Residual Flow After Cerebral Aneurysm Coil Occlusion

Diagnostic Accuracy of MR Angiography

Pascale Lavoie, MD; Jean-Luc Gariépy, MD; Geneviève Milot, MD; Steve Jodoin, MD; Fernand Bédard, MD; François Trottier, MD; René Verreault, MD

Background and Purpose—The purpose of this study was to estimate the performance measures of MR angiography (MRA) in the diagnosis of aneurysm residual flow after coil occlusion.

Methods—Patients having at least 1 cerebral aneurysm treated with coil occlusion were prospectively and consecutively enrolled. Time of flight and contrast-enhanced MRA were performed the same day of the DSA follow-up. The degree of aneurysm occlusion and dimensions of the residual flow were evaluated by independent readers at MRA and digital subtraction angiogram. MRA performance measures were estimated in a cross-sectional analysis and repeated in subgroups of aneurysm sizes and locations. MRA predictive values for recurrence were also estimated using a longitudinal design.

Results—We obtained 167 aneurysm evaluations for each imaging modality. Class 3 residual flow was seen on digital subtraction angiogram follow-up in 27%. The sensitivity and specificity of MRA was 88% (95% CI, 80–94) and 79% (95% CI, 67–88), respectively. The positive predictive value for a Class 3 recurrence was 67% (95% CI, 51–80) and the negative predictive value was 93% (95% CI, 86–97). Time-of-flight MRA underestimated the length of the residual flow (P=0.039), whereas contrast-enhanced MRA overestimated its width (P<0.0001). MRA sensitivity for a Class 3 residual flow was lower for aneurysms <6 mm (P=0.01).

Conclusions—MRA has sufficient accuracy for screening of aneurysm residual flow after coil occlusion. Due to its lower negative predictive value, recurrent aneurysms should be confirmed with digital subtraction angiogram before planning a retreatment. Routine use of MRA to follow small aneurysms should wait better estimation of its performance in this particular subgroup. (Stroke. 2012;43:00-00.)

Key Words: coils ■ endovascular ■ magnetic resonance angiography ■ predictive value ■ sensitivity ■ specificity

Endovascular coil occlusion has become a standard treatment in cerebral aneurysm management.1 However, reopening of the aneurysm can occur in approximately 20% of all cases,2 which involves a retreatment rate of approximately 9%.3 Consequently, most endovascular teams plan long-term follow-up of coiled aneurysms with repeated vascular imaging. Cranial digital subtraction angiogram (DSA) is the standard test but it exposes patients to cerebral thromboembolic risks, contrast nephrotoxicity, and ionizing radiations.4,5 Therefore, many centers have replaced DSA for cerebral MR angiography (MRA), a noninvasive and nonirradiating vascular imaging modality.

Estimates of MRA performance measures in the diagnosis of a residual flow after cerebral aneurysm coil occlusion have been reported in several studies with highly variable results6–19 and poor to moderate methodological quality.20,21 In many of these studies, the cohort was not representative of the general coiled aneurysms population (method of cohort assembly and patient selection unknown or nonconsecutive),6,8,10,13,14,16,19,22 DSA and MRA images interpretations were not clearly blind to each other,8,11–13,18,19,22 and data collection was mainly retrospective.6,8,10,13,14,16,19,22 Test accuracy studies with such methodological issues may produce substantial biases, generally toward an overestimation of the accuracy of a test.23,24 In our opinion, the usual cross-sectional design used in many studies14,15,25 may also overestimate the positive predictive values of MRA, in including some aneurysms having already a residual flow since the last treatment.

The aim of this study was to estimate MRA performance measures in the diagnosis of any residual flow in the sac or the neck of the aneurysm and in the diagnosis of a residual

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flow distinctly in the sac of the aneurysm using DSA as the reference test. We also wanted to evaluate MRA accuracy in estimating the dimension of this residual flow. In addition, we planned to analyze the effect of adding a contrast-enhanced sequence and the influence of aneurysms size and location on MRA accuracy. We conducted our study using a longitudinal design with an adequate blinding procedure and method of cohort assembly to avoid potential biases frequently encountered in test accuracy studies.

Materials and Methods

This study is reported in accordance with The Statement for Reporting Studies of Diagnostic Accuracy.26 The protocol was approved by the Research Ethics Board of the Laval University-affiliated Centre hospitalier affilié universitaire de Québec.

