive of residual flow within the interstices of the coil mass. However, hemorrhage and artifacts can mimic residual aneurysmal flow. This occurred with low frequency in our study (two of 18 MR angiographic examinations) and could be resolved by comparing the MR images with the posttreatment DSA studies.

On the other hand, MR angiography showed no flow within the aneurysm in three studies of

aneurysms with DSA evidence of residual filling. MR angiography correctly showed the absence of flow in 16 other examinations. The MR angiographic finding of no flow within an aneurysm, therefore, may not be reliable.

MR angiographic examinations yielded clinically useful information in several patients. This technique may serve as a reasonable proxy for conventional DSA in patients who cannot tolerate arteriography. In the acute clinical setting, it may complement a parenchymal MR examination by providing a quick and noninvasive assessment of the patency status of parent and large branch vessels (Fig 4). MR angiography may find a role in the long-term follow-up of patients beyond the first year after treatment.

One limitation of this study that may represent a source of error is the length of time separating MR angiography and DSA. For example, a minimal amount of slow flow within the coil mass may infrequently be seen on the immediate posttreatment angiogram and may not be present on follow-up arteriograms. This situation probably did not cause significant error in this analysis. In the three MR angiographic studies in which no residual flow was found, but was present on DSA, subsequent MR angiographic examinations revealed residual flow.

A second limitation of this study is the lack of postprocedural vascular complications. No thromboembolic complications and only one parent artery occlusion were observed in this series. This study, therefore, did not evaluate the ability of MR angiography to identify unsuspected parent or branch vessel occlusion or nonocclusive thrombus.

Although the quality of the MR angiographic examinations was very good, better results may be obtained by using shorter echo times and higher spatial resolution (G. Nicoli, "MR Angiography in the Follow-Up of Intracranial Aneurysms Treated by GDC," presented at the annual meeting of the American Society of Neuroradiology, June 1996). Contrast enhancement may improve the sensitivity to slow flow.

We cannot explain the high-signal artifacts in the frequency-encoding direction. The dipolar susceptibility artifact sometimes observed on gradient-echo images in microscopic B_0 field conditions associated with cavernous hemangiomas may be in part responsible (8). However, this artifact is typically a ring of high signal seen inside the signal void, not an ellipse of high signal outside the signal void and seen only in the frequency-encoding direction. No temporal differences in the appearance of the artifact were found among the studies reviewed, as one might expect if the artifact were related to accumulation of iron storage products.

In summary, MR angiography can identify a residual aneurysmal neck and the presence of flow in parent and branch vessels after treatment with GDCs. It can identify flow within a treated aneurysm, but with less accuracy. In addition, hemorrhage and artifacts may mimic flow. DSA remains the primary diagnostic tool for examining patients after GDC therapy. The role of MR angiography has yet to be defined; but for some clinical situations, such as those illustrated here, MR angiography may find a role as a useful adjunct to DSA.

References

1. Guglielmi G, Vinuela F, Sepetka I, Macellari V. Electrothrombosis of saccular aneurysms via endovascular approach, 1: electrochemical basis, technique, and experimental results. *J Neurosurg* 1991;75:1–7
2. Guglielmi G, Vinuela F, Dion J, Duckwiler G. Electrothrombosis of saccular aneurysms via endovascular approach, 2: preliminary clinical experience. *J Neurosurg* 1991;75:8–14
3. Guglielmi G, Vinuela F, Dion J, et al. Endovascular treatment of posterior circulation aneurysms by electrothrombosis using electrodetachable coils. *J Neurosurg* 1992;77:515–524
4. Richling B, Bavinzski G, Gross C, Gruber A, Killer M. Early clinical outcome of patients with ruptured cerebral aneurysms treated by endovascular (GDC) or microsurgical techniques: a single center experience. *Intervent Neuroradiol* 1995;1:19–27
5. Graves VB, Strother CM, Duff TA, Perl J. Early treatment of ruptured aneurysms with Guglielmi detachable coils: effect on subsequent rebleeding. *Neurosurgery* 1995;37:640–648
6. Mawad M, Mawad J, Cartwright J, Gokaslan Z. Long-term histopathologic changes in canine aneurysms embolized with Guglielmi detachable coils. *AJNR Am J Neuroradiol* 1995;16:7–13
7. Hanley JA, Lippman-Hand A. If nothing goes wrong, is everything all right? Interpreting zero numerators. *JAMA* 1983;1:1743–1745
8. Kim JK, Kucharczyk W, Henkelman RM. Cavernous hemangiomas: dipolar susceptibility artifacts at MR imaging. *Radiology* 1993;187:735–41