CARDIAC CT AND MRI: STATE OF THE ART

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INTRODUCTION

- Cardiac MRI and CT were first introduced in the 1980's although cardiac CT only became widely used after 2000
- They serve as complementary techniques to other cardiac imaging including nuclear imaging and echocardiography

OBJECTIVES

- CARDIAC CT – THE BASICS
- CARDIAC CT – MAJOR INDICATIONS
- CARDIAC MRI – THE BASICS
- CARDIAC MRI – MAJOR INDICATIONS

CARDIAC CT ANGIOGRAPHY
PROS AND CONS

Advantages

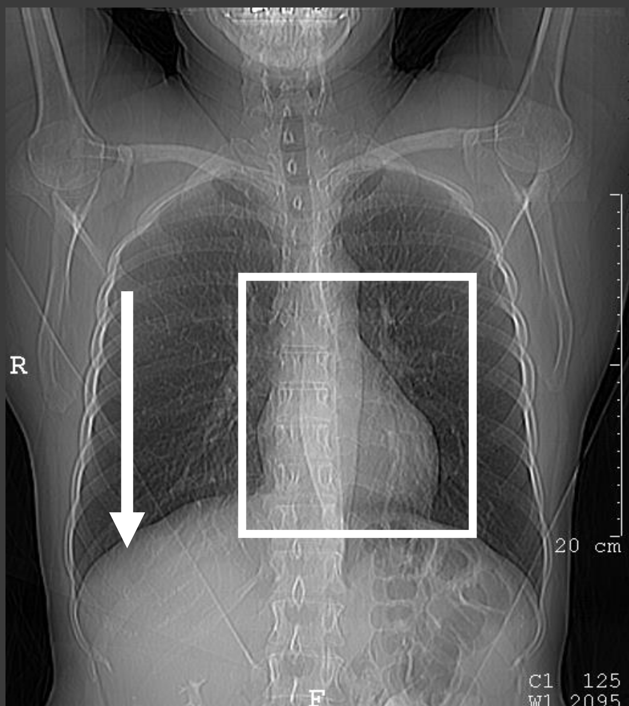
- Wide field-of-view
- Superb anatomic detail
- Some functional information

Limitations

- Ionizing radiation
- Iodinated contrast
- Some functional limitations (cannot directly measure gradients)

CORONARY CTA PROTOCOL

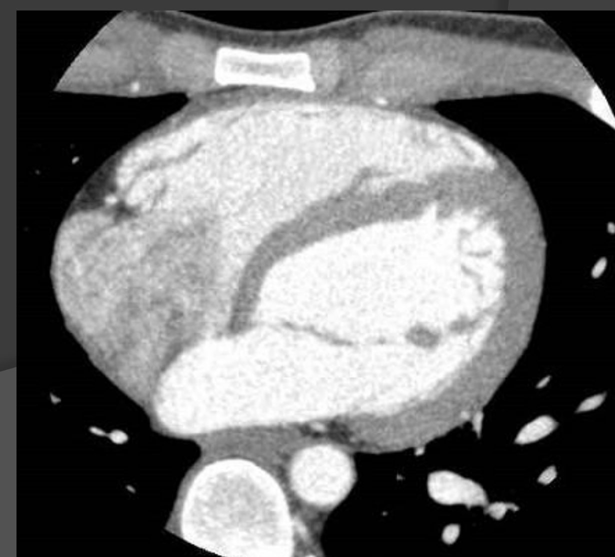
COR CTA



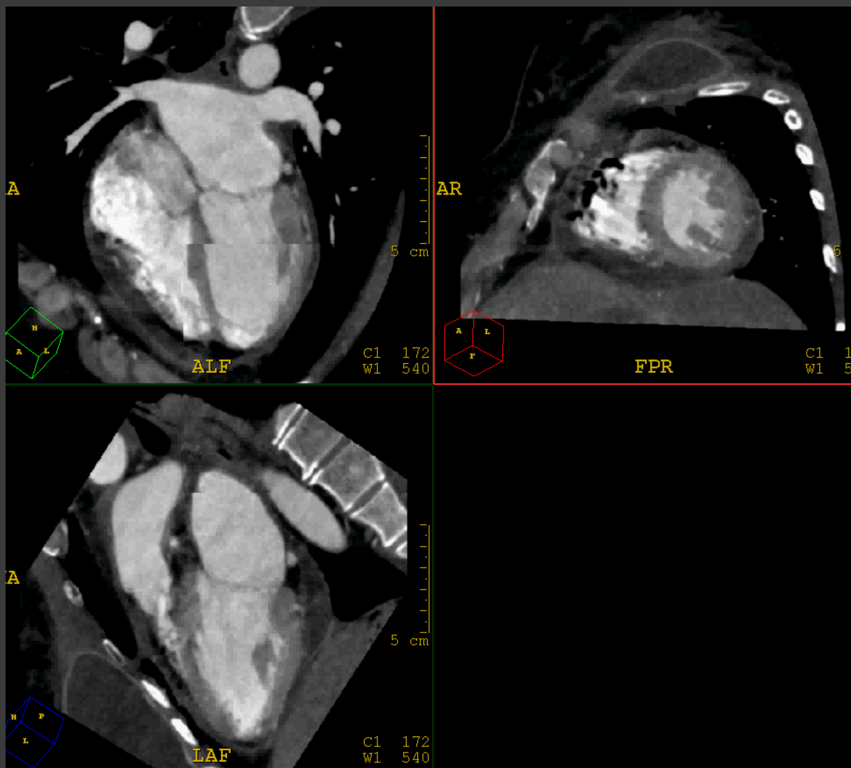
Recon cardiac phase(s)

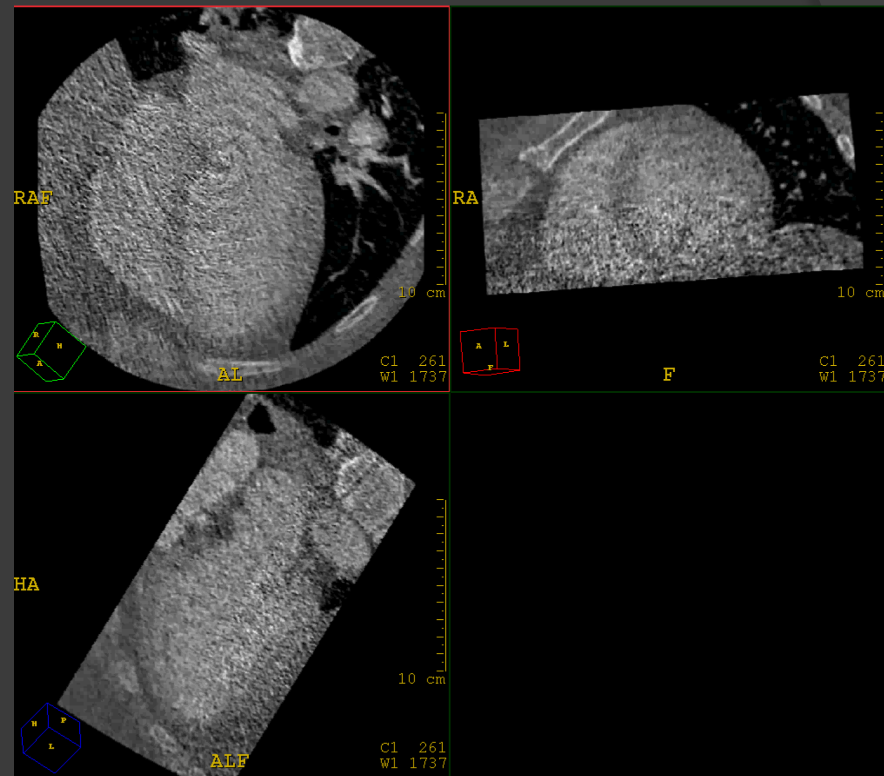
Coronary CTA contrast protocol

- Test injection (IV check)
  - 20 ml (saline) @ 6 cc/sec
- Injection protocol (3 phase)
  - 70 ml (100%) @ 6 cc/sec
  - 30 ml (50/50) @ 5 cc/sec
  - 50 ml (saline) @ 5 cc/sec
- Bolus tracking

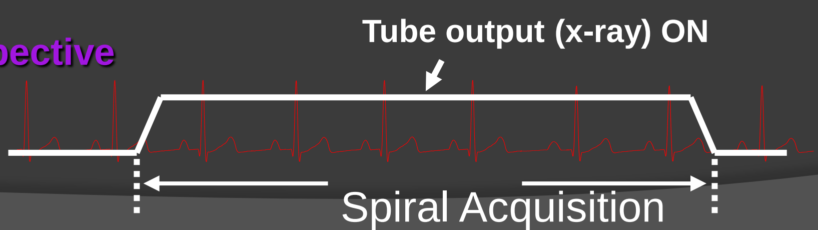


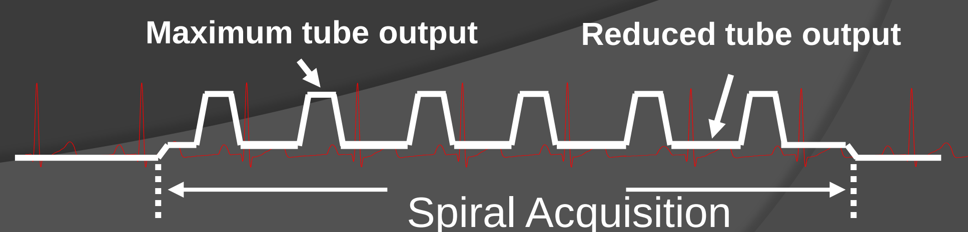
LV WALL MOTION ASSESSMENT



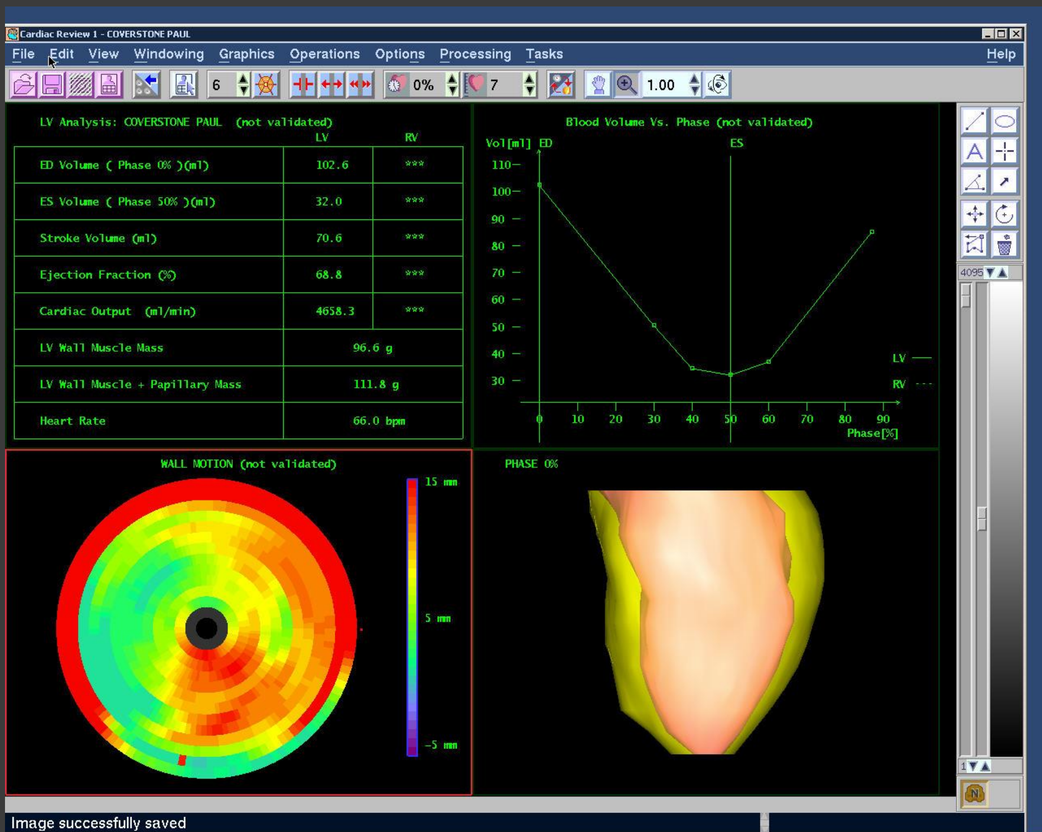


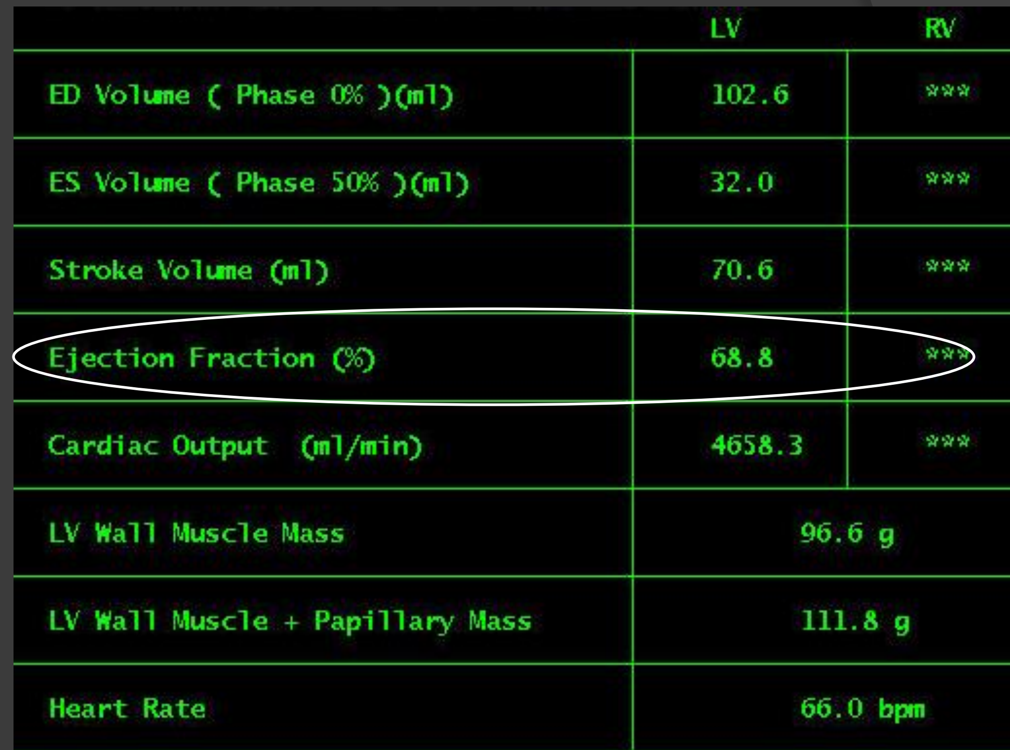
Retrospective ECG Gating





LV FUNCTIONAL ASSESSMENT



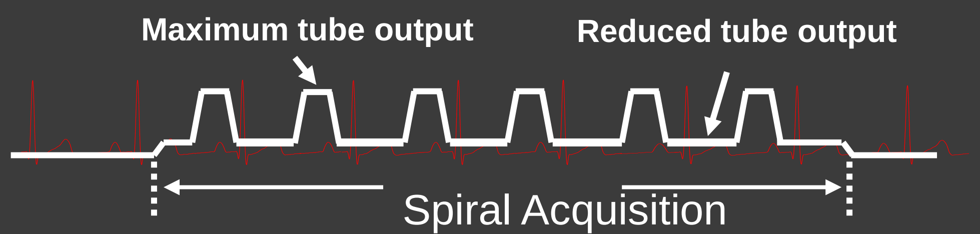


	LV	RV
ED Volume (Phase 0%)(ml)	102.6	***
ES Volume (Phase 50%)(ml)	32.0	***
Stroke Volume (ml)	70.6	***
Ejection Fraction (%)	68.8	***
Cardiac Output (ml/min)	4658.3	***
LV Wall Muscle Mass	96.6 g	
LV Wall Muscle + Papillary Mass	111.8 g	
Heart Rate	66.0 bpm	

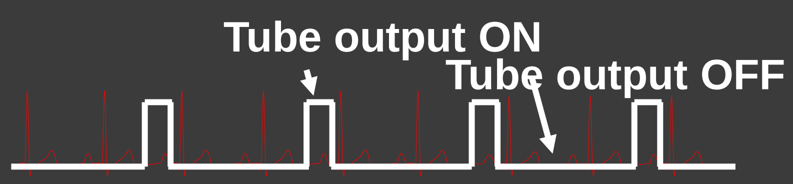
Strong correlation between CT and MRI LV function (r> 0.95)

Yamamuro Radiology 2005

RETROSPECTIVE VS PROSPECTIVE GATING



Retrospective-gating with dose modulation



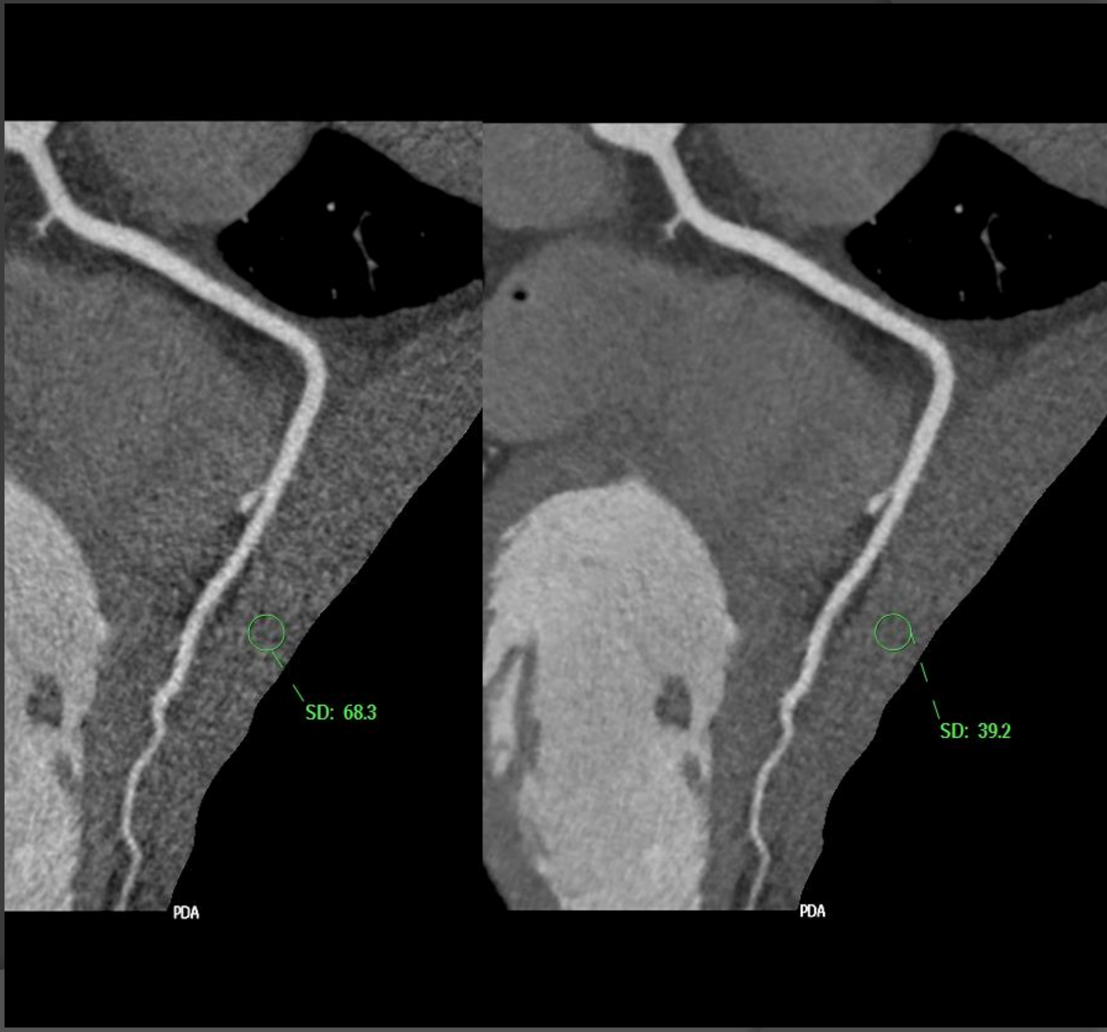
Prospectively-gated Step & Shoot scan

Prospective gating

- Around 80% lower radiation
- No functional analysis
- Not always suitable
  - Certain arrhythmias
  - Higher heart rates >70
  - Large pts

