Intracranial Aneurysms Treated With Guglielmi Detachable Coils
Imaging Follow-Up With Contrast-Enhanced MR Angiography

Jean-Yves Gauvrit, MD; Xavier Leclerc, MD; Sabine Caron, MD; Christian A. Taschner, MD; Jean-Paul Lejeune, MD; Jean-Pierre Pruvo, MD

Background and Purpose—To compare the utility of contrast-enhanced MR Angiography (CE-MRA) with digital subtraction angiography (DSA) after endovascular treatment of intracranial aneurysms with Guglielmi detachable coils.

Methods—From April 1999 to August 2002, 106 patients with 107 aneurysms treated by endovascular coiling using Guglielmi detachable coils underwent simultaneous DSA and CE-MRA at follow-up (mean: 12.9 range: 5 to 27 months). DSA was performed as the standard reference. MR angiographic images were analyzed independently by 2 senior radiologists (J.-Y.G., S.C.) and DSA by a third radiologist (X.L.). Findings were assigned to 1 of 3 categories: complete obliteration (class 1), residual neck (class 2) and residual aneurysm (class 3).

Results—DSA at follow-up demonstrated 65 (60.6%) complete obliterations (group 1), 21 (19.7%) residual necks (group 2) and 21 (19.7%) residual aneurysms (group 3). One patient (0.9%) experienced aneurysm rebleed during the follow-up period. Among 101 assessable imaging comparisons, interobserver agreement was determined to be very good for CE-MRA (κ=0.96) with only 4 discrepancies between both examiners. Comparison between CE-MRA and DSA showed an excellent agreement between techniques (κ=0.93). Of the 21 with residual necks described on DSA, 20 were seen on CE-MRA. CE-MRA detected all 19 residual aneurysms.

Conclusion—CE-MRA after selective embolization of intracranial aneurysm is useful and comparable to DSA in the assessment of aneurysmal recanalization either as residual neck or aneurysmal sac. (Stroke. 2006;37:1033-1037.)

Key Words: endovascular therapy ■ intracranial aneurysm ■ MRA

Endovascular treatment of intracranial aneurysms is widely used in routine clinical practice and constitutes an excellent alternative to surgery.1–4 However, the outcome of patients treated with Guglielmi detachable coils (GDC) is poorly documented, and neck recurrence after endovascular treatment is not uncommon.

Follow-up imaging is recommended in order to identify potential aneurysmal re-growth and to assess the need for further treatment. Digital subtraction angiography (DSA) is usually performed and is considered the method of reference for aneurysm evaluation because of its inherent high spatial resolution. But this technique is invasive, limiting its use in clinical practice. Magnetic resonance angiography (MRA) using time-of-flight (TOF) sequences has been suggested as an alternative to conventional angiography.5–7 However, the relatively long scanning time and the presence of flow-related artifacts constitute a major limitation of this technique. Contrast-enhanced MRA (CE-MRA), reference technique for extracranial carotid disease, can be performed to image intracranial vessels and to follow-up aneurysms treated with GDC.8,9,10,11

The aim of this study was to perform follow-up imaging after treatment of intracranial aneurysms with GDC using CE-MRA and to assess this usefulness for the detection of aneurysm recanalization. Findings were compared with those DSA as the technique of reference.

Study Design
To evaluate the interest of CE-MRA in the detection of aneurysm recanalization, CE-MRA and DSA were carried after treatment.

Patients
From April 1999 to August 2002, 106 patients (56 female, 50 male; median age: 46 years; range: 14 to 71) harboring 107 coiled aneurysms treated by endovascular coiling with GDC underwent simultaneous DSA and CE-MRA at follow-up. A few patients were already included in another study.10 Among 106 patients, 89 admitted with a subarachnoid hemorrhage confirmed by brain CT scan. Aneurysms were located in the anterior circulation in 90 cases (anterior communicating artery [n=75], internal carotid artery [n=9], anterior cerebral artery [n=4], middle cerebral artery [n=2]) and in the posterior circulation in 17 cases (basilar artery [n=8],
inferior cerebellar artery \( [n=3] \), posterior cerebral artery \( [n=3] \), superior and middle cerebellar artery \( [n=3] \). Aneurysm size ranged from 2 to 18 mm (mean: 5 mm), and the ratio between the aneurysmal sac diameter and the neck was judged small in 85 cases (ratio <50%) and large in 22 (ratio >50%). In the group of ruptured aneurysms \( (n=89) \), the Hunt and Hess grade was I–II in 50 (57%), III in 19 (21%) and IV–V in 20 (22%).

