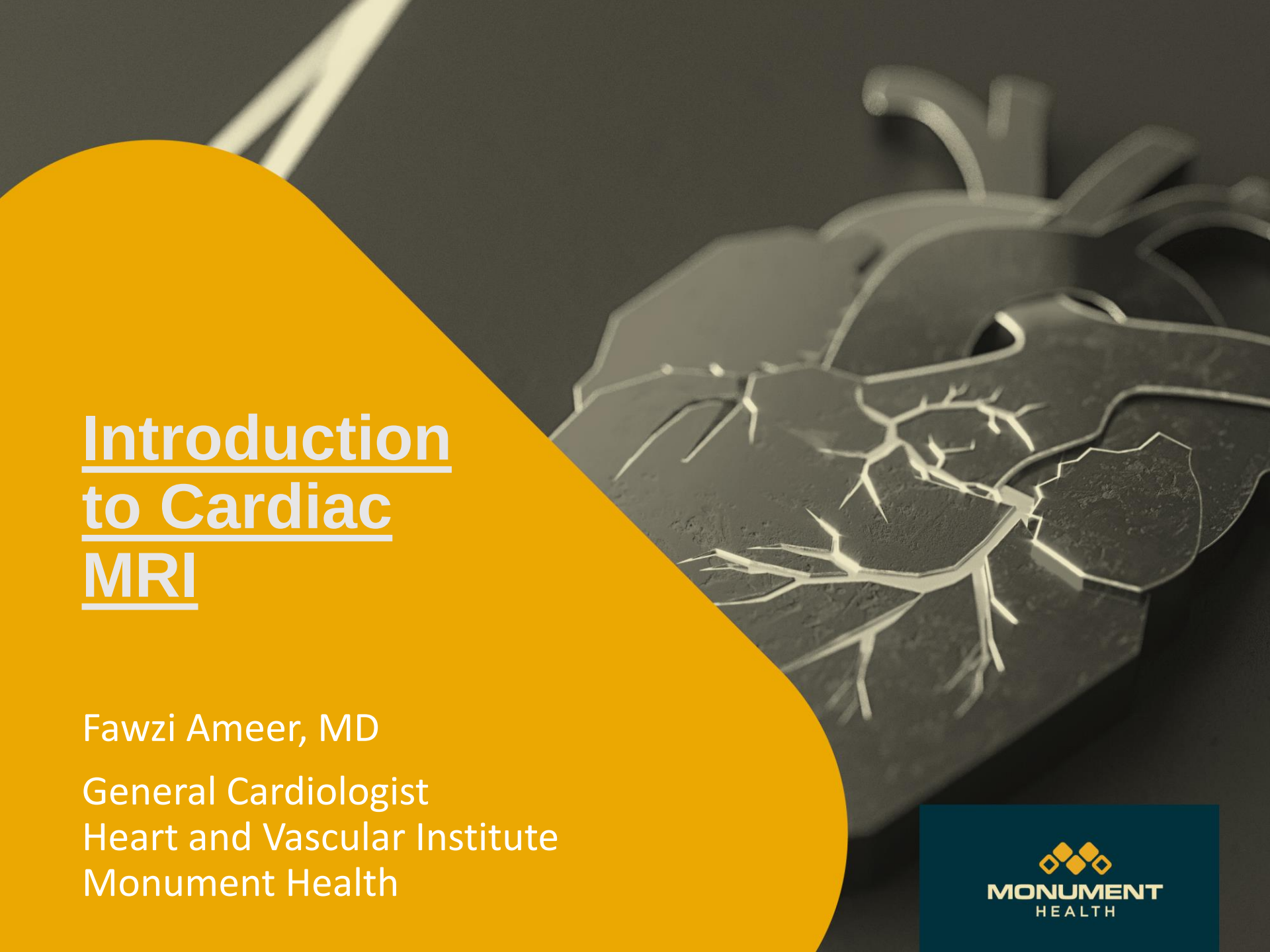

Introduction to Cardiac MRI

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General Cardiologist
Heart and Vascular Institute
Monument Health

MONUMENT HEALTH

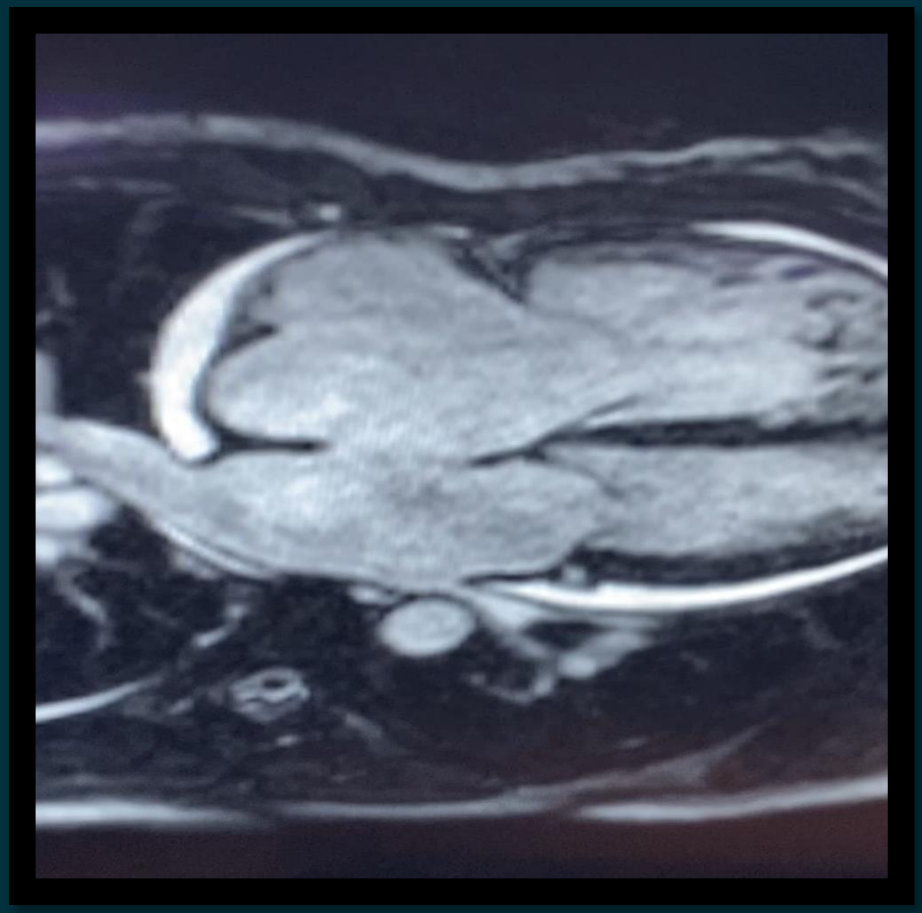
Objectives

Understand	Basic Concepts of Cardiac MRI Physics, Image Acquisition and Safety
Familiarize	What can CMR provide for your patients and how to implement it in your practice?

- 55-year-old morbidly obese man with a rumbling diastolic murmur at the upper left sternal border with an enlarged RV on echo

- What do we order?

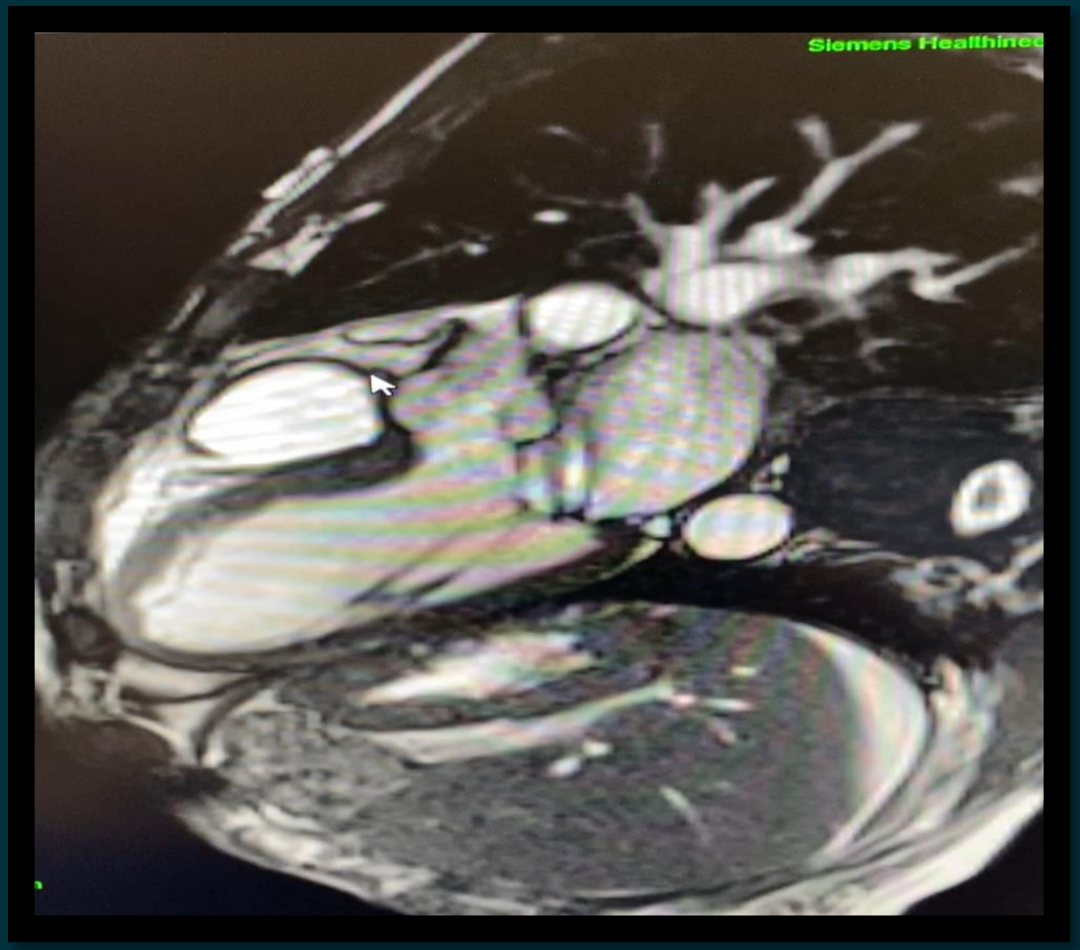
What can CMR do for you?



- 67-year-old woman with history of EtOH abuse, IVDA, esophageal varices who presents with systolic murmur at apex with worsening dyspnea on exertion

- What do we order?

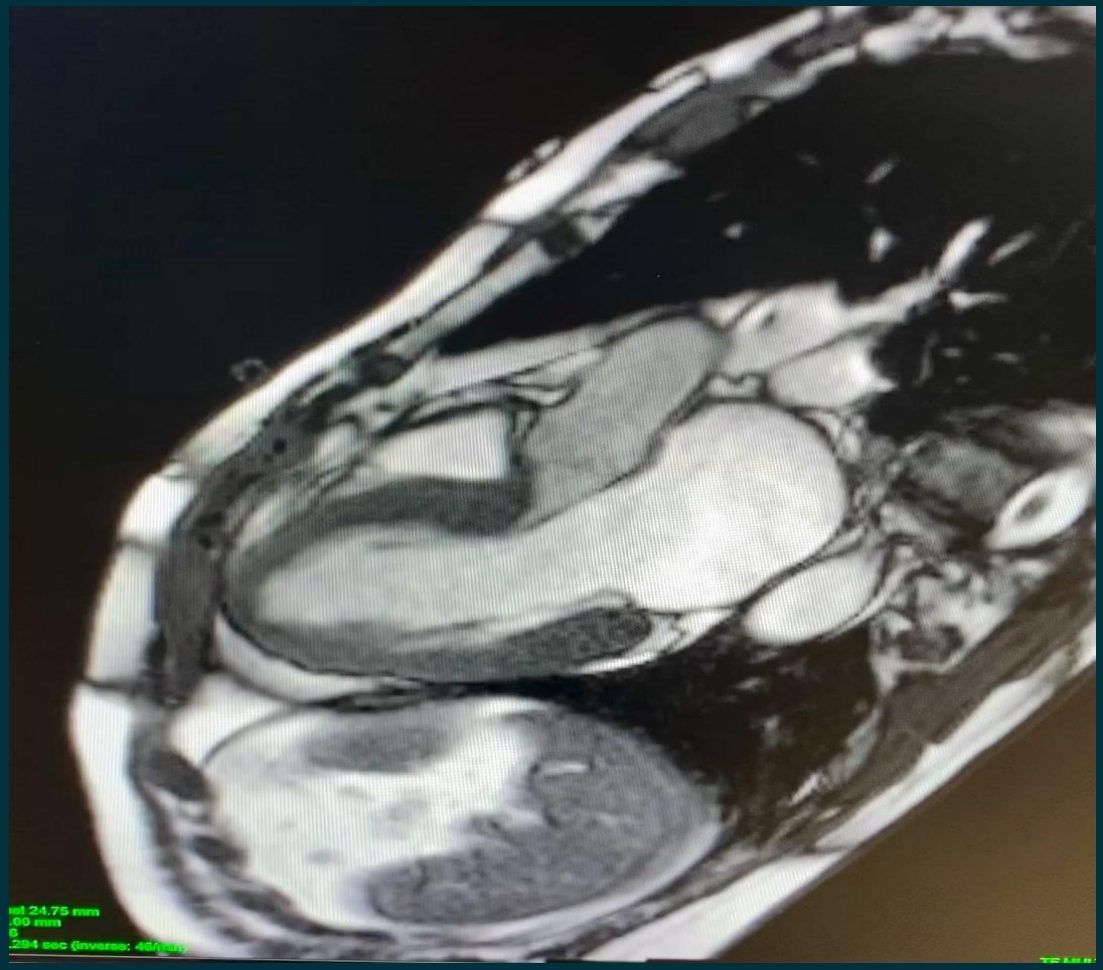
What can CMR do for you?



- 48-year-old man with history of syncope with exercise and LVH on ECG and Echo?

- What do we order?

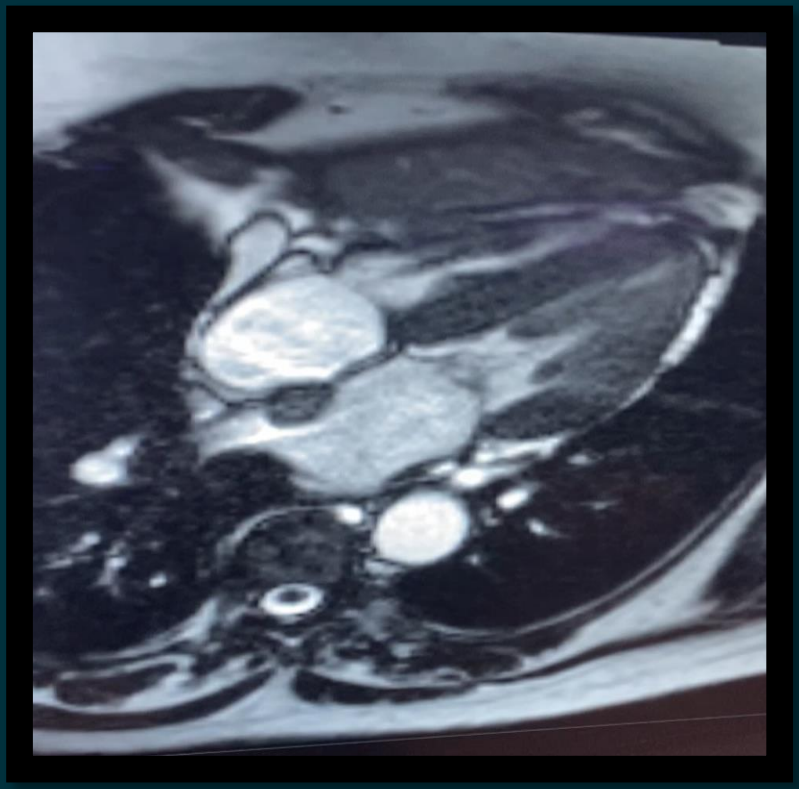
What can CMR do for you?

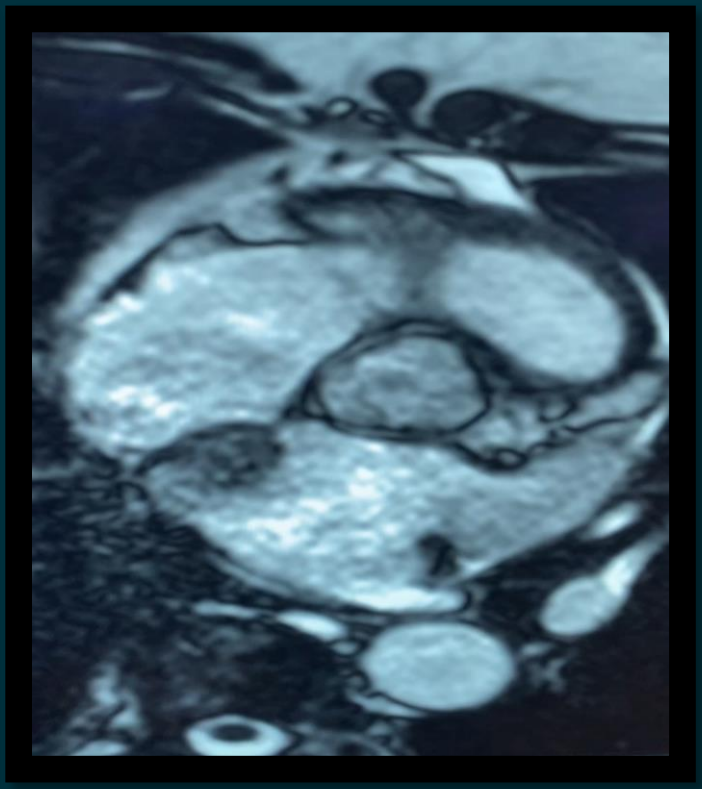


- 41-year-old man with worsening dyspnea and fatigue with an early diastolic murmur and undifferentiated echo density on TTE

- What do we order?

