

# CCTA and CMRI Imaging in Cardiovascular Risk Assessment



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# Presenter Disclosure Information

- ✦ I will discuss off label use of gadolinium-DTPA
  - ✦ Gadolinium-DTPA is considered off label use for imaging the heart
- ✦ Financial relationships to disclose: none



# Cardiovascular Disease

- Leading cause of mortality in men and women
- 500,000 cardiac related deaths per year
- 8 million ED visits in US annually
- 2.8 million “unnecessary” hospital admissions / year for chest pain (low risk patients) (Prina LD. *Ann Emer Med* 2004)
- Acute chest pain cost: \$ 10-12 billion



# Cardiac Imaging

Echocardiography

Catheterization

SPECT/PET

IVUS



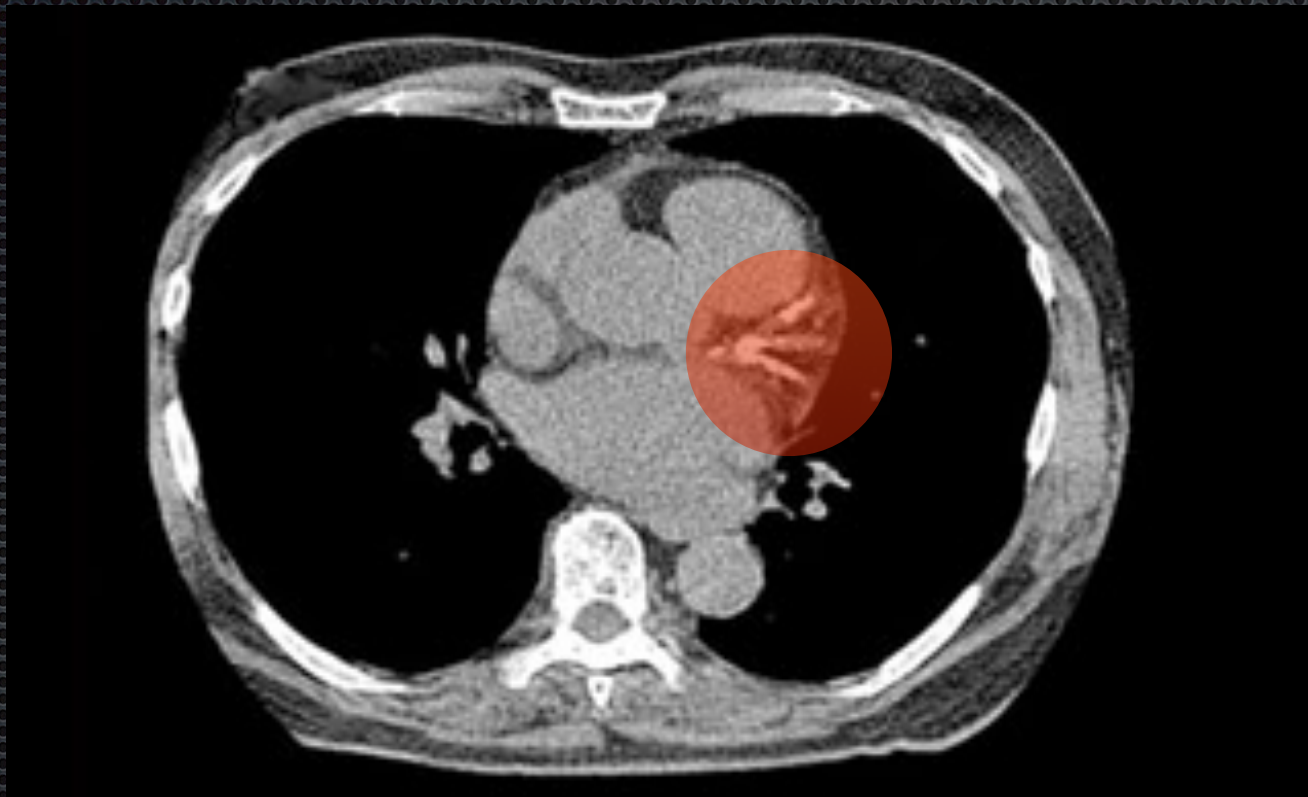
MRI

CTA

Calcium  
score



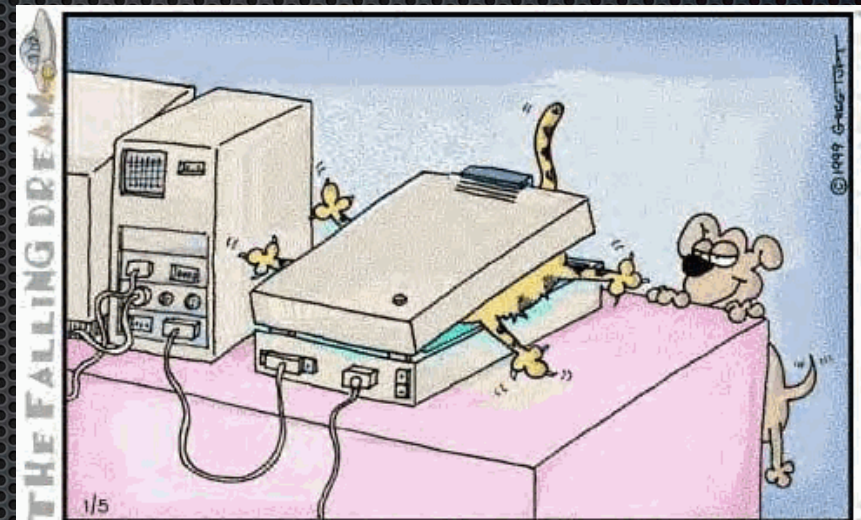
# CT Calcium Score





# Calcium score

- ✦ CT - almost all CT scanners
- ✦ Gated to patient's EKG
- ✦ No contrast/IV
- ✦ <10 second scan
- ✦ Low radiation exposure ~1mSv
- ✦ Low cost - \$99



"Cat Scan"

"Cat Scan"





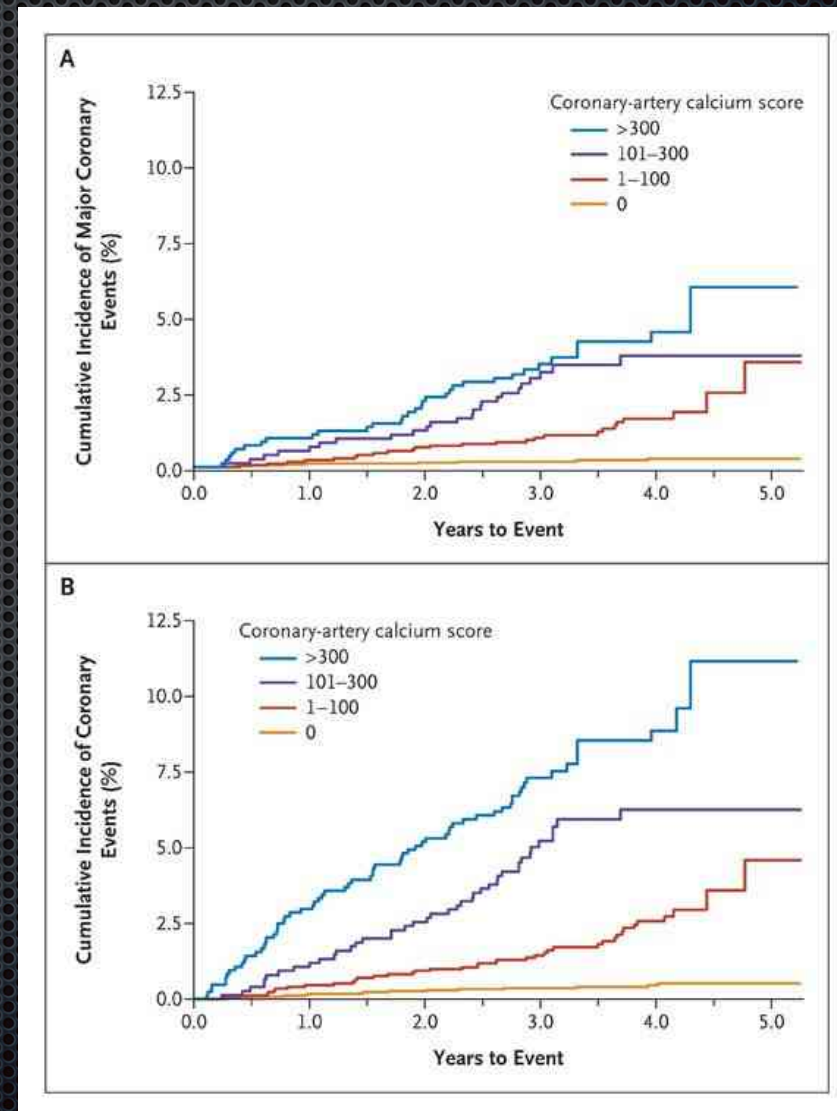


- Amount of calcium is quantified in the:
  - LM/LAD
  - LCx
  - RCA



# Calcium score

- ✦ Scores:
  - ✦ 0 - no calcium <100: mild
  - ✦ 100-400: moderate >400: severe
- ✦ Patient's CAD risk stratified by age, gender and race
  - ✦ Agatston Method
  - ✦ MESA
- ✦ Predictor of CAD events
- ✦ Benefit from patient compliance with prevention interventions - ASA, statin, lifestyle





# Calcium Score Prognostic Value

- ✦ CAC provides incremental value over standard coronary risk factors - Detrano R, NEJM 2008.



The NEW ENGLAND  
JOURNAL of MEDICINE

- ✦ CAC can be used to adjust CHD risk compared to conventional CHD risk factors (Framingham) - Pletcher MJ, Circulation 2013.

**Circulation**

An American Heart Association Journal

- ✦ Extent of CAC accurately predicts 15-year all-cause mortality in a cohort of 9715 asymptomatic patients-Ann Int Med 2015

**Annals of Internal Medicine**

Established in 1927 by the American College of Physicians



# Cardiac CTA





# Advancements in Cardiac CTA

Slice War	2 -> 320	Spatial resolution
Faster gantry	600ms -> 280ms	Motion Artifact
Gating	Retrospective -> prospective	Radiation
Post processing	MPR -> CPR	Interpretation
Sensitivity	>95%	Accuracy
NPV	>95%	Accuracy

- ACCURACY (Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. J Am Coll Cardiol. 2008;52(21):1724–32.
- The CORE-64 (Coronary Artery Evaluation Using 64-Row Multidetector Computed Tomography Angiography) International Multicenter Study
- Diagnostic accuracy of 64-slice computed tomography coronary angiography: a prospective, multicenter, multivendor study. J Am Coll Cardiol. 2008;52(25):2135–44



# Common Indications for Cardiac CT

- Coronary artery disease
  - chest pain (atypical) without unstable angina
  - inconclusive noninvasive study
  - refusal of cath
  - bypass grafts
- Cardiac / coronary anatomy
  - anomalous coronary artery
  - pulmonary vein mapping
- Cardiac function
- Cardiac masses



## 7. Cardiac Computed Tomography Appropriate Use Criteria (By Indication)

**Table 1. Detection of CAD in Symptomatic Patients Without Known Heart Disease\***

Indication		Appropriate Use Score (1–9)		
Nonacute Symptoms Possibly Representing an Ischemic Equivalent				
Pretest Probability of CAD		Low	Intermediate	High
1.	• ECG interpretable AND • Able to exercise	U (5)	A (7)	I (3)
2.	• ECG uninterpretable OR • Unable to exercise	A (7)	A (8)	U (4)
Acute Symptoms With Suspicion of ACS (Urgent Presentation)				
3.	• Definite MI	I (1)		
4.	• Persistent ECG ST-segment elevation following exclusion of MI	U (6)		
5.	• Acute chest pain of uncertain cause (differential diagnosis includes pulmonary embolism, aortic dissection, and ACS [“triple rule out”])	U (6)		
	Pretest Probability of CAD	Low	Intermediate	High
6.	• Normal ECG and cardiac biomarkers	A (7)	A (7)	U (4)
7.	• ECG uninterpretable	A (7)	A (7)	U (4)
8.	• Nondiagnostic ECG OR • Equivocal cardiac biomarkers	A (7)	A (7)	U (4)

\*Note: All indications are for CTA unless otherwise noted.  
A indicates appropriate; I, inappropriate; and U, uncertain.



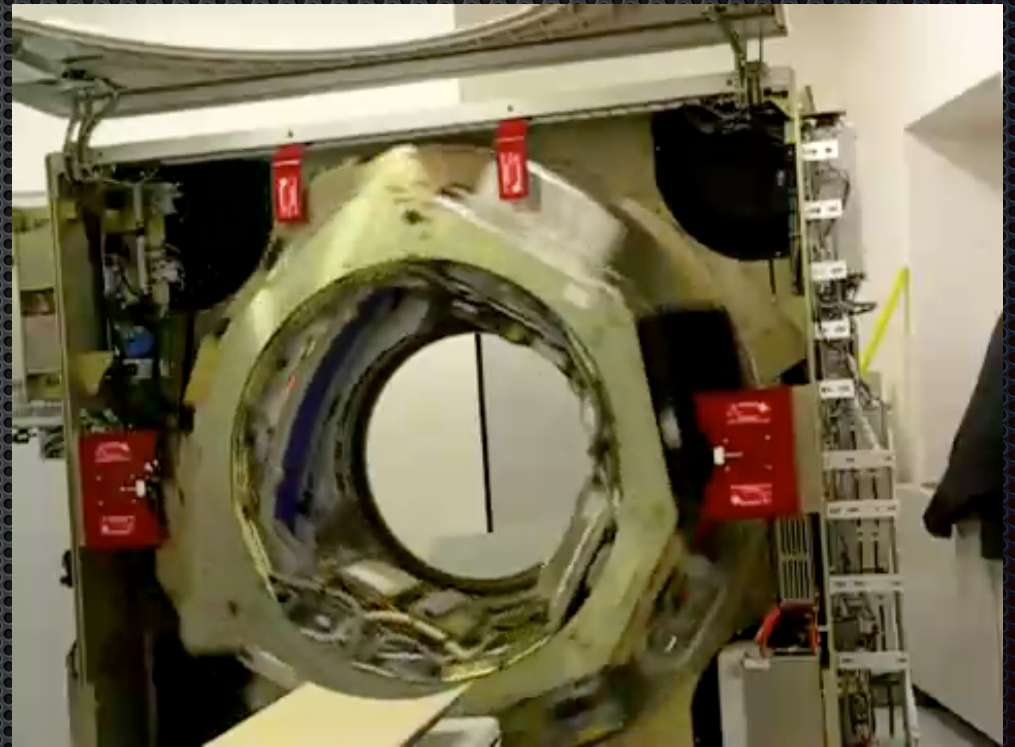
# Limitations for Cardiac CT

- Not ideal for **high risk** patients with documented CAD
  - These patients better suited for cath as intervention can be performed at the same time if needed
- **Extensive calcium** can overestimate degree of stenosis due to blooming artifact
- **Stents**
  - unreliable evaluation for in-stent restenosis
  - only able to identify in-stent thrombosis
- **Poor renal function**
  - approximately 60-80 ml contrast needed for exam
- **High heart rates** or arrhythmias



# Protocol

- Heart rate control
- Scan acquisition
- Field of view





# Heart Rate Control

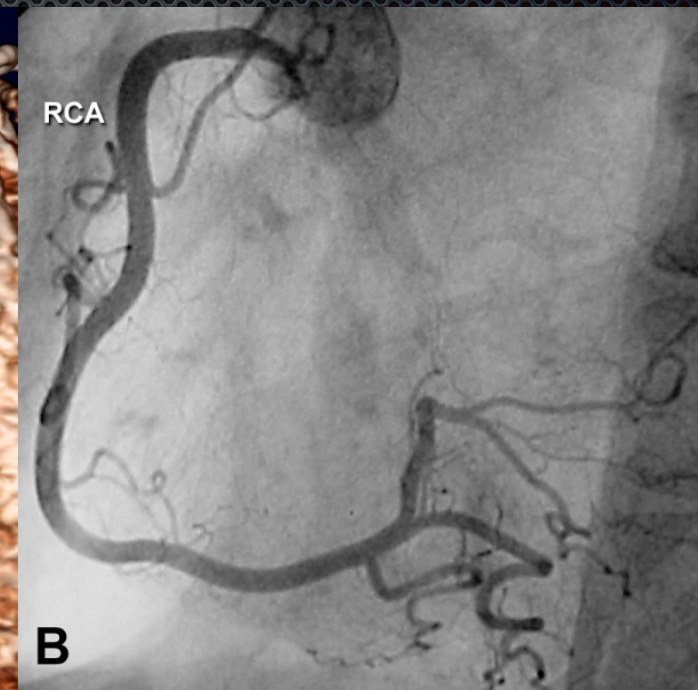
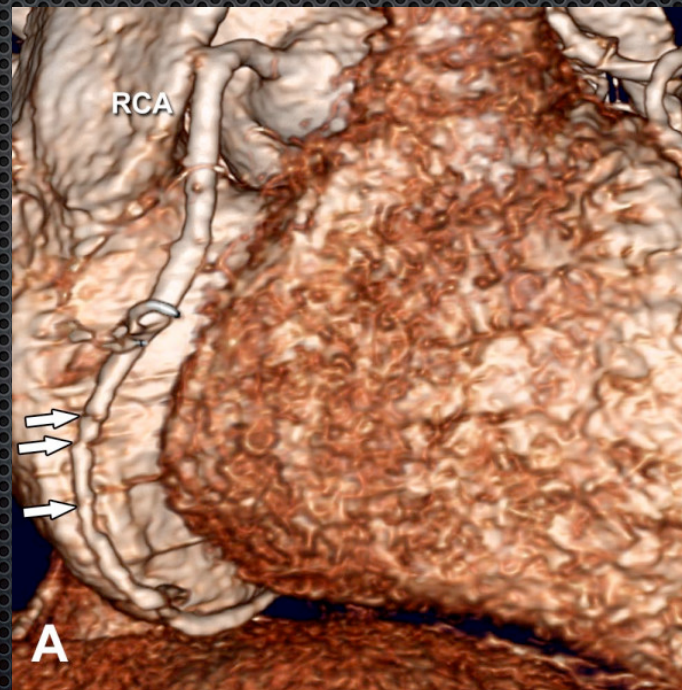
Reduce heart rate to minimize motion:

RCA on average will deflect 4 cm during systole

Oral beta-blockers: (50-100mg PO)

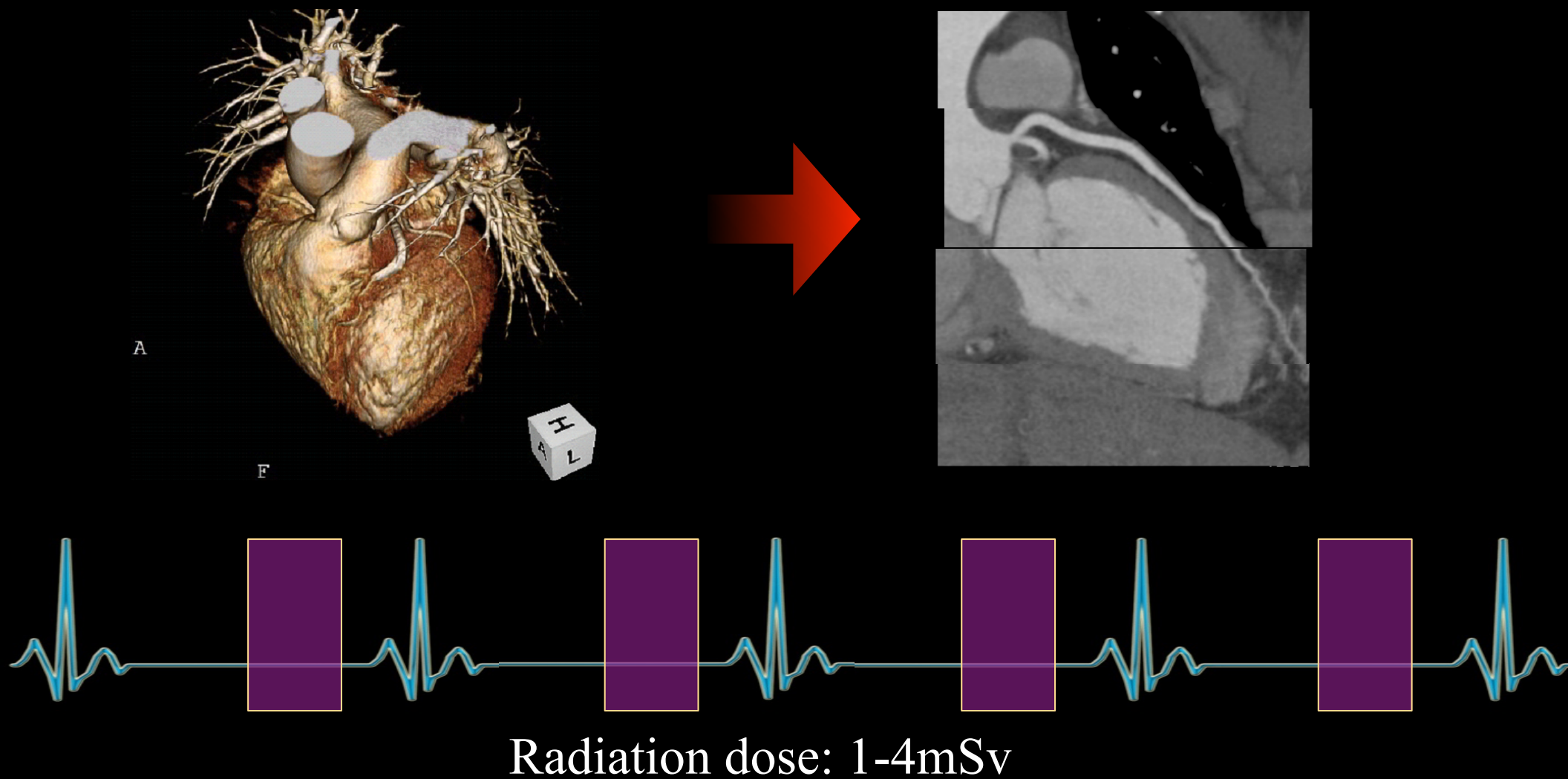
IV beta-blockers: (5-20mg IV)

