Vascular Problem Solving and Case Presentation:

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MRA of the Run-Off Vessels: Upper and Lower Extremities

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Background:

Although atherosclerotic narrowing can affect any part of the body the greatest burden falls on the lower extremity arteries. Patients with peripheral vascular disease present either intermittent claudication, a life-style modifying disease predominantly reflecting proximal arteries or with limb threatening ischaemia, the majority of whom are diabetics, and in whom severe distal (small vessel) disease is present.

Traditional algorithms for investigating peripheral vascular disease have been influenced by the fact a “road-map” could only be acquired by invasive catheter angiography. Patients with limb-threatening disease required angiographic documentation of the distribution and severity of disease, and in some cases immediate surgery without pre-operative imaging. However, because of the limited availability and morbidity of catheter angiography, referring physicians traditionally have referred patients with intermittent claudication for catheter angiography only after non-invasive testing (e.g. Doppler sonography and/or plethysmography) was performed. These non-invasive studies help to determine the severity of disease and are useful for stratifying patients into those with “inflow” (aorto-iliac) and “outflow” (femoro-popliteal) disease.

Because of the widespread and systemic nature of the disorder and the multiplicity of lesions that typically occurs, optimal therapeutic strategies can be formulated only when accurate “mapping” of the arterial tree has been performed. Because of its non-invasive nature MRA offers substantial benefit to physician and patient alike as a screening test. Refinements in MRA technique over the last decade have led to the potential for comprehensive non-invasive evaluation of the vasculature from above the aortic bifurcation to the pedal arch, without arterial catheterization, ionizing radiation or nephrotoxic contrast agents. Although other competing modalities such as multi-detector CT (MDCT) show promise, CT is more invasive than MRA and has the drawbacks of ionizing radiation and nephrotoxic contrast agent exposure.

Indications for MRA:

In order for MRA is to replace DSA as a diagnostic tool it must be reproducible, readily available, accurate, artefact-free and time-efficient. Because traditional non-contrast (TOF) techniques are time inefficient and artefacts-prone, non-contrast MRA was not never established as a valid alternative to DSA. It was however, widely used for patients with contra-indications to conventional arteriography. However, developments in CE-MRA, which deliver similar “road-mapping” capability to DSA without the associated risks of iodinated contrast material or arterial catheterization, made the above goals achievable.

MRA Techniques:

Non-Contrast MRA (Time-of-flight MRA & Phase-Contrast MRA)
Although TOF techniques historically played a role in evaluation of the peripheral arteries, non-contrast techniques have now been almost entirely replaced by contrast-enhanced techniques for evaluation of the upper and lower extremities. Substantial advantages of CE-MRA over NC MRA techniques include greater scan-time efficiency (at least a factor of 4), absence of in-plane saturation effects and insensitivity of CE-MRA techniques to flow velocities and turbulence around stenoses. Although there has been some resurgence in interest in “new” NC techniques (such as “balanced” techniques and fresh-blood imaging) for some MRA applications, these techniques have not established themselves in the clinical routine.

Contrast-enhanced MRA:
The technique of CE-MRA relies on intravenous injection of paramagnetic contrast agent in conjunction with a heavily T1w gradient-echo acquisition for generation of intra-vascular signal and is ideally suited to evaluation of the upper and lower extremities. This flow-independent enables image acquisition in the coronal plane, exploits heavily T1W imaging with short TR’s and is ideally suited for implementation of parallel imaging techniques with high speed-up factors. Further advantage can be gained by optimizing k-space filling strategies to the arterial bolus. However, for the lower extremities 2 significant hurdles must be overcome as follows:

1. Current scanners give anatomical coverage of 45-50cms only (less than the distance from abdominal aorta to pedal arch).
2. The temporal resolution offered by commercially available scanners is insufficient to capture the arterial phase at all imaging locations of a three (or four) station peripheral MRA in all patients.

Different techniques for CE-MRA of the lower extremities have evolved accordingly:

1. Single-station CE-MRA.
2. Multi-station CE-MRA with multiple contras injections.
3. Multi-station CE-MRA with a single injection (bolus chase/moving table MRA).
4. Hybrid approaches (3D CE-MRA + another approach such as TOF MRA or 2D MR-DSA for the 3rd location).

1. Single-station MRA of the peripheral arteries

Images are targeted to a single FOV as dictated by the clinical scenario. However, prediction of occlusive lesion location may be difficult and in any case few patients have a single site of disease only.

2. Multi-station, multi-injection MRA of the peripheral arteries

This is essentially the same approach as 1 above, but the technique is repeated at each of two or three consecutive locations, with a separate injection for each location. This approach is now rarely employed since refinements in moving-table approach have been made.

3. **Moving Table Contrast-Enhanced MRA (MT CE-MRA)**

By acquiring 3D data-sets at multiple (usually three) coronally-oriented overlapping FOV’s, the lower extremity arteries can be evaluated during a single contrast injection. The approach has evolved from one with “fixed” imaging parameters (i.e. identical parameters for all locations) to one with highly adaptable imaging parameters tailored to each individual FOV. The requirements are:

- Automated table movement (a “floating” table).
- A method for reproducible repositioning of the table between pre- and post-contrast scans.
- A robust method for detecting contrast arrival in the first imaging volume.
- (Ideally) “Flexible” imaging parameters (in-plane resolution, 3D scan volume and k-space filling optimized individually for each location).

