Assessment of brain aneurysms by using high-resolution magnetic resonance angiography after endovascular coil delivery

JOHN H. WONG, M.D., M.SC., ALIM P. MITHA, M.D., MORGAN WILLSON, M.D., MARK E. HUDON, M.D., ROBERT J. SEVICK, M.D., AND RICHARD FRAYNE, PH.D.

1Division of Neurosurgery, Department of Clinical Neurosciences, and 2Department of Diagnostic Imaging, Foothills Medical Centre, University of Calgary, Alberta, Canada

Object. Digital subtraction (DS) angiography is the current gold standard of assessing intracranial aneurysms after coil placement. Magnetic resonance (MR) angiography offers a noninvasive, low-risk alternative, but its accuracy in delineating coil-treated aneurysms remains uncertain. The objective of this study, therefore, is to compare a high-resolution MR angiography protocol relative to DS angiography for the evaluation of coil-treated aneurysms.

Methods. In 2003, the authors initiated a prospective protocol of following up patients with coil-treated brain aneurysms using both 1.5-tesla gadolinium-enhanced MR angiography and biplanar DS angiography. Using acquired images, the subject aneurysm was independently scored for degree of remnant identified (complete obliteration, residual neck, or residual aneurysm) and the surgeon’s ability to visualize the parent vessel (excellent, fair, or poor).

Results. Thirty-seven patients with 42 coil-treated aneurysms were enrolled for a total of 44 paired MR angiography–DS angiography tests (median 9 days between tests). An excellent correlation was found between DS and MR angiography for assessing any residual aneurysm, but not for visualizing the parent vessel (κ = 0.86 for residual aneurysm and 0.10 for parent vessel visualization). Paramagnetic artifact from the coil mass was minimal, and in some cases MR angiography identified contrast permeation into the coil mass not revealed by DS angiography. An intravascular microstent typically impeded proper visualization of the parent vessel on MR angiography.

Conclusions. Magnetic resonance angiography is a noninvasive and safe means of follow-up review for patients with coil-treated brain aneurysms. Compared with DS angiography, MR angiography accurately delineates residual aneurysm necks and parent vessel patency (in the absence of a stent), and offers superior visualization of contrast filling within the coil mass. Use of MR angiography may obviate the need for routine diagnostic DS angiography in select patients. (DOI: 10.3171/JNS-07/08/0283)

KEY WORDS • detachable coil • digital subtraction angiography • endovascular occlusion • intracranial aneurysm • magnetic resonance angiography

Since the early 1990s, treatment of brain aneurysms has increasingly involved the use of the endovascular detachable coils first described by Guglielmi.11 The endovascular approach has become an established and reliable technique for the treatment of certain types of aneurysms, particularly in persons who are at high risk if open surgical intervention is performed, and for lesions in anatomic locations that are difficult to access via a direct approach such as the basilar apex.55,57 The long-term outcome of aneurysms treated with endovascular techniques, however, remains uncertain. Aneurysms treated by coil placement have been demonstrated to recur due to a variety of mechanisms, such as compaction of the coil mass, growth of the untreated remnant at the aneurysm neck, or expansion of the aneurysm fundus. As a result, regular radiologic follow-up evaluation is recommended for years to assess patients for lesion recurrence, which occurs in up to 30% of incompletely occluded small aneurysms.57

The current gold standard for the evaluation of coil-treated intracranial aneurysms is invasive DS angiography, but this test carries a small risk of stroke, can be painful, and requires specialized resources and active physician involvement. As a consequence, noninvasive brain imaging techniques such as MR angiography have been pursued as potential methods for follow-up assessment of coil-treated aneurysms. Currently, x-ray angiography has superior absolute spatial resolution with its ability to visualize vessels on the order of hundreds of microns, compared with 1.5-tesla MR angiography. However, with regard to brain aneurysms, which are measured on a scale of at least an order of magnitude larger (millimeters to centimeters), the question is whether high-field MR angiography has sufficient resolution to visualize such structures reliably when compared with DS angiography.

