



## Cardiac MRI Sequences and Protocols

*Frandics Chan, M.D., Ph.D.*

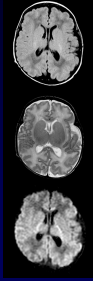


Stanford University  
Medical Center

Lucile Packard  
Children's Hospital

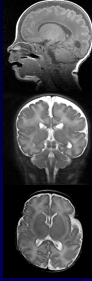


## Traditional Protocol Model for Tomographic Imaging




Techniques

×



Orientations

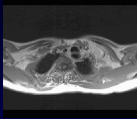
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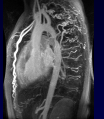


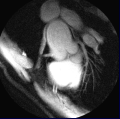
Interpretation


## Challenges in Cardiac Imaging

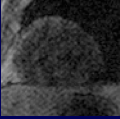
- Large number of techniques

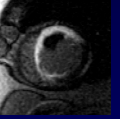
  
T1/DIR

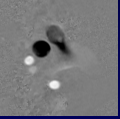
  
MRA

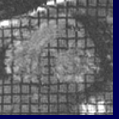
  
Coronary MRA



  
ssfp cine

  
Perfusion

  
Delayed Enhance

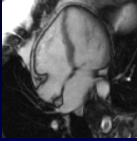
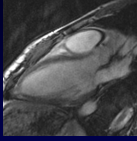

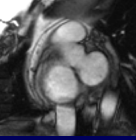

  
Phase Contrast



  
Tagging

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## Challenges in Cardiac Imaging



- 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

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### Basic Cardiac MRI Sequences

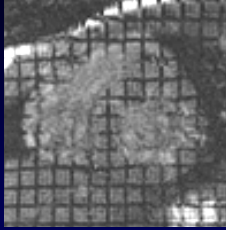


Balanced-SSFP

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

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### Basic Cardiac MRI Sequences

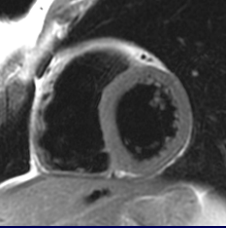


Myocardial tagging

- “Grey” blood
- Cardiac gated
- Cardiac cine
- Breath-hold
- Non-contrast
- Names
  - mtag (Stanford)
  - Tagged fastcine (GE)

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### Basic Cardiac MRI Sequences

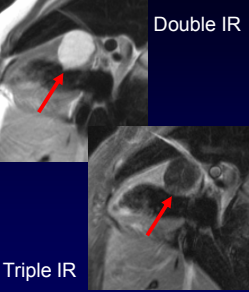


Double IR

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

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### Basic Cardiac MRI Sequences




Double IR  
Triple IR

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

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### Basic Cardiac MRI Sequences

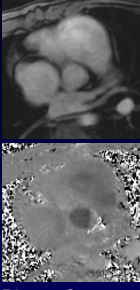


3D CEMRA

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

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### Basic Cardiac MRI Sequences

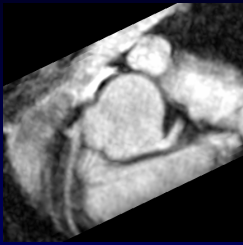


Phase Contrast

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

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### Basic Cardiac MRI Sequences




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

Coronary MRA

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### Basic Cardiac MRI Sequences

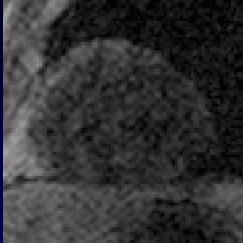


- Dark myocardium
- Cardiac gated
- Single cardiac phase
- Breath-hold
- Post-contrast
- Names
  - IrPFSE / MDE (GE)
  - TFLASH (Siemens)

Delay-enhancement

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### Basic Cardiac MRI Sequences



- Dark myocardium
- Cardiac gated
- Single cardiac phase
- Breath-hold
- 1<sup>st</sup> Pass-contrast
- Multiple contrast phases
- Names
  - IrP-EPI/GRE (GE)

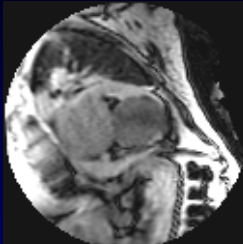
Myocardial Perfusion

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### How to record a moving heart?

