

review

Advances in contrast-enhanced MR-angiography: Indications and limitations

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Introduction. Gadolinium(Gd)-enhanced three-dimensional (3D) magnetic resonance angiography (MRA) is a newer technique that provides high resolution data rapidly for depiction of both arteries and veins throughout the body.

Conclusions. Contrast-enhanced 3D MRA represents a milestone for non-invasive vascular imaging. While its clinical utility has already been established in many vascular territories, the continuous development of hard- and software, as well as of new contrast agents, will likely result in a further widening in the spectrum of indications. Delayed 3D acquisitions of the kidney, ureters and bladder can be performed routinely to demonstrate and characterise obstruction, delayed function, filling defects and masses. Some patients are not candidates for MRA because of pacemakers, some kind of stents or immobilisation coils that cause considerable artifacts and obscure important structures. The resolution of CE-3D-MRA is lower compared with that of conventional angiography and visualisation of small peripheral arteries is limited.

Key words: magnetic resonance angiography – methods; contrast media

Introduction

Gadolinium(Gd)-enhanced three-dimensional (3D) magnetic resonance angiography (MRA) is a newer technique that provides high resolution data rapidly for depiction of both arteries and veins throughout the body.¹

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Improvements in gradient technology now allow an entire volume of 3D-Gd-enhanced MRA to be performed at 4 second intervals. It is now possible to acquire several volumes of high temporal resolution 3D data sets in a 10-20 second breath hold. Because it relies on T1 shortening effects of circulating Gd-chelate contrast media and not inherent flow characteristics, Gd-enhanced 3D-MRA can often depict pathologic vascular segments that are not adequately visualised using unenhanced flow based MRI-techniques. In addition, Gd-enhanced 3D-MRA provides volumetric data that can be processed for multiplanar refor-

mation (MPR) and maximum intensity projection (MIP) viewing.

This article will review the basic techniques for MR-angiography with contrast media and the potential applications of MRA will be discussed with particular emphasis on the 3D-contrast-enhanced technique.

Clinical applications

Paramagnetic contrast agents shorten the T1 relaxation time of blood. Gadolinium has a high relaxivity and a favourable safety profile when bound to a chelate.² During the short intravascular phase the intravenously injected T1-shortening contrast agent provides a signal in the arterial or venous system, thereby enhancing the vessel to background contrast to noise ratio and eliminating flow artifacts. Hence signal of flowing blood is no longer flow-dependent. Flow-induced artifacts seen with time of flight (TOF) or phase contrast MRA are therefore largely eliminated. This allows coverage of large vascular territories in short imaging times and generates images, which are similar in appearance to conventional contrast angiography.

Beyond the absence of ionising radiation, side effects of the paramagnetic contrast agents used for the examination are rare. Paramagnetic contrast agents are non-nephrotoxic and have a low incidence of allergic reactions. They are safe for use in patients with renal insufficiency as well as in patients with a history of allergic reactions to iodinated contrast media.

To achieve maximal T1-weighting, the sequence employed should be spoiled.³ Repetition and echotimes should be chosen as short as possible; a flip angle ranging between 20° and 45° provides adequate suppression of the surrounding tissues and has been shown to render excellent image quality.

Section thickness should be adjusted to between 1.5 and 2.5 mm in order to assure for

full coverage of the vascular system under consideration and still permit multiplanar reformations.

Breath-holding is crucial for achieving a good 3D-MRA image quality in the thorax and abdomen. The breath-hold interval can be increased by allowing the patient to practise before the exam and by providing some oxygen through a nasal canula.

It is essential to inject sufficient paramagnetic contrast agent to reduce arterial blood T1 to well under the T1 of surrounding tissues. Even though most extracellular agents available in European markets are approved up to a dose of 0.3 mmol per kg, cost considerations require careful dosing independent of the vascular territory under consideration. A dose ranging between 0.1 and 0.2 mmol per kg body weight is sufficient for most single-territory artery imaging protocols. Display of the run of arteries in multiple stations requires administration of the maximum allowable dose of 0.3 mmol per kg body-weight.⁴

If data collection is sufficiently fast for time resolved imaging, optimal image quality is virtually guaranteed in at least one of the collected data sets. Otherwise, timing of the contrast bolus is crucial (with a test bolus injection or automated bolus detection). The use of an automated injector facilitates contrast timing and delivery as it allows precise infusion of paramagnetic contrast using predefined weight adjusted rates and volumes. Maximal contrast concentration in the vessel of interest should be achieved during the acquisition of the central, contrast-determining portion of k-space.³

Image analysis

Analysis should not be limited to viewing maximum intensity projections but instead should include evaluation of reformatted images in all three planes and should include also the evaluation of the source images, viewed interactively on a work station.