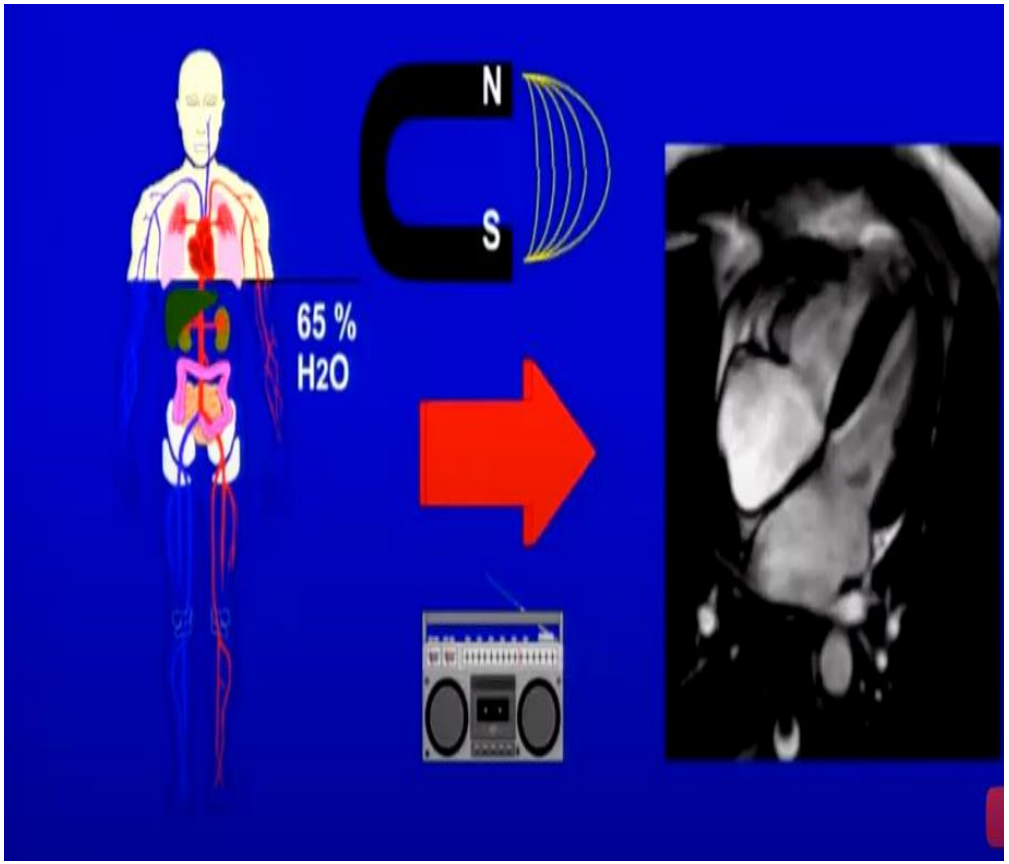
What can CMR do for you?



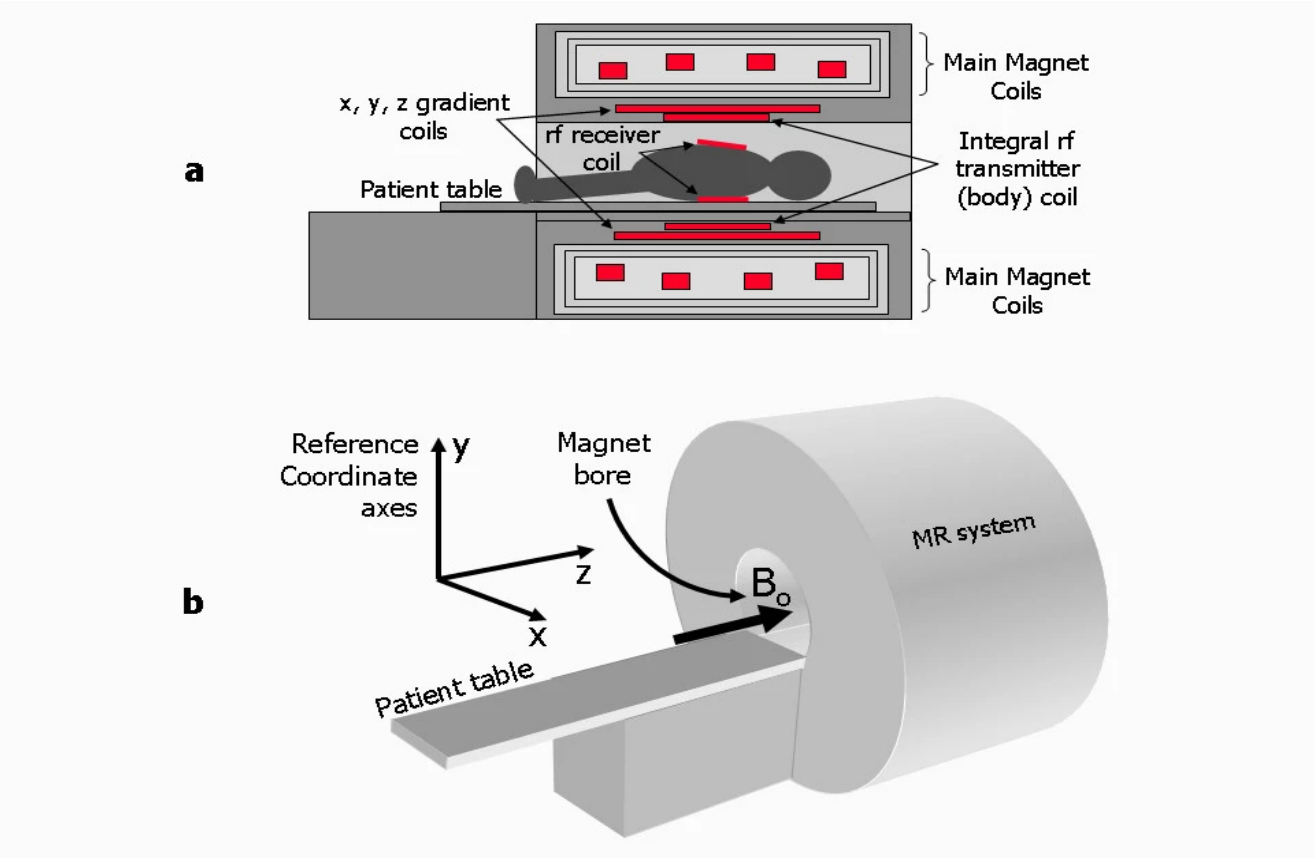


Basics of MRI

- First MRI in human subject was in 1977
- 2/3 of body is composed of water (H2O)
- Hydrogen is the most important element for MR imaging

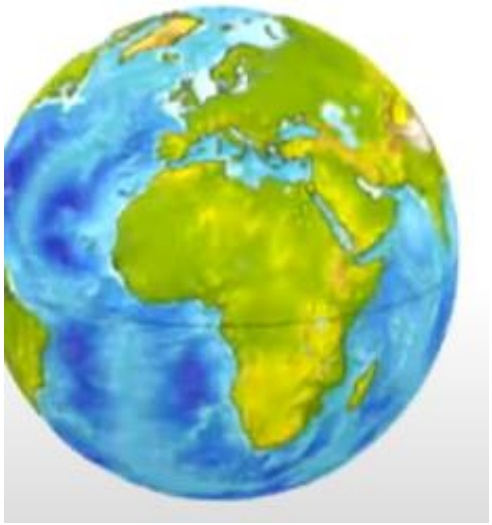


MR System Components



Main Magnet

- Strong, constant magnetic field
- Defines the strength of the MR System
- 1 Tesla is 20,000 times the Earth's magnetic field

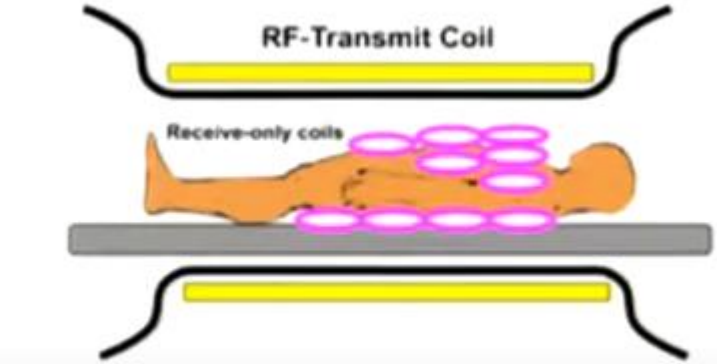


Gradient Coils

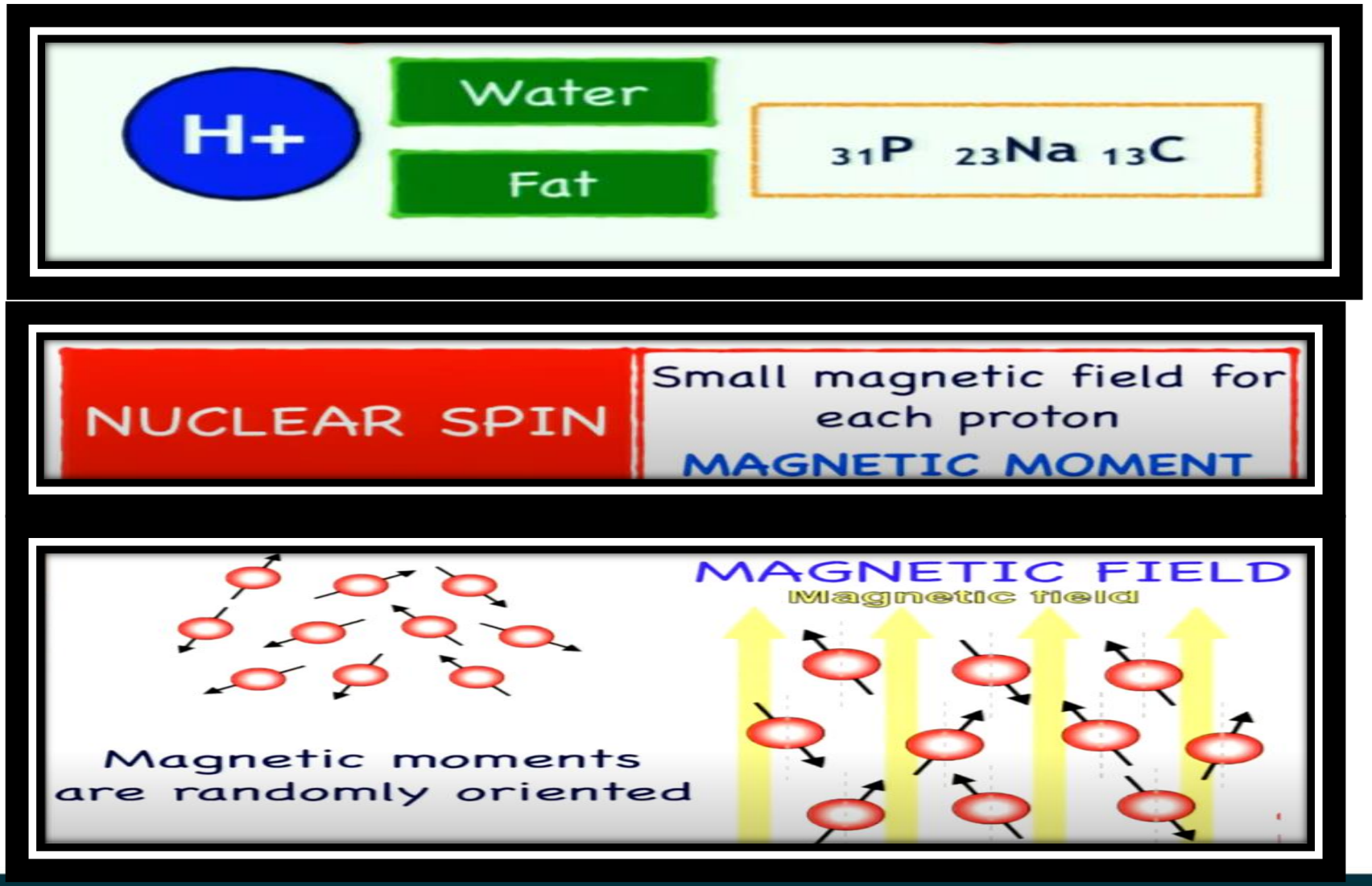
- Generate a magnetic field
- They are within in the MRI system
- Generate alteration in the MR field
- Aligned in variety of different directions—gradient in all three directions
- Strength is defined as the steepness of its slope (mT/m)

Radiofrequency Coils

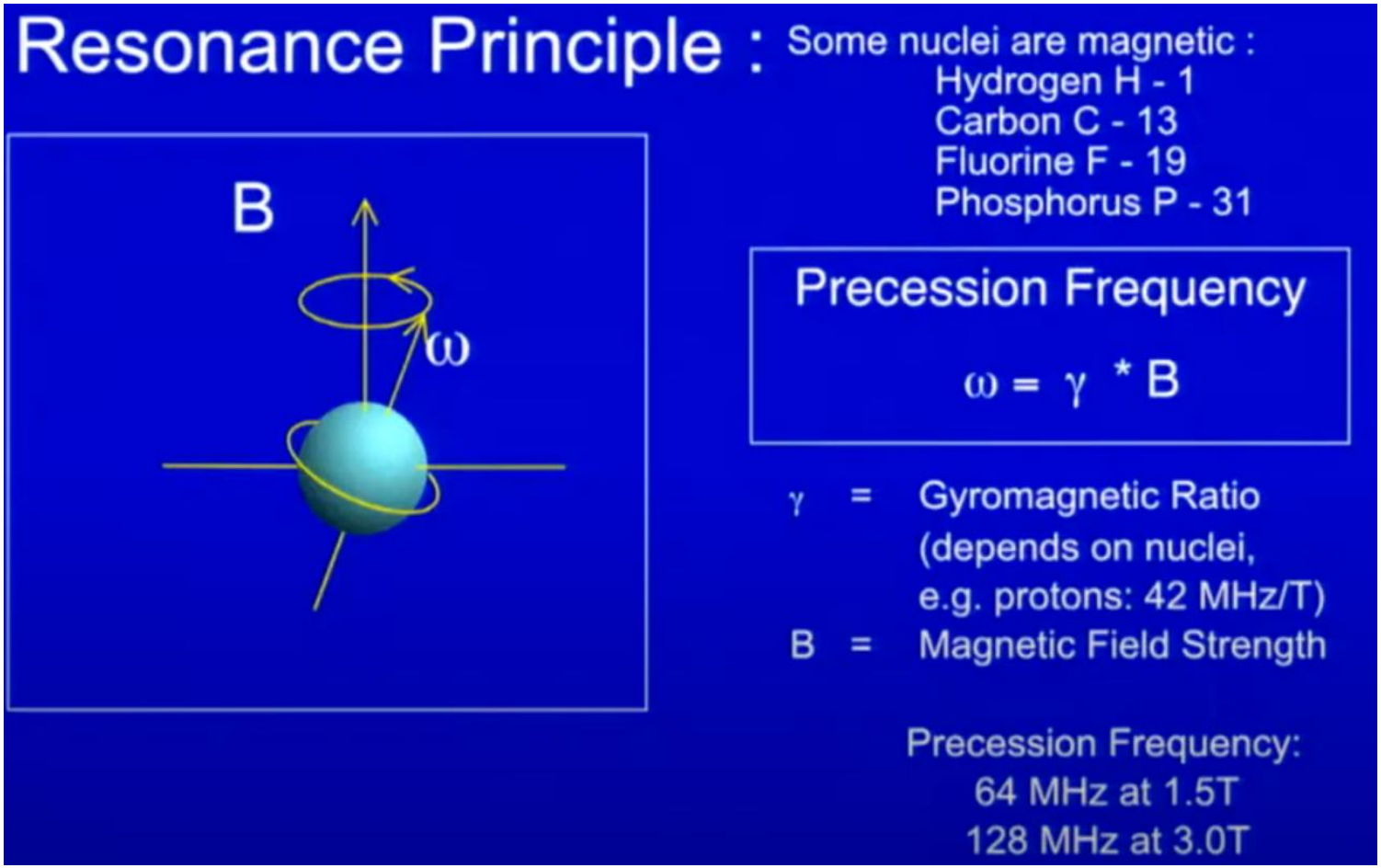
- Transmitter RF Coils
  - Smaller amplitude than other fields
  - Generate RF magnetic field
- Receiver RF Coils receive the wave to generate MRI image



