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Review

Whole-body magnetic resonance angiography

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Vascular disease, whether it be atherosclerosis, inflammatory, or hereditary vasculitide, is a systemic disorder with disease in one territory predictive of disease in another. Despite this, current approaches focus on single-territory assessment ignoring the global burden of disease. Advances in MRI have enabled us to surmount previous limitations and expand our approach to such conditions with the ability to simultaneously assess the entirety of the arterial tree in a single examination, allowing a staging examination as it were, of the vascular health in its totality. This review will cover the acquisition technique, reporting, clinical utility, and current evidence base for such an approach.

Introduction

Vascular disease, whether it be atherosclerosis, inflammatory or hereditary vasculitide, is a systemic disorder with disease in one territory predictive of disease in another.[1–3] Despite this, routine clinical assessment is typically restricted to a single vascular territory or, when multisite assessment is required, will be performed with multiple investigations over multiple visits to the hospital. A routine approach to the global detection and "staging" of vascular disease has yet to be ingrained in the vascular assessment. Part of this is the difficulty in performing whole-body (WB) staging and stratification of vascular disease: ultrasound cannot adequately visualise the deeper vessels, WB computed tomography (CT) involves radiation exposure, and historically, technical limitations have restricted magnetic resonance imaging (MRI) to single sites; however, although the former remain true, the latter has changed substantially in recent years. Advances in scanner hardware, the spatial and temporal resolution of modern sequences, table length, and the ability to scan during active table movement, means WB-MRA is now feasible and practicable in a routine clinical environment.[4] This article will explore the technique for WB-MRA, the analysis of the data obtained and the clinical scenarios in which WB-MRA should be considered.

WB-MRA technique

WB-MRA has been described using both 1.5 and 3 T clinical systems, with the only hardware requirements being surface coils to cover the WB, a dual pump injector system capable of separating contrast medium and saline injections, and a table with sufficient reach as to allow full-body coverage.[5,6] Similar technical success has been described at 1.5 and 3 T; however, 3 T systems offer the benefit of a twofold increase in signal-to-noise ratio (SNR) and an associated fourfold increase in contrast-to-noise ratio (CNR) secondary to longer T1 relaxation times exerted by contrast medium at the higher field strength when the same contrast medium dose is used.[7] As a result higher

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image resolution can be achieved with a smaller volume of contrast medium required with previous work showing contrast medium dose reduction from 40 ml to 25 ml at 3 T without a significant reduction in the SNR.[8]

For the acquisition of the WB-MRA, several techniques have been described including the acquisition of four body stations using either a single prolonged injection[9]; two separate contrast injections with two stations acquired per injection[10]; and a continuously moving table technique.[11] Of these, both our group and others have found the two separate bolus injection technique offers the most consistent results in terms of achieving peak arterial enhancement and optimal image quality.[8,12,13]

Patients are imaged head first and supine without the need for manual repositioning mid-protocol. Surface coils are used to cover the entirety of the body (Fig 1). This typically requires separate head, neck, spine, two body matrices, and peripheral angiography coils. This arrangement makes full utility of the maximal achievable SNR at each site maximising spatial resolution, which is essential given the 20 seconds acquisition window for MRA.

Imaging of the WB is acquired in four separate numbered stations as follows: (1) head and neck vessels extending to the level of the diaphragm, (2) abdominal vessels, (3) upper aspect of the lower limb, and (4) lower aspect of the lower limb. WB time-of-flight (TOF) scouts are used for mapping the orientation of the vessels for planning the aforementioned stations. Once the scout sequences for the individual stations are acquired, pre-contrast mask sequences are obtained of stations 1 and 4 using a three-dimensional (3D) gradient echo sequence. Subsequent to this, the first contrast medium injection is administered via a single 20 G intravenous cannula sited in the antecubital fossa. Contrast medium is administered via a MRI-compatible contrast medium pump injector with contrast medium injection volumes and rates as used in the published literature are described in Table 1.[14] Sagittal oblique fluoroscopic MRI images of the thoracic aorta are used, with signal acquisition triggered when the contrast reaches the aortic arch. Angiographic image acquisition of station 1 and then

Figure 1 Body coil set-up for performing WB-MRA.

Table 1
Injection protocols available in the literature for the dual bolus injection technique.