Patients were referred to the neuroradiology department for endovascular treatment according to our protocol. All ruptured aneurysms were treated within 1 to 70 days (mean: 5.5 days) after subarachnoid hemorrhage.

**Endovascular Treatment**

Endovascular coil embolization with GDC was performed on a digital subtraction system (Integris V 3000; Philips Medical Systems). All patients were treated under general anesthesia. The technique of endovascular coiling with GDC has previously been described. The endovascular procedure was completed with immediate angiographic controls, including the working projection used during embolization. These immediate postinterventional DSA controls served as a reference for follow-up imaging.

**Follow-Up Imaging**

**DSA**

Angiograms included a selective injection of common or internal carotid or vertebral arteries with intracranial views (frontal, sagittal), corrected by additional views when necessary. No 3-dimensional (3D) rotational angiography has been performed. The DSA was performed within 6 to 26 months (mean: 12.8 months).

**CE-MRA**

CE-MRAs were performed on a Siemens 1.5 T system (Magnetom Vision; Siemens). All examinations were performed with a standard head coil. A CE-MRA FISP (fast imaging with steady-state precession) sequence with a rectilinear k-space sampling \( (6.8/2.3, \text{flip angle}=35^\circ, \text{field of view}=25 \times 150 \times 512) \) was acquired in the coronal plane. The acquisition time was 40 seconds. Thirty-seven percent zero-fill interpolation was performed in the section direction. The acquisition volume was placed on the sagittal scout image so that the volume included the cervical and intracranial carotid arteries, the A1 and A2 segments of the anterior cerebral arteries, the M1 and M2 segments of the middle cerebral arteries, the basilar artery and the initial segment of the posterior cerebral arteries. The antero-posterior diameter was 60 mm and the section thickness was 1.12 mm with 54 partitions. A bolus of 0.2 mmol/kg of gadolinium chelate \( (Gadodiamide Omniscan; Amersham Health SA) \) was injected at a rate of 2 mL/s using an MR-compatible power injector. The circulation time of contrast media from the antecubital vein to the carotid or vertebral arteries was estimated using a test bolus (2-dimensional turboflash sequence) before CE-MRA. Source images were then reconstructed by using a maximum intensity projection (MIP) algorithm. Multiple projections using a large field-of-view were obtained every 15° over 180° in lateral and antero-posterior views and provided 24 views on the whole.

CE-MRA was performed within 5 to 27 months (mean: 13 months). The time interval between CE-MRA and DSA was on average <5 days.

**Image Analysis**

Image quality of CE-MRAs was judged according to the following criteria: image contrast, artifact (coil, motion), vessel overlap and patency of intracranial arteries. Image contrast was graded as low when the signal intensity in the enhanced arterial lumen was only slightly higher than the signal intensity in the background, as moderate when the signal intensity was clearly higher, and as high when the signal intensity was optimal. Artifacts and vessel overlap were judged as minor when they did not prevent the interpretation of images and as major when they degraded the image quality.

Each aneurysm was assigned to 1 of 3 categories, as suggested by Raymond et al.13–15: class 1 = complete obliteration; class 2 = residual neck; class 3 = residual aneurysm. A recurrence was qualified as any increase in the size of the remnant or defined as a change of classification of the anatomic result. The recurrence was qualified as major if retreatment could theoretically be performed.

For the detection of aneurysm recanalization, DSAs were reviewed by 1 radiologist (X.L.), and MRAs were independently and blindly reviewed in a randomized fashion by 2 radiologists (J.-Y.G., S.C.) on hard copy in lateral and antero-posterior MIP views. Pretreatment DSA images were shown to orient the reviewers to the nature of aneurysm. One of 2 MR reviewers was independent of coilers. Cases that led to a disagreement between observers were reviewed by both readers to reach a consensus.

**Statistical Analysis**

The first step of the analysis consisted of an evaluation of the level of interobserver agreement for set of MR images by the means of the \( \kappa \) statistic. The second step consisted of a comparison between CE-MRAs and DSAs for the detection of a residual neck or aneurysm with the use of the same statistical test. \( \kappa \) values >0.6 suggested a substantial agreement, and values \(<0.8\) indicated an excellent agreement. \( P \) values \(<0.05\) were regarded as significant.

