Real-Time Measurement of Cardiac Function and Flow

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Motivation

- Cardiac MRI with navigators or breath-holds require patient cooperation, and consistent cardiac rhythm.
  \[ \approx 10\% \text{ of CMR patients have arrhythmia at rest.} \]
  \[ \approx 10\% \text{ of CMR patients cannot hold breath for } \geq 10 \text{ seconds while supine in the scanner.} \]
  Many patients (including non-sedated kids) are simply not cooperative.

- Reduce total examination time!
- Examine beat-to-beat variations!
“Gated”

Plethysmograph or EKG signal

Approx. 10 to 100 ms per image

“Real Time” (RT)

No gating or synchronization

Approx. 10 to 100 ms per image
“Gated”

(source: Siemens)

“Real Time” (RT)

(source: Peter Kellman)
“Gated”

“Real Time” (RT)
Echocardiography

- Inexpensive (10x)
- Can be Portable
- Real-Time (>30 fps)
- Operator-Friendly

Image Quality Issues
Limited Flexibility
- scan-plane
- flow direction

Incomplete Exam

(source: YouTube)
Outline

• Introduction

• RT-MRI of Cardiac Function

• RT-MRI of Cardiovascular Flow

• Remarks
RT Cardiac Function

- Best Image Quality: 1.5T with hi-speed gradients.
Spiral GRE  Spiral SSFP
User Interfaces

(source: Philips)
Arrhythmias

courtesy of Peter Kellman
Clinical Results

• Consistent image quality, better than that what is routinely achieved by Echo.

• Measurements of LV Mass, EF, ESV, EDV, have been validated against CINE MRI.

• Used as a “backup” for when the patient is non-cooperative or has arrhythmia. Longer processing time.

Yang, Nagel, Kaji, Narayan, and others
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RT Color Flow

- Why Spirals?
  - In-plane flow produces tolerable image distortion shift and blurring in the direction of flow.
RT Color Flow

• Why Spirals?

2DFT GRE-PC → Spiral GRE-PC → Spiral GRE-PC w/ Par. Img. (offline recon)
Spiral Phase Contrast

2-interleaves, 2-images, 100 ms
2.7 mm resolution, 20 cm FOV

Nayak et al., MRM 2000
Color Flow Image Formation

Two images

Magnitude

Phase Difference \( \propto \) Velocity

Color Overlay

one velocity component
Color Flow Image Formation

Two images

Magnitude

Phase Difference \(\propto\) Velocity

Color Overlay

Color Flow Image

one velocity component
Valve Regurgitation Trial

- 85% detection of clinically significant disease
- >90% agreement with echo within one grade
  (none / mild / moderate / severe)

source: Pedro Rivas
Congenital Defect Trial

9 VSD, 4 ASD, 1 Aortic Coarct., 2 Surgical Shunts. Flow seen in multiple scan planes without aliasing.

source: Erasmo de la Pena
Spiral SENSE

source: Reza Nezafat
Stroke Volume

source: Joao Carvalho
**Stroke Volume: Valsalva**

I: inspiratory pressure  
→ increased SV

II: sympathetic response  
→ reduced variability, increased HR, reduced SV

III: expiratory pressure  
→ dip in SV

IV: vagal response  
→ reduced HR, increased SV, increased variability

*source: Joao Carvalho*
Stroke Volume: Handgrip

- **Sympathetic response**
  - → increased HR,
  - reduced HRV
- **Shorter diastoles**
  - → reduction in SV

source: Joao Carvalho
Talk #30: Jennifer Steeden, et al.
Cardiac Output in response to Exercise (RT Spiral SENSE)

Talk #56: Iain Pierce, et al.
Venous Blood Flow (RT Spiral)
MR Doppler

Phase-Contrast MRI
Requires 2D spatial encoding

Real-Time FVE
Requires 1D spatial encoding

Velocity Spectrum every ~20ms

source: B. Hu, P. Irrarazabal, C Macgowan
MR Doppler

Pulse Sequence

K-space Trajectory

source: J DiCarlo
Spatial Position

scout image

pencil excitation

velocity

Marfan syndrome, aortic insufficiency

source: Chris Hardy
In-Vivo Examples

Mitral valve

Aortic valve jet

0.8 m/s - 2.4 m/s -

source: Juan Santos, Bob Hu
Putting them Together

3D Mouse

Accurate placement of MR Doppler “pencil beam”

source: HeartVista
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Remarks

• Making an Expensive Echo Machine?
  – NO! but learning many lessons from it.

• Engineering Advances: GUIs, SSFP, parallel imaging.

• Vendors: RT Function / Localizer

• Opportunities: variations in cardiac output (and other flow volumes), regional wall thickening, and other applications.