Improving Vascular Image Quality in Congenital Heart Disease Cardiac MRI

Animesh (Aashoo) Tandon, MD, MS
Assistant Professor, Pediatrics and Radiology
Division of Cardiology
University of Texas Southwestern Medical Center
October 10, 2017
North American Society of Cardiovascular Imaging Annual Meeting
What Is The Goal Of Vascular Imaging In CHD?

- Evaluate vascular stenosis and dilation
- Evaluate coronary artery anatomy
- Understand spatial relationships for surgical planning
Cardiac and Respiratory Motion

Cardiac motion + Respiratory motion

Cardiac motion: ~1-2cm (>60/min)
Respiratory motion: ~1-2cm (>12/min)

Courtesy of M. Henningsson, KCL, London
Current Standard Vascular Imaging

- 3D whole heart sequences (bSSFP)
  - Generally can be timed for end systole or mid diastole
  - Can be done without gadolinium contrast
  - Done over multiple heartbeats, usually with respiratory navigator
Current Standard Vascular Imaging

- Time-resolved magnetic resonance angiogram
  - Gives some idea of the flow through the vessels through multiple dynamics
  - Generally, can’t time it to the cardiac cycle
  - Generally requires gadolinium contrast
  - Is not gated
Overview – How Can We Do Better?

- Cardiac rest periods
- Respiratory motion correction
- Improving image contrast
  - Water-fat separation
  - Contrast-enhanced angiography
Cardiac Rest Periods
For 3D SSFP, want to image when there is little motion to shorten total acquisition time

- Generally this is in mid-diastole with slow heart rates, but end-systole can also be used
  - As heart rate increases, mid-diastole shortens

- Usually inspected visually on high-temporal res 4CH cine
Batsis M et al. Mitral valve phase contrast imaging is a more reproducible method of determining cardiac rest periods for whole-heart CMRA in CHD than 4 chamber cine. American College of Cardiology 2017 Poster.
Mitral Valve Inflow

Batsis M et al. Mitral valve phase contrast imaging is a more reproducible method of determining cardiac rest periods for whole-heart CMRA in CHD than 4 chamber cine. American College of Cardiology Poster.
Dual Phase Imaging

- Cardiac chambers (RA, RV, LA, and LV) and PVs had both higher CNR and image quality scores at end-systole.
- Diastolic imaging appears preferable for arterial imaging.
- Dual-phase 3D bSSFP can provide ECG-gated 3D imaging in both cardiac rest periods in a single sequence, taking approximately the same time as single-phase.

Dual Phase 3D CMRA (PB)

Dual Phase 3D CMRA (PB)

Respiratory Motion Correction
1D Navigator (Pencil Beam)

Suppression of respiratory motion: MR navigator technology:

Breathing curve

Diaphragm

Gating window

Courtesy of M. Stuber, Lausanne, Switzerland
1D Navigator (Pencil Beam; PB)

Disadvantages:

• The movement of the diaphragm is monitored, not of the heart!

• Diaphragmatic shift during MRI scanning increases acquisition time or discontinues data acquisition.

Variable acquisition time and image quality
Image Based Navigation (iNAV)

Trigger delay
ECG: R-wave → iNAV → CMRA

iNAV

CMRA

AO → RV → LV

RCA → LAD

Clinical Application: iNAV

Why not treat respiratory motion as another dimension and correct for it?

Combines the acceleration capabilities of reduced k-space sampling and sparse reconstruction with the self-navigation properties of a hybrid radial and Cartesian (stack-of-stars) sampling scheme to reconstruct additional motion dimensions.
XD-GRASP

