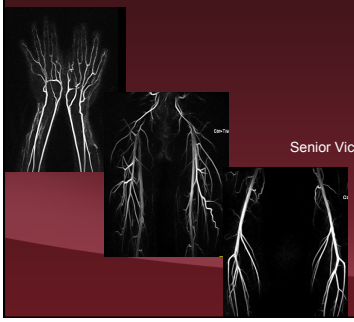
Non-Contrast-Enhanced MRA



Vivian S. Lee, MD, PhD, MBA
Senior Vice President for Health Sciences
Dean, School of Medicine
CEO, University Health Care
University of Utah
USA

Nephrogenic Systemic Fibrosis

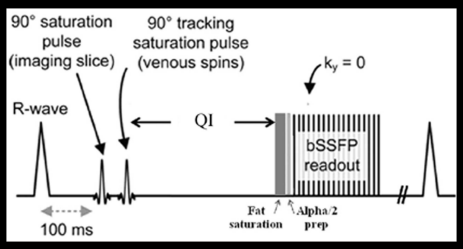
- With NSF, a renewed interest in non-contrast-enhanced MRA
  - Highest risk in high doses of Gd (> 30 ml) in patients with renal insufficiency
- Renal insufficiency common in patients with atherosclerotic disease
  - Veterans PVD study (n=5787):
    - 30% moderate renal insufficiency (GFR 30 – 59 ml/min/ 1.73m^2)
    - 8% severe renal failure (GFR < 30)

Grobner T et al. Nephrol Dial Transplant 2006; 21:1104-1108
O'Hare AM et al J Am Soc Nephrol 2005;16: 514; www.fda.gov

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

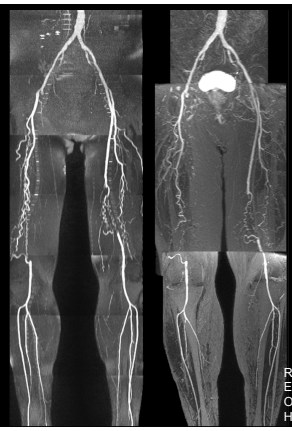


Robert Edelman, M.D., Evanston
Edelman RR et al MRM 2010; 63:951

QISS

	Tri-plane localizer	30s
1	Foot	1 min
2	Distal Calf	1 min
3	Proximal Calf	1 min
4	Knee	1 min
5	Distal Thigh	1 min
6	Proximal Thigh	1 min
7	Groin	1 min
8	Pelvis	1 min
9	Abdomen	1 min
	Total	**9.5 min**

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



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

CE-MRA

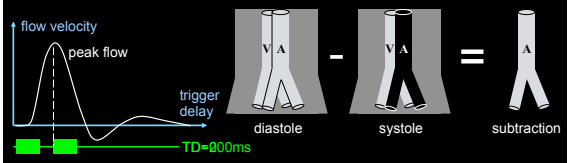
Robert Edelman, M.D., Evanston
Edelman RR et al MRM 2010; 63:951
Offerman EJ et al JMRI 2011;33:401
Hodnett PA et al Radiology 2011;260:282

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

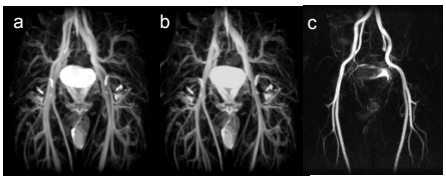
FSE-based non-contrast MRA

- 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



*M. Miyazaki et al P. Storey, NYU

ECG-Gated FSE

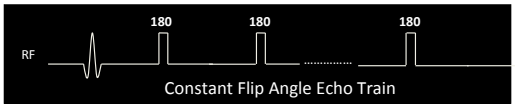


TD = 600 ms TD = 100 ms Subtraction MRA (a) – (b)

Wedeen VJ et al. Science 1985; 230:946
Meuli RA et al. Radiology 1986; 159: 411
Miyazaki M et al. JMRI 2000; 12:776
Miyazaki M et al. Radiology 2003; 227:890

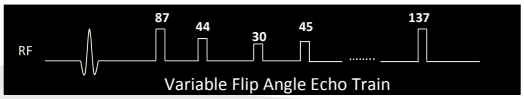
ECG-Gated FSE: Flip angle evolution

CFA: Constant flip angle selective refocusing pulses



VFA: Non-selective variable flip angle pulses

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

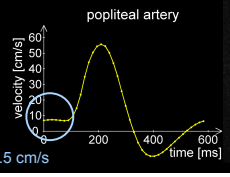


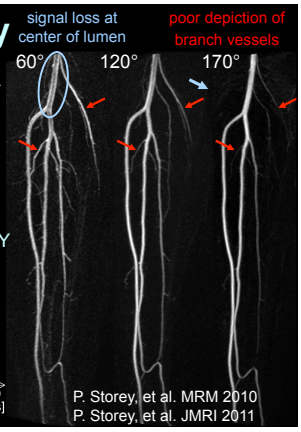
Mugler et al. ISMRM 2003; 203
Xu et al. ISMRM 2008; 730