Population

Patients were eligible for study if they were ≥18 years old and if they had at least 1 DSA planned in our center between October 26, 2005, and May 6, 2007, for the follow-up of at least 1 cerebral aneurysm previously treated with selective coil occlusion. Patients with a second DSA follow-up evaluation planned during the study period could be recruited twice. Patients were excluded if they had any contraindication or refused to perform either 1 of the 2 test or if it was impossible to carry out both tests on the same day. Aneurysms treated with occlusion of the parent artery and those clipped before or after coil occlusion were not included. Patient entry into the study was prospective and consecutive until the desired sample size was reached. Every weekday in our center, 1 or 2 patients with coiled aneurysms were scheduled to have a DSA follow-up. When the MR facility could not accommodate the 2 patients scheduled on the same day, a nurse drew at random the name of the patient who would have both test and thus be eligible for study. The patients not included in the study were followed as usual with DSA only.

Imaging Techniques

All DSAs were obtained with anteroposterior, lateral, oblique, contraoblique, and working view acquisitions.

All MRAs were performed in a 1.5-Tesla MRI unit (Siemens Avanto) with a standard head coil. Time-of-flight (TOF) and contrast-enhanced (CE) MRA sequences were obtained. See the Online Supplement (http://stroke.ahajournals.org) for detailed imaging techniques.

Image Interpretation

Each investigator had to be blind to other test results, including previous DSA. Prospectively registered data were defined as follows: aneurysm location, image interpretability, angiographic degree of occlusion according to Roy’s classification,27 and largest size of residual aneurysm in length and width (perpendicular and parallel to the neck of the aneurysm, respectively). Two neurointerventional specialists with >5 years of experience in DSA interpretation at study onset had to separately and blindly evaluate each coiled aneurysm on each DSA. In case of disagreement in aneurysm remnant class, a third neurointerventional specialist had to determine the final class, which represented the result for comparison with MRA. Three neuroradiologists with >5 years of experience in MRA interpretation at the study onset were designated for MRA readings. Each aneurysm in each MRA was read separately by 1 of them, starting with the TOF MRA. All TOF MRA evaluations were blind from CE MRA. Source images of both TOF MRA sequences and CE MRA sequences were reconstructed by using the maximum intensity projection algorithm. Other data, collected by a different investigator unaware of DSA and MRA results, included: clinical presentation of aneurysms, patient age and gender, aneurysm and neck pretreatment size, last endovascular treatment date, immediate class result after the last endovascular treatment, retreatment planning, and complications after MRA or DSA.

Statistical Analysis

Sample size calculations were based on the assumption that the study should be able to detect an MRA sensitivity of approximately 90%. Assuming a prevalence of residual aneurysm (Class 2 or 3) of 40% (based on estimates from previous pilot results in our center), and a range of uncertainty of <7% around the estimate of MRA sensitivity, a sample size of 175 imaging comparisons was required.

Using DSA as the reference test, all test performance measures were estimated in a cross-sectional design after dichotomization between Class 1 versus Class 2 or 3 and after dichotomization between Class 1 or 2 versus Class 3. Results were compared between the tests using a χ² test or Fisher exact test when appropriate. Calculations were first performed with exclusion of imaging failures and then repeated with inclusion of failures using the worst case scenario (false-negative or false-positive for all imaging failures) and inversely for the best case scenario. All comparisons were repeated according to predefined subgroups of aneurysm size (< 6 mm; >6 mm), neck size (< 3 mm; 3 mm), and aneurysm location (on major bifurcation or on the vessel wall).

For follow-up of aneurysms with initially no residual flow in the sac immediately after coiling (Class 1 or 2), calculations of negative and positive predictive value were repeated in a separate longitudinal design after dichotomization between no change in class and class increase compared with the postcoiling results.

Differences of length and width were compared between the tests and repeated in predefined subgroups of residual flow dimension using a nonparametric Wilcoxon signed rank test. The mean dimension between the 2 DSA readers’ results represented the value used for comparison with the dimension obtained from MRA interpretation. Only cases for which residual flow measurements were performed (Class 2 and 3) were entered in the analysis of residual flow dimension.

All statistical analyses were performed using SAS software (Version 9.2; SAS Institute, Inc., Cary, NC). All probability values are 2-sided and a probability value <0.05 was considered statistically significant.