XD-GRASP

XD-GRASP

<table>
<thead>
<tr>
<th></th>
<th>Coronal</th>
<th>LAD</th>
<th>LCX</th>
<th>RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrected</td>
<td><img src="XD-GRASP_uncorrected_coronal.png" alt="Image" /></td>
<td><img src="XD-GRASP_uncorrected_LAD.png" alt="Image" /></td>
<td><img src="XD-GRASP_uncorrected_LCX.png" alt="Image" /></td>
<td><img src="XD-GRASP_uncorrected_RCA.png" alt="Image" /></td>
</tr>
<tr>
<td>1D Respiratory Self-Navigation</td>
<td><img src="XD-GRASP_1D_respiratory_self-navigation_coronal.png" alt="Image" /></td>
<td><img src="XD-GRASP_1D_respiratory_self-navigation_LAD.png" alt="Image" /></td>
<td><img src="XD-GRASP_1D_respiratory_self-navigation_LCX.png" alt="Image" /></td>
<td><img src="XD-GRASP_1D_respiratory_self-navigation_RCA.png" alt="Image" /></td>
</tr>
<tr>
<td>4-Phase XD-GRASP</td>
<td>![Image](XD-GRASP_4-phase XD-GRASP_coronal.png)</td>
<td>![Image](XD-GRASP_4-phase XD-GRASP_LAD.png)</td>
<td>![Image](XD-GRASP_4-phase XD-GRASP_LCX.png)</td>
<td>![Image](XD-GRASP_4-phase XD-GRASP_RCA.png)</td>
</tr>
</tbody>
</table>

XD-GRASP

Piccini D et al. Magn Reson Med. 2017;77:1473-1484. Courtesy of: Pr. M. Stuber (CIBM), Pr. J. Schwitter (Cardio MRI, CHUV), Dr. P. Monney (Cardio MRI, CHUV), Dr. J. Yerly (CIBM) and Dr. D. Piccini (Siemens)
Improving Image Contrast
Non-contrast Options

- Black blood imaging
  - HASTE
    - Slow/in plane flow creates areas where the blood signal is not nulled

- Bright blood imaging
  - 3D SSFP whole heart (mainstay)
    - Pericardial fluid is not nulled

- mDixon water-fat
Slow Flow/In Plane Flow Flow Artifact

http://mriquestions.com/dark-blooddouble-ir.html
Pericardial Fluid
Dixon Water-Fat Separation

- Fat information might be useful in cardiac tumors
- Might give insights into whether a coronary is fully embedded in fat – anomalous origin?
- Works by targeting the chemical shift between water and fat, so creates a water and fat image
Dixon Water-Fat Separation

Dixon Water-Fat Separation in CHD

Image courtesy Dr. Michael Taylor and Dr. Ryan Moore, Cincinnati Children’s Hospital
Contrast-Enhanced Angiography

- Increase the signal from the vascular space compared to the muscle and other tissue
  - Gadolinium contrast
  - Ferumoxytol contrast
Advantages Of Gad Contrast Enhancement

- Shortens T1 time of blood, allowing better image contrast separation of blood from surrounding tissues with inversion pulse
- Allows time-resolved imaging
- Allows inversion recovery imaging
Gadolinium Contrast + Inversion Recovery

T2-prep SSFP

SSFP IR

Ferumoxytol Contrast Imaging

- Ferumoxytol is an ultrasmall superparamagnetic iron oxide (USPIO) particle
- FDA approved as an IV treatment of iron-deficiency anemia in patients with chronic kidney disease
- Has a prolonged intravascular residence time of more than 12 hours
4D MUSIC with Ferumoxytol

4D MUSIC with Ferumoxytol

Images courtesy Dr. Paul Finn, UCLA
4D MUSIC with Ferumoxytol

Images courtesy Dr. Paul Finn, UCLA
Contrast Risks

- **Gadolinium**
  - recent findings of gadolinium deposits in the brain, along with NSF in impaired renal function

- **Ferumoxytol**
  - the risk of acute adverse events with ferumoxytol is likely higher than that of gadolinium-based agents
  - has a strong safety profile and may provide unique diagnostic information
  - may be a valuable alternative for patients with renal insufficiency
Many techniques exist today to improve vascular imaging in CHD, a challenging population.

More work needs to be done to bring these techniques to all centers.
Acknowledgements

- UTSW/Children’s Medical Center
  - Dr. Gerald Greil
  - Dr. Tarique Hussain

- Cincinnati Children’s:
  - Dr. Michael Taylor
  - Dr. Ryan Moore

- CHUV/U. Lausanne:
  - Pr. M. Stuber (CIBM)
  - Pr. J. Schwitter (Cardio MRI)
  - Dr. P. Monney (Cardio MRI)
  - Dr. J. Yerly (CIBM)
  - Dr. D. Piccini (Siemens)

- UCLA:
  - Dr. Paul Finn