Contrast-enhanced MRA is Currently the Preferred Approach

Contrast agents markedly shorten the T1 relaxation time of blood during the first pass through the arteries; Excellent T1 contrast with fat and muscle even with very short TR (e.g. 3 ms), keeping 3D scan times reasonable.

<table>
<thead>
<tr>
<th>Dose</th>
<th>T1 (ms) Pre-Contrast</th>
<th>T1 (ms) After Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1mL</td>
<td>&lt;1.3</td>
<td></td>
</tr>
<tr>
<td>0.2mL</td>
<td>5.6</td>
<td></td>
</tr>
</tbody>
</table>
35yo with decreased peripheral pulses in the upper extremities

Takayasu's Arteritis

Courtesy Dr. James Carr, Northwestern

CEMRA for Renal Artery Stenosis
41-year-old female with hypertension

fibromuscular dysplasia
CEMRA: Need to Use Optimal Imaging Parameters to Maintain Accuracy

Why did CEMRA exaggerate the renal artery stenosis here?
• Slice was too thick: 1.5 mm after interpolation, but true slice thickness was 3 mm => partial volume averaging
• TE was too long: 3 msec (should be 1-2 msec) => signal loss from flow-related dephasing

Contrast Agent Timing is Critical with “Static” CEMRA

Contrast Agent Timing is Critical with “Static” CEMRA

Dynamic Contrast-Enhanced MRA
Time-resolved CEMRA (e.g. TRICKS, TWIST)

Contrast ejection (~5 cc at 2 cc/sec)

Avoids issues with timing and venous enhancement

Korosec et al

MRM 36, 1996

Aortic Dissection

46yo female, history of sickle cell anemia w/ LLE swelling and pain.
AAA + Left SFA Occlusion

Note delayed contrast arrival on left indicating proximal hemodynamically significant stenosis (arrowhead).

Stepping Table MRA Technique

1. Acquire mask images for each station
2. Three-station stepping table CE-MRA: Gd 0.1mmol/kg @2cc/sec, then 0.1mmol/kg @0.5cc/sec
3. Subtract mask images from CEMRA for each station.

Non-Subtractive Peripheral CEMRA Using a Dixon Technique

Leiner et al. Proc. of ISMRM 20th Annual Meeting 2012; 525
Contrast Agent Options for CEMRA

**Standard Extra-Cellular Agents**
- First pass
- Use double dose for steady-state imaging of veins

**Blood Pool Agents (Gadobovist®, Ferumoxytol)**
- First pass
- Steady-state imaging for high resolution imaging of arteries, venous imaging

**High Relaxivity Agents (Gadobenate, Gadobutrol)**
- Decreased contrast agent dose

Alternatives to Gd for MRA: Iron-Based Contrast Agents

**Feraheme (ferumoxytol):**
- Recently approved as an iron-replacement therapy for anemia of chronic kidney disease
- "Safe" in patients with severe renal disease (though some patients have had severe anaphylactic reactions resulting in "black box" warning)
- Paramagnetic iron
- "True" blood pool contrast agent
- "High cost, not FDA approved as contrast agent"

Impact of Field Strength on MRA: 3 Tesla

**Benefits**
- Can reduce contrast agent dosage by half
- Improve SNR by 50-100%
- Better fat suppression
- Higher parallel acceleration factors

**Limitations**
- Multi higher SAR limits flip angle
- Worse B1 field inhomogeneity

Concerns with Use of Iodine and Gadolinium-Based Contrast Agents

- Nearly 40% of patients with PAD have renal dysfunction
- CTA => risk of contrast-induced nephropathy
  - Nefrologia 2012;32(1):313-320
- MRA => risk of nephrogenic systemic fibrosis (NSF)
  - Radiology 2007; 242:647–649
- Concerns about Gd deposition in brain
- NSF can be avoided with simple precautions
- Unfortunately CE-MRA, the “go-to” test for patients with poor renal function, is now viewed by many clinicians as unsafe, resulting in decreased utilization

Motivations for Development of Nonenhanced MRA

- Provide alternative to CEMRA in patients with poor renal function (avoid risk of NSF and Gd deposition in tissue)
- Reduce cost (e.g. eliminate need for contrast agents, disposables, and point-of-service renal function testing)
  => >$100 - $200/patient!
- Provide backup in case of technical failure of CEMRA
- Reduce need for specialized technologist expertise (e.g. required for peripheral CEMRA)