Results

The Figure shows the flow of participants during the recruitment process and the distribution of the population according to degree of coil occlusion on the DSA follow-ups. A total of 274 patients, having at least 1 aneurysm treated with selective coil occlusion, had 1 or 2 angiographic follow-ups planned between October 26, 2005, and May 6, 2007, at our institution. Of those, 117 patients were excluded, mainly because both tests could not be performed the same day due to practical issues (MRI availability). In addition, 8 MRA files were lost in the course of the study, leaving a total of 149 patients with 167 images of coiled aneurysms for comparison and final analyses. There was no significant difference in distribution of degree of coil occlusion at follow-up between included and excluded cases (P = 0.67).

Table 1 shows the baseline distribution of participants, aneurysms, and DSA characteristics. A total of 107 females and 42 males with a median age of 53 years had 160 coiled aneurysms included in the study with 167 follow-ups performed over the study period. Of those, 8 patients had >1 coiled aneurysm. More than 80% of aneurysms were located in the anterior circulation with the anterior communicating artery being the most frequent location and 57% presented with rupture. Median aneurysm lumen and neck size before coil treatment were 6 and 2.5 mm, respectively. Initially, a total of 147 aneurysms (92%) were totally (Class 1) or subtotally (Class 2) occluded immediately after coiling. The interval between coil treatment and follow-up examinations

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was 6 months for 82, 12 months for 13, 18 months for 43, and >20 months for 29 patients. The proportion of aneurysms having incomplete occlusion (Class 3) on DSA follow-up was 27%, whereas the proportion of aneurysms with total (Class 1) or subtotal (Class 2) occlusion was 40% and 33%, respectively. Dimension of residual flow (Class 2 or 3) measured on DSA follow-up varied from 1 to 9.5 mm in length and from 0.75 to 7.25 mm in width. Of the 147 initially totally or subtotally (Class 1 or 2) occluded aneurysms, 37 (25%) presented sac recanalization (Class 3) on DSA examination follow-up over a total follow-up of 3384 months. Retreatment was planned for 9 of them.

Concordance of readings between DSA readers was 81%. The $\kappa$ coefficient of agreement for aneurysm class between them was 0.75, which did not change significantly in subgroups of aneurysm size and location. The difference in residual flow length measurements between DSA readers was statistically significant ($P=0.0002$). However, this difference was <1 mm in 84% of cases and its median was only 0.3 mm. There was no significant difference between readers for residual flow width measurements. DSA interobserver comparisons are in the Online Supplement (online-only, Supplemental Table S1).

Table 2 shows estimates from cross-sectional analysis of TOF and CE MRA performance measures. The sensitivity (Se) of TOF MRA to detect any residual flow into a coiled aneurysm was 78% and its specificity (Sp) was 81%. The negative predictive value (NPV) of TOF MRA for the absence of any residual flow into a coiled aneurysm was 70% and the positive predictive value (PPV) for its presence was 86%. CE MRA was always read after TOF MRA. Readers changed their reading after CE MRA review in 21 cases. After readings of CE MRA, Se for the detection of any residual flow increased to 88% (95% CI, 80–94), but the difference between before and after CE MRA did not reach statistical difference ($P=0.07$); Sp (79%; 95% CI, 67–88) and the NPV (81%; 95% CI, 70–90) and PPV (86%; 95% CI, 78–92) remained similar. For the diagnosis of a residual flow distinctly into the sac of the aneurysm (Class 3), Se and Sp of TOF MRA were 76% (95% CI, 60–87) and 85% (95% CI, 77–91), respectively, whereas NPV increased to 90% (95% CI, 82–95) and PPV decreased to 67% (95% CI, 52–79). MRA performance measures for the diagnosis of a Class 3 residual flow remained similar after adjusted reading from CE sequence. From all Class 3 cases on DSA, Class 2 misclassification occurred in 8 cases on TOF MRA and in 9 cases on CE MRA, whereas Class 1 misclassification occurred in 3 cases on TOF MRA and in no case on CE MRA. From all Class 1 or 2 occlusions on DSA, Class 3 false-positive results occurred on both TOF and CE MRA in 17 and 18 cases, respectively. See Supplemental Figures S1 and S2 for examples of false-negative and false-positive results. Image failure occurred in 8 cases with TOF MRA (coil artifacts in 4 cases, aneurysm not included in the field of view in 4 cases), in 1 case with CE MRA (aneurysm not included in the field of view), and in no case with DSA.
estimates of TOF and CE MRA performance measures remained very similar after inclusion of the imaging failure with either the best or the worst scenario as well as with exclusion of second imaging interpretation of a same aneurysm.

