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Sprengers, M.E.S.

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Chapter 2

MR angiography at 3T versus digital subtraction angiography in the follow-up of intracranial aneurysms treated with detachable coils

Charles B. L. M. Majoie
Marieke E. Sprengers
Willem Jan van Rooij
Cristina Lavini
Menno Sluzewski
Jeroen C. van Rijn
Gerard J. den Heeten

ABSTRACT

Background and purpose: To assess the feasibility and usefulness of 3-dimensional time-of-flight (3D-TOF) MRA performed at 3.0-Tesla compared to digital subtraction angiography (DSA) for the follow-up of coiled intracranial aneurysms.

Methods: In a prospective study, 20 consecutive patients with 21 coiled intracranial aneurysms underwent DSA, unenhanced and enhanced multiple overlapping thin slab acquisition (MOTSA) 3D-TOF MRA at 3.0-T on the same day at a mean follow-up of 6 months (range 4-14 months) after coil placement. MRA was evaluated for presence of artefacts, presence and size of aneurysm remnants and recurrences, patency of parent- and branch vessels and added value of contrast enhancement. MRA findings were compared to DSA.

Results: Interobserver agreement of MRA was good as was agreement between MRA and DSA. All three recurrences that needed additional treatment were detected on MRA. Minor disagreement occurred in 4 cases: 3 coiled aneurysms were scored on MRA as having a small remnant, while on DSA these aneurysms were occluded and the other aneurysm was scored on MRA as having a small remnant, while on DSA this was a small recurrence. The use of contrast material had no additional value. Coil-related MR imaging artifacts were minimal and did not interfere with evaluation of the occlusion status of the aneurysm.

Conclusion: High-spatial resolution 3D-TOF MRA at 3.0-T is feasible and useful in the follow-up of patients with intracranial aneurysms treated with coil placement.
INTRODUCTION

Endovascular treatment with detachable coils has become an established technique for patients with intracranial aneurysms. In 14-33% of cases the aneurysm may partially recur due to coil compaction or enlargement of a remnant, depending on the original size of the aneurysm, initial occlusion rate and length of follow-up. Therefore, all patients with coiled intracranial aneurysms are followed by Digital Subtraction Angiography (DSA) to identify aneurysm recurrence and to determine the subsequent need for additional endovascular or surgical treatment. DSA is, however, an invasive imaging technique that involves a small but significant risk of neurologic complications, estimated to occur in 0.3-1.8% of cases.

Previous in vitro studies have demonstrated that detachable coils are compatible with MR imaging in terms of safety and image quality both at 1.5-Tesla (T) and 3.0-T. Magnetic Resonance Angiography (MRA) is a safe and non-invasive imaging technique, which has become a realistic diagnostic option for the follow-up of coiled intracranial aneurysms, as demonstrated in previous studies performed on MR units with field strengths of 1.0-T or 1.5-T. Some of these studies advocate the use of contrast-enhanced MRA to increase sensitivity to detect residual flow. MRA at 3.0-T provides images with higher resolution than MRA at 1.5-T, and improvement of sensitivity to detect aneurysm remnants or recurrences is to be expected.

The purpose of our study was to prospectively assess the feasibility and usefulness of MRA, including unenhanced and contrast-enhanced multiple overlapping thin slab acquisition (MOTSA) 3-dimensional time-of-flight (3D-TOF) MRA, performed at 3.0-T as compared to DSA for the follow-up of aneurysms treated with detachable coils.

METHODS

Patients

Between November 2003 and July 2004, 20 consecutive patients (9 men, 11 women; 18 to 74 years old, mean 49 years) with 21 aneurysms (20 ruptured, 1 unruptured) underwent DSA and MR imaging on the same day, at a mean follow-up period of 6 months (range 4-14 months) after endovascular treatment with detachable coils (Guglielmi Detachable Coils, Boston Scientific, Freemont, CA). The local ethics committee approved the study and written informed consent was obtained from all patients. The locations of the aneurysms were as follows: anterior communicating artery (n=6), posterior communicating artery (n=5), middle cerebral artery (n=2), internal carotid artery (n=1), basilar tip (n=3), posterior inferior cerebellar artery (n=2), superior cerebellar artery (n=1) and anterior inferior cerebellar artery (n=1). The size of the aneurysms was 5 mm or less in 6, 6-10 mm in 11, and more than 10 mm in 4.