It was our hypothesis that high-resolution MR angiography could offer equivalent resolution of brain aneurysms and the local vasculature, and therefore potentially supplant the use of invasive x-ray angiography as the preferred

Abbreviations used in this paper: DS = digital subtraction; MIP = maximum intensity projection; MR = magnetic resonance; SAH = subarachnoid hemorrhage; TOF = time-of-flight.
means of radiological follow-up for patients with brain aneurysms. The objective of our study was to examine the use of high-resolution MR angiography for evaluating coil-treated brain aneurysms, and compare these results with catheter-based x-ray angiography, the current gold standard for investigating cerebrovascular anatomy, in a rigorous and standardized manner.

For this study, we assessed the reliability of MR angiography, in comparison with DS angiography, to differentiate between complete aneurysm obliteration, the presence of a neck remnant, and penetration of blood flow into the coil mass, as well as to assess patency of the parent vessel.

Clinical Material and Methods

Patient Population

Between October 2003 and September 2006, patients at our institution who had undergone endovascular coil placement and who required neuroimaging follow-up review were enrolled in a prospective protocol in which they would undergo high-resolution MR angiography generally timed around a concurrent DS angiography study performed for routine medical care. Those who had contraindications to MR imaging or who did not receive the high-resolution MR angiography protocol (described in the following section) were excluded. If the paired DS and MR angiography investigations were separated by more than 4 months, these patients were also excluded from analysis because it is conceivable that the aneurysm may have undergone significant change such as recanalization or regrowth in the interim.

All patients were able to tolerate imaging within the MR gantry with no ill effect. The MR angiography studies were performed using a 1.5-tesla Sonata unit (Siemens) set at the following parameters: TR 35 msec; TE 2.85 msec; flip angle 25; field of view 150 × 150 mm; slice thickness, 0.6 mm; matrix size 256 × 256; one acquisition; acquisition time 9 minutes 8 seconds. The MIP reconstructions were performed at the time of imaging. The data were reconstructed around both the head-to-foot axis and the right-to-left axis, and target MIP reconstructions of vessels of interest were made. Furthermore, 3D reconstructed MR angiography images for which a volume-rendering technique was used were produced on a workstation (Advantage Windows 2.0; General Electric Medical Systems) by using the source MR angiography images. Standard MIP images were generated through the entire imaging volume. The thickness of the subvolumes for targeted MIPs varied depending on the size of the aneurysm.

All DS angiography examinations and coil placement procedures were performed using a biplane DS angiography unit (General Electric AdvantX, General Electric Medical Systems) via transfemoral catheterization. The protocol for DS angiography before treatment included selective injection of intracranial arteries with the acquisition of sufficient views to display the aneurysm sac accurately in the “working position,” which is the term for the viewing angle best demonstrating the aneurysm and local arterial anatomy. Each angiogram was acquired at a rate of three images per second with a 1024 × 1024 matrix size and a 9-cm field of view. Intraarterial bolus administration of noniodinated contrast material was performed by hand or mechanical injector and DS images of the vasculature were obtained. Typically, multiple static images as well as spin angiography were performed to visualize the coil-treated aneurysm and efferent arterial vessels near the aneurysm neck. In some cases, 3D reconstructed images were produced at the time of the examination by using a volume-rendering technique (Advantage Workstation 3.1, General Electric Healthcare). No patient complications associated with DS angiography were encountered. Images were stored on a computer network for later interpretation and review.

For image analysis, hard-copy MR angiography images best depicting the aneurysm in the working position were chosen from the reconstructed MIP images of the region of interest and retained for comparison to equivalent views obtained with DS angiography. Axial contrast-enhanced source 3D TOF images were also chosen to provide cross-sectional information about the presence of flow within the coil mesh. For DS analysis, archival DS angiography images were selected that best depicted the aneurysm in the working position, that is, to demonstrate the aneurysm orifice and efferent arterial branches of the parent vessel.

In this study, we examined two separate aspects of the imaged vasculature, the aneurysm and the parent vessel, in a qualitative but standardized manner. The DS and MR angiography studies were each assessed in a nonblinded manner by using the same classification schemes as detailed later, by two physicians with experience in diagnostic and therapeutic angiography (J.H.W. and A.P.M.). The investigators qualitatively analyzed all the studies in concert to reach a consensus opinion for every test. Any disagreement was decided by reviewing the written interpretation of the study recorded by the original interpreting diagnostic neuroradiologist.

