Diagnosis of renal artery stenosis with magnetic resonance angiography: update 2003

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Keywords: magnetic resonance angiography; parenchymal disease; renal artery stenosis; vascular disease

Introduction

Three-dimensional (3D) gadolinium magnetic resonance angiography (MRA) has been established as a safe and reliable technique for detection and grading of renal artery stenosis. Due to the lack of need for nephrotoxic contrast agents and ionizing radiation, this technique is particularly attractive for patients with kidney transplants or those with renal failure. With the introduction of high performance MR systems with fewer upfront costs and cheaper maintenance, the technique has gained widespread use even in community hospitals and private practices.

Despite its overall significant role in the diagnostic work-up of patients with renal artery stenosis, the technique currently faces several new challenges to be overcome. Although a reproducible quality of the 3D gadolinium MRA images with a high level of accuracy has been well documented in numerous studies, doubts have been cast on the results recently by new data from multicentre trials [1,2]. These studies question the initially reported high sensitivities and specificities exceeding 95%. However, at the same time, the evolution of the 3D gadolinium MRA technique itself has continued, and therefore new data on MRA with improved spatial resolution might again lead to more optimistic results. A second problem, which has been well documented recently by a number of authors, is the high interobserver variability of the technique, which directly contributes to the ambiguous results [3–5]. Thirdly, renal artery stenosis is now viewed as only one manifestation of a systemic arteriosclerotic process. Recent improvements of MR scanners now allow coverage of large anatomic areas in a single scan, thereby offering the possibility to screen almost all vascular territories of the human body [6]. Finally, several studies have shown that patients with renal artery stenosis often do not improve after angioplasty despite technical success [7]. Therefore, the severity of stenosis cannot be considered a valuable predictor of post-intervention improvement.
MR imaging offers a unique possibility for both non-invasive morphological and functional imaging, including assessment of blood flow and tissue perfusion. In the following, an update is provided on a comprehensive morphological and functional MR imaging protocol that allows many of the current diagnostic challenges to be addressed.

New technical developments: high resolution renal MRA and extended anatomic coverage

Compared with digital subtraction angiography (DSA), the spatial resolution of 3D gadolinium MRA used to be substantially lower, by a factor of 3–5. It is important to remember that the achievable spatial resolution of 3D gadolinium MRA is a compromise of anatomical coverage and scan time in a single breath-hold, resulting in typical voxel sizes of \(~1.5 \times 1.5 \times 1.5\) mm. Therefore, 3D gadolinium MRA was notorious for over- and underestimating the exact degree of stenosis when compared with DSA. The recent introduction of parallel acquisition techniques allows the spatial resolution to be doubled in the same scan time [8,9]. Thus, at present, data sets with isotropic spatial resolution of \(<1\) mm\(^3\) can be acquired in breath-hold times of \(~20–25\) s (Figure 1). Using multiplanar reformats, the exact morphology of the stenosis can be viewed in any plane, thereby substantially reducing misinterpretation of the degree of stenosis (Figures 1 and 2). Preliminary results show improved agreement with DSA. However, it must be pointed out that DSA by itself has limitations in cases of eccentric stenoses or tortuous vessels in which assessment of the exact morphology of the stenosis requires a high level of operator experience as well as multiple views at various angles to image the stenosis in-plane. This results in a high level of operator dependency. On the contrary, in 3D gadolinium MRA, the most diagnostic imaging plane can be reformatted after the study on a workstation (Figure 1).

For accessory renal arteries, good results have been reported for the evaluation of kidney donors prior to transplantation with regard to the correct identification of the absolute number and location of supernumery vessels [10]. So far, however, no large study is available with respect to grading of accessory renal artery stenoses. While hypertension can result from the stenosis of an accessory renal artery, the therapeutic impact of the correct identification of such a lesion remains unclear, as these stenoses cannot be easily addressed by vascular interventions.

The high-resolution MRA techniques can be combined with automatic table movement in the MR scanner, thereby allowing assessment of not only the renal artery but also the peripheral arterial vascular tree in high resolution after a single contrast media injection [6]. It is well documented that patients with severe peripheral arterial disease reveal renal artery stenoses in a large percentage of cases [11]. Thus, these patients can now be assessed effectively for both the peripheral arteries and the presence of a renal artery stenosis in a single non-invasive study without putting the patients at risk for nephrotoxic contrast agents.

In addition, this assessment of the major vascular territories can be easily combined with an evaluation of cardiac function and perfusion (Figure 3). Several studies have shown that renal artery stenosis is an independent risk factor for death secondary to myocardial hypertrophy and coronary artery disease [12]. MR imaging offers a unique possibility to add absolute measurements of cardiac functional parameters such as ejection fraction, end-diastolic and end-systolic volume, as well as measurements of regional cardiac tissue perfusion to angiographic studies of the renal arteries (Figure 3). While the coronary arteries themselves can still not be imaged reliably by 3D gadolinium MRA, the assessment of cardiac perfusion under pharmacological stress provides valuable
Feasibility of a comprehensive morphological and functional evaluation: experience of 5 years