Flow sensitivity

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

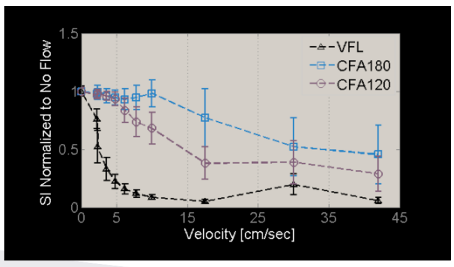
M, 27Y



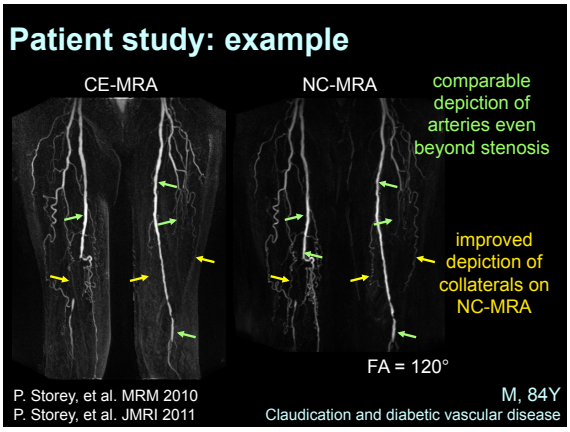


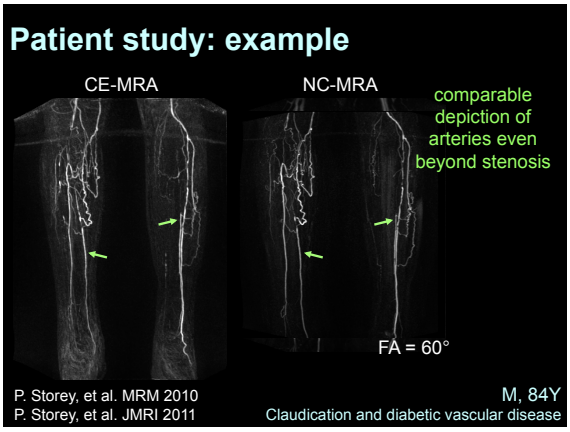
P. Storey, et al. MRM 2010
P. Storey, et al. JMRI 2011