Table 3 shows estimates of MRA predictive values from prospective analysis. Estimates were generally lower than those from cross-sectional analysis, because PPV for any change in class from Class 1 was 72% (95% CI, 56–85) both for TOF and CE MRA. PPV for any change to Class 3 were also relatively low in the prospective analysis (62% for TOF and 67% for CE MRA). NPV for no change in class from Class 1 or 2 was 91% (95% CI, 83–96) for TOF MRA and 93% (95% CI, 86–97) for CE MRA. NPV for no change in class from Class 1 was 79% (95% CI, 60–89) and 86% (95% CI, 72–95), respectively.

Table 4 shows median residual flow dimensions measured on DSA, TOF, and CE MRA. Considering DSA as the reference test, TOF MRA significantly underestimated the length of the residual flow (P < 0.04), whereas CE MRA overestimated its width (P < 0.0001). Length differences between TOF MRA and DSA measurements were more significant for aneurysms with residual flow length > 3 mm (P < 0.06) than for those with residual flow length ≥ 3 mm (P = 0.74).

Table 5 shows estimates of Se and Sp of MRA for diagnosis of a Class 3 in subgroups of aneurysm sizes. Se of TOF MRA for detection of a Class 3 appeared significantly much lower for small (<6 mm) than for larger aneurysms (46% versus 87%; P = 0.007). Similarly, Sp was significantly lower for small than for larger aneurysms (46% versus 74%; P = 0.007). Readings of CE MRA did not significantly im-

![Image](http://stroke.ahajournals.org/)

**Table 1. Baseline Characteristics of 149 Patients With 160 Aneurysms and 167 Follow-Up Examinations**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Count (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female sex</td>
<td>107 (72)</td>
</tr>
<tr>
<td>Age, y*</td>
<td>53 (46–60, 26–83)</td>
</tr>
<tr>
<td>No. of patients with multiple coiled aneurysms</td>
<td>8 (5)</td>
</tr>
<tr>
<td>No. of coiled aneurysms</td>
<td>160</td>
</tr>
<tr>
<td>No. of ruptured aneurysms</td>
<td>92 (57)</td>
</tr>
<tr>
<td>Size of aneurysm before coil occlusion, mm*</td>
<td>6 (4.5–8.7, 2–20)</td>
</tr>
<tr>
<td>Size of aneurysm neck before coil occlusion, mm*</td>
<td>2.5 (4–1.5, 1–9)</td>
</tr>
<tr>
<td>Location of coiled aneurysm (%)</td>
<td></td>
</tr>
<tr>
<td>Carotid artery-supraclinoid</td>
<td>52 (32)</td>
</tr>
<tr>
<td>Carotid artery bifurcation</td>
<td>6 (4)</td>
</tr>
<tr>
<td>Middle cerebral artery</td>
<td>16 (10)</td>
</tr>
<tr>
<td>Anterior cerebral artery–proximal</td>
<td>47 (30)</td>
</tr>
<tr>
<td>Anterior cerebral artery–distal</td>
<td>8 (5)</td>
</tr>
<tr>
<td>Basilar tip</td>
<td>19 (12)</td>
</tr>
<tr>
<td>Vertebral or basilar artery</td>
<td>12 (7)</td>
</tr>
<tr>
<td>No. of aneurysms with residual flow after coil (%</td>
<td></td>
</tr>
<tr>
<td>In the neck (Class 2)</td>
<td>60 (37)</td>
</tr>
<tr>
<td>In the sac (Class 3)</td>
<td>8 (5)</td>
</tr>
<tr>
<td>Unknown†</td>
<td>5 (3)</td>
</tr>
<tr>
<td>Total no. of DSA examinations in the study</td>
<td>167</td>
</tr>
<tr>
<td>No. of DSA examinations showing a residual flow (%)</td>
<td></td>
</tr>
<tr>
<td>In the neck of the coiled aneurysm (Class 2)</td>
<td>55 (33)</td>
</tr>
<tr>
<td>In the sac of the coiled aneurysm (Class 3)</td>
<td>45 (27)</td>
</tr>
<tr>
<td>No. of coiled aneurysms with increase in class on first DSA (%)‡</td>
<td></td>
</tr>
<tr>
<td>From Class 1 to 2</td>
<td>26 (18)</td>
</tr>
<tr>
<td>From Class 1 to 3</td>
<td>12 (8)</td>
</tr>
<tr>
<td>From Class 2 to 3</td>
<td>25 (17)</td>
</tr>
</tbody>
</table>