	First injection[a]	Second injection[a]
0.5 M Gadolinium-based contrast medium agent		
1.5 T	20 ml at 1 ml/s	20 ml at 1 ml/s
3 T standardised	10 ml at 1 ml/s	15 ml at 1.5 ml/s
3 T weight adjusted (0.3 mmol/kg)	40% total volume at 1ml/s	60% total volume at 1 ml/s
1 M Gadolinium-based contrast medium agent		
1.5 T (0.2 mmol/kg diluted to 60 ml)	Biphasic injection protocol: 1.3 and 0.7 ml/s	

[a] All protocols use a 10–30 ml saline bolus to immediately follow each contrast medium injection.

station 4 is performed with three sets of volumetric data for station 4 obtained to optimise calf vessel enhancement. A 10-minute delay between contrast medium injections is advised to allow for contrast medium washout and reduce artefact from venous contamination.[8] Following this delay, the second contrast medium injection is administered, this time coronal oblique fluoroscopic MRI images of the abdominal aorta are used to time MRA acquisition, with acquisition of station 2 triggered when contrast medium reaches the abdominal aorta, immediately followed by station 3. See Table 2 for typical sequence acquisition parameters. A breath-hold for station 3 should be performed when the primary purpose of the examination is to evaluate the renal arteries. Adjustment for height is typically done by increasing or reducing the degree of overlap of the stations. In exceptionally tall individuals (>200 cm), where the four stations cannot capture the entire vascular tree, we would recommend excluding the cranial component, with addition of a 3D TOF sequence to compensate for the loss of this.

The whole examination including set-up would usually take approximately 40 minutes. Despite the risk of the seemingly restrictive nature of the WB coils potentiating patient claustrophobia, we have found this to be highly tolerable both in healthy volunteers and patients. Locally we have performed over 1,700 scans with this technique with a <5% drop out rate due to inability to tolerate the examinations to date which is of equivalence to our routine clinical MRI.[15–17]

Future technical advances in WB-MRA acquisition

Dual-injection protocols were originally adopted to reduce the effects of venous contamination experienced with single-injection methods and to allow for more reliable arterial phase imaging due to sensitive control of bolus timing; however, as MRI sequence acquisition times become shorter with parallel imaging and under-sampling a re-examination of the benefits may have to be performed. Fenchel *et al.*[6] demonstrated successful outcomes in WB-MRA with a single contrast medium injection and a 3 T scanner in just 60 seconds (excluding preparation and scouts) using enhanced parallel imaging techniques. Image quality was deemed to be very good with the exception of

Table 2
Image acquisition parameters at 3 T for a combined whole-body magnetic resonance angiography (WB-MRA) and cardiac magnetic resonance imaging (MRI) protocol.

Description	WB-MRA	WB-MRA	Cardiac	Cardiac	Cardiac	WB-MRA	WB-MRA
Location	Station 1	Station 4	Heart	Heart LV	Heart LV	Station 2	Station 3
Sequence	3D TurboFLASH	3D TurboFLASH	2D bSSFP	2D bSSFP	2D PSIR	3D TurboFLASH	3D TurboFLASH
Cardiac phases	–	–	25	25	–	–	–
ECG gating	–	–	Retro	Retro	Pro	–	–
Lines/segment	–	–	14	26	25	–	–
Orientation	Coronal	Coronal	4ch, 3ch & 2ch	SA	SA	Coronal	Coronal
TR/TE (ms)	2.68/1.00	2.61/0.96	3.37/1.48	3.40/1.50	5.21/1.99	2.60/0.96	3.47/1.21
FA (°)	19	22	>50	>50	20	16	37
FOV (mm)	360×500	360×500	>360	>360	>360	344×500	344×500
Phase FOV (%)	71.9	68.8	84.4	84.4	75.0	68.8	71.9
Section thickness (mm)	1.1	1.0	6.0	6.0	6.0	1.3	1.4
No. sections	96	80	1	2	2	96	96
Matrix (pix)	313×512	277×448	216×256	173×256	144×256	264×512	242×448
Voxel size (mm)	1.0×0.8x1.1	1.1x1.1x1.4	Variable	Variable	Variable	1.1x0.9x1.0	1.0x0.9x1.3
Parallel imaging	×3	×3	×2	×2	×2	×3	×3
K-space	Linear	3D centric	Linear	Linear	Linear	3D centric	3D centric
BW (Hz/pix)	700	700	930	930	287	700	740
Scan time (s)	18	14	<20	<20	<20	14	16

