4D flow MRI in Congenital Heart Disease

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Outline

• Overview of phase contrast MRI
• 4D flow MRI – what is it?
• How we perform 4D flow MRI in congenital heart disease
• Workflow
• Applications and examples
All MR Images have Magnitude and Phase

Magnitude

Phase
Bipolar Gradients in Presence of Moving Spins

Static Spins

Moving Spins

\[ M_y F_0 = 0 \]

Bipolar Gradients in Presence of Moving Spins
Phase Contrast Velocity Imaging

Segmentation
(Spatial Integration)

Volume (ml/heartbeat)

Area under flow curve
(Temporal Integration)
“4D”-Flow MRI

- Volumetric coverage
  - 3-directional flow encoding: 4 acquisitions
- ECG gating
- Breathing motion in abdomen and chest
  - Respiratory gating/triggering

Courtesy Oliver Wieben, PhD – UW-Madison
Radial Sampling and Undersampling with MRA

$k_x, k_y$
Radial 4D flow MRI: \textit{PC VIPR}\textsuperscript{1}

\textsuperscript{1}TL Gu, et al. AJNR 2005.
\textsuperscript{2}KM Johnson, et al. MRM 2008.
NCE intracranial MRA with PC VIPR

Normal Volunteer
PC VIPR Parameters
- Dual Echo
- FOV: 20 x 20 x 20 cm
- Res: 0.6 x 0.6 x 0.6 mm
- 9000 Projections (36x)
- TR=15.9
- Bandwidth = 31.25
- VENC = 50 cm/s
- 5:07 min Scan Time

Same Cartesian PC
- 48+ min Exam (Partial)

Same TOF
- 24+ min Exam (Partial)

1KM Johnson et al. Magn Reson Med. 2008 Dec;60(6):1329-
Source 4D flow MR Images
Applications in Congential Heart Disease

• **Qualitative**
  – Anatomy
  – Flow direction

• **Quantitative**
  – Flow (ml/cycle)
  – Velocity
  – Pressure gradients
  – Shear stress
  – Kinetic energy

• **Aortopathy**
  – Coarctation
  – Bicuspid aortic valve
  – Aneurysms, dissection

• **Congenital Cardiac disease**
  – Comprehensive flow assessment, eg. Qp/Qs
  – Fontan evaluation
  – Complex anatomy
  – *Multiple abnormalities*
2 month old boy with Scimitar Syndrome
2yo boy with Right Lung PAPVR

CINE SSFP

CE-MRA

4D flow MRI

ASD

LPV

RPV
2yo boy with Right Lung PAPVR

CE-MRA

4D flow MRI
Complex Congenital Heart Disease: Swaddled Infant

Findings

- Coarctation
- Aberrant right subclavian
- AV canal
- Patent ductus arteriosus
- Patent ductus venous with PV shunting

17 day old girl with complex congenital heart disease
Complex Congenital Heart Disease: *Swaddled Infant*

17 day old girl with complex congenital heart disease

*Flow quantification*

*AV Canal*

*Coarctation*
Comprehensive Flow Assessment: *Fontan*

15yo female with DORV s/p extra-cardiac Fontan
Comprehensive Flow Assessment: *Fontan*

15yo female with DORV s/p extra-cardiac Fontan

DICOM report in PACS
**Fontan Circulation**: Flow Distribution Quantification

A: time = 0 ms  
B: time = 52 ms  
C: time = 104 ms  
D: time = 1435 ms  
E: PC-MRA  
F: mixing

Kelly Jarvis, Northwestern University
Computational Fluid Dynamics:
Virtual Surgery and Rapid Prototyping
Computational Fluid Dynamics: Virtual Surgery and Rapid Prototyping

MRA

3D Printing

Flow Phantom
2 year-old male with aortic coarctation
Navier-Stokes Equation

\[ \nabla P = -\rho \left( \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) + \rho g + \mu \nabla^2 \mathbf{v} \]

- \( P = \text{pressure} \)
- \( \mathbf{v} = \text{velocity} \)
- \( \mu = 4 \text{ cP (centipoise)} \)
- \( \rho = 1066 \text{ kg/m}^3 \)
- \( g = 9.8 \text{ m/s} \)
Non-invasive Pressure Measurements

Bley, et al. Radiology
Pressure Gradients Across Coarctation

18 month old with aortic coarctation

Complete hemodynamic assessment possible
“Image Once, Cut Many”

- Large imaging volume acquired in single 8-12 minute acquisition
- Neonates / infants
  - Feed, swaddle, image in ~ 10 minutes without sedation
- Comprehensive, time-resolved data
- Requires significant post-processing
- Can interrogate any vessel post-acquisition
- Works well with clinical workflow
- Technologists can acquire images without a radiologist
- Post-processing requires experience
Thank you!

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