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### Fast, Real-Time Imaging



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

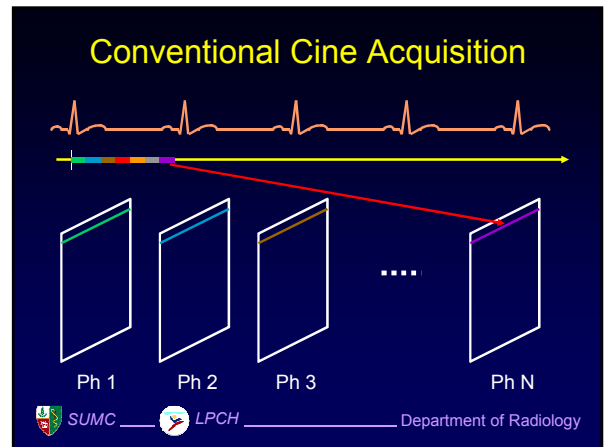
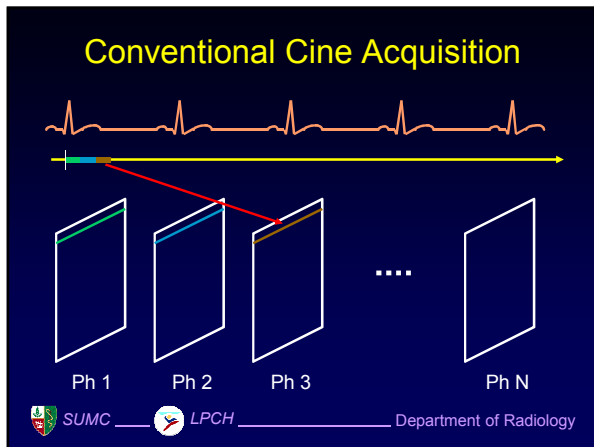
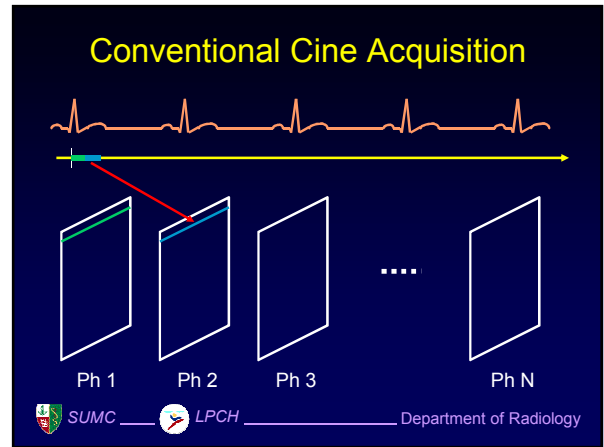
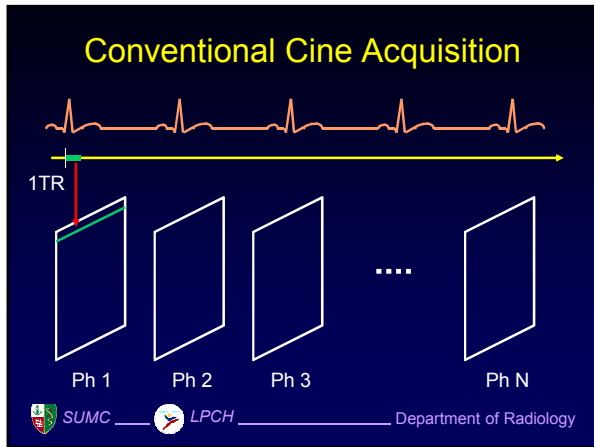
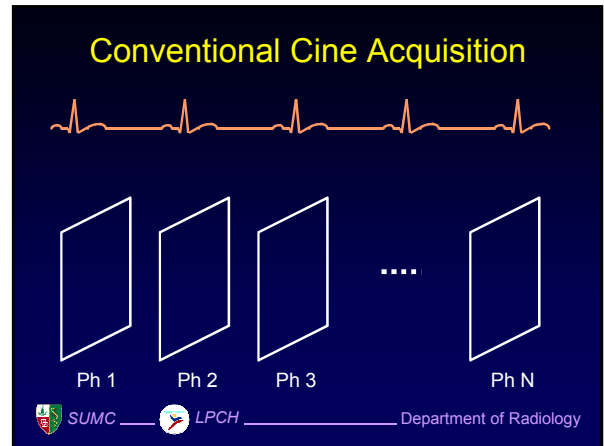
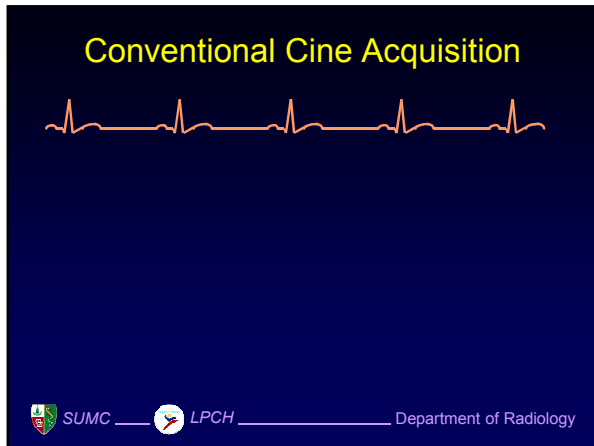
Real-time imaging