1. Pulmonary arteries: Using a breath hold technique, the pulmonary artery tree can be visualized to its periphery (Figure 1). Contrast-enhanced 3D-MRA has also been shown to be a safe and reliable technique for the detection of pulmonary embolism. Emboli are clearly identifiable on the reformatted images as filling defects.⁵
2. Aorta: Contrast-enhanced 3D-MRA is emerging as the imaging modality of choice for assessing the whole aorta as an organ. Employing the described strategy all relevant disease processes of the aorta as well as the major neck and arm vessels can be fully depicted on the 3D-MR-angiography images. The possible complex morphology of the diseased aorta and/or its branches may result in an inadvertent exclusion of important portions of the arterial anatomy from the 3D imaging volume. Therefore it is important to carefully con-

duct the localising process using breath-hold techniques. Stenoses are visualized as well as aneurysmal dilatations. Congenital lesions, such as coarctations, are particularly well suited for analysis with this technique. In addition, surgical grafts are well depicted. Furthermore MRA provides comprehensive analysis in suspected aortic dissection: The extent and relationship to branch vessels can be fully depicted and the true lumen can be separated from the false lumen (Figure 1).⁶

For evaluation of the aorta the advantages of cross sectional imaging over conventional catheter angiography is well established.

Furthermore it is possible to evaluate the renal arteries to the level of the renal hilum, as well as the superior mesenteric artery and even the celiac trunc and the inferior mesenteric artery.

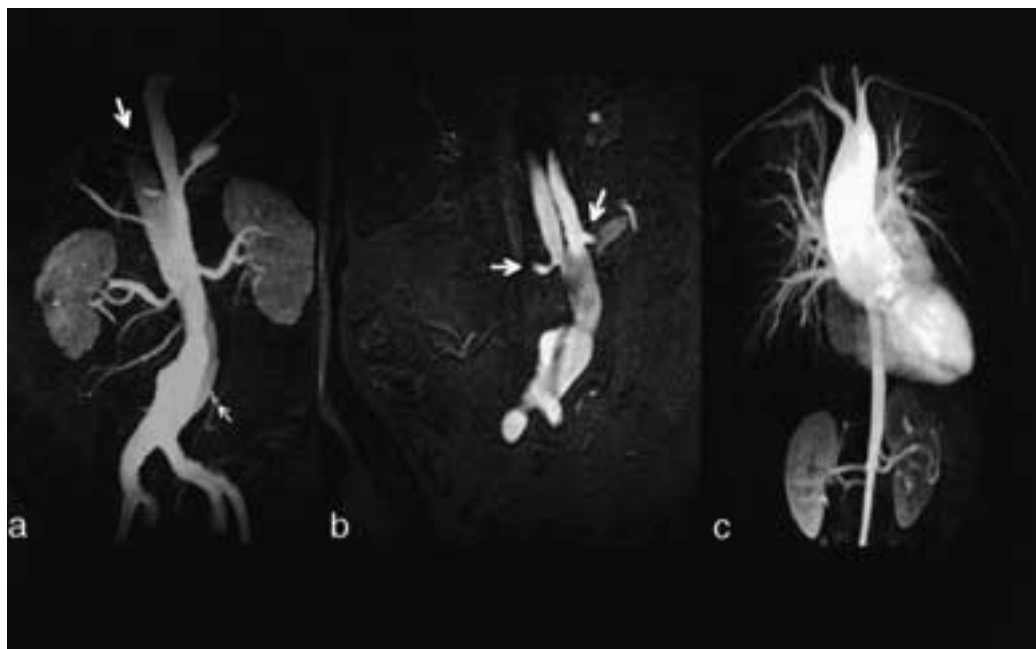


Figure 1. MR angiography of the aorta showing

1. dissection (a,b) with exact delineation of true and false lumen and the dissection membrane, notice inferior mesenteric artery.
2. ascendens aneurysma in Marfan's Syndrom (notice also pulmonary arteries).