**Table 2. TOF and CE MRA Performance Measures (% [95% CI])* in the Diagnosis of Residual Flow After Aneurysm Coil Occlusion (Cross-Sectional Analysis)**

<table>
<thead>
<tr>
<th>Residual Flow</th>
<th>TOF MRA</th>
<th>CE MRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any Residual Flow (Class 2 or 3)</td>
<td>Se 78 (69–86)</td>
<td>88 (80–94)</td>
</tr>
<tr>
<td></td>
<td>Sp 81 (69–90)</td>
<td>79 (67–88)</td>
</tr>
<tr>
<td></td>
<td>PPV 86 (77–93)</td>
<td>86 (78–92)</td>
</tr>
<tr>
<td></td>
<td>NPV 70 (58–81)</td>
<td>81 (70–90)</td>
</tr>
<tr>
<td>Residual Flow Distinctly in the Sac (Class 3)</td>
<td>Se 76 (60–87)</td>
<td>80 (65–90)</td>
</tr>
<tr>
<td></td>
<td>Sp 85 (77–91)</td>
<td>85 (77–91)</td>
</tr>
<tr>
<td></td>
<td>PPV 67 (52–79)</td>
<td>67 (52–79)</td>
</tr>
<tr>
<td></td>
<td>NPV 90 (82–95)</td>
<td>92 (85–96)</td>
</tr>
</tbody>
</table>

**Table 3. Prospective Analysis: Predictive Values (% [95% CI]) of MRA in Diagnosis of a Change in Class From an Aneurysm Initially Totally or Subtotally Occluded After Treatment (Class 1 or 2)**

<table>
<thead>
<tr>
<th>Change From Class</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOF MRA Any change from Class 1</td>
<td>72 (56–85)</td>
<td>79 (60–89)</td>
</tr>
<tr>
<td>CE MRA Any change from Class 1</td>
<td>72 (56–85)</td>
<td>86 (72–95)</td>
</tr>
<tr>
<td>TOF MRA Any change to Class 3</td>
<td>62 (47–76)</td>
<td>91 (83–96)</td>
</tr>
<tr>
<td>CE MRA Any change to Class 3</td>
<td>67 (51–80)</td>
<td>93 (86–97)</td>
</tr>
</tbody>
</table>

MRA indicates MR angiography; PPV, positive predictive value; NPV, negative predictive value; TOF, time of flight; CE, contrast-enhanced; CI, confidence interval.

*Expressed as percentage with (95% CIs).
prove Se for small aneurysms but increased its Sp compared with TOF MRA. Se of CE MRA for detection of a Class 3 appeared also significantly lower for small than for larger aneurysms (54% versus 90%; \( P = 0.01 \)), but Sp appeared significantly better for smaller than for larger aneurysms (92% versus 74%; \( P = 0.02 \)). All other estimates, both from cross-sectional and prospective analyses, of TOF and CE MRA performance measures remained similar in subgroups of aneurysm lumen size, neck size, and aneurysm location.

No complication was recorded after DSA or MRA in the course of the study.

**Discussion**

We found that the Se and the Sp of CE MRA to detect any residual flow into a previously coiled aneurysm was 88% (95% CI, 80–94) and 79% (95% CI, 67–88), respectively. MRA NPV for the absence of a Class 3 recanalization on DSA was high (93%; 95% CI, 86–97), but the PPV of MRA for the presence of aneurysm recurrence on DSA was relatively low in our study. Our results also suggest that MRA Se and Sp for the diagnosis of a Class 3 residual flow in small aneurysms is poor.

