ISMRM Clinical MRI Course: Cardiac Protocols

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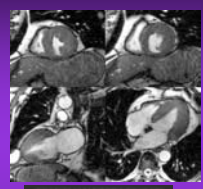
www.med.nyu.edu/mri

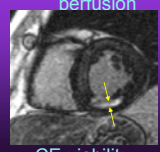
Cardiac MR: Coming of Age



True FISP

CE-First pass perfusion

CE-MRA



CE-viability

Overview

- Safety Issues
- Imaging Planes
- Clinical Protocols: A How To …
  - Cardiac Morphology and Masses
  - Valvular Disease
  - LV Function
  - Ischemic Heart Disease

MR Safety Issues

- Contraindications
  - Pacemaker/Defibrillator/Pumps
  - Recent (< 6 wks) coronary stenting
- Not Contraindications
  - Prosthetic valves
  - Vascular stents (> 6 wks)
  - Sternotomy wires
  - IVC filters
  - Arrhythmias (use special sequences)

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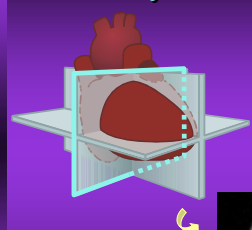
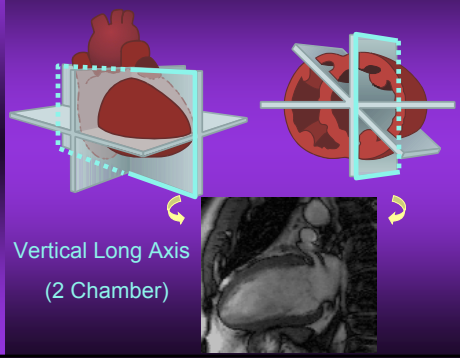
Commonly Used Imaging Planes



Short Axis

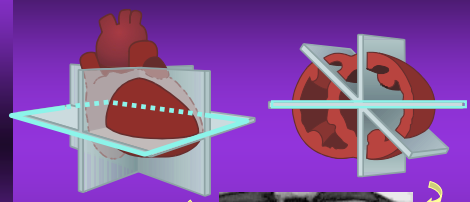
Commonly Used Imaging Planes



Vertical Long Axis

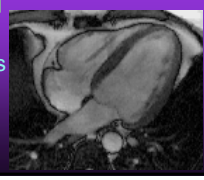
(2 Chamber)

Commonly Used Imaging Planes

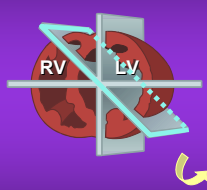


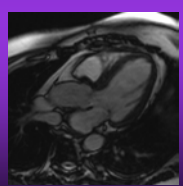
Horizontal Long Axis

(4 Chamber)



Commonly Used Imaging Planes





Three-chamber view

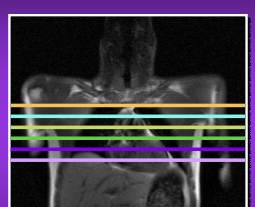
Imaging Planes

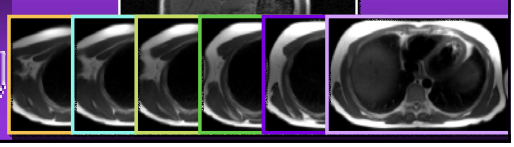
A Step-by-Step Guide ...

Imaging Planes

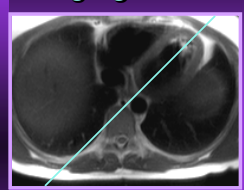
Coronal

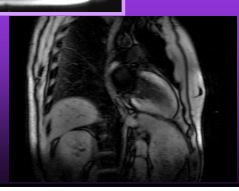
Scout





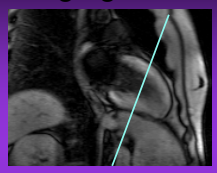
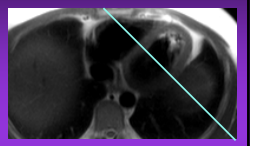
Imaging Planes





2 chamber scout

Imaging Planes: Short Axis

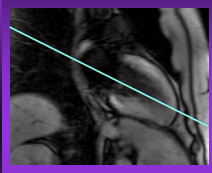
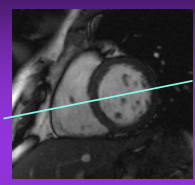

