Cardiac MRI Sequences and Protocols

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**Traditional Protocol Model for Tomographic Imaging**

- Techniques
- Interpretation
- Orientations

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**Challenges in Cardiac Imaging**

- Large number techniques

- Finite number techniques

- Infinite number of imaging planes

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**Objectives**

- To know the basic types of clinically used cardiac MRI sequences
- To understand how cardiac MRI records the moving heart
- To understand trade-off in noise and performance
- To learn how to set up standard cardiac planes and a cardiac function protocol

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**Basic Cardiac MRI Sequences**

- T1/DIR
- MRA
- Coronary MRA
- ssp cine
- Perfusion
- Delayed Enhance
- Phase Contrast
- Tagging
Basic Cardiac MRI Sequences

- Bright blood
- Cardiac gated
- Cardiac cine
- Breath-hold
- Non-contrast
- Names
  - Fiesta (GE)
  - True Fisp (Siemens)

Basic Cardiac MRI Sequences

- "Grey" blood
- Cardiac gated
- Cardiac cine
- Breath-hold
- Non-contrast
- Names
  - mtag (Stanford)
  - Tagged fast cine (GE)

Basic Cardiac MRI Sequences

- Dark blood
- Cardiac gated
- Single cardiac phase
- Breath-hold
- Non-contrast
- Names
  - DIRFSE (GE)
  - HASTE (Siemens)

Basic Cardiac MRI Sequences

- Dark blood, Fat suppressed
- Cardiac gated
- Single cardiac phase
- Breath-hold
- Non-contrast
- Names
  - TIRFSE (GE)

Basic Cardiac MRI Sequences

- Bright blood
- Non-gated
- Breath-hold
- 1st Pass-contrast
- Names
  - FAST (GE)
  - FLASH (Siemens)

Basic Cardiac MRI Sequences

- Velocity Imaging
- Cardiac gated
- Cardiac cine
- Breath-hold
- Contrast-improved
- Names
  - FastCine-PC (GE)
  - Phase Contrast (Siemens)
Basic Cardiac MRI Sequences

- Bright-blood
- Cardiac gated
- Single cardiac phase
- Navigator echo
- Non-contrast
- Names
  - MSLAB (GE)

Basic Cardiac MRI Sequences

- Dark myocardium
- Cardiac gated
- Single cardiac phase
- Breath-hold
- Post-contrast
- Names
  - IrPFSE / MDE (GE)
  - TFLASH (Siemens)

How to record a moving heart?

Basic Cardiac MRI Sequences

- Dark myocardium
- Cardiac gated
- Single cardiac phase
- Breath-hold
- 1\textsuperscript{st} Pass-contrast
- Multiple contrast phases
- Names
  - IrP-EPI/GRE (GE)

Fast, Real-Time Imaging

- Bright blood
- Non-gated
- Breath-hold optional
- Non-contrast
- Low spatial and temporal res.
- Names
  - MR Echo (GE)

Gated cine

- Almost all cardiac sequences assume periodic, repeating cardiac motion
- Each RR-interval records part of the k-space information
- To build up multiple frames of k-space information requires multiple heart beats
- The method of dividing up the k-space is called \textit{segmented k-space}. 

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Conventional Cine Acquisition

Ph 1
Ph 2
Ph 3
Ph N

1TR

8/17/2011
Questions

- How long does this scan take?
  - Phase encodes x RR-interval
- At 60 bpm, 192 lines, how long?
  - 3 minutes 12 seconds
- What is the temporal resolution?
  - TR
- In real terms?
  - ~ 5 ms
Problem: How to shorten scan time?

Solution: Acquire more than one phase encoding line per heart beat.

GE: View per segment (vps) = number of lines per heart beat
Questions

• How long does this scan take?
  – Phase encodes x RR-interval / view per segment
• At 60 bpm, 192 lines, 8 vps, how long?
  – 24 seconds
• What is the temporal resolution?
  – TR x view per segment
• In real terms?
  – 40 ms for 8 v/s and TR=5 ms

FIESTA at Different V/S

10 v/s
20 v/s
30 v/s
60 v/s

How to improve a noisy image?