**Target HR:  
<65 bpm**



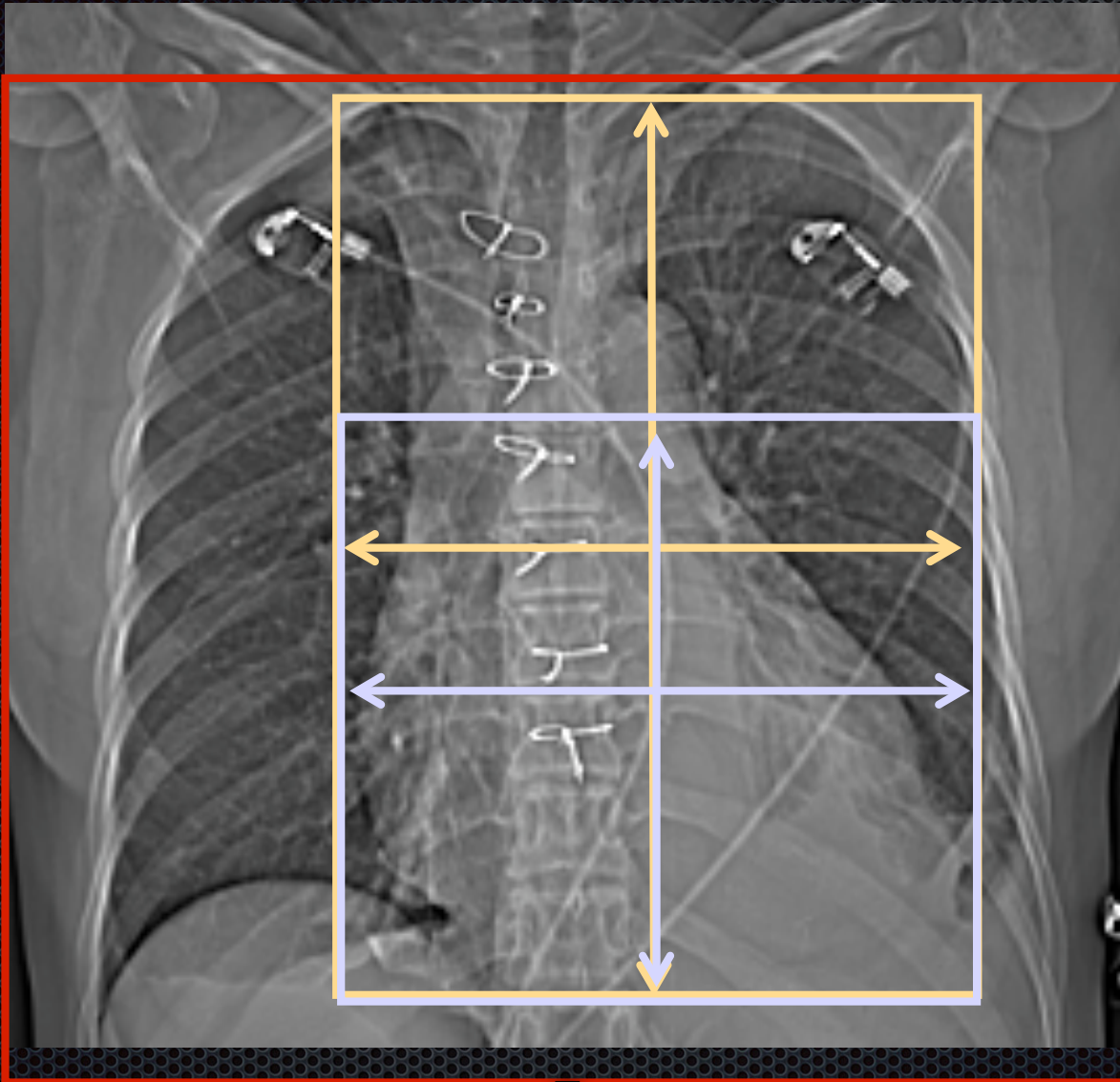


# Scan Acquisition





# Field of View (FOV)



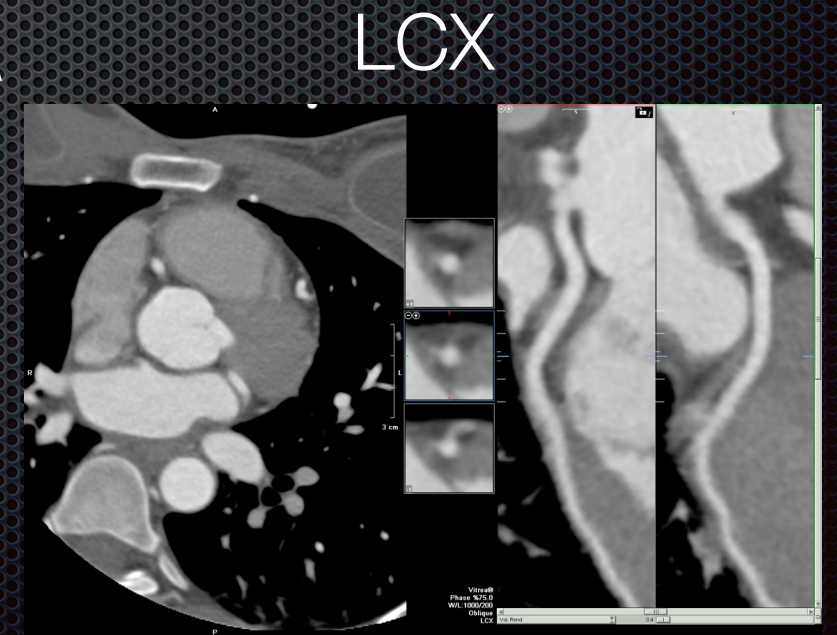
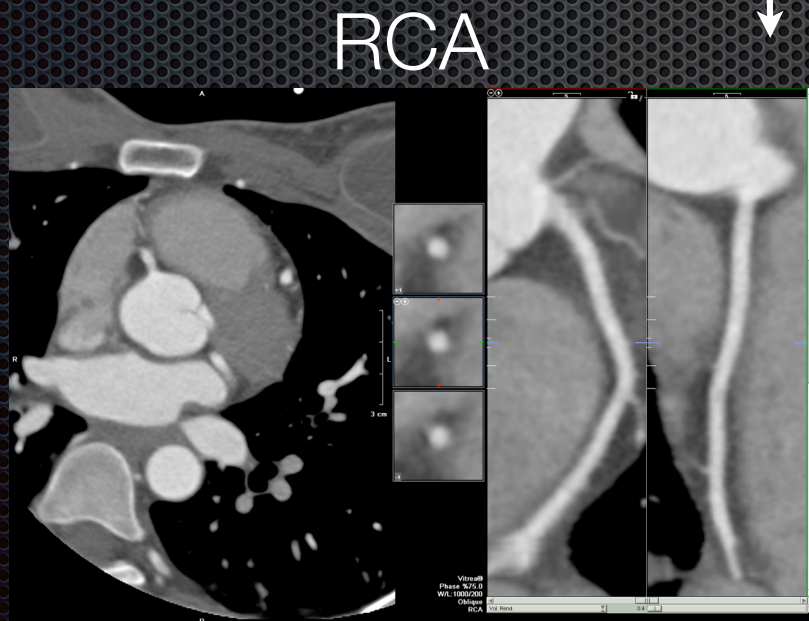
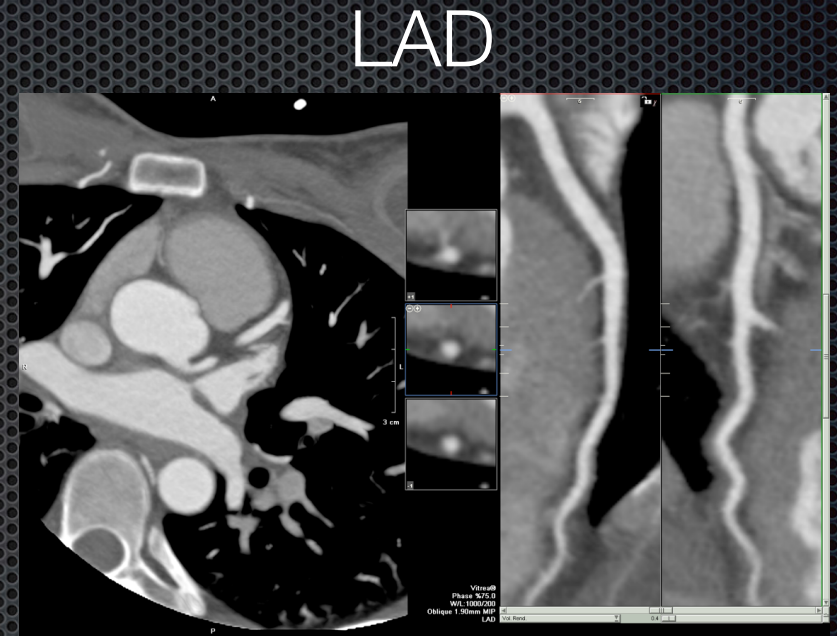
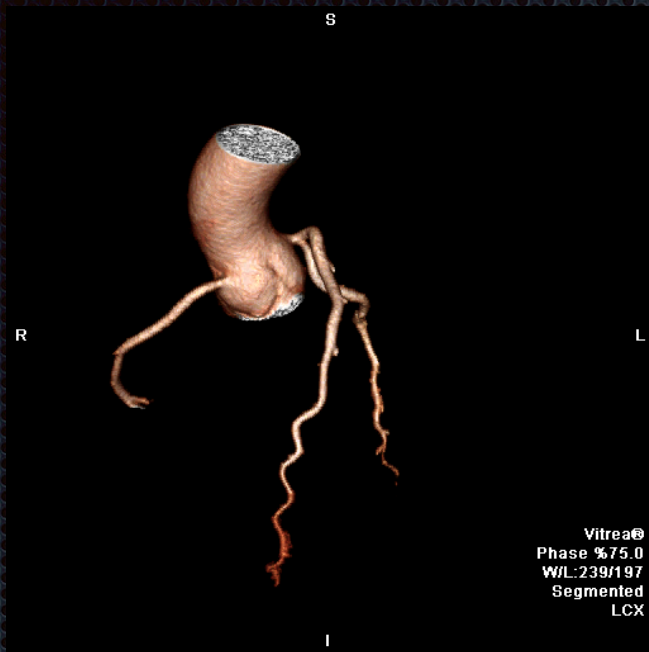
**Coronary CTA**

**Bypass graft  
analysis**

**Chest Pain  
Imaging  
(to the aortic  
bifurcation)**



# Coronary Anatomy



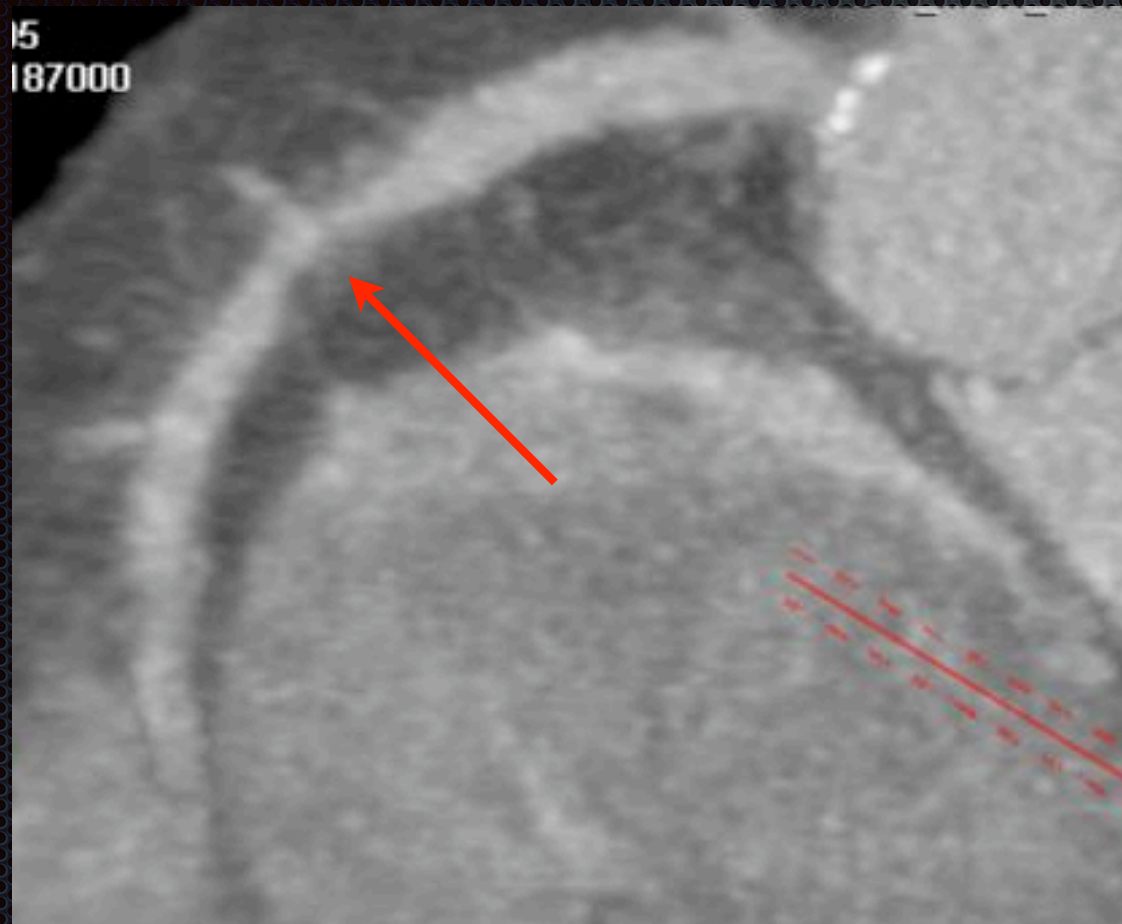


# Coronary Artery Disease





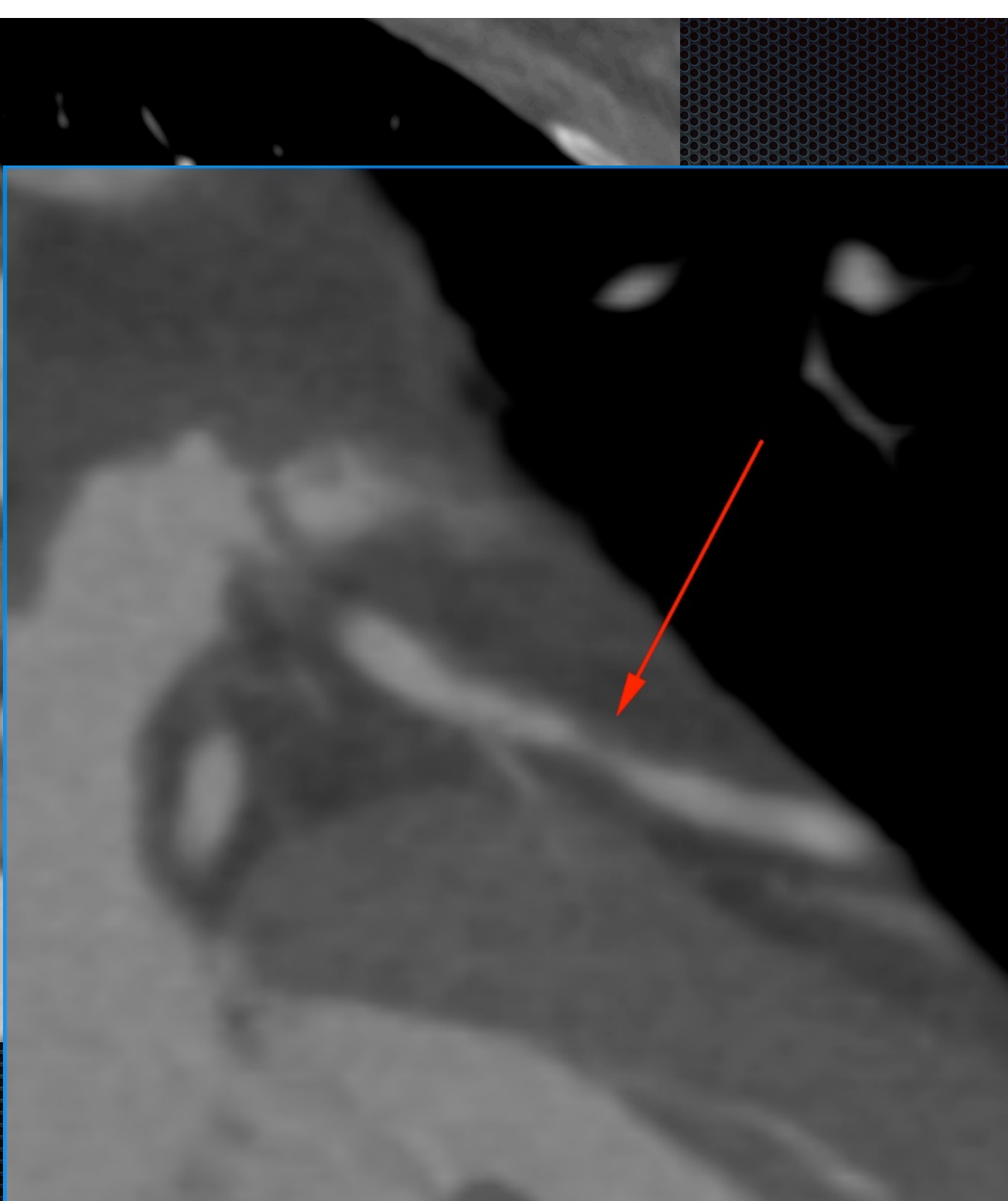
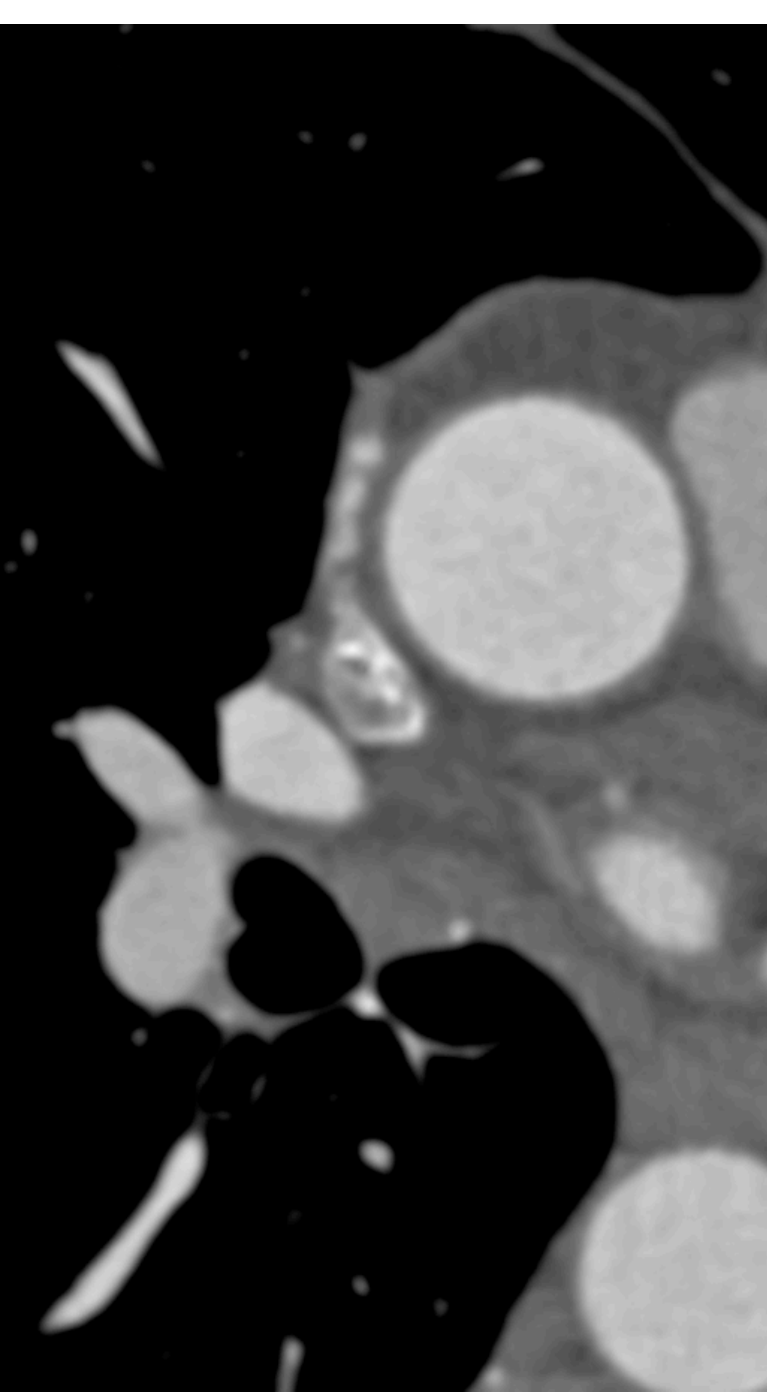
CTA



Cath







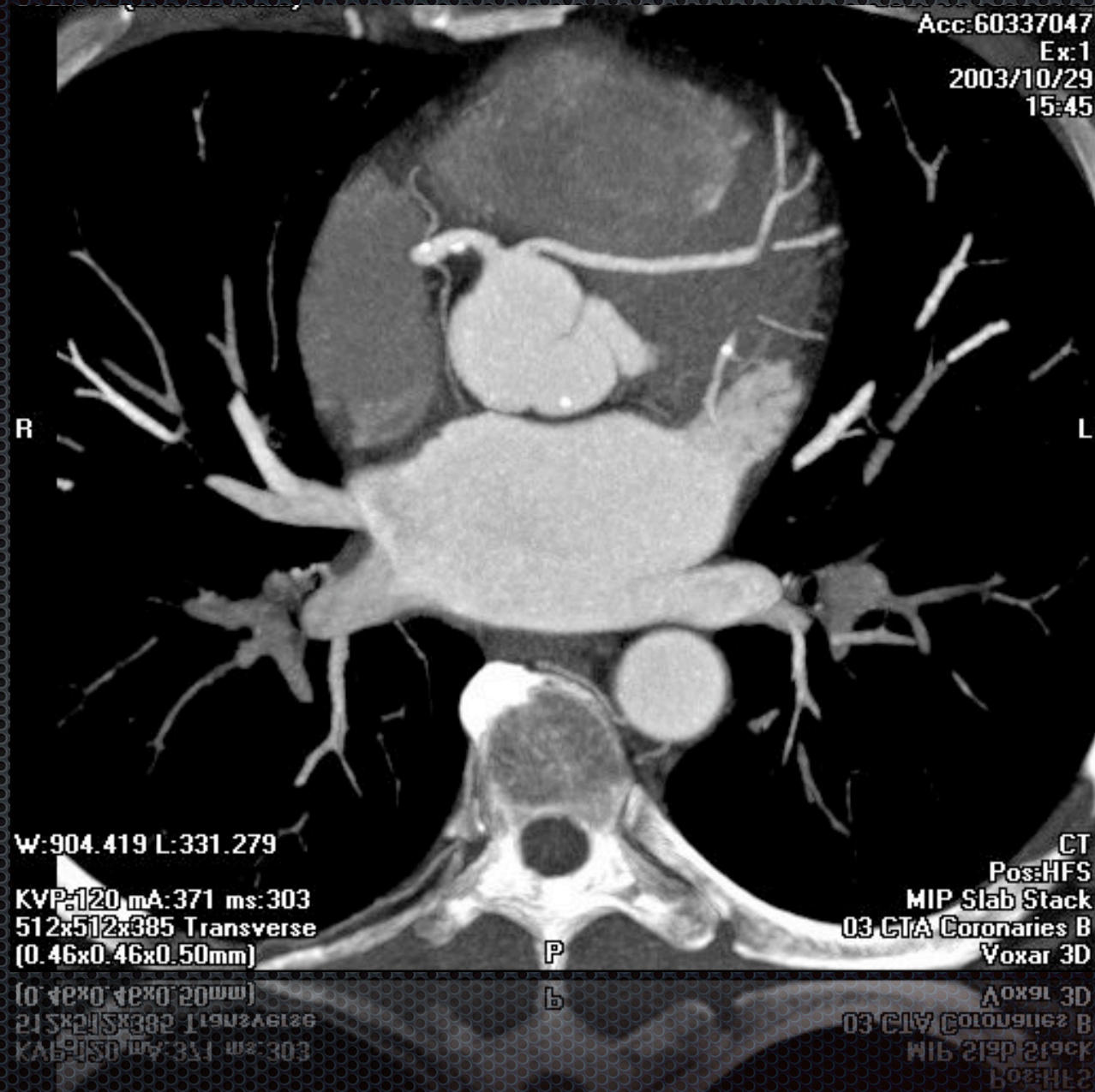


# Bypass Graft Evaluation





# Anomalous Coronary Arteries



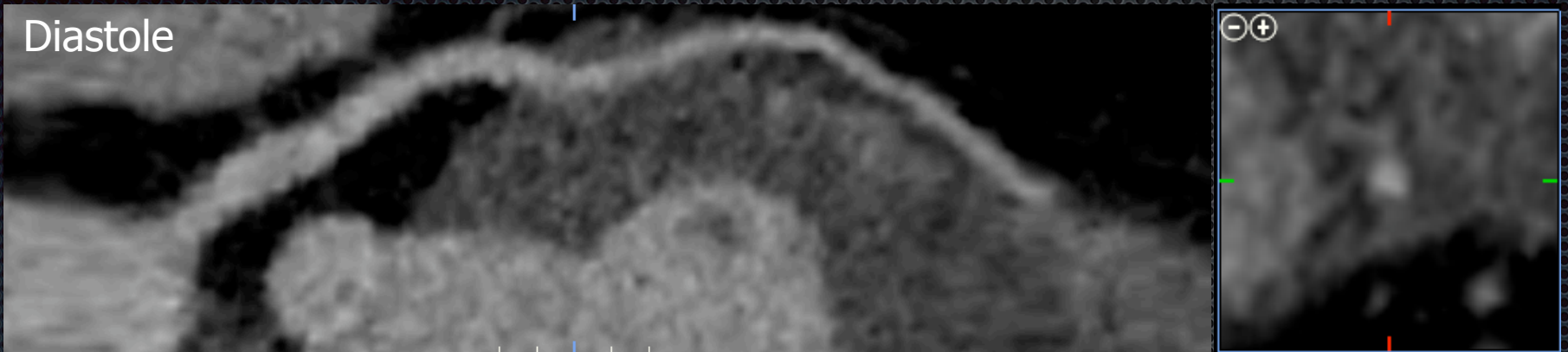


# Myocardial Bridge

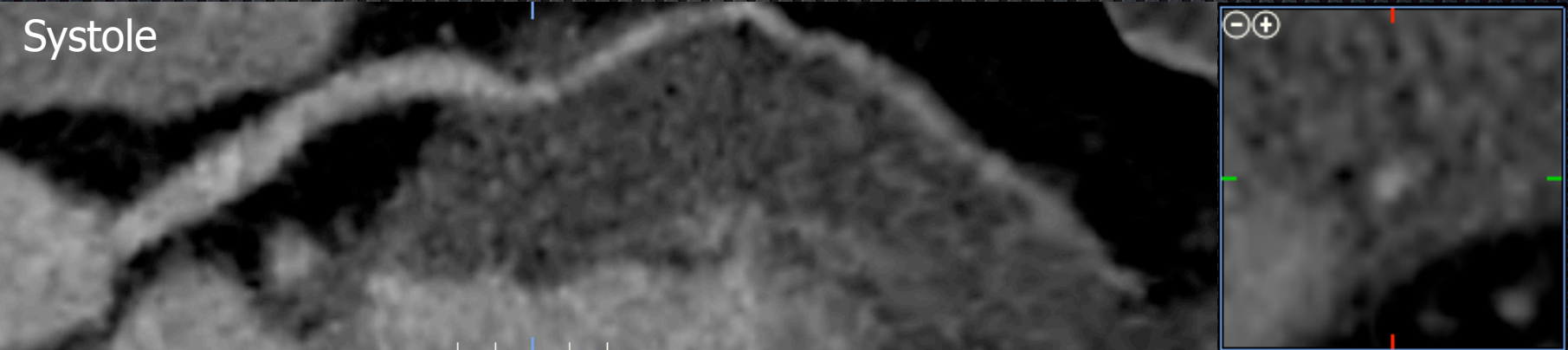




Diastole

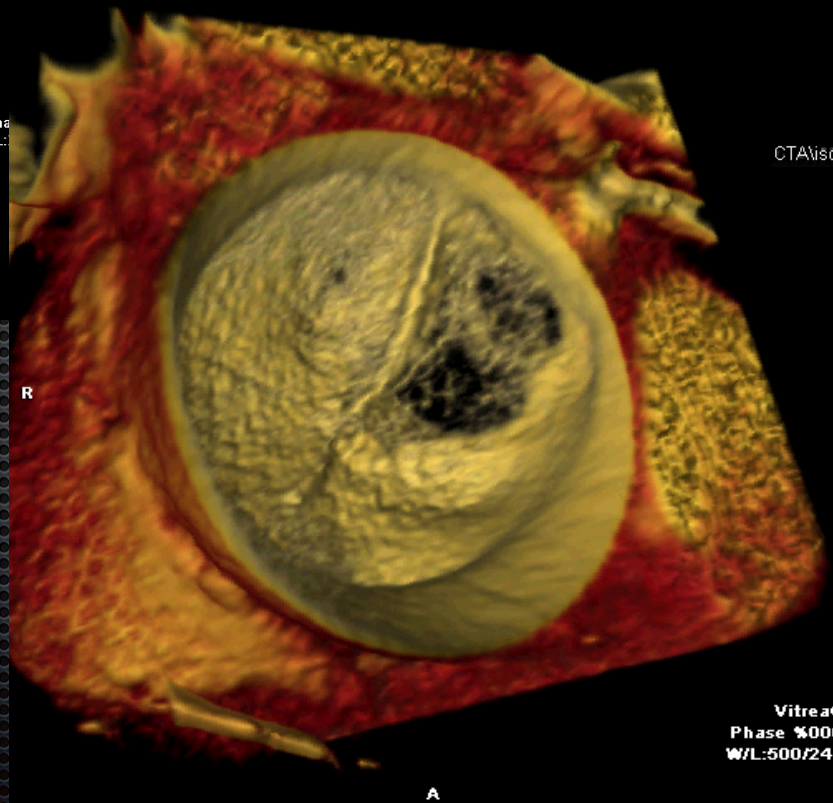
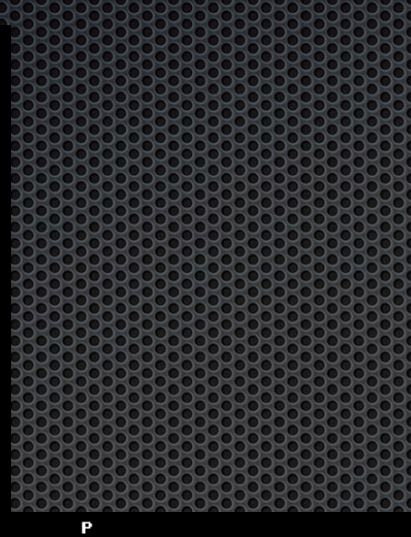
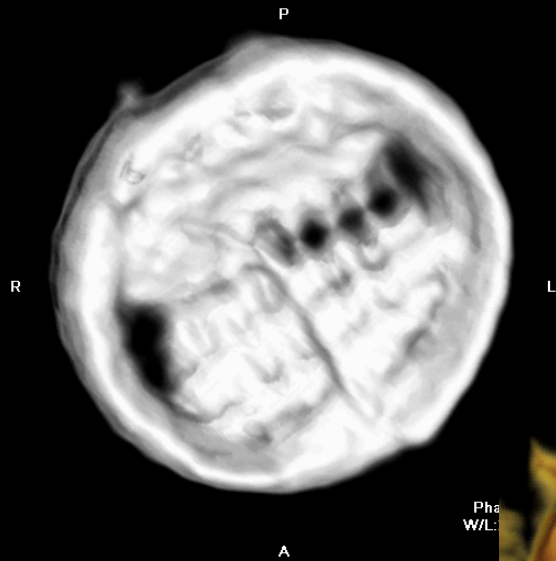