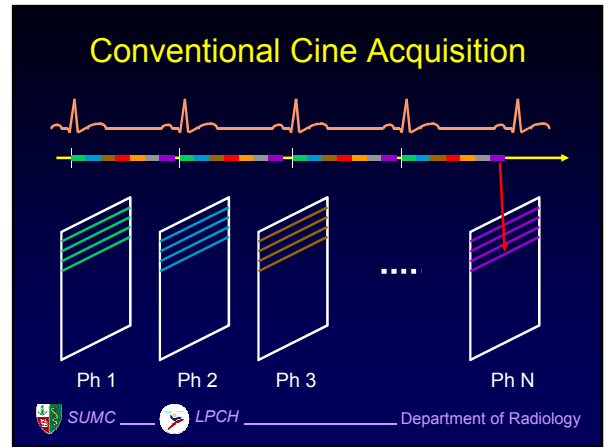
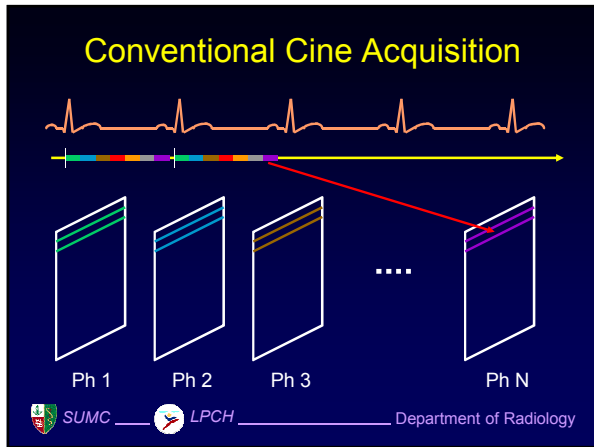
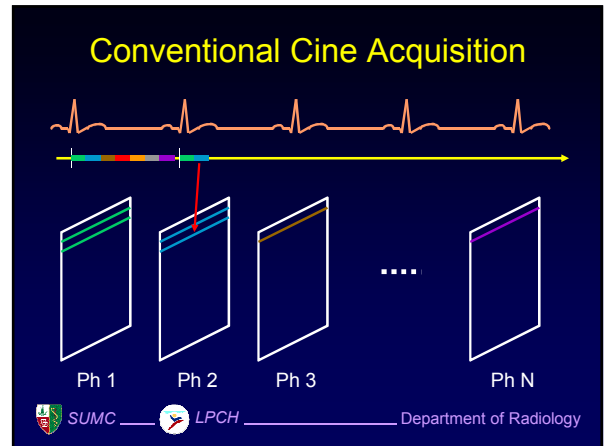
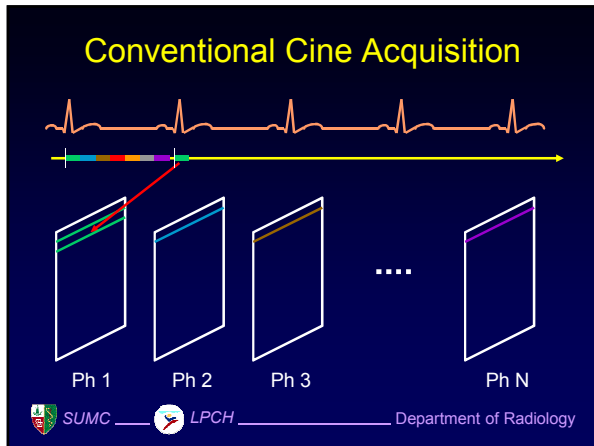
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### Gated cine

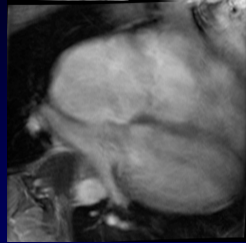
- Almost all cardiac sequences assume periodic, repeating cardiac motion
- Each RR-interval records part of the k-space information
- To build up multiple frames of k-space information requires multiple heart beats
- The method of dividing up the k-space is called **segmented k-space**.