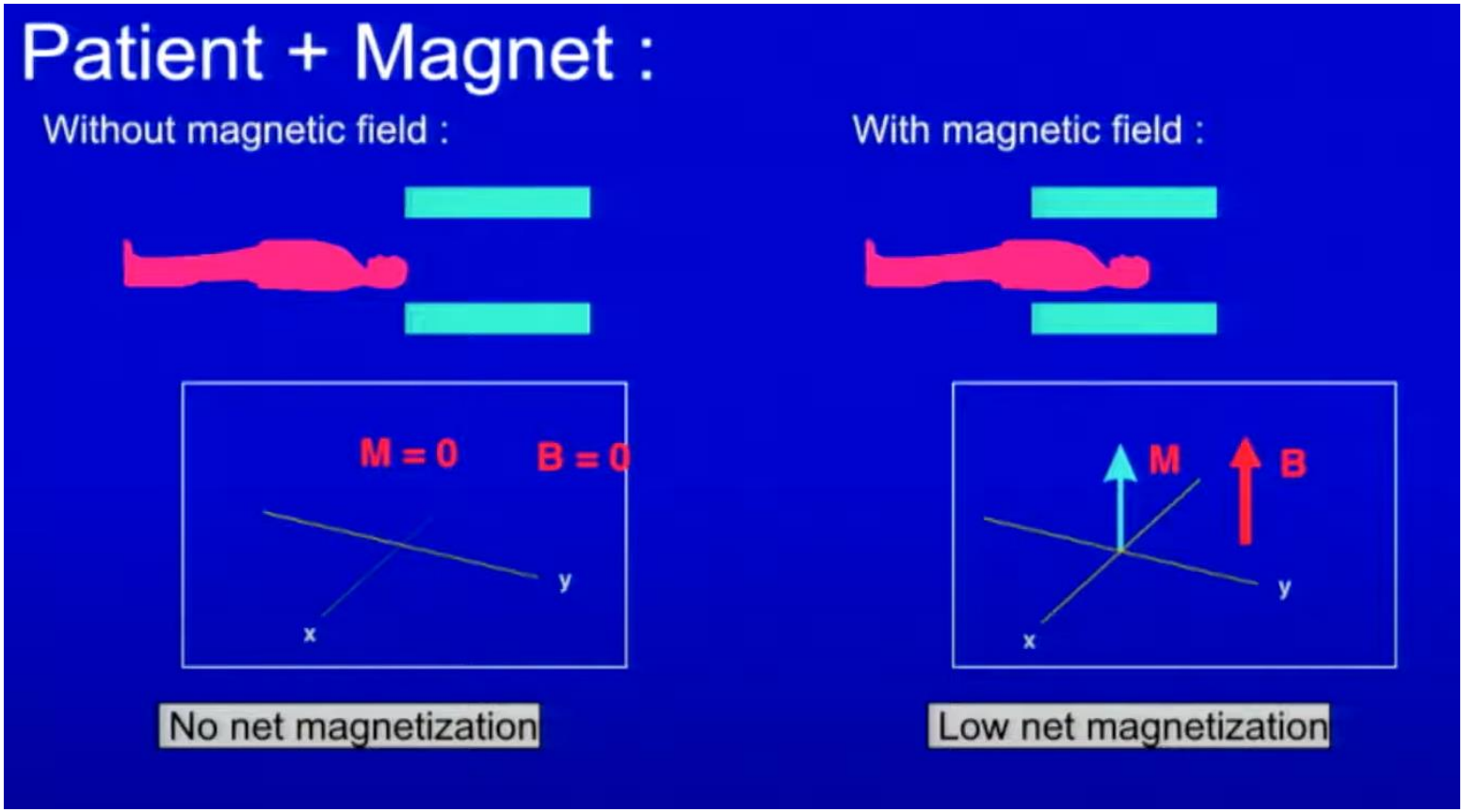
Origin of the MR signal



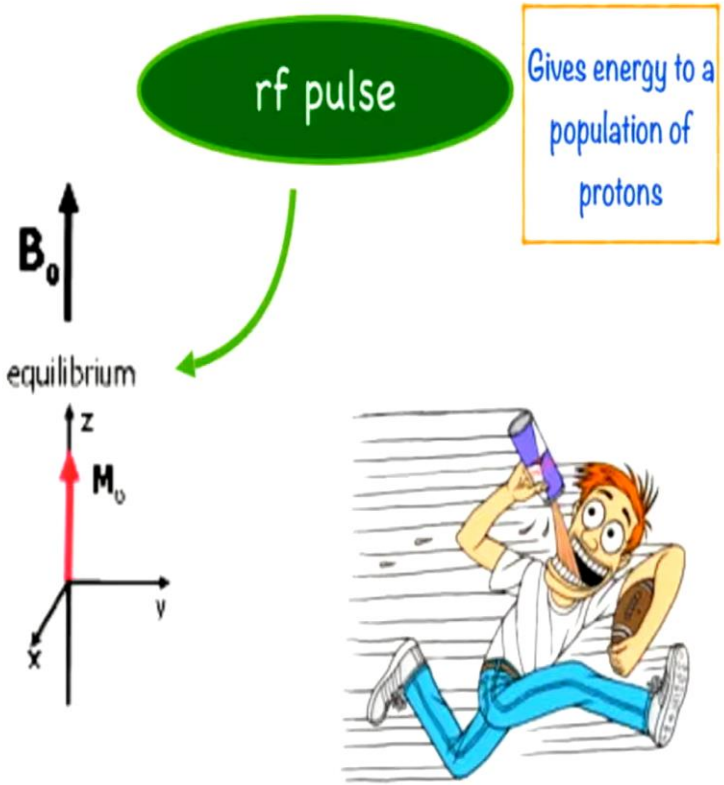
Larmor Equation

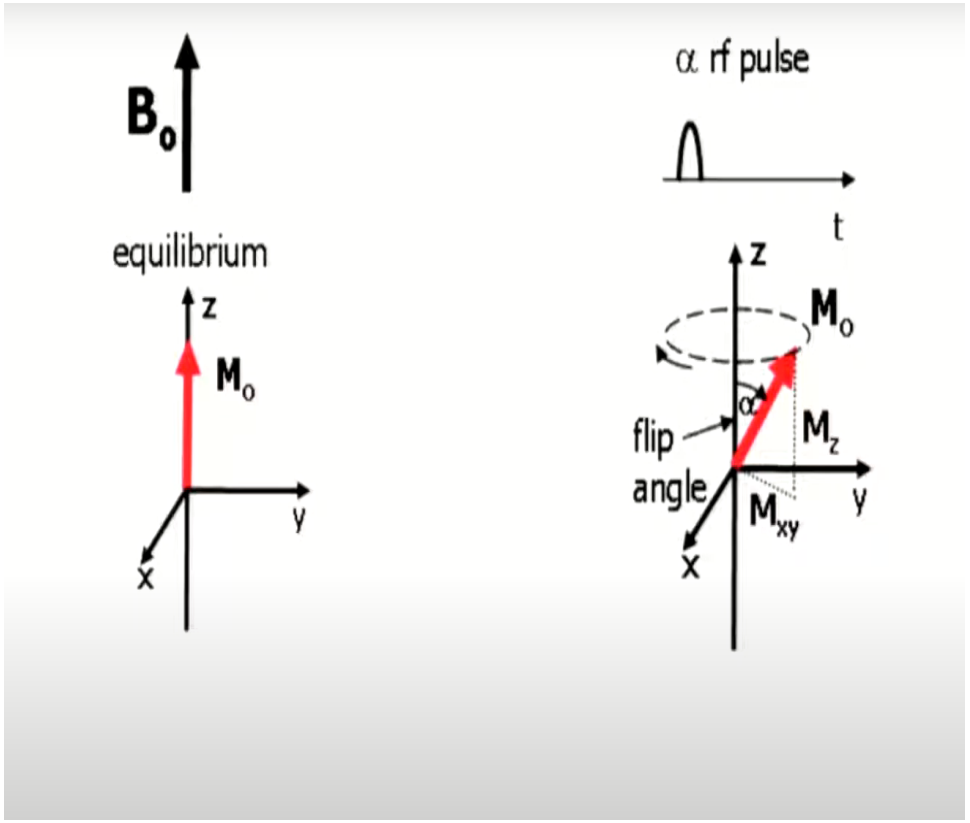


Scanner Magnetization



Excitation Pulse

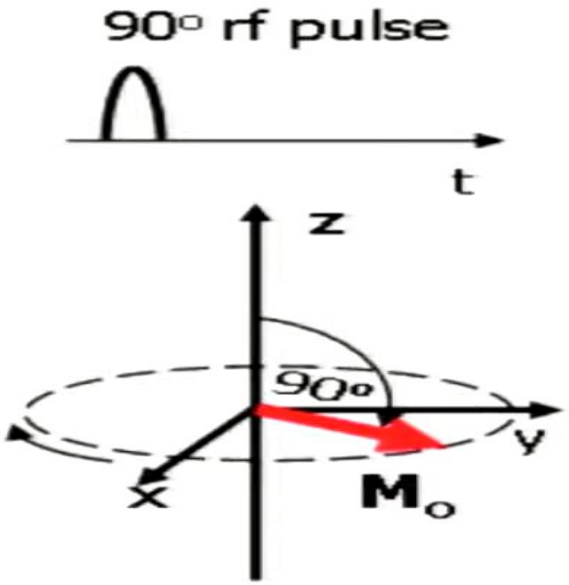




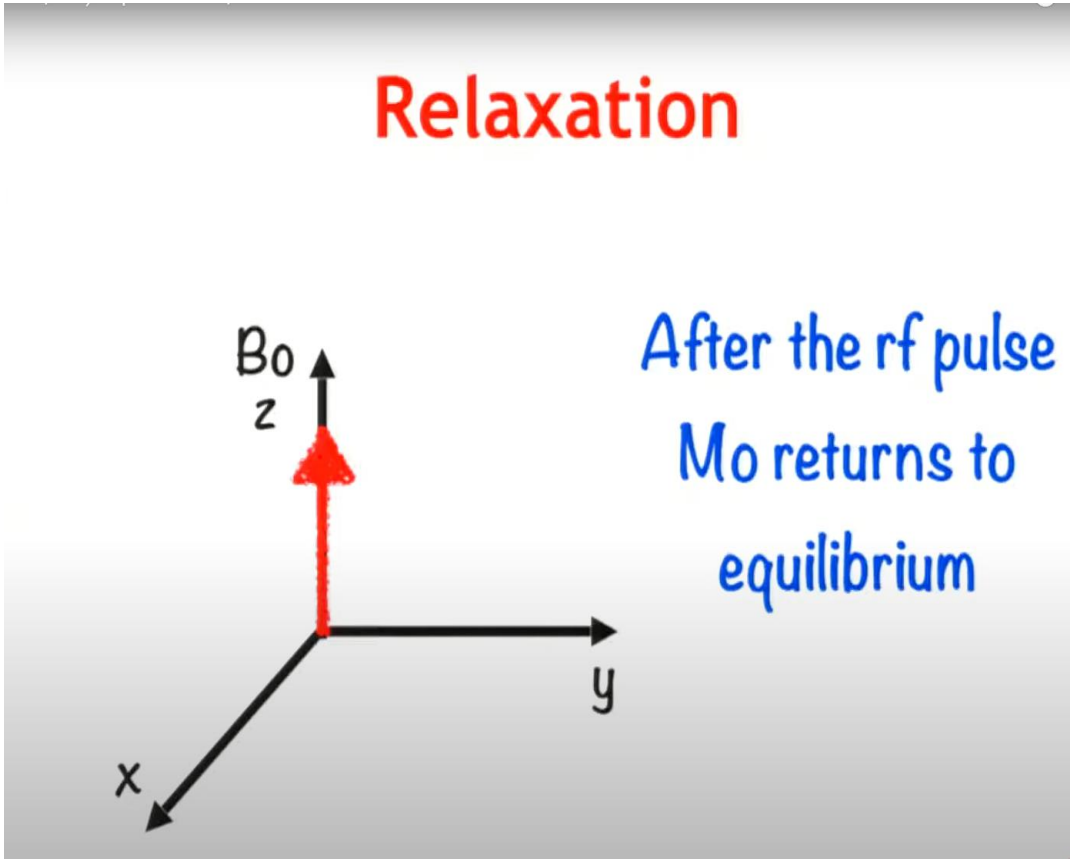
Saturation Pulse

Saturation Pulse

90°

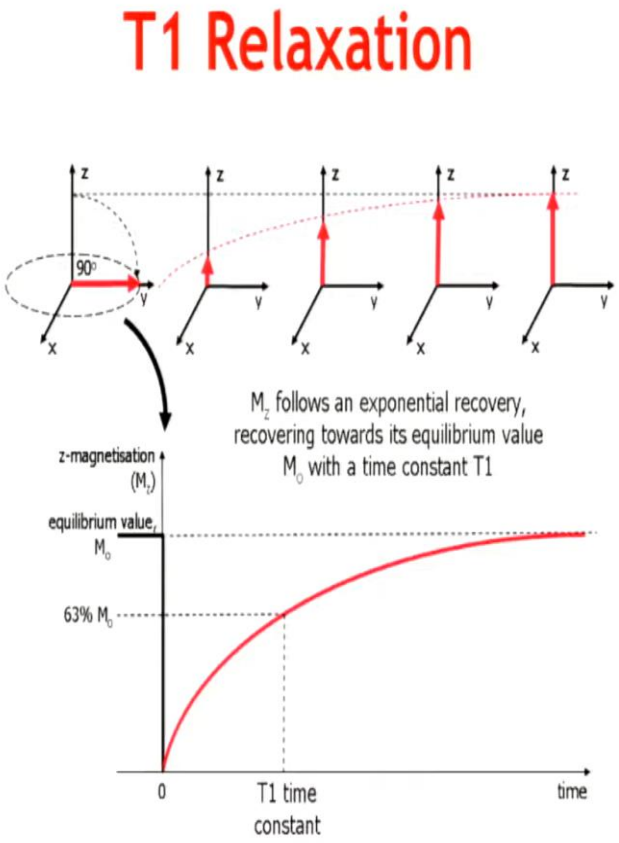


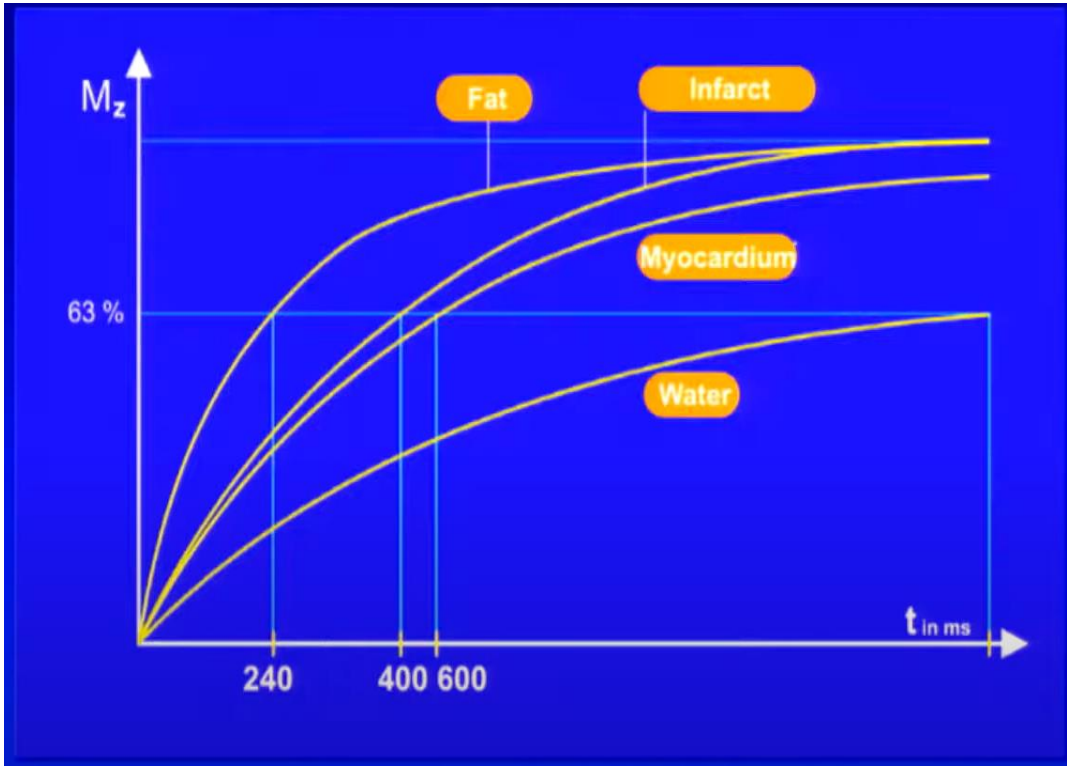
MR Relaxation



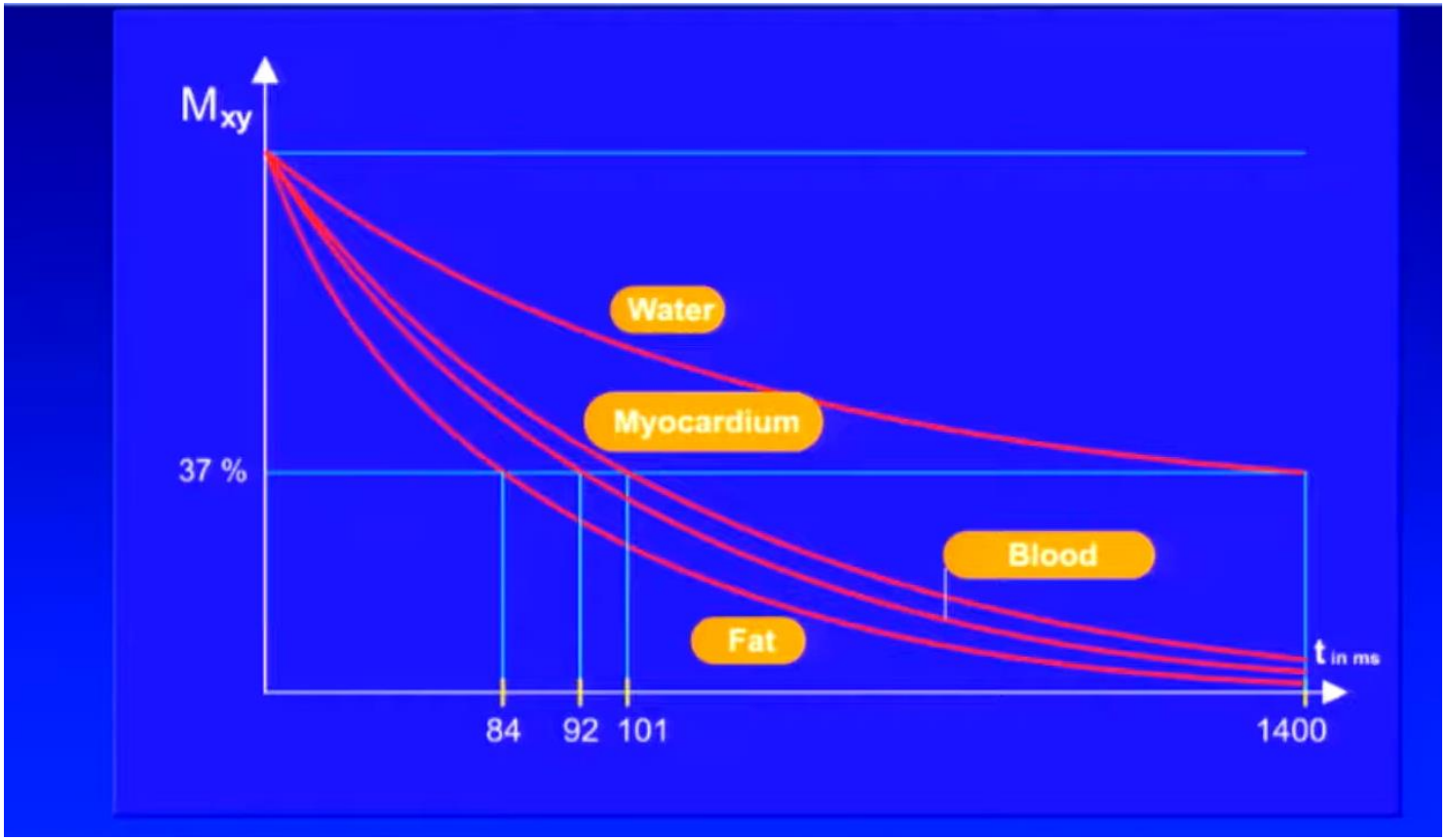
Longitudinal	Transverse
M_z	M_{xy}
T_1	T_2^*