MR Imaging Techniques

All MR examinations were performed on a 3.0-T system (Philips Intera R10, Philips Medical Systems, Best, The Netherlands) using the sensitivity encoding (SENSE) phased array head coil (MRI Devices, Gainesville, FL). All patients underwent the same MR imaging protocol including axial T2-weighted fast spin echo, unenhanced and enhanced axial T1-weighted spin echo and MOTSA 3D-TOF MRA sequences. Imaging parameters for the T1-weighted spin echo sequence were 570/12 (TR/TE), 256x256 matrix (reconstructed to 512x512), 180-mm field of view, 90% rectangular field of view, 3-mm thick sections with a 0.3-mm gap. Parameters for the T2-weighted fast-spin echo...
sequence were 3394/80 (TR/TE), 400x400 matrix (reconstructed to 512x512), 230-mm field of view, 70% rectangular field of view, 5-mm thick sections with a 0.5-mm gap. The volume of the MOTSA 3D-TOF MRA was localized on a sagittal 2D phase-contrast scout image. A presaturation band was applied above the imaging volume in order to saturate incoming venous blood. For the MOTSA 3D-TOF MR sequence the parameters were as follows: 3D fast field echo T1-weighted sequence, 21/4 (TR/TE), flip angle 20°, 512x512 matrix (reconstructed to 1024x1024), 200-mm field of view, 85% rectangular field of view, 1.0-mm thick sections, interpolated to 0.5 mm, 160 slices acquired in 8 chunks. The measured voxel size of the MOTSA 3D-TOF MR sequence was 0.39x0.61x1-mm and the reconstructed voxel size 0.2x0.2x0.5-mm. Imaging time of the high-resolution MOTSA 3D TOF sequence was reduced by parallel imaging. For parallel imaging we used SENSE, a technique that uses multiple coil elements to encode spatial information in addition to traditional gradient encoding. Less gradient encodings are required, resulting in shorter scan times (27). By using the SENSE head coil with a SENSE reduction factor of 1.5, we could limit the acquisition time to 7 minutes and 14 seconds. Tilted optimized non-saturating excitation (TONE) was used in this protocol to optimize excitation profiles (3).

After the intravenous administration of 0.2 mL dimegluminegadopentetate (Magnevist; Schering AG, Berlin, Germany) per kilogram of bodyweight, the MOTSA 3D-TOF MRA and the axial T1-weighted spin-echo sequences were repeated. The T1- and T2-weighted images were obtained to evaluate the degree to which coils produce artifacts at 3.0-T. The T1-weighted spin echo images were also obtained to detect T1- shortening due to thrombus that may occasionally be interpreted as residual flow within the aneurysm on the MR angiogram.

The total examination time of the MRI scan was 45 minutes.

**DSA Technique**

DSA was performed after the MR examination on the same day at a single plane angiographic unit (Philips Integris Allura Neuro, Philips Medical Systems, Best, The Netherlands). Six to eight millilitres of non-ionic contrast material (iodixanol, Visipaque 320mgI/ml, Amersham Health, Cork, Ireland) were injected into the internal carotid or vertebral artery with a power injector at 4-6 ml/s. Three views were acquired in each patient, including the view that showed the aneurysm best at the time of embolization. 3D angiography was performed before endovascular treatment but was not performed for follow-up. Complications of angiography were recorded.

**Image Analysis**

Findings at follow up DSA were classified by two neuroradiologists in consensus, in conjunction with the pre-treatment DSA and the DSA performed during the coiling procedure. A remnant was defined as residual aneurysm filling (including a neck remnant, dog ear or residual filling in the aneurysm sac) present on the DSA immediately after coil placement. It was also called a remnant at the follow-up study if it did not increase in size. An aneurysm recurrence was defined as filling of the aneurysm at the follow-up study that was not present on DSA immediately after coil placement or as an enlargement of a remnant.

