Peripheral Vascular Surgery and Magnetic Resonance Arteriography – a Review

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Objectives: to review the current status of lower limb MRA.


Materials and methods: twenty-eight articles, concerning non-enhanced MRA (13), gadolinium-enhanced MRA (14) or both (1), met the predefined requirement for quality.

Results: gadolinium-enhanced MRA (CE-MRA) seems to be more accurate, quicker and associated with fewer problems than non-enhanced (TOF) MRA. TOF-MRA has a sensitivity and specificity of 93% (range 64–100%) and 88% (range 57–100%) respectively, and CE-MRA presents values of 96% (range 71–100%) and 96% (63–100%), respectively, using conventional arteriography as the gold standard. Some articles report a substantial incidence of runoff vessels suitable for distal bypass visible on MRA but invisible on conventional arteriography. Gadolinium contrast is given intravenously and is generally well tolerated and has no known nephrotoxicity.

Conclusion: CE-MRA is accurate compared to conventional arteriography, has the potential to increase the limb salvage rate for selected patients, is non-invasive and well tolerated.

Key Words: Arterial occlusive diseases; Leg; Magnetic resonance angiography; Vascular surgical procedures.

Introduction

Successful surgical and endovascular arterial revascularisation is dependent on accurate and detailed imaging of the location and degree of the occlusive arterial lesions. Contrast arteriography (CA) has been considered as the imaging standard in evaluating peripheral arteries and planning treatment of lower limb ischaemia. However, CA has been questioned as the gold standard because it may fail to reveal patent infrapopliteal vessels in patients with multi-segmental occlusive lesions and low inflow pressure. Other imaging modalities, such as magnetic resonance arteriography or duplex ultrasound, have emerged as possible non-invasive alternatives and have been reported to show patent runoff vessels not visible on CA, but still suitable for a distal bypass.1,4

Furthermore, a non-invasive alternative to CA is attractive due to a small but significant risk of serious complications of 2–3% using the transfemoral technique.10–12 With this review, the authors wish to present the current status of MRA of the lower limb with special attention to areas of interest for the vascular surgeon.

Magnetic Resonance Arteriography

Magnetic resonance arteriography (MRA) was experimentally introduced in the mid 80s in visualising major blood vessels of the neck, abdomen and thigh.13–16 Since the introduction, principally two different MRA techniques have been used in clinical imaging of vascular disease. Initially, time of flight MRA (TOF-MRA) where no injection of contrast material is needed,17,18 and more recently the contrast enhanced MRA (CE-MRA), using intravenous injection of gadolinium contrast.19

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**Time of flight magnetic resonance arteriography (TOF-MRA)**

Several studies concerning MRA prior to surgical and endovascular treatment has been reported since the introduction of the technique.\(^1\)\(^3\)\(^-\)\(^8\)\(^,\)\(^1\)\(^9\)\(^-\)\(^2\)\(^0\) TOF-MRA is based on the signal difference between moving protons in the blood and stationary protons in the vessel wall and surrounding tissue. A two-dimensional TOF-MRA technique has evolved as the preferred method despite several drawbacks. Imaging of the iliac arteries is complicated by their curved course relative to the acquisition plane, causing in-plane saturation effect that can lead to false-positive diagnosis of stenosis and occlusions. Artefacts caused by tri-phasic flow (pulsation artefacts) are also seen. TOF-MRA requires an acquisition time of approximately 60–120 min for a full lower limb examination. Different techniques, as ECG gating, have been introduced to eliminate some of these limitations and a pulse sequence that reduces the pulsation artefacts has evolved.\(^2\)\(^1\) Still, the TOF-MRA technique has never become a common alternative to CA, except in a few highly experienced centres.\(^3\)\(^5\)

**Contrast-enhanced magnetic resonance arteriography (CE-MRA)**

Within the last 5 years, gadolinium-enhanced three-dimensional magnetic resonance arteriography (CE-MRA) has been introduced. Gadolinium shortens the T1 relaxation of blood thereby increasing the intravascular signal. This means the inflow pressure is not as essential as in TOF-MRA or conventional contrast arteriography. Three-dimensional CE-MRA with short echotimes reduce the examination time; minimise clip-artefacts and artefacts caused by movements. When T1 of the arterial blood is reduced compared to the T1 of the surrounding tissue, the arteries will appear white. It is essential to inject sufficient gadolinium contrast in order to reduce the T1 relaxation time of blood far below the T1 relaxation time of the background tissue, where fat tissue has the lowest T1. Gadolinium is administrated intravenously and is associated with a much lower frequency of adverse reactions than iodinated contrast materials.\(^2\)\(^3\)\(^-\)\(^4\)\(^0\) There is no nephrotoxicity and maximum doses can be used safely in patients with renal insufficiency. When desirable, dialysis can speed up the gadolinium elimination in anuric patients.\(^2\)\(^5\)\(^-\)\(^2\)\(^7\) The total examination time is now less than 30 min for a full lower limb examination, with an acquisition time of 20–40 s for each station imaged. This allows data collection during a single breath-hold. A standard 1.5T MR scanner is satisfactory and special coils are not obligatory. (However, a dedicated lower extremity coil is beneficial in imaging small distal vessels.) The timing of the contrast injection is crucial. Although pump devices are convenient they are not mandatory.