Previous reports of MRA performance measures in the diagnosis of a residual flow after cerebral aneurysm coil occlusion are highly variable\(^6\)–\(^9\)\(^,\)\(^11\)\(^–\)\(^19\) and have relatively low statistical power due to the small sample sizes of most series.\(^6\)–\(^9\)\(^,\)\(^11\)\(^–\)\(^19\) A meta-analysis found a pooled Se and Sp similar to those found in our study, but the authors concluded that the findings should be interpreted with caution due to the moderate methodological quality of included studies.\(^20\)\(^,\)\(^21\)

More recently, a large multicenter study, including 381 aneurysm assessments, reported similar estimates of MRA performance measures than those reported in our study.\(^25\) The poor Se of MRA to detect a Class 3 residual flow in small aneurysms has also been reported by others. Deutschmann et al also found that MRA sensitivity was poor for aneurysm <3 mm\(^3\)\(^6\). Schlaefmann et al found that a small residual lumen (1–3 mm) was independently associated with discrepancy between DSA and MRA results\(^2\)\(^6\); and Okahara et al found that the diameters of residual/recurrent aneurysms that could not be detected by MRA were significantly smaller than those of detected aneurysms (mean 1.1 versus mean 2.3 mm).\(^9\)

According to our results, approximately 12% (95% CI, 6–20) of all aneurysms with a residual flow will not be detected on MRA, and the probability of finding a Class 3 residual flow on DSA when MRA shows a Class 1 or 2 occlusion is approximately 7% (95% CI, 3–14). A higher Se would have necessarily some related cost, including a lower Sp and the potential for a higher retreatment rate, which is also not without risk.\(^2\)\(^8\) Because it is unclear whether the rebleeding risk after aneurysm coiling\(^2\)\(^)\(^–\)\(^2\)\(^9\) is worth the risks of recurrent aneurysm retreatment, we must question the benefit and cost-effectiveness of using very high Se criteria. Schlaefmann et al performed a cost-effectiveness study of MRA versus DSA for the follow-up of patients with coiled aneurysms.\(^3\)\(^0\) They found that recurrent aneurysms seen on DSA but not detected by MRA did not significantly increase the expected incidence of subarachnoid hemorrhage for patients followed up with MRA. According to their results, even when cost reduction by MRA was not taken into consideration, there was still some benefit of using MRA instead of DSA related to the gain in quality-adjusted life-years.

The addition of gadolinium to the TOF MRA sequence may improve visualization of part of aneurysms with slow residual flow that may not be seen on TOF MRA due to spin saturation.\(^1\)\(^4\) However, the limited spatial resolution of the CE MRA sequence and the potential for venous enhancement are limiting factors of this imaging modality. Moreover, despite its rare occurrence, gadolinium-induced nephrotoxicity can occur in patients with impaired renal function.\(^3\)\(^1\) Adding a CE sequence has not resulted in significant improvement of MRA performance measures to detect residual aneurysm flow in most reported series\(^1\)\(^1\)\(^,\)\(^1\)\(^5\)\(^,\)\(^1\)\(^6\)\(^,\)\(^2\)\(^0\)\(^,\)\(^2\)\(^5\) and its cost-effectiveness is questioned.\(^3\)\(^0\) In these studies, like in ours, interpretation of CE MRA was not blind from TOF MRA interpretation and therefore cannot be used to formally compare both sequences. However, we designed our study so that TOF MRA interpretation was always blind to CE MRA. In comparing TOF MRA interpretation with TOF and CE

### Table 4. Residual Aneurysm Flow Dimensions on Follow-Up in Millimeters (Median [Interquartile Range, Range])

<table>
<thead>
<tr>
<th></th>
<th>DSA† (N=87)†</th>
<th>TOF MRA (N=88)†</th>
<th>CE MRA (N=101)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>3 (2.1–4, 1–9.5)</td>
<td>2.5 (1.7–3.5, 0.7–12)*</td>
<td>3 (2.3–3.8, 1–12.6)</td>
</tr>
<tr>
<td>Width</td>
<td>2 (1.25–3, 0.75–7.25)</td>
<td>2 (1.35–3.30, 0.5–12)</td>
<td>2.2 (1.5–3.9, 0.5–13)§</td>
</tr>
</tbody>
</table>

DSA indicates digital subtraction angiogram; TOF, time of flight; MRA, MR angiography; CE, contrast-enhanced.

Notes: Paired residual flow dimension on MRA were compared with DSA with the nonparametric Wilcoxon signed rank test: *\( P<0.05 \), §\( P<0.0001 \). Comparisons were performed only for the cases having measures other than 0 for DSA and MRA.