Systole



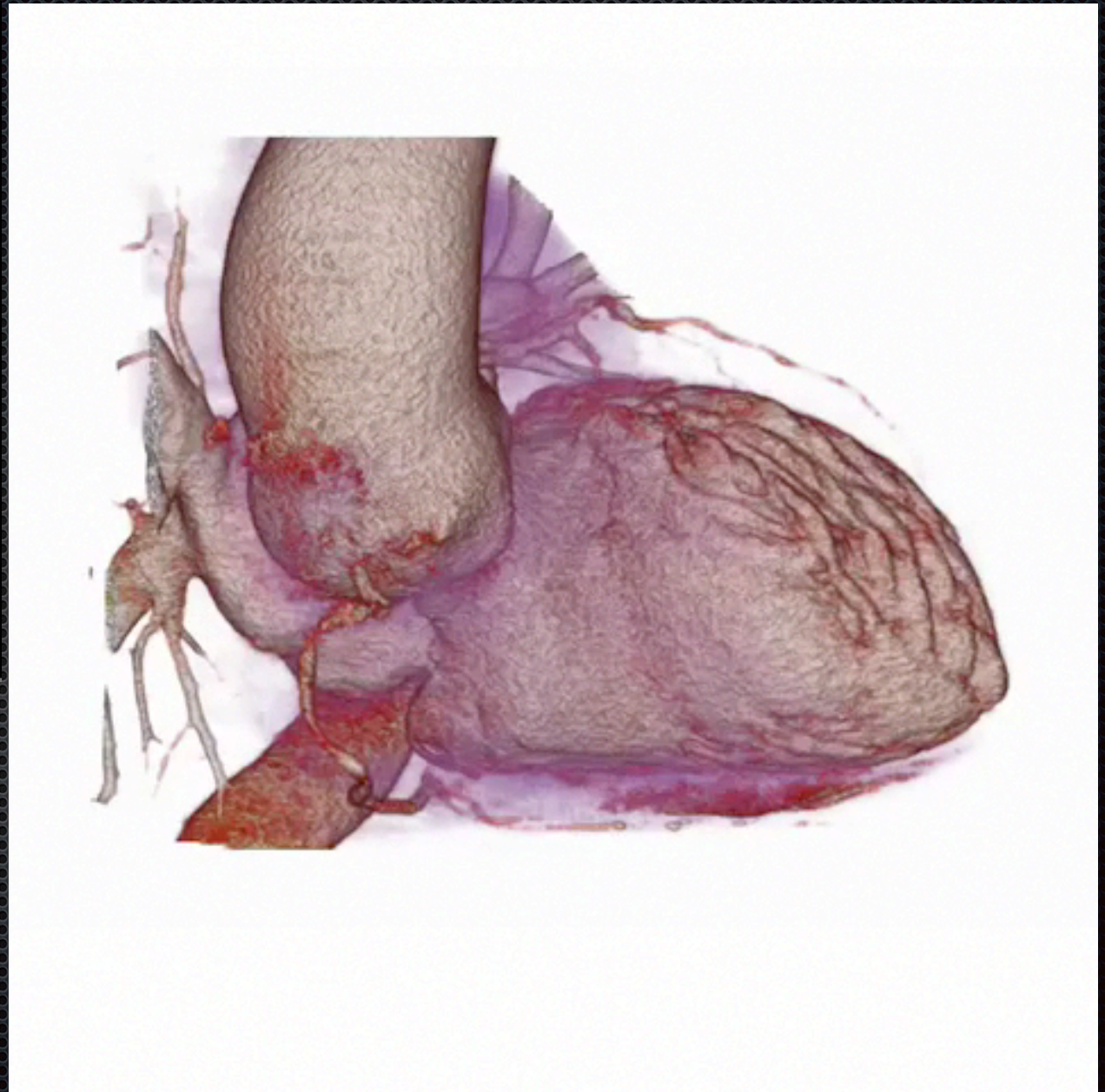
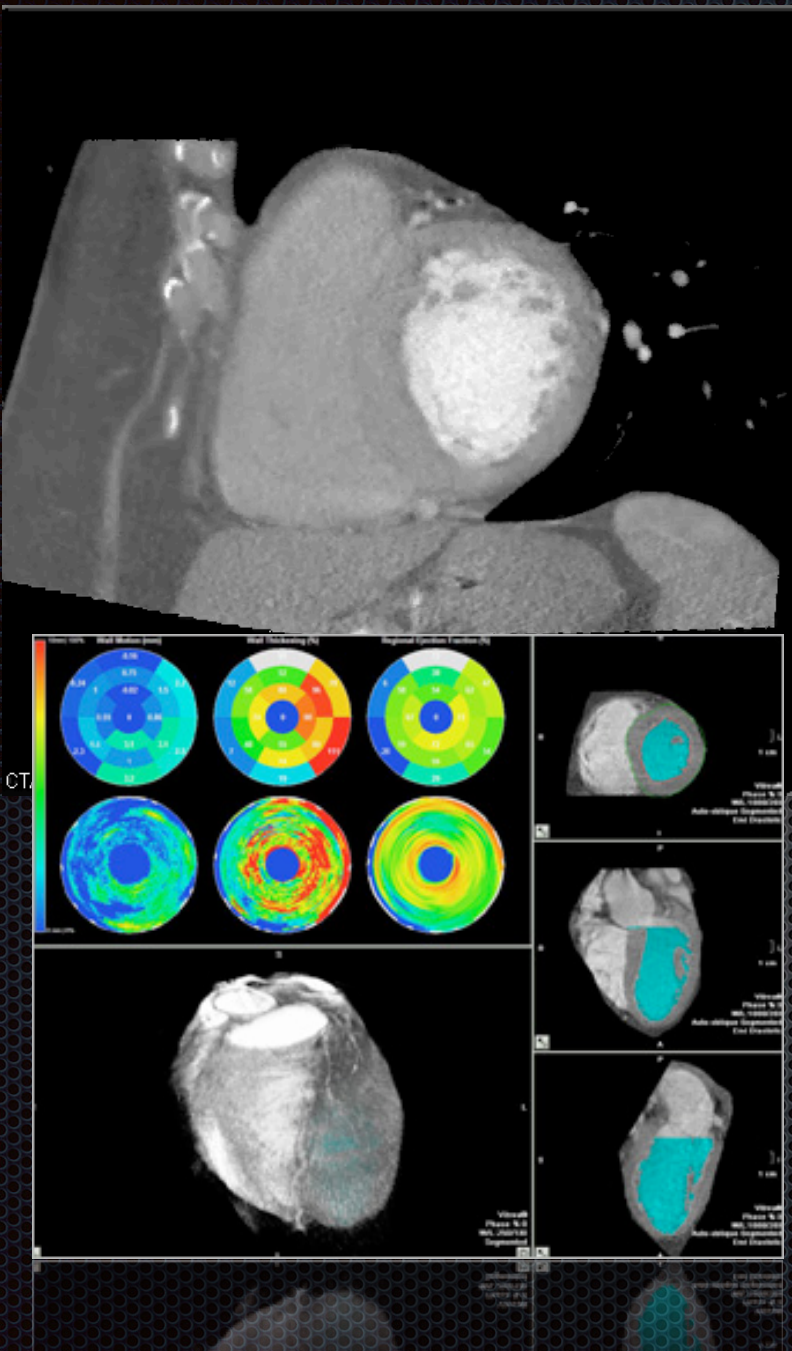


# Valve Imaging



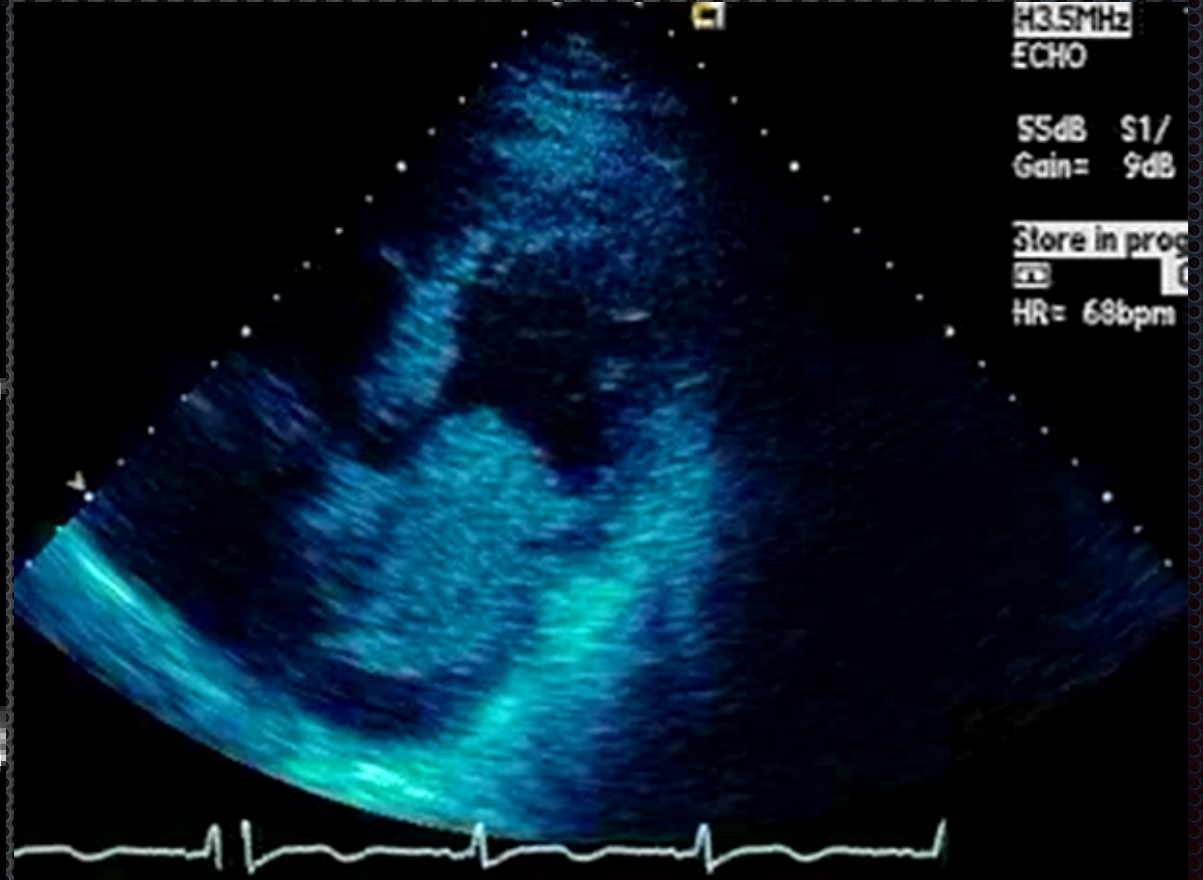


# Cardiac Function





# Cardiac Masses



Atrial myxoma



# CTA Value in ED Chest Pain

Study	Goldstein, CT-STAT, JACC	Hoffmann, ROMICAT II, NEJM
Year	2011	2012
CT scanner	64-slice or greater	64-slice or greater
Number of patients in CT group	361	501
Number of patients in control group	338	499
Follow-up (months)	6	1

Study	CT group	Control group	CT group	Control group
Rate of direct discharge from ED in CT group	262/361 (72.6 %)	271/338 (80.2 %)	233/501 (46.5 %)	62/499 (12.4 %)
Time-to-diagnosis in CT group (mean $\pm$ SD) (h)	2.9 $\pm$ 2	6.2 $\pm$ 7	10.4 $\pm$ 12.6	18.7 $\pm$ 11.8
Costs of care in ED [mean $\pm$ SD (thousand dollars)]	2.1 $\pm$ 0.7	3.5 $\pm$ 0.7	2.1 $\pm$ 0.1 <sup>a</sup>	2.5 $\pm$ 0.1 <sup>a</sup>
Rate of ED re-admission	2/361 (0.6 %)	4/338 (1.1 %)	14/501 (2.8 %)	19/499 (3.8 %)

CT computed tomography, ED emergency department, SD standard deviation, n.a. not available

CT computed tomography, ED emergency department, SD standard deviation, n.a. not available

Rate of ED re-admission: 0.6% (0.6%), 1.1% (1.1%), 2.8% (2.8%), 3.8% (3.8%)



# CTA Prognostic Value in Chest Pain

Hollander et al, Ann Emerg Med 2009

- 568 patients with potential ACS with low pretest probability
- 84% patients ruled out and d/c home
- Follow up 30 days - 0 CV deaths or nonfatal MI

National Institutes for Health and Care Excellences (NICE) Guidelines (March 2017)

“Cardiac CT is the non-invasive test of choice  
in the evaluation of stable angina”

- Low cost
- High sensitivity
- Being implemented as the first line test in chest pain pathways
- Projected **\$20 million** in cost savings in England alone



# CTA Prognostic Value

*Does a negative CTA (no significant stenosis) predict outcomes in symptomatic patients?*

426 patients

- symptomatic with positive SPECT stress test

All patients had 64-slice CTA

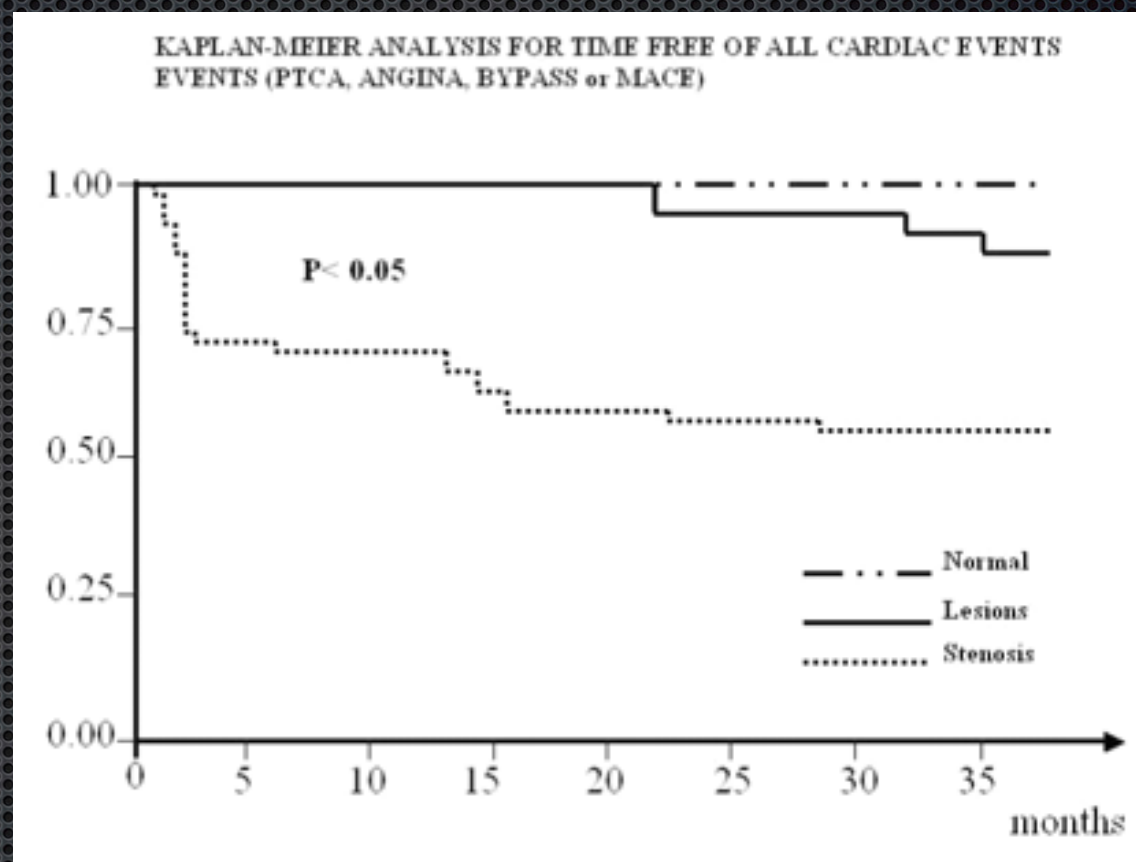
343 patients ruled out for CAD by CTA

- followed for 15 months
- 0 deaths and only 1 required revascularization



# CTA Prognostic Value

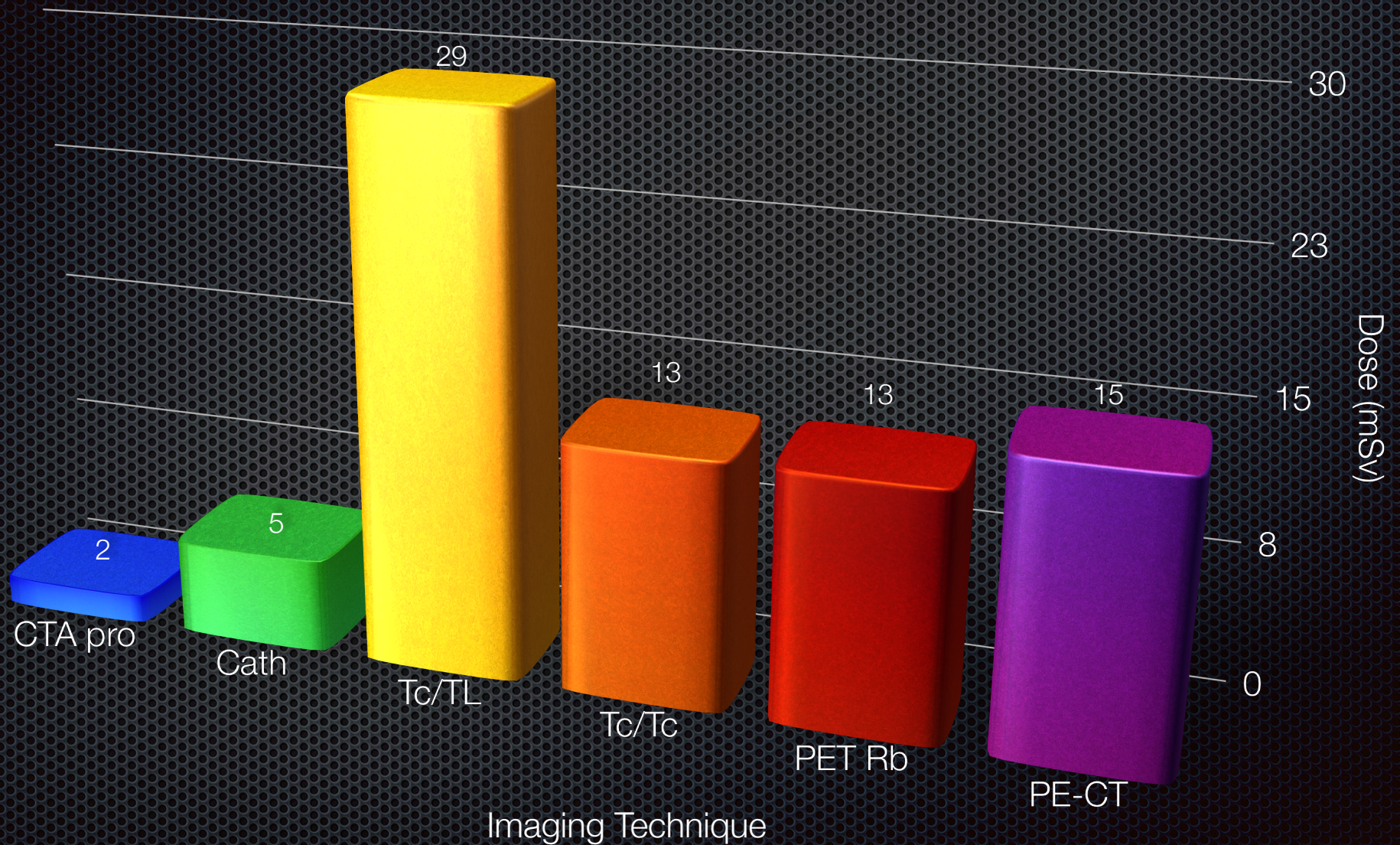
- 205 patients scheduled for cath
- All underwent 64-slice CTA
- Normal, lesion (<50%), stenosis (>50%)
- 30 month follow up







# Radiation Exposure





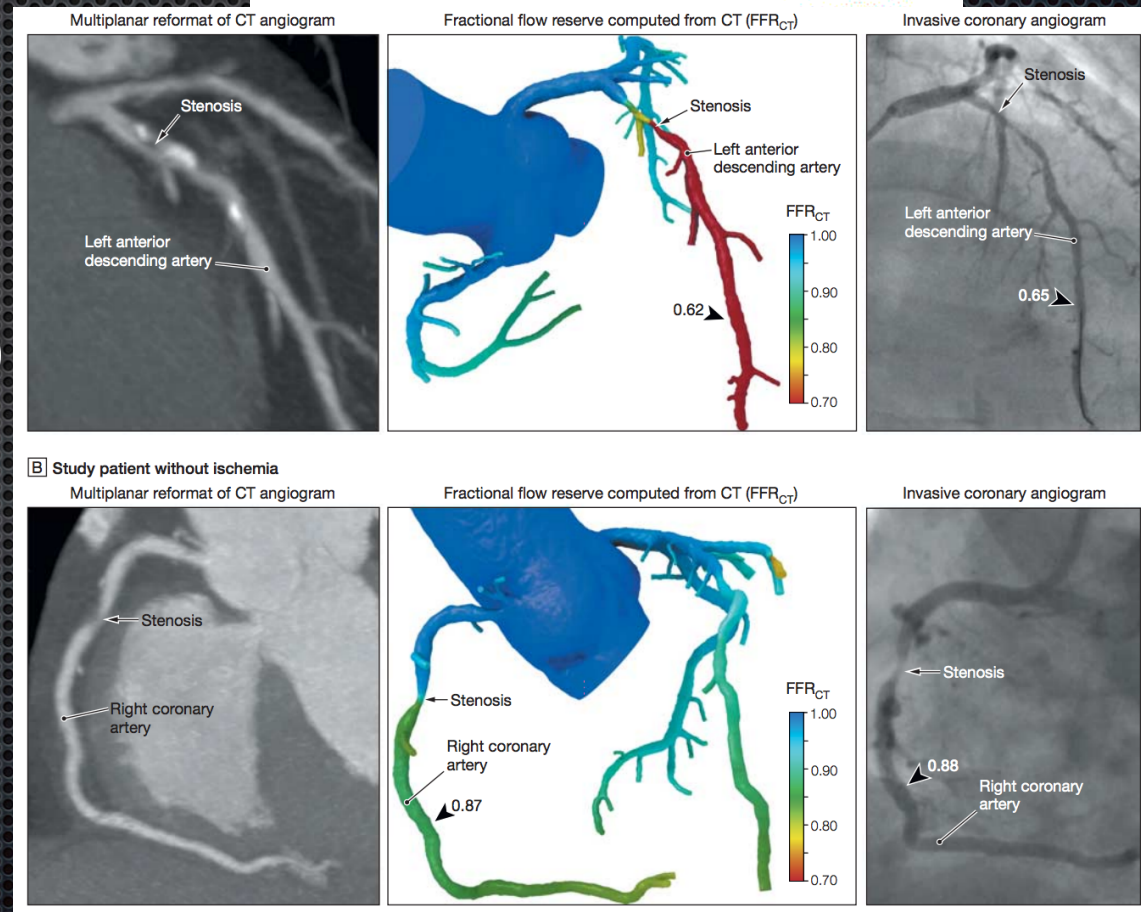
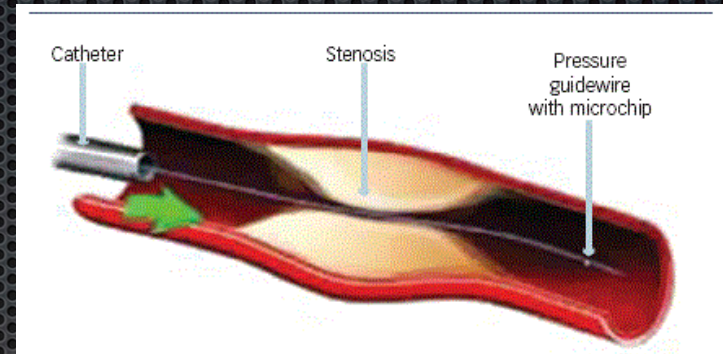
# FFR

- ❖ CTA limitation - physiologic significance of intermediate lesion
- ❖ Fractional Flow Reserve
  - ❖ Gold standard in cath for lesion specific ischemia
  - ❖  $P_{\text{distal}}/P_{\text{proximal}}$  ( $NL > 0.75$ )