More than 5 years ago, a comprehensive morphological and functional MR imaging protocol for detection and grading of renal artery stenoses was introduced using time-resolved 3D gadolinium MRA as well as cardiac-gated phase contrast flow measurements [13]. This approach allows not only a grading of the morphological degree of stenosis but also an assessment of the haemodynamic significance of the stenosis by means of time-resolved velocity curves in the renal artery. Agreement between the morphological degree of stenosis and changes in the pattern of the flow profile has been well documented in both animal and human studies [14,15]. In particular, the loss of the so-called early systolic peak has been established as a sensitive indicator of the loss of the autoregulatory capacity and onset of significant mean flow reduction. In addition to the assessment of haemodynamic significance, the flow measurement technique provides a functional grading of the degree of stenosis independent of the accurate assessment of stenosis morphology (Figure 2). Thus, the two techniques of flow and MRA can be used for a combined interpretation of renal artery stenosis. A multicentre trial has shown that this combined approach allows a significant reduction in interobserver variability and an improvement of overall accuracy compared with DSA, with sensitivities and specificities exceeding 95% [16]. The authors believe that the discussion of the accuracy of 3D gadolinium MRA, as recently initiated by data from the RADISH study, can be addressed effectively by the use of such a comprehensive MR protocol that does not base its assessment on the morphological degree of stenosis alone [2] (Figure 2). In addition, several papers have reported poor interobserver agreement for both DSA and MRA alone, which can be explained in part by the fact that the exact measurement of the degree of stenosis is subject to a high level of interobserver dependence as well as a variable definition of the measurement criteria [3–5]. The comprehensive protocol of MRA and flow was shown to reduce interobserver variability significantly [16].

Another advantage of the MR flow measurement technique is the fact that it can still be applied after...
stent placement in the renal artery, while grading of the morphological degree of stenosis on the 3D gadolinium MRA images is not possible due to artefacts and signal void from the metal stents.

A recent report in the New England Journal of Medicine has again highlighted the fact that renal artery stenosis comprises only a small entity in a large complex of overlapping diseases ranging from essential hypertension to primary parenchymal disease of the kidney [17]. The high incidence of co-existing parenchymal disease can be considered as one important factor explaining the observation that a substantial number of patients do not improve after revascularization of renal artery stenosis. Parenchymal disease can result from both primary causes such as diabetes or glomerulonephritis and secondary causes resulting from long-standing renal artery stenosis with the consequence of ischaemic kidney disease. Recently, quantitative perfusion measurements of the kidney have been introduced, which offer an independent measure of parenchymal blood flow in the renal cortex as well as the medulla [18]. There is increasing evidence that MR techniques based on the assessment of renal perfusion allow renal function to be assessed independent of the presence of renal artery stenosis [19]. Changes of these quantitative parameters have been found in patients with primary parenchymal disease in whom no underlying renal artery stenosis was present. Thus, these techniques appear to be promising for the separation of renovascular disease from parenchymal causes. So far, absolute quantification of parenchymal blood flow has only been possible with the use of intravascular contrast agents. While several of these agents (both gadolinium chelate-based and iron oxide-based compounds) currently are being evaluated in phase 2 and phase 3 trials, none of them has as yet been approved for clinical use outside control trials. With the use of faster MR techniques such as saturation recovery perfusion imaging, semi-quantitative assessment of renal parenchymal perfusion has now become feasible [20] (Figure 4). Thus, perfusion imaging can be easily integrated at present in a complete comprehensive MR examination.

A number of other functional MR techniques exist, such as captopril-enhanced MR renography or diffusion imaging of the kidneys, which have also been shown to assess adequately the haemodynamic significance of stenosis. However, these techniques have not been used for the evaluation of primary renal parenchymal disease in a larger number of patients.

Fig. 3. A 63-year-old patient with the suspicion of a renal artery stenosis because of arterial hypertension, not completely controlled by antihypertensive drugs. High-resolution 3D gadolinium MRA of the entire body with the moving table technique (A) reveals normal renal arteries with an accessory renal artery on the left as well as a complete normal assessment of the peripheral arterial vessels and carotid arteries. However, cardiac-gated perfusion imaging (satura-
tion recovery gradient echo technique) of the heart demonstrates a large septal perfusion defect suggestive of significant coronary artery disease (B). Imaging of cardiac function with a steady-state free precession gradient echo technique (TrueFISP) shows thinned, hypokinetic myocardium (C–E).
Fig. 4. A 64-year-old male with bilateral renal artery stenoses. High-resolution 3D gadolinium MRA (top) shows bilateral high-grade stenoses exceeding 80% reduction of vessel diameter. Colour-coded semi-quantitative maps (bottom) from dynamic gadolinium perfusion imaging show the right kidney still adequately perfused, while there is a substantial decrease of the perfusion on the left, confirming the presence of unilateral ischaemic kidney disease.

Impact on patient management

Recently, the use of the resistive index in ultrasound has proved to be a highly valuable parameter for the prediction of patient improvement after interventional balloon angioplasty of renal artery stenosis [21]. Given the fact that renal artery stenosis is an independent factor for 5-year patient survival, it is important to select carefully those patients who would benefit from an intervention [22]. The role of the prediction of outcome after interventional or operative revascularization has not been fully established yet for MR imaging. The potential to differentiate patients with predominant renovascular or renoparenchymal disease based on a single comprehensive MR examination could lead to an important role for this technique in the near future [19]. Currently, comparative studies using both ultrasound and MR imaging prior to and after revascularization are ongoing.

In summary, the high diagnostic accuracy of the technique, the assessment of both haemodynamic and functional changes and large anatomic coverage make MR imaging a highly attractive method for the detection, grading and differentiation of renovascular disease.

References