Time-of-Flight MRA

- Good for Intracranial Vessels
- Bad for Vessels in Body
Gated Inflow-Based Non-Subtractive 3D MRA
Using Navigator-gated Inversion Recovery bSSFP

Proximal Left Renal Artery Stenosis

Arterial Spin Labeling: “MR DSA”
→ Subtract Radiofrequency Labeled from Unlabeled Images
Arterial Spin Labeling:
Rapid Evaluation of Flow Patterns Using Breath-hold Cine FISS ASL

Temporal resolution = 12.2 msec

Gated Subtractive FSE MRA
Using Systolic and Diastolic Acquisitions

Several studies report excellent accuracy (e.g. 96%, Nakamura et al. for FBI;)

Technique is vendor-dependent, time-consuming, and not always reliable:
- requires precise timing of systolic pulse wave
- very motion sensitive


Gated Subtractive MRA
Advantages of QISS MRA

**Simple, robust, fast**

- No scout required
- Imaging parameters are fixed (no variation from patient to patient)
- Technologist requires no special expertise
- Scan time ~7-8 minutes
- Resistant to patient motion (each image acquired in ~1/3 second)
- Insensitive to arrhythmias
- Allows efficient breath-holding for abdomen and pelvis

1.5T:
- Hodnett et al. Radiology 2011; 260:282

3T:
- Amin et al. AJR Am J Roentgenol 2014 Apr;202(4):886-93
- *Wagner et al. Intl J of Cardiovascular Imaging 2015 Feb 3 (published online ahead of press)*

7T:
Benefits of QISS for Peripheral MRA

- Patients with poor renal function
- Scout technique for stepping table CEMRA
- Fallback for CEMRA technical failure
- Primary MRA technique to save cost of contrast material and injection paraphernalia, avoid need for POS renal function testing

66 year old male with limiting LLE claudication

CTA non-diagnostic due to extensive vascular calcifications

What If You Need to Show Calcifications for Vascular Access Planning?

CTA Maximum intensity projection
Proton density-weighted In-Phase RadVIBE Maximum intensity projection
51 year old male with history of elevated cholesterol and triglycerides presents with new onset right calf claudication. Right calf ABI = 0.75, ankle/DP = 0.61.

Nonenhanced MRA:
Sometimes Provides More Information than CEMRA

Mild stenosis in distal right popliteal artery

Nonenhanced MRA prompted additional scanning with T1w and T2w sequences

Diagnosis = Cystic adventitial disease with intramural hematoma causing arterial stenosis
We Use QISS MRA As Scout Sequence for CEMRA

\(\Rightarrow\) Provides a Backup for CEMRA In Case of Technical Failure

Delayed arrival of contrast bolus causes poor visualization of pelvic arteries

QISS Arteriogram
QISS Venogram

Next-Gen NEMRA

Radial QISS

Benefits of Radial vs. Cartesian scans
- Better immunity to flow and motion artifacts
- Higher acceleration \(\Rightarrow\) faster scanning
- No fold over artifacts \(\Rightarrow\) can use smaller fields of view

Free-breathing Cartesian QISS
Free-breathing Radial QISS
Breath-hold Radial QISS MRA of the Great Vessels

Breath-hold and Free-breathing, navigator-gated

Pulmonary Sarcoidosis

Breath-hold Radial QISS

Massive Pulmonary Embolism

Clinically unsuspected prior to cardiac MRI

Radial QISS and CTA
When would CTA or CEMRA be preferred to NEMRA?

- State-of-the-art NEMRA techniques are not available
- Patient cannot cooperate
- Severe arrhythmia
- Orthopedic implants
- Need information from contrast enhancement

QISS using a bSSFP Readout is Sensitive to Magnetic Susceptibility Artifacts

CEMRA preferred to NEMRA

Nonenhanced MRA
Conclusions

- There are many flavors of MRA, encompassing contrast-enhanced and nonenhanced techniques.
- CEMRA remains the dominant technique for MRA due to its speed and robustness.
- TOF is limited to carotids and intracranial circulation.
- Newer nonenhanced MRA techniques permit screening for vascular disease with no risk and high accuracy, eliminate need for (and cost of) contrast agents in many cases and can potentially provide useful functional information not available with CTA or CEMRA.
- Promising future developments include blood pool contrast agents, faster scanning based on artificial intelligence (e.g. deep learning), etc.