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- ### 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
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- ### Conventional Cardiac cine
- 
- Best possible temporal res.
  - Long scan time
  - Respiratory motion
  - Means of control
    - Resp. comp.
    - Resp. gating
    - Breath-hold
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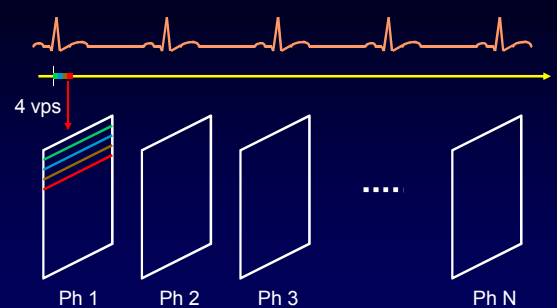
Problem: How to shorten scan time?

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




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### Segmented K-Space



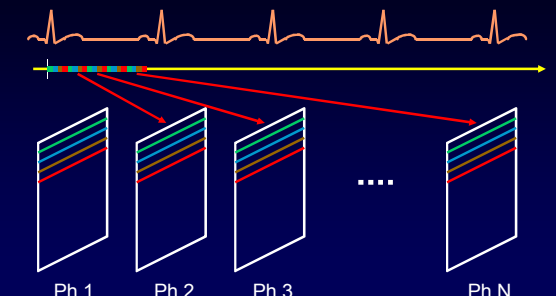
4 vps

Ph 1 Ph 2 Ph 3 ... Ph N




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### Segmented K-Space

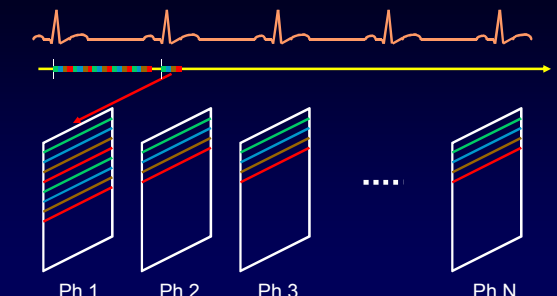


Ph 1 Ph 2 Ph 3 ... Ph N




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### Segmented K-Space

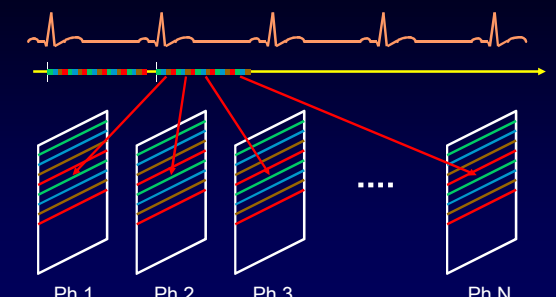


Ph 1 Ph 2 Ph 3 ... Ph N




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### Segmented K-Space




Ph 1 Ph 2 Ph 3 ... Ph N



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