T1 Relaxation



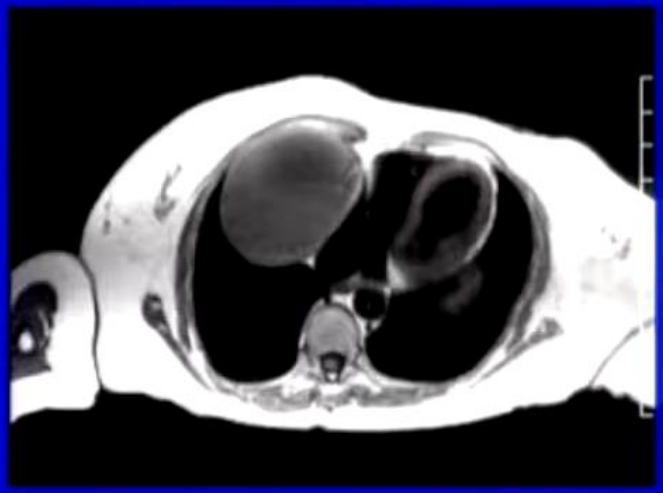


T2 Time



T1 and T2 Weighting Imaging

Dark Blood T1 Spin Echo



Dark Blood T2 Spin Echo with Fat Supression (FS)

T1 spin echo characteristics:

- *Fat = high signal intensity*
- *Moving blood = low signal intensity*
- *Water = intermediate signal intensity*

T2 w/ FS spin echo characteristics:

- *Fat = low signal intensity*
- *Moving blood = low signal intensity*
- *Water = high signal intensity*

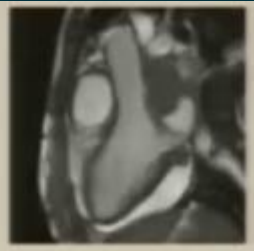
Siemans Altea 1.5T

MRI Safety

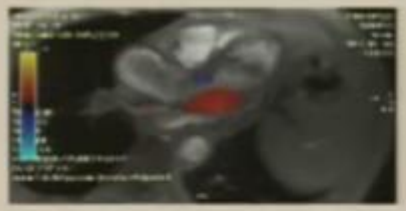
Cardiac MRI Contraindications – The Magnet is ALWAYS ON!!!

- Cerebral Aneurysm Clips.
- Pacemakers/ICDs (relative). New MRI-conditional systems are now available.
- Pulmonary artery catheters.
- Cochlear Implants.
- Retained metallic foreign bodies.
- All prosthetic valves are safe, including TAVR (exception pre 1968 Starr Edwards Valve).
- Severe renal impairment (GFR < 30) → can't use Gadolinium

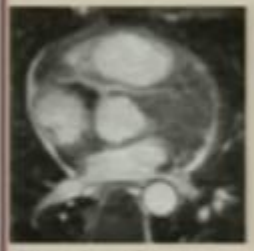
Stress Perfusion



Cardiac Mass



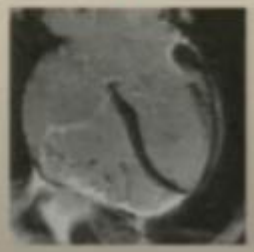
Valve Disease



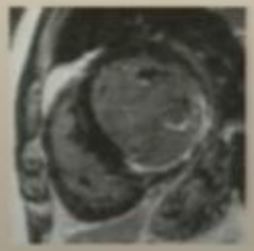
Anomalous Coronaries

CMR

Pericardial Constriction



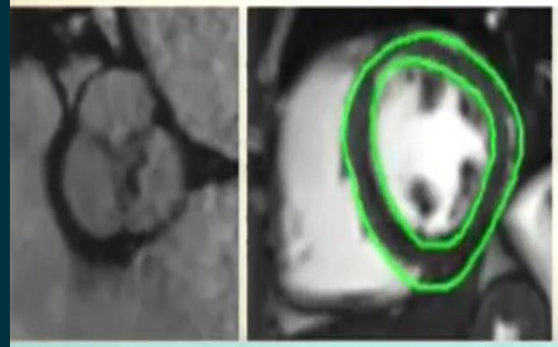
RV Dysplasia



Viability/Cardiomyopathy

- Structure & Function
- Myocardial Viability
- Cardiomyopathy
- Valvular Heart Disease
- Stress Myocardial Perfusion/Ischemia Evaluation
- Left Atrial/Pulmonary Vein Imaging (for A-fib ablation planning)
- Pericardial Diseases
- Cardiac Masses
- Vascular Assessment

Uniqueness of CMR Imaging



Parameters	Values
LVEF (%)	42 (55 – 70)
LVEDVi (ml/m²)	112 (68-103)
LVESVi (ml/m²)	65 (19 – 41)
LV Mass index (g/m²)	103 (59 – 93)

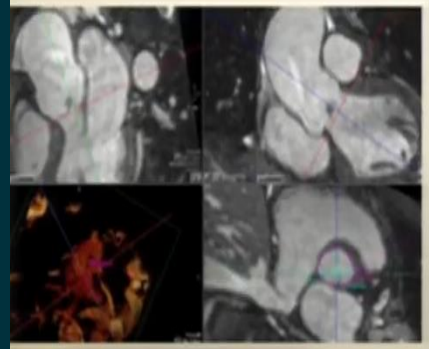
Valve + Biventricular Function

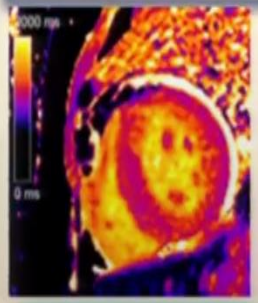
Structural Remodeling

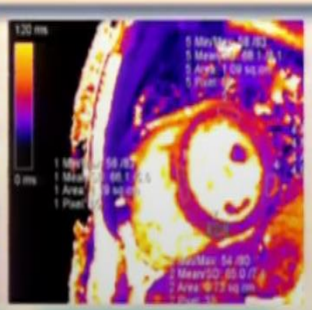
Flow and Velocities

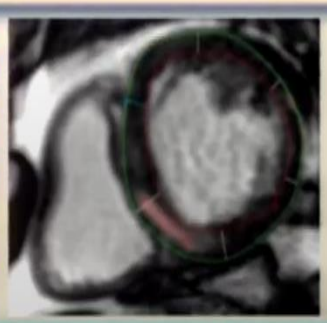
Perfusion

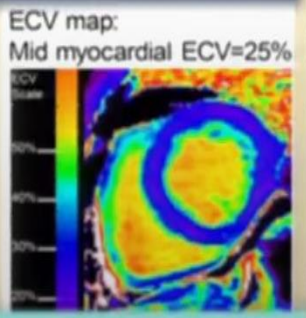
Tissue Characterization











3D Anatomy

T1 Mapping

T2 Mapping

LGE – Replac. Fibrosis

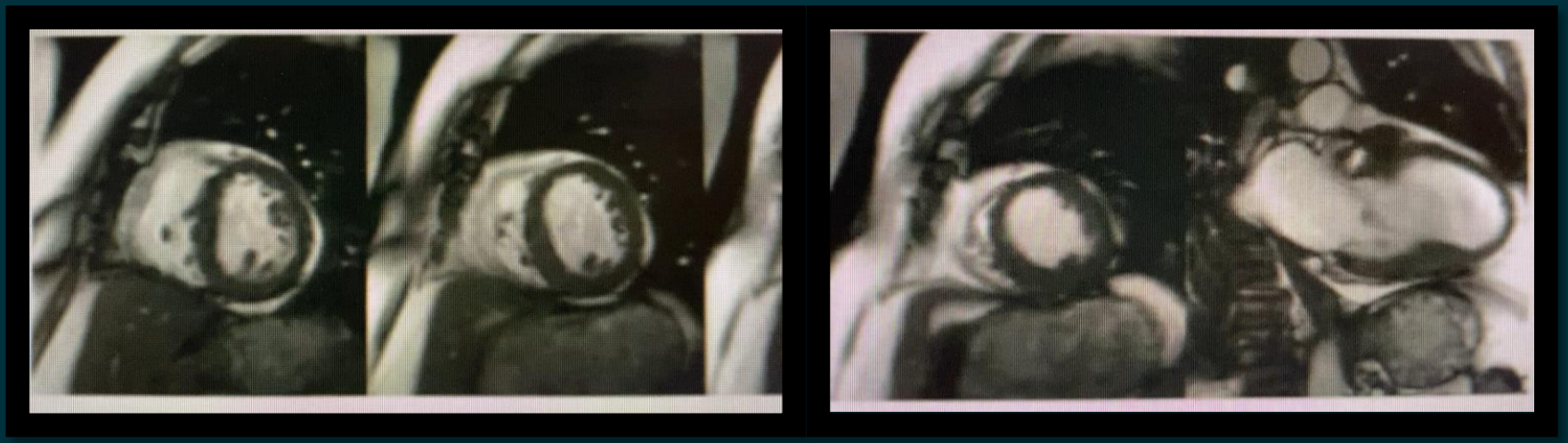
Interstitial Fibrosis

Function and Viability Case

- 63 M with DM with dyspnea on exertion for 3 months. Nuclear Stress test shows **fixed defect in LAD distribution (implies scar)**. LHC shows a 90% proximal LAD lesion.

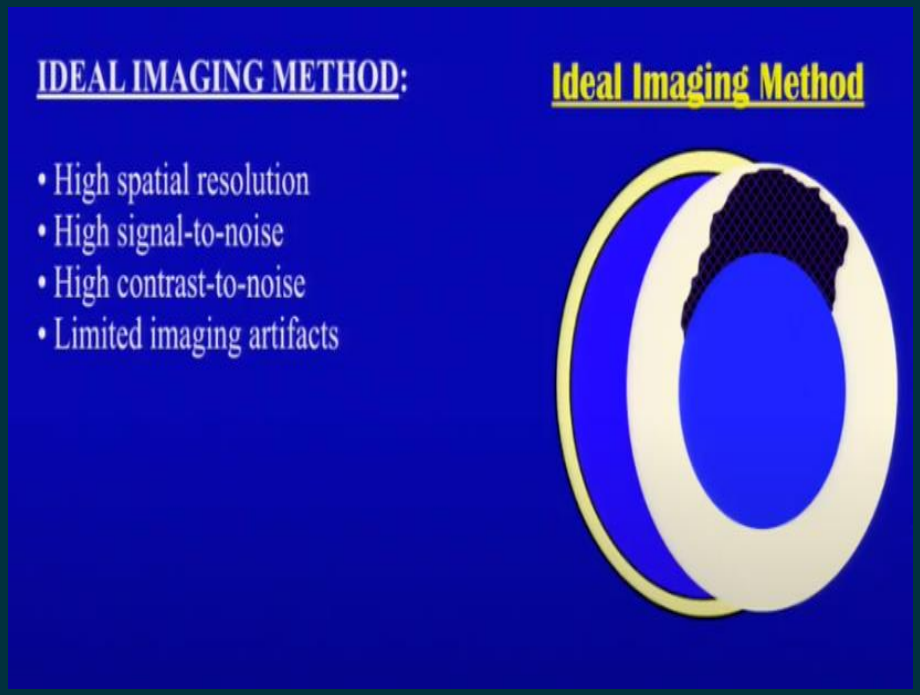
- Echo prior to LHC showed an akinetic, thinned out anterior apical wall

Function and Viability Case

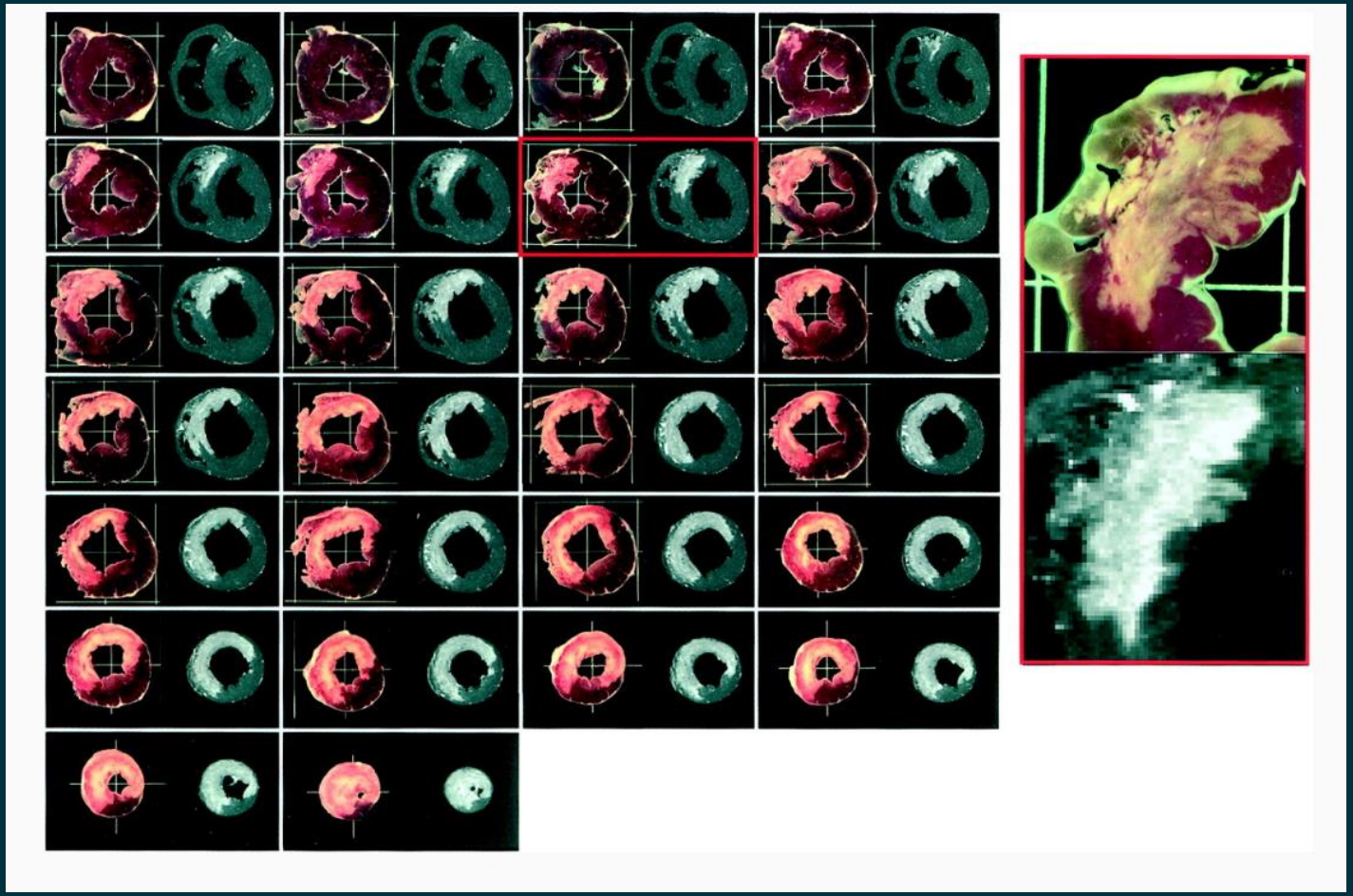


What is myocardial viability?