2 chamber scout

Axial HASTE

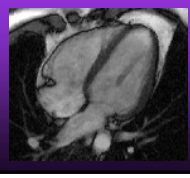
Short Axis

Imaging Planes: 4 chamber

2 ch scout

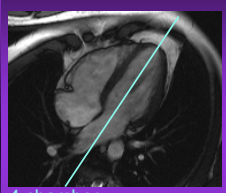
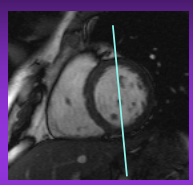



Short axis



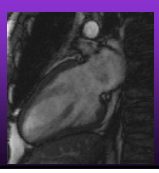
4 chamber (HLA)

Imaging Planes: 2 chamber

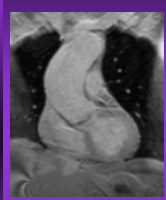
4 chamber

Short axis

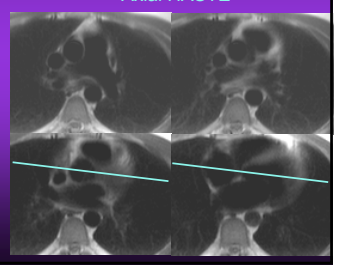


2 chamber (VLA)

Imaging Planes: LVOT



Axial HASTE



Overview

- Safety Issues
- Imaging Planes
- Clinical Protocols: A How To …
  - Cardiac Morphology and Masses
    - Cardiac Masses
    - Pericardial Disease
    - ARVD
  - Valvular Disease
  - LV Function
  - Ischemic Heart Disease

Cardiac Masses/Pericardium

- Set-up
  - ECG leads
  - IV/Gd optional
- Axial/Coronal SS TSE/HASTE
- Multiplanar T1 TSE (limited coverage)
- Selected multiplanar cine GRE
- Optional
  - Gd-DTPA, Post-contrast T1 TSE
  - Single slice BH STIR or FS-TSE

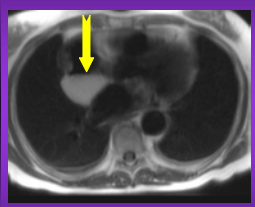
Cardiac Masses

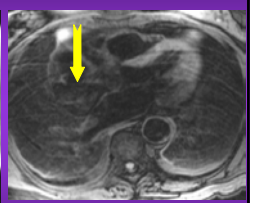
- Benign
  - Myxoma: left atrium most common
  - Lipoma
  - Rhabdomyoma
  - Fibroma
  - Thrombus
- Malignant
  - Metastases
  - Angiosarcoma
  - Rhabdomyosarcoma

Cardiac Masses

- Characterization of masses
  - Lipoma—fatty mass
  - Myxoma—classic septal attachment
  - Thrombus
    - Gd-enhancement/Viability imaging
- Location and extent
- Effect on hemodynamics

Cardiac Masses

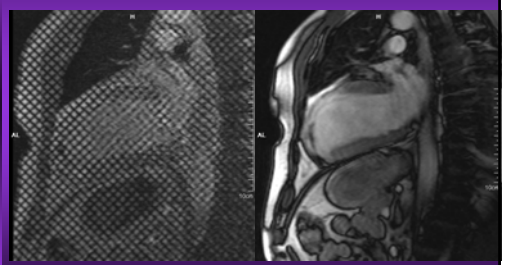




Fat-suppressed T2

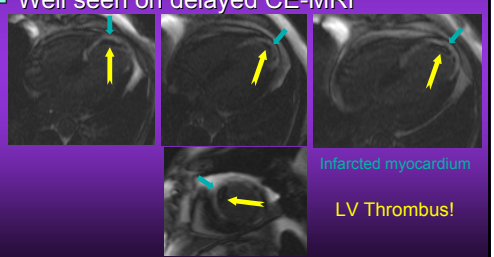
Lipomatous hypertrophy
of the interatrial septum

Thrombus (LV infarct)



LV Thrombus

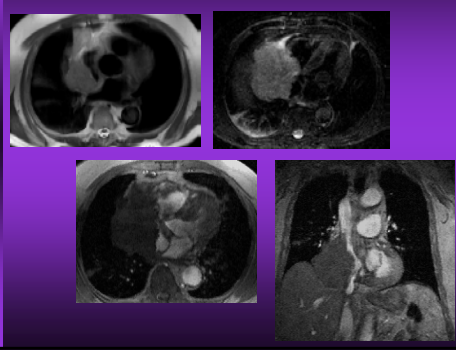
- Non-enhancing
- Well seen on delayed CE-MRI



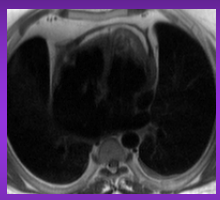
Infarcted myocardium

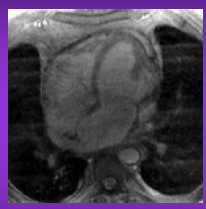
LV Thrombus!