bSSFP, balanced steady state recovery; BW, bandwidth; ECG, electrocardiogram; FA, flip angle; FLASH, fast low angle shot; FOV, field of view; i-PAT, integrated parallel acquisition technique; LV, left ventricle; Pro, prospective; Pix, pixels; PSIR, phase sensitive inversion recovery; Retro, retrospective; SA, short axis; SSFP, steady state free procession; TE, echo time; TR, repetition time; 2ch, two chamber; 3ch, three chamber; 4ch, four chamber.

abdominal stations, raising the possibility that this technique might produce suboptimal images in larger patients. A further advance is the development of new moving table hardware, which allows for the acquisition of WB images in a single continuous head-to-toe movement rather than in individual stations. The feasibility of this has been shown by Naguib *et al.*[11] who performed WB-MRA using a Tim-CT platform at 1.5 T. The total scan time was quick at around 7 minutes (inclusive of scout sequences and planning) and the examination was completed with a single contrast medium injection. Although the overall data appears promising, only around half of the assessed vascular segments were noted to be excellent or good, with 22% being satisfactory and 15% being inadequate for analysis, which is significantly below the current bar set by dual-injection protocols. With evolving protocols, this is a technique to be further explored in achieving a quickly obtained and clinically useful dataset. Similarly, an alternative avenue, which holds potential for substantial benefits in the time efficiency of the procedure, is the mDIXON sequence, which allows partial background suppression without the need for a pre-contrast volume for subtraction.[18]

Tailoring WB-MRA protocols

Given the two-stage injection/scanning protocols and the requirement of a suitable time interval between them, a dead space exists in the WB-MRA protocol that can be capitalised on according to the underlying indication. Given that most scans are performed for atherosclerosis, one of the most frequently used is the addition of cardiac MRI with left ventricular assessment and late gadolinium enhancement sequences. Such an approach has been demonstrated to be feasible, both in the combined examination of WB-MRA and cardiac MRI including the assessment of cardiac structure, function, and late gadolinium enhancement (LGE), useful for detection of scarring, and in the addition of neuroimaging for detection of prior stroke.[19,20] In our experience combining the WB-MRI protocol with cardiac cine sequences and LGE sequences only incrementally increases examination time from a mean of 40–51 minutes (although this does not include additional time setting up the ECG). See Fig 2 for the order of sequence acquisition in the combination of these. Coronary MRA is another potential use of this time, which would ideally complement the remainder of the WB-MRA being the most significant vascular territory not covered with this technique; however, although coronary MRA sequences are improving, they are still some way off routine clinical use outside specialist centres.[21] Alternately, in high-risk groups, such as diabetics with pedal symptoms or those with peripheral neuropathy, dedicated sequences of the feet have been utilised with good results, with abnormal findings in 25% of such patients in one study of WB-MRA.[22]

Although WB MRA provides an extensive arterial luminal assessment of stenosis and occlusion, which may be attributable to atherosclerosis, other underlying arterial pathological processes, such as large vessel vasculitis, dissection, or fibromuscular dysplasia (FMD), may be suggested by the patient history or site and morphology of stenoses. In such cases, WB MRA may require supplementary MRI sequences to be acquired. These may include contrast-enhanced T1-weighted imaging for wall enhancement in keeping with large vessel vasculitis, T1 and T2-weighted imaging in cases suggestive of dissection. If FMD is suspected, it is recognised that high-resolution imaging with CT may be more sensitive than MRA, and so WB MRA should not be used to exclude the diagnosis of FMD. In addition, incidental findings of arterial pathology may also require additional imaging such as arteriovenous malformation.