RADIATION SPARING
ITERATIVE RECONSTRUCTION ALGORITHM

- Computationally intense
- Better modeling of geometry
- Two options
  - Save on dose
  - Maximize image quality



CARDIAC RADIATION DOSES

	Dose (mSv)
Background - Yearly	3.6
Sesta/Thal – rest/stress	1.5-5/6-25
Cardiac Cath	3-15
Chest CT (conventional)	5
Gated Coronary CTA (CCTA)	10-15
Gated CCTA – dose modulated	6-9
Gated CCTA - prospective axial	3-4
Gated CCTA – prospective/IR	2-3
Gated CCTA- prospective helical/IR/low kVp	<1

OBJECTIVES

- CARDIAC CT – THE BASICS
- CARDIAC CT – MAJOR INDICATIONS
- CARDIAC MRI – THE BASICS
- CARDIAC MRI – MAJOR INDICATIONS

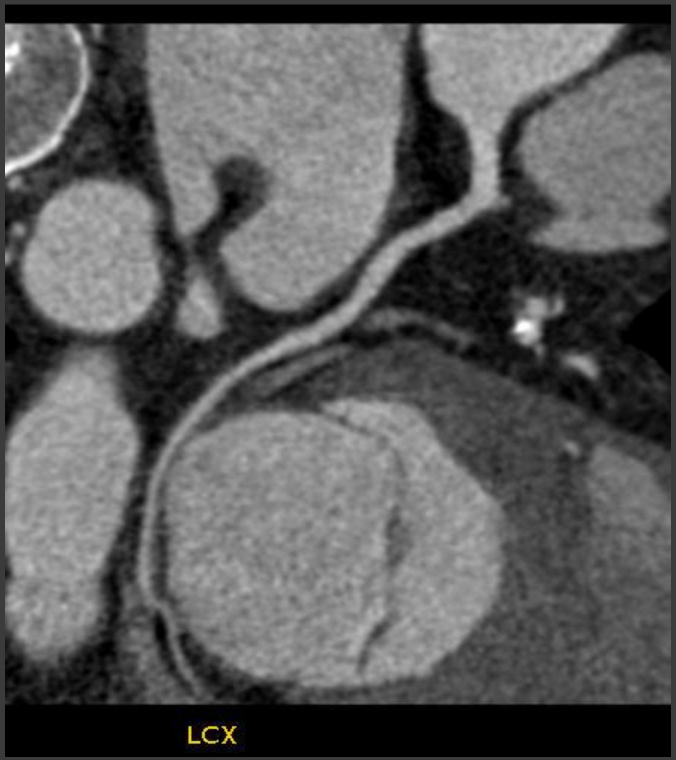
#1 OBSTRUCTIVE CORONARY DISEASE

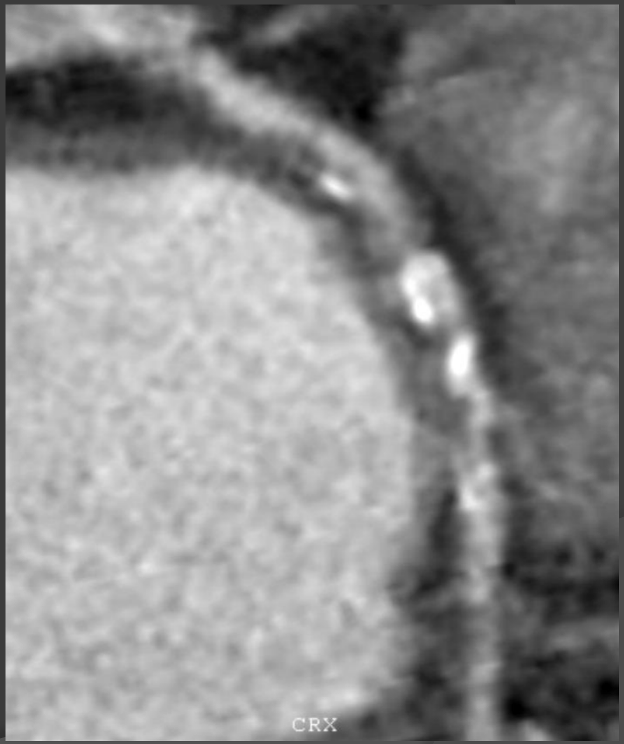
- Best is low-intermediate risk symptomatic pt.
- Stenosis >70% is significant; >50% in L main
- Can assess plaque characteristics
  - Vulnerable plaque
- Supplement with flow dynamics
  - eg, CT fractional flow reserve (FFR)

www.lmp.facmed.utoronto.ca

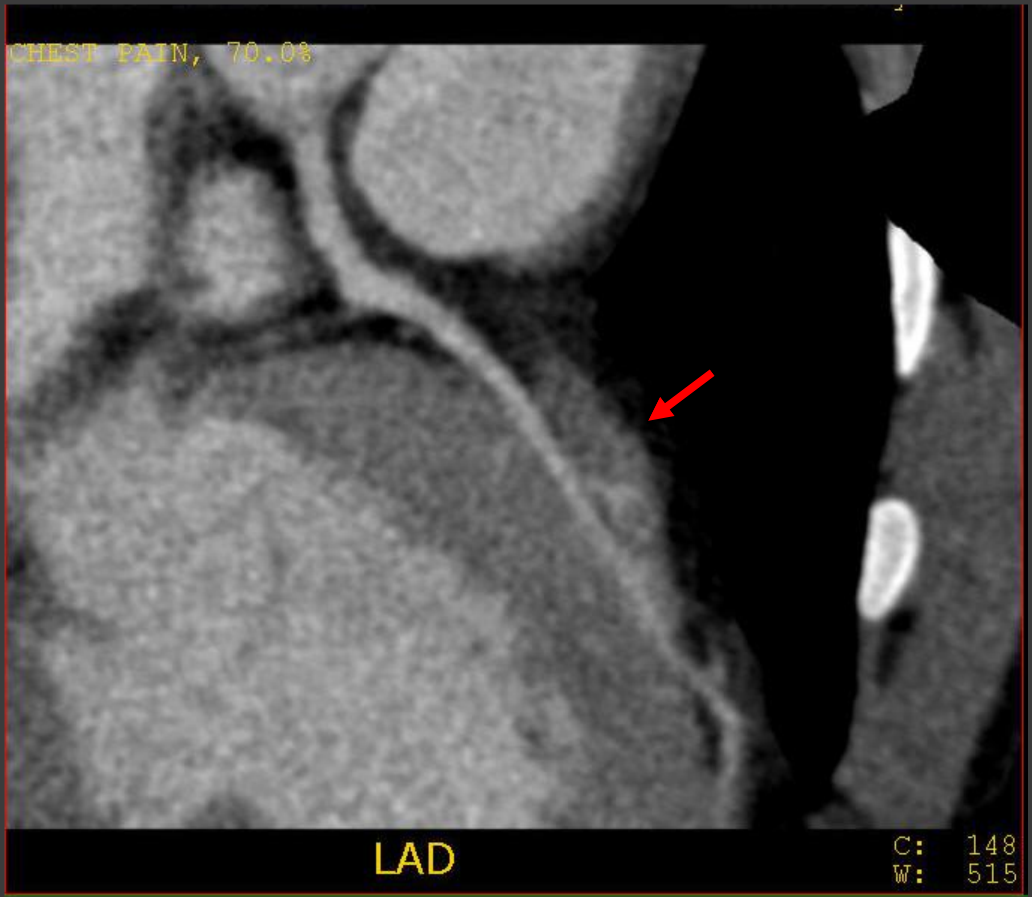
OBSTRUCTIVE CORONARY DISEASE

OBSTRUCTIVE CORONARY DISEASE





OBSTRUCTIVE CORONARY DISEASE



Myocardial bridge

OBSTRUCTIVE CORONARY DISEASE LITERATURE (CCTA VS CATH)

	N	Sensitivity	Specificity	PPV	NPV	Comment
CorE64 JACC 2008	291	85	90	91	83	Stable CP Prevalence 56%
ACCURACY JACC 2008	230	94	83	48	99	Stable CP Prevalence 13%
Meijboom JACC 2009	360	99	64	85	97	Acute/stable CP Prevalence 68%

OBSTRUCTIVE CORONARY DISEASE VULNERABLE PLAQUE

Multislice Computed Tomographic Characteristics of Coronary Lesions in Acute Coronary Syndromes

Sadako Motoyama, MD, PhD,[*] Takeshi Kondo, MD, PhD,[†] Masayoshi Sarai, MD, PhD,[*] Atsushi Sugiura, MD, PhD,[*] Hiroto Harigaya, MD,[*] Takahisa Sato, MD, PhD,[*] Kaori Inoue, MD,[*] Masanori Okumura, MD,[*] Junichi Ishii, MD, PhD,[*] Hirofumi Anno, MD, PhD,[‡] Renu Virmani, MD, FACC,[§] Yukio Ozaki, MD, PhD,[*] Hitoshi Hishida, MD, PhD,[*] Jagat Narula, MD, PhD, FACC[¶]

Toyoake and Takasaki, Japan; Gaithersburg, Maryland; and Irvine, California

"The CT characteristics of plaques associated with ACS include **positive vascular remodeling, low plaque density, and spotty calcification**. It is logical to presume that plaques vulnerable to rupture harbor similar characteristics.."

JACC 2007;50:319

OBSTRUCTIVE CORONARY DISEASE
CT FRACTIONAL FLOW RESERVE

One weakness of CT has been difficulty in getting flow information from CT angiography

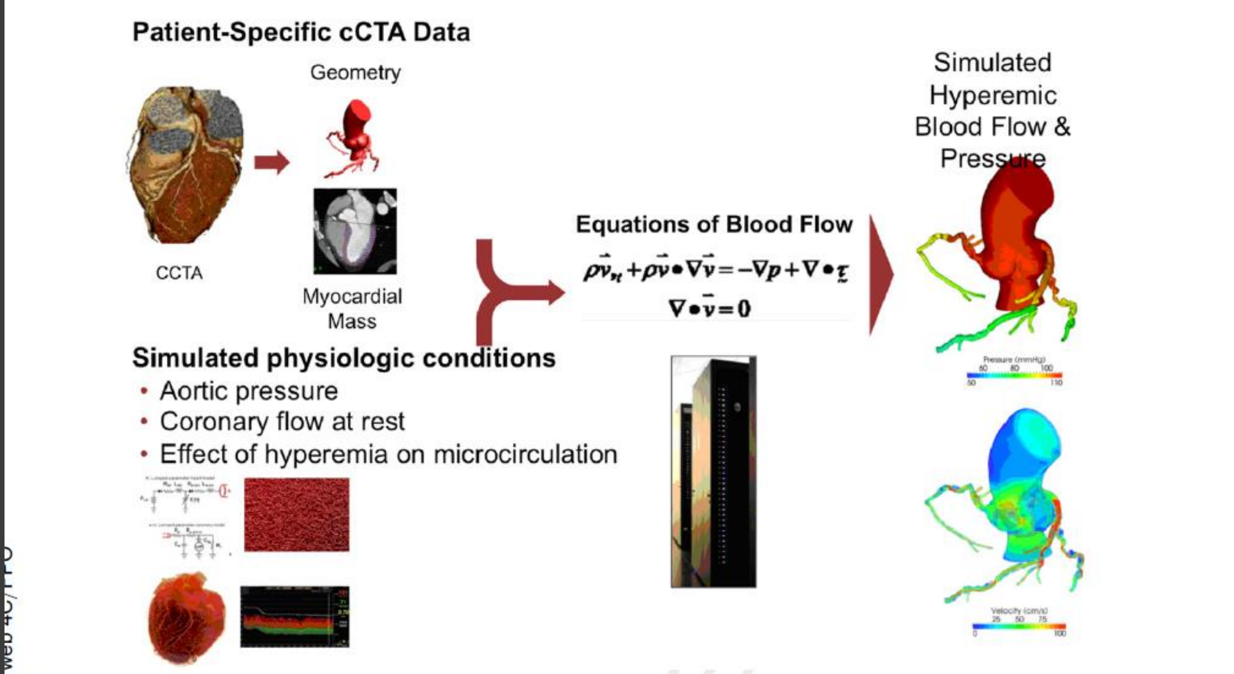
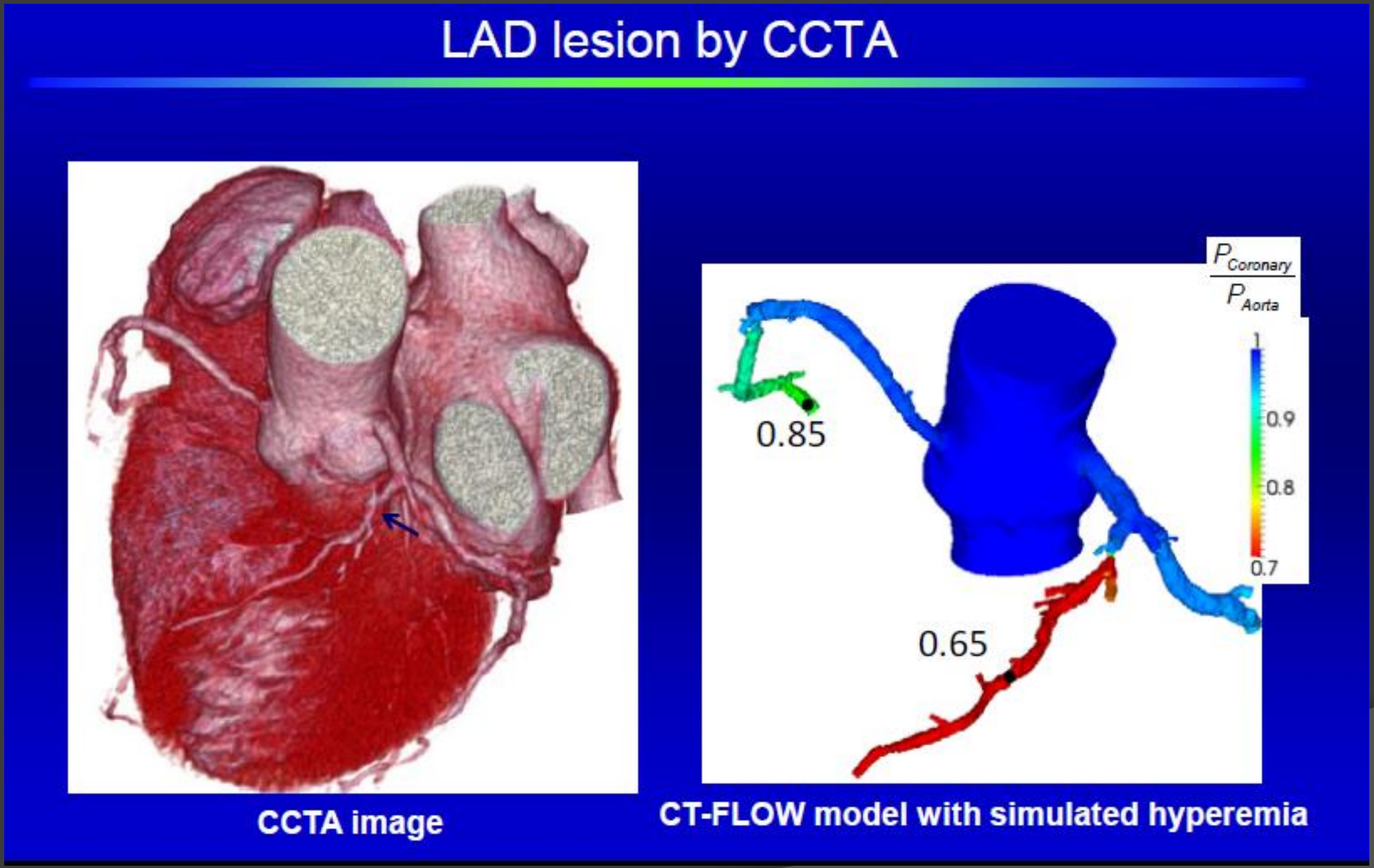


Figure 1 Simplified schematic of computation fluid dynamic techniques applied to CTA data for simulation of hyperemic coronary artery flow and pressure.

FRACTIONAL FLOW RESERVE = pressure difference across coronary stenosis (usually measured during cath)

Courtesy: Heartflow.com

OBSTRUCTIVE CORONARY DISEASE FRACTIONAL FLOW RESERVE



Courtesy: Heartflow.com

OBSTRUCTIVE CORONARY DISEASE FRACTIONAL FLOW RESERVE

N=252 DeFACTO study

Table 4. Per-Patient Diagnostic Performance of $FFR_{CT} \leq 0.80$ and CT $\geq 50\%$ vs FFR ≤ 0.80 in the Intention-to-Diagnose Sample

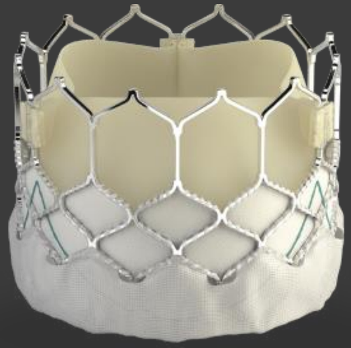
	$FFR_{CT} \leq 0.80$		CT $\geq 50\%$	
	Estimate, % (95% CI)	No. of Patients in Group	Estimate, % (95% CI)	No. of Patients in Group
Accuracy	73 (67-78)	252	64 (58-70)	252
Sensitivity	90 (84-95)	129	84 (77-90)	129
Specificity	54 (46-83)	123	42 (34-51)	123
PPV	67 (60-74)	172	61 (53-67)	180
NPV	84 (74-90)	80	72 (61-81)	72

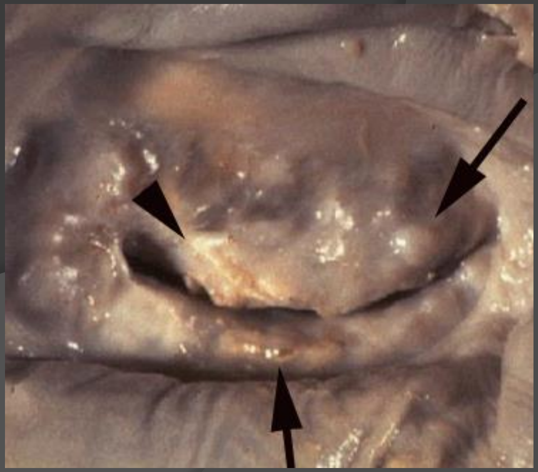
Abbreviations: CT, computed tomographic angiography; FFR_{CT}, fractional flow reserve calculated from CT; NPV, negative predictive value; PPV, positive predictive value.