Lymphoma



Constrictive Pericarditis



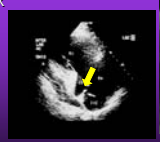


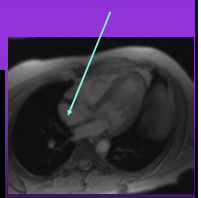
- ✓ Pericardial thickening > 3 – 4 mm
- ✓ Small RV and LV
- ✓ Enlarged RA and LA
- ✓ Paradoxical Septal Motion

Cardiac Mass?

Right Atrial Pseudomass

- Nodular thickening, linear strands
- Between IVC and coronary sinus
- 59-90% of cardiac MR studies
- Normal anatomic structures
  - Crista terminalis
  - Eustachian valve
  - Thebesian valve
  - Chiari network





Mirowitz SA, Radiology 1992;182:231;
Meier RA, JCAT 1994;18:398

ARVD

Arrhythmogenic right ventricular dysplasia
- Ventricular tachycardia
- 30% familial

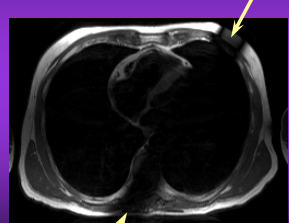
- Diagnosis difficult
  - Biopsy
  - Echocardiography
  - Electrophysiology
  - MRI
    - Fibrofatty replacement of right ventricular myocardium
    - Right ventricular aneurysmal dilatation
    - Dyskinesis

ARVD Protocol

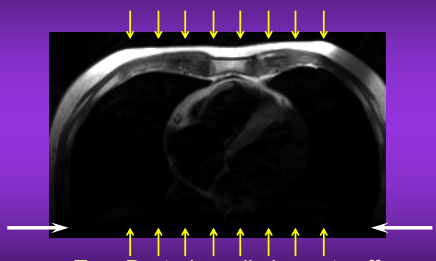
- Set-up
  - ECG leads
  - No iv, no Gd
- Axial SS TSE/HASTE
- Axial TSE
  - High resolution
- Axial cine GRE

ARVD FSE: Imaging Tricks

Saturation band over LV



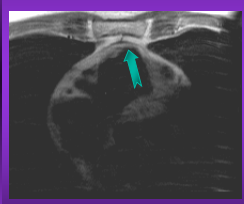
ARVD FSE: Imaging Tricks

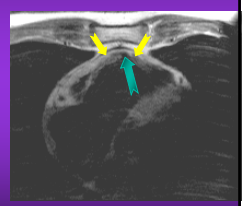


Turn Posterior coil elements off

Decrease FOV

ARVD FSE





Fibrofatty replacement of RV wall

ARVD

RV Dyskinesis

Cine GRE

ARVD Diagnostic Criteria

Table 2. Task Force Criteria for the Diagnosis of Right Ventricular Dysplasia in Probands*

Family history
- Major: familial disease confirmed at necropsy or surgery.
- Minor: family history of premature sudden death (<35 years of age) due to suspected right ventricular dysplasia; family history (clinical diagnosis based on present criteria).

ECG depolarization/conduction abnormalities
- Major: epsilon waves or localized prolongation (>110 ms) of QRS complex in right precordial leads (V_1–V_3).
- Minor: late potentials on signal-averaged ECG.

ECG repolarization abnormalities
- Minor: inverted T waves in right precordial leads (V_2 and V_3) in persons >12 years of age and in the absence of right bundle branch block.

Arrhythmias
- Minor: sustained or nonsustained left bundle branch block–type ventricular tachycardia documented on ECG or Holter monitoring or during exercise testing; frequent ventricular extrasystoles (>1000/24 hours on Holter monitoring).