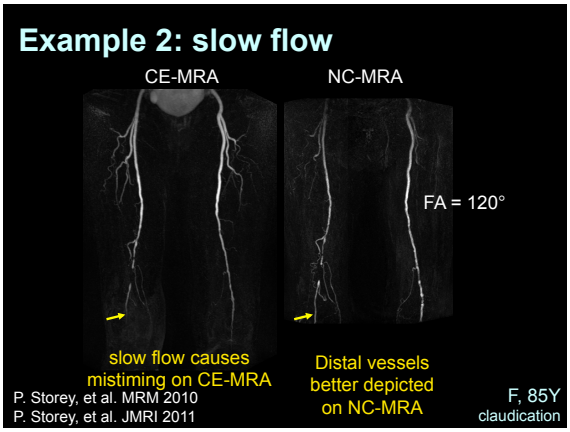
Phantom results

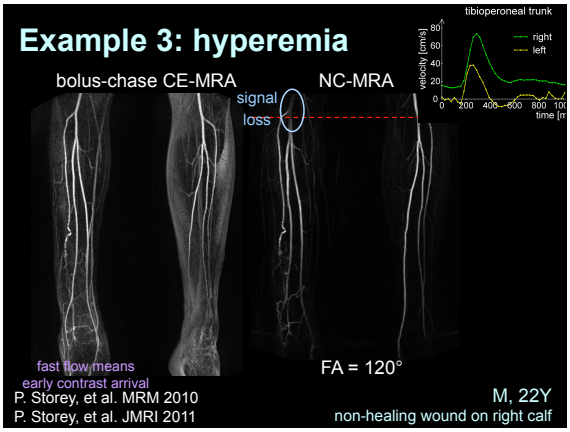


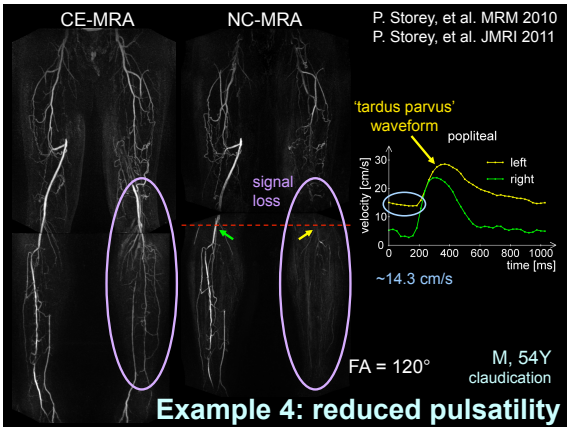
Atanasova I, et al ISMRM 2009

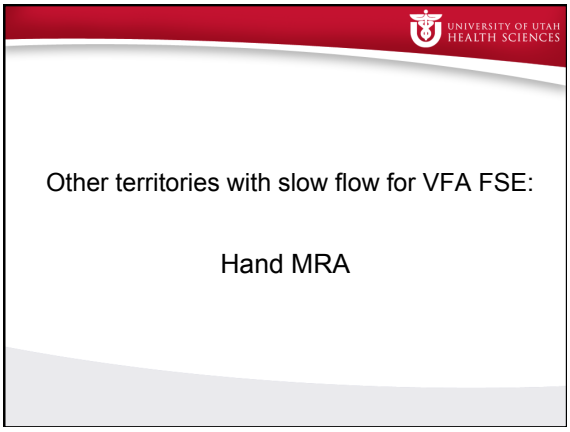

Patient study: example
CE-MRA
NC-MRA
comparable depiction of arteries even beyond stenosis
improved depiction of collaterals on NC-MRA
FA = 120°
P. Storey, et al. MRM 2010
P. Storey, et al. JMRI 2011
M, 84Y
Claudication and diabetic vascular disease


Patient study: example
CE-MRA
NC-MRA
comparable depiction of arteries even beyond stenosis
FA = 60°
P. Storey, et al. MRM 2010
P. Storey, et al. JMRI 2011
M, 84Y
Claudication and diabetic vascular disease

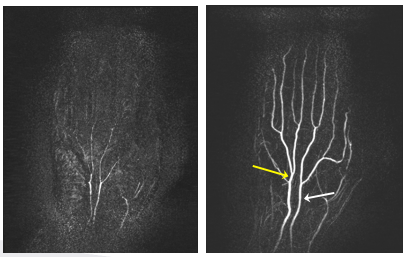

Example 2: slow flow
CE-MRA
NC-MRA
FA = 120°
slow flow causes mistiming on CE-MRA
Distal vessels better depicted on NC-MRA
P. Storey, et al. MRM 2010
P. Storey, et al. JMRI 2011
F, 85Y
claudication


Example 3: hyperemia
bolus-chase CE-MRA
NC-MRA
signal loss
tibioperoneal trunk
velocity [cm/s]
right
left
time [ms]
fast flow means early contrast arrival
FA = 120°
P. Storey, et al. MRM 2010
P. Storey, et al. JMRI 2011
M, 22Y
non-healing wound on right calf


CE-MRA
NC-MRA
P. Storey, et al. MRM 2010
P. Storey, et al. JMRI 2011
'tardus parvus' waveform
popliteal
signal loss
velocity [cm/s]
left
right
time [ms]
~14.3 cm/s
FA = 120°
M, 54Y
claudication
Example 4: reduced pulsatility


UNIVERSITY OF UTAH HEALTH SCIENCES
Other territories with slow flow for VFA FSE:
Hand MRA

Temperature challenge: Non-Gd MRA



COLD WARM

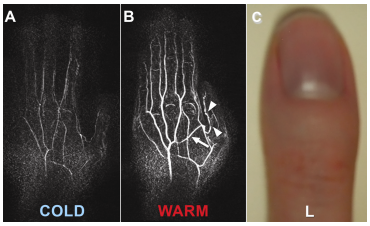
3T
VFA FSE

Healthy female volunteer

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

Lim R et al. Radiology 2009

Temperature challenge: Non Gd MRA History of L thumb cold sensitivity

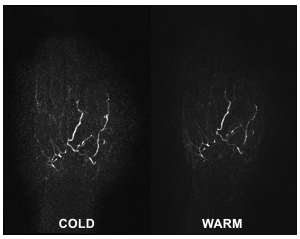


A & B. Left hand. Increased vessel visualization and caliber following warming (superficial arch visualized, arrow), note beading of princeps pollicis (arrowheads) suggesting underlying vascular abnormality. Images acquired with VFA-FSE at 3T
C. Cyanosis of left nailbed on cold exposure