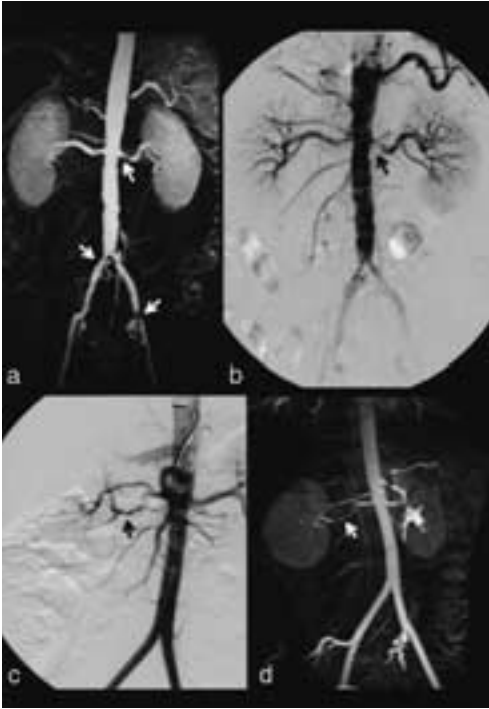


Figure 2. Renal angiograms showing
 1. exact correlation between a) MRA and b) conventional angiography regarding the high grade renal artery stenosis with better delineation of pelvic artery stenoses in MRA.
 2. discrete renal artery irregularities in fibromuscular dysplasia in d) MRA and c) conventional angiography.

With sensitivities and specificities up to 100 % it appears likely that the 3D-MRA techniques will replace conventional angiography (Figure 2) as a primary means for the assessment of renal artery disease.⁷ 3D-MRA is also the modality of choice for assessing complex arterial anatomy following renal transplantation.

3. Peripheral vessels: Also in the peripheral vasculature the contrast-enhanced approach offers several advantages over conventional MRA-techniques including rapid acquisition without arterial puncture. This technique uses several 3D-MRA-acquisitions in conjunction with movement of the MRA-scanning table to follow the bolus of contrast into the lower extremities (Figure 3).^{8,9}

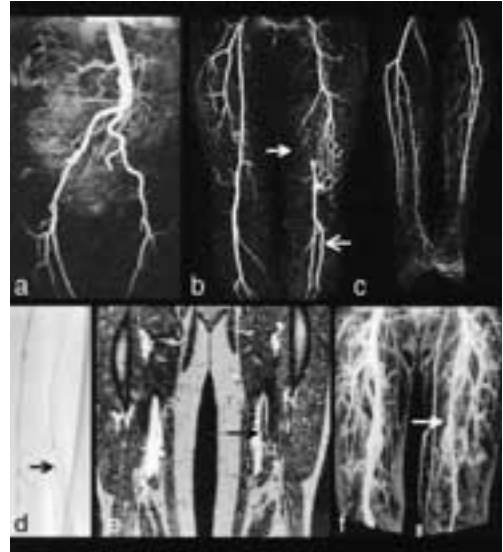


Figure 3. MR angiography of the outflow-tract:
 1. with Gadolinium (a,b,c): chronic long occlusion of the left femoral superficial artery and double popliteal artery
 2. with blood pool agent (e,f): fresh thrombus visible in the superficial femoral vein according to conventional phlebography (d).

Three or even more 3D-data-sets, each consisting of 30 to 40 images are collected at set intervals over the lower extremities, resulting in a morphologic display of the entire run off system. To avoid venous overlap, which might mask patent arterial segments, imaging has to be completed before a too much contrast is present in the venous system. Therefore, for moving bed imaging a low infusion rate for the administration of contrast agent (0.3 to 0.6 ml per sec) is recommended to minimize venous enhancement. So the clinically relevant vascular pathologies are well displayed as confirmed in recent studies. Contrast-enhanced 3D-MRA achieves sensitivity and specificity values exceeding 90 % in differentiating non-significant from haemodynamically significant stenosis.

4. Whole body 3D-MRA: Since arteriosclerotic disease affects entire arterial system, extended coverage allowing the concomi-

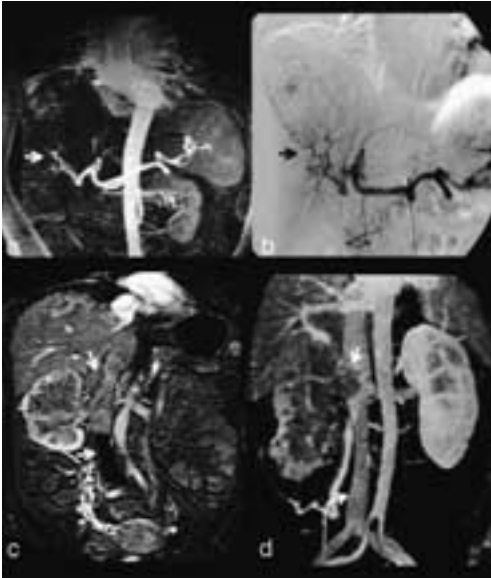


Figure 4. Abdominal angiograms in oncologic patients:

1. showing preembolization feeding vessels in a) MRA and b) conventional angiography (hepatocellular carcinoma).
2. differentiation between c) tumour thrombus (proximal) and clot (distal) in the VCI (renal cell carcinoma) and d) partial tumor ingrown with patent VCI (also renal cell carcinoma).

tant assessment of the arterial system from supraaortic arteries to the distal run of vessels appears desirable. Five 3D data sets are collected over 72 seconds during a continuous contrast infusion lasting 60 seconds. It allows displaying of the arterial vascular tree from supraaortic arteries to distal run of vessels in a single examination lasting nearly 72 seconds.¹⁰

Extended coverage including the entire arterial vascular tree, high diagnostic accuracy, non-invasiveness, lack of side effects and very short examination times combine to open interesting perspectives regarding the use of this technique for vascular disease screening.