## CT FFR

- ❖ DeFACTO (Diagnostic Accuracy of FFR from Anatomic CTA)
- ❖ 252 pts,  $>50\%$  stenosis

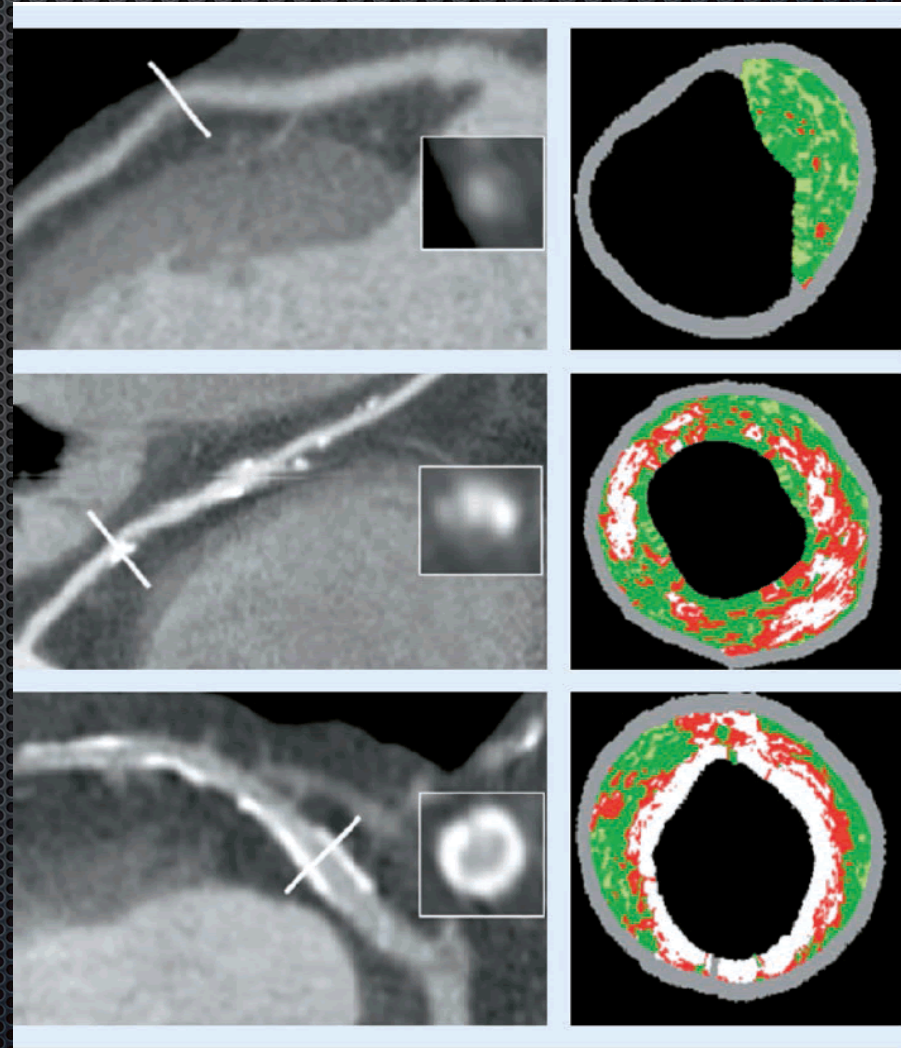
**Accuracy 67-78%, Sens 84-95%, NPV 74-90%**





# CTA Plaque Analysis

- ✦ Characterize plaque based on HU
  - ✦ Calcified vs non-calcified
  - ✦ Limited for sub-classification
    - ✦ Fibrous
    - ✦ Fatty
- ✦ New techniques with dual energy CT are promising





# Future of Cardiac Catheterization?

- ✦ As technology advances, cardiac CTA will become the non-invasive imaging modality of choice in the assessment of CAD
- ✦ Cardiac cath will be used in “true positive” cases where intervention is required
- ✦ Decrease in the number of negative caths





# Cardiac MRI



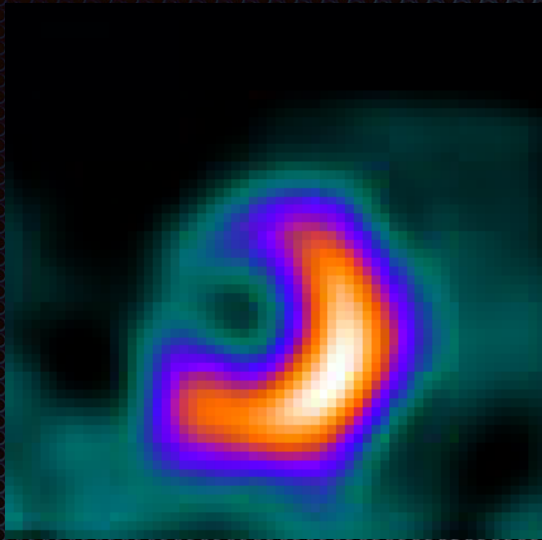


# Advantages of CMR

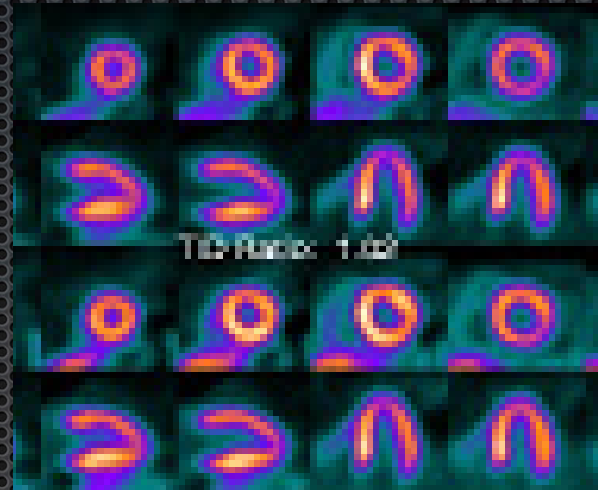
1. Excellent soft tissue contrast
2. No radiation
3. High spatial ( $<1\text{mm}$ ) and temporal resolution
4. Multi-planar imaging
5. Dynamic / cine imaging
6. Quantitative assessment
7. Valve disease with quantification
8. Tissue characterization (fat, iron)



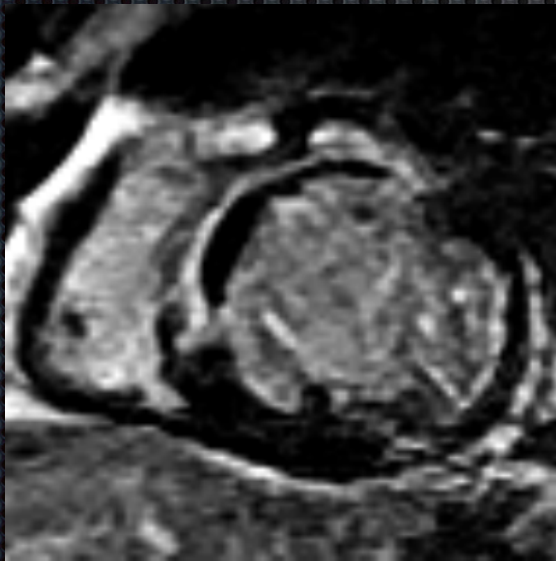
# Spatial Resolution



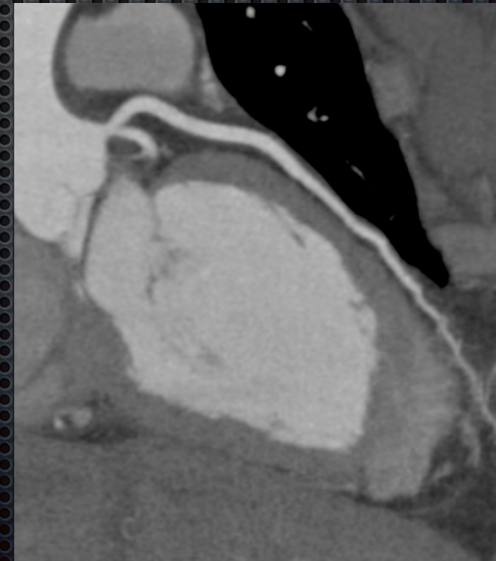
Tc-99m MIBI  
10-12mm



Rb-82 PET  
6-7mm

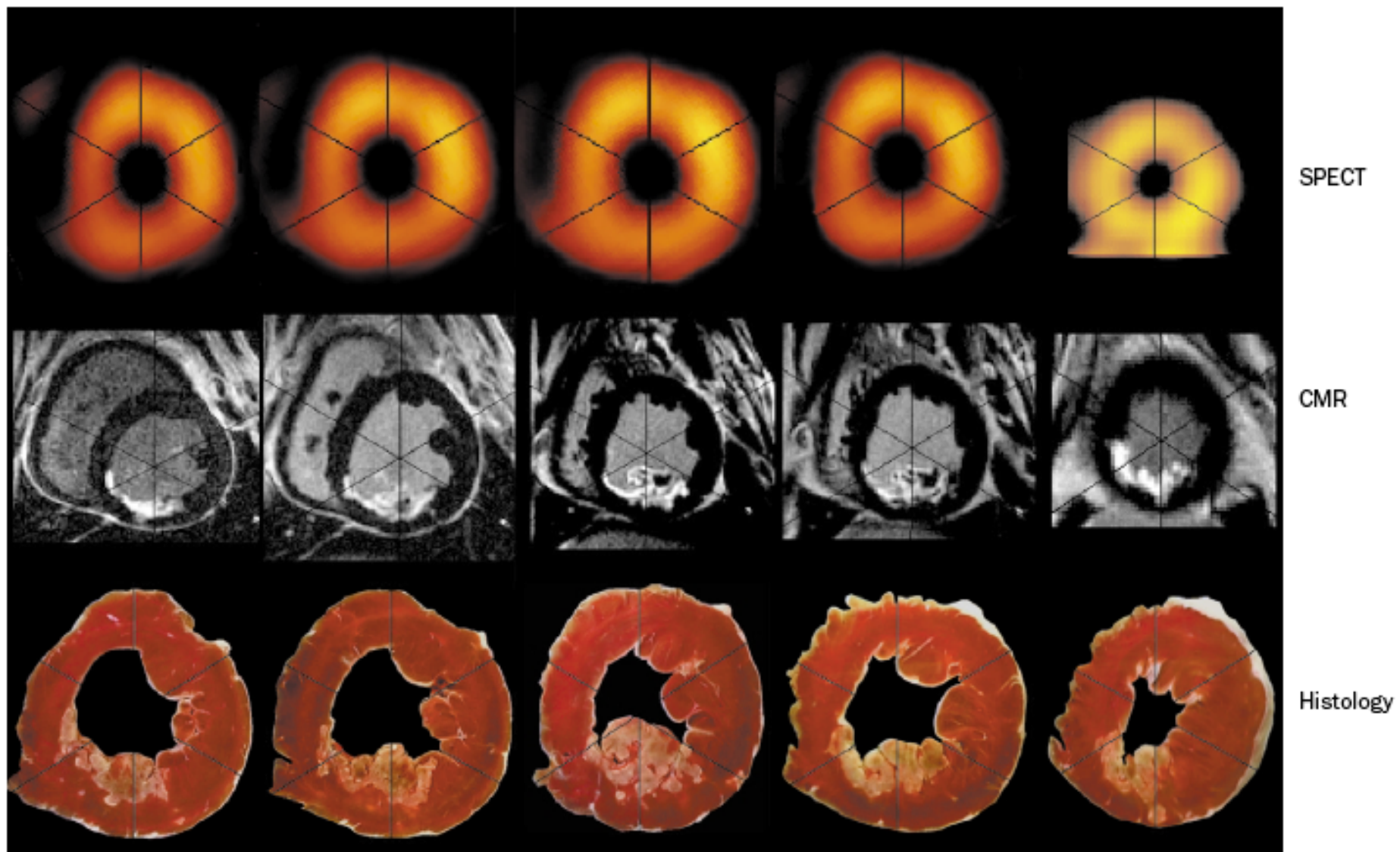


MRI  
Seq. specific  
1-2mm



CTA  
0.4mm





Base

Midventricular

Apex

Base

Midventricular

Apex



# Disadvantages of CMR

- Availability

- ECG monitoring during stress (magnetohydrodynamic effects)

- Access to patient in emergency

- Claustrophobia

- Patient metal

- Renal insufficiency (NSF)



# MRI Safety

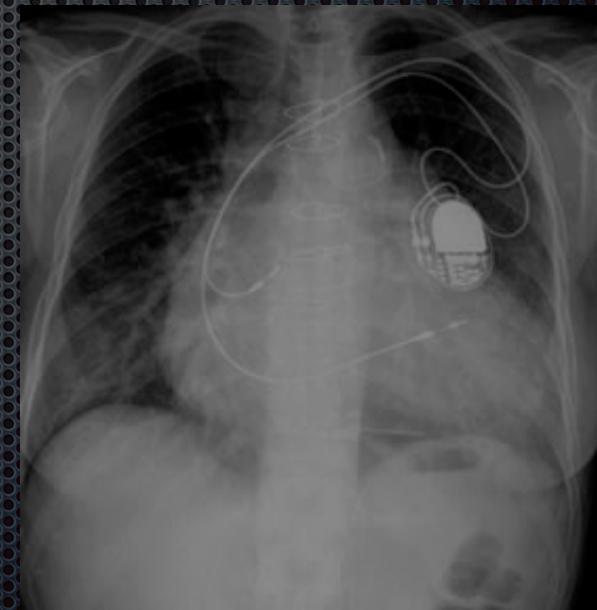
Most cardiac hardware is safe at 1.5T including:

- Mechanical and bioprosthetic valves
- Sternal wires
- CABG clips
- Coronary stents

These will cause signal void/artifacts at the site

Standard pacemakers are **not safe**

**Risk** - ventricular stimulation during switching of gradients, arrhythmia, or localized heating





# Basic CMR Protocol

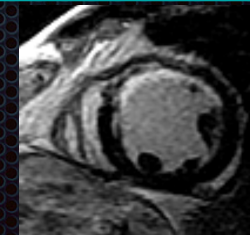
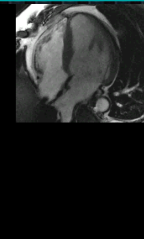
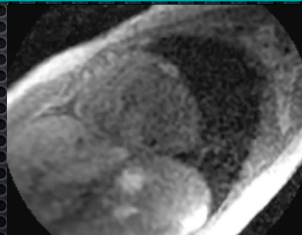
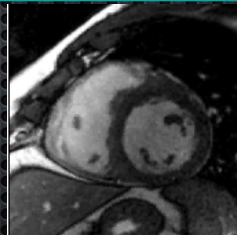
**Cardiac Localizers**

***Cine Function  
Images***

***Rest Perfusion***  
0.1 mmol/kg Gd

**Radials**

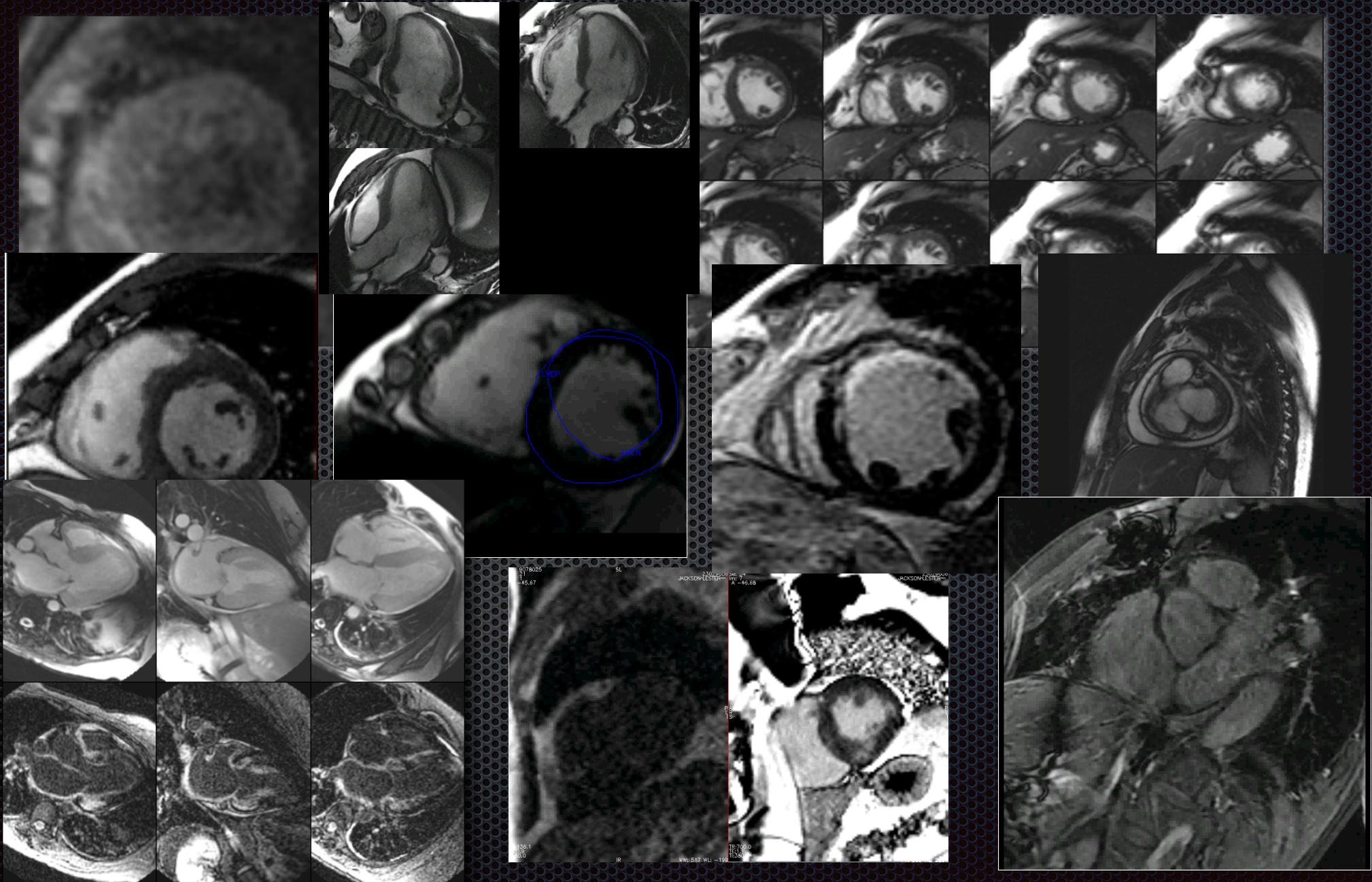
***Delayed Myocardial  
Enhancement***



Total Examination Time: 30 Minutes



# CMR protocols vary per indication





# Common Indications for CMR

- Cardiac & valvular anatomy
- Cardiac function
- Viability / scar imaging
- Cardiomyopathy
  - Ischemic
  - Non-ischemic (tissue characterization)
- Cardiac masses
- Vascular assessment (coronaries, aorta, PV, etc.)
- Valvular assessment
- CHD



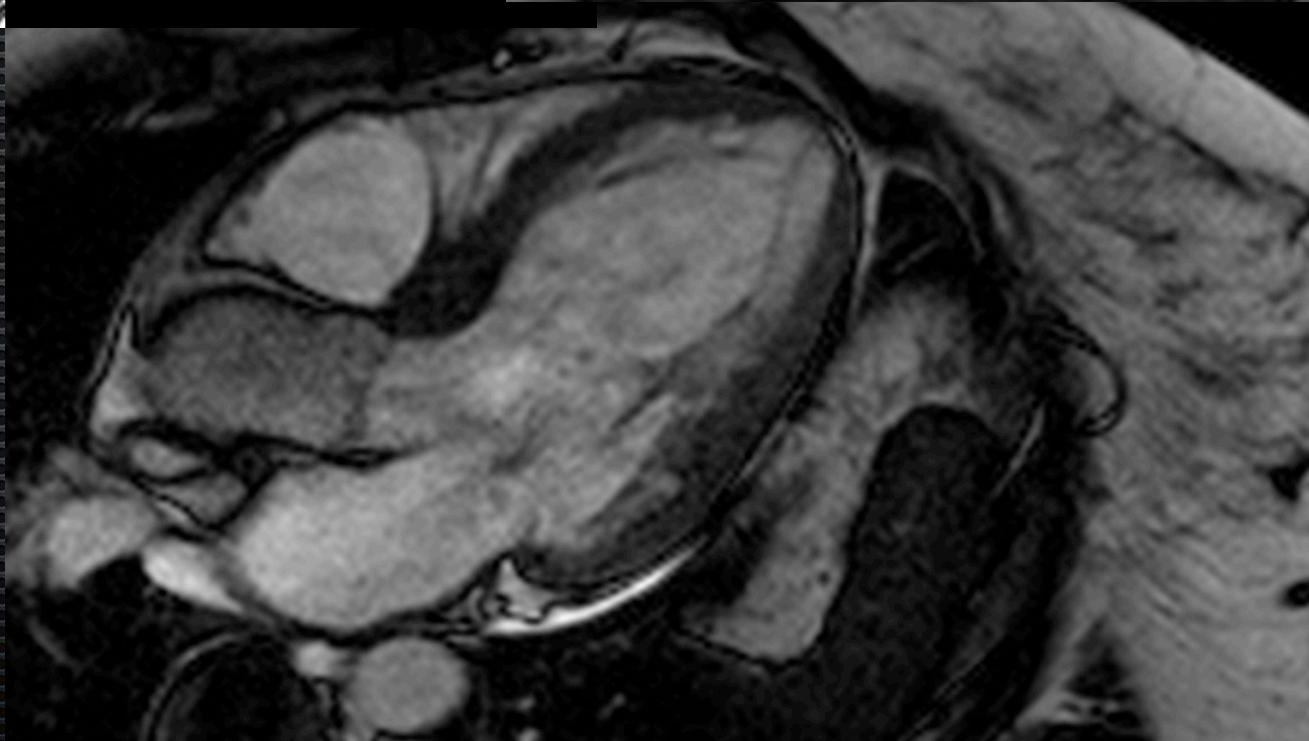
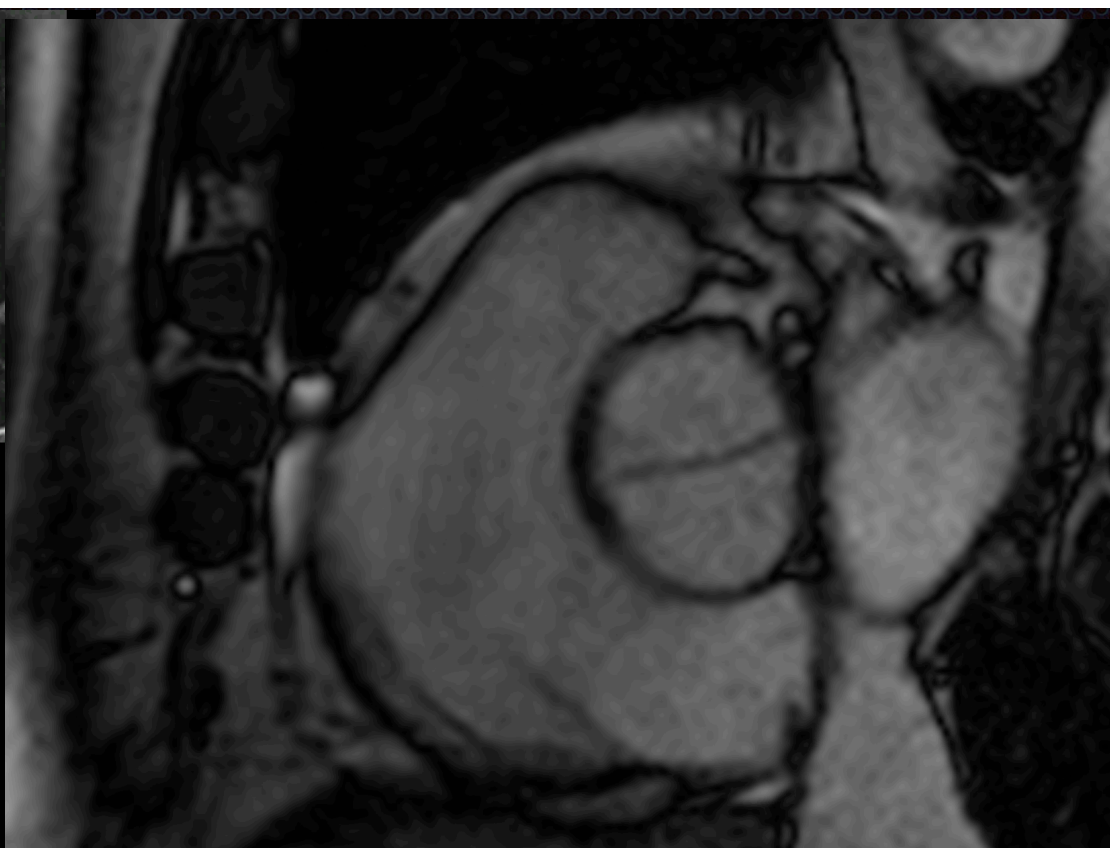
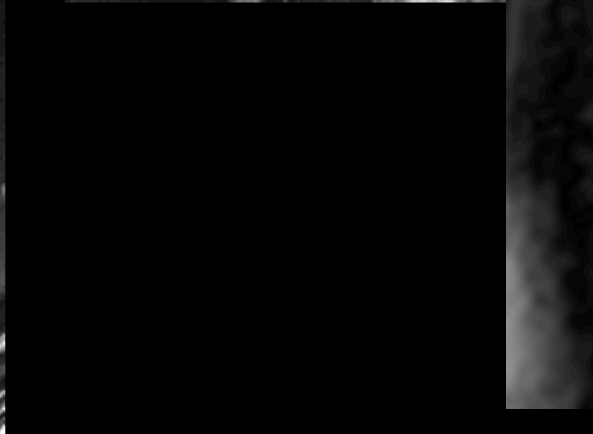
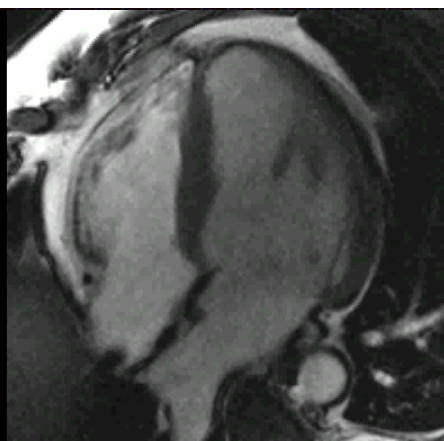
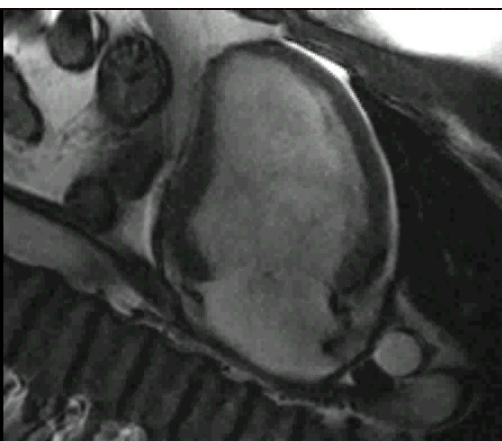
**Table 19.** Appropriate Indications (Median Score 7–9)