Two observers, blinded to follow-up DSA images, assessed MR images independently, together with the pre-treatment DSA and the DSA during the coiling procedure. Source images and multiple maximum intensity projections of MRA were both used. MRI was evaluated for artifacts, presence and size of aneurysm remnants and recurrences, patency of parent- and branch vessels, and added value of contrast enhancement. The contrast-enhanced MR angiograms were scored separately from the unenhanced examinations with an interval of 2 months. These were also evaluated for the
presence of venous overlap. For MRA, sizes of aneurysm remnants or recurrences were directly measured on a workstation and for DSA these sizes were estimated by comparison with the diameter of the internal carotid or basilar artery. Interobserver variability was assessed with kappa statistics. After the blinded study, discrepancies were resolved by consensus. Finally, the consensus data of the MR angiograms were compared to DSA findings.

Figure 1
Interobserver disagreement on MRA and disagreement between MRA and DSA on the occlusion of a basilar tip aneurysm after treatment with coils.
A. DSA immediately after treatment with coils shows complete aneurysm occlusion.
B. Unenhanced MOTSA 3D TOF MRA 5 months after treatment shows filling of the aneurysm neck (arrow), which was interpreted by one observer as a 2 mm remnant and by the other observer as a 2 mm recurrence. During the consensus reading it was scored as a remnant. Note minor signal loss in the proximal P1-segment of the left posterior cerebral artery.
C. DSA study 5 months after treatment with coils. This examination was interpreted as occlusion.

Figure 2
Posterior communicating artery aneurysm with small neck remnant 7 months after treatment with coils.
A. Axial unenhanced MOTSA 3D TOF MRA source image demonstrates a 2-mm neck remnant (arrow).
B. Unenhanced MOTSA 3D TOF MR target MIP image also shows small neck remnant (arrow).
C. DSA confirms the presence of a small neck remnant (arrow).
RESULTS

MRA and DSA were of sufficient quality in all patients. One patient had a transient visual deficit related to DSA, there were no complications from MRA.

Interobserver agreement for the identification of aneurysm occlusion, remnant or recurrence with MRA was good (kappa=0.77; 95% CI: 0.54-1.0), with a full agreement in 18 of 21 aneurysms (86%). Disagreement occurred in 3 cases: one observer interpreted 3 coiled aneurysms as having a 2mm remnant, while the other observer judged these as occluded in 2 and as a 2mm recurrence in 1 (Figure 1). Correlation between MRA and DSA was good (kappa=0.70; 95% CI: 0.44-0.95), with full agreement in 17 of 21 aneurysms (81%) (Table 1), including 9 occlusions, 5 remnants (Fig 2) and 3 recurrences (Figures 3 and 4). Of the 5 remnants, 4 measured 3mm or less and one 5mm. Of the 3 recurrences, 2 measured 4mm and 1 measured 6mm. The 3 recurrences were additionally treated with coiling in 2 and clipping in 1. Disagreement between MRA and DSA occurred in 4 cases: 3 coiled aneurysms were scored on MRA as having a 2mm remnant, while on DSA these were judged as occluded (Figure 1). Another aneurysm was scored on MRA as having a 2mm remnant, while on DSA this was scored as a 2mm recurrence (including a 1mm remnant) due to minor coil compaction (Figure 5). This small recurrence did not require additional treatment.

Enhancement of venous structures was present on all contrast-enhanced 3D TOF MR angiograms, but venous overlap did not interfere with image interpretation. The use of contrast material had no additional value in the evaluation of the occlusion status of the coiled aneurysms (Figure 3), nor to the evaluation of parent- or branch vessel patency (Figure 6).