Global or regional dysfunction and structural alterations
- Major: severe dilatation and reduction of right ventricular ejection fraction with no or mild left ventricular involvement; localized right ventricular aneurysms (akinetic or dyskinetic areas with diastolic bulgings); severe segmental dilatation of right ventricle.
- Minor: mild global right ventricular dilatation or ejection fraction reduction with normal left ventricle; mild segmental dilatation of right ventricle; regional right ventricular hypokinesia.

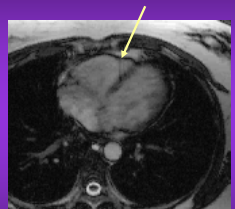
Tissue characteristics of walls
- Major: fibrofatty replacement of myocardium on endomyocardial biopsy.

- Two major criteria
- One major and two minor criteria
- Four minor criteria

McKenna WJ, et al Brit Heart Journal 1994; 71:215-218

Not Right Ventricular Dysplasia

- Potential Pitfalls
  - Moderator band
  - Apical thinning



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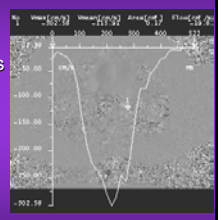
Valvular Disease

- Set-up
  - ECG leads
  - No i.v.
- Axial SS TSE/HASTE
- Double oblique scouts
- LV function cine GRE
- Cine GRE biplane through valve
- Phase contrast flow quantification
- Optional:
  - High resolution black blood TSE

Phase Contrast Applications

- Peak velocity tracings
  - Doppler-like waveforms
  - Pressure gradient estimates



Modified Bernouilli Equation

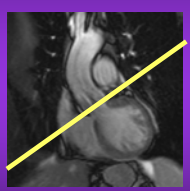
$\nabla P \cong 4 \times v_{max}^2$

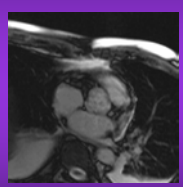
∇P = pressure gradient (mm Hg)

v_{max} = maximum velocity (m/sec)

- Volume flow rates
  - Total blood flow (Aorta, PA)
  - Regurgitant volume

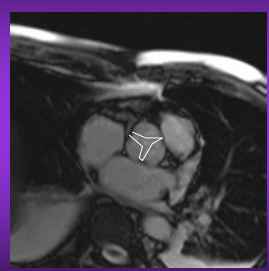
Aortic Stenosis





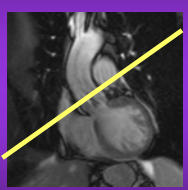
Aortic Valve

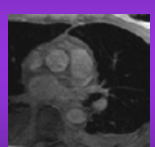
Aortic Valvular Disease



By planimetry: 1.2 cm^2 (Mild stenosis)

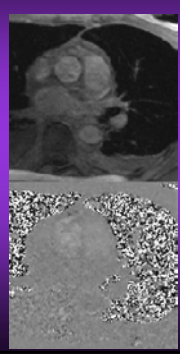
Aortic Stenosis

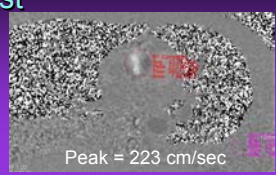




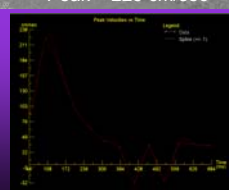
PC through Jet
Venc = 500

Phase Contrast



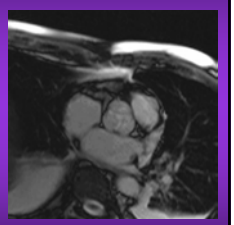


Peak = 223 cm/sec

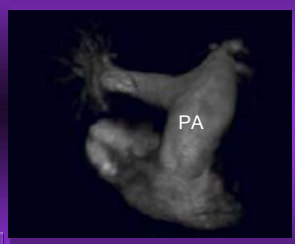


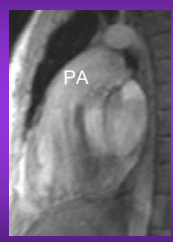
Aortic Valvular Disease

- Peak systolic velocity
  = 223 cm/sec
  = 2.23 m/s
- Peak pressure gradient
  = 4 x v^2
  = 20 mmHg



Volume Flow Measurements

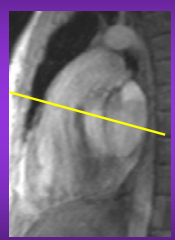




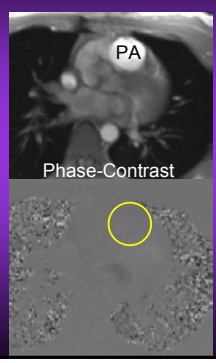
Clinical History: Status post pulmonic valvulotomy

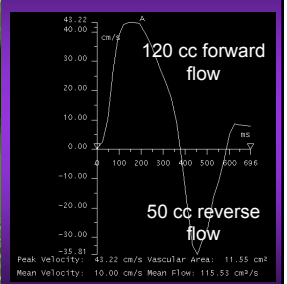
Clinical question: Is there pulmonic insufficiency?