The degree of residual aneurysm was assessed using the descriptive Raymond classification scheme (Table 1), in which the aneurysm on either modality was classified into three categories as follows: Class 1, absence of any residual neck; Class 2, contrast filling of the neck alone; and Class 3, contrast filling of the saccular portion of the aneurysm. Although the Raymond classification system was originally used for catheter-based angiography, we found no difficulties with applying this scheme to the reconstructed MR angiography MIP images in our study. Of note regarding the axial TOF MR angiography images, contrast filling within the coil mass was deemed to represent a Raymond Class 3 category of residual aneurysm.

Parent vessel delineation was categorized into excellent, fair, and poor, based on the presence of a paramagnetic susceptibility artifact, radiologically confirmed patency of the vessel, and the ability to delineate neighboring branch vessels in the area of the aneurysm neck. Parent vessel delineation was considered excellent if there was no difficulty in the assessment of the local microvasculature, fair if there were only minor issues with demonstration of vascular anatomy, and poor if major vessels could not be reliably assessed or if there was an artifactual intraluminal filling defect. The presence of an intravascular microstent was noted.

Statistical Analysis

Several comparisons were used to evaluate the ability of DS and MR angiography to provide accurate follow-up for
Magnetic resonance angiography for coiled aneurysms

Results

Between October 2003 and September 2006, 37 patients (34 women and three men 34 to 79 years old; mean age 54 years) with 42 coiled-treated aneurysms were followed up with both concurrent DS and MR angiography. All angiographic examinations were performed within 4 months of each other (range 0–114 days, mean 22 days, median 9 days) for comparison. The time interval between the last coil embolization and the follow-up MR or DS angiography study ranged from 0 days to 5.5 years (mean 330 days). In two patients, a second set of paired DS–magnetic source angiography follow-up examinations were additionally performed. In total, 44 paired MR–DS angiography tests were available for analysis.

All patients were treated endovascularly with platinum-based detachable coils for intracranial aneurysms. Coated coils were said to have been used if greater than 50% of the total length of the coils deposited were either Matrix (Boston Scientific/Target) or HydroCoils (Microvention, Inc.); these were used in 28 (67%) of 42 cases. To facilitate successful coil placement, a Neuroform stent (Boston Scientific/Target) or HydroCoils (Microvention, Inc.) was positioned across the aneurysm orifice in 15 (36%) of 42 cases. Nineteen (45%) of 42 aneurysms presented with SAH; in the remaining patients the aneurysms were unruptured and discovered incidentally or due to mass effect. Twenty-six (62%) of 42 lesions were located in the anterior circulation and 16 (38%) of 42 were found in the posterior circulation (Table 2); the mean aneurysm size was 10 mm (Table 3).

Table 4 provides data from the comparative neuroimaging analysis of the coil-treated aneurysms on DS and MR angiography. For the determination of residual aneurysm, the kappa statistic for intermethod correlation was 0.86, indicating excellent agreement between DS and MR angiography (Fig. 1). In two cases, with MR angiography we were able to identify contrast permeation of the coil mass that was not revealed by DS angiography (Fig. 2). For parent vessel visualization, the kappa statistic for intermethod correlation was 0.10, indicating poor agreement between the two modalities. Chi-square analysis of the association between the presence of a Neuroform stent and disagreement between DS and MR angiography in aneurysm detection was not statistically significant (p = 0.15, chi-square test). Similarly, although the paramagnetic susceptibility artifact from the coil mass on visualization of the aneurysm fundus was minimal, the presence of a Neuroform stent tended to impede proper visualization of the parent vessel on MR angiography (Fig. 1), but this association was not statistically significant (p = 0.22, chi-square test).

Discussion

Endovascular coils for the repair of brain aneurysms were introduced in 1991 and approved for widespread use in 1995, and this procedure has become an increasingly popular alternative to open surgery. For certain patients, there are sufficient intuitive benefits and subjective esthetic advantages of the minimally invasive approach that compel them to choose coil occlusion over a craniotomy. It has been suggested in several institutional reviews and case–control studies that there is an increased margin of safety and reduced hospitalization for patients who undergo coil treatment as opposed to clip occlusion. In a recent large randomized controlled trial it was found that patients with aneurysmal SAH who underwent coil placement fared better statistically than those undergoing open surgery, with a significantly reduced risk of postprocedural stroke or death.

