Non-Contrast-Enhanced MRA

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• This work has been supported by NIH R01: CA092439
• Together with Jian Xu, Siemens, we have filed a provisional patent for variable flip angle 3D ECG-triggered non-contrast-enhanced MRA P080412-01/US, Reg 12/622/061

Nephrogenic Systemic Fibrosis

• 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

QISS MRA

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

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Flow sensitivity

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

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Human subjects results

- VFL flow sensitivity cut-off 5 – 10 cm/sec
- Below 5 – 10 cm/sec flow (systolic or diastolic), VFL results in flow void

Example 2: slow flow

- Distal vessels better depicted on NC-MRA
- Slow flow causes mistiming on CE-MRA

Example 3: hyperemia

- Fast flow means early contrast arrival
- Tibioperoneal trunk

Patient study: example

- Comparable depiction of arteries even beyond stenosis
- Claudication and diabetic vascular disease

 Phantom results

- Atanasova I, et al ISMRM 2009

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Example 4: reduced pulsatility

Other territories with slow flow for VFA FSE:

Hand MRA

Temperature challenge: Non-Gd MRA

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

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); red beading of princeps pollicis (arrowheads) suggesting underlying vascular abnormality. Images acquired with VFA-FSE at 3T
C. Cyanosis of left nailbed on cold exposure

45 F with limited scleroderma

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

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Flow sensitive dephasing-bSSFP

- bSSFP sequence
- Two acquisitions:

  - Use flow sensitive dephasing (like T2 prep) during systole to reduce signal during systole (make arteries dark)

Flow sensitive dephasing-bSSFP

- \[ \phi = \gamma \cdot \mathbf{G} \cdot \mathbf{v} \cdot \mathbf{t} \] where \( \mathbf{G} \) is the first-order gradient moment

MRA = Bright Blood - Black Blood Imaging

FSD-prepared SSFP

- ECG
- Delay
- Triggering
- Black Blood Imaging
  - Triggered at Systole
  - Matrix: 384x300x80; Sl: 1.3mm
  - FOV: 380x450mm
  - 3D bSSFP
- Bright Blood Imaging
  - Triggered at Diastole

80M with claudication

- Gd
- FSE
- CFA
- VFA
- Flow sensitivity

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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: Methods

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

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

Less sensitive to field inhomogeneities
Flow compensated in 3 directions—better for complex flow patterns

Arterial Spin Labeling: Method 2

- Spatially selective and non-selective inversion pulses (1 acc)
- 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)
Selective Inversion (tagged blood with full magnetization)

Non-Selective Inversion (whole abdomen)

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

Arterial Spin Labeling: Method 2

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## Non-Gd MRA Options

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<th>Non-Contrast-Enhanced Method</th>
<th>Notes</th>
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<td>Intracranial MRA</td>
<td>3D TOF</td>
<td>TONE and MOTSA improve sensitivity to slower flow</td>
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<tr>
<td>Carotid MRA</td>
<td>3D TOF ± with 3D bSSFP or FSE</td>
<td></td>
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<tr>
<td>Thoracic-Aorta MRA</td>
<td>3D TOF</td>
<td>EG, contrast-all</td>
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<td>Mesenteric MRA</td>
<td>3D TOF</td>
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<tr>
<td>Lower Extremity MRA</td>
<td>3D TOF</td>
<td>EG, contrast-all</td>
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<tr>
<td>Coronary MRA</td>
<td>3D bSSFP</td>
<td>3D SSFP or ASL, No flow-spoiling, TONE and MOTSA improve sensitivity to slower flow</td>
</tr>
<tr>
<td>Abdominal Aorta/Celiac MRA</td>
<td>3D bSSFP, ± ASL</td>
<td>3D SSFP or ASL, No flow-spoiling, TONE and MOTSA improve sensitivity to slower flow</td>
</tr>
<tr>
<td>Peripheral MRA</td>
<td>3D FSE or 3D TOF in 3DTOF or GISS</td>
<td>Multidirectional flow pattern favors bSSFP over gated FSE</td>
</tr>
<tr>
<td>Hand and Foot MRA</td>
<td>FSE or ASL ± with 3D bSSFP</td>
<td>3D SSFP or ASL, No flow-spoiling, TONE and MOTSA improve sensitivity to slower flow</td>
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Modified from Miyazaki M & Lee VS, Radiology, 2008

## Non-Gd MRA: Future Directions

- Multicenter study: Three station non-Gd MRA (< 30 min)
  - Option 1: QISS (time-of-flight)
  - Option 2:
    - Abdominopelvic: IR-bSSFP
    - Thigh and calf station: ECG-gated FSE
- Non-Gd MRA at 3T: overcoming B1 inhomogeneities
- "Dynamic" non-Gd MRA
  - Variable flip angle imaging with compressed sensing
  - "FERAL" phase contrast-MRA (Edelman RR et al. SCMR abstract, JCMR 2011)

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