Pulmonic Artery Phase Contrast



Pulmonic Insufficiency





Effective forward flow = 70 ml

Regurgitant fraction = 0.42

Tricks for Quantifying Regurgitation

- Regurgitant Fraction =
  Regurgitant flow/Forward flow
- Mitral Regurgitant Fraction =
  (SV – Aortic Forward Flow)/SV or
  (SV – Pulmonary Forward Flow)/SV

Overview

- Safety Issues
- Imaging Planes
- Clinical Protocols: A How To …
  - Cardiac Morphology and Masses
  - Valvular Disease
  - LV Function
  - Ischemic Heart Disease

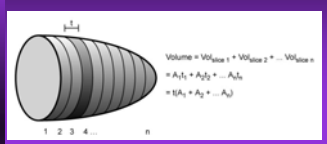
LV Function

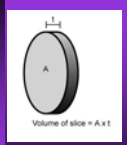
- Set-up
  - ECG leads
  - No i.v.
- Axial SS FSE/HASTE
- Double Oblique Scouts
- Cine GRE
  - Short axis from base to apex (6-8mm/2mm)
  - Long axes views
- Phase contrast flow quantification
  - Aortic outflow (SV)

LV Functional Parameters

- LV End Diastolic Volume (EDV) (ml)
- LV End Systolic Volume (ESV)
- Stroke Volume (SV) = EDV – ESV
- Ejection Fraction = SV/EDV (%)
- Cardiac Output = SV x HR (L/min)
- Cardiac Index = Cardiac Output/BMI
  - (BMI based on height and weight)
- LV Mass = LV myocardial vol x 1.04 g/ml

Calculating LV Volumes



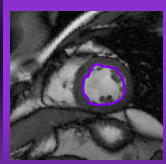


- Cine GRE Short Axis
- Modified Simpson's rule
  - LV = A1 + A2 + … + An
  - Assuming t = 1 cm (8/2 gap)

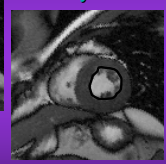
Calculating LV Volumes

Short axis - Base

End diastole



End systole



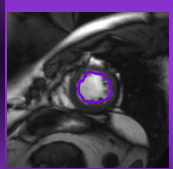
EDV A_2 = 19 cm^2

ESV A_2 = 9 cm^2

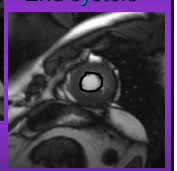
Calculating LV Volumes

Short axis - Apex

End diastole



End systole

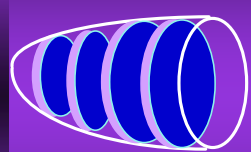


EDV A_5 = 12 cm^2

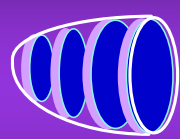
ESV A_5 = 6 cm^2

Calculating LV Volumes

End diastole



End systole



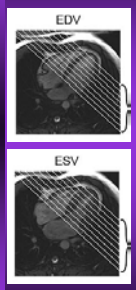
EDV = (A_1 + A_2 + …)

ESV = (A_1 + A_2 + …)

Stroke Volume = EDV - ESV

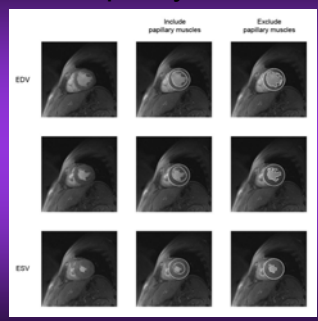
EF = SV / EDV x 100%

Tip #1: Choosing the slices



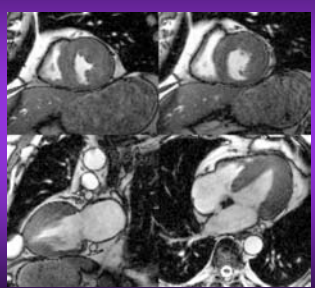
- LV covers larger number of slices at EDV and ESV
- Avoid including LA
- Tip:
  - Include only slices that have circumferential muscle ring

Tip #2: Papillary muscles?