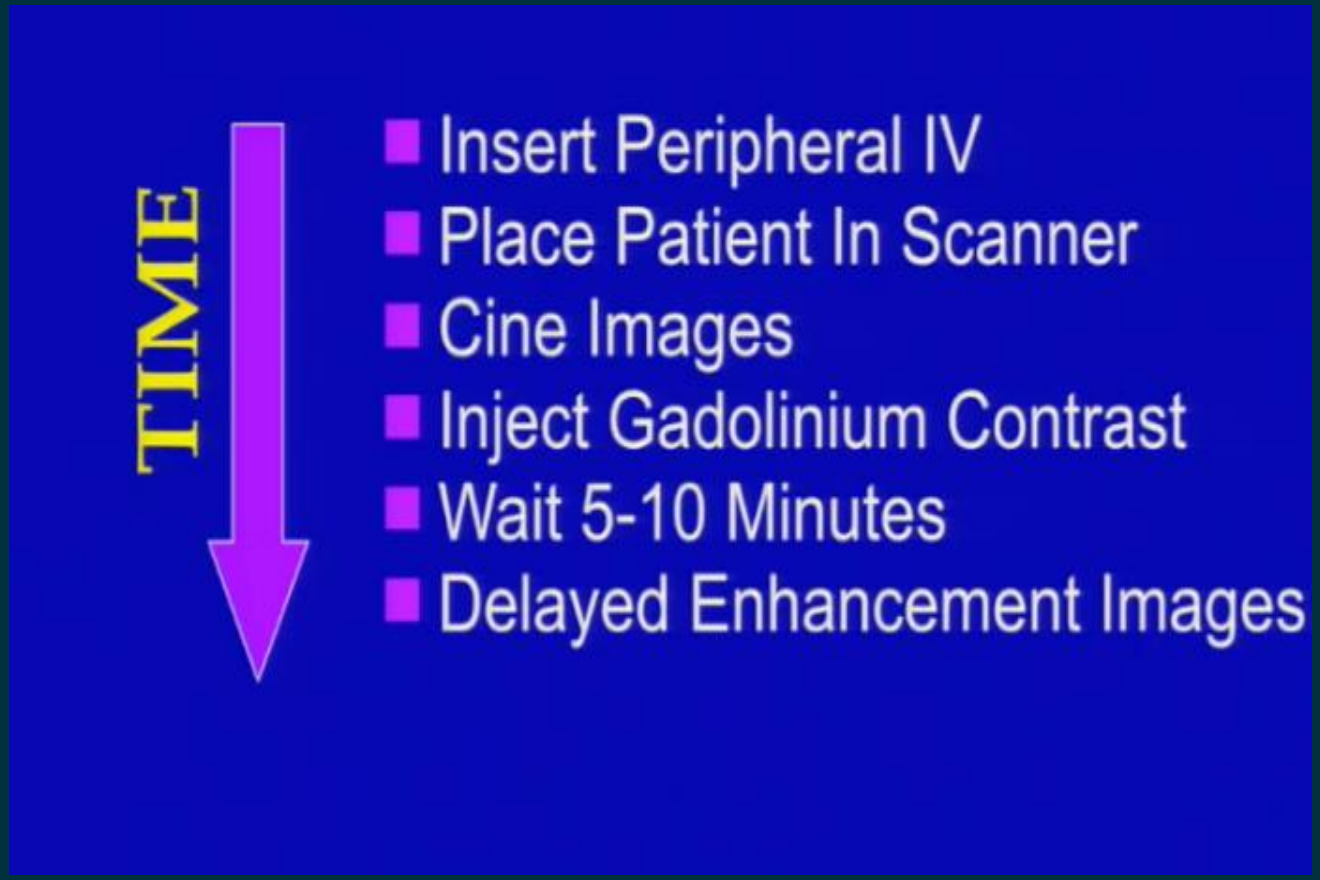
- Clinical Definitions
  - Improvement in contraction after revascularization
  - Improvement in contraction with low dose dobutamine
  - Absence of fixed thallium defect
  - Presence of glucose uptake
  - Preserved wall thickness and/or thickening
- Histologic Definition
  - Presence of living myocytes