A high signal intensity rim artefact was present on T1- and T2-weighted MR images around 16 of 21 (76%) coiled aneurysms (Figure 3a), and around 3 aneurysms (14%) on MRA. This rim artefact was less pronounced on the MRA images than on the T1-weighted and T2-weighted images and did not interfere with interpretation of the occlusion status of the aneurysms. On the 3D-TOF axial source images the high signal intensity rim was not observed at the neck area. A large high signal intensity area due to clot containing methemoglobin was observed on the T1-weighted and MRA images in 1 giant and partially thrombosed posterior inferior cerebellar artery aneurysm. This was, however, not present at the neck area and did not influence the evaluation of the occlusion status. Coil-related signal loss mimicking narrowing of parent or branch vessels was observed in 7 of 21 aneurysms (33%), both on unenhanced and contrast-enhanced MRA, but it did not prevent evaluation of the aneurysm neck (Figures 6 and 1). These 7 aneurysms included three anterior communicating artery aneurysms, one posterior communicating artery aneurysm, one middle cerebral artery aneurysm, one basilar tip aneurysm and one superior cerebellar artery aneurysm. Artifactual occlusions of parent or branch vessels were not observed.
Figure 3
Middle cerebral artery aneurysm with high signal intensity rim artifact and recurrence 6 months after treatment with detachable coils.
A. Axial fast spin echo T2-weighted MR image (3394/80) shows a 2-mm rim of increased signal intensity around the coils (arrow).
B. Axial unenhanced MOTSA 3DTOF MRA source image demonstrates recurrence of the aneurysm.
C. Unenhanced MOTSA 3D TOF MR angiographic image shows recurrence (arrow).
D. Contrast-enhanced MOTSA 3D TOF MR angiographic image shows the same recurrence (arrow).
E. DSA confirms the recurrence (arrow).

Figure 4
Anterior communicating artery aneurysm with recurrence 8 months after treatment with coils.
A. DSA shows large anterior communicating artery aneurysm.
B. Complete occlusion after coiling.
C. Axial unenhanced MOTSA 3D TOF MRA source image obtained 8 months after treatment demonstrates recurrence (arrow).
D. Unenhanced MOTSA 3D TOF MRA demonstrates recurrence (arrow).
E. DSA 8 months after treatment confirms the presence of recurrence due to coil compaction (arrow).
**DISCUSSION**

We found a good interobserver agreement on 3.0-T MRA and a good agreement between 3.0-T MRA and DSA in the evaluation of the occlusion status in the follow up of coiled aneurysms. One small recurrence due to coil compaction was interpreted as a remnant on MRA: subtle changes in the coil mesh configuration that indicate compaction are more easily appreciated on (non-subtracted images of) DSA. MRA showed three 2mm remnants, not demonstrated on DSA. The detection of these small remnants may be attributed to the high resolution of our MOTSA 3D-TOF MRA technique at 3.0-T and to the fact that follow-up DSA was performed in 3 projections, while on MRA any projection was available. These small remnants may have been obscured by the overlying coil mesh on the DSA projections. We did not perform 3D angiography for the follow-up of coiled cerebral aneurysms since the large difference in density between the platinum coils and the contrast agent in the vessels precludes thresholding the 3D dataset in a way that both the coil mesh and the vessels are visualized simultaneously. One may argue that knowledge of the findings of the pretreatment DSA and of the DSA performed immediately after the coil procedure might have influenced the interpretation of the MR angiograms in the present study. We however believed that this method of image analysis resembled clinical practice and was, therefore, justified.

MRA at 1.0-T and 1.5-T has been shown to be useful in assessing the occlusion status of aneurysms treated with detachable coils. In most of these studies remnants and recurrences are combined as residual flow. Sensitivity of 1.0-T and 1.5-T MRA ranges from 60 to 100% and the specificity from 90% to 100%. MRA at a higher field strength results in a more efficient suppression of the background tissue as the T1 longitudinal relaxation time (on which the magnetic labelling is based) is longer. The higher field strength also provides better signal to noise ratio, which is beneficial for detecting and resolving small vessels, aneurysm remnants and recurrences. The use of small voxels reduces intravoxel dephasing. Our study was limited to the evaluation of MRA at 3.0-T compared with DSA. Therefore we cannot draw any conclusion with respect to the added value of MRA at 3.0-T compared with MRA at 1.0 or 1.5-T.

In general, sensitivity of MRA is limited by flow saturation caused by turbulent or slow flow in aneurysm remnants. These saturation effects may be reduced by the use of the MOTSA 3D-TOF MRA technique at 3.0-T.
technique instead of a single volume 3D-TOF. MOTSA 3D-TOF MRA minimizes signal loss due to spin saturation, maintains small voxels and short TE to minimize intravoxel phase dispersion and allows larger imaging volumes. With MOTSA 3D-TOF MRA at 3.0-T we were able to reconstruct a voxel size of 0.2x0.2x0.5mm, and aneurysm remnants and recurrences smaller than 3 mm could be detected.