- Bottom line: Be consistent

Wall Motion/Contractility



Overview

- Safety Issues
- Imaging Planes
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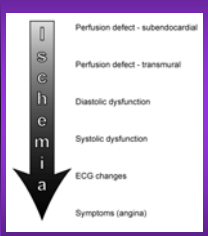
  - Cardiac Morphology and Masses
  - Valvular Disease
  - LV Function
  - Ischemic Heart Disease
    - Stress testing
    - Viability

Ischemic Heart Disease

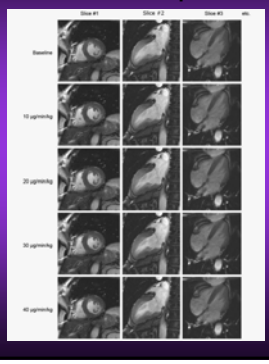


- Exercise impractical
- Dobutamine for increased contractility and oxygen consumption
  - Target HR 0.85 x (220-age)
- Adenosine/persantine for differential hyperemia

Stress Protocol Option #1

- Dobutamine Cine GRE
  - Careful monitoring
    - BP, Pulse ox, ECG (rate/rhythm)
    - Beta blocker to reverse
  - Cine GRE following incremental doses
    - Rest
    - 10 ug/min/kg 3 min
    - 20 ug/min/kg 3 min
    - 30 ug/min/kg 3 min
    - 40 ug/min/kg 3 min
    - Optional Atropine 0.25 mg x 4 to achieve HR
  - Real-time image reconstruction/display

Dobutamine Example

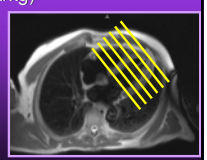


Stress Protocol Option #2

- Adenosine/Persantine Perfusion
  - Careful monitoring
    - BP, Pulse ox, ECG (rate/rhythm)
    - Aminophylline to reverse
  - Stress perfusion
    - Adenosine 140 ug/min/kg 6 min (image at 3 min)
    - Dipyridamole 0.56 mg/kg over 4 min
  - 20 min delay
  - Rest perfusion

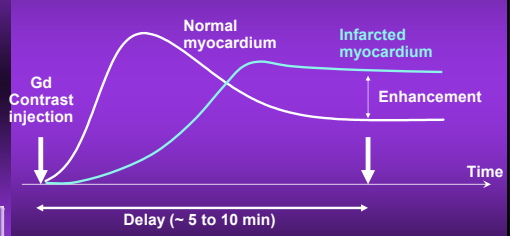
Myocardial Perfusion

- Sequences
  - Gated single-shot SR or IR turboFLASH or true FISP
  - Notched interleaved SR spoiled GRE
- Typically 3 – 6 short axis slices every HB or every other HB
- First pass Gd (0.02 – 0.1 mmol/kg)
  - 5 – 20 ml

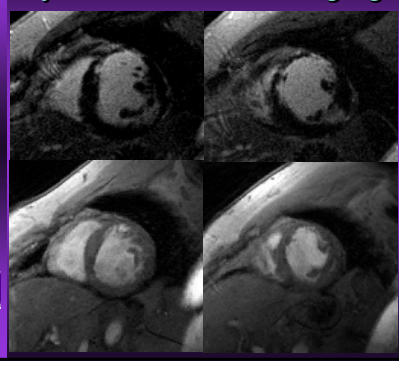


Perfusion Example

Myocardial Infarct Imaging



Myocardial Infarct Imaging

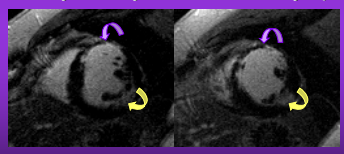


Viability Images

Cine GRE

Myocardial Infarct Imaging

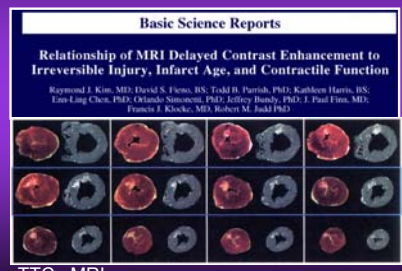
- 52-year-old diabetic woman
  - History of prior MI
  - 4 day history of nausea/GI symptoms