Min JAMA 2012;308:1237

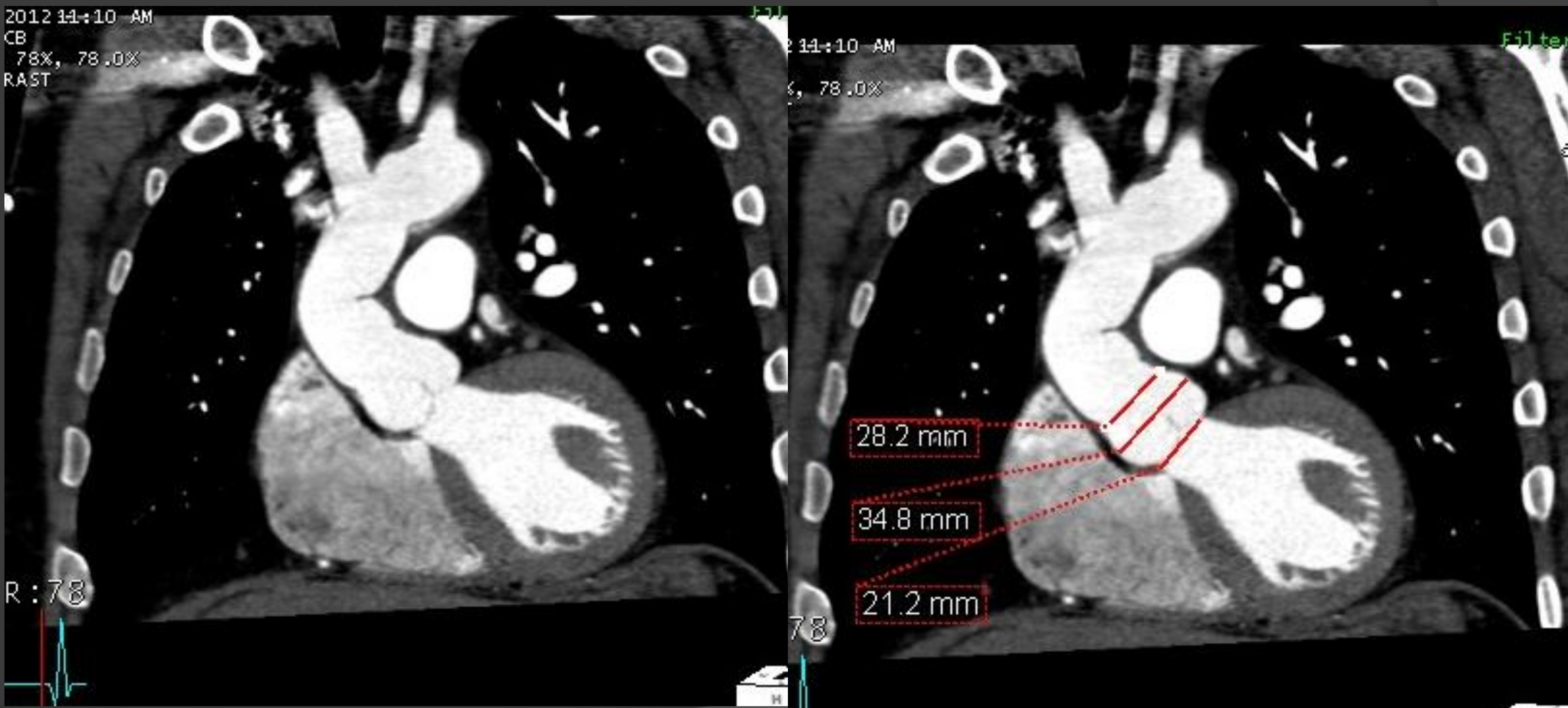
#2 PRE-PROCEDURE CARDIAC VALVES

- Used prior to transcatheter aortic valve replacement (TAVR)
- Assess size/shape of annulus
- Distance from annulus to coronary orifices
- Also useful for other valves



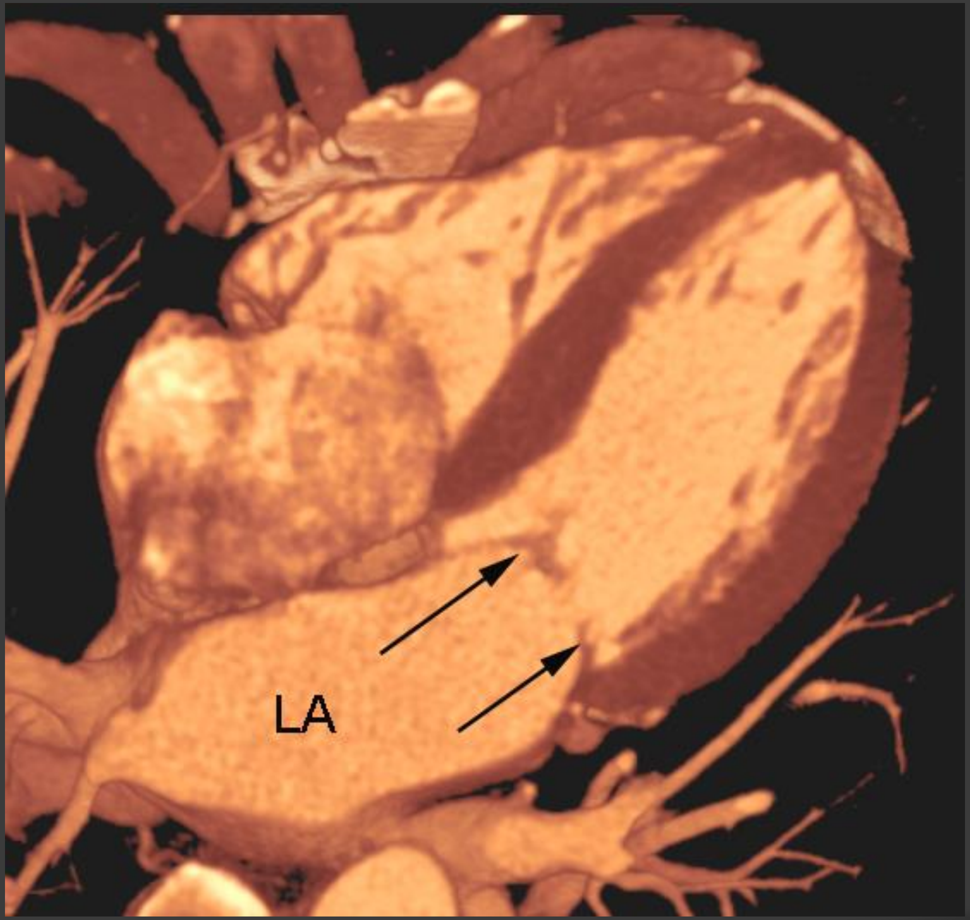


TAVI REFORMATS



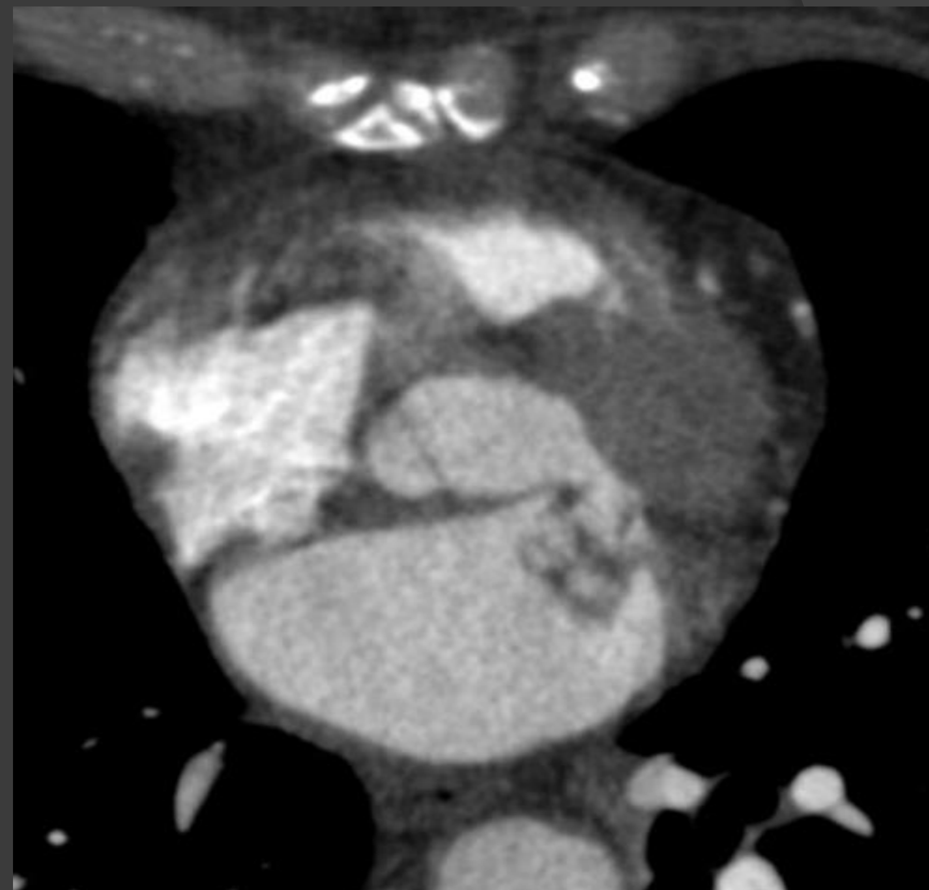
TRANSCATHETER AORTIC VALVE IMPLANTATION (TAVI OR TAVR)

MITRAL VALVE ASSESSMENT



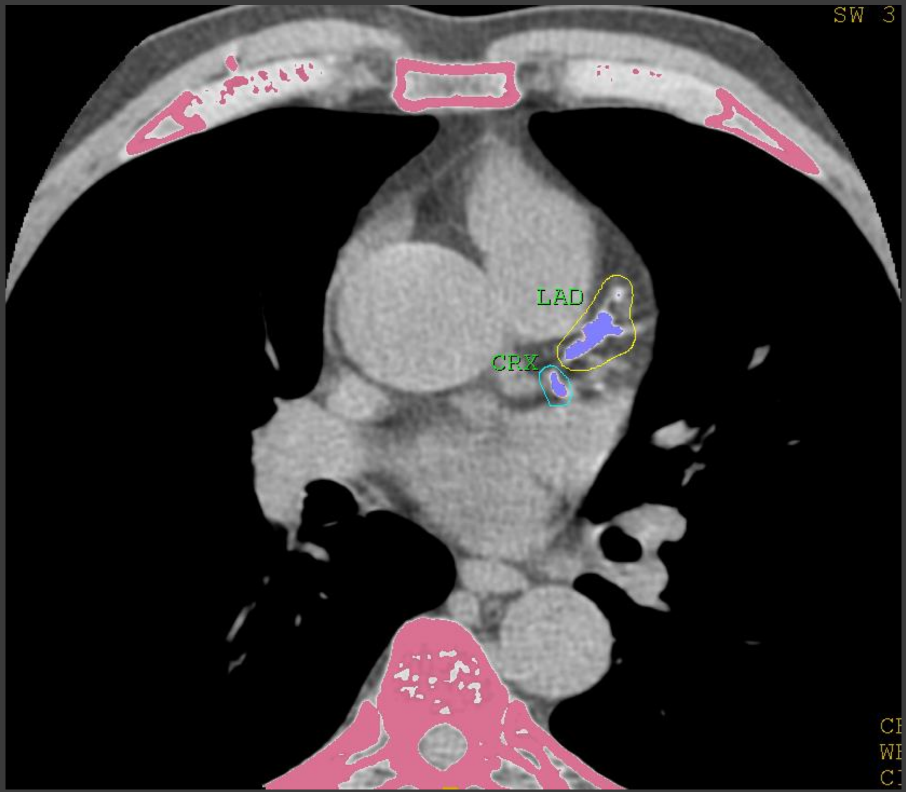
Chen RadioGraphics 2009;29:1393

MITRAL VALVE

MV vegetation

#3 CALCIUM SCORING



Threshold =130HU

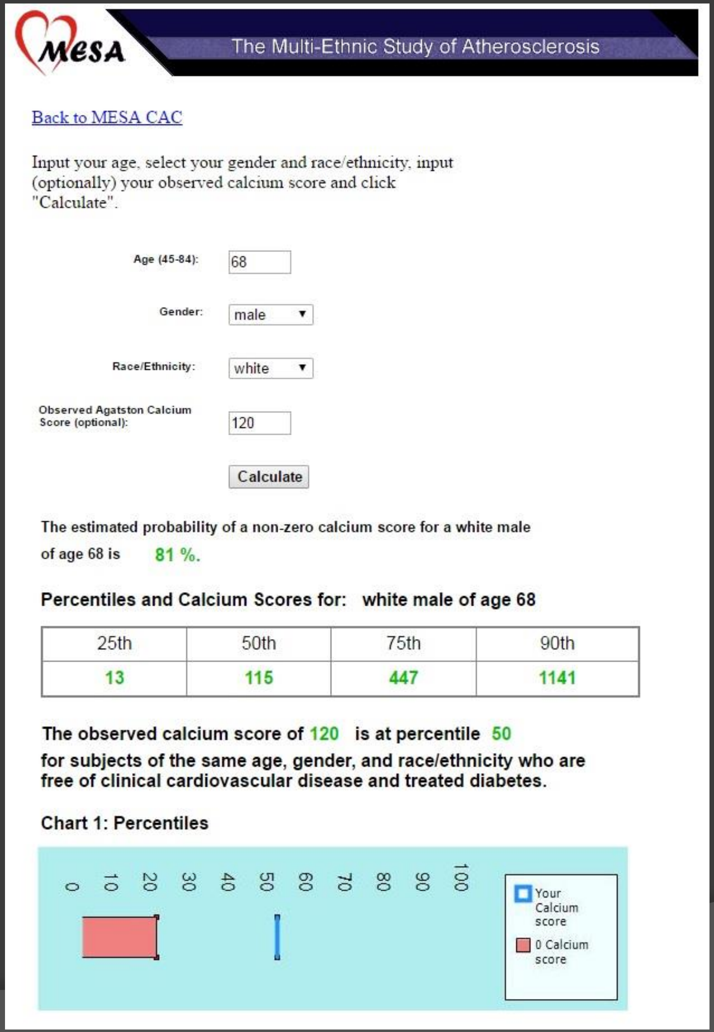
91463 - 0   Z 1.0

Calcium Analysis Results

Organ	Number of ROIs	Mass (mg)	Mass CDI	Area (sq.mm)	Score	Score CDI
L.MAIN	0	0.0		0.0	0.0	
LAD	5	108.5	21.7	145.0	543.4	108.7
CRX	2	4.2	2.1	8.6	21.5	10.7
RCA	0	0.0		0.0	0.0	
PDA	1	0.3	0.3	1.0	1.0	1.0
Total	8	113.0	14.1	154.5	565.8	70.7

Agatston score

CALCIUM CT SCORES RISK STRATIFICATION



MESA

The Multi-Ethnic Study of Atherosclerosis

Back to MESA CAC

Input your age, select your gender and race/ethnicity, input (optionally) your observed calcium score and click "Calculate".

Age (45-84): 68

Gender: male

Race/Ethnicity: white

Observed Agatston Calcium Score (optional): 120

Calculate

The estimated probability of a non-zero calcium score for a white male of age 68 is 81 %.

Percentiles and Calcium Scores for: white male of age 68

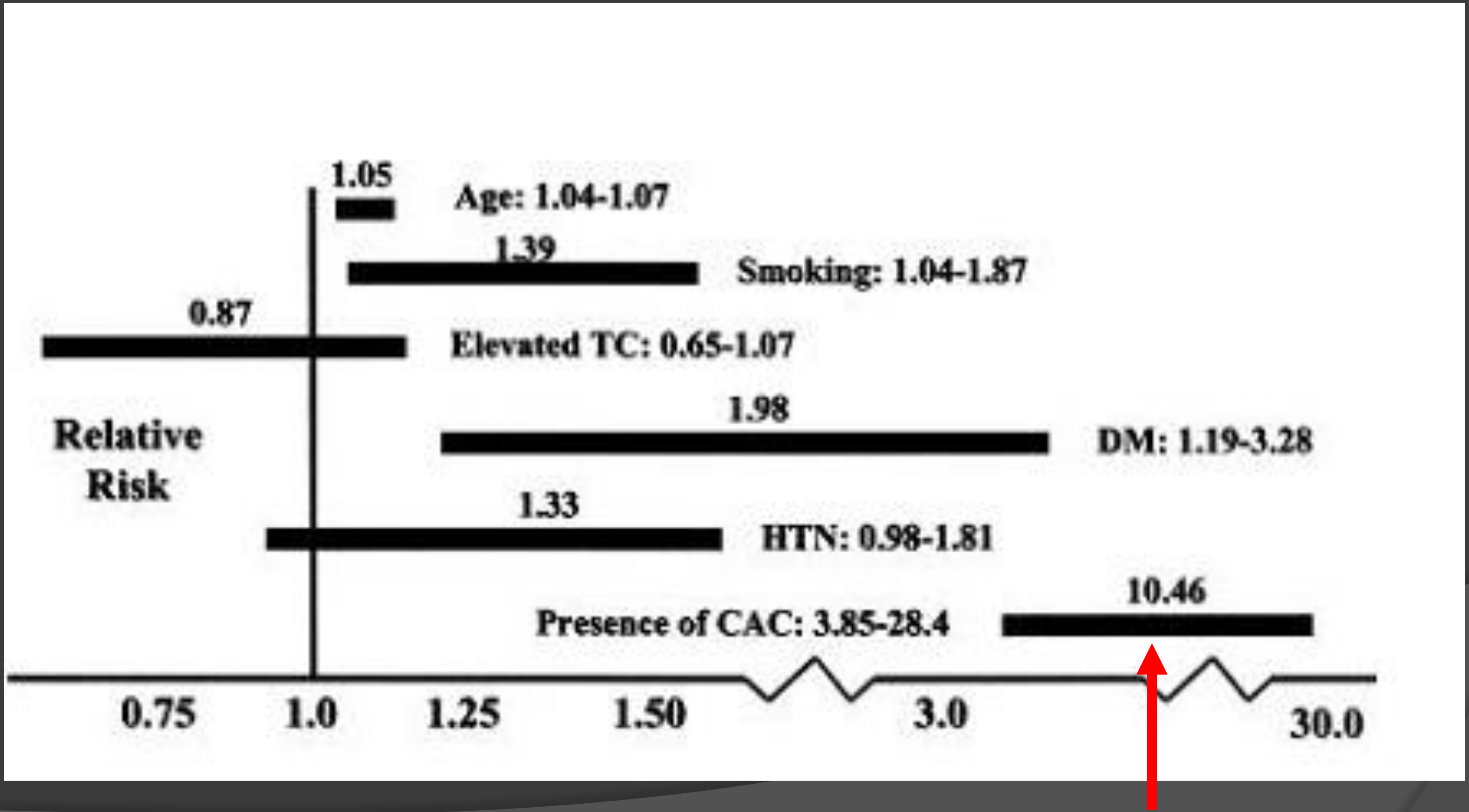
25th	50th	75th	90th
13	115	447	1141

The observed calcium score of 120 is at percentile 50 for subjects of the same age, gender, and race/ethnicity who are free of clinical cardiovascular disease and treated diabetes.