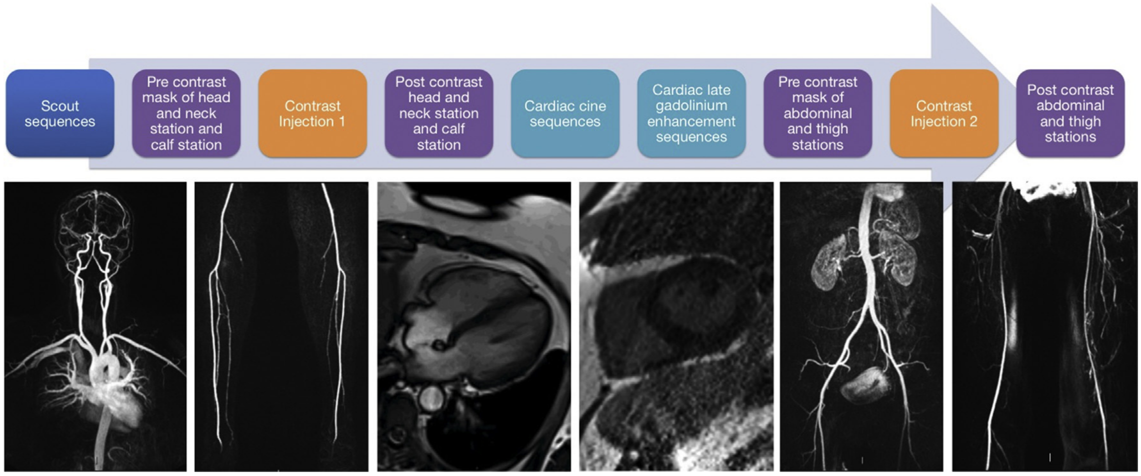

Figure 2 Schematic of the order of sequence acquisition for integrated WB-MRA and cardiac MRI.

Alternate MRI techniques

Although gadolinium-based agents are currently the agent of choice in contrast-enhanced vascular imaging, there is a growing burden of literature supporting the use of ultra-small superparamagnetic iron oxide-based contrast agents in vascular imaging.[23] To date, this has been used mainly for single-site vascular imaging; however, there is a single case series in paediatric patients with chronic kidney disease demonstrating its potential for WB vascular imaging.[24] Given its long vascular half-life, this holds significant potential for WB angiography, where its vascular steady state can be capitalised on to improve spatial resolution and image quality compared to first-pass image acquisition.[25,26]

Venous access can often be challenging, particularly in those with chronic diseases, in addition to which those with severe chronic kidney disease are at risk of nephrogenic systemic fibrosis (NSF) secondary to gadolinium-based agents. Although MRA provides excellent luminal assessment, it does not provide any information on the plaque causing the stenosis, and can miss non-stenotic atheroma with positive vessel remodelling. Unenhanced techniques, which obviate the need for cannulation and/or provide arterial wall assessment, are thus an attractive option. A multitude of unenhanced medium protocols are currently used in clinical practice for regional MRA, some of which have been available for decades with others being only more recently pioneered. These include TOF, phase-contrast (PC), black blood (BB), ECG-gated fast-spin echo, bSSFP (balanced steady state free precession), bSSFP with arterial spin labelling, and QISS (quiescent interval steady state) sequences. Each has its respective strengths and weaknesses and numerous studies have been published comparing these to contrast-enhanced MRA, the examination of which is beyond the scope of this article. To date, none of these have been used to obtain unenhanced WB-MRA, although in a healthy volunteer, the feasibility of combining multiple different non-contrast medium sequences tailored to each of the arterial territories in the body has shown to be feasible.[27] This will no doubt continue to be an exciting area of development in years to come.

Analysis and quantification of vascular disease

Reporting of WB-MRA images is not any different to the reporting of routinely performed regional MRA. The increased coverage does, however, increase the chance of incidental findings, which are particularly frequent in the cohort typically seen for WB-MRA assessment (see Fig 3); however, to simply report the location and severity of stenosis, while clinically useful, potentially overlooks the additional information, such a systemic assessment brings. There are several scoring systems that attempt to address this issue. Although each is distinct and separate from one another, they all contain the same key themes: the scoring of the major arteries according to the maximum degree of stenosis in each, followed by the summation of these results. The most published of these is the "standardised atheroma score" as described by Weir-McCall.[16] In this technique, the vascular system is split into 31 vessels, with each scored following a five-point scoring system based on the maximal luminal stenosis: 0=normal vessel; 1=<50% stenosis; 2=50–70% stenosis; 3= >70% stenosis; and 4=completely occluded vessel (Fig 4). Such scores have been shown to be highly reproducible in both those with and without known cardiovascular disease, and to correlate highly with cardiovascular risk factors.[16,19,28] Regardless of the precise formula used, the prognostic power of this summative data has been well established in several studies. Lundberg *et al.* demonstrated that the atheroma burden better predicted major adverse cardiovascular events than traditional risk scores, carotid intima media thickness, or ankle-brachial pressure index in 305 seventy-year olds.[29] Bamberg *et al.* showed similar findings in a diabetic cohort with the atheroma score predictive of both single and recurrent cardiovascular events.[30,31] They found that the atheroma score was a stronger predictor than any