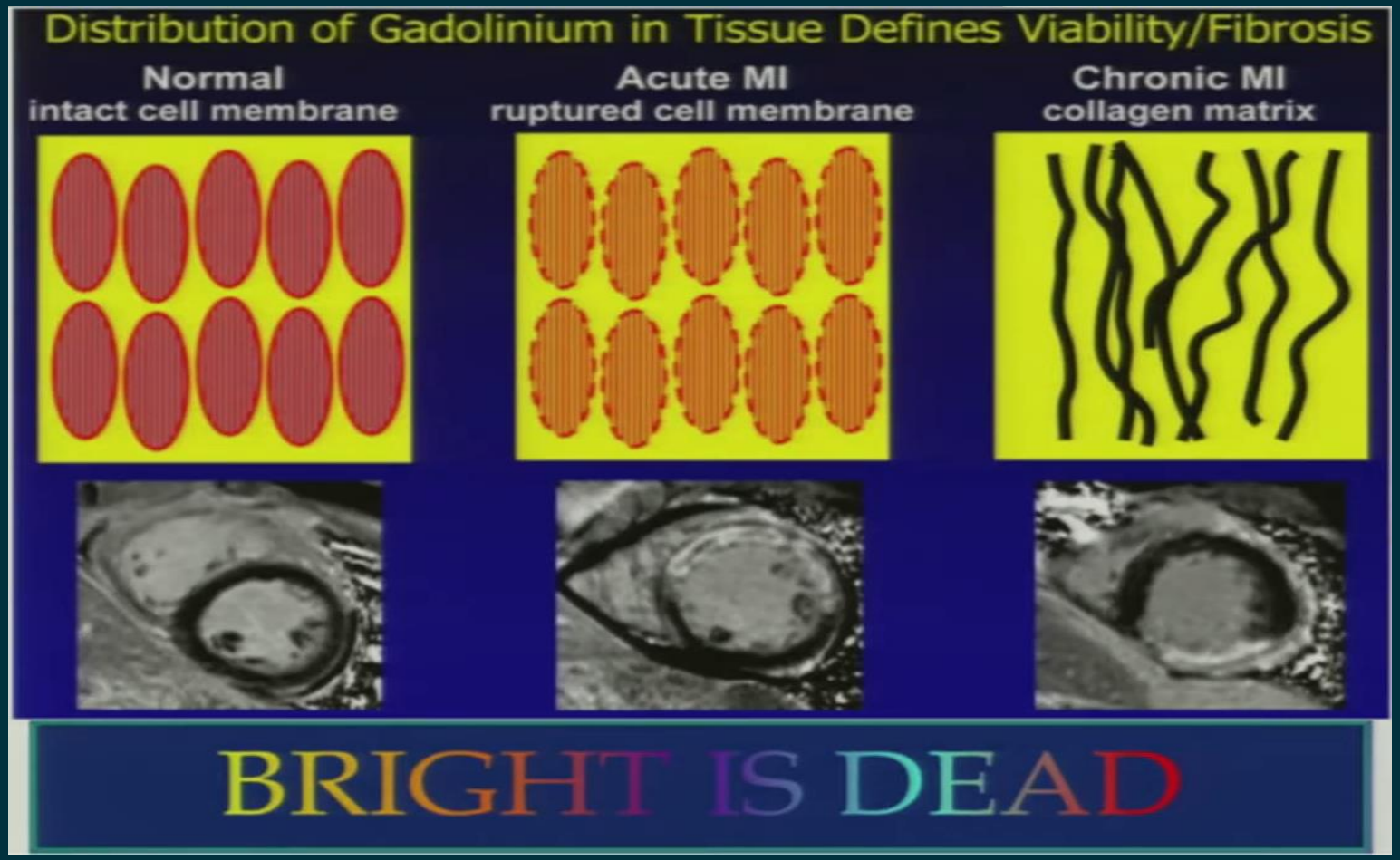
CMR Viability Assessment



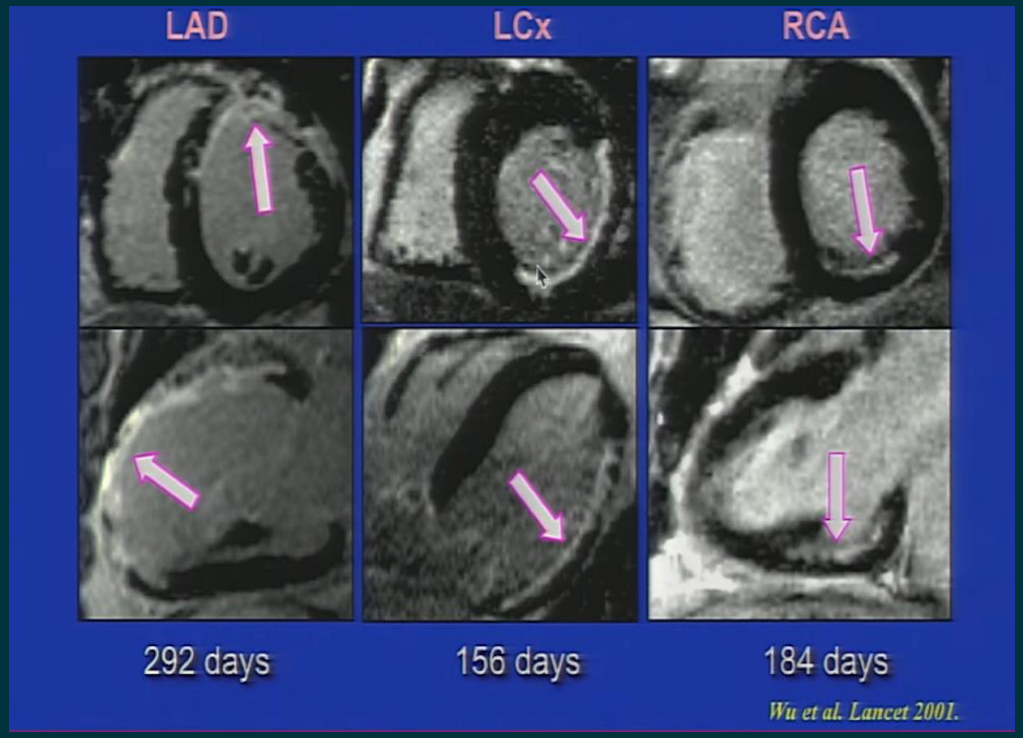
Viability Protocol

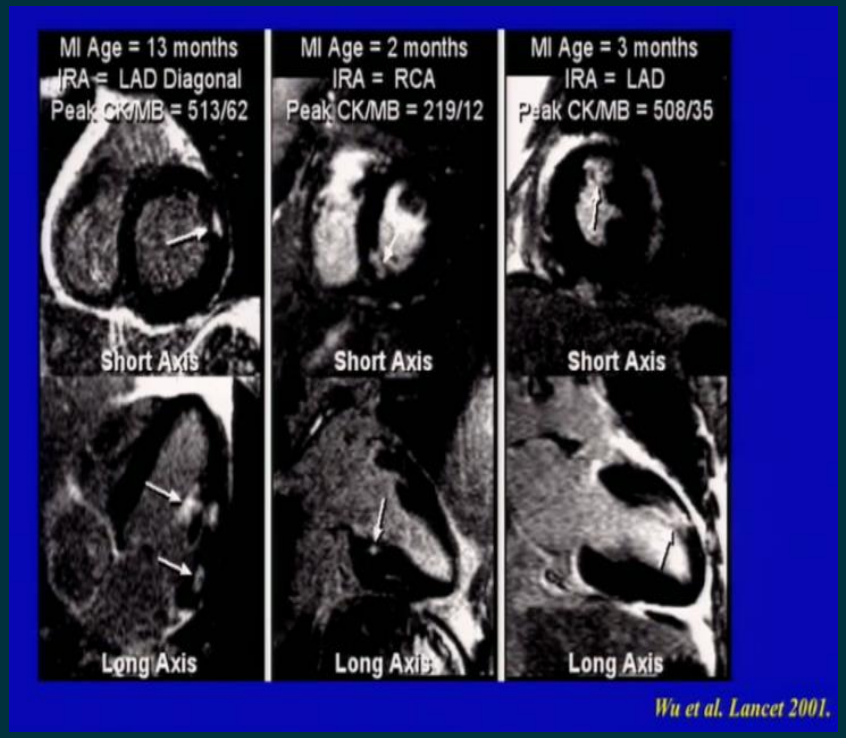


Late Gadolinium Enhancement

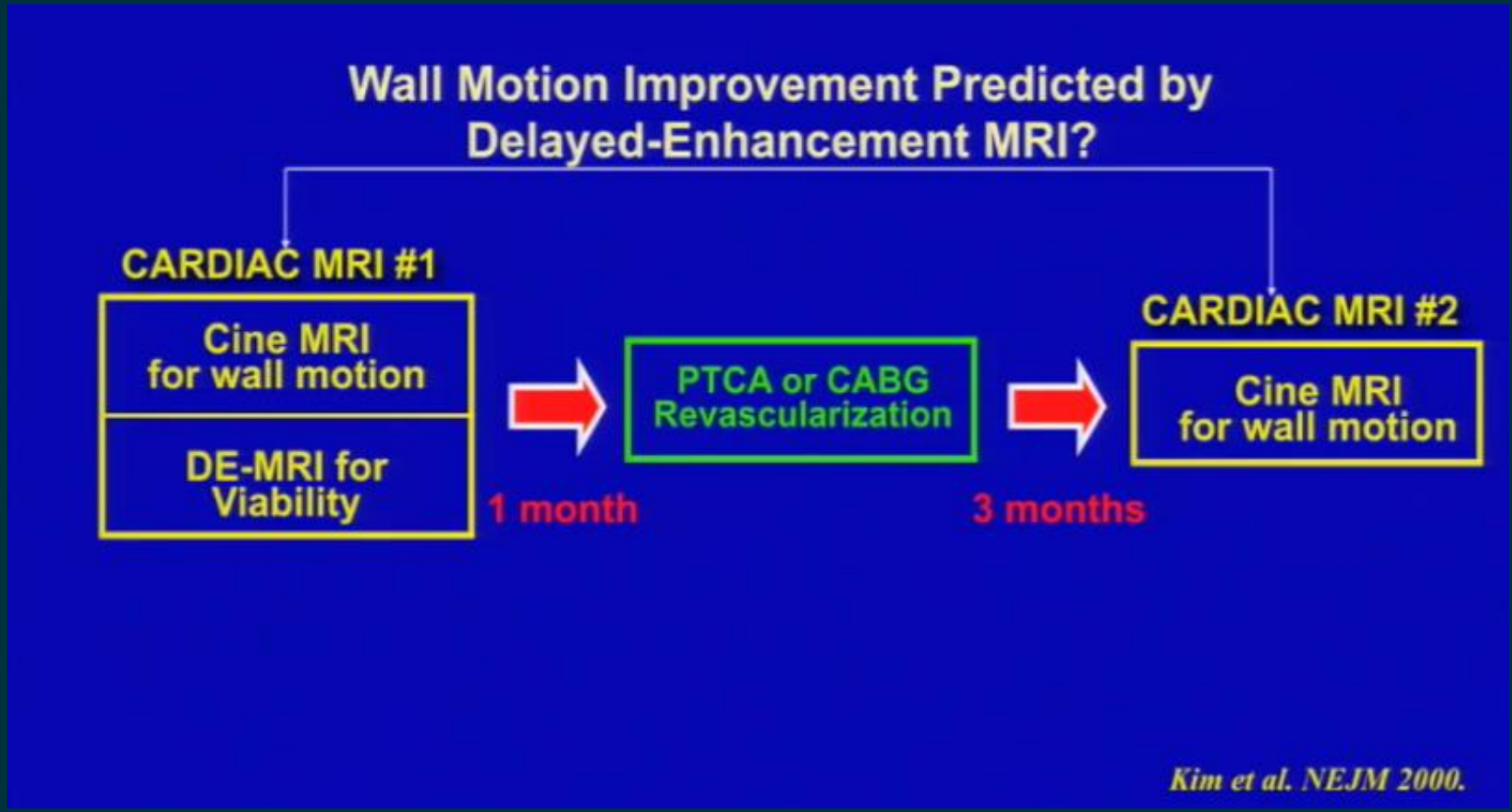


Infarct Vessel and LGE CMR

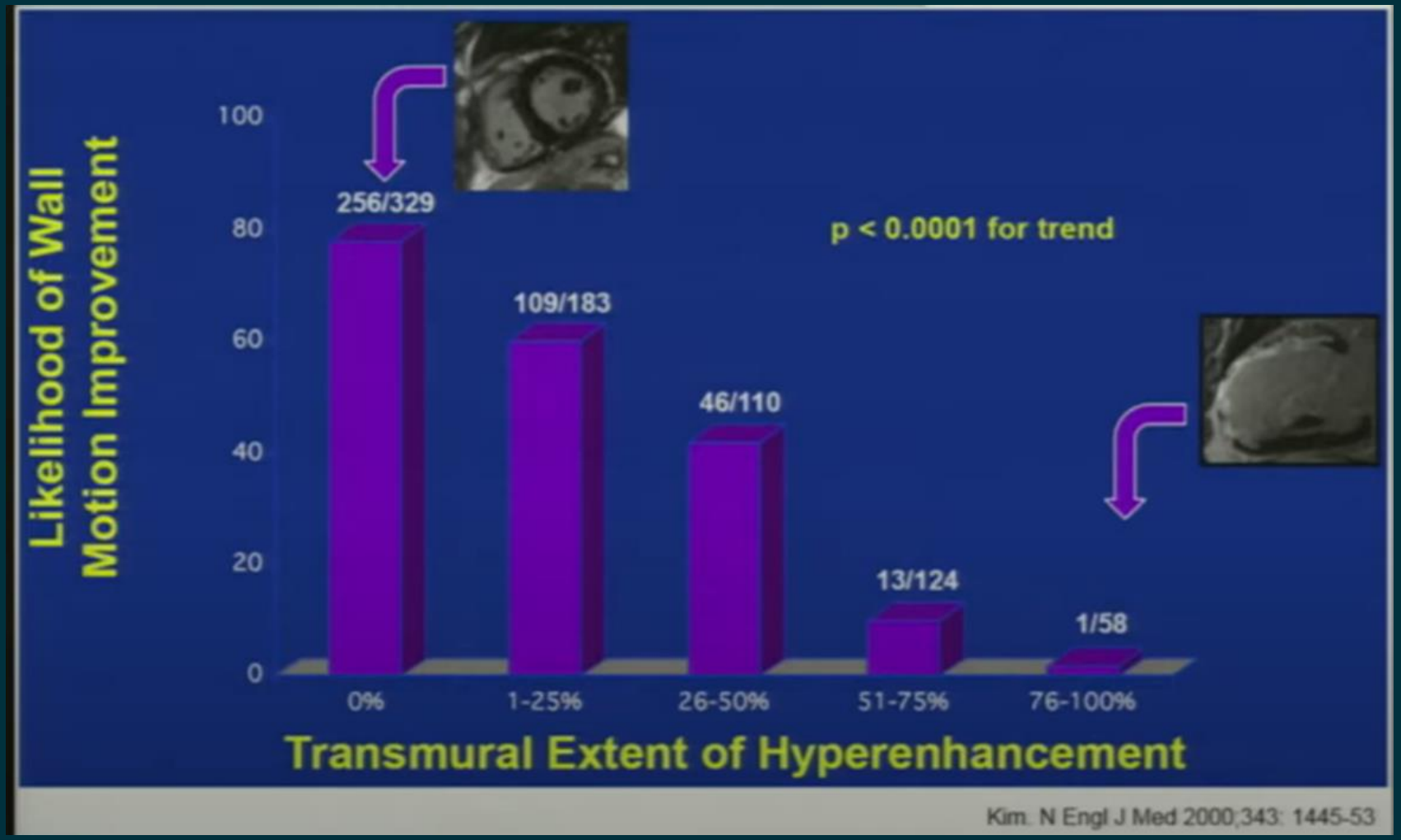




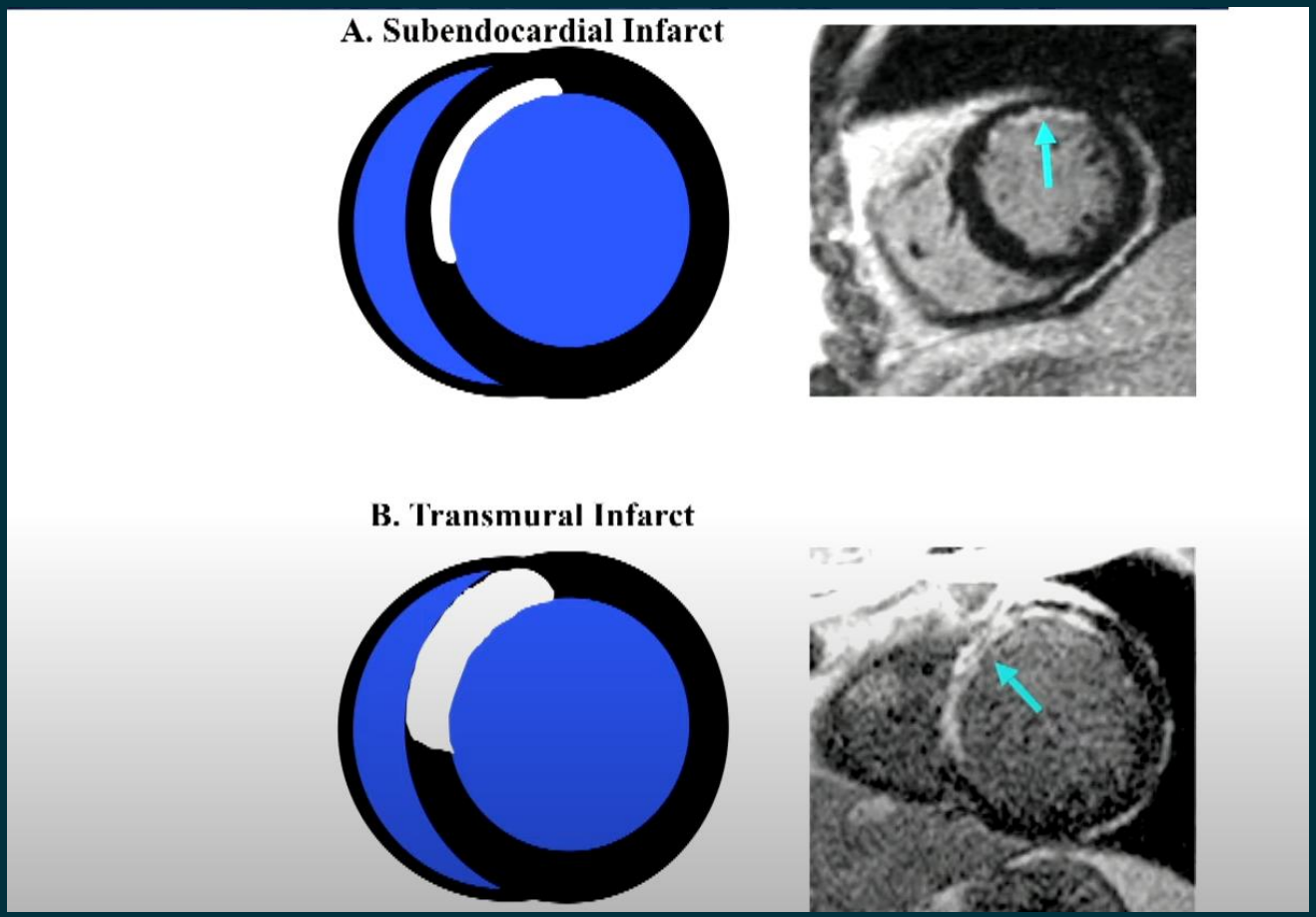
Revascularization Protocol



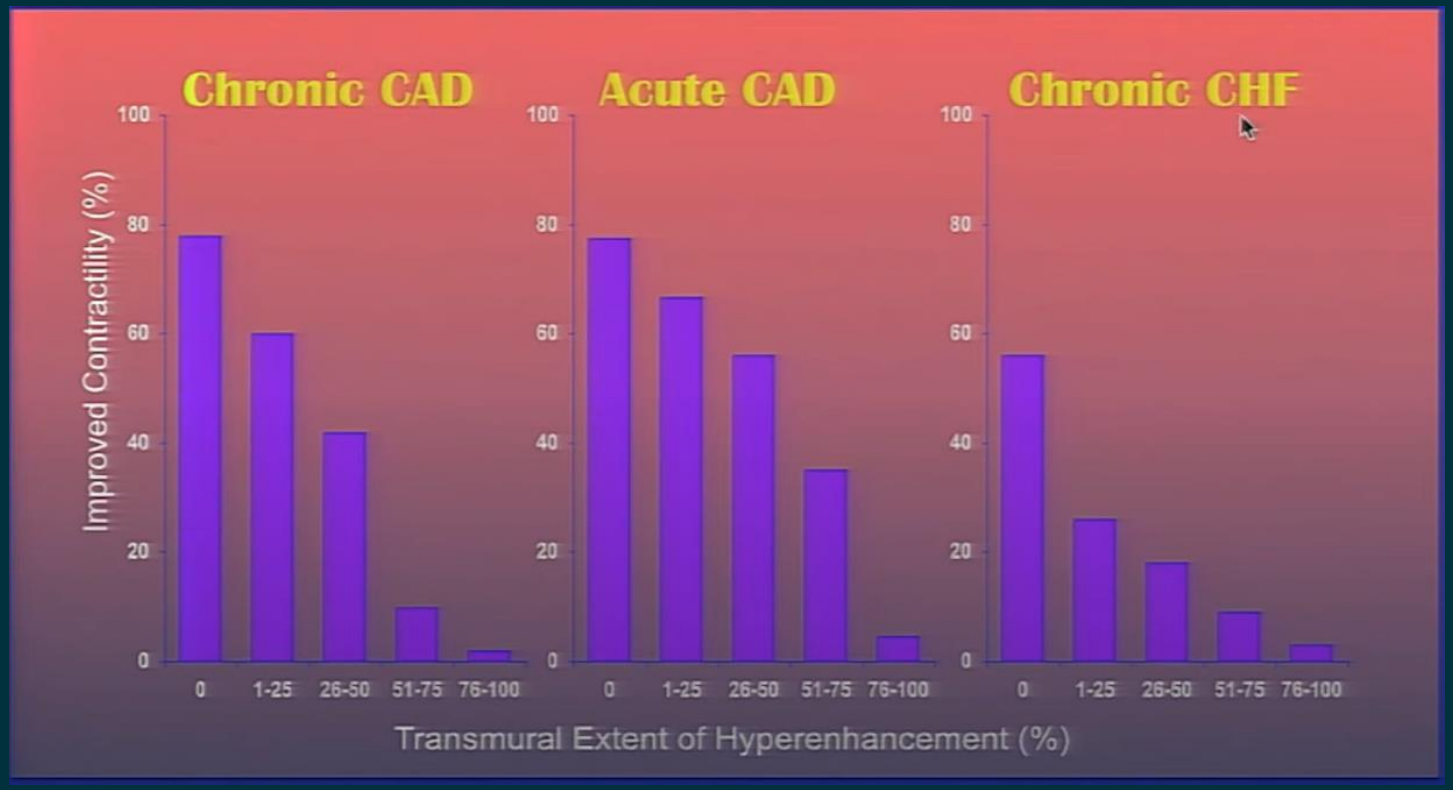
LGE Determines Myocardial Viability & Predicts Recovery of Function After Revascularization



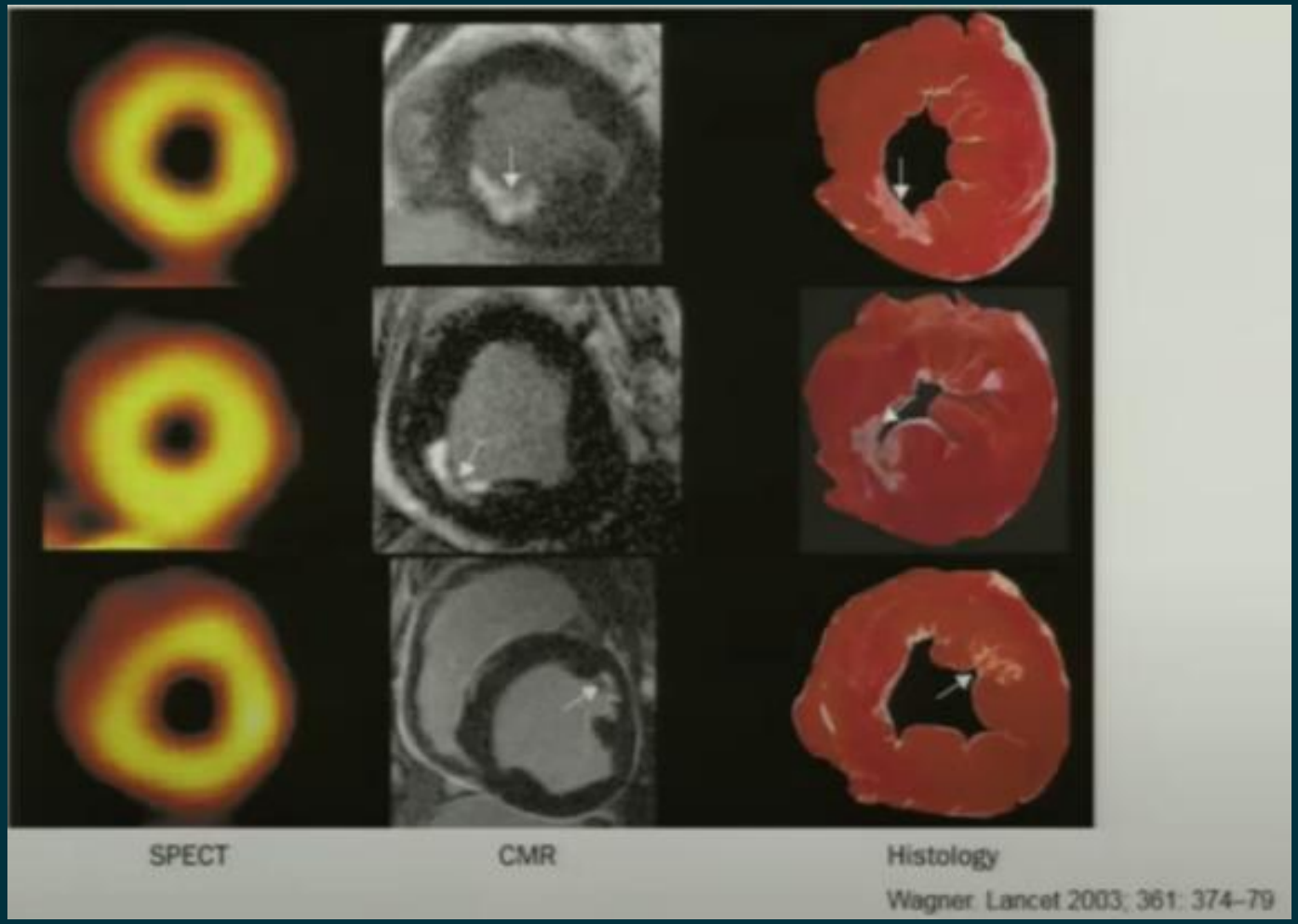
Ischemic Enhancement Pattern



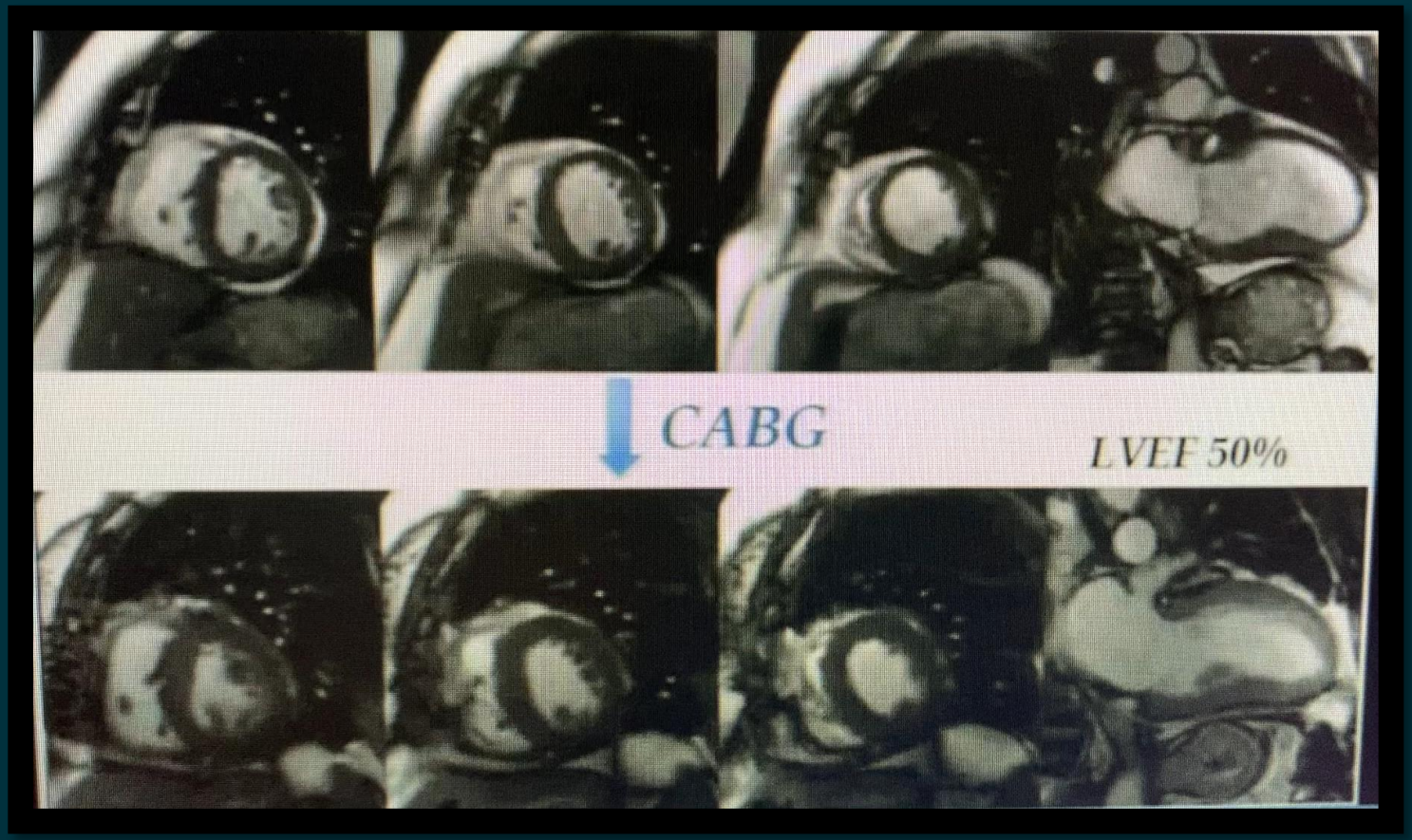
LGE and Myocardial Viability



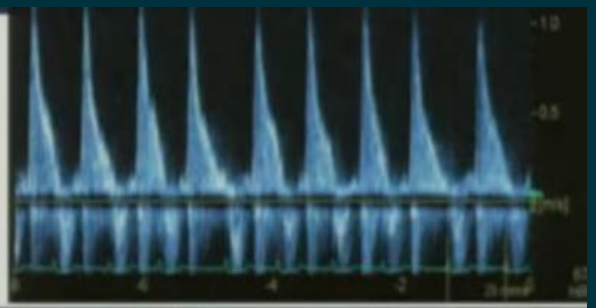
CMR Detects Subendocardial Infarcts Missed by SPECT