**Contrast-Enhancement**

Contrast-enhancement may reduce saturation effects on 3D TOF MRA and dynamic ultra-fast MRA, improving the visualization of giant aneurysms and large remnants or recurrences of aneurysms treated with coils. Contrast-enhanced 3D-TOF MRA also benefits from imaging at 3.0-T. T1-shortening in enhanced blood combined with T1-lengthening due to increased field strength in background tissues improves blood-to-background contrast. However, the use of intravenous contrast material had no additional value in the current study. Saturation reduction by the use of the MOTSA technique and the absence of large remnants or recurrences in our relatively small study of 21 aneurysms may explain the lack of added value of contrast administration.

**Figure 5**

Disagreement between MRA and DSA on the occlusion status of a posterior inferior cerebellar artery aneurysm 14 months after treatment with coils.

A. DSA immediately after coiling shows a small area of residual filling (arrow).

B. Unenhanced MOTSA 3D TOF MR angiographic image 14 months after treatment shows flow in the aneurysm neck, which was interpreted as a 2mm remnant by both observers.

C. DSA shows filling of the aneurysm neck (arrow), which was interpreted as a 2mm recurrence (including a 1mm remnant) due to coil compaction. Both observers thought that additional treatment for this small recurrence was not indicated.
Figure 6
Anterior communicating artery aneurysm with coil-related signal loss in parent and branch vessels.
A. Axial unenhanced MOTSA 3D TOF MRA source image obtained 8 months after treatment shows narrowing of the anterior communicating artery (arrow). No neck remnant or aneurysm recurrence was found.
B. Unenhanced MOTSA 3D TOF MR angiographic image shows narrowing of the anterior communicating artery (arrow) and the proximal part of both A2-segments of the anterior cerebral arteries (arrowheads).
C. Enhanced MOTSA 3D TOF MR angiographic image shows similar narrowings as described in (b).
D. DSA shows complete occlusion of the aneurysm without narrowing of parent- and branch vessels

Coil-related Artifacts
The platinum coil wires can produce susceptibility artifacts, although previous studies found a relative lack of susceptibility effects of coils in vitro and in vivo at 1.5-T.9,10,14 At higher field strength increased susceptibility artifacts from paramagnetic substances are expected. In an in vitro study of MR compatibility of detachable coils at 3.0-T, however, only minor susceptibility artifacts were found in the readout direction on gradient-echo sequences.11 Magnetic field mapping showed no induced field inhomogeneity.11 Also, no change in temperature was measured during movement into the imager bore or within the bore and no evidence of deflection of the coil mass was found.24 At 3.0-T, we found a high signal intensity rim artifact on T1-weighted spin echo and T2-weighted fast spin echo sequences around the coil mesh in most aneurysms, but on MRA around only 3 aneurysms. This artifact did not interfere with interpretation of the occlusion status because the high signal intensity rim was not observed on the 3D-TOF axial source images at the neck area.
Coil-induced signal loss mimicking parent and branch vessel narrowing or occlusion has been described previously on 3D-TOF MRA images.16-18 This signal loss may prevent evaluation of the parent artery and aneurysm neck in up to 11% of cases on 1.5-T.18 Although this artifact was observed in 7 (33%) of 21 coiled aneurysms in our study, it was not so severe as to prevent evaluation of the aneurysm neck.

CONCLUSION
We conclude that MOTSA 3D-TOF MRA at 3.0-T is feasible and useful in the follow-up of patients with intracranial aneurysms treated with coil placement. Aneurysm recurrences and remnants are accurately depicted. Imaging artifacts are minimal. The use of intravenous contrast material had no additional value. MRA might become the primary imaging method for the follow-up of coiled aneurysms. Larger studies are warranted to validate these conclusions and to evaluate the added value of MRA techniques at 3.0-T compared with those performed at lower field.
REFERENCES