†Analysis were performed for aneurysms having a residual flow measure other than 0.

‡Dimension of residual flow on DSA=mean of the 2 DSA readers’ measures.

### Table 5. Sensitivity and Specificity (% [95% CI]) of MRA in Diagnosis of Class 3 Residual Aneurysm Flow in Subgroups of Aneurysm Sizes

<table>
<thead>
<tr>
<th>Aneurysm Sizes</th>
<th>2–6 mm</th>
<th>&gt;6 mm</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOF MRA Se</td>
<td>46 (19–75)</td>
<td>87 (71–96)</td>
<td>0.007</td>
</tr>
<tr>
<td>TOF MRA Sp</td>
<td>46 (19–75)</td>
<td>74 (59–86)</td>
<td>0.007</td>
</tr>
<tr>
<td>CE MRA Se</td>
<td>54 (25–81)</td>
<td>90 (75–98)</td>
<td>0.01</td>
</tr>
<tr>
<td>CE MRA Sp</td>
<td>92 (83–97)</td>
<td>74 (60–86)</td>
<td>0.02</td>
</tr>
</tbody>
</table>

MRA indicates MR angiography; TOF, time of flight; Se, sensitivity; Sp, specificity; CE, contrast-enhanced; CI, confidence interval.

*Expressed as percentage with (95% CIs).
MRA interpretation read together, we found that MRA Se and NPV tended to be lower before than after adjusted reading from the CE sequence, but the difference did not reach statistical significance.

In our study, sensitivity of MRA to diagnose a Class 3 residual flow compared with any residual flow tended to decrease and its Sp tended to increase. Like in previous studies, we found that the interpretation of the degree of coil occlusion suffers from some interobserver variability. This variability may account for part of false-negatives or false-positives independently from the accuracy of the test and could explain the observed variability in Se and Sp.

We also observed a significant difference in estimation of the length of the residual flow between DSA observers. Therefore, the difference in length measurement between DSA and MRA could well be influenced by some degree of interobserver variation in measurement. The width of the residual flow measured on DSA was similar for both observers. If we assume that the overestimation of residual flow width on CE MRA is not due to interobserver variability, it may account for some of the false-positives found with CE MRA. On the other hand, many authors believe that some false-positives with MRA could be in fact true-positives not seen on DSA due to the opacity of the mass of coils that may hide a residual flow. The limited image projection of 2-dimensional imaging, compared with the wider range of projection seen on 3-dimensional MRA, may explain this phenomenon. This assumption implies that DSA is an imperfect reference test and that MRA Sp and PPV could be higher than what has been estimated so far.

To have a representative spectrum of cases with residual flow, our cohort was assembled prospectively and consecutively from a general population of patients with coiled aneurysm being followed up in our center. We excluded a large proportion of eligible cases, mainly due to a practical issue (MRI availability), but this was performed randomly, so we did not expect it to have biased our results. As a matter of fact, the proportion and distribution of residual flow remained similar between included and excluded cases. The initial prevalence of residual flow in our cohort of patients was similar to that reported in previous studies. Therefore, we believe that despite these exclusions, our cohort assembly gave a representative spectrum of the general population of coiled aneurysms.

Because DSA was used as the reference test, efforts were made to assess interobserver variability and to maximize the validity of interpretations by using 3 different observers. However, interobserver variability was not assessed for MRA readings. Our study first aimed to assess test performance measures of MRA in a manner as close as possible to the usual clinical context, in which only 1 reader among several radiologists usually share the task of MRA readings and thus to maximize external validity of our results. External validity of our study is however limited by the lack of a 3-dimensional DSA imaging protocol, which is used in many centers. Using 3-dimensional DSA instead of 2-dimensional DSA could have decreased the proportion of false-positives seen on MRA when compared with 2-dimensional DSA.

Conclusions
Our study showed that MRA has sufficient accuracy to be used for screening of residual flow after aneurysm coil occlusion. This is reinforced by a recent cost-effectiveness study, in which the Se and Sp used in the model were similar to those found in our study. A Class 3 residual flow in a small aneurysm may not be ruled out without reasonable doubt on MRA. Routine use of MRA to follow small aneurysms should wait better estimation of its performance in this particular subgroup. Because MRA PPV is somewhat low, DSA should be performed before any therapeutic decision is made when a recurrent aneurysm is seen on MRA. On the other hand, high NPV justifies no further test when MRA shows no aneurysm sac recanalization. The value of adding a CE sequence to MRA imaging protocol is still unresolved and should be assessed in a larger study with blind interpretation of both sequences at the same time as comparing with DSA.