Venous Enhancement in the infra-popliteal circulation: The Major Limitation of MT CE-MRA:

Successful MT CE-MRA requires imaging coincident with the arterial peak for all locations and completion of central k-space data prior to onset of venous enhancement. For the 1st location, this is ensured by using bolus "detection" (timing run or fluoroscopic triggering). Venous enhancement is virtually unknown in the 1st and 2nd (femoro-popliteal) locations assuming a relatively short acquisition time for the 1st location (8-12seconds), rapid table movement (<4 seconds) and use of centric phase-encoding for the 2nd location (i.e. sampling of central k-space data at the start of the scan). However, data collection at the 3rd location is delayed until scan data for the first two locations is completed and venous enhancement in the 3rd location occurs when the combined time for imaging the first two locations plus two table movements is greater than the circulation time from aorta to calf vein.

Therefore, careful optimization of MT peripheral MRA is required as follows:

1. Tailor the 3D scans to the anatomy and use individually tailored scan parameters for each RO.
2. Use Parallel Imaging (at all locations if possible).
3. Tailored the Contrast infusion rate
4. Scan initiation at the first location must start as early as possible.
5. Use optimized k-space filling strategies
6. Use image subtraction.

Other considerations:

Time-resolved imaging:

This can be performed with a 2D approach, a hybrid 2D/3D approach or a 3D (TRICKS) approach.

2D:

2D images offer much shorter scan times compared to 3D imaging thus shortening scan time overall and diminishing the likelihood of venous enhancement. The disadvantage is that 2D images do not visualise the arteries in multiple orientations (usually). 2D/3D hybrid technique exploiting 3D acquisitions for the aorto-iliac location, 2D for the thighs, and 2D or 3D for the legs and feet may be advantageous.

Use of "segmented" k-space approach:

Two separate approaches which exploit the unique nature of the k-space domain (where central k-space data governs image contrast and peripheral k-space data governs resolution) have been implemented as follows:

3D TRICKS:

A different approach to contrast-enhanced MR angiography involves acquiring multiple 3D volumes during the passage of the contrast agent bolus by using time-resolved acquisition. With one time-resolved acquisition imaging of contrast kinetics (TRICKS)—the repeated sampling of the critical central k-space views is combined with temporal interpolation to produce a series of time-resolved 3D images. Time-resolved acquisitions such as TRICKS obviate timing tests and a separate acquisition of pre-contrast images for mask-mode subtraction.

"Shoot 'n' Scoot":

Foo, Ho et al have successfully demonstrated the feasibility of acquiring central k-space data only during first arterial pass of contrast material bolus passage for the first two locations for moving table peripheral MR angiography of the lower extremities. Once the table moves to the 3rd location a full k-space data-set is acquired. After acquisition of scan data for the 3rd location, the table moves back to the second and first locations where the higher spatial-frequency k-space data is filled in during recirculation of the contrast material.

Use of Sub-SystolicThigh Compression with Tourniquets (to deley onset of venous enhancement):

Several authors have reported reduced venous enhancement in moving-table peripheral MRA with use of thigh compression. Zhang and Prince have demonstrated that unilateral thigh compression during time-resolved MR angiography with elastic tourniquets increases contrast travel time from common femoral artery to the popliteal artery by 62% whereas subsystolic (60mmHg) inflation of thigh blood pressure cuffs slows travel time by 94%. The improved sharing of the gadolinium contrast bolus between stations may result in better correlation of peak arterial enhancement with the center of k-space and correspondingly increases the arterial signal-to-noise ratio.

Summary of Clinical results:

Although numerous studies have reported efficacy of CE-MRA for the lower extremities, of importance is the fact that peripheral MRA has been subjected to three meta-analyses of the reported literature as follows:

Summary of meta-analyses results for lower extremity peripheral MRA.

	Technique	**# studies**	**# patients**	**Sens %**	**Spec %**	**DOR***
Nelemans	2D TOF	13	344	64-100	68-96	1.0
	3D CE-MRA	10	253	92-100	91-99	7.46
Koelemay	2D TOF	18	474	69-100	73-97	1.0
	3D CE-MRA		482	85-97	83-98	2.8
Visser & Hunink	3D CE-MRA	9	216	97.5	96.2	
	Duplex US	18	1059	87.6	94.7	

* The diagnostic odds ratio (DOR) is a measure for the discriminative power of a diagnostic test: the ratio of the odds of a positive test result among diseased to the odds of a positive test result among the non-diseased.

Upper Extremities:

Although vascular disease of the upper extremities is relatively uncommon, indications include evaluation of suspected subclavian steal syndrome, evaluation of surgically created fistula function in patients undergoing dialysis, embolism, atherosclerotic stenosis trauma to the upper extremity arteries and narrowing of the diatal arteries in patients with connective tissue disorders or vasculitis. For some indications involving the proximal upper extremity arteries (e.g. subclavian steal syndrome) images are targeted to the aortic arch and great vessel origins. For more distal disease, high resolution images are required to accurately delineate the vasculature. Although arterio-venous transit times in the upper extremity are relatively short compared to the lower extremities (owing to a lower muscle bulk), use of “timed-arterial-compression (tac-MRA) is a useful technique to ensure capture of the arterial phase. This techniques advocates use of supra-systolic arterial compression with tourniquets (once contras agent has arrived in the FOV) and appears to be well tolerated by patients. Images of even the small arteries of the hands with exquisite resolution can be generated without venous overlap.

Conclusion:

Imaging of the upper and lower extremity arteries with CE-MRA is possible. For the more commonly diseased arteries of the lower extremities, there has been an evolution from cumbersome and not widely accepted non-contrast MRA through single-location contrast-enhanced MRA to extended FOV imaging with a moving table approach for peripheral artery evaluation. The goal of highly optimized images with spatial resolution adequate for each location and temporal resolution sufficient to eliminate venous enhancement has already been met. Further improvements in technology will offer even greater diagnostic capability in the future.

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