Although endovascular coil occlusion is believed to be potentially safer than open surgery, its long-term durability is still in question. It is important to note that although an aneurysm may be satisfactorily occluded immediately after the procedure, its orifice remains open and the coils remain exposed to pulsatile blood flow (as opposed to coil place-

### Table 1

<table>
<thead>
<tr>
<th>Aneurysm Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>complete obliteration (no residual neck &amp; no contrast w/in the aneurysm sac)</td>
</tr>
<tr>
<td>2</td>
<td>residual neck (any remaining portion of the original defect in the arterial wall but w/o any contrast present w/in the aneurysm sac)</td>
</tr>
<tr>
<td>3</td>
<td>residual aneurysm (any contrast present w/in the aneurysm sac)</td>
</tr>
</tbody>
</table>

* Based on the Raymond classification scheme described by Roy et al.

### Table 2

<table>
<thead>
<tr>
<th>Aneurysm Location</th>
<th>No. of Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>anterior cerebral &amp; anterior communicating arteries</td>
<td>5</td>
</tr>
<tr>
<td>basilar &amp; posterior cerebral arteries</td>
<td>16</td>
</tr>
<tr>
<td>middle cerebral artery</td>
<td>2</td>
</tr>
<tr>
<td>internal carotid &amp; posterior communicating arteries</td>
<td>19</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Aneurysm Size (mm)</th>
<th>No. of Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;7</td>
<td>11</td>
</tr>
<tr>
<td>7–12</td>
<td>24</td>
</tr>
<tr>
<td>13–24</td>
<td>4</td>
</tr>
<tr>
<td>&gt;25</td>
<td>3</td>
</tr>
</tbody>
</table>

* Categories established in a study by Wiebers et al. Abbreviation: ISUIA = International Study of Unruptured Intracranial Aneurysms.
Therefore, repeated brain imaging is necessary for years after coil treatment of an aneurysm to ensure satisfactory and permanent occlusion. Besides maintaining vigilance for coil compaction, vascular imaging may be prudent in younger patients because there is a low but defined risk of de novo aneurysm formation in a different location.

The most accurate diagnostic means of assessing the cerebral vasculature remains catheter-based x-ray angiography, also known as DS angiography. The immediacy of image acquisition and submillimeter resolution of the vasculature are advantages of angiography that render it currently the best diagnostic test for aneurysm assessment. Nevertheless, cerebral angiography carries a number of disadvantages that cumulatively may render this test undesirable for many patients. The procedure is associated with a small risk of iatrogenic stroke in approximately 0.4 to 0.7% of patients and transient ischemic attack occurs in approximately 2.3 to 5.2% of patients. Nonneurological complications, including pain, bleeding, and pseudoaneurysm (which can affect up to 15% of patients), are more common. At the least, the procedure is inconvenient and time intensive for patients. Given the additional expenses of x-ray angiography related to active physician involvement during the procedure, obligatory use of endovascular devices and contrast media, and patient recuperation, it seems probable that the financial impact of DS angiography may be considerable from an institutional and societal viewpoint.

To circumvent the need and risk for catheter-based angiography, less invasive imaging modalities have been advocated to monitor coil-treated aneurysms. Although computed tomography angiography is useful for delineating aneurysm morphology prior to intervention, the presence

### Table 4

**Comparative analysis of coil-treated aneurysms on DS and MR angiography**

<table>
<thead>
<tr>
<th>Classification</th>
<th>DSA</th>
<th>MRA</th>
<th>k Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of aneurysm occlusion†</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>11</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Class 2</td>
<td>14</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Class 3</td>
<td>19</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Parent vessel visualization</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>39</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td>5</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>0</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

† Aneurysm occlusion was graded based on the Raymond classification scheme (described in Roy et al. as follows: Class 1, total obliteration; Class 2, residual neck; Class 3, residual sac).
Magnetic resonance angiography for coiled aneurysms

of metallic coils will cause significant streaking (or “beam hardening artifact”) on the images that can render interpretation of any residual aneurysm impossible. Metallic coils may be very damaging to MR imaging, investigators have reported the use of follow-up 1.5-tesla MR imaging of coil-treated brain aneurysms, but examination of treated brain aneurysms with high-field MR angiography is rare.