Figure 3 Selection of incidental findings on WB-MRA including a cerebral arteriovenous malformation (arrow), inflammatory arthritis (arrowhead), and lung malignancy (asterisk).

regional vessel analysis, evidence of prior stroke on cranial MRI, or the presence of ventricular systolic dysfunction or late gadolinium enhancement on cardiac MRI, demonstrating the prognostic strength of a systematic vascular assessment. These findings have also been replicated in a clinical cohort of peripheral arterial disease (PAD) patients with the atheroma score being the only independent clinical or imaging variable predictive of all-cause mortality at 6-year follow-up[32]; however, there remain many unanswered questions with further work required to determine what the best scoring system is, what its implications are in those of low-intermediate cardiovascular risk, and how best to use these data to better tailor and guide intervention in a manner that improves patient related outcomes.

Clinical applications

Atherosclerosis

That arterial disease does not occur in isolation has been widely accepted in the literature for many years.[1] Having intermittent claudication as a marker of arterial disease confers a risk of cardiac death of up to three- or four-times more than those without, while cardiac death accounts for up to 75% of deaths in these patients.[33–35] Multi-site cardiovascular disease further portends a poor outcome, being a stronger independent predictor of mortality than recent cardiovascular events.[36] Pursuant to this, there have at varying times, been attempts to utilise surrogate markers to predict the likelihood of significant morbidity with the intention of gaining this knowledge to reduce risk of cardiovascular disease by instigating preventative measures; however, scoring mechanisms based on clinical variates largely employs probability of the effect of the risk factors. Scoring systems such as the Framingham risk score have been shown to significantly overestimate risk in higher risk individuals.[37] Direct visualisation of clinical and subclinical atherosclerosis offers an opportunity to go beyond this to provide witness to the extent of disease already in situ.

The ability of WB-MRA to detect and quantify atherosclerotic burden has been well evidenced in both symptomatic and asymptomatic cohorts. Laible *et al.*[5] showed