Indication		Appropriateness Criteria (Median Score)
<b>Detection of CAD: Symptomatic—Evaluation of Chest Pain Syndrome (Use of Vasodilator Perfusion CMR or Dobutamine Stress Function CMR)</b>		
3.	<ul style="list-style-type: none"> <li>• Intermediate pre-test probability of CAD</li> <li>• ECG uninterpretable OR unable to exercise</li> </ul>	A (7)
<b>Detection of CAD: Symptomatic—Evaluation of Intra-Cardiac Structures (Use of MR Coronary Angiography)</b>		
8.	<ul style="list-style-type: none"> <li>• Evaluation of suspected coronary anomalies</li> </ul>	A (8)
<b>Risk Assessment With Prior Test Results (Use of Vasodilator Perfusion CMR or Dobutamine Stress Function CMR)</b>		
13.	<ul style="list-style-type: none"> <li>• Coronary angiography (catheterization or CT)</li> <li>• Stenosis of unclear significance</li> </ul>	A (7)
<b>Structure and Function—Evaluation of Ventricular and Valvular Function</b> Procedures may include LV/RV mass and volumes, MR angiography, quantification of valvular disease, and delayed contrast enhancement		
18.	<ul style="list-style-type: none"> <li>• Assessment of complex congenital heart disease including anomalies of coronary circulation, great vessels, and cardiac chambers and valves</li> <li>• Procedures may include LV/RV mass and volumes, MR angiography, quantification of valvular disease, and contrast enhancement</li> </ul>	A (9)
20.	<ul style="list-style-type: none"> <li>• Evaluation of LV function following myocardial infarction OR in heart failure patients</li> <li>• Patients with technically limited images from echocardiogram</li> </ul>	A (8)
21.	<ul style="list-style-type: none"> <li>• Quantification of LV function</li> <li>• Discordant information that is clinically significant from prior tests</li> </ul>	A (8)
22.	<ul style="list-style-type: none"> <li>• Evaluation of specific cardiomyopathies (infiltrative [amyloid, sarcoid], HCM, or due to cardiotoxic therapies)</li> <li>• Use of delayed enhancement</li> </ul>	A (8)
23.	<ul style="list-style-type: none"> <li>• Characterization of native and prosthetic cardiac valves—including planimetry of stenotic disease and quantification of regurgitant disease</li> <li>• Patients with technically limited images from echocardiogram or TEE</li> </ul>	A (8)
24.	<ul style="list-style-type: none"> <li>• Evaluation for arrhythmogenic right ventricular cardiomyopathy (ARVC)</li> <li>• Patients presenting with syncope or ventricular arrhythmia</li> </ul>	A (9)
25.	<ul style="list-style-type: none"> <li>• Evaluation of myocarditis or myocardial infarction with normal coronary arteries</li> <li>• Positive cardiac enzymes without obstructive atherosclerosis on angiography</li> </ul>	A (8)



# Cardiac & Valvular Anatomy





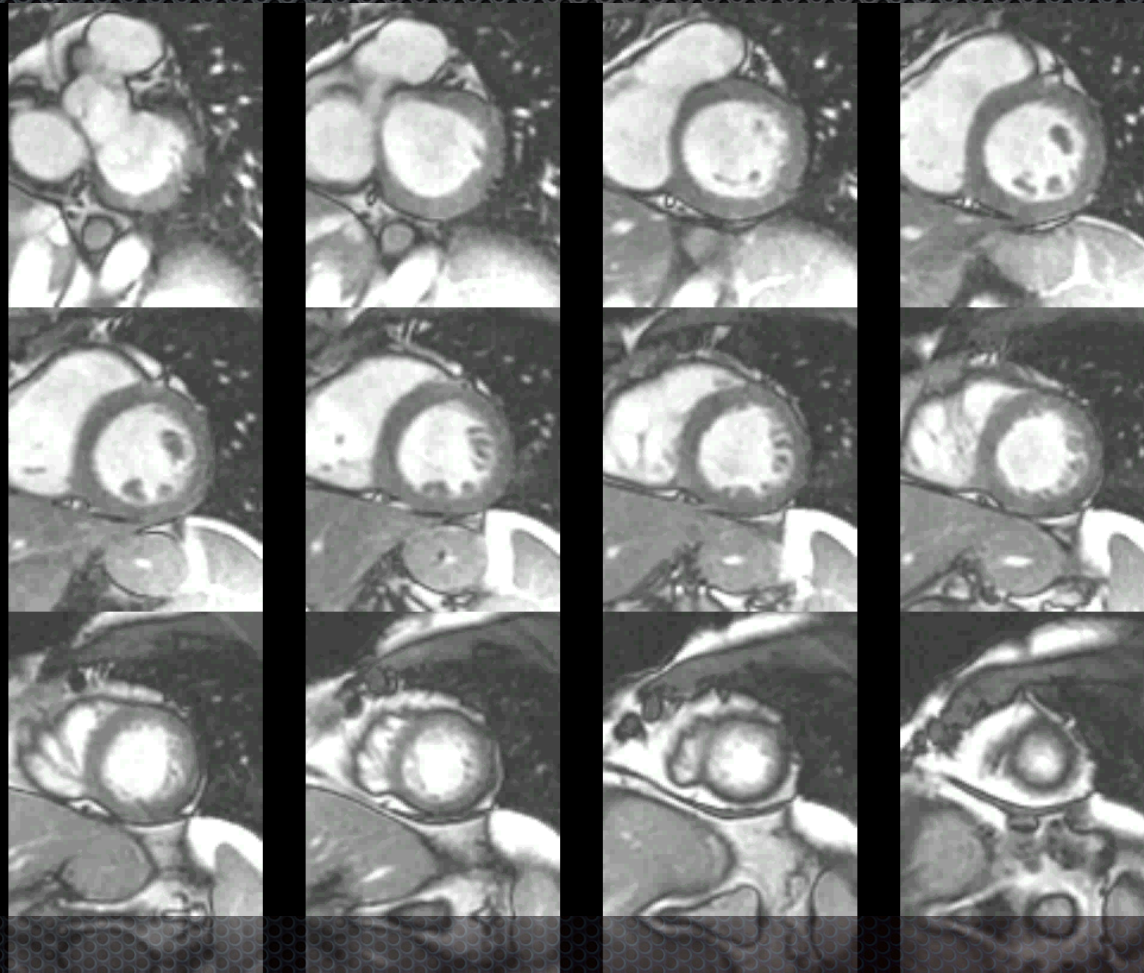


# Cardiac Function



# Cardiac Function

- Excellent soft tissue contrast with high spatial resolution
- Cine imaging with high temporal resolution





# Viability & Scar Imaging



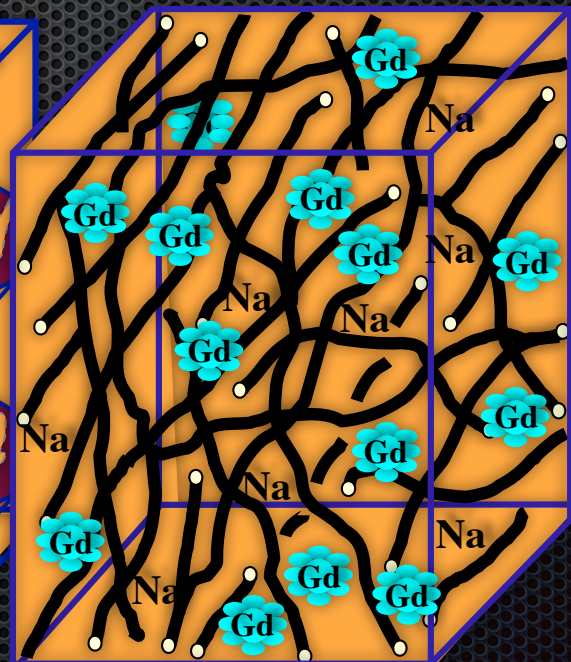
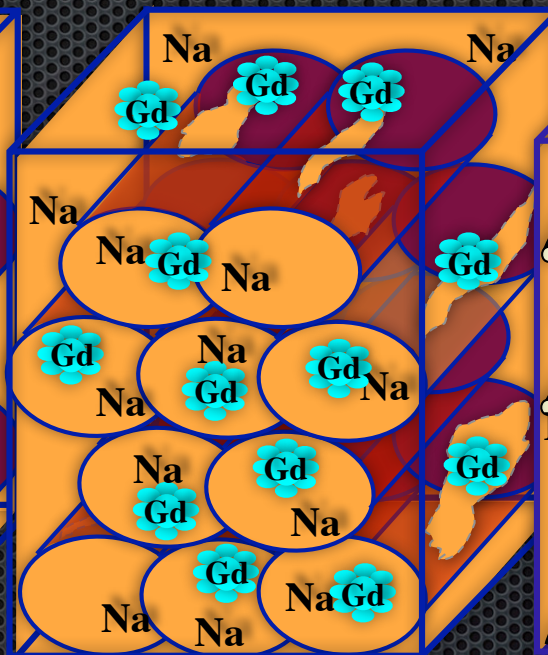
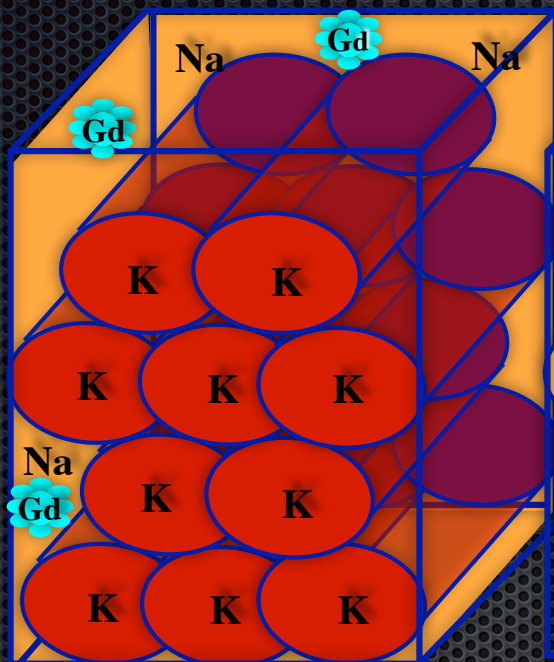
# Delayed Enhancement Mechanism:

Higher Gd = more hyperintense/bright

Viable Myocardium

Acute MI

Scar



Intact cell membranes

Ruptured cell  
membranes

Collagen matrix

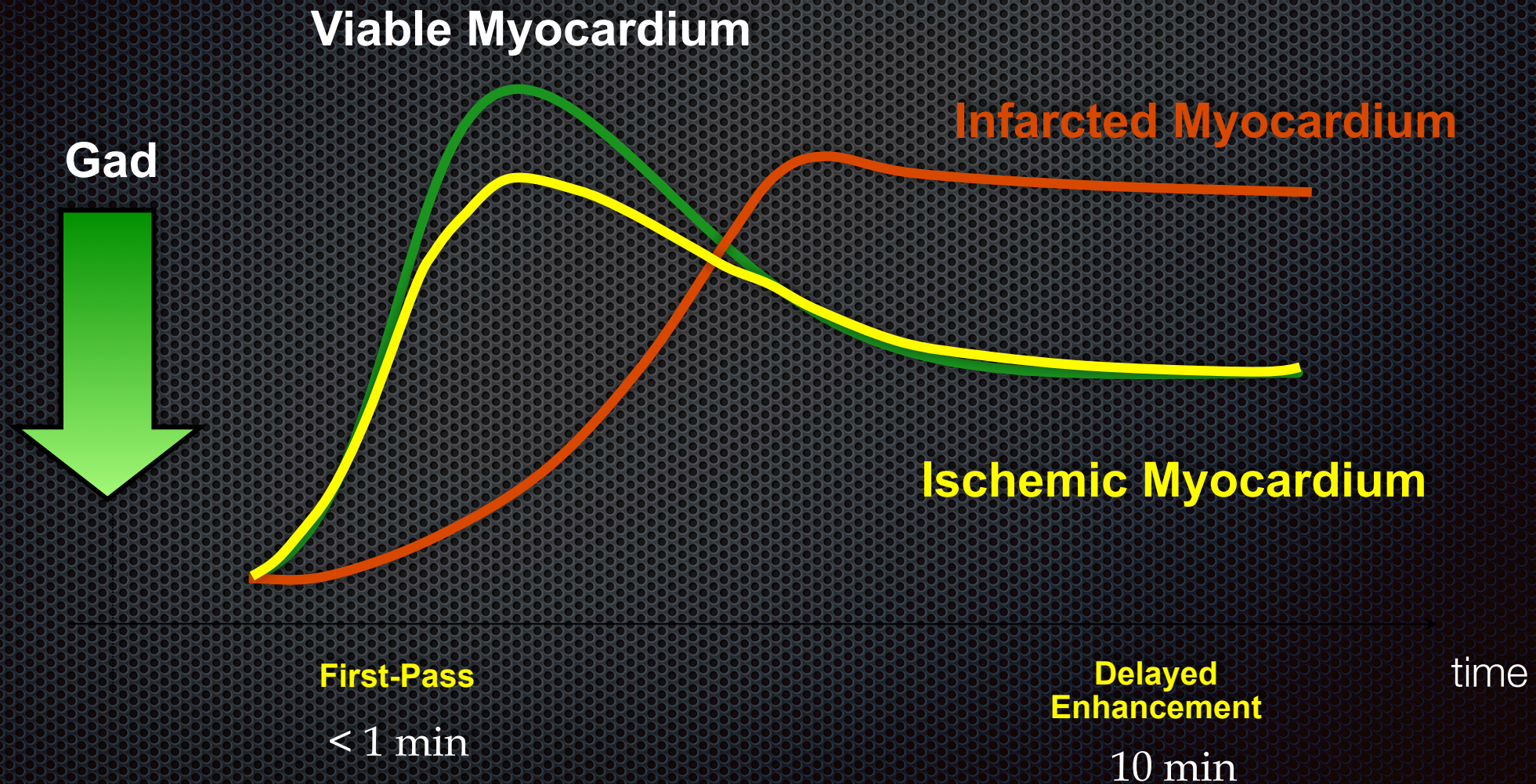
[Gd] = Low

[Gd] = High

[Gd] = High

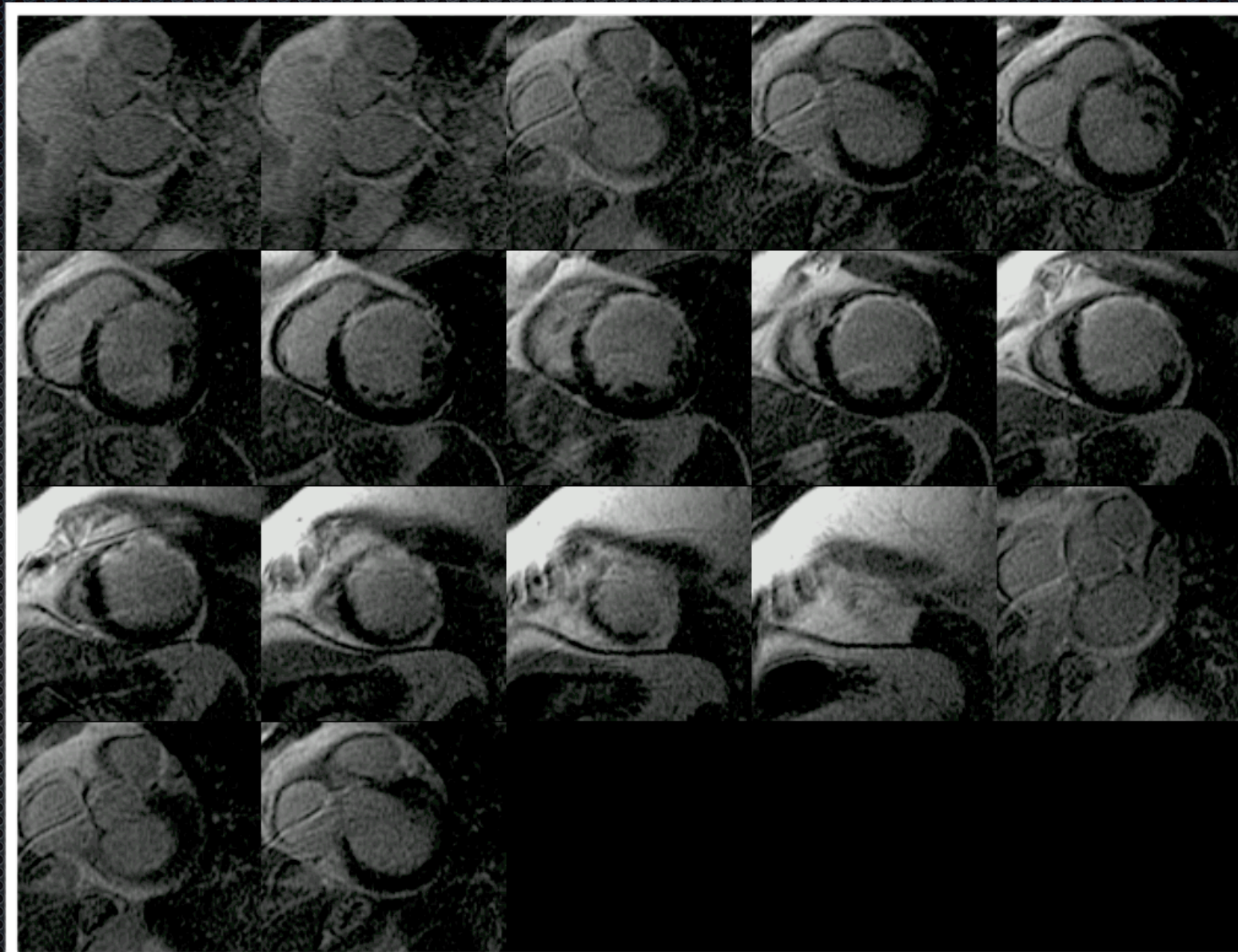


# Phases of Myocardial Enhancement



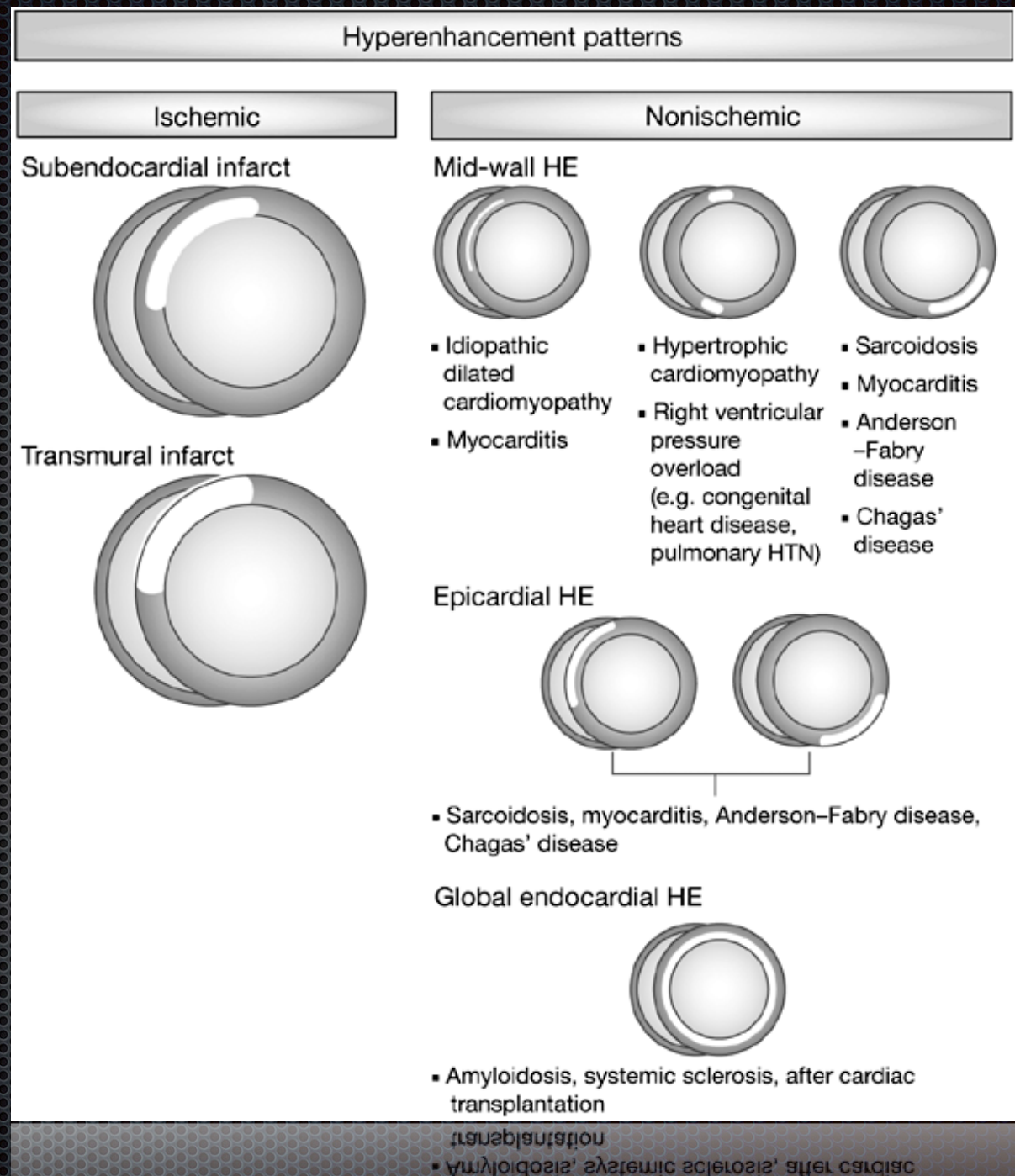


# MDE





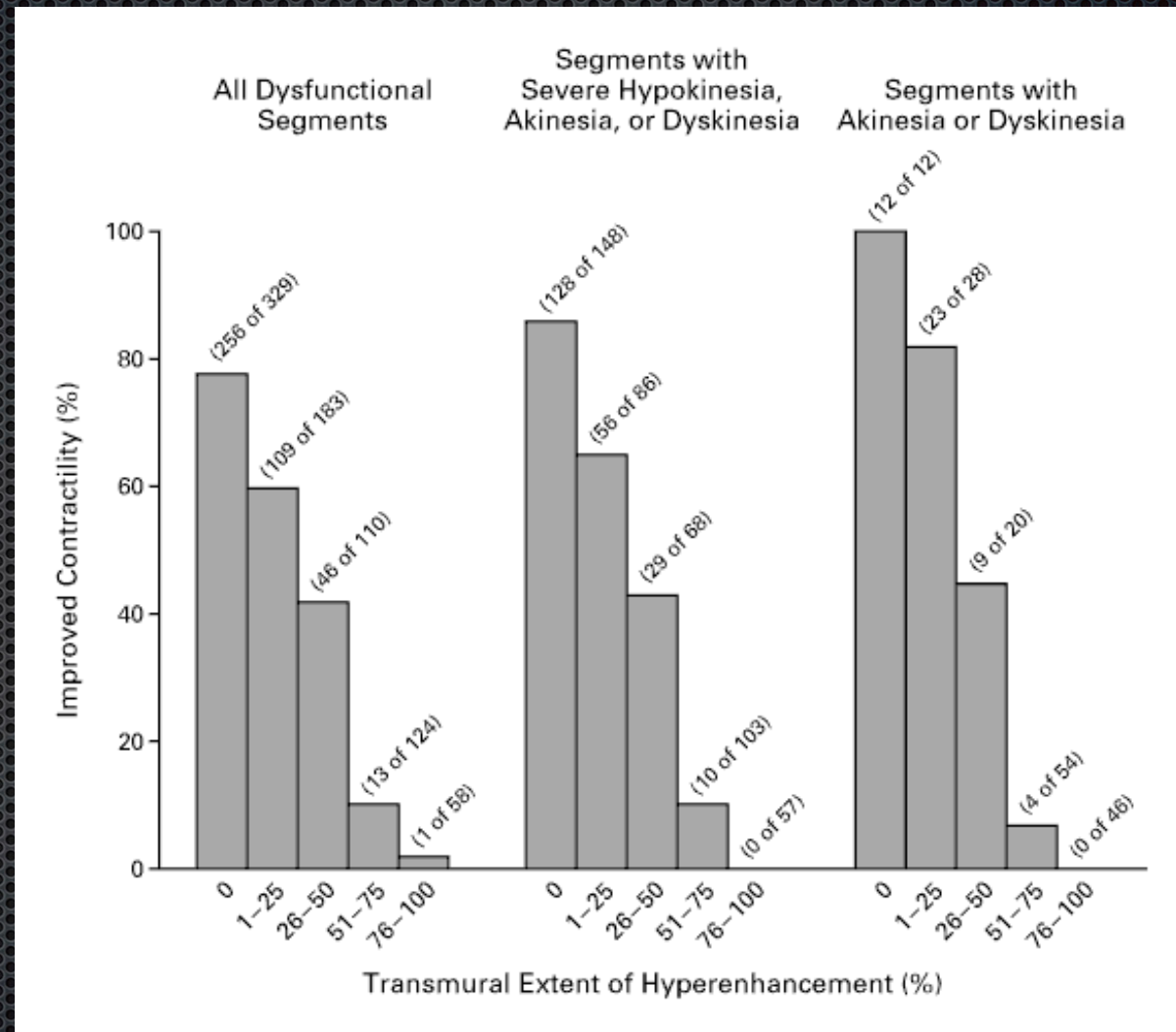
# MDE





# MDE Prognostic Value

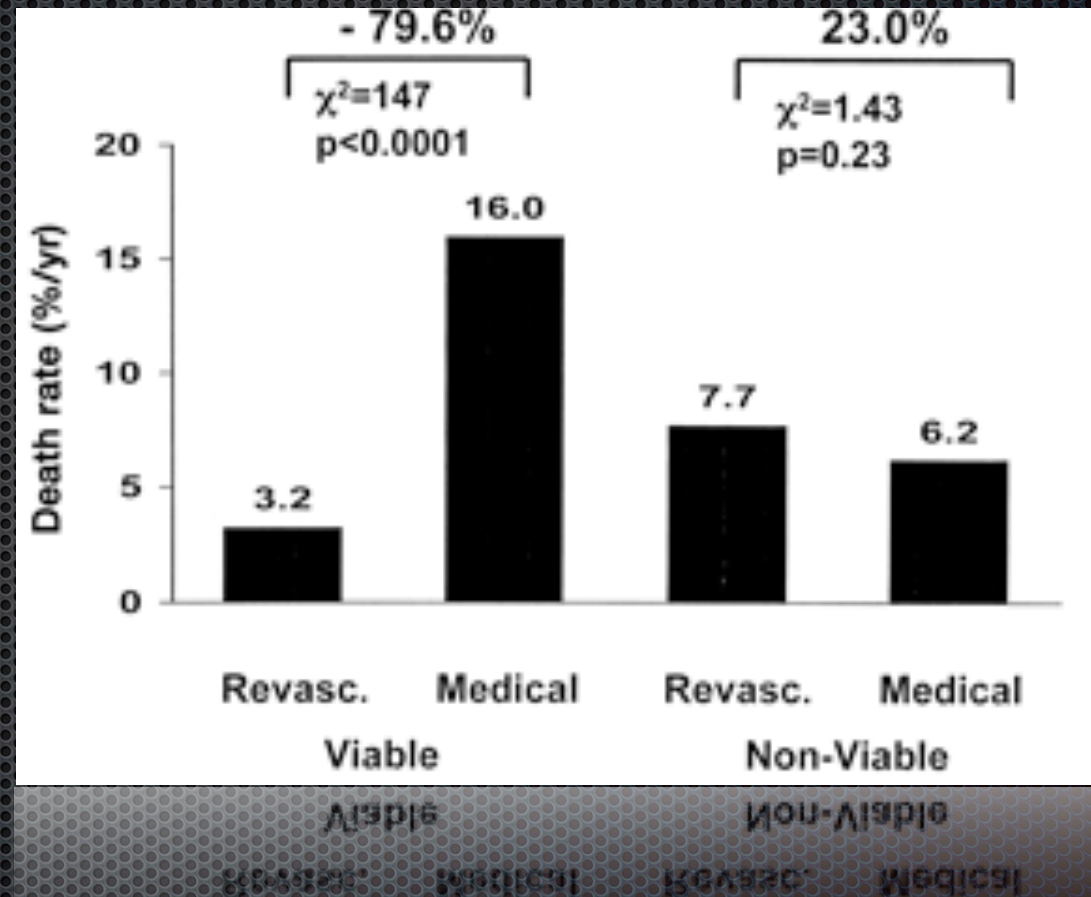
In patients with ischemic LV dysfunction, transmural extent of delayed enhancement predicts the recovery of regional function after percutaneous or surgical intervention