Our analysis of 1.5-tesla MR angiography and angiographic images obtained in this patient cohort suggests excellent correlation between the two modalities when examining the aneurysm itself. Although paramagnetic susceptibility artifact from the platinum coil mass could theoretically lead to signal loss within the aneurysm fundus and obscuration of flow-related enhancement, we found that this was not a significant issue for visualization of the lesion. Magnetic resonance angiography consistently and reliably demonstrated residual aneurysm, even in the presence of saccular coils, when compared with x-ray angiography, with an intermethod kappa value of 0.86 that is indicative of excellent agreement. The MIP images of the vasculature were also able to replicate the fluoroscopic appearance of the coil-treated aneurysm and parent vessel. Importantly, MR angiography was also able to provide additional details of the aneurysm beyond conventional angiography. High-resolution axial TOF MR images provided detailed cross-sectional views through the aneurysm fundus, showing the degree of contrast filling within the coil mesh, which was not apparent on DS angiography (Fig. 2). This implies that MR angiography may be superior to DS studies in diagnosing the presence of persistent flow into the coil mass and fundus, which may be an imaging harbinger for future aneurysm recurrence.

Although based on previous experience with a canine model of sidewall and bifurcation aneurysms we may infer feasibility of MR visualization of the parent vessel through implanted stents, our own data in human patients show that intravascular microstents are associated with significant obscuration of local vascular anatomy on MR angiography. For imaging of the parent vessel associated with an aneurysm, our intermethod kappa value was lower (0.10), indicating poor correlation between MR and DS angiography. Most typically, we noted some degree of signal dropout on MR angiography that we believe is due at least in part to the influence of the adjacent coil mass. We found a possible statistical trend toward poor visualization of the parent vessel in patients harboring an intravascular stent, as opposed to those treated using coils alone (p = 0.22, chi-square test). We hypothesize that the presence of artifact and loss of spatial resolution in the stent-treated vessel is related to stent composition, although local flow turbulence through the stent struts may also be a factor.

In the quest to obtain more accurate noninvasive brain imaging, investigators have begun to use high-field 3-tesla MR imaging to investigate the cerebral vasculature, but examination of treated brain aneurysms with high-field MR angiography is rare.

Study Implications

Our analysis of 1.5-tesla MR angiography and angiographic images obtained in this patient cohort suggests excellent correlation between the two modalities when examining the aneurysm itself. Although paramagnetic susceptibility artifact from the platinum coil mass could theoretically lead to signal loss within the aneurysm fundus and...
phy would then become the preferred means of neuroimaging follow-up for patients with coil-treated brain aneurysms, a population that numbers in the thousands in North America, thereby mitigating the inherent pain, inconvenience, and risk to the patient that are associated with catheter angiography.

Conclusions

Magnetic resonance angiography is a promising and noninvasive method of assessing brain aneurysms treated by endovascular coil placement. High-resolution 1.5-tesla MR angiography correlates well with x-ray angiography in its ability to detect aneurysm remnants, and can demonstrate persistent blood flow into the coil-treated aneurysm that is not apparent on DS angiography. In the presence of an intravascular stent, however, visualization of the parent vessel may be limited due to artifact. For select patients with coil-treated brain aneurysms, high-resolution MR angiography may reduce the need for and frequency of invasive angiography.

Disclaimer

None of the authors has any financial interest in the devices or manufacturers mentioned in this study.

References

Magnetic resonance angiography for coiled aneurysms


Manuscript submitted August 31, 2006. Accepted February 15, 2007. Address reprint requests to: John H. Wong, M.D., M.Sc., Division of Neurosurgery, University of Calgary, Foothills Medical Centre, 1403–29th Street N.W., Calgary, Alberta, Canada T2N 2T9. email: jwong@ucalgary.ca.