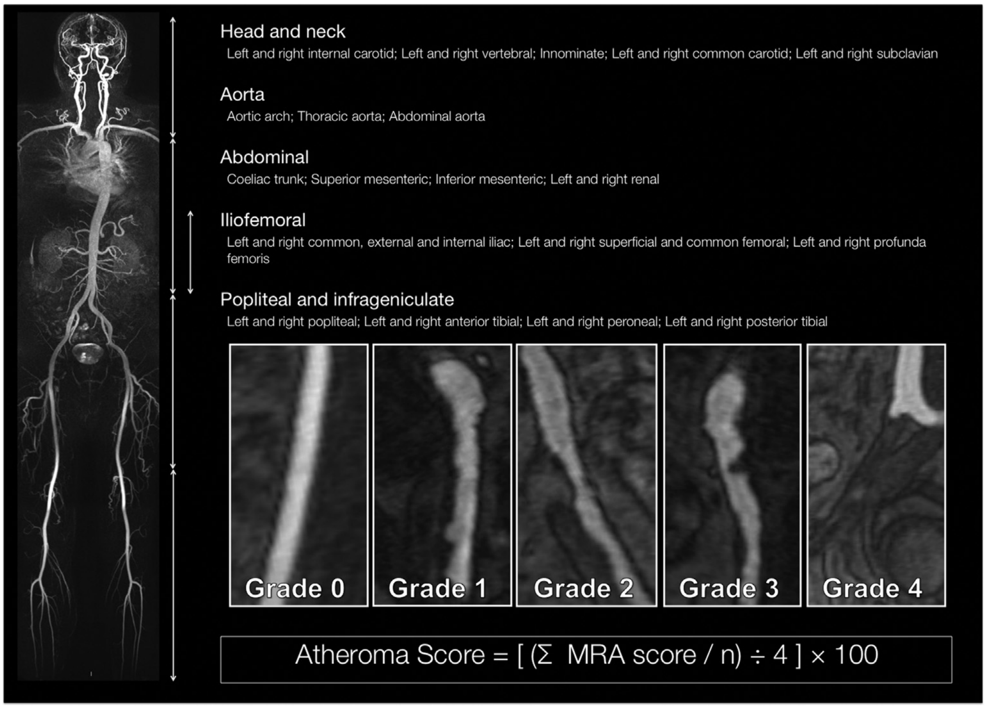

Figure 4 Example of a whole body atheroma scoring system. The WB-MRA is separated into 31 vessels (described on the right) with each scored according to their degree of stenosis. This score is then summated, normalised to the number of assessable segments and then divided by four and expressed as a percentage of the maximum possible score. Adapted from Duce *et al.*[15]

that subclinical vascular disease was present in 27% of a cohort of 138 individuals free from cardiovascular disease. Weckback *et al.*[22] have shown the high prevalence of occult atherosclerotic disease in a prospective case–control population of 65 well-treated longstanding diabetic patients, with 57% demonstrating at least one vessel with >50% stenosis, and with 50% of these lesions detected on WB-MRA not previously known about. In those with clinical cardiovascular disease WB-MRA detects occult significant stenotic disease (>50% stenosis) in 37–55% of those with coronary artery disease,[38–40] 33% of those with cerebrovascular disease,[40] and 21–47% of those with PAD (Fig 5).[40,41] The inclusion of cardiac assessment into the WB-MRA protocol reveals further hidden disease, with silent myocardial infarcts reported in 29% of those with PAD, 14% of those with diabetes and up to 20% of healthy 70-year-olds.[22,40,42]

The impact of the atheroma burden in terms of prognosis is significant. In a study of 305 seventy-year-old patients the presence of atherosclerosis on WB-MRA was associated with an odds ratio of 8.86 for a major adverse cardiovascular event compared to those with a normal study after adjusting for sex, waist circumference, body mass index, fasting blood glucose, systolic blood pressure, high-density lipoprotein (HDL) and low-density lipoprotein (LDL)–cholesterol, serum triglycerides, smoking, and high sensitivity (hs)C-reactive protein.[29] In another study by Bamburg *et al.*, those with a normal WB-MRA had no cardiovascular events at 6 years, and in those who did have evidence of atherosclerosis, each point increase in atheroma score was associated with a hazard ratio of 13.2 for major adverse cardiovascular events.[30] Inclusion of a WB-MRA derived atheroma score yielded a 0.32 improvement in net reclassification of risk, with an increase in the C-statistic ROC (receiver operator curve) from 0.681 for the Framingham risk score alone, to 0.750 for the Framingham risk score and atheroma score combined.[29] Yet it is still to be fully established how best to utilise this information. Indications of the potential clinical utility in helping guide instigation and intensification of therapeutic strategies can be seen in coronary CTA where coronary artery disease presence and severity are associated with increased uses of preventative medications, and improved blood pressure and cholesterol control.[43–45] Given the additive prognostic benefit of multisite screening WB-MRA may prove to be an even more powerful tool for disease detection and risk stratification.

It could be argued that since patients with clinically apparent cardiovascular disease in one site will result in patients being treated for atherosclerotic risk factors that further information about disease elsewhere is superfluous; however, this ignores several factors. Two trials have demonstrated benefit for carotid endarterectomy in asymptomatic individuals with incidentally detected carotid stenosis >70%.[46,47] Building on these the CREST-2 trial is awaited to determine the role of carotid artery stenting in this arena, and whether the benefits of carotid endarterectomy seen in these two previous trials hold true in the context of more modern optimal medical therapy strategies.[48] Recognition of unrecognised myocardial infarctions through the incorporation of a cardiac MRI into the WBMRA