Chart 1: Percentiles

https://www.mesa-nhlbi.org/Calcium/input.aspx

RELATIVE RISK



Courtesy: J. Rumberger MD

CALCIUM SCORING - INDICATIONS

ACCF/AHA 2010 guideline on coronary calcium

Class IIa

1. Measurement of CAC is reasonable for cardiovascular risk assessment in asymptomatic adults at intermediate risk (10% to 20% 10-year risk).[52,53] *(Level of Evidence: B)*

Class IIb

1. Measurement of CAC may be reasonable for cardiovascular risk assessment in persons at low to intermediate risk (6% to 10% 10-year risk).[53–55] *(Level of Evidence: B)*

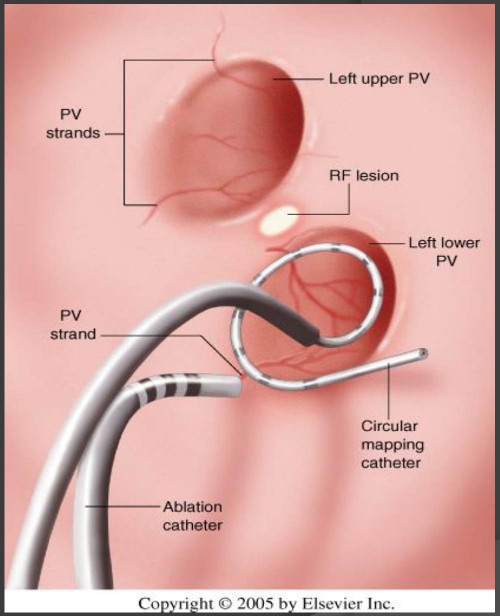
Class III: No Benefit

1. Persons at low risk (<6% 10-year risk) should not undergo CAC measurement for cardiovascular risk assessment.[52,53,56] *(Level of Evidence: B)*

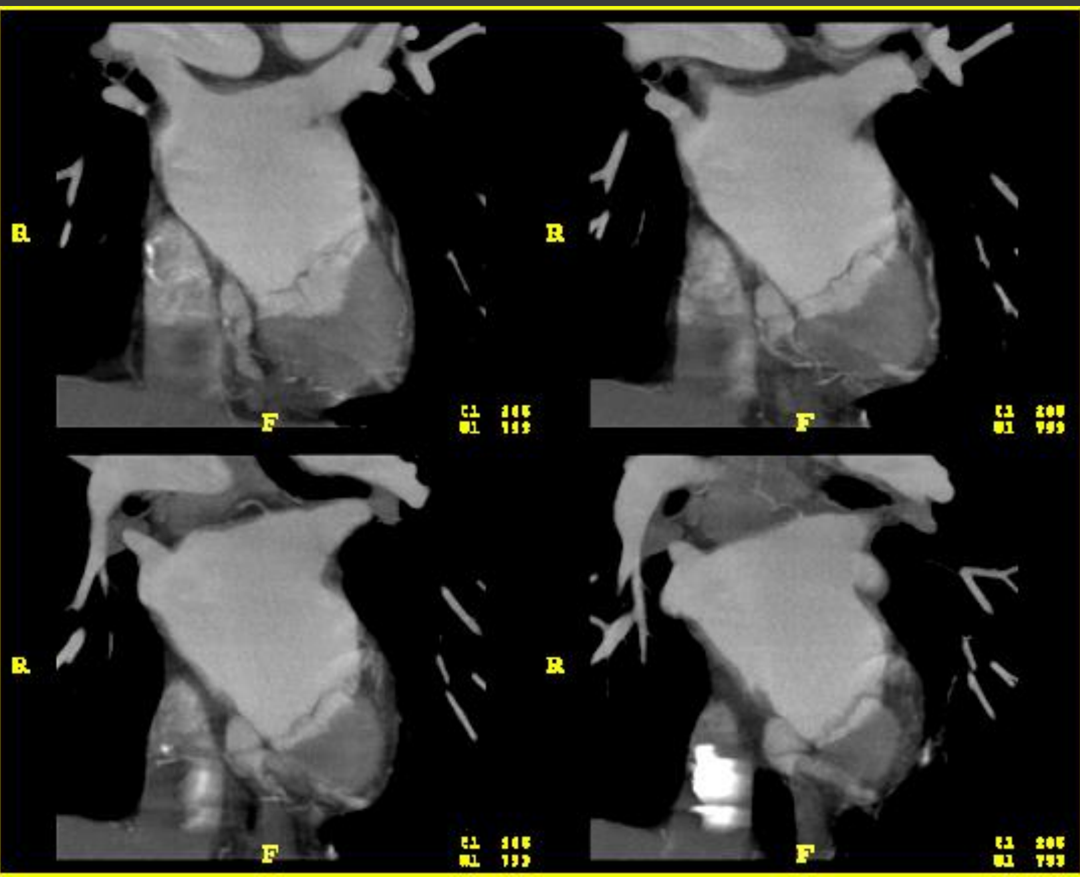
Circ 2010;122:2748

#4 LEFT ATRIAL EVALUATION MAPPING FOR RF ABLATION

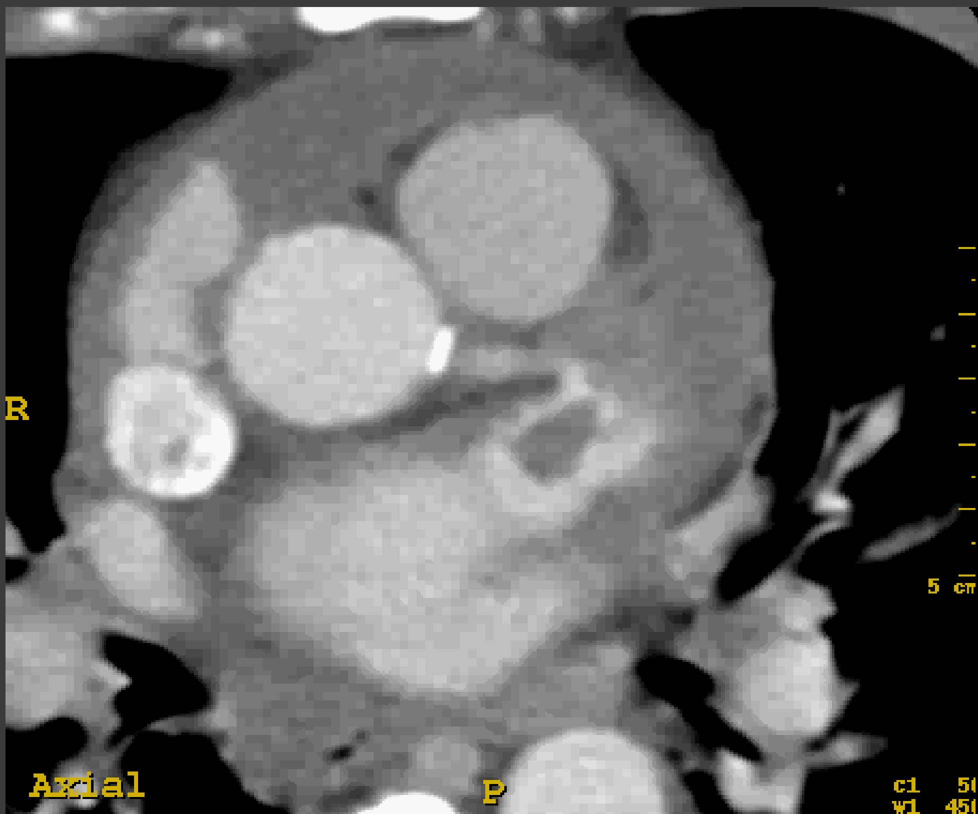
- Treatment for Atrial Fibrillation
- Usually radiofrequency ablation
- Probing tool destroys abnormal conduction pathways in LA
  - Most near PV ostia
- Risk of post-procedure pulmonary vein stenosis



LEFT ATRIAL EVALUATION
RF ABLATION



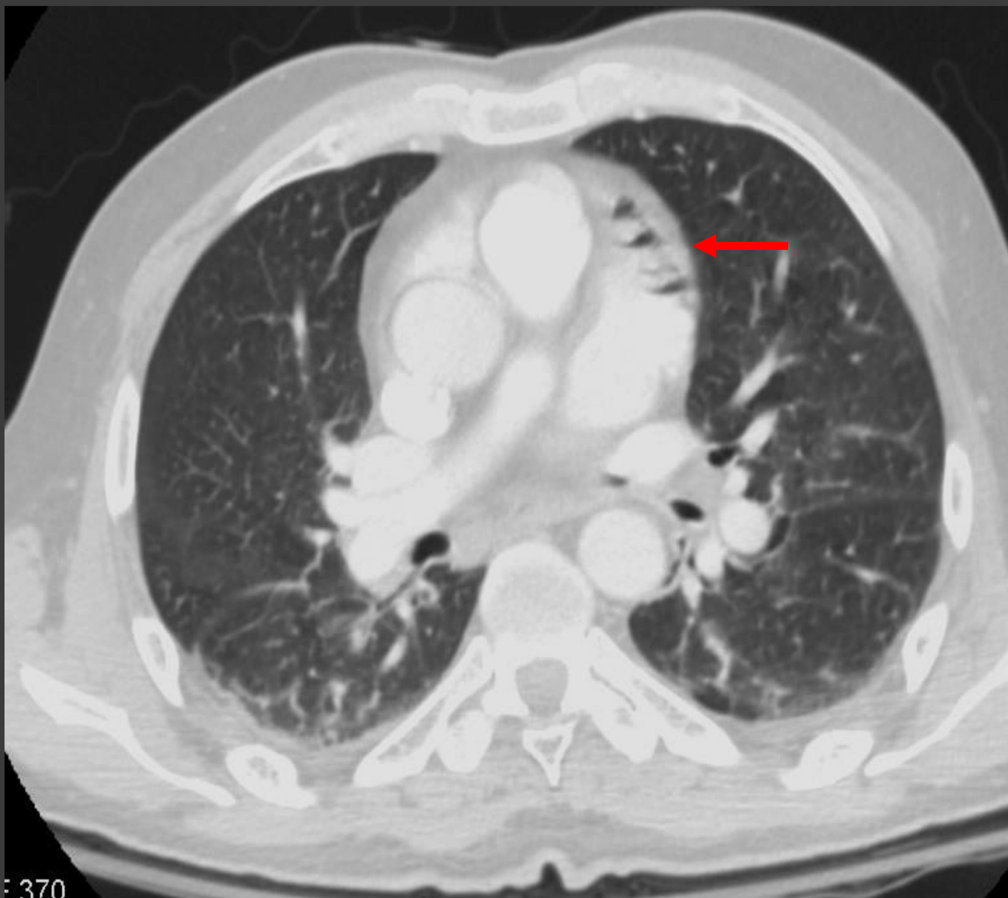
LEFT ATRIAL EVALUATION

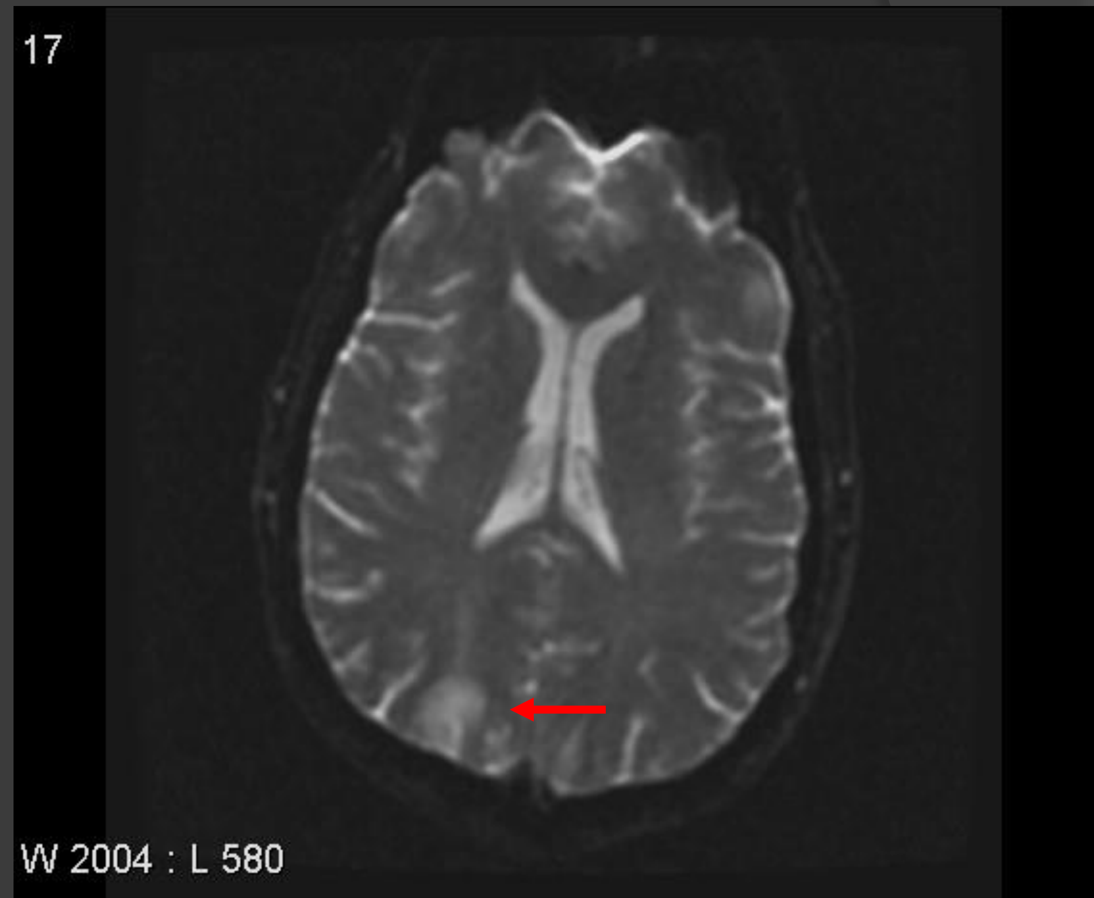


Left atrial appendage thrombus

Pulmonary vein occlusion

LA RF ABLATION COMPLICATION



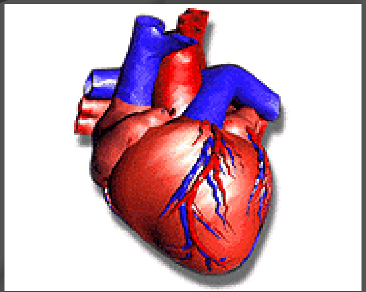


Aortoesophageal fistula

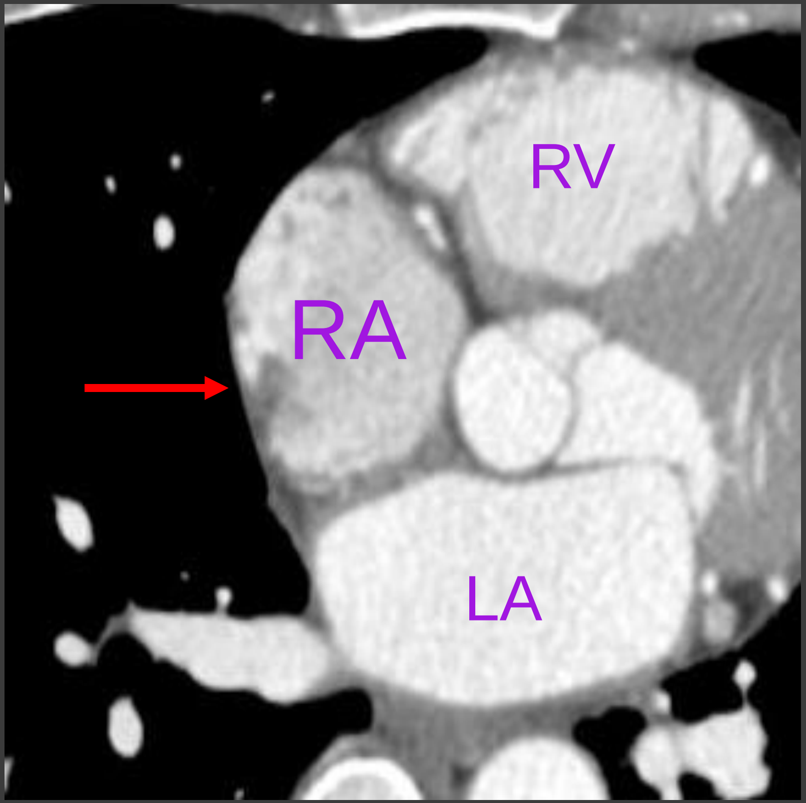
Courtesy: S. Aquino MD

#5 CARDIAC MASSES

- Cardiac masses are uncommon – beware of mimics
- Thrombi most often seen on imaging
- Metastases 40-100X more common than primaries (but not imaged that frequently)
- Most common primary benign cardiac tumor is myxoma
- Most common primary malignant tumor is angiosarcoma (rare)



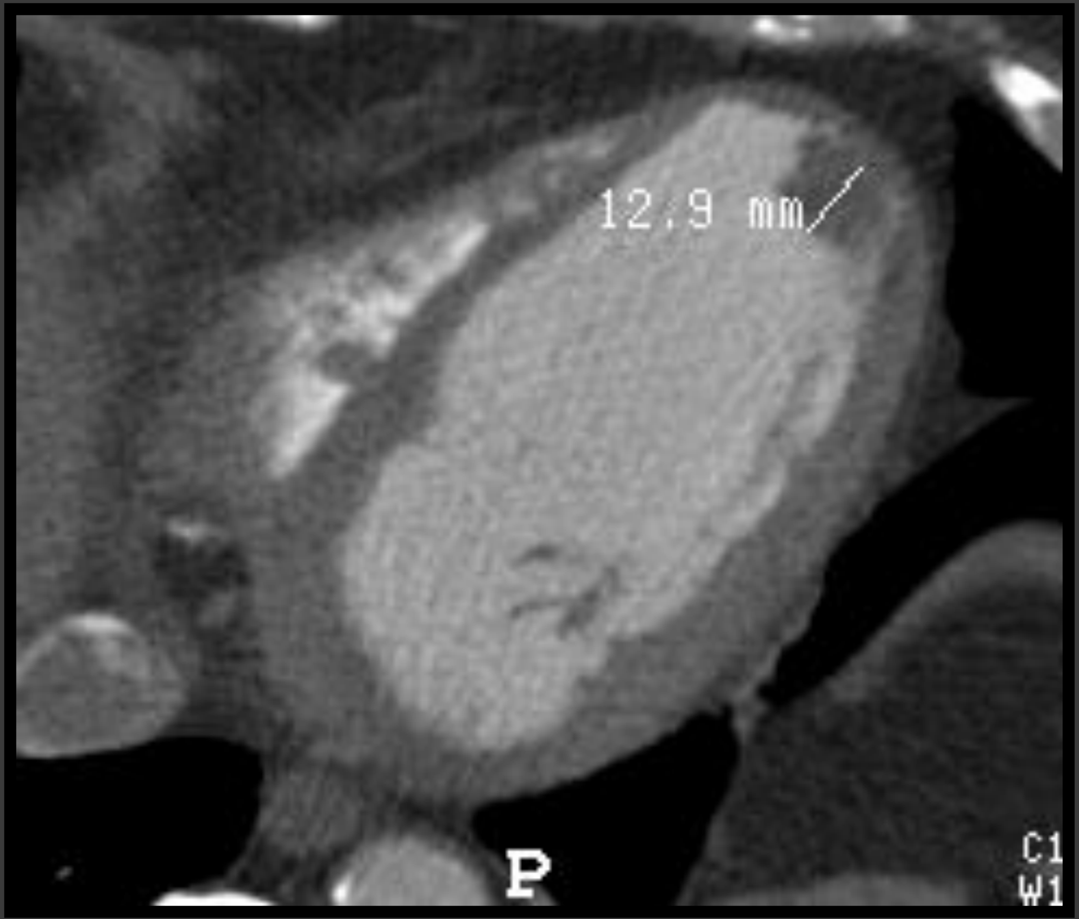
CARDIAC MASSES
ANATOMIC VARIANT



CRISTA TERMINALIS

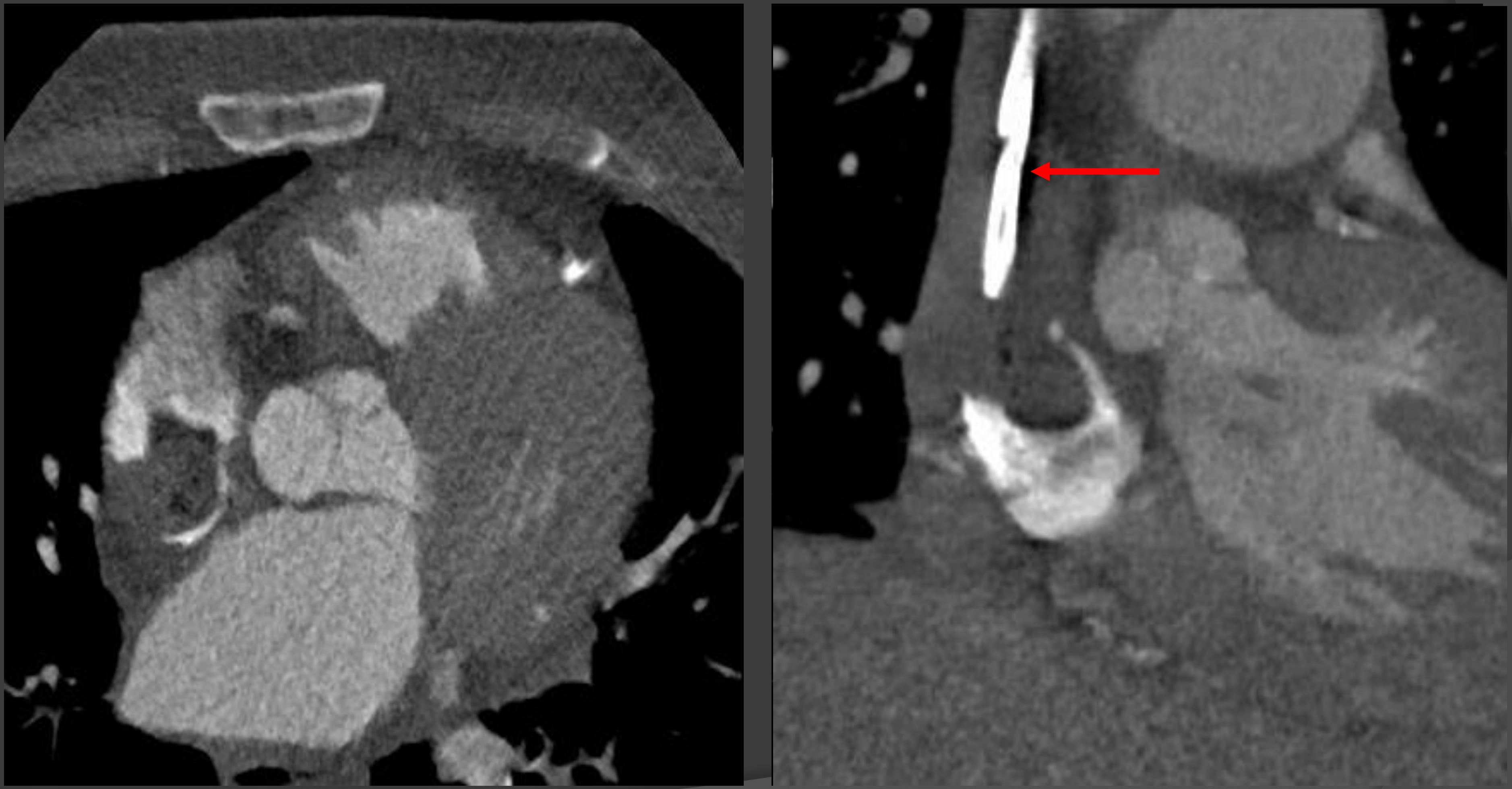
- Smooth muscle ridge from the superior vena cava to the inferior vena cava
- Fusion point between primitive RA and smooth sinus venosus portion of RA
- Occasional mistaken for thrombus on echocardiography

