Non-contrast enhanced renal MR angiography – why now?

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Background to magnetic resonance angiography

The potential to use MRI for angiography has been realised since the 1980s. Early techniques were non-contrast methods using the difference in signal between flowing blood and stationary tissue. Time of flight (TOF) and phase contrast (PC) techniques became widely used by the early 1990s but had many drawbacks. Though an advantage of these methods was reliance on intrinsic contrast rather than an injected contrast medium, they were lengthy and prone to artefacts. TOF angiography, for example, requires flow perpendicular to the direction of acquisition to maintain a supply of fresh spins entering the imaging slice. Though PC angiography could overcome this by acquiring data in more than one plane, it takes much longer. In consequence, MRA was applied mainly in the carotid and intracranial circulation. The length of acquisitions and resulting motion artefacts limited further application in the body.

This changed in the mid-1990s following the introduction of contrast-enhanced MR angiography (CE-MRA). Over the next decade, this method became established for imaging an ever wider variety of vascular territories. This was possible because of developments such as improved gradient performance, centric k-space filling which reduced venous contamination by allowing early filling of central k-space and, later, parallel imaging.

Single breathhold contrast-enhanced MRA became a valuable screening test, particularly for renal artery stenosis, with high sensitivity and specificity compared to the gold standard, intra-arterial catheter angiography. Some limitations remained, for example limited sensitivity for fibromuscular dysplasia and small accessory arteries.

The resurgence of non-contrast enhanced MR angiography (NCE-MRA)

Though the rise of contrast-enhanced MRA seemed inexorable, two factors changed this. The first was the cost of gadolinium-based contrast media. Though this cost became accepted in some wealthier economies, it remained a limitation in many parts of the world and the development of non-contrast techniques continued. In particular, the use of ECG-gated fast spin echo techniques showed potential in the peripheral arterial tree.

The second change was the recognition of nephrogenic systemic fibrosis (NSF). This is a fibrotic condition of skin and other organs occurring in a small proportion of patients with end stage renal failure who have been administered gadolinium agents. It is thought to be the result of limited stability of the gadolinium chelate. With modifications in practice the incidence of this condition has fallen dramatically. However, particularly as the patient cohort requiring MRA often has impaired renal function, there has been renewed interest in non-contrast MRA techniques.

What non-contrast MRA techniques are available?

ECG gated 3D fast spin echo

The first technique to gain clinical use as an alternative to contrast enhanced MRA was ECG gated fast spin echo imaging of the peripheral arterial system, developed by Miyazaki and a group at Toshiba. There is signal from slow flow in veins throughout the cardiac cycle. In the arteries, signal is obtained during diastole but during systole the high velocity results in spin dephasing and low signal. These differences are exploited to generate a subtraction arteriogram.

Balanced steady-state free precession (SSFP)

This technique has been the most successful in imaging of the renal vessels. It has been established in clinical practice for some years to study the heart and great vessels. In their conventional form, balanced steady-state gradient echo sequences (FIESTA by GE, balanced FFE by Philips and TrueFISP by Siemens) provide good contrast between high signal blood and the vessel wall or cardiac chamber, but show high signal in both the arteries and veins. This can be very useful, for example in studying the extent of tumour thrombus in the inferior vena cava of patients with renal cell carcinoma (figure 1).

To obtain a renal arteriogram without background or venous signal requires additional modifications. A 180°
inversion pulse is used to invert all signal in a volume including kidneys and renal vessels. At the inversion time when longitudinal magnetisation is close to zero for most tissues in the volume, a 3D SSFP sequence will provide readout only from tissue with longitudinal magnetisation, ie the fresh spins entering the volume from arterial blood. An additional fat suppression pulse is applied because of the rapid T1 recovery of fat. The scan is usually respiratory triggered. The physical principles of non-contrast techniques are discussed in more detail in a previous review for this publication.6

Advantages of non-contrast renal MRA in practice
There are advantages in avoiding the use of intravenous contrast medium in patients in terms of cost and safety. Patients referred for renal artery imaging often have impaired renal function and avoiding gadolinium administration removes the risk of NSF. Other idiopathic reactions are well reported, with an estimated incidence of 0.17%7 and are generally mild and self-limiting, such as nausea, hives and, very rarely, anaphylaxis. Intravenous cannulation and the associated morbidity are also avoided. This reduces scanning delays and patient anxiety.

Unlike a non-contrast study, CE-MRA can only be attempted once at an attendance. Errors in timing of contrast infusion, patient movement or poor breath-holding can result in a non-diagnostic study.

Diagnostic accuracy of NCE-MRA
The quality of diagnostic images, accessory detection (figure 2) and lesion assessment appear to be similar for CE-MRA and NCE-MRA.7,8 Some authors7,9 have described a tendency to over-estimation of some renal artery stenoses compared to CE-MRA.

NCE-MRA has some diagnostic advantages over CE-MRA. It has been observed that segmental and intra-renal branches of the main renal arteries are better demonstrated at NCE-MRA (figure 3). Only the arteries return high signal in a non-contrast study. Parenchymal enhancement occurs in contrast-enhanced MRA and can obscure distal vessels, particularly in the subtracted image dataset.

NCE-MRA has been shown to demonstrate accessory vessels with high accuracy. In our experience it demonstrates some accessory vessels not seen at CE-MRA, but has limitations. Some accessory arteries may not be seen in their entirety because a limited scan volume is acquired in the axial plane. This may result in accessory arteries with origins at a distance from the main renal arteries, such as those arising from iliac arteries, being excluded from the imaging volume.9 For this reason we always acquire a contrast study in the coronal plane as well as an NCE-MRA if this is critical, for example in assessing transplant donor renal vascular supply.

The sensitivity for fibro-muscular dysplasia remains to be defined. An example diagnosed using NCE-MRA is shown with catheter angiography correlation (figure 4). There is distal signal loss on the non-contrast study because of poor flow distal to a severe stenosis. Good correlation between a non-contrast study and an arterial study showing a proximal renal artery stenosis is demonstrated (figure 5).

NCE-MRA is more successful in healthy individuals with a normal cardiac output and little vascular disease (such as potential renal transplant donors). This is because higher arterial flow rate results in higher signal to noise ratio. This limitation can in part be overcome by increasing field strength and caution needs to be exercised in the use of parallel imaging to avoid signal reduction at the expense of short scan duration.

FIGURE 2
Non-contrast 3D maximum intensity projection of a normal patient demonstrating multiple renal arteries on either side.

FIGURE 3
Non-contrast 3D maximum intensity projection of the renal arteries in a normal patient demonstrating excellent visualisation of the whole renal artery and its distal branches with an aneurysm of the intrarenal branches on the right.

FIGURE 4a
Non-contrast study with poor signal in the main renal artery due to a stenosis secondary to fibromuscular dysplasia (FMD), recognised at MRA.

FIGURE 4b
Digital subtraction angiography confirming the findings of the MRA in figure 4a, with the typical angiographic appearance of FMD.
Conclusion
NCE-MRA has several advantages. It does not require the use of intravenous gadolinium chelates or breath-holding and has good sensitivity and specificity for stenoses and accessory vessels compared to contrast studies. It may overestimate stenoses compared with CE-MRA and omit the origins of distant accessory arteries from the imaging volume. However, it provides a real alternative to CE-MRA without the cost and attendant risks of a gadolinium contrast agent.

References