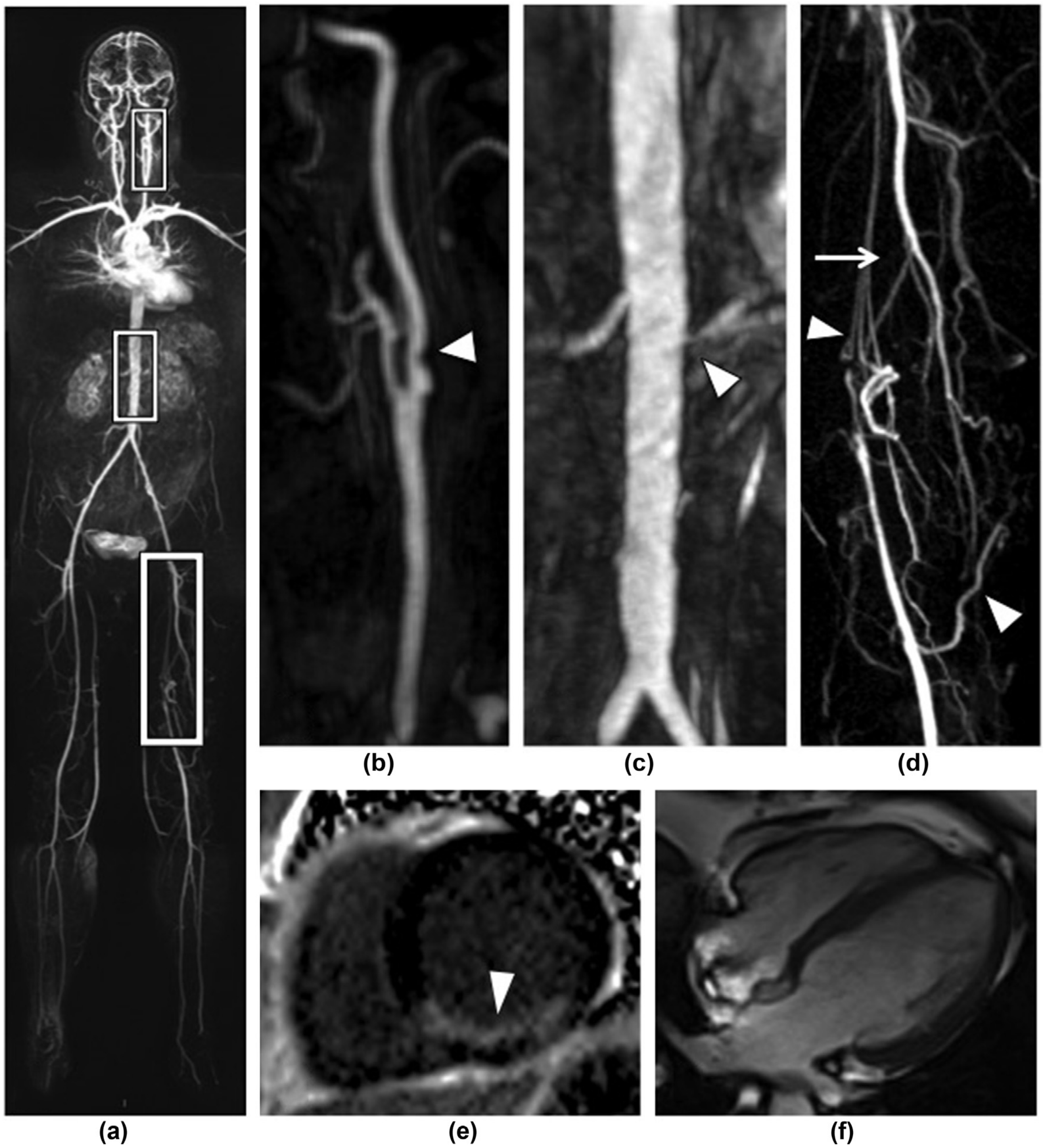

Figure 5 Peripheral arterial disease patient with multisite disease revealed by whole body magnetic resonance angiography (WB-MRA). (a) WB angiogram. (b) Sagittal maximum intensity projection (MIP) showing >50% stenosis of the internal carotid artery (arrowhead). (c) Coronal MIP of the renal arteries showing a normal right renal artery but >70% stenosis of the left renal artery (arrowhead). (d) Coronal MIP showing a long segment occlusion of the left superficial femoral artery (arrow) with extensive collateral formation (arrowheads). (e) Short-axis LGE showing a large unrecognised myocardial infarct (arrowhead). (f) Four-chamber view of the heart showing normal dimensions of the ventricles. Reproduced from Weir-McCall et al.[40].