Signal-to-Noise Ratio

• B0, Magnet Strength
• Receiver coil
• Slice thickness
• In-plane resolution
• Flip angle
• Bandwidth
• Gadolinium Contrast
• In-flow

Slice Thickness

4 mm
8 mm

Field of View

32 cm
25 cm
How to do a cardiac function MRI study?

Optimal MRI Protocol

- Every image taken must serve a diagnostic goal.
- The number of sequences and breath-holds should be minimized.
- Fast sequences and parallel imaging should be used whenever possible, but ...
- Sequences should be grouped according to contrast usage.
- Oblique planes should be prescribed in the least number of intermediate steps.
Protocol: Cardiac Function
- Pre-contrast
  - 3-plane SSFP localizer
  - Optional axial localizer
  - LAX SSFP cine localizer
  - SAX SSFP cine
  - 4ch SSFP cine
  - LV3ch SSFP cine
  - LV2ch SSFP cine
  - RV2ch SSFP cine
  - RVOT SSFP cine
  - Ao long SSFP cine localizer
  - PA long SSFP cine localizer
  - Ao PC cine
  - PA PC cine
  - TV PC cine
  - MV PC cine

Optional axial localizer
- LAX SSFP cine localizer
- SAX SSFP cine
- 4ch SSFP cine
- LV3ch SSFP cine
- LV2ch SSFP cine
- RV2ch SSFP cine
- RVOT SSFP cine
- Ao long SSFP cine localizer
- PA long SSFP cine localizer
- Ao PC cine
- PA PC cine
- TV PC cine
- MV PC cine

Protocol: Viability
- Pre-contrast
  - 3-plane SSFP localizer
  - Optional axial localizer
  - Loc LAX SSFP cine
  - SAX SSFP cine
  - 4ch SSFP cine
  - LV3ch SSFP cine
  - LV2ch SSFP cine
- Post-contrast
  - Cine IR
  - 4ch Test for TI
  - SAX IR at TI
  - LV3ch, LV2ch IR at TI

Protocol: TOF
- Pre-contrast
  - 3-plane SSFP localizer
  - Optional axial localizer
  - LAX SSFP cine localizer
  - SAX SSFP cine
  - 4ch, LV-LAX, RV-LAX SSFP cine
  - RVOT SSFP cine
  - Ao long SSFP cine localizer
  - PA long SSFP cine localizer
- 1st Pass
  - CE MRA
- Post-contrast
  - Ao PC cine
  - PA sup, PA sub PC cine
  - TV sup PC cine

Coronal Localizer
- Options: GRE, single phase SSFP, SSFSE, T1-SE, or double-IR

Axial Localizer
- ECG-gated, Breath-hold

Oblique Sagittal Cine
- ECG-gated, Breath-hold

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**Short Axis Cine**
- Scan from base to apex

**Ventricular Volumes / Mass**

**SAX Valve Plane**
- PV
- AV
- MV
- TV

**4-Chamber View (HLAX)**

**LV 3-Chamber View**
Aortic Regurgitant Flow

SSFP cine diastole
Phase contrast cine

Cardiac Output / Shunt Ratio

Cardiac Outputs (Phase Aligned)

Qp/Qs = 1.06

Tricuspid Flow

Inlet Valves Flow

MR Flow Imaging

Cardiac Phase Flow (cc/min)

TR Flow Imaging

4ch, RVLAX views
Phase contrast cine

PA Flow Imaging

SSFP cine diastole
Phase contrast cine

Cardiac Outputs (Phase Aligned)

Cardiac Phase Flow (cc/min)

4ch, RVLAX views
Phase contrast cine

MR Flow Imaging

4ch, RVLAX views
Phase contrast cine
Summary

• The practice of cardiac MRI is an integration of
  – Clinical knowledge
  – Technical knowledge
  – Patience and interest
• Like the making of a violin virtuoso, it is
  – 99% practice
  – 1% gift