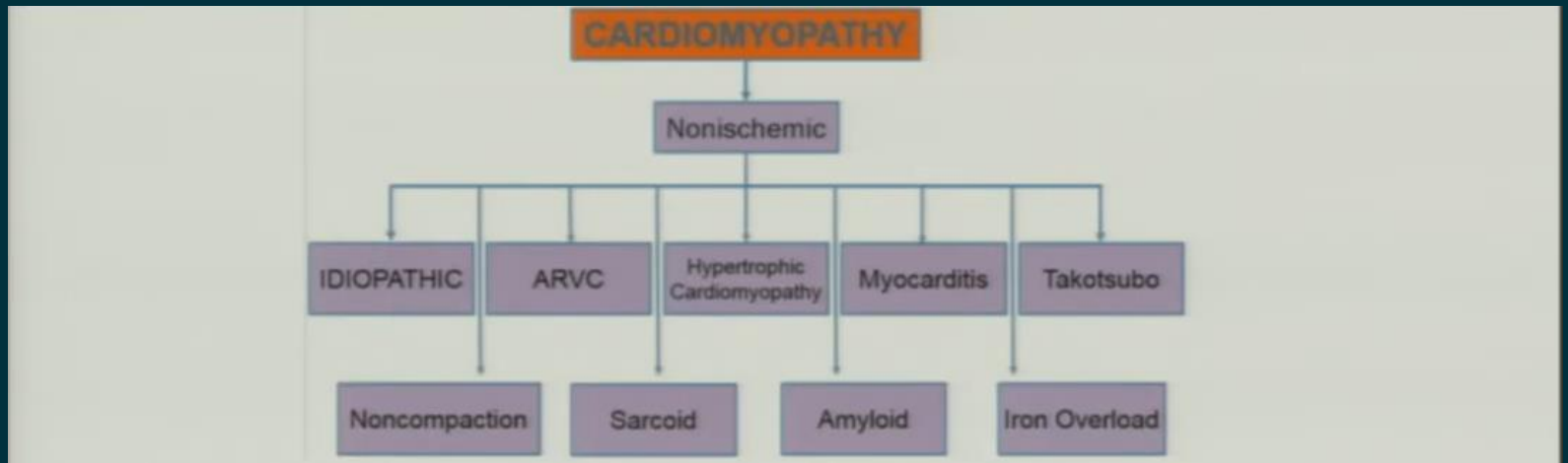
Post Revascularization



75F with PMH of HTN, CKD3, A Fibrillation presets with SOB



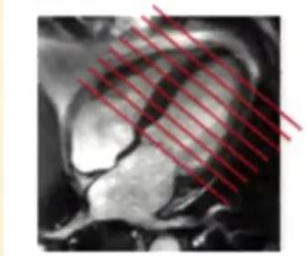
Cardiomyopathy Assessment



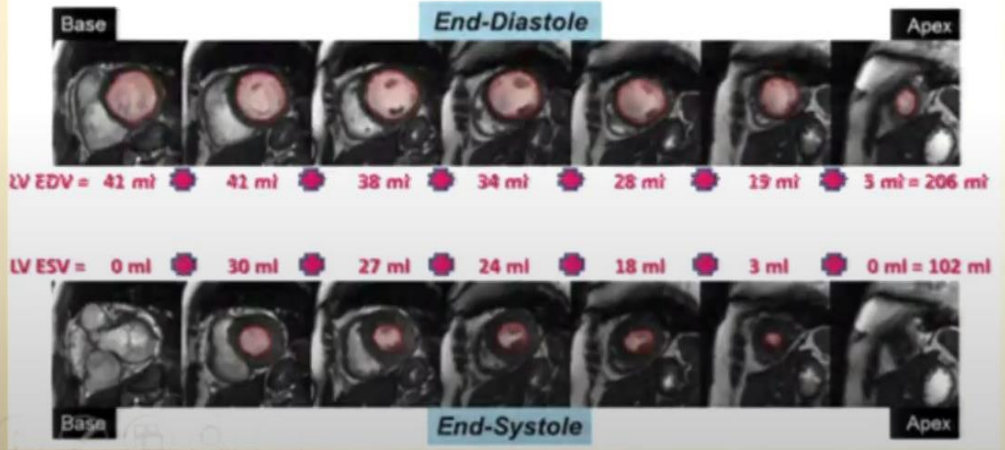
- ✓ 3D visualization of the heart & thoracic structures
- ✓ Quantification of cardiac volumes and function (gold standard)
- ✓ Accurate flow quantification (VHD)
- ✓ Coronary and microvascular stress perfusion
- ✓ Determining Etiology
  - ✓ Tissue characterization: MI, scar, fatty infiltration, thrombus, iron
- ✓ Prognosis / Risk assessment

Quantification

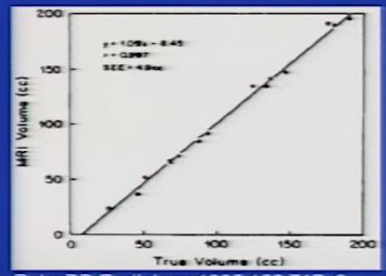
Quantification of Ventricular Function by CMR



Volume = Area x Thickness



CMR in casts of cadaveric hearts



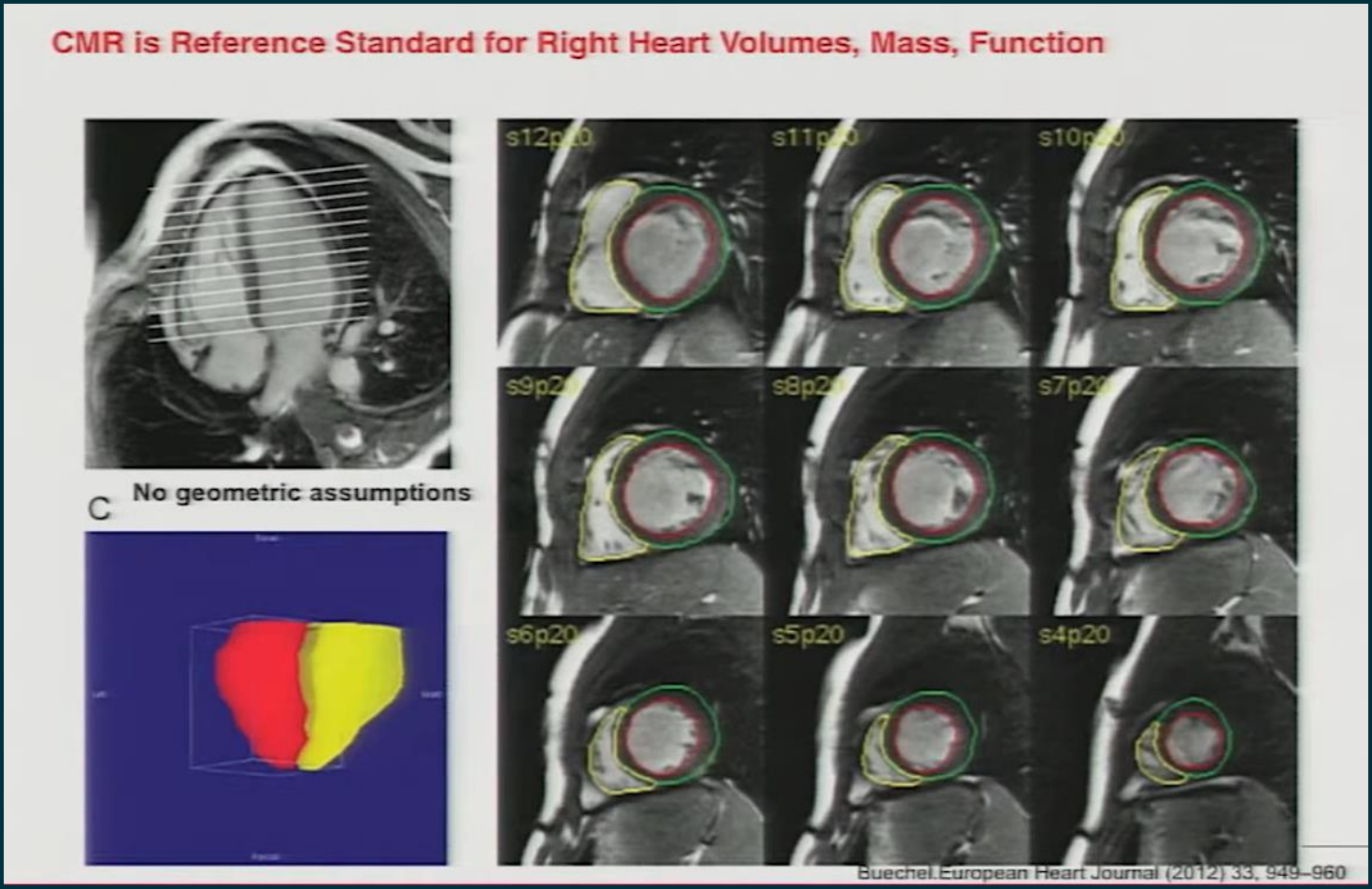
Rehr RB.Radiology 1985;156:717–9

CMR volumetry validated:
- Animals
- In vitro
- In vivo
- Ex vivo

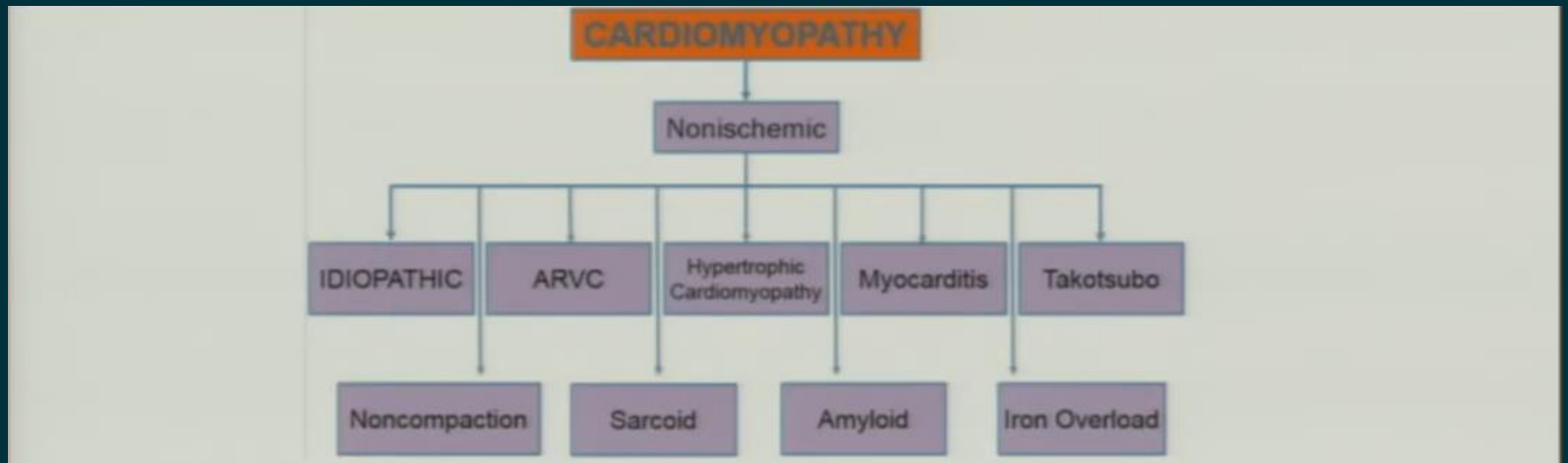
Superior to ECHO
- Highly accurate
- Highly reproducible
- Low intra-observer variability
- Low inter-observer variability
  - LVEF: 2-7%
- Low inter-study variability

Zoghbi WA et al. J Am Soc Echocardiogr. 2017 Apr;30(4):303-371.

Gold Standard to RV Volume, Mass, and Function

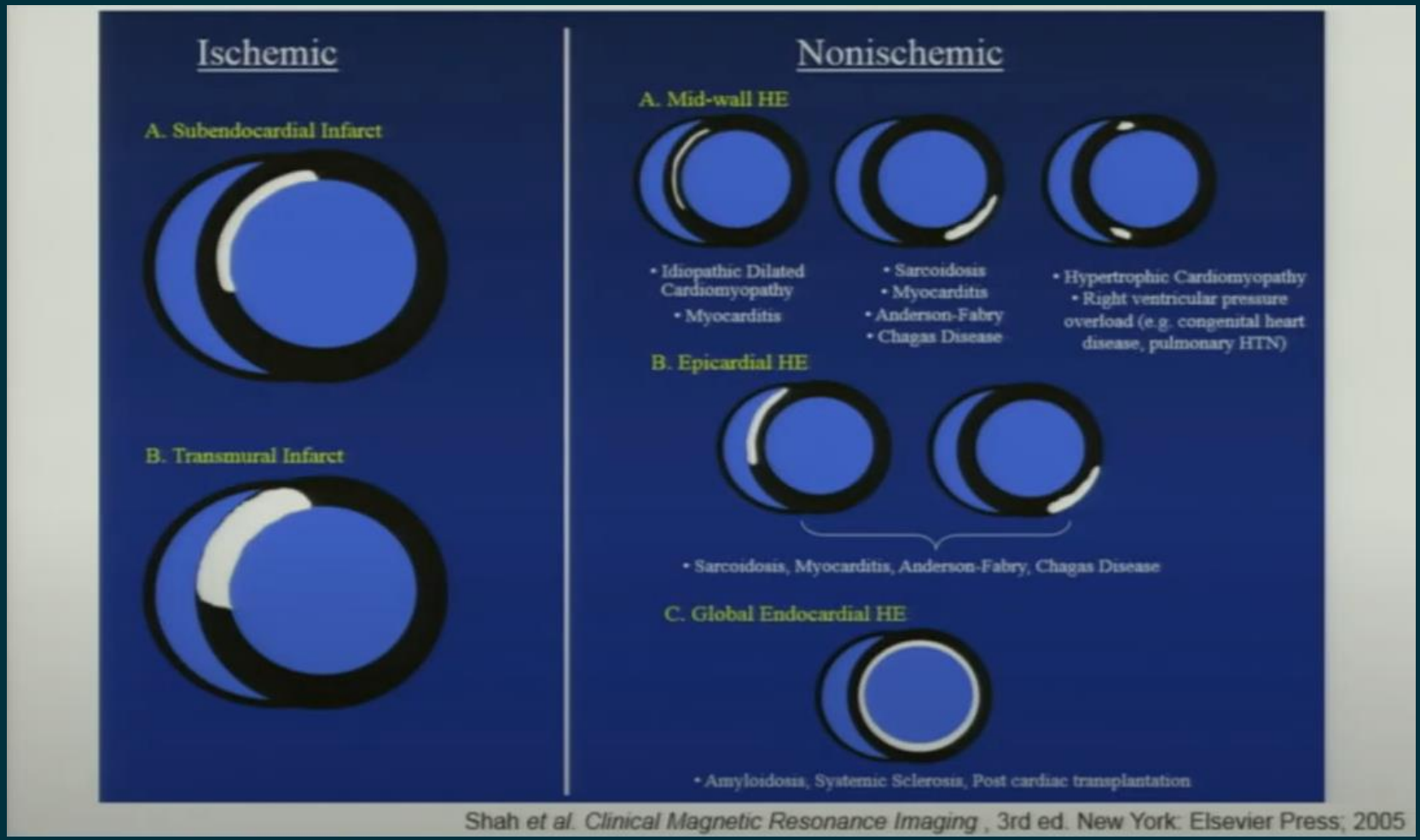


Cardiomyopathy Assessment



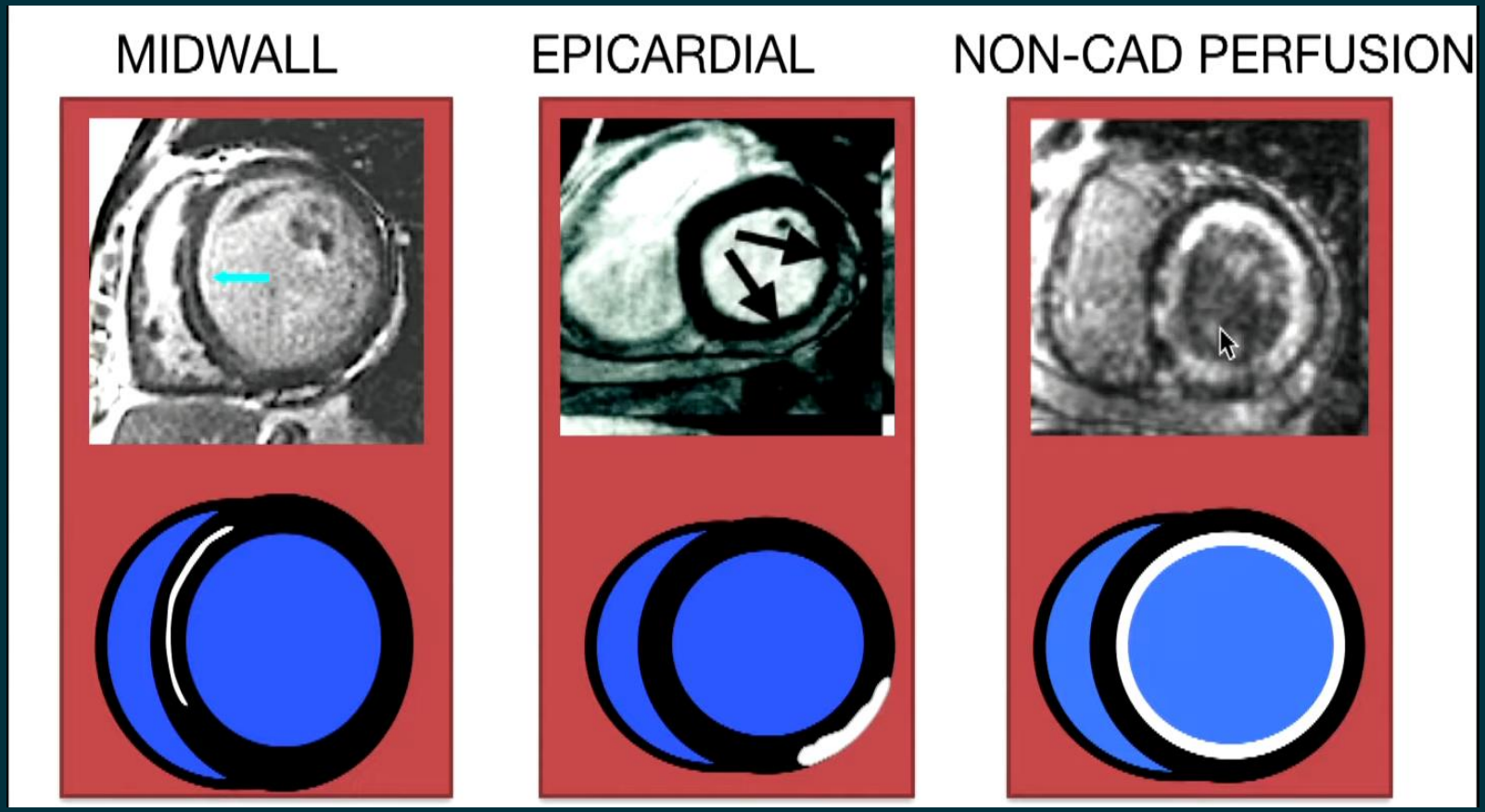
- ✓ 3D visualization of the heart & thoracic structures
- ✓ Quantification of cardiac volumes and function (gold standard)
- ✓ Accurate flow quantification (VHD)
- ✓ Coronary and microvascular stress perfusion
- ✓ Determining Etiology
  - ✓ Tissue characterization: MI, scar, fatty infiltration, thrombus, iron
- ✓ Prognosis / Risk assessment