**Results**

**Patients**

One patient (0.9%) experienced aneurysm rebleeding at 15 days after endovascular treatment with aneurysm recurrence at conventional angiography, whereas the immediate control after embolization showed residual aneurysm. He retreated by surgical clipping.

**Imaging**

**DSA**

**Initial Results**

Immediately after embolization, 89 aneurysms (83.1%) were completely obliterated, 16 (15%) showed a residual neck and 2 (1.9%) presented a residual aneurysm related to technical difficulties (one 5-mm diameter aneurysm and one 12-mm diameter aneurysm).

**Follow-Up (Tables 1 and 2)**

All angiograms were interpretable. DSA follow-up showed 65 (60.6%) complete obliterations (group 1), 21 (19.7%) residual necks (group 2) and 21 (19.7%) residual aneurysms (group 3). Half aneurysms \( (n=11) \) in group 3 were considered

**TABLE 1. Angiographic Results**

<table>
<thead>
<tr>
<th>Class</th>
<th>Initial Result, n=107 (%)</th>
<th>Follow-Up, n=107 (%)</th>
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<tbody>
<tr>
<td>Class 1</td>
<td>89 (83.1)</td>
<td>65 (60.6)</td>
</tr>
<tr>
<td>Class 2</td>
<td>16 (15)</td>
<td>21 (19.7)</td>
</tr>
<tr>
<td>Class 3</td>
<td>2 (1.9)</td>
<td>21 (19.7)</td>
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**TABLE 2. Initial Angiographic Results and Recurrences**

<table>
<thead>
<tr>
<th></th>
<th>All Recurrences, n (%)</th>
<th>Major Recurrences, n (%)</th>
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</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>24/89 (27.0)</td>
<td>10/89 (11.2)</td>
</tr>
<tr>
<td>Class 2</td>
<td>8/16 (50.0)</td>
<td>4/16 (25.0)</td>
</tr>
<tr>
<td>Class 3</td>
<td>1/2 (50.0)</td>
<td>0/2 (0.0)</td>
</tr>
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</table>
as occluded immediately after embolization and evolved in
time course to residual aneurysm category. Recurrences were
found in a total of 33 (30.8%) of treated aneurysms comprising
19 (17.7%) judged as minor and 14 (13.1%) judged as
major. Among the 14 major recurrences, 9 were retreated by
neurosurgical treatment (n=6) and by endovascular proce-
dure (n=3), 5 were only followed-up because of stability or
moderate size increase (n=3), poor clinical status (n=1) or
treatment failure (n=1).

**CE-MRA**

**Image Quality**
The contrast of gadolinium-enhanced MR angiographic im-
ages was judged excellent or moderate in 105 cases and poor
in 2 cases. Visualization of vessels was not optimal and
prevented image interpretation in 6 cases because of the poor
image contrast in 2 cases, motion artifacts in 1 case and 3 cases
with surgical clip-related artifacts. Among the 3 last cases, 2
patients were treated with aneurysm clipping before their in-
clusion and 1 treated by surgery after an early rebleeding.

**Follow-Up**
Interobserver agreement was judged as very good and signif-
ificant for CE-MRA (κ=0.92, range 0.85 to 0.99). Four cases
were misclassified, with a residual neck for the first reviewer
and a complete occlusion for the second. In this case, an
additional reading by both examiners together was performed
to reach a consensus.

<table>
<thead>
<tr>
<th>DSA</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
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<tbody>
<tr>
<td>CE-MRA</td>
<td></td>
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<tr>
<td>Class 1</td>
<td>60</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Class 2</td>
<td>1</td>
<td>19</td>
<td>0</td>
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<tr>
<td>Class 3</td>
<td>0</td>
<td>1</td>
<td>19</td>
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</table>

**Figure 1.** A, DSA of the right internal carotid artery performed at
20 months after treatment of a 4-mm aneurysm of the anterior
communicating artery. The frontal head view shows a complete
obliteration (class 1; arrow) at the site of the anterior communi-
cating artery. B, CE-MRA with MIP reconstructions in the frontal
view demonstrates a complete obliteration (arrow) in agreement
with DSA findings.