# Clinical Importance of Identifying Viable Myocardium

- In the presence of known scar, amount of viable myocardium predicts clinical outcomes after treatment
- Meta-analysis of 3088 patients undergoing viability imaging with thallium, FDG-PET, dobutamine echo





# Ischemic Cardiomyopathy

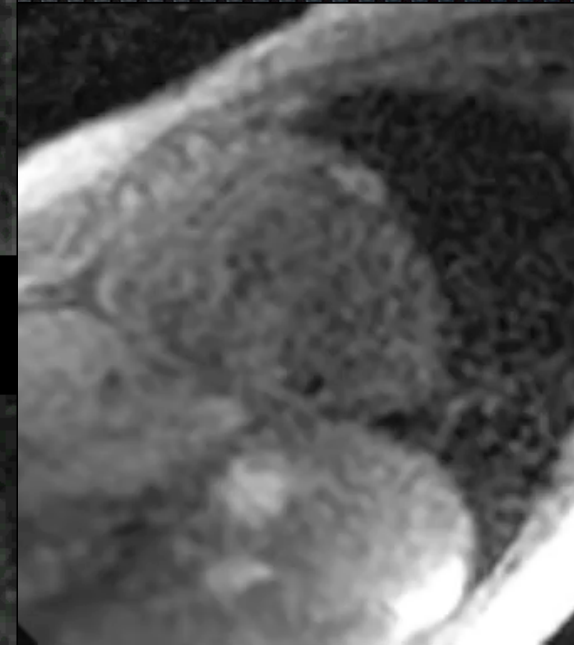
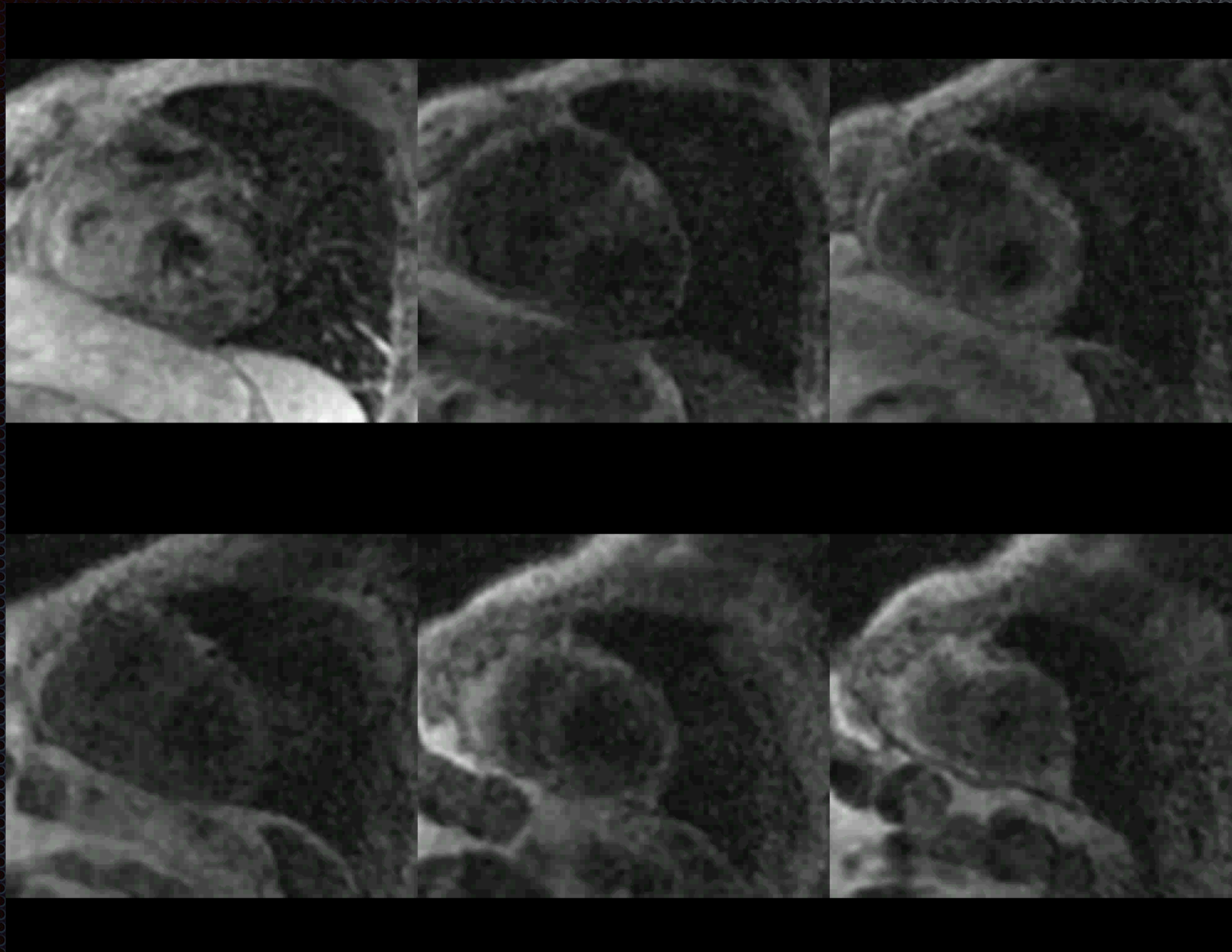


# Types of Stress Testing

Exercise	Exercise Stress with Imaging	Pharmacologic Stress with Imaging
Treadmill	Treadmill SPECT	Vasodilator (adenosine/ dipyridamole) SPECT/PET
Bicycle	Treadmill Echo	Dobutamine SPECT/PET
		Dobutamine Echo
		Vasodilator (adenosine/ Lexiscan) MRI
		Dobutamine MRI



# Vasodilator stress MR



REST

STRESS



# Case: 72 yo male with no h/o CAD

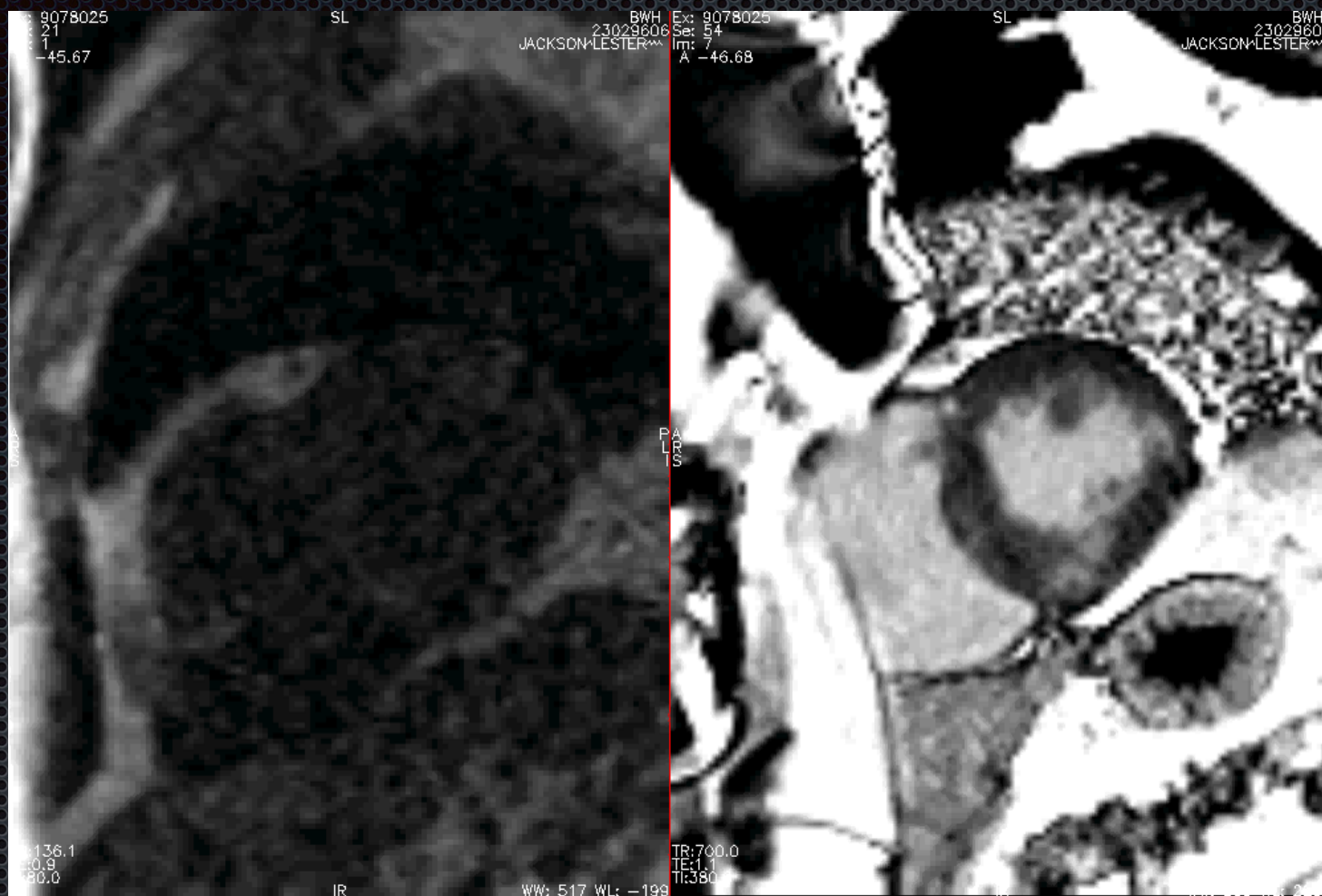
6 months of progressive ankle edema

Admitted after a 10 min episode of dyspnea upon walking up  
2 flights of stairs

Presented to the hospital as per wife's request

Anxious, HR 90 at rest





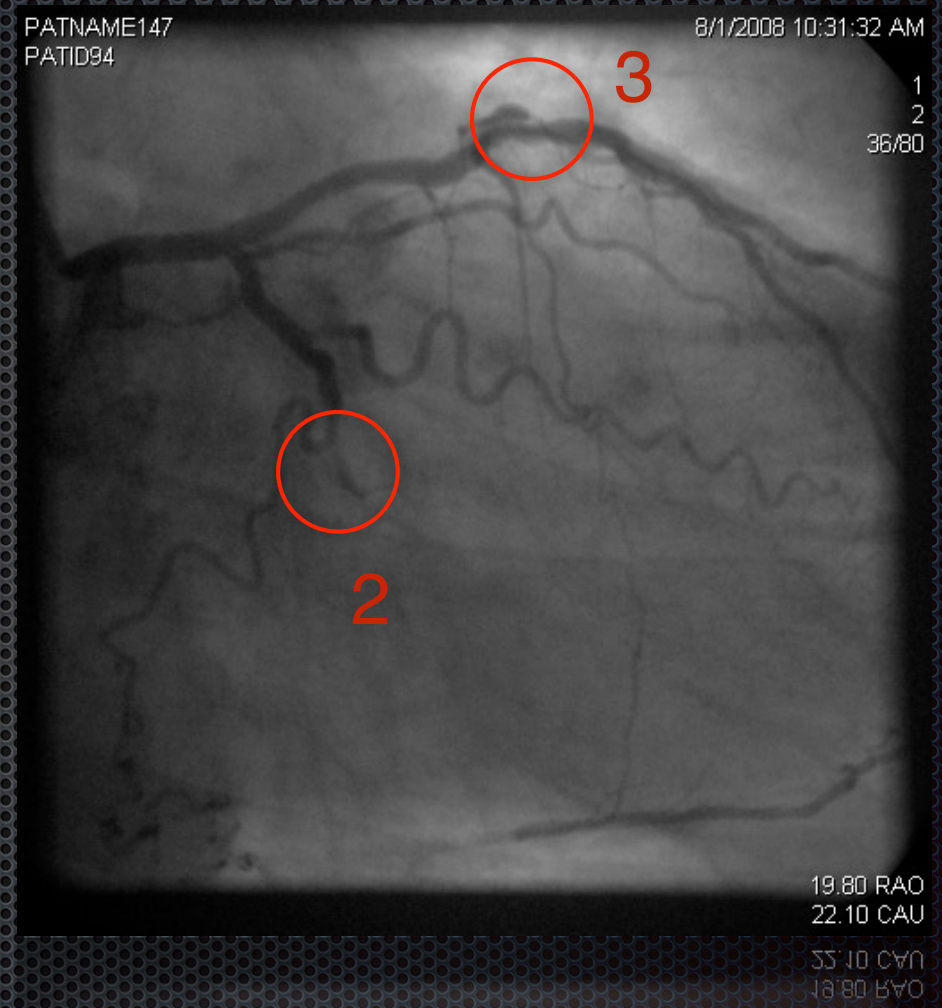
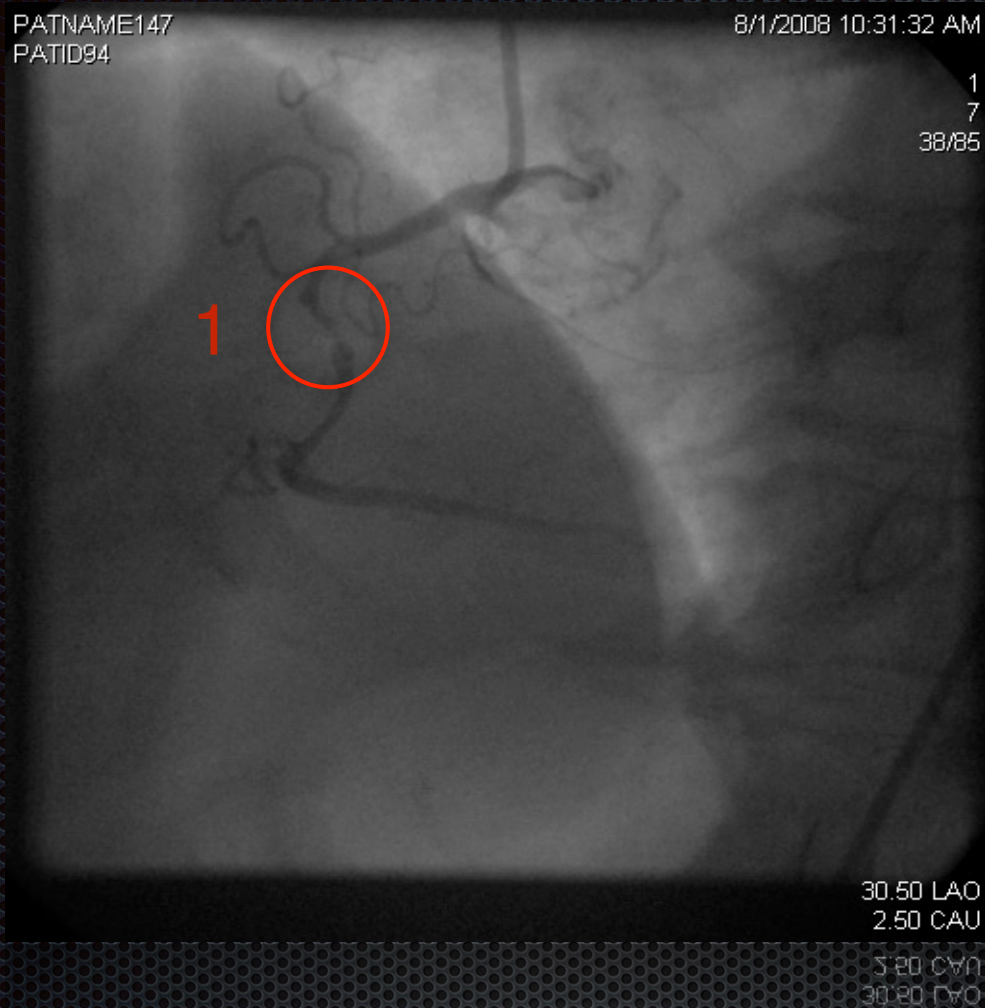
**Adenosine perfusion**

**Late gadolinium enhancement**

No breath holding required, pt tachycardia



# Coronary angiography



Findings:

- 1) 95% stenosis in mid RCA
- 2) 100% occlusion of OM
- 3) 70% mid LAD



# Prognostic value in CMR

- ✦ Meta-analysis of 2993 patients (Weng Z, et al. JACC Imaging. Dec 2016)
  - ✦ + LGE: sudden cardiac death, all-cause mortality, cardiovascular mortality, heart failure death.
  - ✦ Extent of LGE -> increased risk of sudden cardiac death, heart failure death, all-cause mortality, cardiovascular mortality.



| JACC

Cardiovascular Imaging

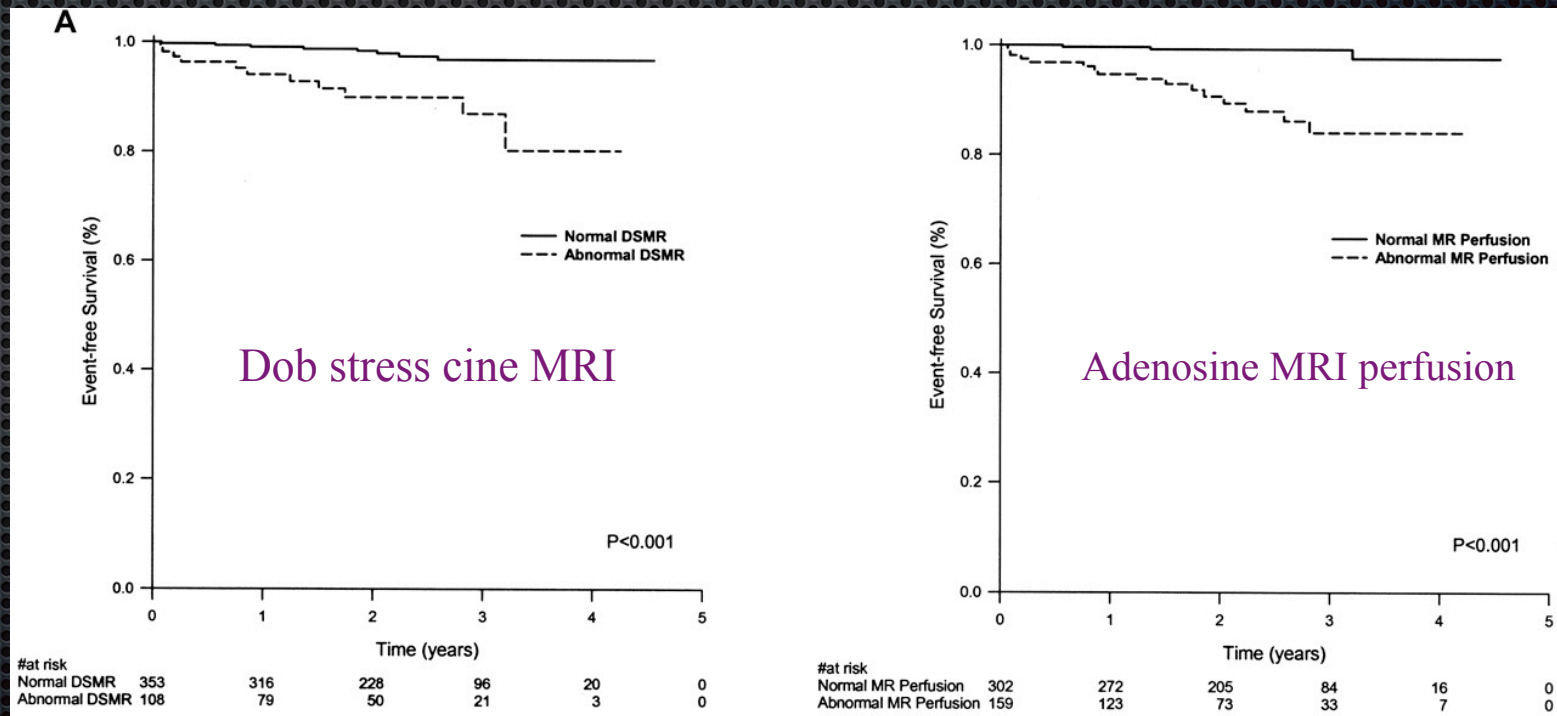


# 5-year Prognostic Value of CMR Stress Imaging: Adenosine Stress Perfusion vs. Dobutamine Stress

Single-Center Study (n = 513)

A Negative CMR Stress study: 3-year event-free survival = 99.2%

If ischemia detected on MRI: 12x (adenosine) and 5x (dobutamine) increased risk of subsequent event