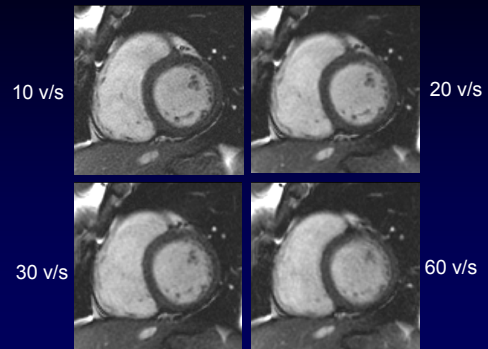


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### Questions

- 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

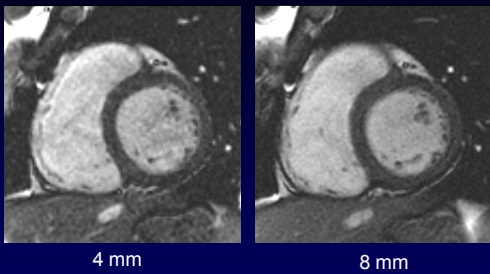


### How to improve a noisy image?

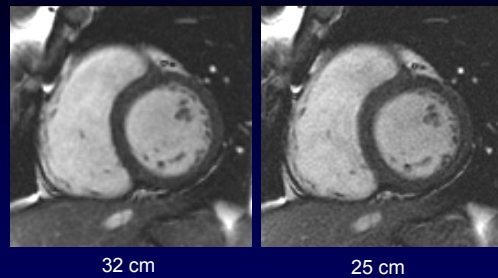
### Signal-to-Noise Ratio

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

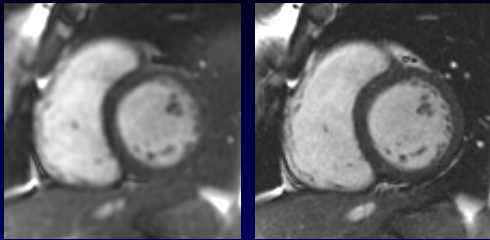
### Slice Thickness



### Field of View



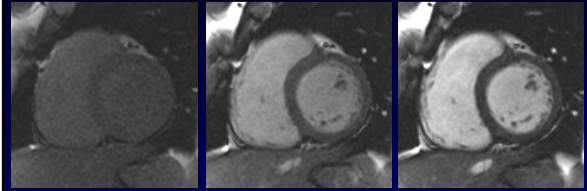
### Matrix Size



128 x 128

224 x 224

### Flip Angle

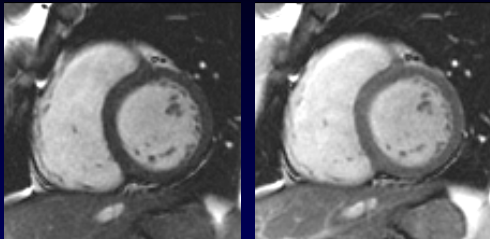


10 degree

30 degree

50 degree

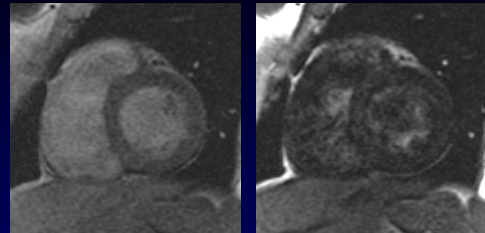
### Contrast



Non-contrast

Contrast

### In-Flow (FastCine)



10 degree

50 degree

## 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
  - RV3ch 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

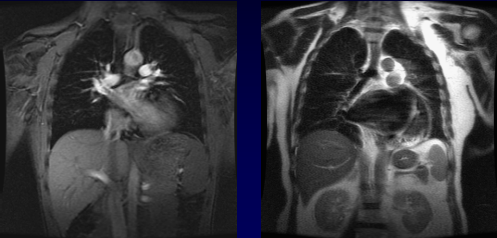
- Pre-contrast
  - 3-plane SSFP localizer
  - *Optional* axial localizer
  - *Loc* LAX SSFP cine
  - SAX SSFP cine
  - 4ch SSFP cine
  - LV3ch SSFP cine
  - LV2ch SSFP cine
- Post-contrast
  - Cine IR
  - 4ch Test for TI
  - SAX IR at TI
  - LV3ch, LV2ch IR at TI