- Interpretation:
  - Old anterior wall infarct
  - New inferior infarct (RCA disease)

Myocardial Infarct Imaging

- Enhancement on delayed imaging = infarct



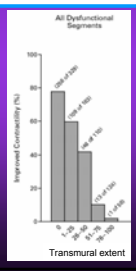
TTC MRI

Kim RJ et al. Circulation 1999; 100:1992

Myocardial Viability

THE USE OF CONTRAST-ENHANCED MAGNETIC RESONANCE IMAGING TO IDENTIFY REVERSIBLE MYOCARDIAL DYSFUNCTION

Raymond J. Kim, M.D., Edwin Wu, M.D., Allen Rafael, M.D., Enn-Ling Chen, Ph.D., Michele A. Parker, M.S., Orlando Simonetti, Ph.D., Francis J. Klocke, M.D., Robert O. Bonow, M.D., and Robert M. Judd, Ph.D.



N Engl J Med 2000 343:1445-53

Delayed Hyperenhancement

- Causes
  - Subacute/Chronic myocardial infarct
  - Acute myocardial infarct
  - Hypertrophic cardiomyopathy*
  - Sarcoidosis*
  - Acute myocarditis*

*Patchy distribution differentiates these from coronary causes which arise from subendocardial surface and extend to subepicardial region

Viability Protocol: 30 min

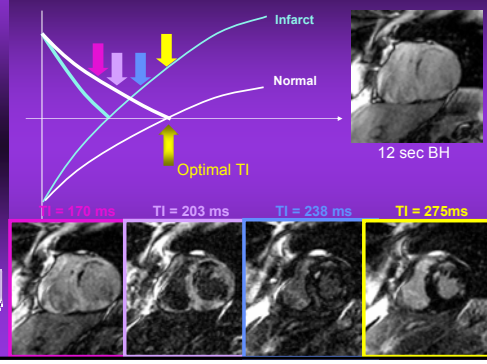
- Set-up
  - ECG leads
  - 20 – 30 ml Gd*
- Axial HASTE
- Scouts for double oblique
- Inject Gd
  - Optional: Perfusion (± stress)
- Cine GRE
  - Short and long axes
- Viability (scar)
  - Slice planes matched to cine GRE

*Gd-DTPA for cardiac MRI is off-label application

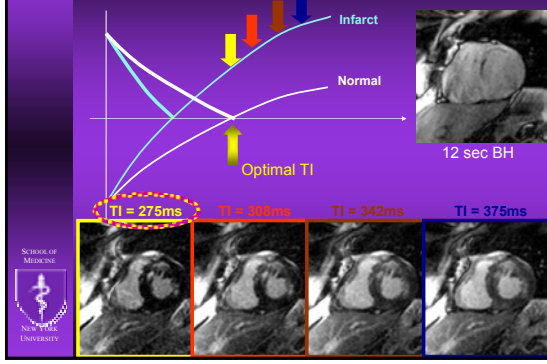
Viability

- Conventional Viability sequences
  - CHOOSE TI (Inversion Time)
  - IR turboFLASH
  - IR true FISP (1 – 3 slices/BH)
  - New sequences
    - Single shot IR true FISP
    - 3D IR turboFLASH
    - 3D IR true FISP
- Phase-Sensitive IR Viability