CE-MRA can be performed as a multi-station exam, using a single slow infusion of contrast followed by series of MRA images at 3 stations using a special moving table.\(^1\)\(^9\) Alternatively, MRA can be performed as 1–3 series of separate contrast injections and image acquisitions, using image subtraction to eliminate the effect of the preceding contrast injection.\(^2\)\(^6\) Using only one station, super selective images with a minimum of venous or tissue signal, can be performed – i.e. visualising distal runoff.\(^6\) At present, no single method has emerged as the preferred option, each having different strengths and weakness.\(^2\)\(^7\)

**Material and Methods**

This review article is based on a MEDLINE search retrieving all English-language articles reporting diagnostic accuracy of MRA in peripheral occlusive arterial disease in the lower limb from January 1991 to October 2000. The search terms used were: peripheral vascular disease, peripheral arterial disease, extremities, lower limb ischaemia, claudication, arterial occlusive disease, arteriosclerosis, magnetic resonance angiography, gadolinium. Additional articles were obtained tracing citations from original articles. In order to evaluate the MRA-results, only studies fulfilling a set of predefined conditions were compared.

The conditions were: (1) only original and prospective studies; (2) only results concerning native arteries; (3) a clearly defined “gold standard” was mandatory, be it CA, intraoperative arteriography or intra-arterial pressure measurements; (4) haemodynamically significant lesions were defined as 50–99% stenosis or occlusion; (5) only studies presenting sensitivity and specificity or data allowing their derivation were included; (6) if results from more than one observer were reported, the results from the first observer were used; (7) results regarding a complete lower limb arterial segment were preferred, and if this was not available the results representing the segment with the worst result were used.

The reported sensitivity and specificity in the enhanced and the non-enhanced group were compared and presented as median and range.
Table 1. Time of flight MRA in arteries of the lower limb (TOF-MRA).

<table>
<thead>
<tr>
<th>Year</th>
<th>n</th>
<th>Author et al.</th>
<th>Segment</th>
<th>Fontaine grade III + IV (%)</th>
<th>Gold standard</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Kappa</th>
<th>Agreement (%)</th>
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Table 2. Contrast enhanced MRA of arteries of the lower limb (CE-MRA).

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<th>Author et al.</th>
<th>Segment</th>
<th>Fontaine grade III + IV (%)</th>
<th>Gold standard</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
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Results

Of 57 articles retrieved,1–6,14,15,18,19,21–68 28 were found to fulfill the above conditions; 13 concerning non-enhanced MRA, 14 concerning gadolinium-enhanced MRA and one concerning both techniques (Tables 1 and 2).

TOF-MRA

Reviewing the literature, TOF-MRA seems to perform well compared to CA with a reported sensitivity of 93% (range 64–100%) and specificity of 88% (range 57–100%) (Table 1). Except for one preliminary study comparing CA with TOF-MRA the sensitivity is above 71%.52 Using intraoperative arteriography (IOA) as the gold standard, Huber et al. reported a sensitivity of TOF-MRA as low as 51% in the crural and pedal arteries.45 More patent pedal segments were seen on IOA compared to MRA explaining the inferior MRA results. In a meticulous multicenter study, Baum et al. compared TOF-MRA and CA in 155 patients using intraoperative arteriography (IOA) as the gold standard.29 TOF-MRA had a sensitivity and specificity of 82% and 84%, respectively, and CA was found equivalent in diagnostic accuracy having comparable values of 77% and 92%, respectively.

CE-MRA

With a reported sensitivity of 96% (range 71–100%) and a specificity of 96% (range 63–100%) against CA, CE-MRA seems to perform as well as TOF-MRA – if not better (Table 2). This is in accordance with a recent meta-analysis by Nelemans et al. finding the diagnostic accuracy of CE-MRA superior to that of TOF-MRA.
using summary ROC analysis on 23 selected studies. Wikström et al. found that MRA, DSA and duplex ultrasound had identical diagnostic accuracy in the aorto-iliac region, using intra-arterial pressure measurements as the gold standard, with a reported CE-MRA sensitivity and specificity of 81% and 75%, respectively.

In another meta-analysis, Visser et al. evaluated CE-MRA and duplex ultrasound against conventional arteriography using summary ROC analysis. CE-MRA was found to be superior to duplex ultrasound and highly accurate compared to conventional arteriography, with pooled values of sensitivity and specificity of 98% and 96%, respectively.