### 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

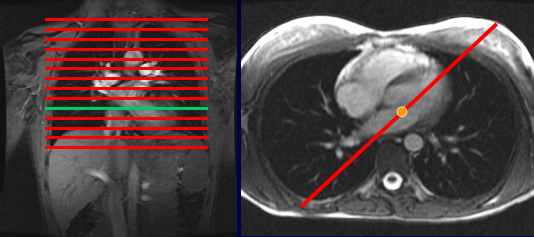
### Coronal Localizer

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



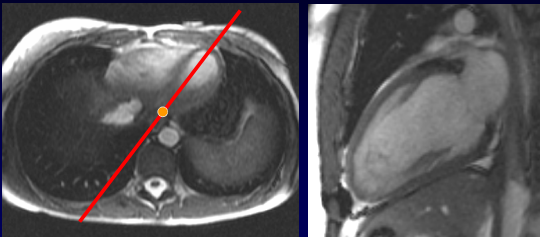
### Axial Localizer

- ECG-gated, Breath-hold



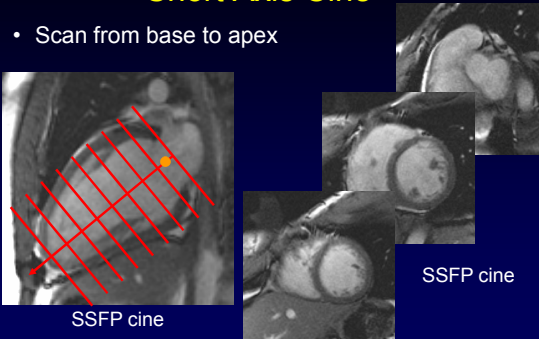
### Oblique Sagittal Cine

- ECG-gated, Breath-hold



### Short Axis Cine

- Scan from base to apex

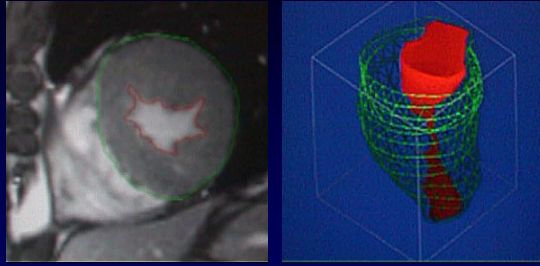


SSFP cine

SSFP cine

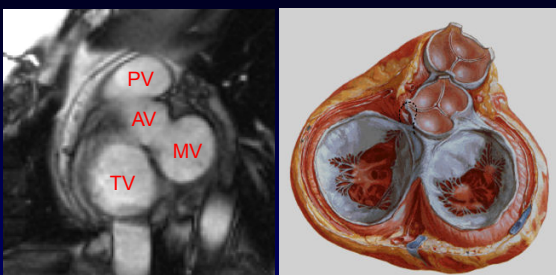
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### Ventricular Volumes / Mass



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### SAX Valve Plane

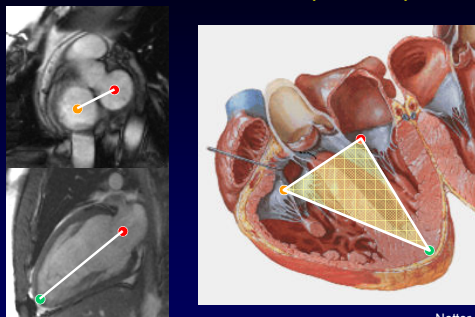


PV  
AV  
MV  
TV

Netter

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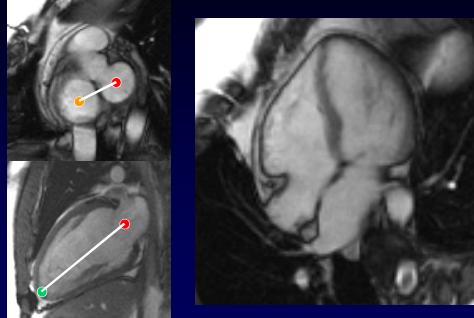
### 4-Chamber View (HLAX)



Netter

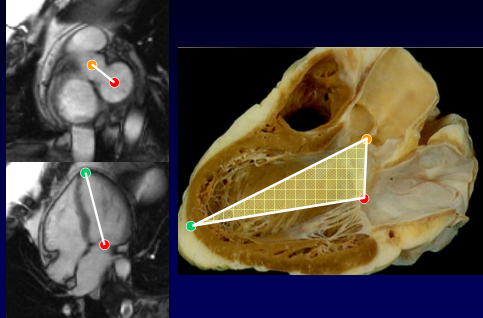
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### 4-Chamber View (HLAX)