Lim R et al. Radiology 2009

45 F with limited scleroderma

3T



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

Lim R et al. Radiology 2009

Non-Contrast-Enhanced MRA

- Time-of-flight and QISS
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- **Balanced SSFP (True FISP, FIESTA, Balanced FFE)**
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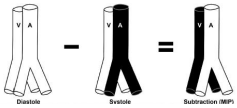
Flow sensitive dephasing-bSSFP

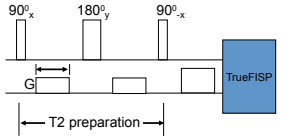
- bSSFP sequence
- Two acquisitions:



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

Fan Z, Li D, et al. MRM 2009 Vol:62

Flow sensitive dephasing-bSSFP



ϕ: Phase shift in a moving isochromat induced by the dephasing gradient

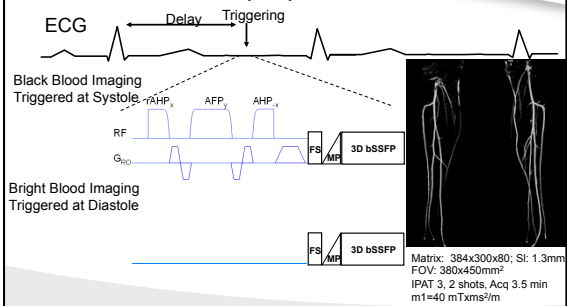
$$\phi = \gamma \cdot v(\vec{r}) \cdot \int G(t) \cdot t \cdot dt = \gamma \cdot v(\vec{r}) \cdot m_1$$

where $m_1 = \int G(t) \cdot t \cdot dt$, the first-order gradient moment

Moment determines flow sensitivity

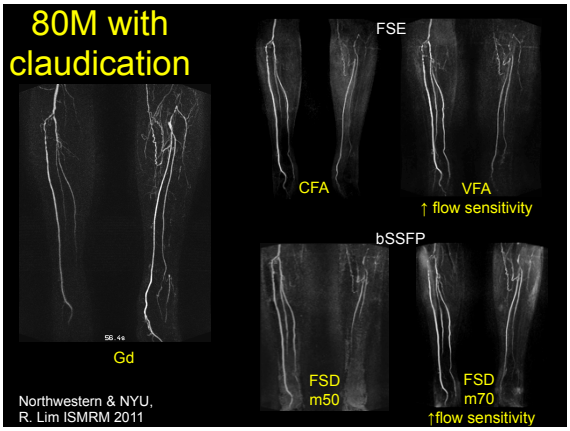
Fan Z, Li D, et al. MRM 2009 Vol:62

FSD-prepared SSFP



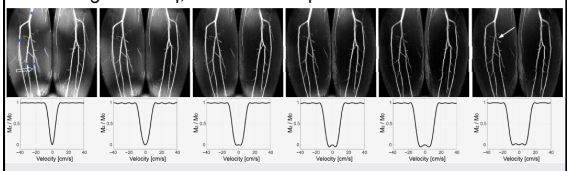
MRA = Bright Blood - Black Blood Imaging

80M with claudication



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



Shin T et al ISMRM 2012

Non-Contrast-Enhanced MRA

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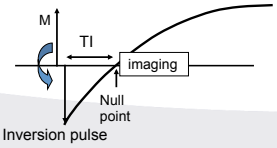
- Balanced SSFP (True FISP, FIESTA, Balanced FFE)
- **Arterial Spin Labeling with Balanced SSFP or FSE**
- Recommendations for Options across MRA applications

Arterial Spin Labeling: Principles

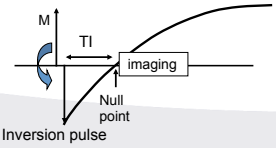
Key ideas

- "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: Methods

Less sensitive to field inhomogeneities

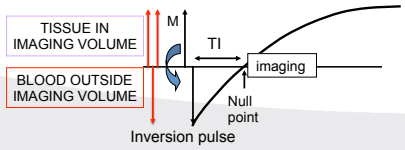
Flow compensated in 3 directions—better for complex flow patterns

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 acq)
  - 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)



Arterial Spin Labeling: Method 2

Inversion time 1100 ms (travel time to imaging slab)

Readout: balanced SSFP (flow-compensation 3D)

Presaturation to null veins

Respiratory triggering: 4 min

Selective Inversion (tagged blood with full magnetization)

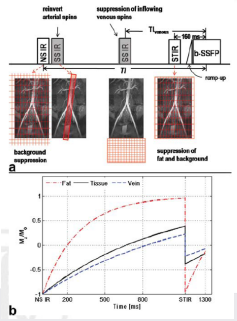
Non-Selective Inversion (whole abdomen)