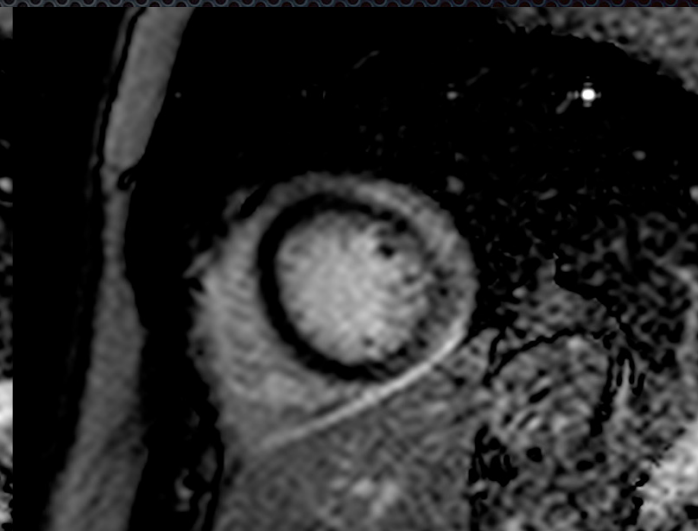
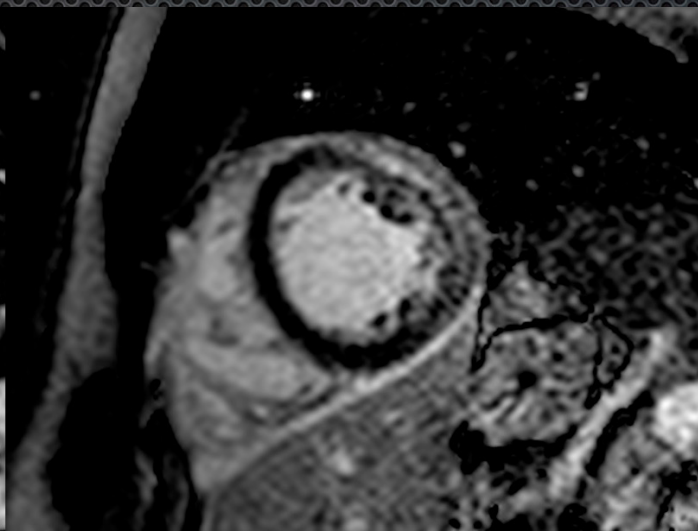
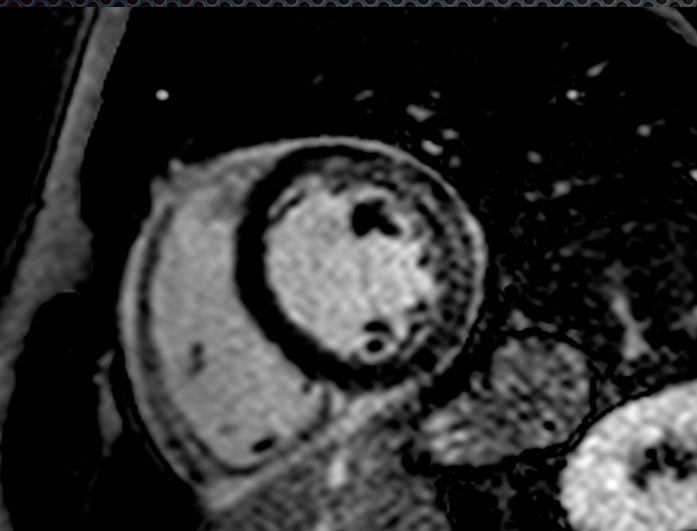
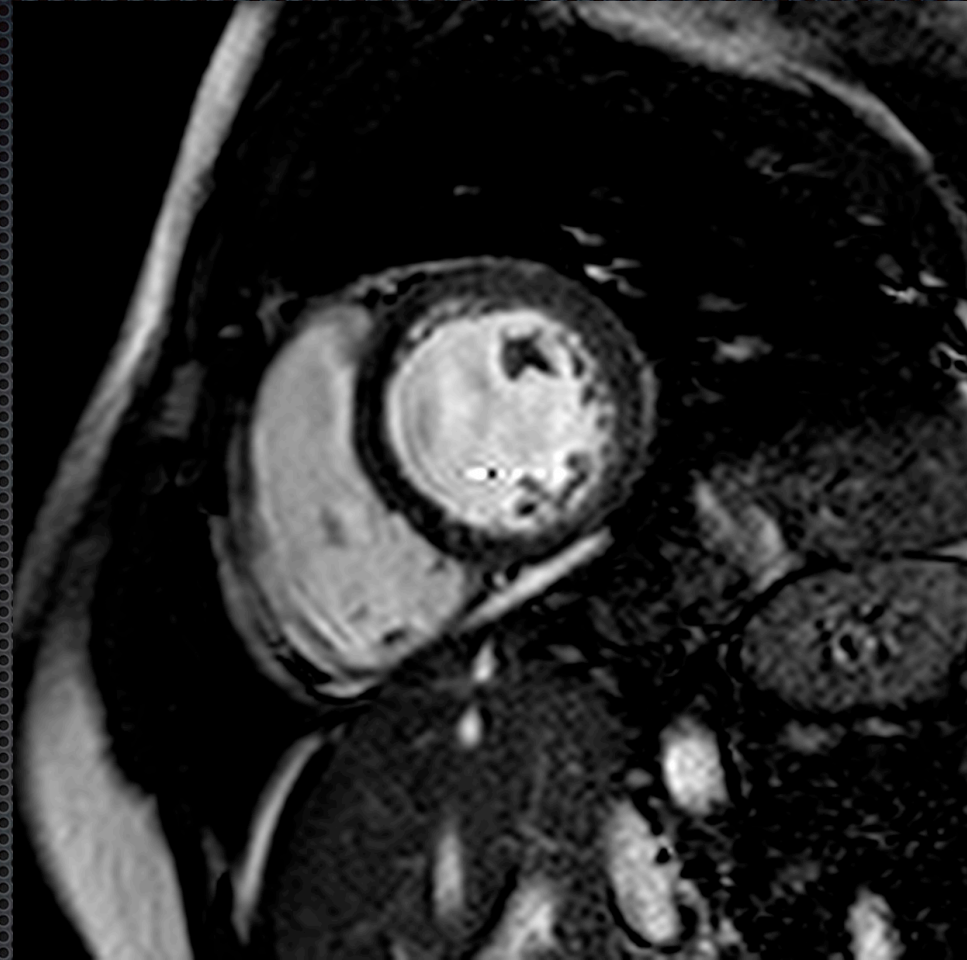




# Non-ischemic Cardiomyopathy



# Myocarditis





# Comparison of Diagnostic Techniques in Myocarditis

TECHNIQUE	n	SENSITIVITY	SPECIFICITY
Troponin	80	53	96
EMB – histology	71	10-36	98
EMB – immunohisto	20	80	85
Gallium-67	71	87	86
CMR – T1, T2, DE	156	84-100	91-100



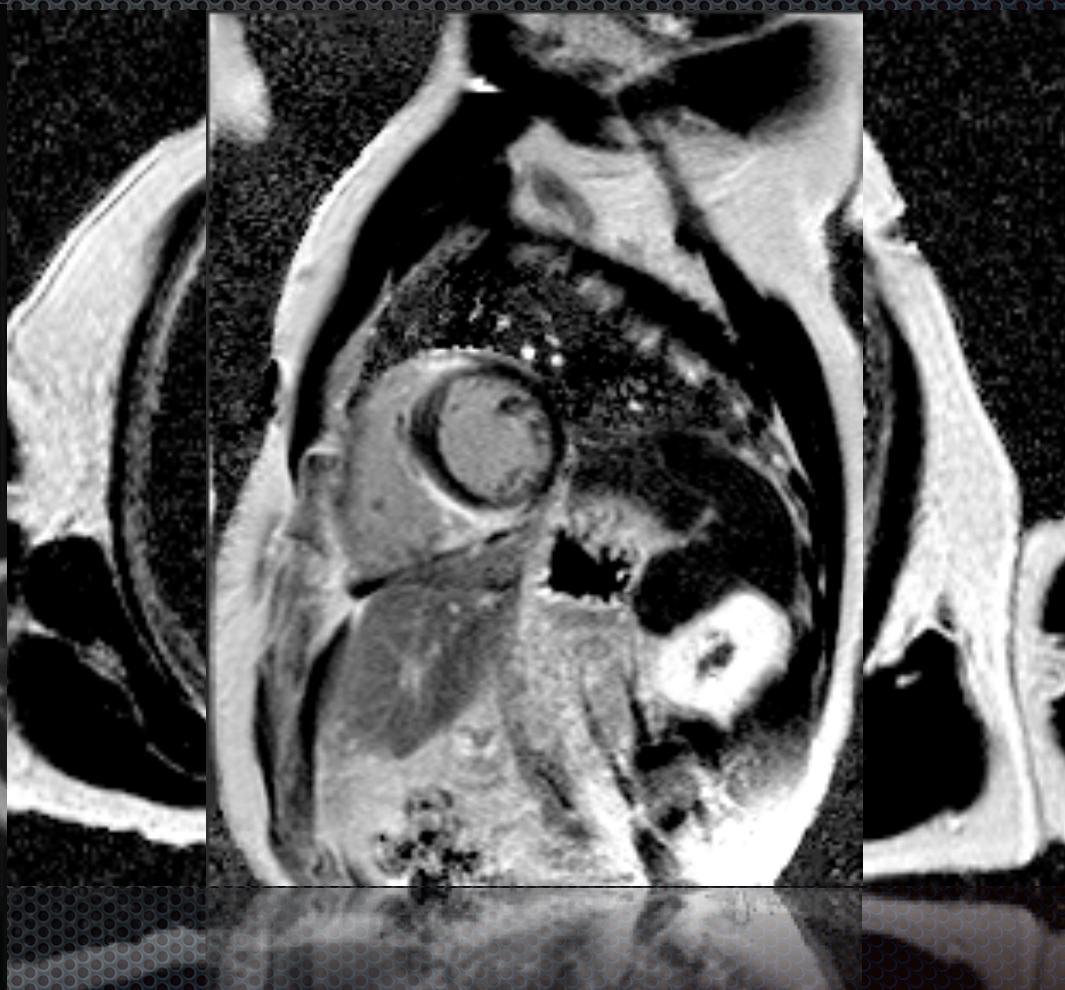
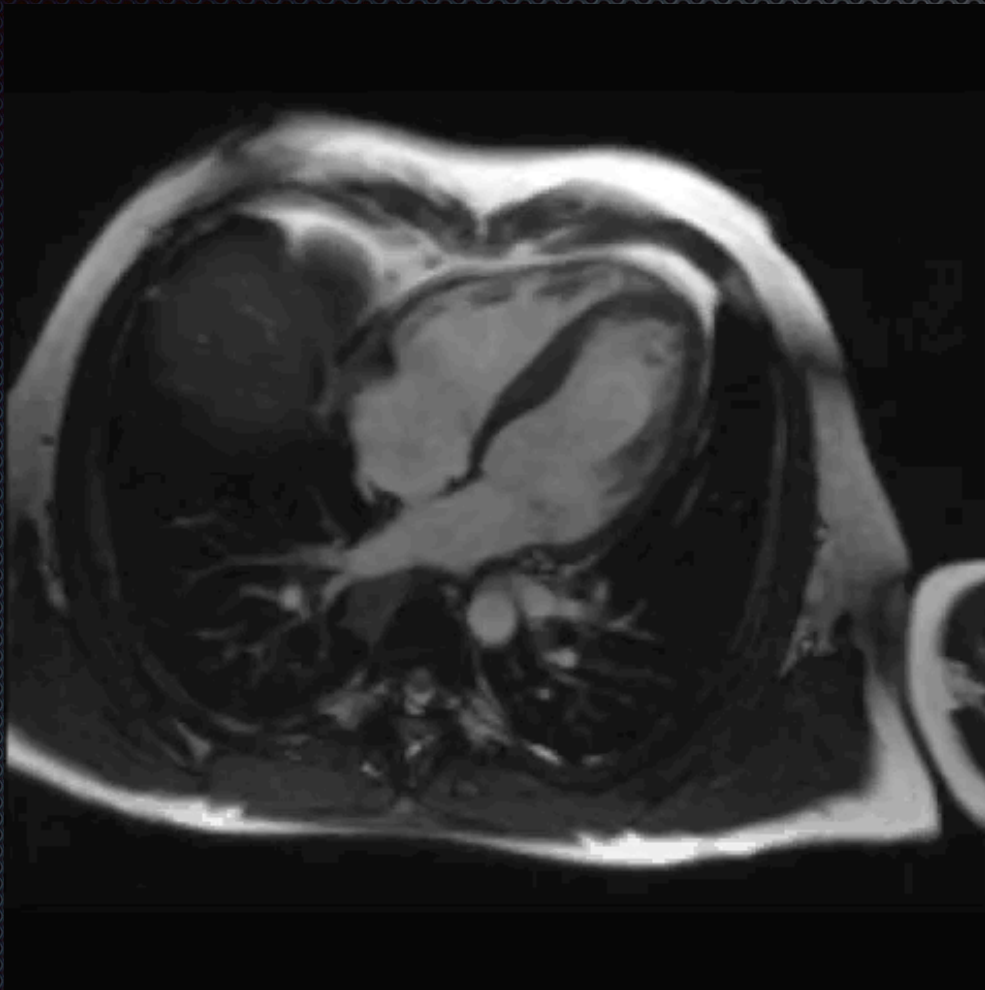
# CMR in Myocarditis to Improve Biopsy Yield

- DE is common in acute myocarditis (88%)
- CMR may improve diagnostic yield of EMB
- 673 patients with myocarditis underwent CMR and followed for 4.7 years.

Presence of LGE associated with double MACE (Grani, C. et al. JACC 2017)



# ARVD





# ARVD CRITERIA

Diagnostic criteria would be fulfilled by the presence of:

- 2 major criteria or
- 1 major plus 2 minor criteria or
- 4 minor criteria

MRI can only satisfy 1 major or 1 minor criteria - not more

## I. Global and/or Regional Dysfunction and Structural Alterations\*

### MAJOR:

- Severe dilatation and reduction of right ventricular ejection fraction with no (or only mild) LV impairment.
- Localized right ventricular aneurysms (akinetic or dyskinetic areas with diastolic bulging.)
- Severe segmental dilatation of the right ventricle.

### MINOR:

- Mild global right ventricular dilatation and/or ejection fraction reduction with normal left ventricle.
- Mild segmental dilatation of the right ventricle.
- Regional right ventricular hypokinesia.

## II. Tissue Characterization of Walls

## III. Repolarisation Abnormalities

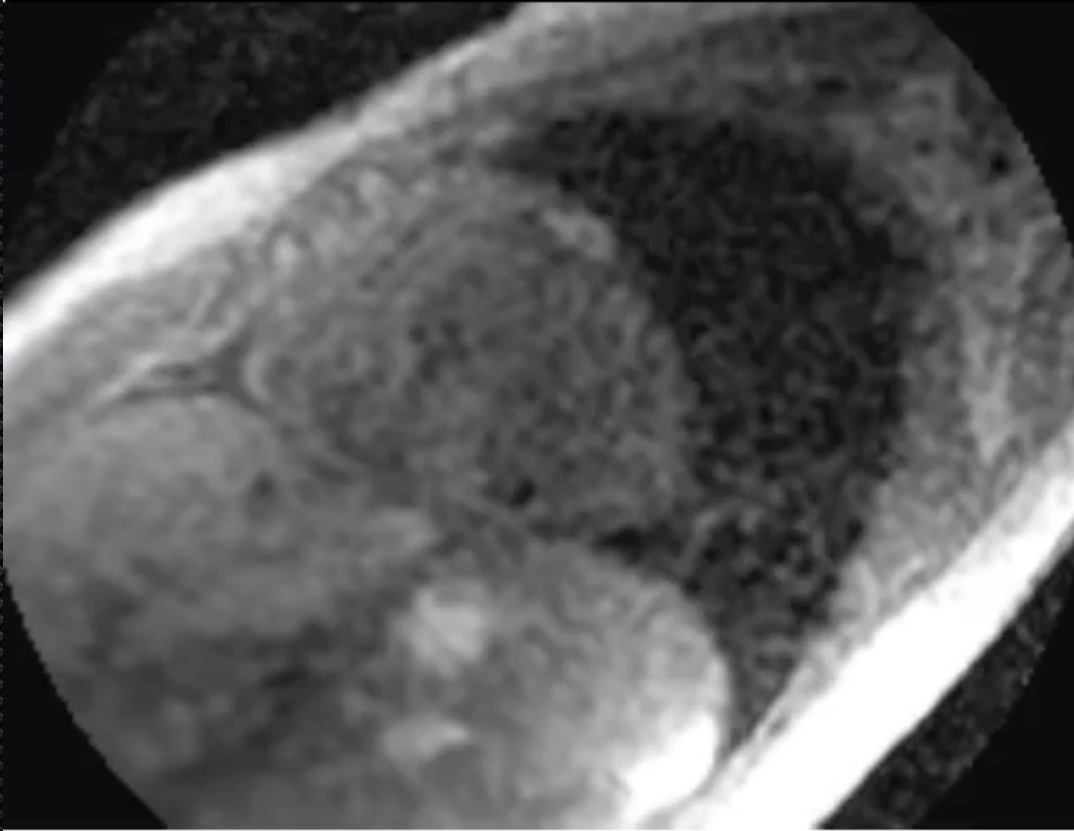
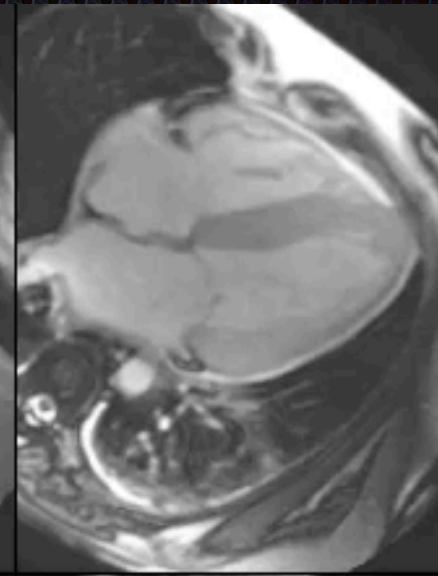
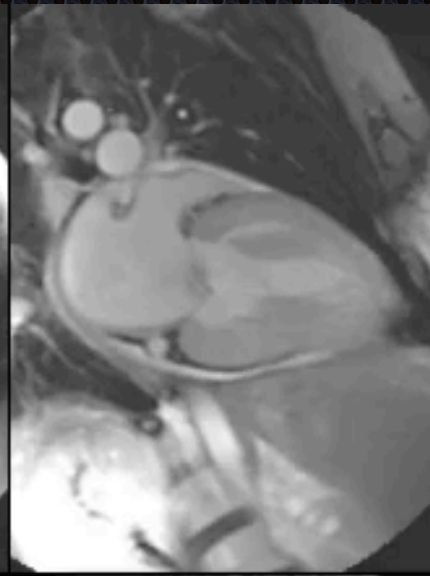
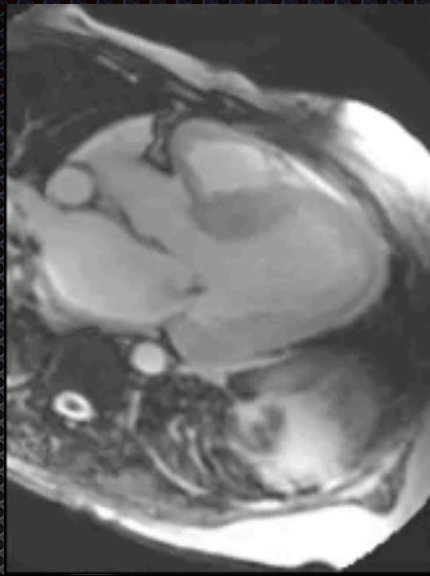
## IV. Depolarization/Conduction Abnormalities

## V. Arrhythmias

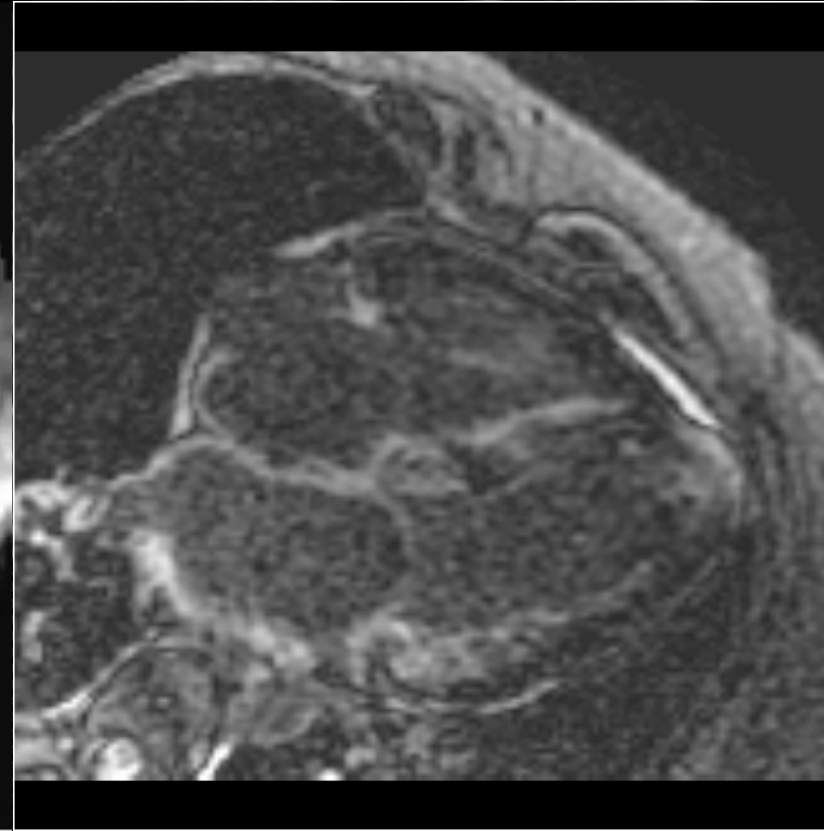
## VI. Family History



# Cardiac Amyloidosis



Normal perfusion



Abnormal MDE



# Cardiac Amyloidosis

Cardiac involvement in primary amyloidosis indicates poor prognosis with 30% mortality within 6 months from onset of heart failure symptoms

Cardiac involvement most commonly results in congestive heart failure and arrhythmias

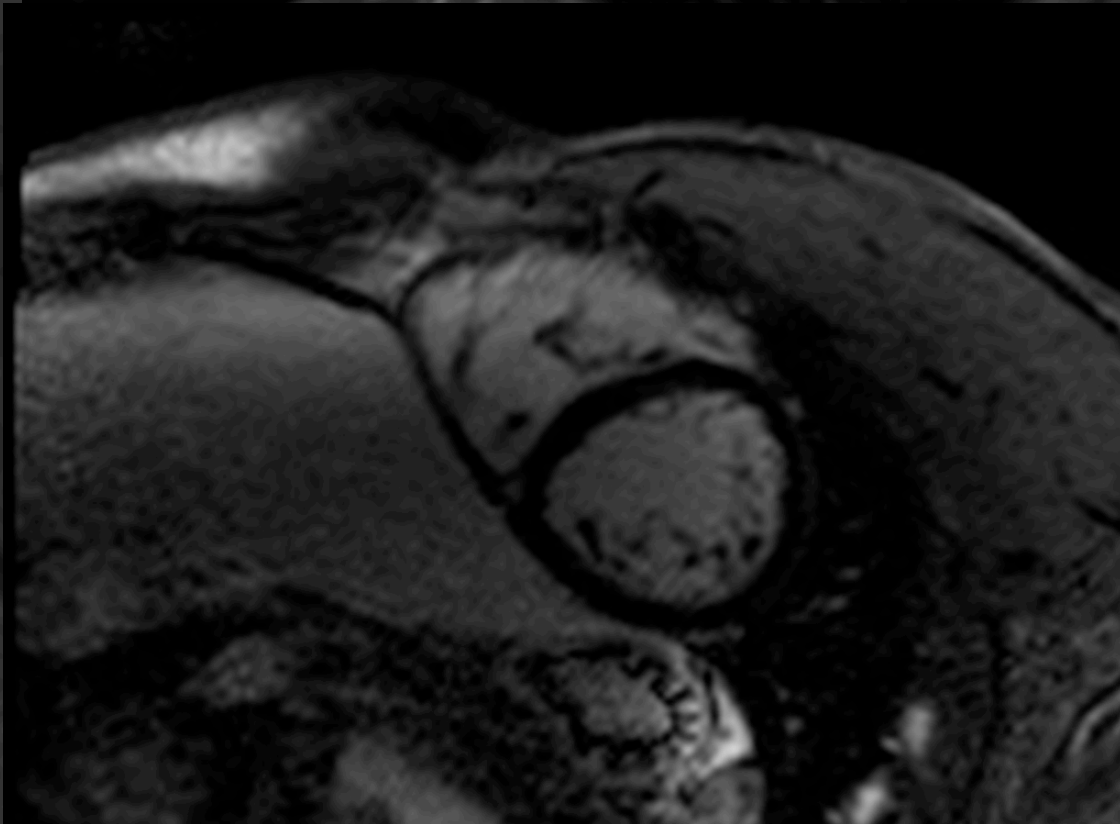
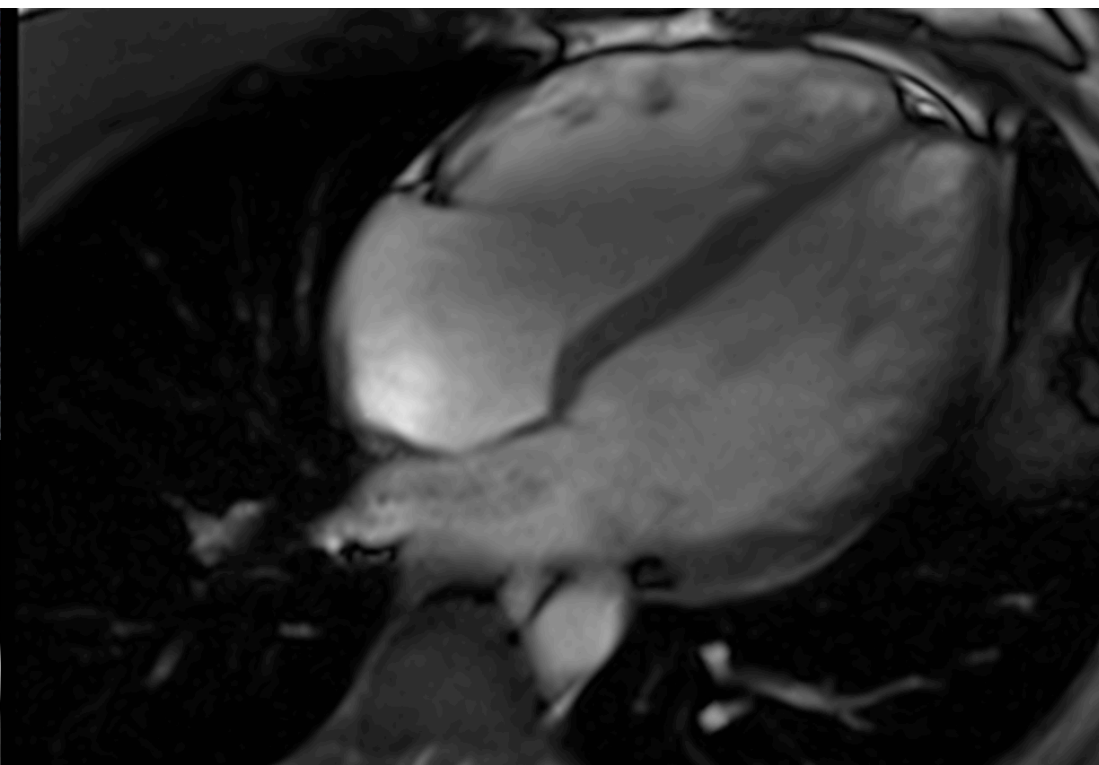
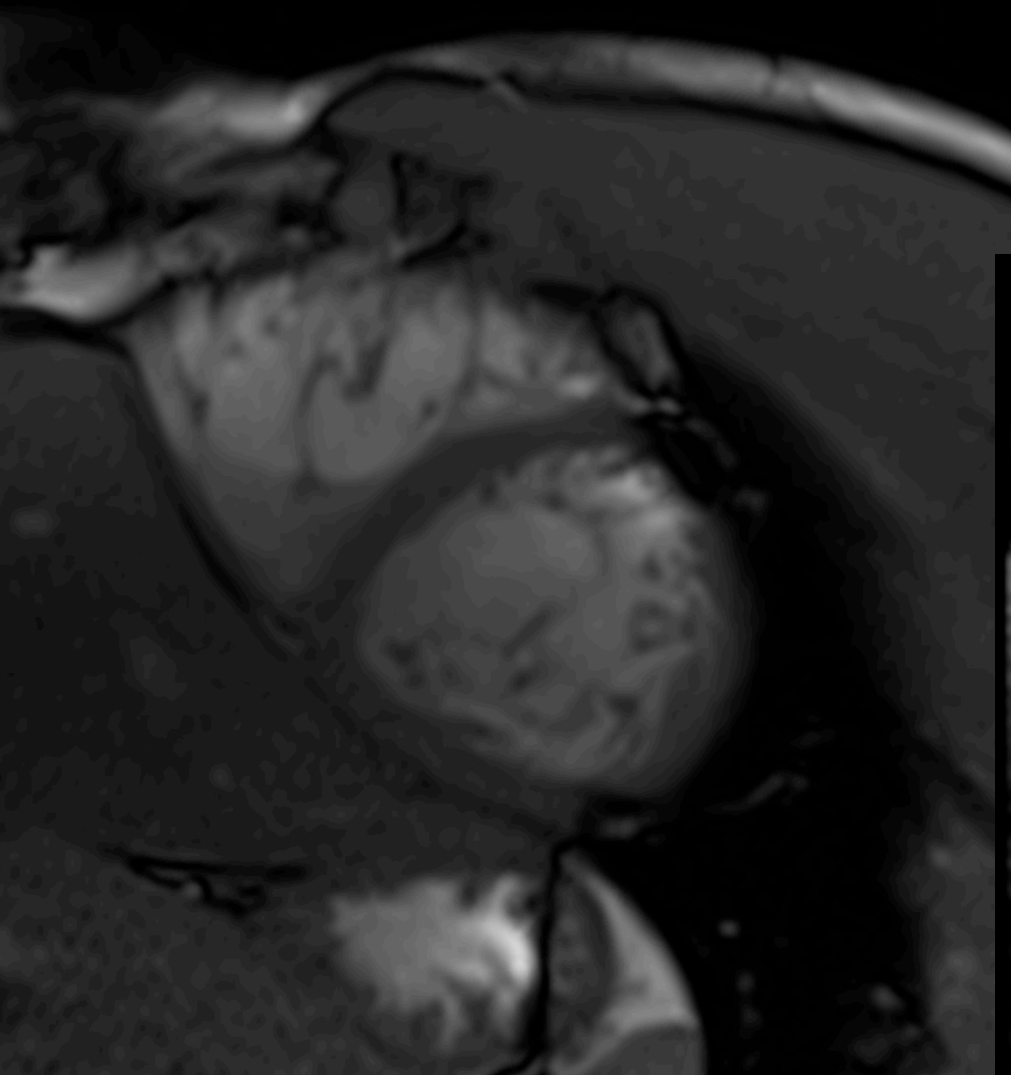
Predominately affects men over the age of 40