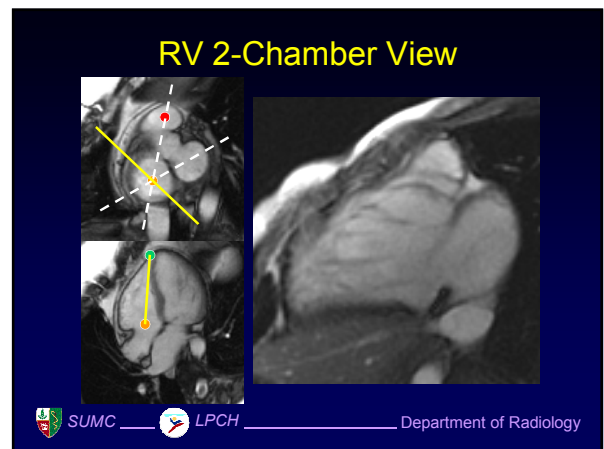
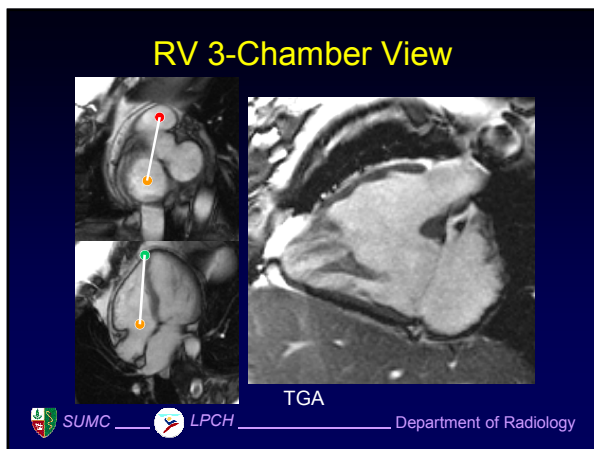
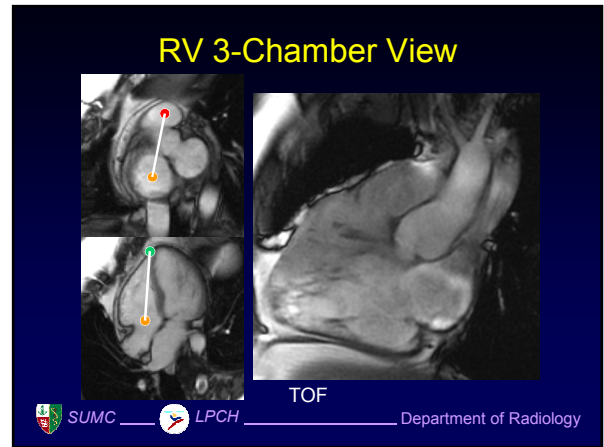
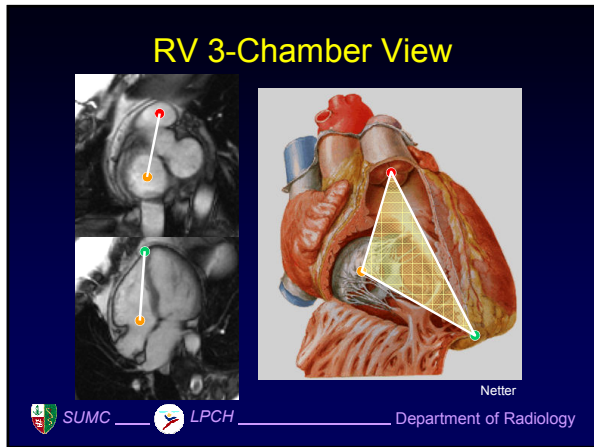
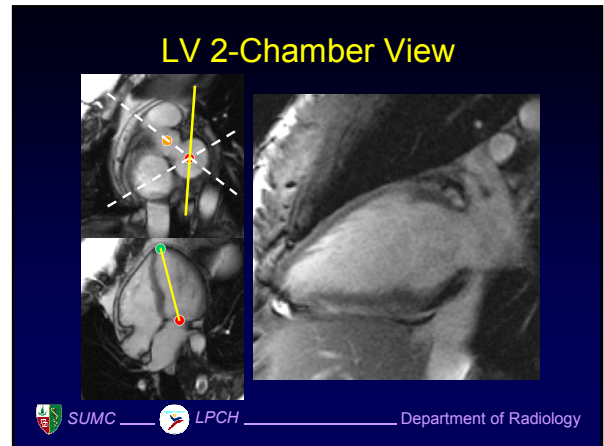
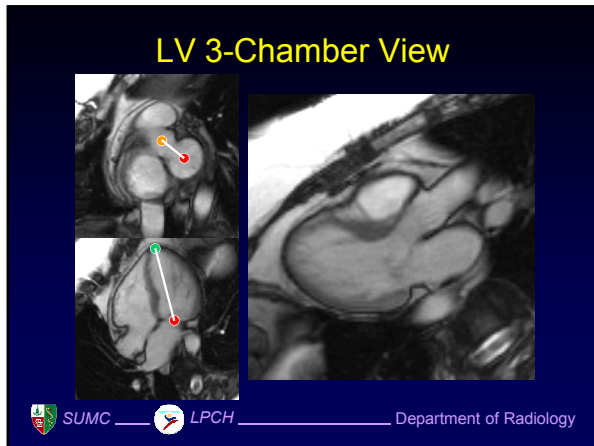