CARDIAC MASS



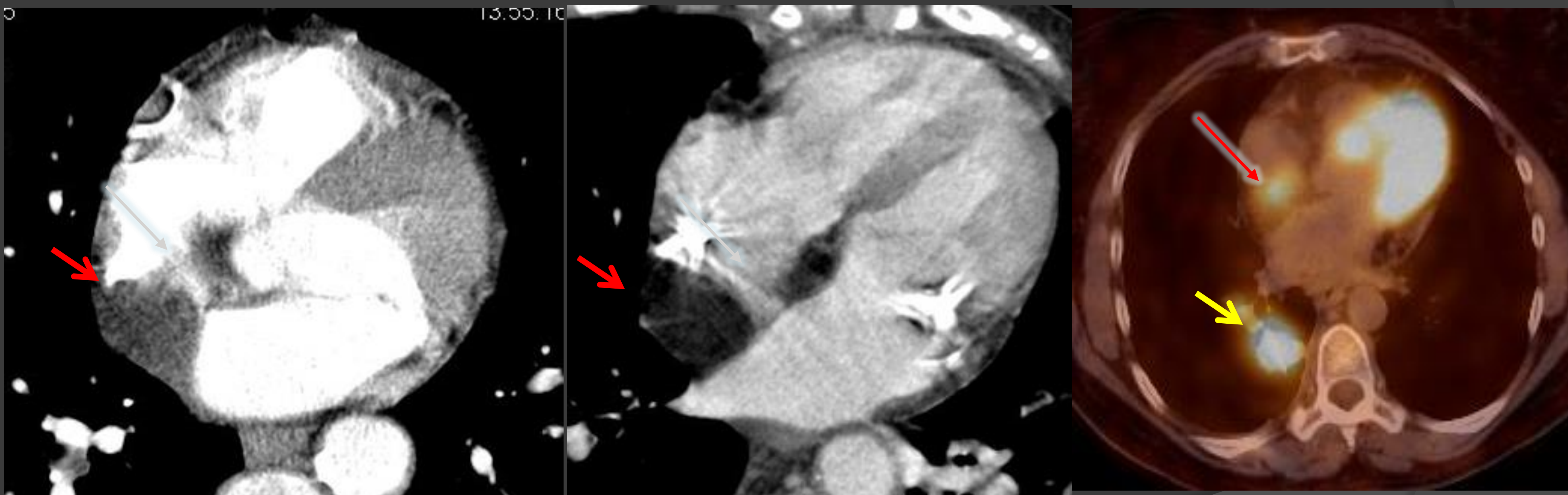
LV Thrombus

CARDIAC MASS



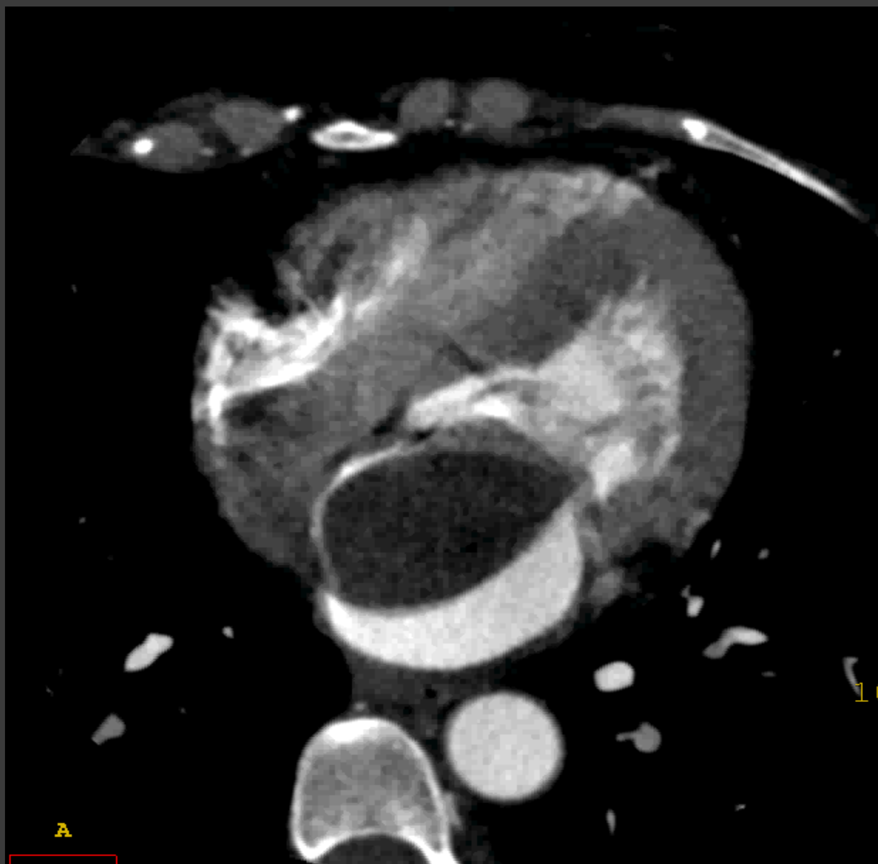
RV catheter related thrombus

CARDIAC MASS



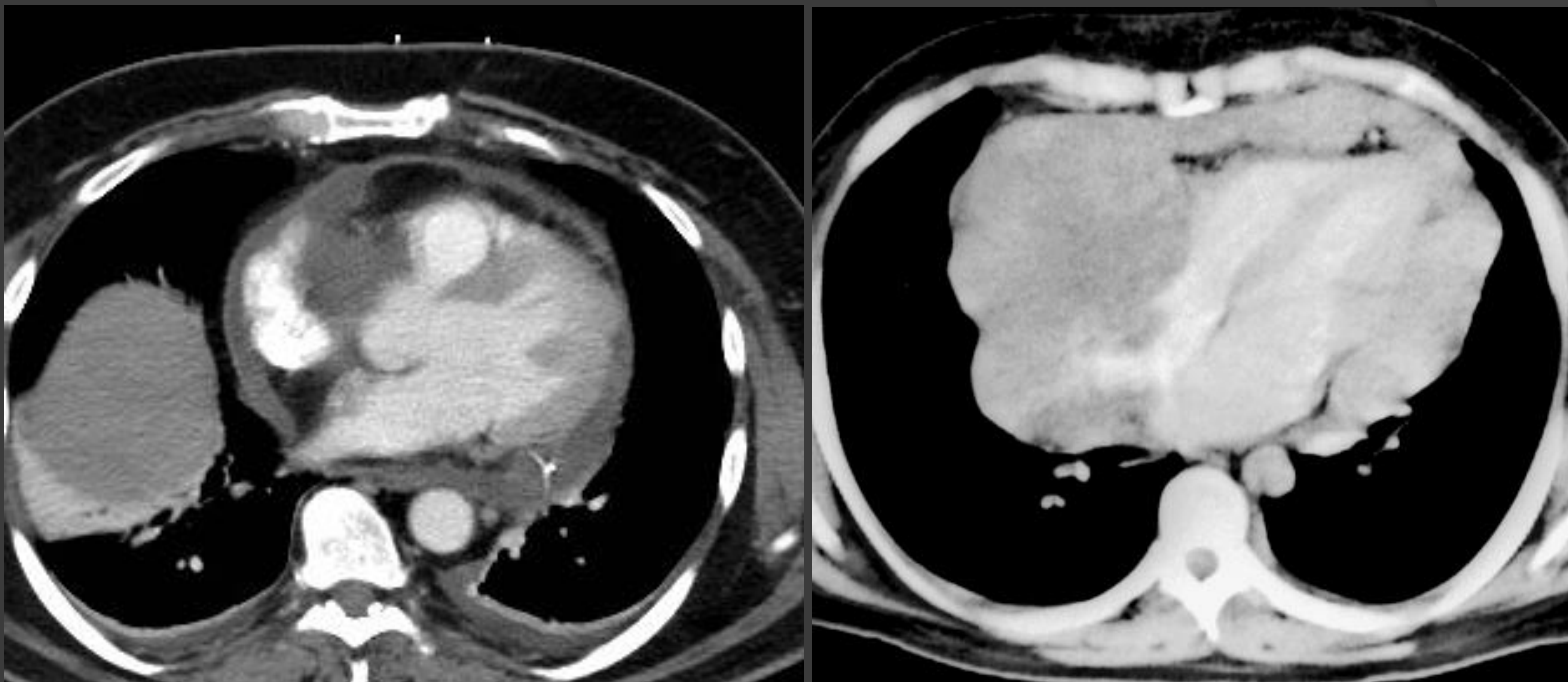
Lipomatous hypertrophy of atrial septum

CARDIAC MASS



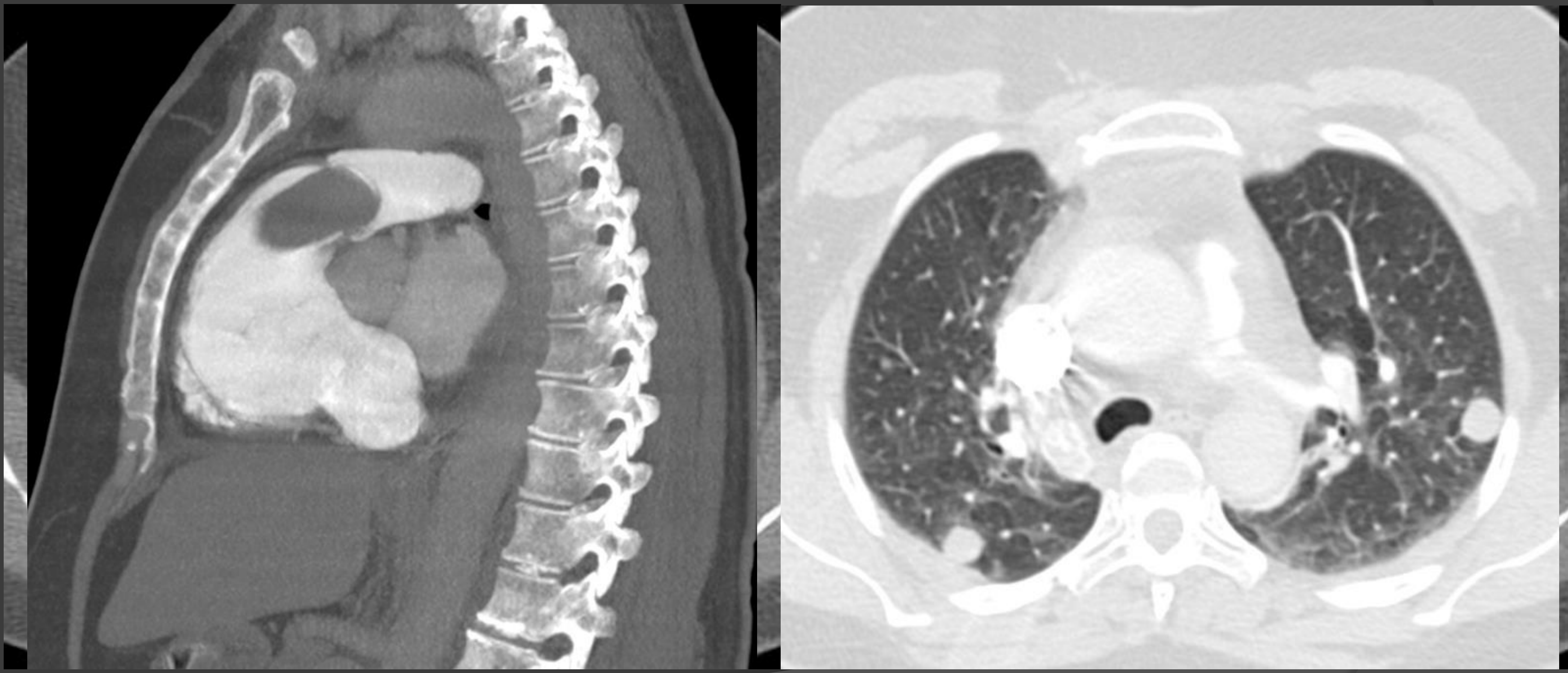
Myxoma

MALIGNANT CARDIAC TUMOR



Angiosarcoma

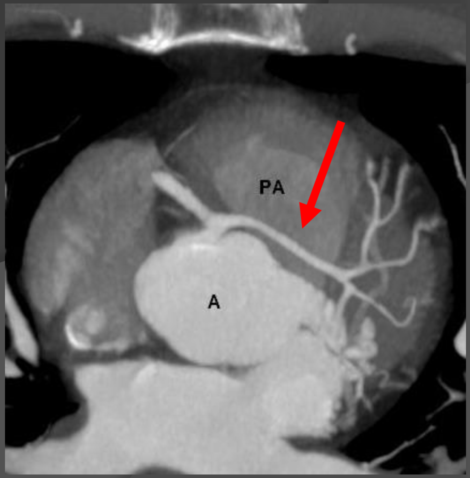
CARDIAC TUMOR



RV/PA uterine sarcoma mets

OTHER INDICATIONS

- CORONARY ANOMALIES
- BYPASS GRAFT AND STENT ANALYSIS
- PERICARDIAL DISEASE
- AORTIC DISEASE
- CONGENITAL HEART DISEASE (ESP. IN ADULTS)
- ACUTE ED CHEST PAIN



OBJECTIVES

- CARDIAC CT – THE BASICS
- CARDIAC CT – MAJOR INDICATIONS
- CARDIAC MRI – THE BASICS
- CARDIAC MRI – MAJOR INDICATIONS

CARDIAC MR IMAGING
PROS AND CONS

Advantages

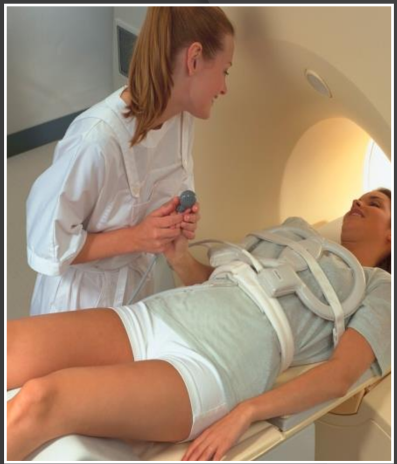
- Wide field-of-view
- Excellent anatomic detail
- Excellent functional information

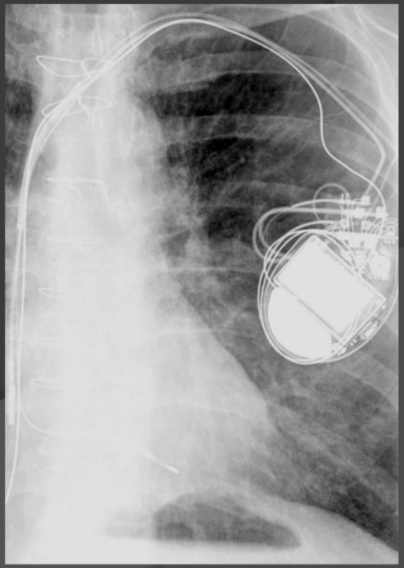
Limitations

- Claustrophobia
- Gadolinium contrast (NSF reports)
- Pacers/ICDs

CARDIAC MRI PREP

- Requires cardiac gating
- A dedicated cardiac coil will permit better image quality with decreased imaging time
- Pacemakers/ICDs may be used with appropriate caution in non-pacemaker dependent patients, particular with MRI conditional devices





MYOCARDIAL ASSESSMENT
MRI PROTOCOL

Bright Blood Cine - SSFP ………… 16-30 phases per cardiac cycle - SSFP

1^{st} Pass Perfusion with Gadolinium ………… IV 0.2 mmol/kg Gd Fast GRE

Viability Imaging ………… Delayed Enhancement LGE

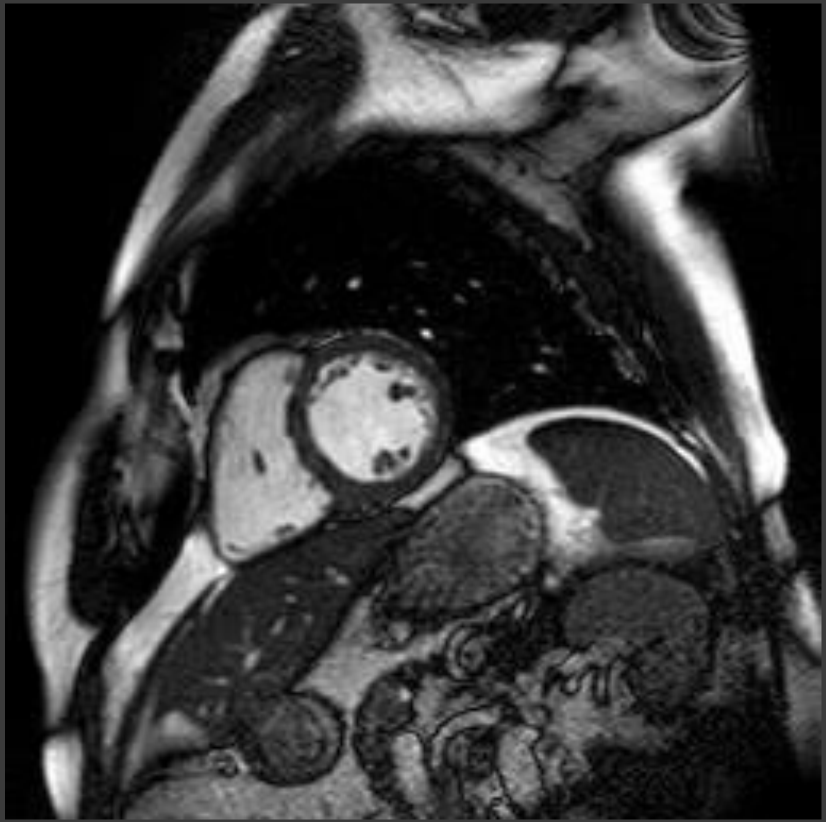
TI-scout - IR pulse with myocardial nulling (10 min) -GRE

