Non-Contrast-Enhanced MRA

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With NSF, a renewed interest in non-contrast-enhanced MRA
- Highest risk in high doses of Gd (> 30 ml) in patients with renal insufficiency
- Renal insufficiency common in patients with atherosclerotic disease
  - Veterans PVD study (n=5787):
    - 30% moderate renal insufficiency (GFR 30 – 59 ml/min/1.73m²)
    - 8% severe renal failure (GFR < 30)


Non-Contrast-Enhanced MRA

- Time-of-flight and QISS
- Phase Contrast
- ECG-Gated Fast Spin Echo
- Balanced SSFP (True FISP, FIESTA, Balanced FFE)
- Arterial Spin Labeling with Balanced SSFP or FSE
- Recommendations for Options across MRA applications

Robert Edelman, M.D., Evanston
Edelman RR et al MRM 2010; 63:951

QISS MRA

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QISS

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- N = 53 subjects
- QISS vs Gd-MRA
- For < vs ≥ 50% stenosis
- Sensitivity 87-89.7%
- Specificity 96.5-94.6%

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FSE-based non-contrast MRA

- 3D ECG-gated fast spin echo with 2 acquisitions*
  - Diastole: arterial flow slow ⇒ bright signal
  - Systole: arterial flow fast ⇒ dephasing
- Subtract ⇒ tissue and veins cancel, leaving arteries

ECG-Gated FSE

**Flow sensitivity**

- Depends primarily on FA of refocusing pulses
- Greater for low FA
- Due to increased mixing between stimulated and spin echoes

- Signal loss at center of lumen
- Poor depiction of branch vessels

ECG-Gated FSE: Flip angle evolution

**Phantom results**

- VFA: Non-selective variable flip angle pulses
- Constant Flip Angle Echo Train
- Variable Flip Angle Echo Train

- Shorter inter-echo spacing
- Reduced T2 blurring
- Faster acquisition
- Decreased SAR

Phantom results

- MIyazaki M et al. JMRI 2000; 12:776
- Miyazaki M et al. Radiology 2003; 227:890
- Wedeen VJ et al. Science 1985; 230:946
- Meuli RA et al. Radiology 1986; 159: 411
- Mugler et al. ISMRM 2003; 203
- Xu et al. ISMRM 2008; 730

* M. Miyazaki et al
P. Storey, NYU

Atanasova I, et al ISMRM 2009
**Patient study: example**

FA = 120°

*CE-MRA*  
*NC-MRA*

Comparable depiction of arteries even beyond stenosis

Improved depiction of collaterals on NC-MRA

**Patient study: example**

FA = 60°

*CE-MRA*  
*NC-MRA*

Comparable depiction of arteries even beyond stenosis

**Example 2: slow flow**

FA = 120°

*CE-MRA*  
*NC-MRA*

Slow flow causes mistiming on CE-MRA

Distal vessels better depicted on NC-MRA

**Example 3: hyperemia**

FA = 120°

*CE-MRA*  
*NC-MRA*

Fast flow means early contrast arrival

Signal loss

**Example 4: reduced pulsatility**

FA = 120°

*CE-MRA*  
*NC-MRA*

Other territories with slow flow for VFA FSE:

Hand MRA

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Temperature challenge: Non-Gd MRA

Healthy female volunteer
Anatomic variation: Persistent median artery (white arrow)
No deep arch
Incomplete superficial arch (yellow arrow)

3T VFA FSE

Lim et al. Radiology 2009

Temperature challenge: Non-Gd MRA

History of L thumb cold sensitivity

A & B. Left hand. Increased vessel visualization and caliber following warming (superficial arch visualized, arrow), note beading of princeps pollicis (arrowheads) suggesting underlying vascular abnormality. Images acquired with VFA FSE at 3T

C. Cyanosis of left nailbed on cold exposure

Lim et al. Radiology 2009

45 F with limited scleroderma

3T

• Little change in vessel visualization and caliber between cooling and warming

Lim et al. Radiology 2009

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Flow sensitive dephasing-bSSFP