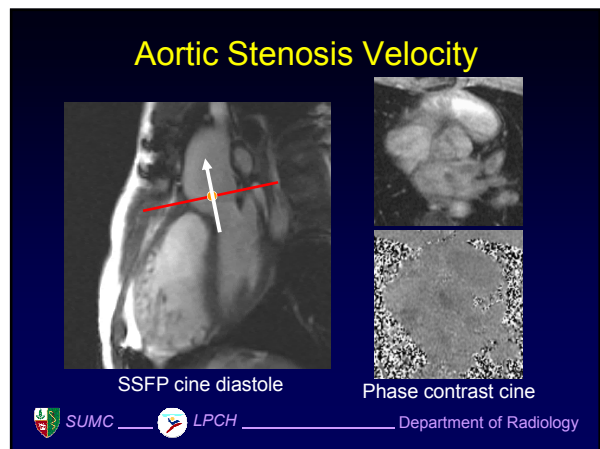
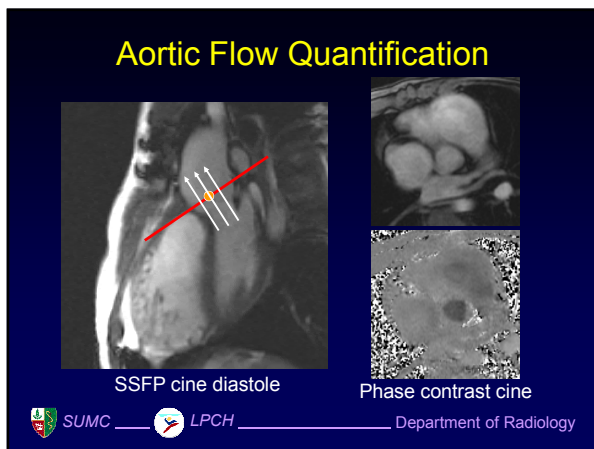
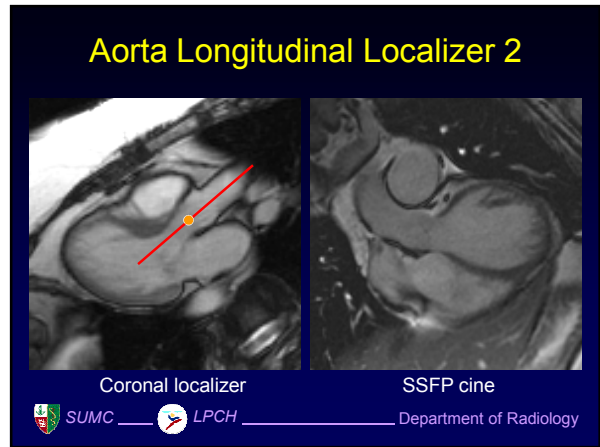
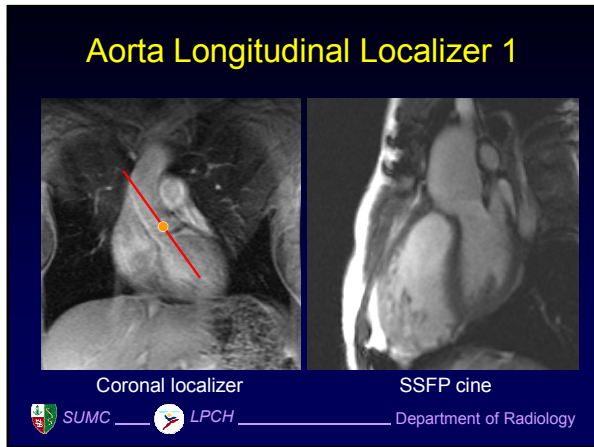
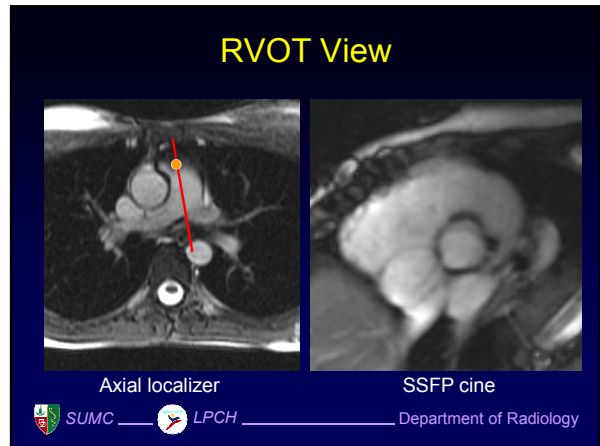
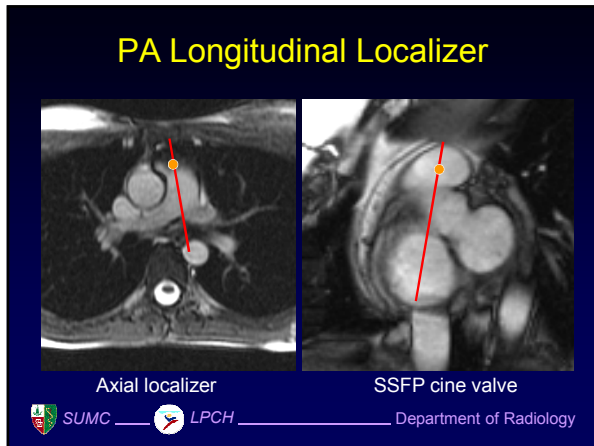
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### LV 3-Chamber View



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### Aortic Regurgitant Flow

SSFP cine diastole
Phase contrast cine

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### PA Flow Imaging

SSFP cine diastole
Phase contrast cine

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### Cardiac Output / Shunt Ratio

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### TR Flow Imaging

4ch, RVLAX views
Phase contrast cine

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### Tricuspid Flow

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### MR Flow Imaging

4ch, RVLAX views
Phase contrast cine

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## 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



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