**Selected Cases: Myocardial edema (T2 weighted), dark blood sequences

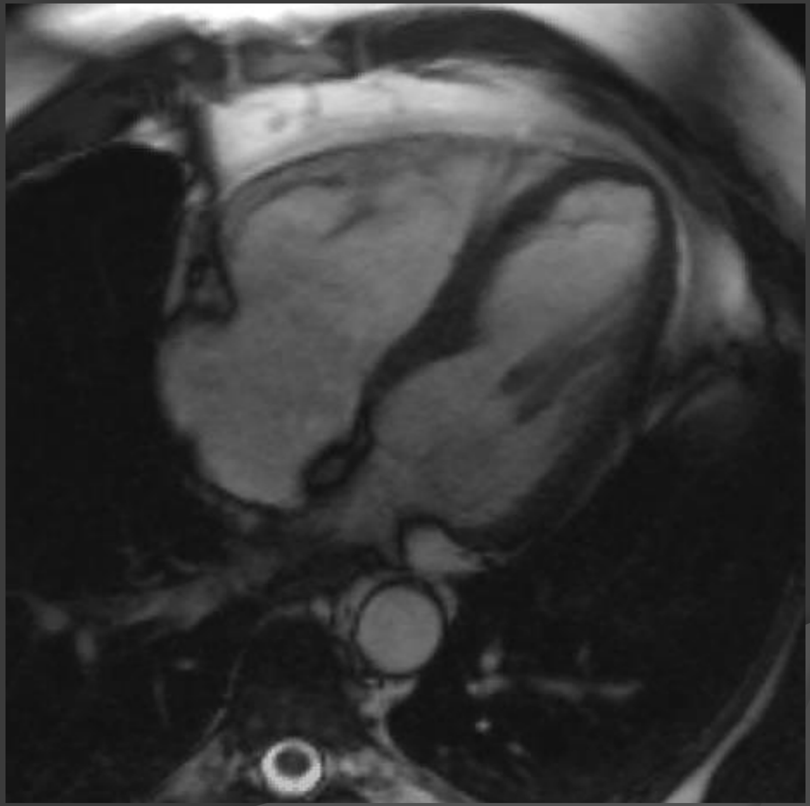
BRIGHT BLOOD CINE -SSFP

- Assess wall motion (global and segmental)
- Evaluate wall thickening
- Valvular stenosis and regurgitation
- Calculations
  - Stroke volume (EDV-ESV/EDV)
  - Ejection fraction (EDV-ESV/EDV)
  - Can adjust parameters for BMI

BRIGHT BLOOD CINE -SSFP

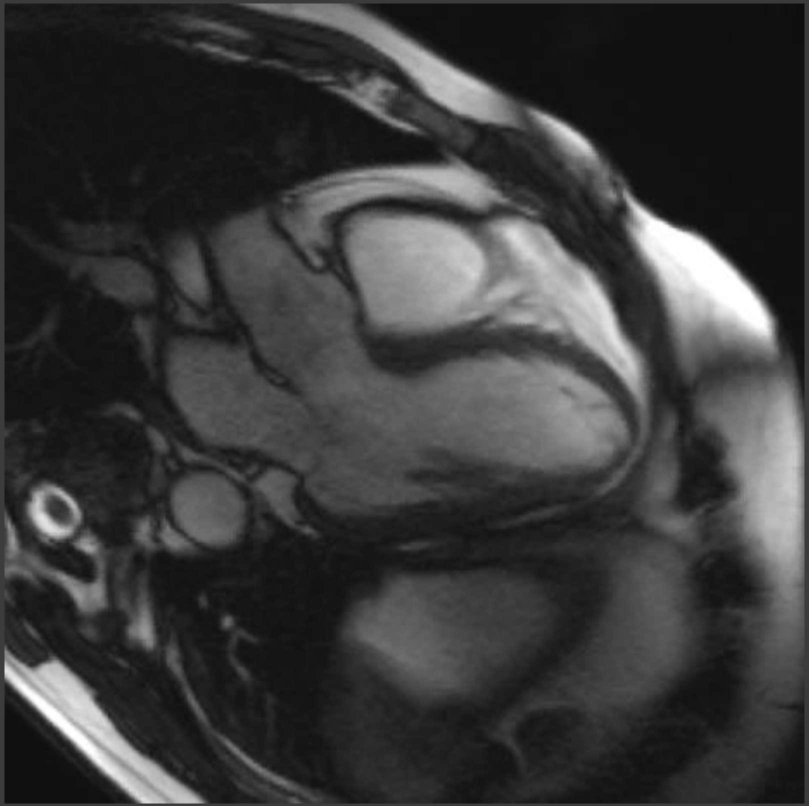


Short axis

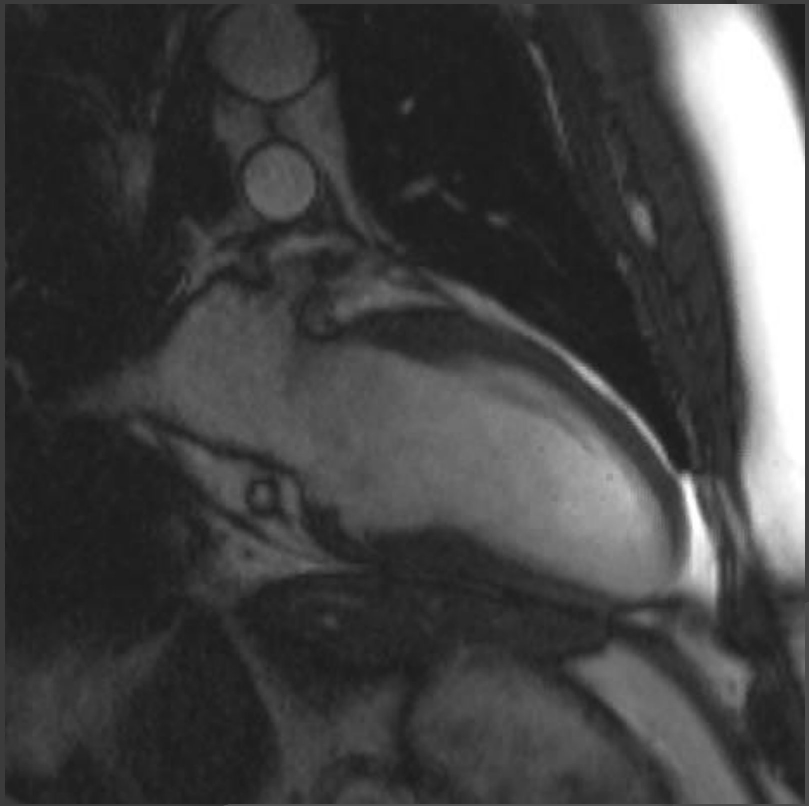


4 chamber

CARDIAC MRI – OTHER AXES



3 chamber (LVOT) view



2 chamber view

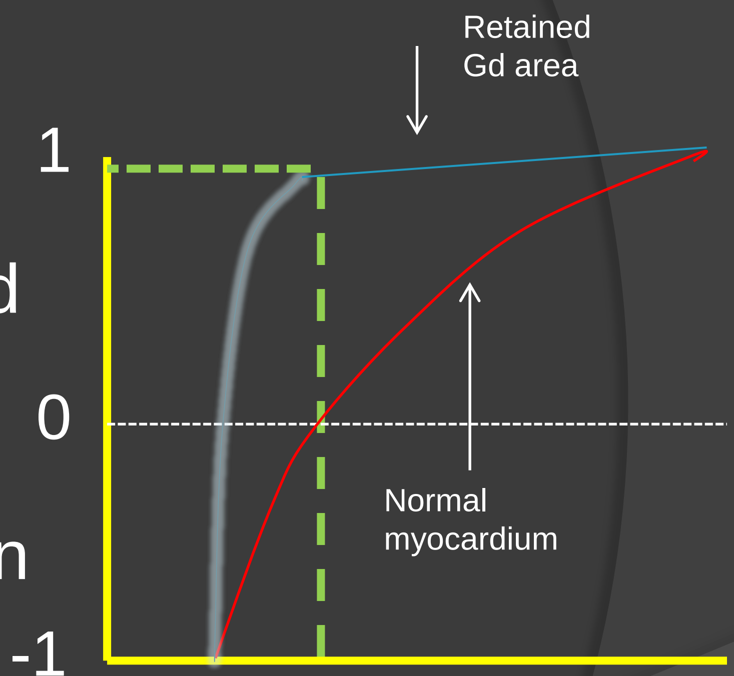
MYOCARDIAL PERFUSION/VIABILITY

- Perfusion
  - First-pass sequence to look for perfusion defects
- Delayed enhancement (LGE)
  - Generally 10-15 min after injection of Gd-chelate
  - Myocardium is “nulled” (black) with an inversion pulse
  - Areas of enhancement (high signal) are abnormal (indicates retention of Gd in myocardium in infarction/fibrosis – cause “T1-shortening”)

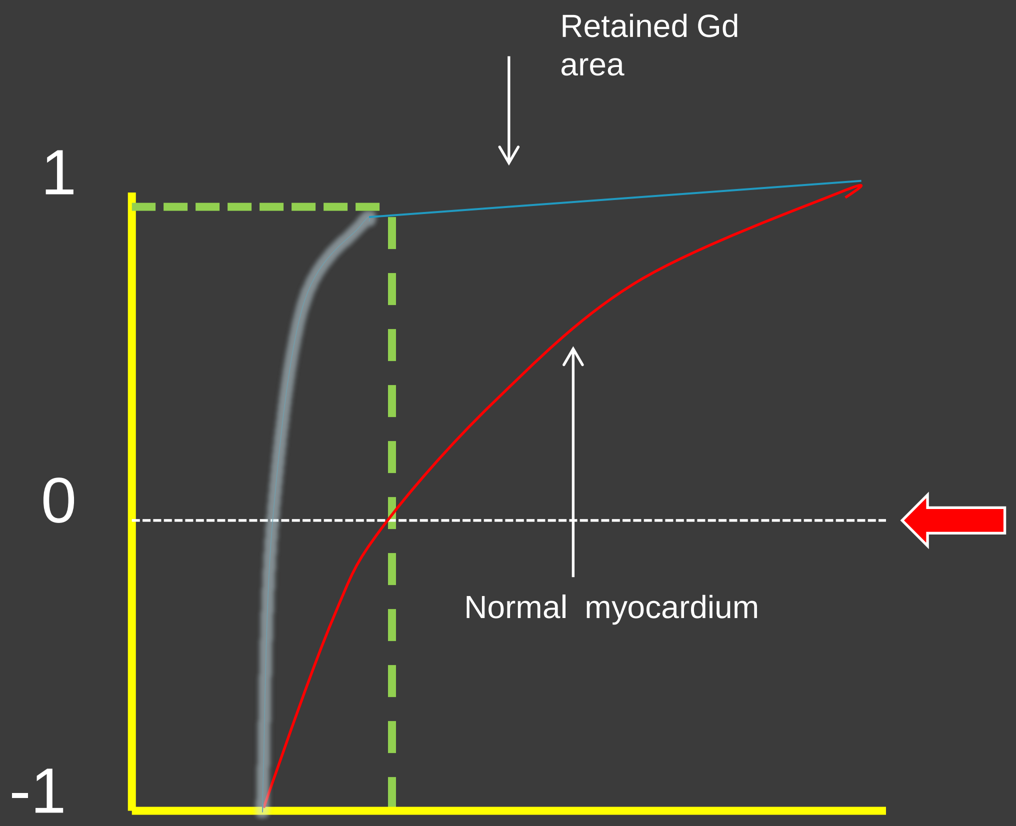
MYOCARDIAL VIABILITY

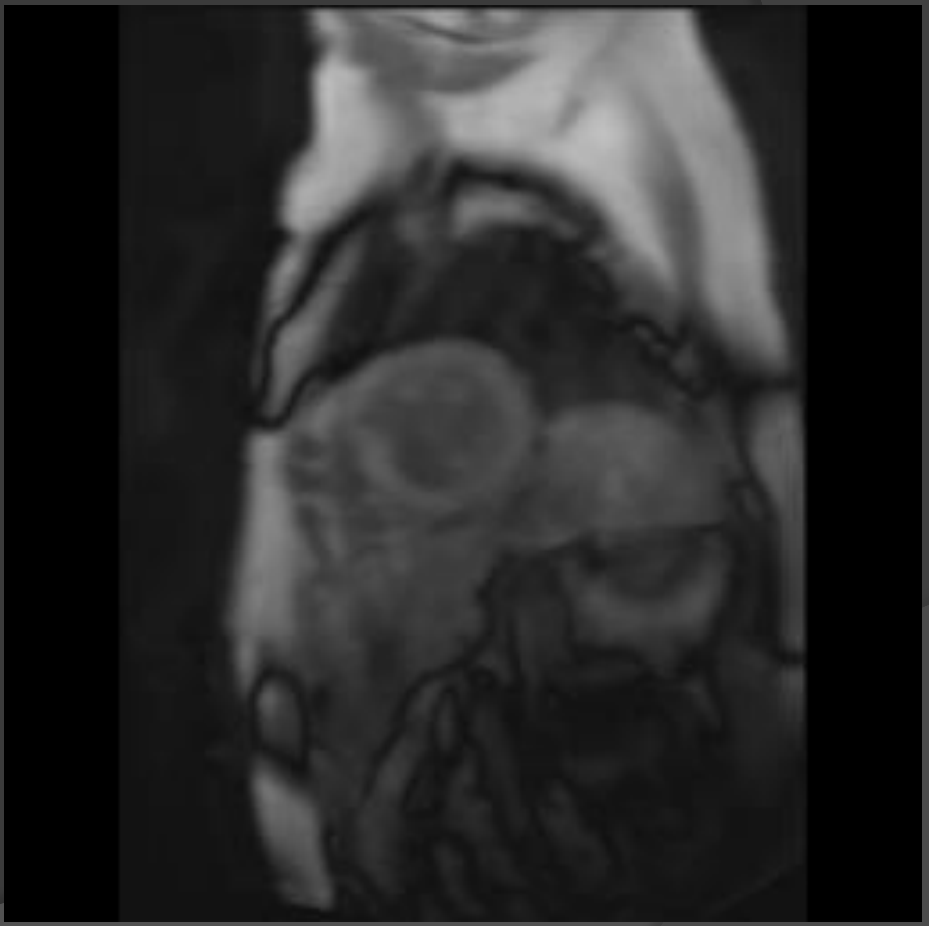
Delayed enhancement (LGE)

- Gd-contrast passes into extracellular spaces in myocardium (both normal and disease
- Infarction or fibrosis/increased extracellular space leads to Gd retention
- Retained Gd shortens T1 relative to wash-out areas leading to enhancement on delayed images



MYOCARDIAL VIABILITY
TI-SCOUT





MYOCARDIAL PERFUSION/VIABILITY

Delayed Enhancement (LGE)

10 minutes after gado

OBJECTIVES

- CARDIAC CT – THE BASICS
- CARDIAC CT – MAJOR INDICATIONS
- CARDIAC MRI – THE BASICS
- CARDIAC MRI – MAJOR INDICATIONS

#1 CARDIAC ISCHEMIA/INFARCTION

- Cardiac MRI has a valuable role in evaluation of cardiac ischemia
- Complementary to nuclear imaging
- Can assess function, perfusion, viability
- MRI stress testing

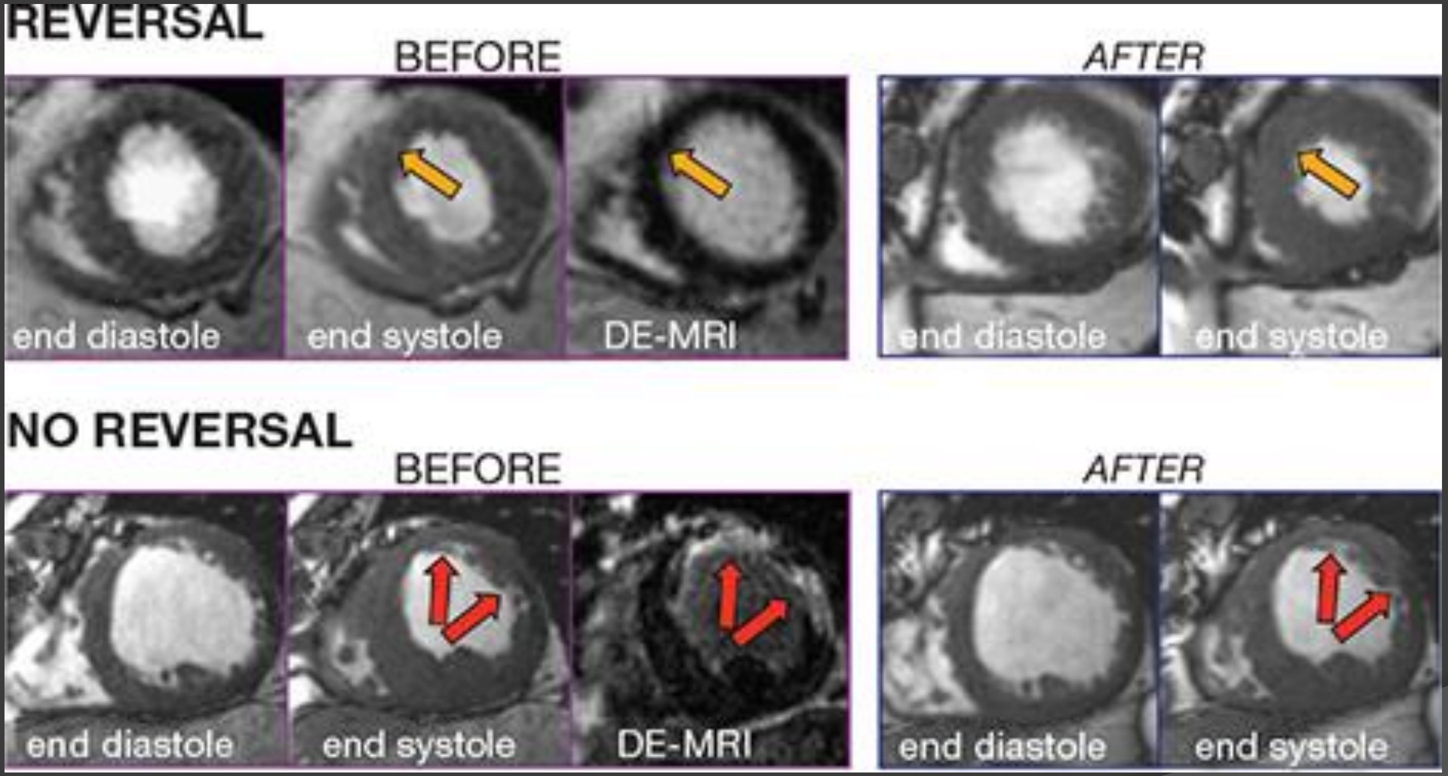
ISCHEMIC INJURY
A SPECTRUM

STUNNED MYOCARDIUM

- Acute occlusion, then reperfusion
  - Spontaneous vs PCT
- Moderate/severe stenosis with exercise
- Causes wall motion abnormality that resolves

Myocardial Status	Wall motion	Perfusion	Viability (LGE)
Stunned	Abnl	NL	NL
Hibernating	Abnl	Abnl	NL
Infarcted	Abnl	Abnl	Abnl

STUNNED MYOCARDIUM



Stunned

Infarcted

Methodist Debakey CV J 2013;9:163

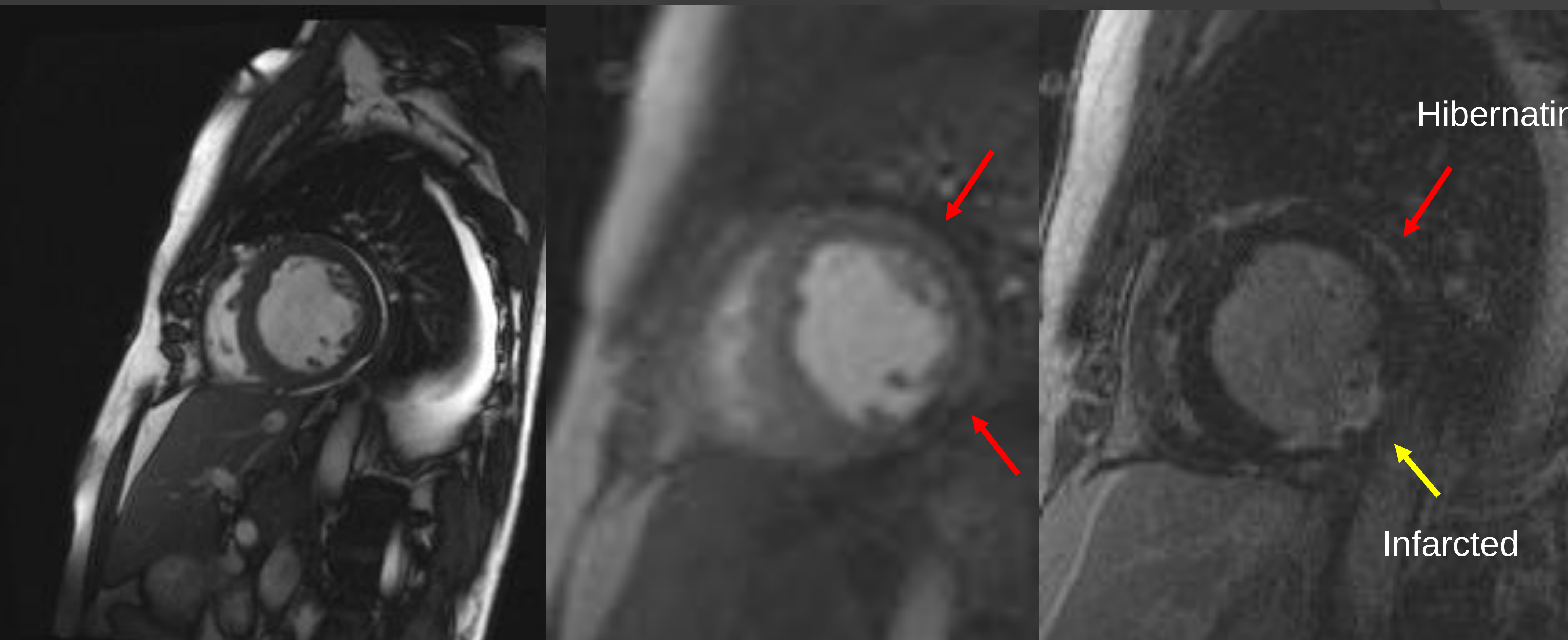
ISCHEMIC INJURY
A SPECTRUM

HIBERNATING MYOCARDIUM

- Chronic low state leading to reduced contractility
- Myocardial cells “down-regulate”
- Reversible