protocol can also yield significant changes in management. These silent myocardial infarcts have the same prognostic implications as recognised myocardial infarcts and are present in approximately 20% of 70-year-olds and 30% of those with PAD.[40,49,50] Furthermore, these patients respond well to both conventional secondary prevention medication and percutaneous coronary intervention.[51–53] This is important as secondary prevention strategies differ between anatomical territories, in particular with beta-blockers recommended in those with myocardial infarcts due to their benefit in mortality reduction, but are not indicated in those with cerebrovascular or peripheral arterial disease.[54]

WB-MRA also provides additional prognostic information. Multisite disease is associated with a significantly raised risk of future major adverse cardiovascular events compared with single site disease, and has a greater detrimental effect on future prognosis than the presence of diabetes.[36,55] Thus patients with polyvascular disease may warrant more intensive management and follow-up as well as being ideal candidates for future novel therapeutic agents.[56] Although current therapeutic strategies of statins and anti-hypertensive drugs are cheap, newer monoclonal agents such as PCSK9 inhibitors and interleukin-1ß inhibitors are significantly more expensive and better disease stratification could optimise patient selection and thus derive maximum benefit from these agents.[57,58]

In a clinical setting, the most immediate application of WB-MRA is to extend already clinically indicated MRA examinations. The cost effectiveness of extending clinically indicated single site MRA into a WB-MRA plus cardiac MRI has been previously demonstrated in those with peripheral artery disease. The extension of the study added only a small cost to the overall cost of the planned MRA and reduced overall healthcare costs due to reduced downstream resource utilisation.[59] Further studies are now needed to determine if the cost savings seen in a PAD population are extendable to those with coronary or cerebrovascular disease where total atheroma burden is known to be less than that of PAD.[40]

Vasculitis

Atherosclerosis is not the only systemic vascular disease. Large-vessel vasculitides, such as giant cell arteritis (GCA) and Takayasu's arteritis (TA), have a systemic distribution. Type V TA arises when the neck, thoracic, abdominal, and pelvic vessels are involved and occurs in 55% of cases.[3] Furthermore, 18% develop moderate to severe aortic regurgitation, providing an additional role for the inclusion of CMR within the WB-MRA protocol in this cohort. The feasibility of WB-MRA in this clinical setting this has been described in a previous study of eight patients with TA where it was able to locate and quantify the full burden of disease.[60] GCA has a similar prevalence of thoracic, abdominal and renal involvement to TA, but has a higher prevalence of aneurysmal vascular involvement with 62% of the vessels involved demonstrating aneurysmal dilation.[61] Thus when reviewing this cohort use of the raw data rather than the subtracted data is needed to ensure partially thrombosed aneurysms with a preserved luminal diameter are not missed. Use of the raw data will also allow for assessment of vascular wall thickening.

Fibromuscular dysplasia

Fibromuscular dysplasia is a non-inflammatory vasculitides, which afflicts predominantly young women, causing vascular stenosis, aneurysms, and tortuosity.[62] Given the young age that this disease typically affects, MRA is the ideal modality for the assessment of this. The typical presentation is with persistent hypertension in a young woman and an angiographic finding of a string of beads within the renal arteries; however, a recently published registry of 921 patients with FMD revealed a high frequency and geographically diverse range of vascular involvement with 22% having aneurysms and 26% having dissections.[2] The extra-cranial carotid, renal, and intra-cranial arteries were the most common sites of aneurysm, while dissection most often occurred in the extra-cranial carotid, vertebral, renal, and coronary arteries. Iliac and popliteal disease was also found but less common. As a result a recommendation was made for full vascular imaging in all FMD patients. The high rate of intracranial abnormalities would suggest for the augmentation of the standard WB-MRA technique with an intracranial TOF angiogram to yield maximum benefits. Additional coronary specific sequences for coronary dissection could be considered and case reports have shown the ability to detect intramural haematoma in those with spontaneous dissection; however, the sensitivity and specificity of this technique has not been established.[63]

Conclusion

Significant advances in MRI technology has allowed for the extension of traditional single site MRA to include the entire vasculature in a single examination. Vascular disease is frequently a systemic disorder; therefore, a systematic approach to the detection and quantification of this may better diagnose and stratify these. WB-MRA is a technique that can be incorporated into the routine clinical workflow, provides a systematic approach to the assessment of vascular disease in a single examination, and yields a high degree of clinically occult but significant vascular disease. Future work is required to determine how best to utilise the information provided to optimise management of vascular disease.

Conflict of interest

None.

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