• bSSFP sequence
• Two acquisitions:

- = (make arteries dark)


Flow sensitive dephasing-bSSFP

\( \phi \) Phase shift in a moving isochromat induced by the dephasing gradient
\( \phi = \gamma \cdot \cdot \int G(t) \cdot \cdot dt \approx \gamma \cdot \cdot v(t) \cdot \cdot m(t) \)

where \( m(t) = \int G(t) \cdot \cdot dt \) the first-order gradient moment

Moment determines flow sensitivity


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**FSD-prepared SSFP**

- **MRA = Bright Blood - Black Blood Imaging**

**Velocity-selective Saturation Prep**

- **VS saturation pulse: spatially non-selective VS excitation**
  - RF sub-pulses designed by Shinnar-Le Roux transform for high velocity selectivity with large flip angles
  - E.g. velocity saturation bandwidth of 12-32 cm/s
- **Single 3D acq, all but arterial protons are saturated**

**Non-Contrast-Enhanced MRA**

- **Time-of-flight and QISS**
- **Phase Contrast**
- **ECG-Gated Fast Spin Echo**
- **Balanced SSFP (True FISP, FIESTA, Balanced FFE)**
- **Arterial Spin Labeling with Balanced SSFP or FSE**
- **Recommendations for Options across MRA applications**

**Arterial Spin Labeling: Principles**

- **Key ideas**
  - "Label" or "tag" usually means a 180° pulse which inverts magnetization
  - Inversion pulses (180°) can be applied in FOV or outside FOV to differentiate between inflowing blood and stationary tissues
  - Then during the delay time (TI)
    - Blood moves
    - Inverted tissue recovers longitudinal magnetization with T1 relaxation
  - If we image at the TI that is where magnetization crosses null point, then we will null or suppress that signal

**Arterial Spin Labeling: Principles**

- **Parameters that can be varied**
  - Which regions are "labeled" (or inverted)
  - At what times you "label" them
  - How long you wait after the label to image (TI)
  - The way you carry out the imaging (spin echo or gradient echo imaging)
Arterial Spin Labeling: Methods

Two labeling methods
1. Tag-on, Tag-off (Two acquisitions) or
2. Spatially selective and non-selective inversion pulses (One acquisition)

Two imaging options
1. FSE (HASTE) or
2. Balanced SSFP (true FISP, FIESTA)

Arterial Spin Labeling: Method 2

- Spatially selective and non-selective inversion pulses (1 acquisition)
  - Goal: bright blood in image with nulled background
  - Invert whole imaging volume (180°)
  - Re-vert blood proximal to and outside of imaging volume (another 180°) back to full magnetization
  - Wait TI for fully magnetized blood to travel into imaging volume
  - At that TI, the background is nulled
- MRA = one acquisition (no subtraction)

Application:
- Abdominopelvic MRA
- Challenge: Large anatomic coverage
- Need tagged blood to traverse from renal to femoral arteries before full T1 recovery of background

Atanasova I et al. JMRI 2011
Non-Gd MRA Options

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<td>Hand and Foot MRA</td>
<td>FSE ± ASL ± ASL</td>
<td>FSE more robust at 3T</td>
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Modified from Miyazaki M & Lee VS, Radiology, 2008

Non-Gd MRA: More work needed

- Practical 3-station non-Gd protocol
  - robust to occlusive disease

- Non-Gd MRA at 3T: overcoming B1 inhomogeneties

- "Dynamic" non-Gd MRA

- Comparative effectiveness of CTA vs non-Gd MRA in renal failure

Acknowledgements

NYU
- Manjil Chatterji
- Qun Chen
- Dan Kim (Utah)
- Ruth Lim
- Niels Oesingmann
- Henry Rusnak
- David Stoffel
- Pippa Storey
- Jian Xu, Siemens
- Graham Wiggins

Northwestern University/Cedar Sinai
- Debiao Li
- Zhanyong Pan
- Columbia University
- Iliyana Atanasova
- Andrew Laine
- Siemens
- Xiaoming Bi

NIH R01 HL092439