Myocardial Status	Wall motion	Perfusion	Viability (LGE)
Stunned	Abnl	NL	NL
Hibernating	Abnl	Abnl	NL
Infarcted	Abnl	Abnl	Abnl

HIBERNATION AND MI



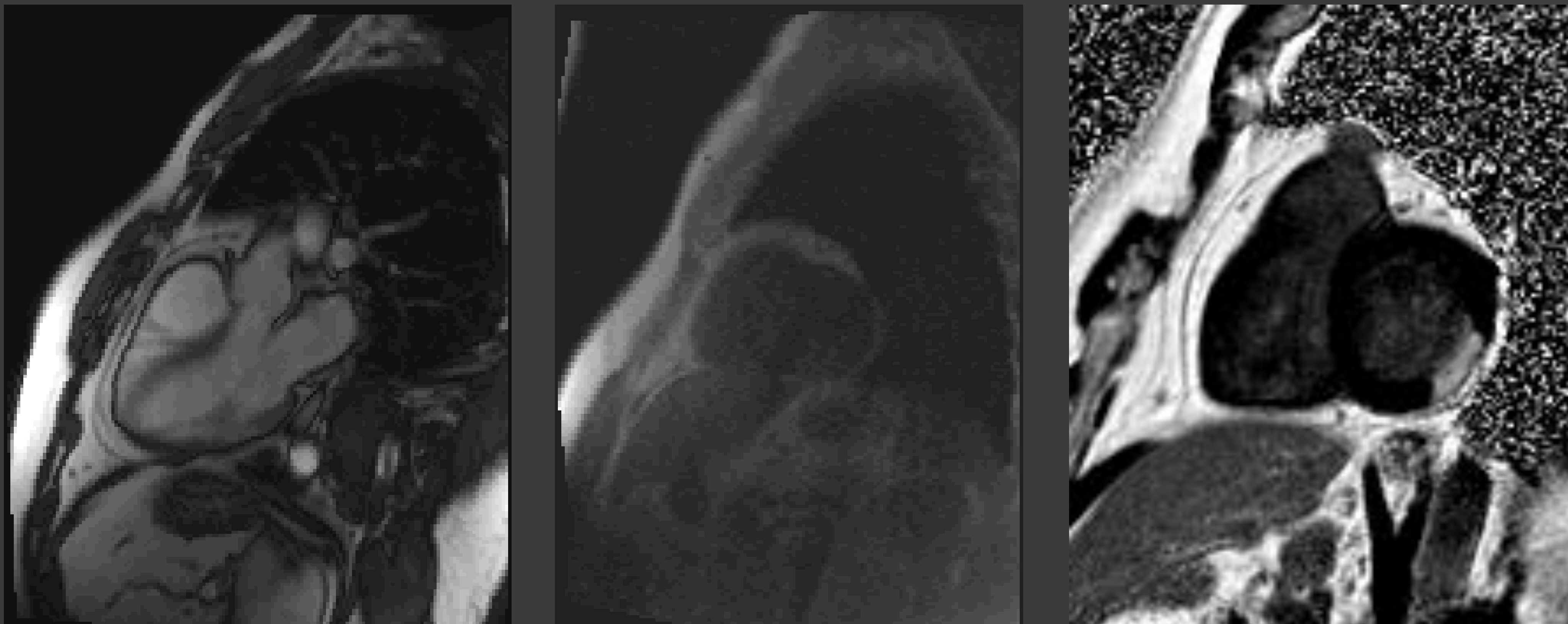
function perfusion LGE

ISCHEMIC INJURY
A SPECTRUM

- INFARCTED – NON-VIABLE

Myocardial Status	Wall motion	Perfusion	Viability (LGE)
Stunned	Abnl	NL	NL
Hibernating	Abnl	Abnl	NL
Infarcted	Abnl	Abnl	Abnl

ACUTE MYOCARDIAL INFARCTION



Acute MI = segmental and subendocardial or transmural LGE – can lead to dilated “ischemic cardiomyopathy”
DDx = non-ischemic cardiomyopathy, typically non-segmental, non-subendocardial LGE

ACUTE ANTEROLATERAL MI

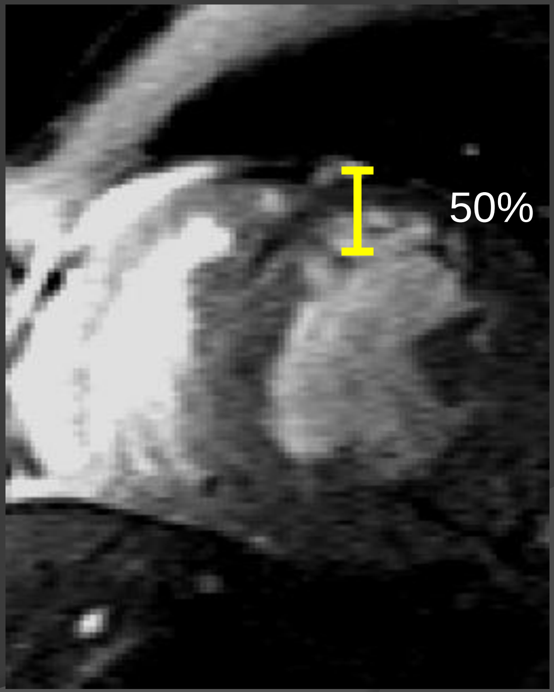
function

perfusion

LGE

THE 50% RULE
TRANSMURAL INFARCT EXTENT

- The transmural percentage of LGE correlates with the likelihood of successful outcome of CABG or stenting-based revascularization (standard used for viability)
- More than 50% transmural involvement is often used as a threshold for pursuing revascularization



THE 50% RULE
TRANSMURAL INFARCT EXTENT

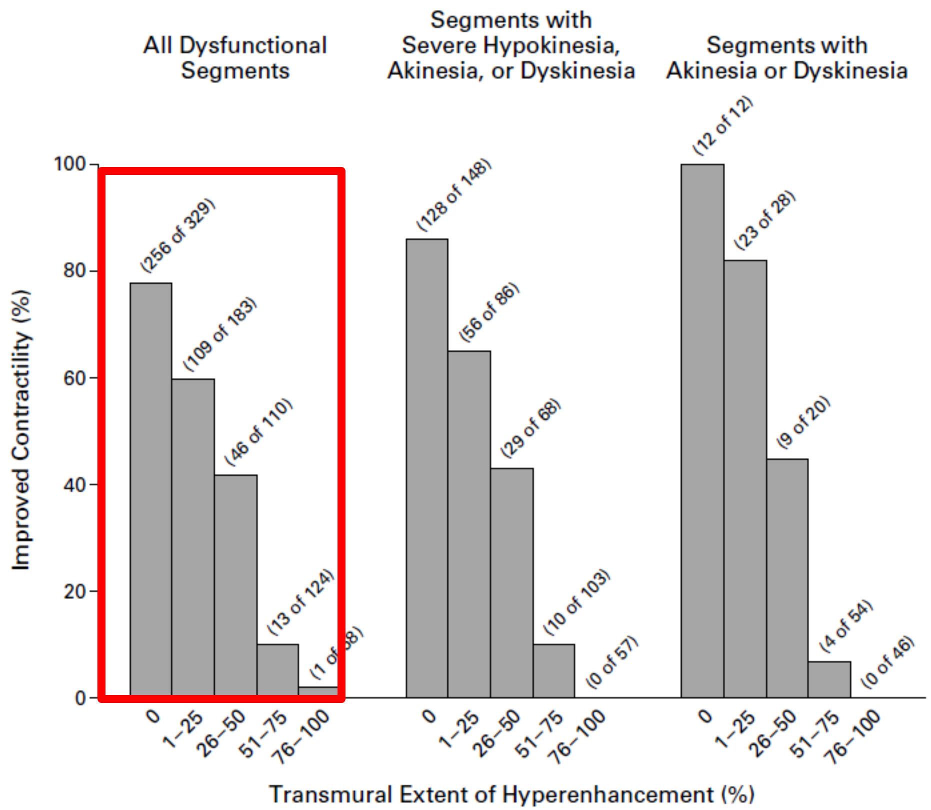


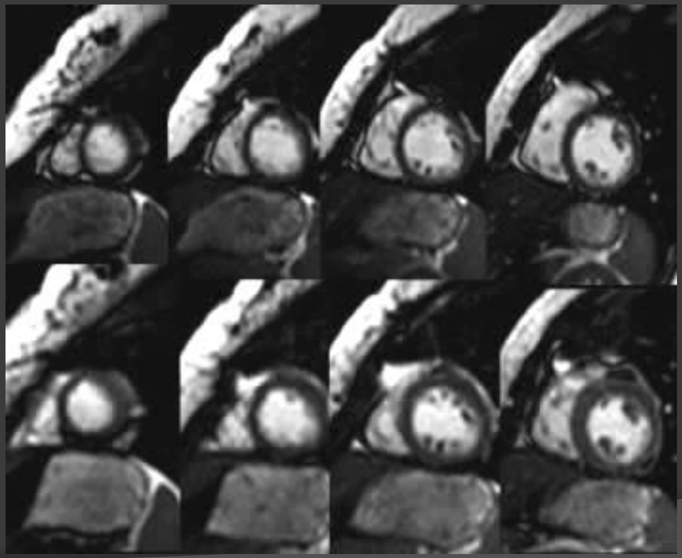
Figure 4. Relation between the Transmural Extent of Hyperenhancement before Revascularization and the Likelihood of Increased Contractility after Revascularization.

Data are shown for all 804 dysfunctional segments and separately for the 462 segments with at least severe hypokinesia and the 160 segments with akinesia or dyskinesia before revascularization. For all three analyses, there was an inverse relation between the transmural extent of hyperenhancement and the likelihood of improvement in contractility.

Kim NEJM 2000;343:1445

MRI STRESS TESTING

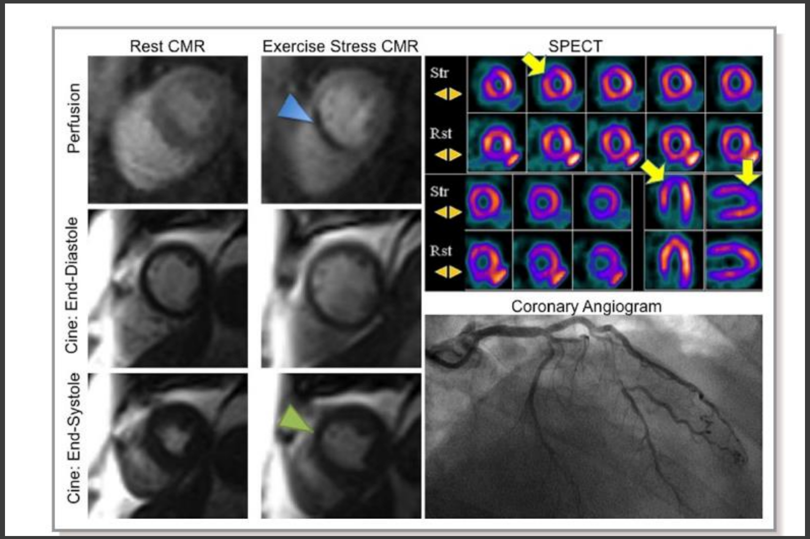
- Can be performed with:
  - Adenosine, Dobutamine, Regadenoson
  - MRI-compatible treadmill
- Generally Rest-Stress
- Stress perfusion with Gd followed by LGE



Rest

Stress

MRI STRESS TESTING



Treadmill MRI Stress/SPECT vs CATH

Table 4. Test Characteristics Compared to Angiography (70% Stenosis Cutoff)

	Sensitivity, %	Specificity, %	Positive Predictive Value, %	Negative Predictive Value, %
Exercise stress CMR	78.6 (48.8–94.3)	98.7 (92.3–99.9)	91.7 (59.7–99.6)	96.3 (88.9–99.0)
Exercise stress SPECT	50.0 (24.0–76.0)	93.7 (85.4–97.7)	58.3 (28.6–83.5)	91.5 (82.7–96.2)

CMR indicates cardiac magnetic resonance; SPECT, single photon emission computed tomography.

Raman JAHA 2016 Aug 19;5(8). pii: e003811

#2 CARDIOMYOPATHIES

- Definition (ESC – 2008)

“A myocardial disorder in which the heart muscle is structurally and functionally abnormal in the absence of coronary artery disease, hypertension, valvular disease and congenital heart disease sufficient to explain the observed myocardial abnormality”

- Major categories from an imaging perspective (WHO -1995)
  - Dilated (congestive) cardiomyopathy
  - Hypertrophic cardiomyopathy (HCM) –obstructive vs nonobstructive
  - Restrictive cardiomyopathy - infiltrative
  - Arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARVD/C)
  - Unclassified cardiomyopathy

CARDIOMYOPATHIES

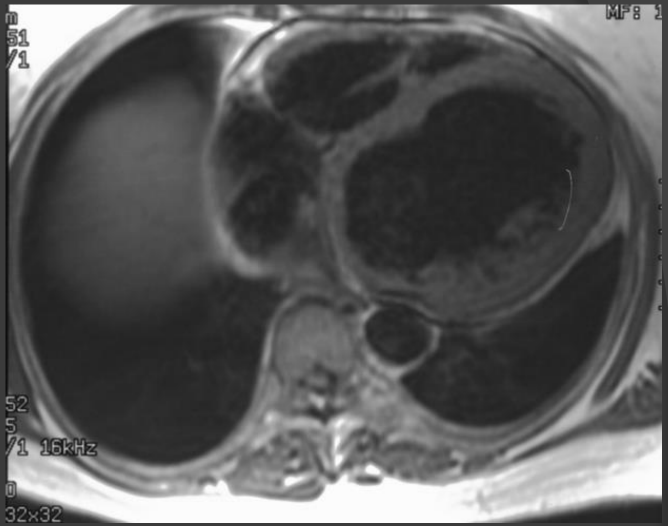
Imaging

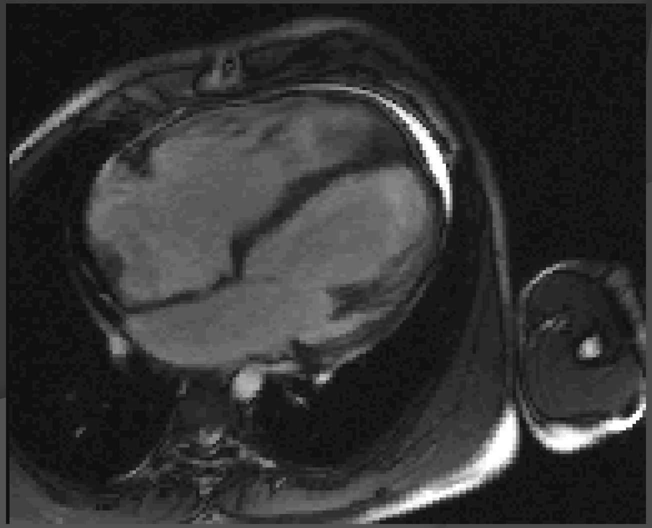
- Assess LVEF and wall motion
  - LVEF may be normal, decreased or increased
  - Wall motion abnormalities, if present are typically global
- Delayed enhancement (LGE)
  - Nonsegmental – distinct from ischemia
  - Often midmyocardial, subepicardial or diffuse

DILATED CARDIOMYOPATHY

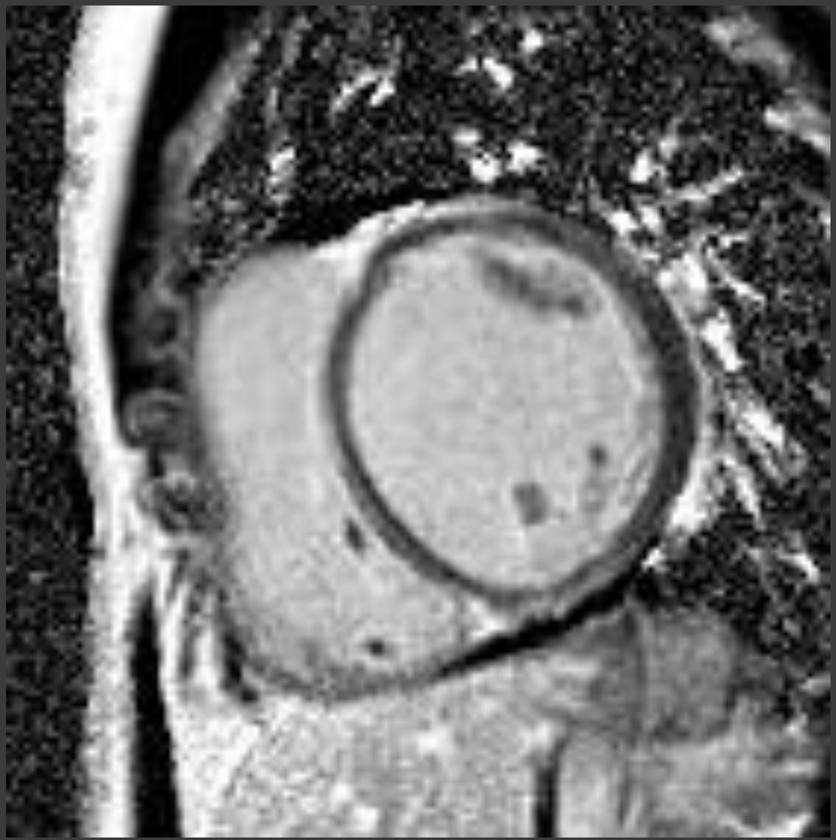
MRI morphology/function

- Markedly dilated LV and/or RV chamber
- Normal to slightly thinned wall
- Reduced ejection fraction
- May have LGE





DILATED CARDIOMYOPATHY
DELAYED ENHANCEMENT (LGE)