5. Systemic veins

Evaluation of the systemic veins not only of the abdomen with 3D-MRA is usually

optimal on the second or third postcontrast acquisition. Applications include evaluation of patients with suspected venous thrombosis, vascular extension by renal, hepatic or other tumors and evaluation of anatomic anomalies of the inferior vena cava and systemic veins (Figure 4).¹¹

Future developments

Blood pool or intravascular contrast agents are large enough that they do not leak out of the capillaries but stay within the intravascular compartment for more than 1 hour.² At this time it appears likely however, that these agents will enhance imaging of the venous system as well as of the coronary arteries (Figures 3 e,f).

Conclusions

Contrast-enhanced 3D MRA represents a milestone for non-invasive vascular imaging. While its clinical utility has already been established in many vascular territories, the continuous development of hard- and software, as well as of new contrast agents, will likely result in a further widening in the spectrum of indications. Including MR-imaging MRA allows the one-stop shop examination of the most pathologies of the abdomen, neck and extremities as well as the thorax. Delayed 3D acquisitions of the kidney, ureters and bladder can be performed routinely to demonstrate and characterise obstruction, delayed function, filling defects and masses. CE-3D-MRA is not without limitations. Some patients are not candidates for MRA because of pacemakers, some kind of stents or immobilisation coils that cause considerable artifacts and obscure important structures. The resolution of CE-3D-MRA is lower compared with that of conventional angiography and visualization of small peripheral arteries is limited.

References

1. Prince MR, Yucel EK, Kaufman JA, Harrison DC, Geller SC. Dynamic gadolinium-enhanced three-dimensional abdominal MR arteriography. *J Magn Reson Imaging* 1993; **3**: 877-81.
2. Knopp MV, von Tengg-Kobligk H, Floemer F, Schoenberg SO. Contrast agents for MRA: future directions. *J Magn Reson Imaging* 1999; **10**: 314-6.
3. Stollberger R, Aschauer M, Hausegger KA, Tiesenhäusen K, Ebner F. Kontrastmittelverstärkte MR-Angiographie in Atemanhaltung. *Biomedizinische Technik* 1998; **43**: 15-7.
4. Goyen M, Ruehm SG, Debatin JF. MR-angiography: the role of contrast agents. *Eur J Radiol* 2000; **34**: 247-56.
5. Meaney JF, Weg JG, Chenevert TL, Stafford Johnson D, Hamilton BH, Prince MR. Diagnosis of pulmonary embolism with magnetic resonance angiography. *N Engl J Med* 1997; **336**: 1422-7.
6. Rofsky NM. MR angiography of the aortoiliac and femoropopliteal vessels. *Magn Reson Imaging Clin N Am* 1998; **6**: 371-84.
7. Hany TF, Debatin JF, Leung DA, Pfammatter T. Evaluation of the aortoiliac and renal arteries: comparison of breath-hold, contrast-enhanced, three-dimensional MR angiography with conventional catheter angiography. *Radiology* 1997; **204**: 357-62.
8. Ho KY, Leiner T, de Haan MW, Kessels AG, Kitslaar PJ, Engelshoven JM. Peripheral vascular tree stenoses: Evaluation with moving bed infusion – tracking MR angiography. *Radiology* 1998; **206**: 683-92.
9. Ruehm SG, Hany TF, Pfammatter T, Schneider E, Ladd M, Debatin JF. Pelvic and lower extremity arterial imaging: diagnostic performance of 3D contrast-enhanced MRA. *AJR* 2000; **174**: 1127-35.
10. Goyen M, Quick HH, Debatin JF, Ladd ME, Barkhausen J, Herborn CU, et al. Whole body 3D MR angiography using a rolling table platform: initial clinical experience. *Radiology* 2002; in press
11. Obernosterer A, Aschauer M, Schnedl W, Lipp RW. Anomalies of inferior vena cava in patients with iliac venous thrombosis. *Ann Intern Med* 2002; **136**: 37-41