Imaging of patients with poor runoff

In the majority of studies concerning both CE-MRA and TOF-MRA, CA is used as the gold standard despite its occasional failure to visualise runoff vessels seen on intraoperative arteriography.

Carpenter et al. and Owen et al. have focused on the ability of TOF-MRA to visualise CA-invisible runoff vessels. In approximately 10–20% of these patients, CA (with or without digital subtraction) failed to visualise runoff being visible on MRA and suitable for a distal bypass.

The same holds true for CE-MRA. In diabetes, Kreitner et al. used CE-MRA and found the incidence of invisible runoff vessels to be as high as 37% using a single station technique. A single station technique will improve the image quality compared to a multi-station technique, but the single station technique can only visualise a small part of the entire vascular tree – i.e. only the foot.

Discussion

Diagnostic performance

CE-MRA seems to be the preferred technique, outperforming TOF-MRA with respect to examination time and visualisation of the iliac and infrapopliteal arteries.

No clear-cut correlation has been found between the anatomic levels (i.e. iliac, femo-popliteal and infrapopliteal) and the diagnostic performance of MRA, be it TOF or CE. Baum et al. found that the accuracy of TOF-MRA as well as CA (IOA as the gold standard) decreased in the pedal segments, being comparable with the findings of Cambria et al. who found the highest incidences of major discrepancies (segments classified as insignificant diseased on one study and significant diseased on the other study) in the distal segments (iliac > femo-popliteal > crural > pedal). By contrast, other authors have found that TOF-MRA is superior to CA in visualising infrapopliteal runoff vessels.

When visualising the entire vascular tree of the lower limb with multi-station CE-MRA, depiction of the runoff arteries can be difficult due to contrast in the veins and tissue from the preceding contrast injections. Also, timing of the contrast bolus can be difficult, especially if there is significant proximal disease. In a recent study, Ruehm et al. found that the diagnostic performance of CE-MRA tend to be lower in the runoff arteries, but also found a frequency of approximately 4% for occult runoff vessels. Kreitner et al. found, using a dedicated single station CE-MRA technique, that CE-MRA was superior to DSA in revealing patient runoff arteries.

Having the inherent deficits of CA in mind, treatment of lower limb occlusive disease based only on CA may be problematic, as well as using CA as the gold standard in evaluating new imaging modalities. In order to use CA in evaluating MRA in the infrapopliteal segment some criteria for an adequate CA must be fulfilled, i.e. vessel opacification, soft tissue blush or imaging of unnamed collateral vessels and if necessary using vasodilatation.

In order to compare MRA and CA, some studies formulate and compare individual treatment plans based on the clinical information and either MRA or CA using the operation actually performed as the diagnostic standard, this being based on all available information (CA, MRA, clinical information, operative findings and intraoperative arteriography). This reporting method may be of more clinical relevance than using descriptive methods based on segment-to-segment agreement, but several unpredictable factors may influence the result, i.e. surgical traditions and experience.

Difficulties

Not all patients are suitable for MRA exams, be it TOF-MRA or CE-MRA, due to implanted metal, i.e. pacemakers, certain cerebral vascular clips and certain ontological prosthesis, where the magnetic field can cause heat or movements of the implant with possible fatal consequences. Other types of metal implants can cause artefacts that – although not dangerous – can
disturb the MRA, i.e. certain hip implants and surgical clips.

Respiratory and bowel movements can cause artefacts, a problem that is partly eliminated by the introduction of the contrast enhanced technique (CE-MRA) that reduces the acquisition time making “breath hold images” possible.

Postprocessing

For both TOF-MRA and CE-MRA, image postprocessing of the MRA-dataset is necessary using dedicated viewing/postprocessing software. For both MRA techniques, approximately 30 min is needed for image postprocessing.

Costs

Only a few cost analyses have been published, reporting TOF-MRA costs identical to very favourable compared to CA. The precise figures are not easy to obtain, but apart from the costs of equipment and contrast that are comparable for the two modalities, the major discrepancies are due to the costs of a short stay CA-admission and occasionally the need to treat procedure related complications. No observations or precautions need to be taken following MRA, being well preformed as an outpatient service. Compared to CA, no time-consuming compression of puncture site is necessary and complications associated with the arterial catheterisation are avoided.

Conclusion

In general, when reviewing the literature the agreement between CA and TOF- and CE-MRA in patients facing vascular reconstruction is good and is proven to be a promising non-invasive alternative to CA in presurgical planning. Contrast enhanced MRA is currently the “state of the art” MRA technique, overcoming the troublesome aorto-iliac region, reducing the examination time and increasing the accuracy compared to the previously TOF-MRA technique. In selected patients, both CE-MRA and TOF-MRA can demonstrate patent runoff vessels not seen on CA, possibly increasing the limb salvage rate. A future more frequent use of CE-MRA in the vascular clinic should be expected.

Acknowledgements

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J. P. Eiberg et al.

402


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