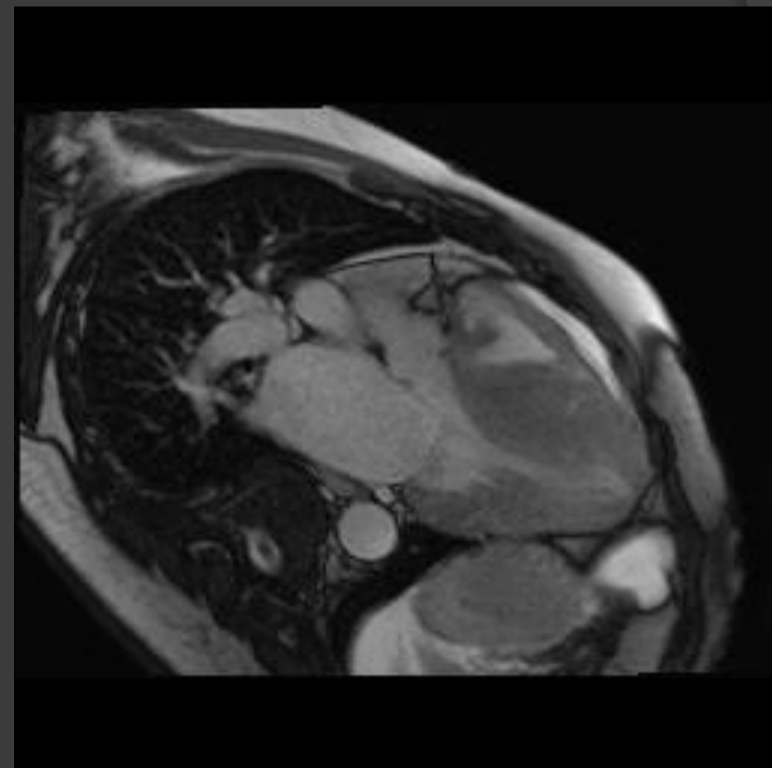
HYPERTROPHIC CARDIOMYOPATHY

Types

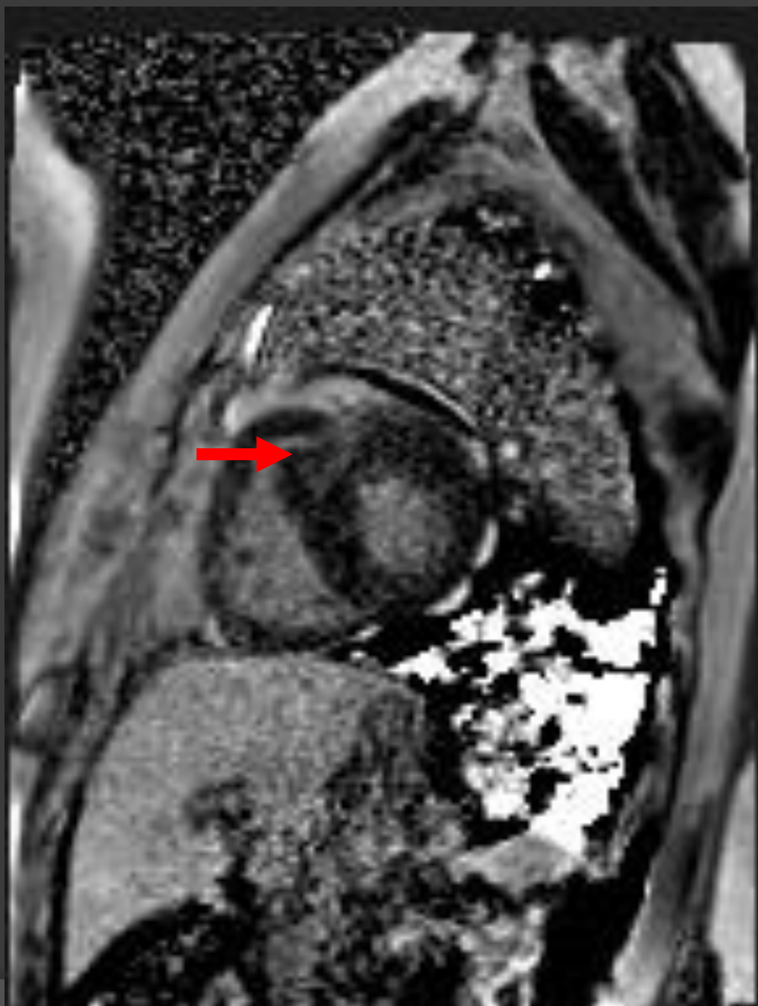
- Asymmetric septal (ASH, IHSS) *
- Midventricular *
- Apical
- Concentric

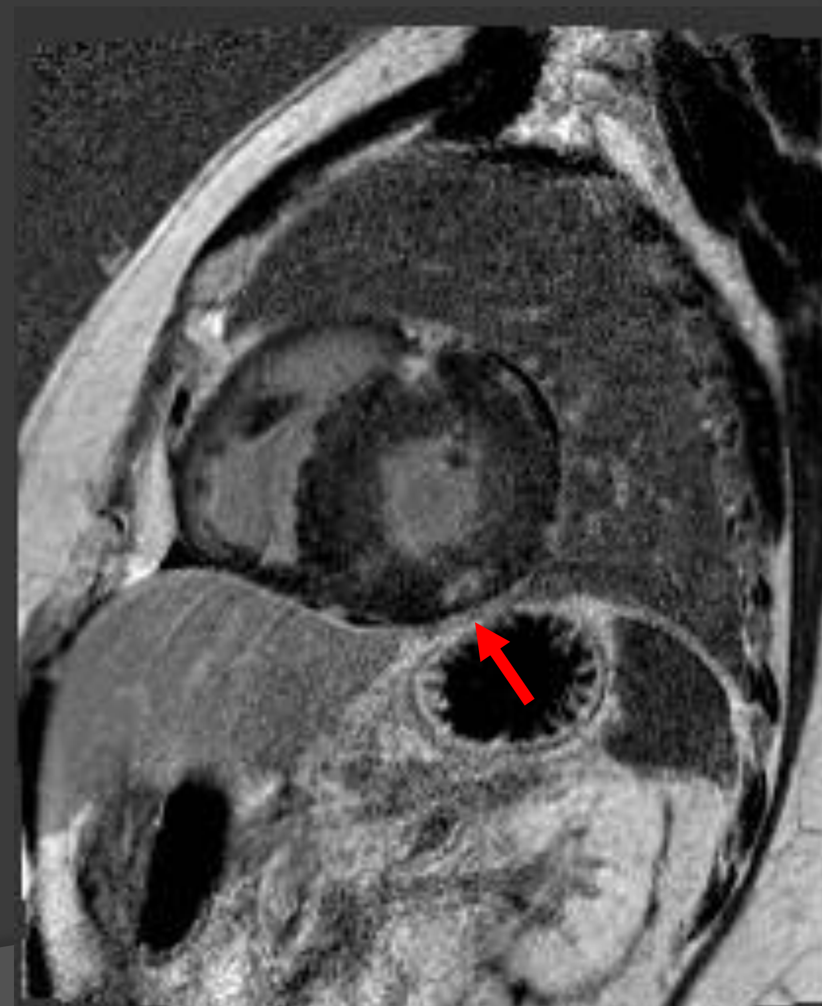
* often obstructive

HYPERTROPHIC CARDIOMYOPATHY



HYPERTROPHIC CARDIOMYOPATHY LGE

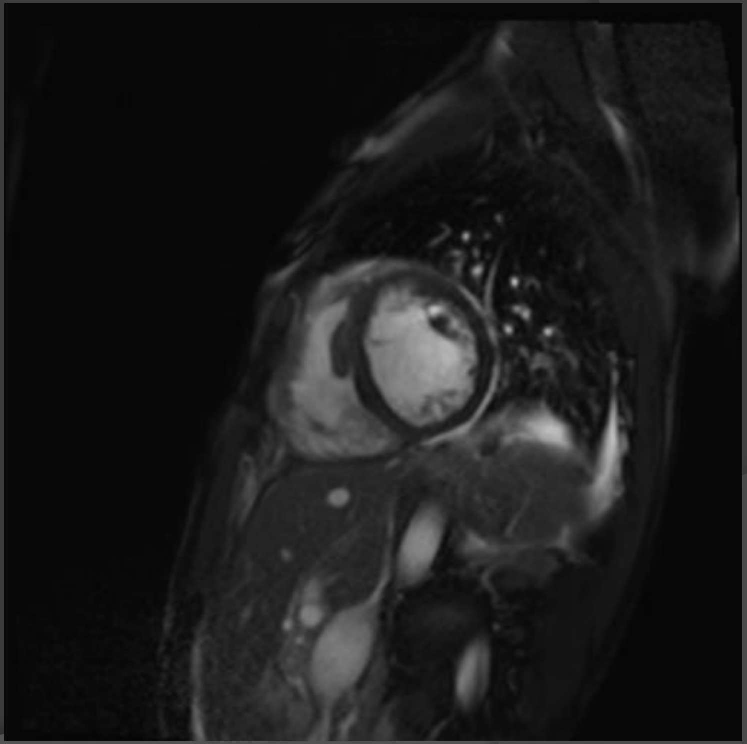




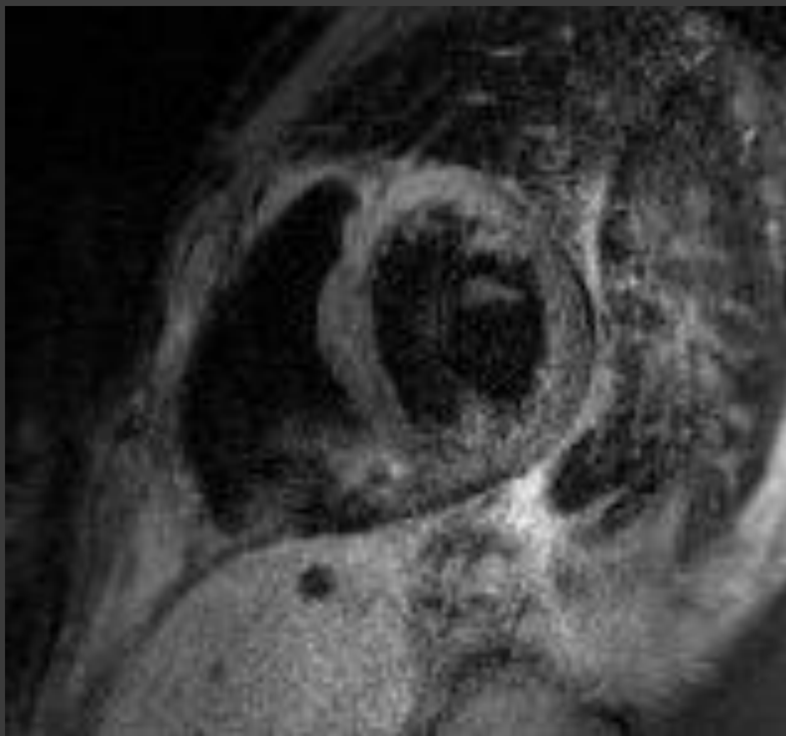
RESTRICTIVE CARDIOMYOPATHY SPECIFIC ETIOLOGIES

Sarcoidosis

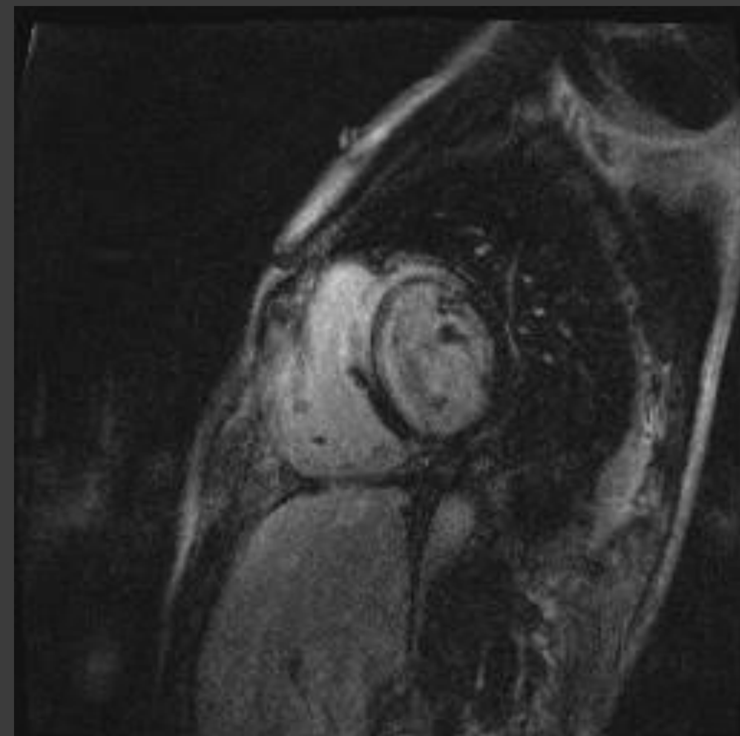
- Cardiac involvement important prognostic factor – sudden death
- Mixed edema/fibrotic changes
- MRI findings:
  - Segmental motion abnormalities
  - T2W edema sequences useful
  - DE – in areas of segmental abnormality



RESTRICTIVE CARDIOMYOPATHY SARCOIDOSIS



T2W edema sequence

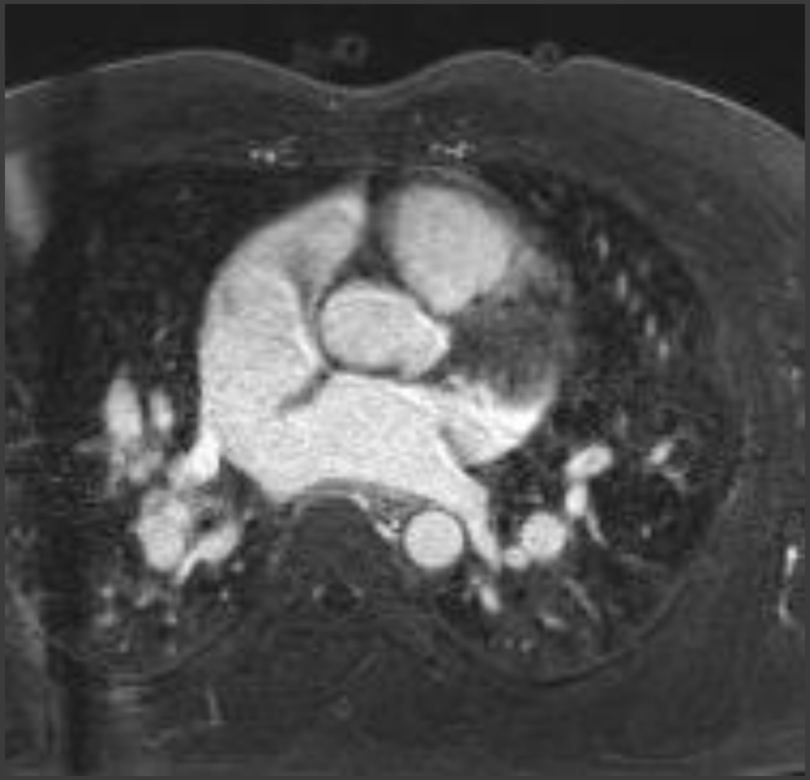


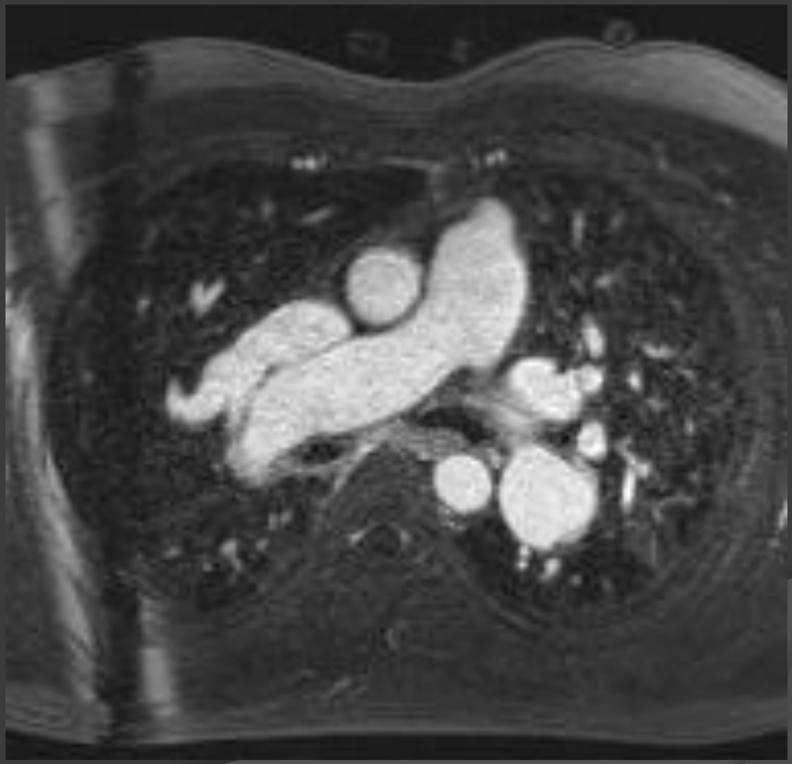
LGE

#3 CONGENITAL HEART DISEASE

- Assess simple or complicated congenital heart disease morphologically
- No radiation for children/infants
- Calculate shunts/gradients
- Time-of-flight imaging
- Post-operative complications

CONGENITAL HEART DISEASE UNREPAIRED





Qp:Qs = 2.9

CONGENITAL HEART DISEASE REPAIRED

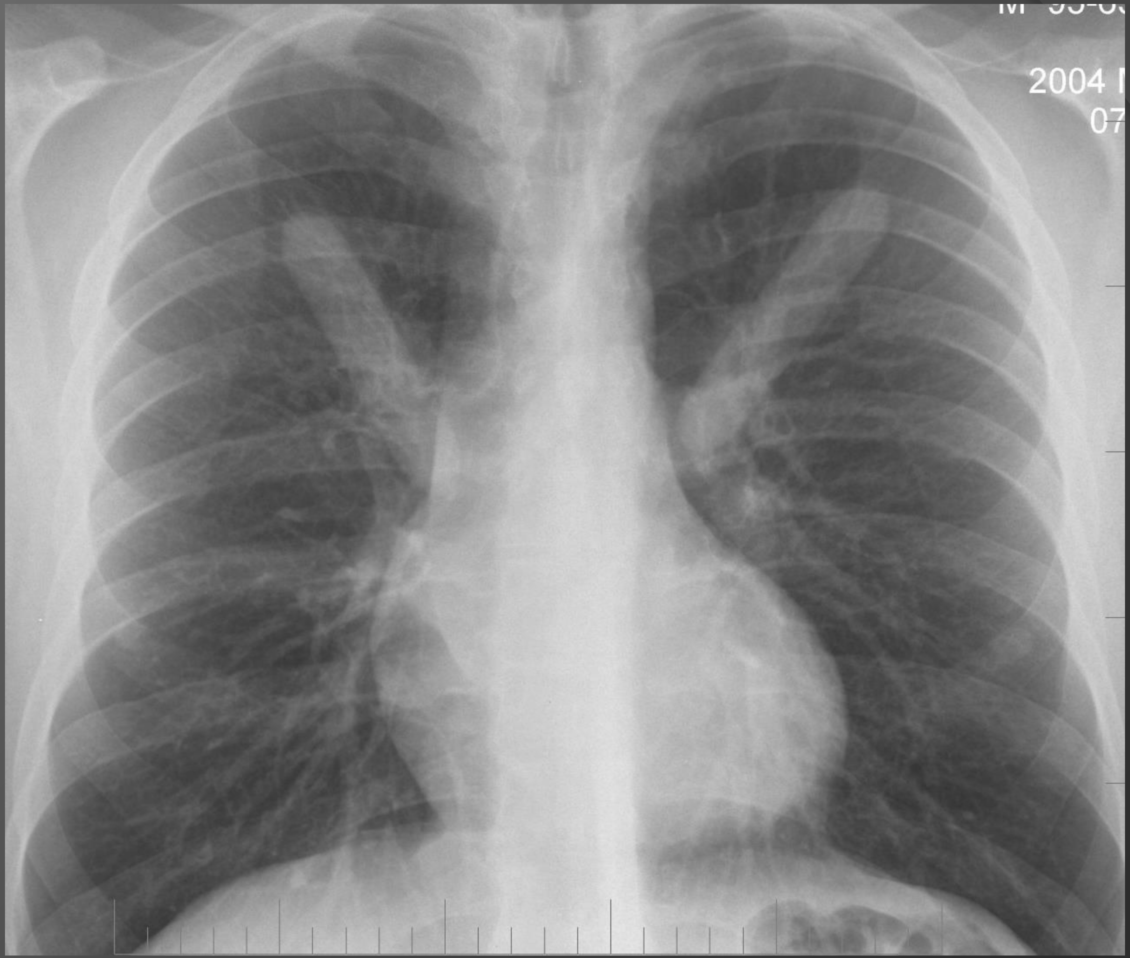
TOF with post-repair pulmonary regurgitation

OTHER INDICATIONS

- PERICARDIAL DISEASE – PARTICULARLY CONSTRICTION
- CARDIAC MASSES
- AORTIC DISEASE
- LEFT ATRIAL EVALUATION PRIOR TO RF ABLATION

CONCLUSION

- Both cardiac CT and MRI have a variety of indications and are complementary to other cardiac imaging techniques
- Cardiac CT provides unsurpassed anatomical detail
- Cardiac MRI provides outstanding functional detail without ionizing radiation



THANK YOU

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