**Figure 2.** A, DSA of the left internal carotid artery at 12 months
after treatment of a 4-mm aneurysm of the anterior communi-
cating artery. The frontal head view shows a residual neck of
2 mm-diameter (class 2; arrow). B, CE-MRA with axial MIP
reconstruction in the frontal plane demonstrates a residual neck
(class 2; arrow) in accordance with DSA.

Among 101 analyzable exams, CE-MRA follow-up showed
61 (60.4%) complete obliterations (group 1), 20 (19.8%)
residual necks (group 2) and 20 (19.8%) residual aneurysms
(group 3).

**Comparison DSA/CE-MRA (Table 3)**
Among 101 possible comparisons, CE-MRA and DSA
showed a good and significant agreement between techniques
(κ=0.94, range 0.88 to 1; Figures 1 through 4). Three cases
were misclassified. Two false-positive cases were described:
1 complete aneurysm occlusion at DSA was misclassified as
a residual neck at CE-MRA, and 1 residual neck at DSA was
misclassified because it was considered as residual aneurysm
at CE-MRA (Figure 5). One false negative occurred with
CE-MRA: 1 complete occlusion at CE-MRA was evaluated as
residual neck at DSA.

**Discussion**
Our study showed follow-up imaging after endovascular
treatment of intracranial aneurysms by CE-MRA is indicated
to detect aneurysm recurrence.

To our knowledge, few reports have addressed the role of
noninvasive techniques for the follow-up of coiled intracra-

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**TABLE 3. MR Angiography Findings as a Function of Conventional Angiography**

<table>
<thead>
<tr>
<th></th>
<th>DSA</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
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<tbody>
<tr>
<td>CE-MRA</td>
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<tr>
<td>Class 1</td>
<td>60</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Class 2</td>
<td>1</td>
<td>19</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Class 3</td>
<td>0</td>
<td>1</td>
<td>19</td>
<td></td>
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</table>

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**Figure 3.** A, DSA of the left internal carotid artery at 12 months
after treatment of a 3-mm aneurysm of the posterior communi-
cating artery. The lateral head view shows a recanalization
(arrow) classified as residual aneurysm (class 3), classified as a
minor recurrence. B, CE-MRA with MIP reconstruction in the lat-
eral plane demonstrates a residual aneurysm (class3; arrow) in
accordance with DSA findings. No retreatment was performed.
rysms, Derdeyn et al \cite{20} reported for the detection of residual artifacts because of coil packing. Among 26 treated aneurysms, most studies assessed the diagnostic potential of 3D TOF MRA sequences. The sensitivity of this technique for the detection and exclusion of a residual flow within the aneurysm ranged from 71% to 91% and from 89% to 100%, respectively. \cite{5,7,16–19} It provides good spatial resolution, an acceptable time and minimal signal loss caused by turbulent flow. However, in this trial of coiled aneurysm, its limitations are more pronounced. First, this technique is insensitive to a slow or complex flow and can interfere with the visualization of residual neck or aneurysm. This signal loss is attributable to the intravoxel dephasing and saturation effects. On the other hand, TOF MRA is more sensitive to susceptibility artifacts because of coil packing. Among 26 treated aneurysms, Derdeyn et al \cite{20} reported for the detection of residual flow in coils, 2 cases of false-negative and 2 cases of false-positive with 3D TOF MRA. This was explained by the presence of a slow flow within the aneurysm leading to a hypointensity misinterpreted as a complete occlusion and by a residual hemorrhage leading to a hyperintensity misinterpreted as a residual flow. In another study, \cite{18} among the 64 aneurysms occluded with GDC, 7 (11%) could not be analyzed by 3D TOF MRA because of coil-related artifacts.

Although CE-MRA has proven its effectiveness for the evaluation of supraaortic extracranial vessels, very few studies used this enhanced technique for imaging the circle of Willis. \cite{21} Metens et al \cite{22} evaluated this technique in 32 patients admitted with a suspected intracranial aneurysm and showed its high sensitivity and specificity (100% and 94%, respectively). Unlu et al \cite{23} studied recently CE-MRA for the identification of ruptured cerebral aneurysms by comparing this technique with TOF MRA and DSA. CE-MRA detected all 23 aneurysms except 1.