Symptoms are nonspecific (fatigue, dyspnea, purpura, macroglossia, atypical chest pain, cardiac arrhythmias, hepatomegaly, peripheral edema, and nephrotic syndrome)

Once MDE identified, median survival time is 6 months

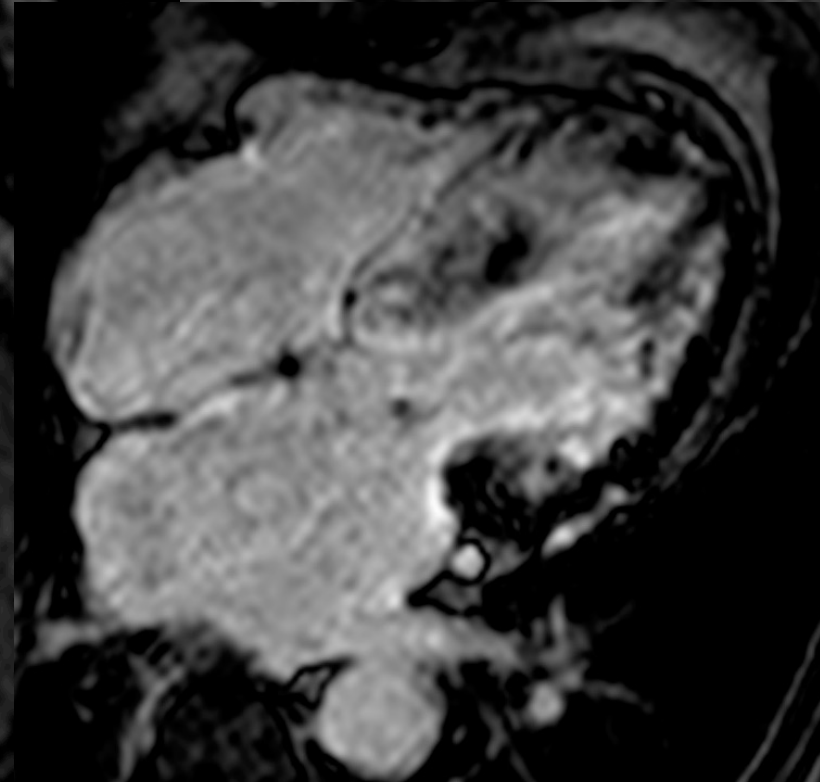
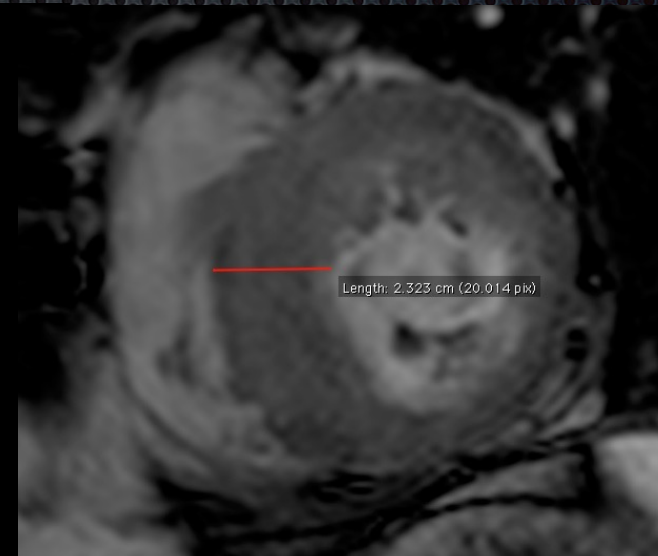
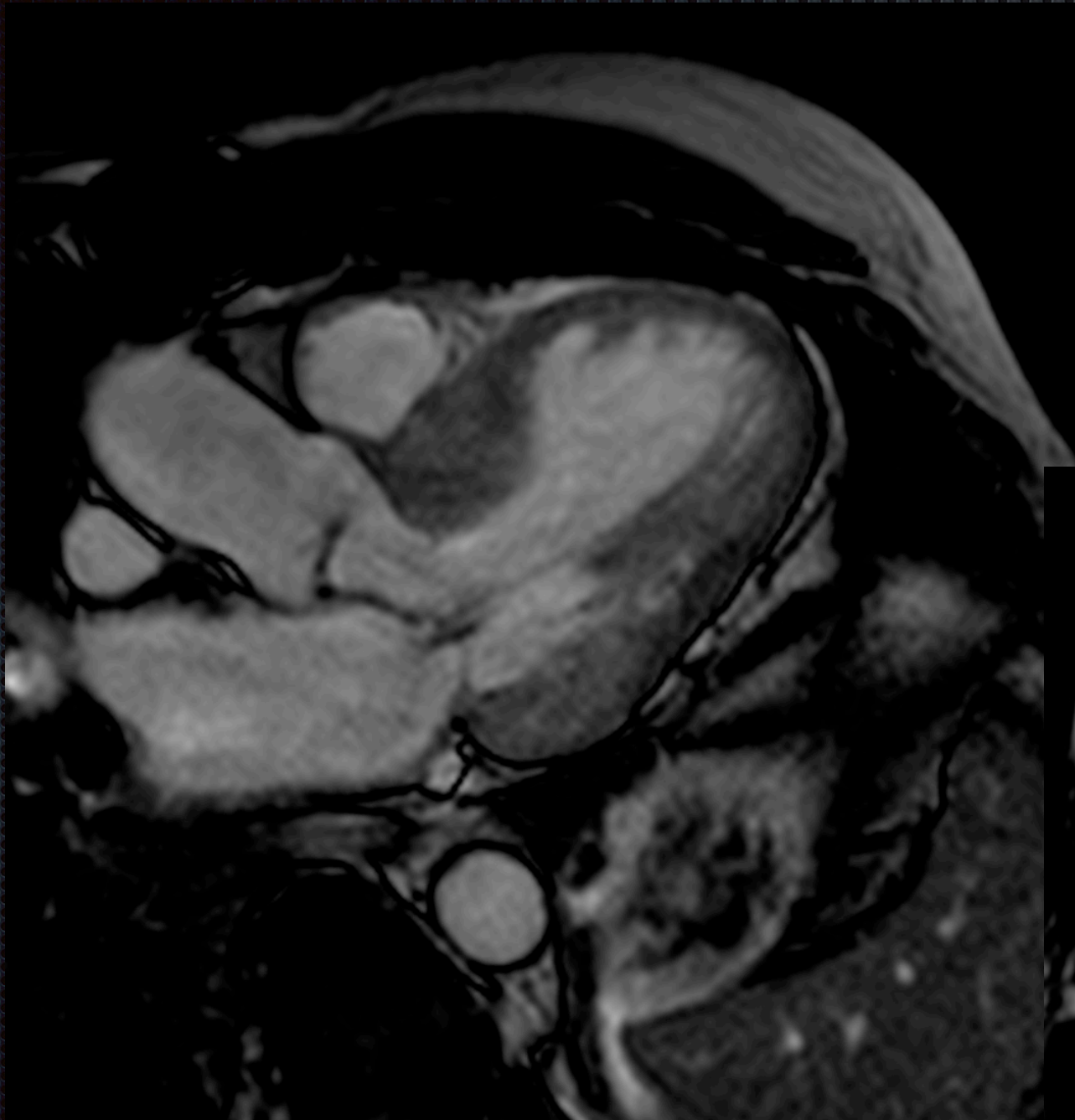


# Noncompaction Cardiomyopathy





# HCM



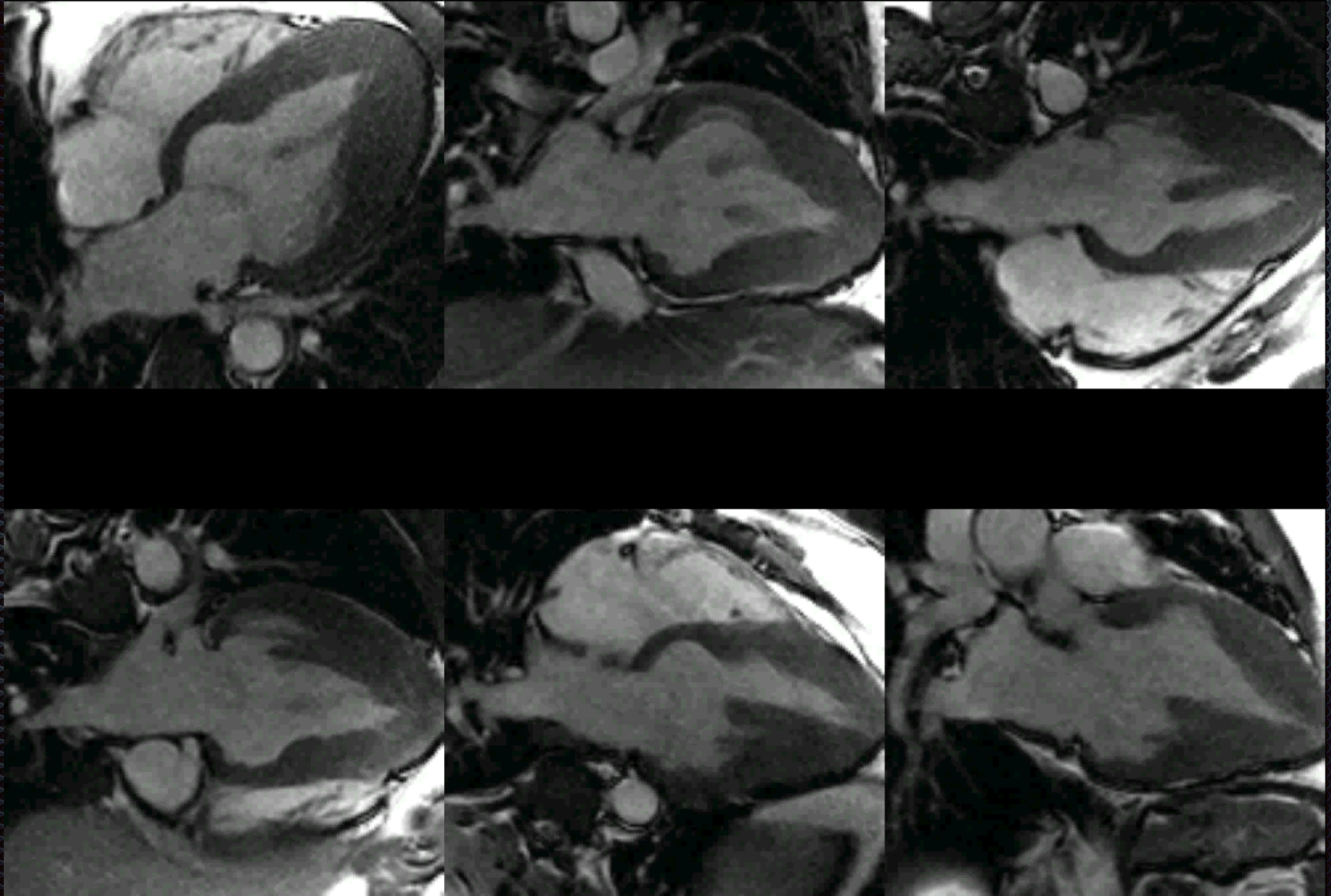


# HCM

- ✦ Myocardial hypertrophy with loss of diastolic function
- ✦ Histology - myofibrillar disarray with patchy areas of necrotic tissue secondary to coronary insufficiency
- ✦ Findings:
  - ✦ Increased LV mass
  - ✦ ESV <10ml
  - ✦ SAM with or without LVOT obstruction
  - ✦ Patchy mid-wall MDE



# Apical HCM





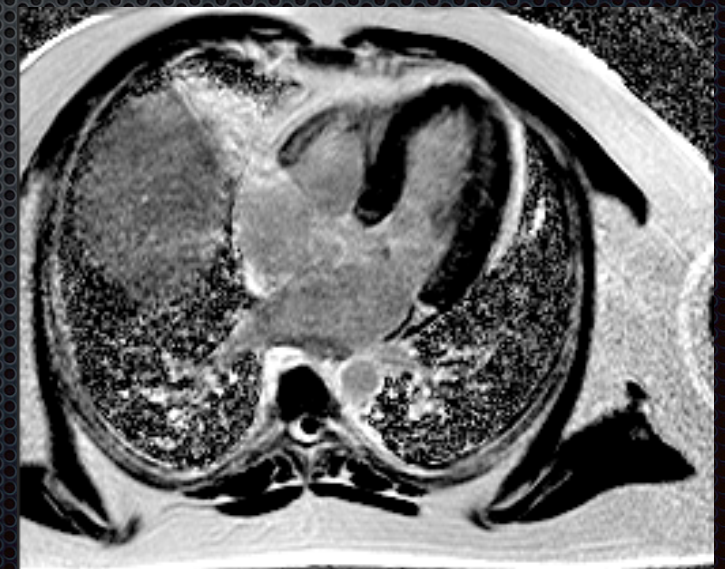
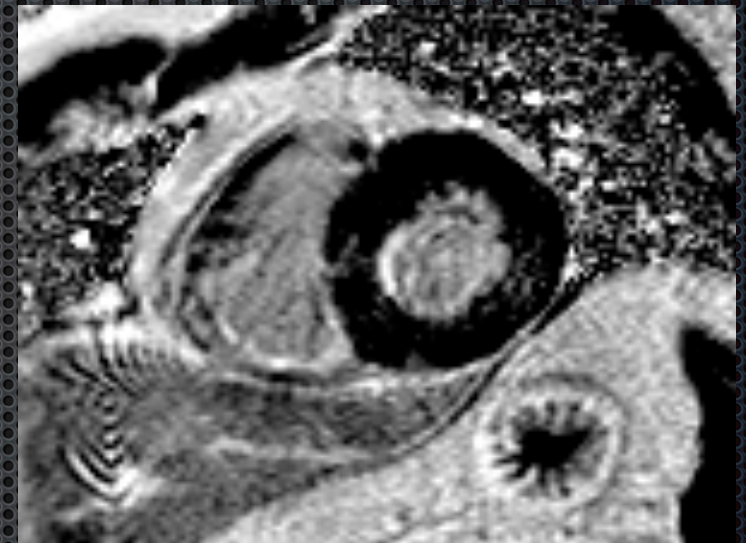
# CMR Role in HCM

- ✦ Accurate measurements of LV wall thickness
- ✦ Patients who have increased risk factors for sudden cardiac death have increased MDE
- ✦ The greater MDE indicated poorer LV function
- ✦ CMR can be used to follow up ventricular remodeling response to treatment with alcohol septal ablation (van Dookum, *Circulation* 2005)



# Sarcoidosis

- ✦ 7% of patients with systemic sarcoid have cardiac involvement
- ✦ MDE was the only independent predictor of adverse events including cardiac death (White ES, *Expert Opin Pharmacother* 2007)
- ✦ CMR allows earlier detection, shorter clinical course, and limits cardiac involvement (Smedema, *JACC* 2005)
- ✦ CMR can be used to monitor response to treatment





# Iron Overload Cardiomyopathy

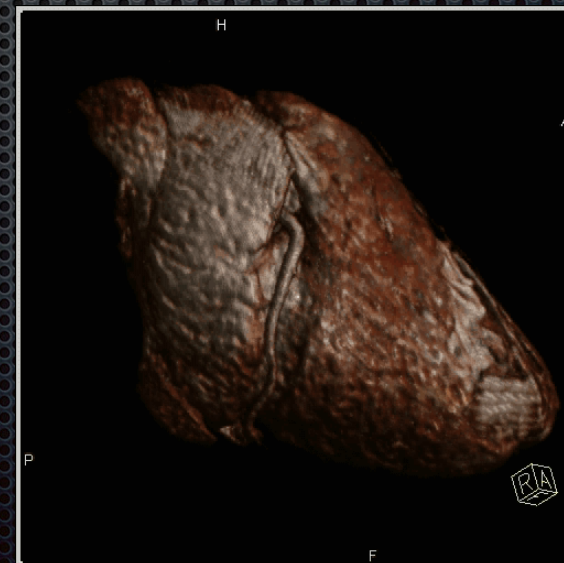
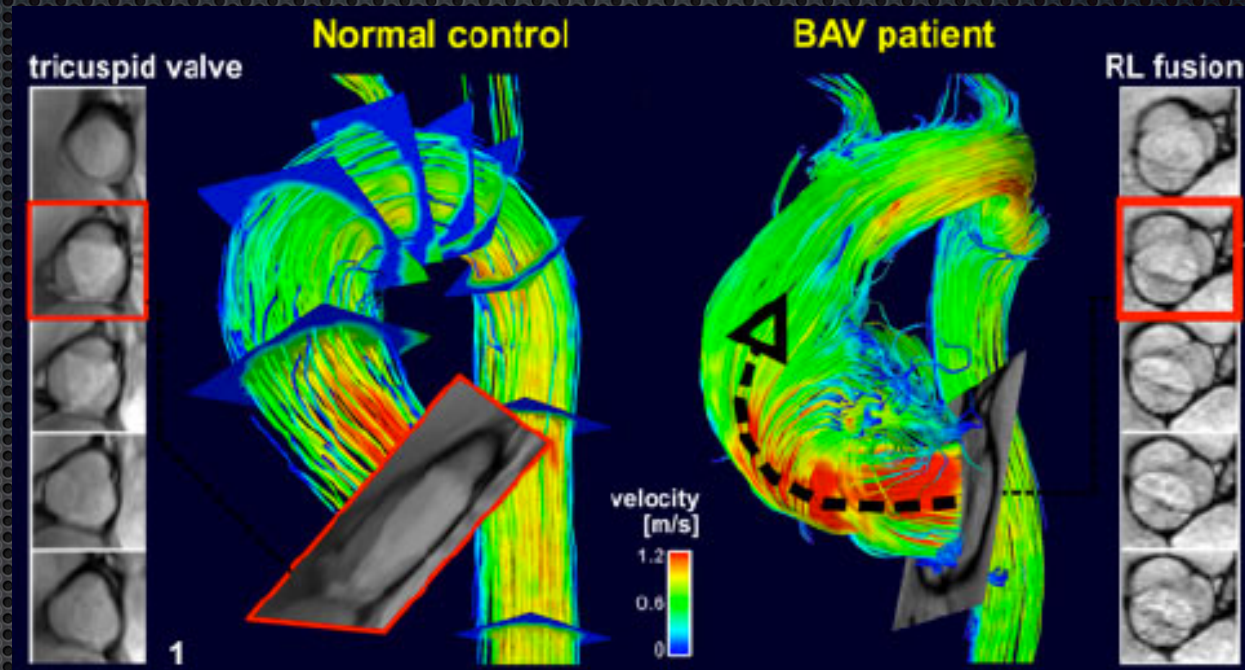
- T2\* relaxation times in CMR are inversely related to the amount of iron deposition in the heart
- Shorter T2\* times correspond with worsening LV dysfunction and heart failure
- CMR can monitor effect of chelation therapy





# Advancements in Cardiac MRI

- ✦ Decrease scan time
- ✦ User friendly
- ✦ Single breath hold cine SSFP
- ✦ Time resolved phase contrast (4D flow)
- ✦ Coronary MRA





# Summary

We reviewed:

CTA:

- protocols
- indications
- prognostic value of negative and positive coronary CTA

MRI:

- advantages / disadvantages
- protocols
- prognostic value of MDE and findings in ischemic and non-ischemic cardiomyopathy



# Summary

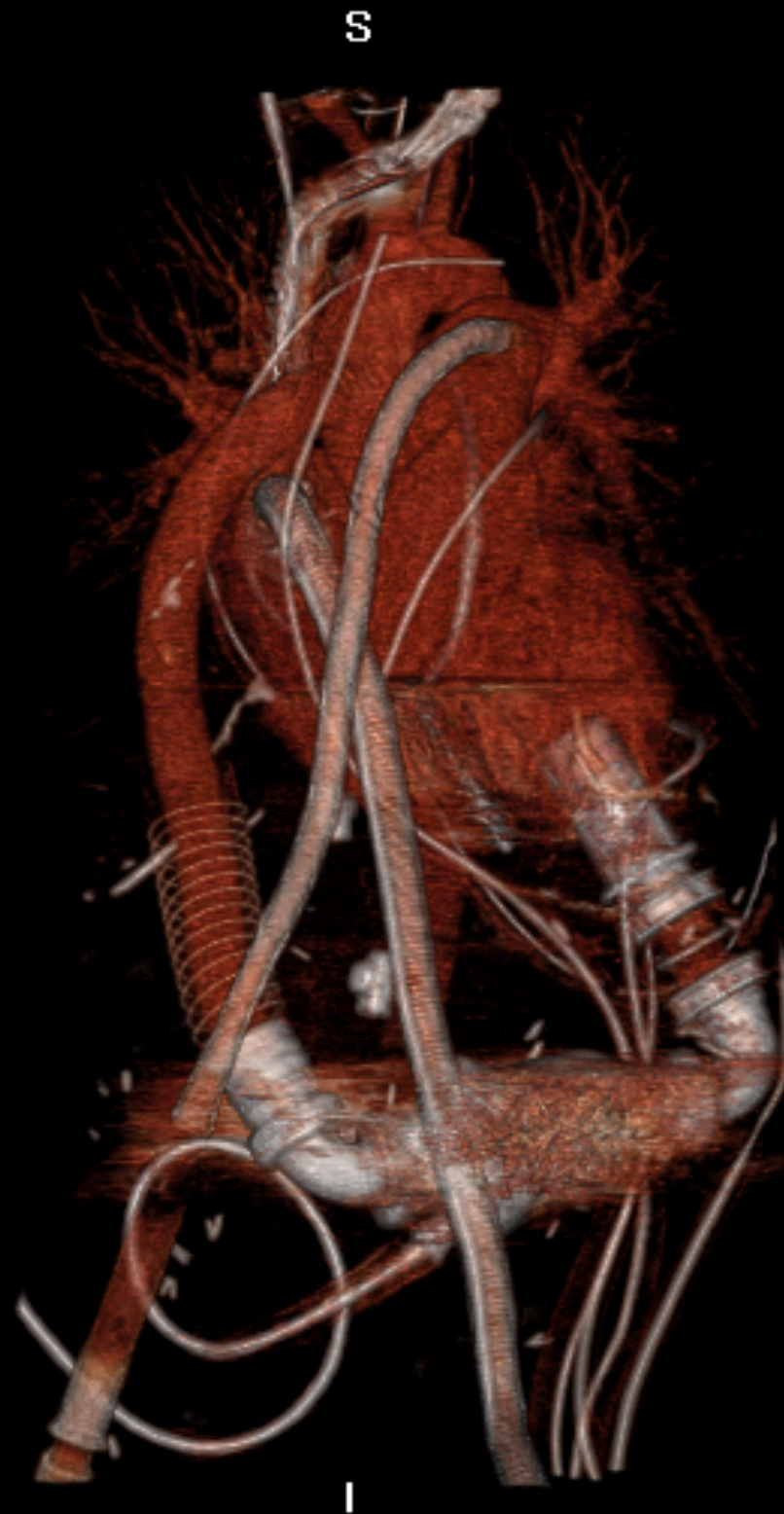
- Calcium score CT is a low cost, non-invasive test to reliably predict cardiovascular outcomes
- Cardiac CT has become a strong tool in the anatomic evaluation of the heart and coronary arteries in a subset of patients
- Cardiac MRI provides high spatial and temporal resolution images to assess cardiac anatomy, ischemic and non-ischemic cardiomyopathies, and valvular disease.



# Thank you!

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