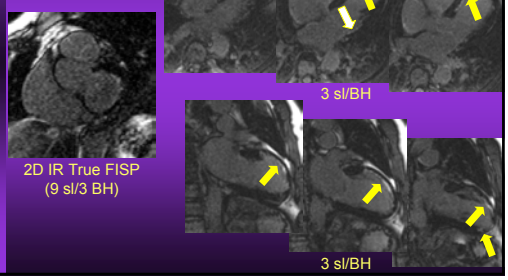
Cine IR True FISP to select TI



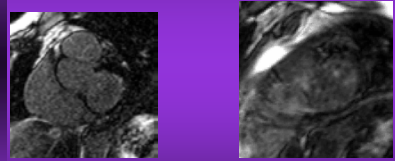
Cine IR True FISP to select TI



Viability: 5 breath holds

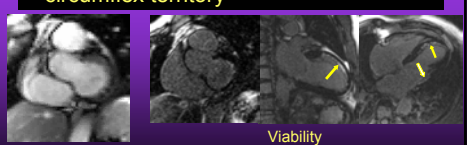


Viability: 1 breath hold

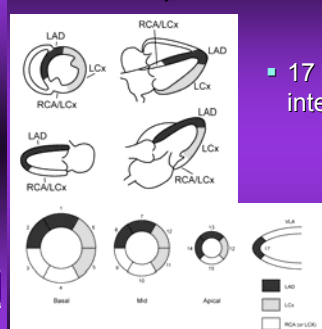


Viability Case: Interpretation

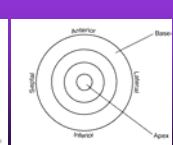
- Subendocardial infarct extends along entire anterior wall/apex, septum, lateral wall (LAD)
- Additional foci in inferolateral base (LCx)
- Impression: Salvageable myocardium LAD and circumflex territory



CAD: Interpretation



- 17 segment interpretation



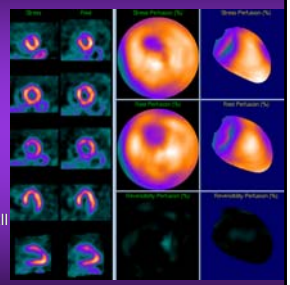
Cerqueira MD et al. Circulation 2002; 105:539

Myocardial Viability

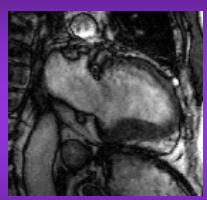
- Clinical applications
  - Hypokinesis: Nonviable vs. Hibernating ?
    - Is revascularization indicated?
  - Equivocal scintigraphy or echocardiography
    - Attenuation artifacts/inadequate window
    - Abnormality too subtle/subendocardial infarct
  - Acute chest pain, r/o MI

Myocardial Viability

- Case: 76-year-old man with DOE
- Stress-rest Sestamibi
  - Normal wall motion
  - EF 67%
  - Fixed defect anterior wall
  - Infarct vs. Attenuation ?

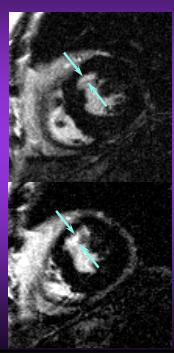


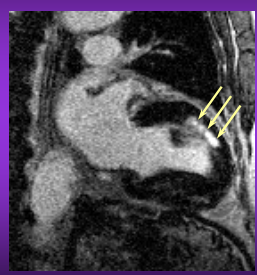
Myocardial Viability



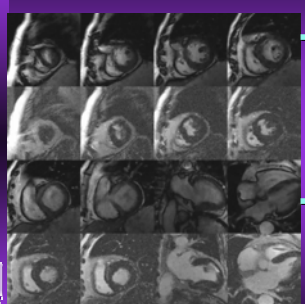
Cine GRE

Myocardial Viability





Myocardial Viability



- Interpretation:
  - Normal wall motion
  - EF 70%
  - Subendocardial infarct
  - LAD territory
- Coronary Cath
  - 3 vessel disease
  - Severe stenosis of 1st diagonal (off LAD)

Lee VS et al, Radiology, 2004

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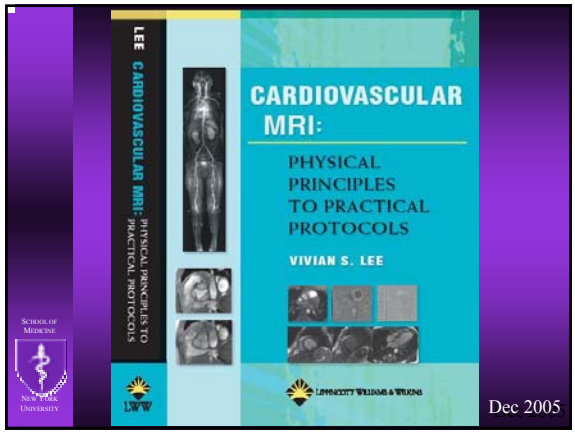
NYU Body/CV MR Imaging

Genevieve Bennett, MD
Gary Israel, MD
Elizabeth Hecht, MD
Barbara Srichai, MD
Bachir Taouli, MD

Leon Axel, PhD, MD
Qun Chen, PhD
Glyn Johnson, PhD
Ray Lee, PhD
Vinay Pai, PhD

Stephen Drew, MD
Ruth Lim, MD
Tejas Parikh, MD
Minnie Kaur, MD

School of Medicine
New York University



ISMRM Clinical MRI Course: Cardiac Protocols

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