Nevertheless, CE-MRA sequences may especially have potential advantages for the follow-up of intracranial aneurysms. A previous study compared DSA and CE-MRA at 6 months and 1 year after treatment of aneurysms and showed a very good and significant agreement between the techniques. \cite{10} Only 1 case at 1 year was misclassified at CE-MRA as a residual neck, whereas DSA showed complete occlusion of the aneurysm. The study of Anzalone et al \cite{18} investigated few patients after treatment of aneurysms with CE-MRA and showed the advantage of contrast material injection in case of large aneurysms. Farb et al \cite{11} recently evaluated 2 MRA techniques, TOF MRA and CE-MRA for the surveillance of intracranial aneurysm. CE-MRA was optimized because it used an automatic triggering tool to ensure optimal synchronization of peak arterial with an elliptic-centric-ordered–scan. They concluded that CE-MRA provides a noninvasive, reliable, imaging method for the follow-up of coiled aneurysms.

CE-MRA may have potential advantages compared with the 3D TOF technique because the flow within an embolized aneurysm is complex. CE-MRA is less sensitive to flow turbulences and saturation effects than TOF sequences because of the high signal intensity within the arterial lumen caused by the T1-shortening effects. Contrast enhancement allows the imaging of low-flow signals. This theoretically allows for a higher conspicuity of a residual aneurysmal. Moreover, CE-MRA has demonstrated a relative insensitivity to coil-related artifacts that may potentially degrade image quality and hinder visualization of a residual neck. \cite{8} Furthermore, the imaging volume may be orientated in the frontal plane, which allows assessment of a large volume compared with TOF MRA. The principal disadvantage of CE-MRA is that venous opacification occurs at the same time as arterial enhancement because of the short time window between the arterial and the venous phase of contrast enhancement. This may lead to a major venous enhancement and degradation of image quality, which could prevent accurate delineation of the residual aneurysmal sac. For each examination in our series, the circulation time was calculated in order to minimize the risk of venous contamination. Some authors recommend the use of an elliptical-centric k-space sampling with automatic synchronization to improve background suppression and negligible venous overlap. \cite{11} Another disadvantage is the possibility of a false neck remnant, which may be explained by the peripheral contrast enhancement of the organized thrombus or by the vasa vasorum within the adventitial layer of the aneurysm wall. A progression of inflammatory changes definitely occurs with time after aneu-

Figure 4. A, DSA of the left internal carotid artery at 12 months after treatment of a 10-mm aneurysm (arrowhead) of the left internal carotid. The oblique head view shows a large recanalization (arrow) classified as residual aneurysm (class 3), classified as a major recurrence. B, CE-MRA with MIP reconstruction in the oblique plane demonstrates a residual aneurysm (class 3; arrow) in accordance with DSA findings. Note the recurrence appears larger than corresponding DSA. One retreatment was performed by embolization.

Figure 5. A, DSA of the right internal carotid artery performed at 19 months after treatment of a 5-mm aneurysm of the anterior communicating (arrow). The frontal head view shows residual neck (class 2). B, CE-MRA with axial MIP reconstruction in the frontal plane shows a hypersignal (arrow) at the site of the anterior communicating artery misinterpreted as a residual aneurysm (class 3).
rysm coiling.\textsuperscript{8,10} This last disadvantage can explain the 2 false-positives observed in our series.

The present study has several shortcomings. First, the lack of rotational angiography with 3D reconstructions does not allow for accurate interpretation of intracranial MR angiograms, especially not for the detection of neck remnants. Different studies reported the false-negative of 2D DSA because of the effect created by the radio-opaque coil mass over and around recanalization and the need for rotational angiography.\textsuperscript{24} Second, the CE-MRA did not compare with 3D TOF used as reference in most of studies. Third, the use of a sequence with a conventional k-space acquisition and without automatic synchronization of peak arterial contrast concentration cannot optimize the spatial and time resolution. These limitations can explain the false-negative in our study. Technical developments such as an elliptical-centric k-space acquisition can increase and optimize arterial visualization with venous suppression.\textsuperscript{25} Finally, source images from MR angiograms were not included for image analysis, and this may lead to a misinterpretation of aneurysm recurrence.

In conclusion, follow-up imaging, with CE-MRA after selective embolization of intracranial aneurysms, can be used to detect late aneurysmal recanalization as residual neck or aneurysmal sac. The long-term outcome of aneurysms is unknown and their surveillance is still required.

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References

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