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Disclosures
None.

References
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SUPPLEMENT MATERIAL

**Title**: Residual Flow after cerebral aneurysm Coil Occlusion: Diagnostic Accuracy of MR Angiography

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**This supplement Contains**:  
Supplemental methods on imaging technique  
Supplemental table and figures:  
- Table S1. DSA exams follow-up: inter-observer data  
- Figure S1. Example of false-negative TOF-MRA result, but true-positive CE-MRA result  
- Figure S2. Example of false-positive TOF-MRA and CE-MRA results
SUPPLEMENTAL METHODS

Imaging Technique for DSA
The DSA exams were performed with a Siemens Neurostar biplan neuroangiography unit or a Siemens Multisystem Mono-plan angiography unit. From a transfemoral access, catheterization of the supra-aortic vessel(s) of interest was performed with the acquisition of at least 5 intracranial views: AP, lateral, oblique, contra-oblique and working views (optimal projection to separate the aneurysm neck, from the aneurysm dome and the adjacent vessels during coil occlusion). Each angiogram was acquired at a rate of three images per second with a 1024 matrix size and with a 17 cm field of view for AP, lateral, oblique and contra-oblique views acquisition; and with a 13 cm field of view for the working view acquisition. Each acquisition was performed with about 8 cc of nonionic contrast agent, using hand injection.

Imaging technique for MRA
All MRA exams were performed in a 1.5 Tesla MRI unit (Siemens Avanto, Germany) with a standard head coil. An 18-gauge catheter was inserted into the patient’s antecubital vein. The protocol included a 3D-TOF and a contrast-enhanced fast imaging steady-state precession sequence. The 3D-TOF sequences were performed in the axial plane. A saturation band was placed above the acquisition volume to eliminate the venous signal. The parameters of the sequence were: TR 23/7 [TR/TE]; flip angle, 25°; field of view, 210; Slice thickness 0.70 mm; Distance factor- 25%; Slabs 4; Slice per slab 44; Voxel size 0.8 x 0.8 x 0.7 mm and Matrix, 204 x 256. The acquisition time was 4 minutes. The contrast-enhanced sequence was performed in the coronal plane. The acquisition volume was placed on the sagittal scout image in an oblique direction: the volume included the cervical carotid arteries, the carotid siphons, 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 parameters were as follows: TR 3.17/TE 1.18; flip angle 30°; field of view, 210; and matrix, 187 x 384; image thickness 1 mm; distance factor 20%; Slab, 1; Slice per slab, 96; voxel size 0.8 x 0.5 x 1 mm. The anteroposterior coverage was 60 mm, and the acquisition time was 40 seconds. A 100% zero-fill interpolation was performed in the section direction and fat saturation was used. A 0.2 mmol/kg bolus of Gadolinium Chelate (Gadodiamide [Omniscan]; Nycomed) was injected at a rate of 2 mL/s with a MR-compatible power injector (Spectris; Medrad, Pittsburgh, PA). The circulation time was estimated by the use of a test bolus before performance of 3D-MRA. Two-dimensional images were acquired every second during 60 seconds at the level of the carotid siphons. The start of the test bolus injection coincided with the start of the sequence. The circulation time was then calculated by means of signal intensity measurements in a region of interest placed over either the carotid siphon or the basilar artery. The delay time was calculated so that the peak of arterial contrast enhancement coincided with the acquisition of the central part of k space according the following equation: delay time = test bolus transit time + 0.5 (injection time in seconds) - 0.35 (acquisition time in seconds).
## Table S1. DSA exams follow-up: interobserver data

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Figure S1. Example of false-negative TOF-MRA result, but true-positive CE-MRA result. Right middle cerebral artery aneurysm treated with coil occlusion that was classified as class 3 on DSA (a) and CE-MRA (c), and as class 1 on TOF-MRA (b) follow-up.
Figure S2. Example of false-positive TOF-MRA and CE-MRA results. Right posterior communicating artery aneurysm treated with coil occlusion that was classified as class 2 on DSA (a) and as class 3 on TOF (b) and CE-MRA (c).