Courtesy of Mr. J Takahashi, Toranomon Hospital, Japan

Arterial Spin Labeling: Method 2

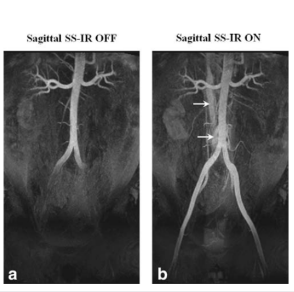
Application:

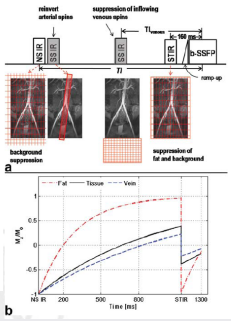
- Abdominopelvic MRA
- Challenge: Large anatomic coverage
- Need tagged blood to traverse from renal to femoral arteries before full T1 recovery of background



Atanasova I et al. JMRI 2011

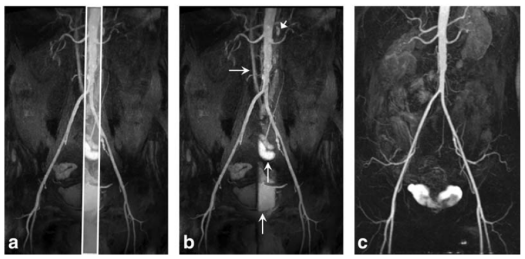
Arterial Spin Labeling: Method 2





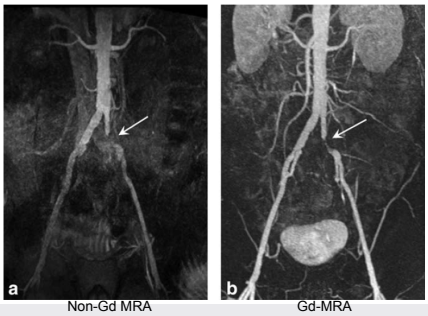
Atanasova I et al. JMRI 2011

Arterial Spin Labeling: Method 2



Atanasova I et al. JMRI 2011

Arterial Spin Labeling: Method 2



Non-Gd MRA Gd-MRA

Atanasova I et al. JMRI 2011

Non-Gd MRA Options

MRA Application	Non-Contrast-Enhanced Method	Notes
Intracranial MRA	3D TOF	TONE and MOTSA improve sensitivity to slower flow
Carotid MRA	ASL with 3D bSSFP or FSE Alternatively, 2D or 3D TOF	
Thoracic Aorta MRA	3D bSSFP	bSSFP ± with ASL No flow spoiling
Pulmonary MRA	Gated 3D FSE or ASL with 3D p-F FSE	Triggering in diastole
Coronary MRA	Gated 3D bSSFP	Breath-hold or navigator-free breathing
Abdominal Aorta/ Renal MRA	ASL with 3D bSSFP	Multidirectional flow pattern favors SSFP over gated FSE
Peripheral MRA	Gated 3D FSE or 2D TOF or QISS	Customize degree of flow-spoiling or flow-comp at each station
Hand and Foot MRA	FSE or ASL with 3D bSSFP or FSD-bSSFP	FSE more robust at 3T

Modified from Miyazaki M & Lee VS, Radiology, 2008

Recommended Reading

JOURNAL OF MAGNETIC RESONANCE IMAGING 36:286–304 (2012)

Review: MR Physics for Clinicians

Non-Contrast Enhanced MR Angiography: Physical Principles

CME

Andrew J. Wheaton, PhD and Mitsue Miyazaki, PhD*

Non-Gd MRA: More work needed

- Practical 3-station non-Gd protocol
  - robust to occlusive disease
- Non-Gd MRA at 3T: overcoming B1 inhomogeneities
- "Dynamic" non-Gd MRA
- Comparative effectiveness of CTA vs non-Gd MRA in renal failure

Acknowledgements

NYU
- Manjil Chatterji
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- Jian Xu, Siemens
- Graham Wiggins

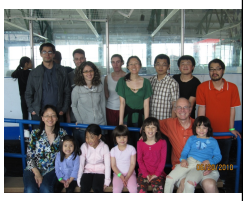
Northwestern University/Cedar Sinai
- Debiao Li
- Zhaoyang Fan

Columbia University
- Iliyana Atanasova
- Andrew Laine

Evanston Radiology
- Robert Edelman

Siemens
- Xiaoming Bi

Mitsue Miyazaki, Toshiba



NIH R01 HL092439