LGE Can Help Identify Underlying Etiology

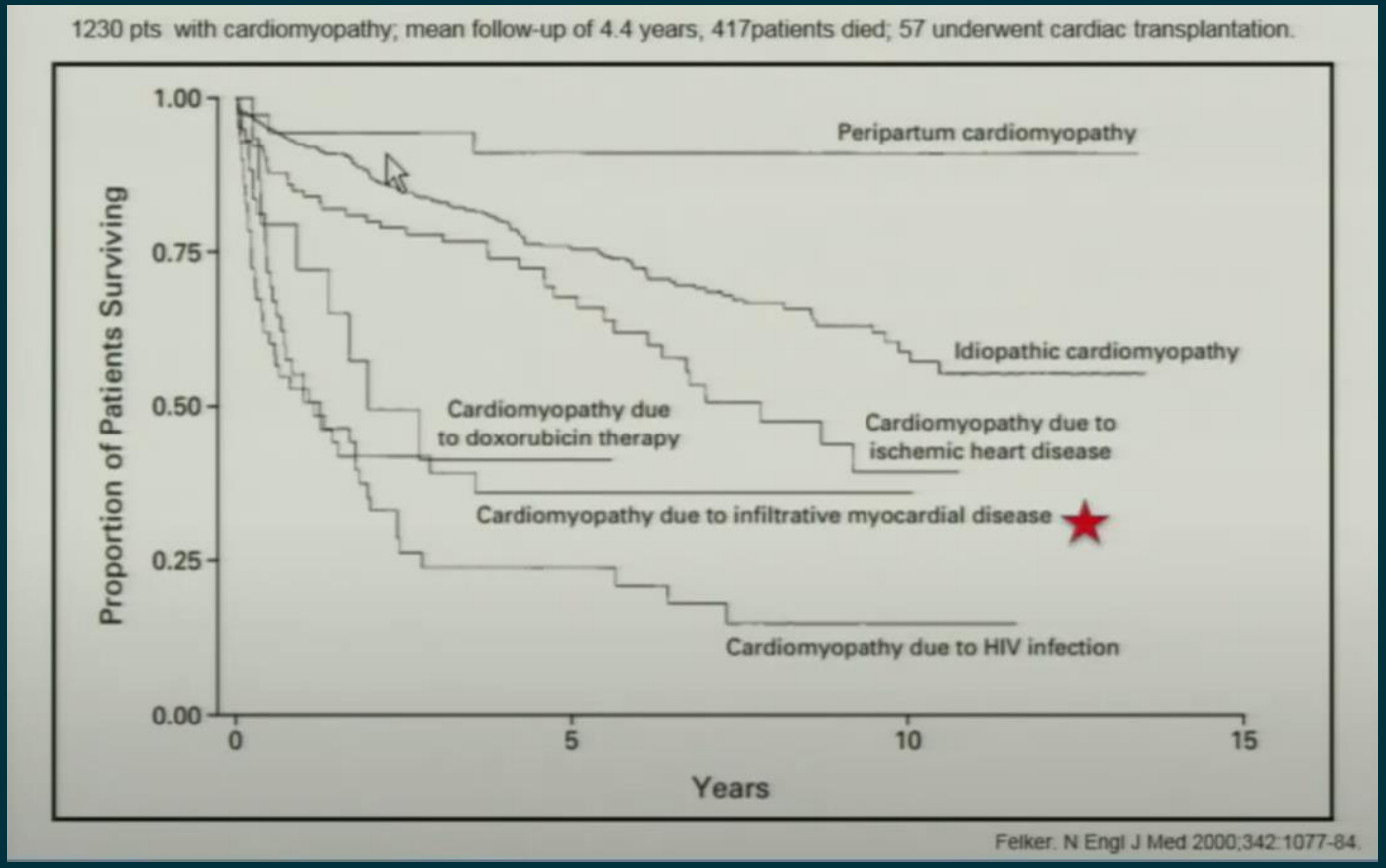


Shah *et al. Clinical Magnetic Resonance Imaging* , 3rd ed. New York: Elsevier Press; 2005

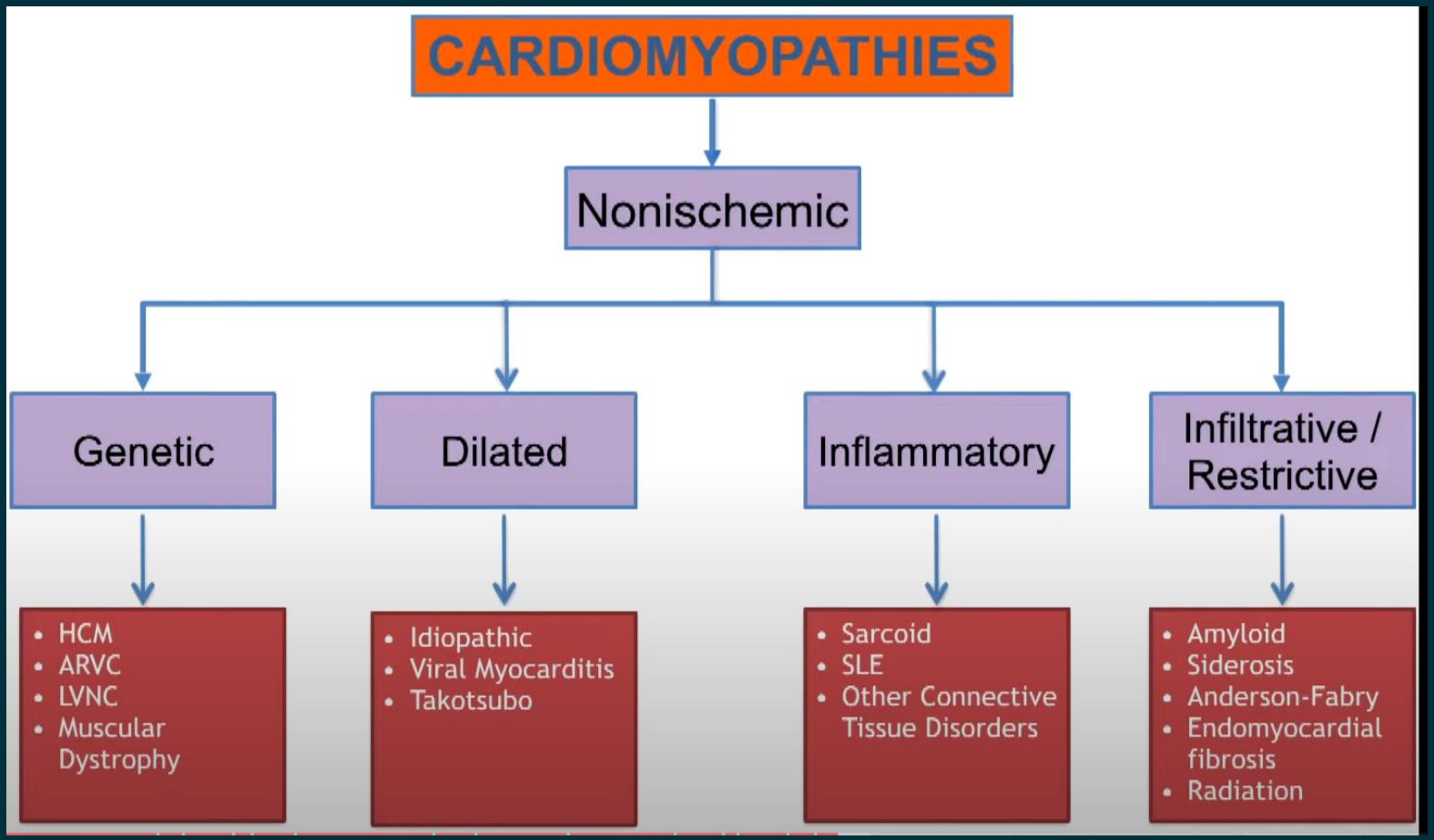
Hyperenhancement that do not fit with ischemic injury



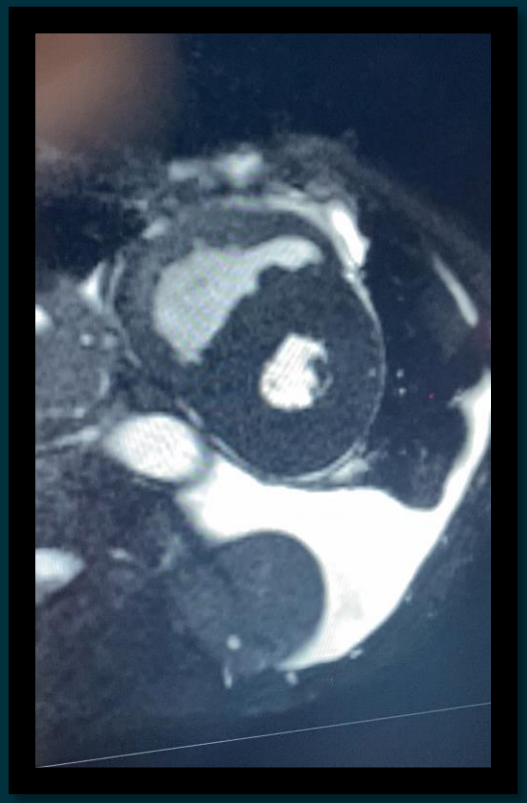
Etiology of Cardiomyopathy and Prognosis



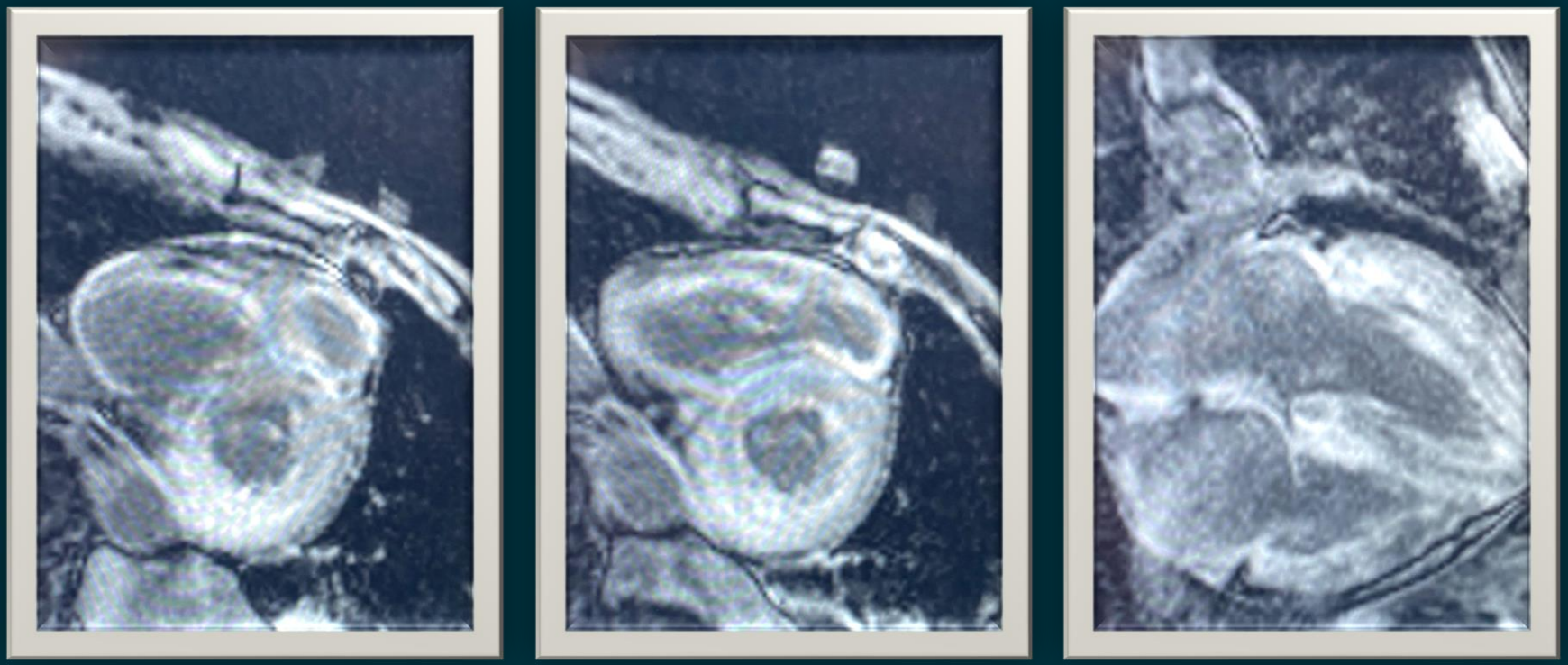
Non-Ischemic Cardiomyopathies



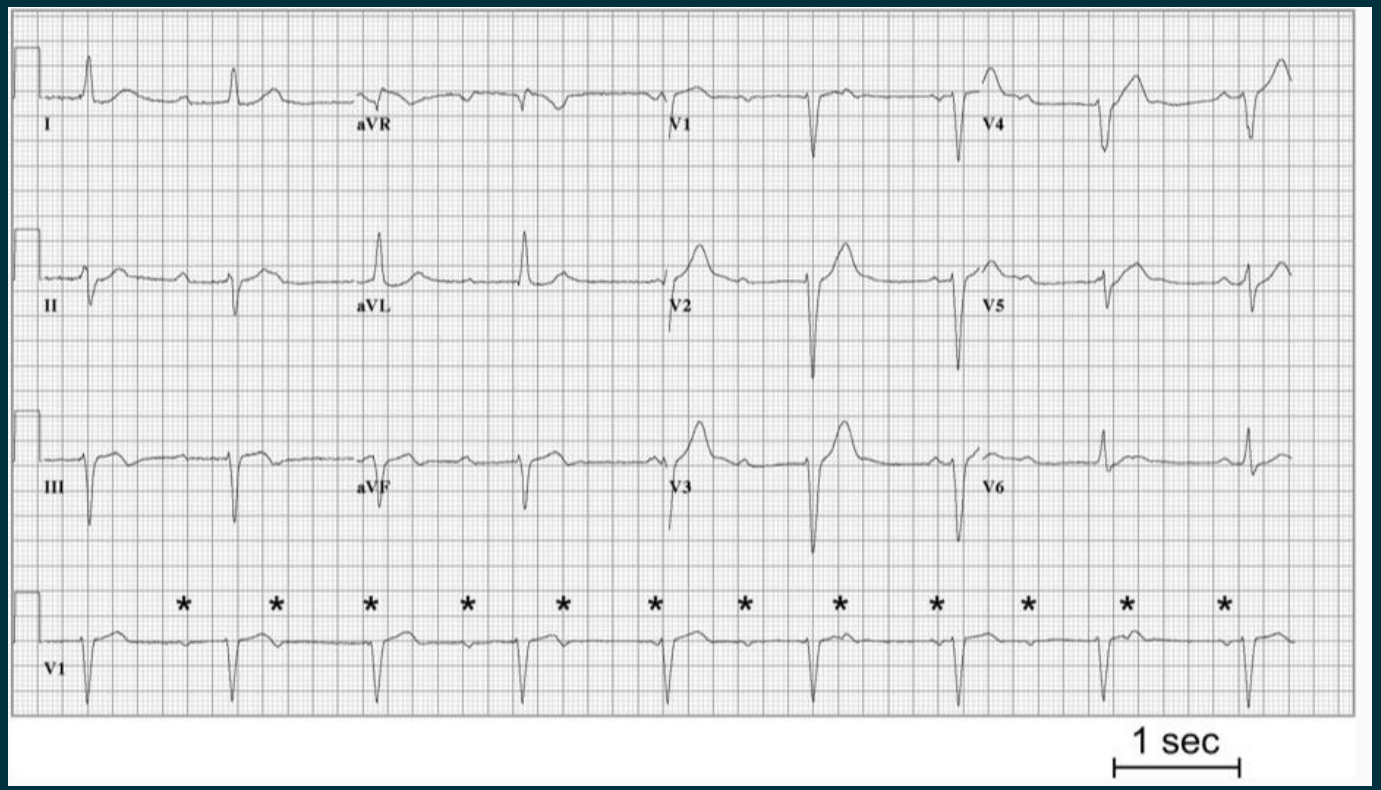
Our patient



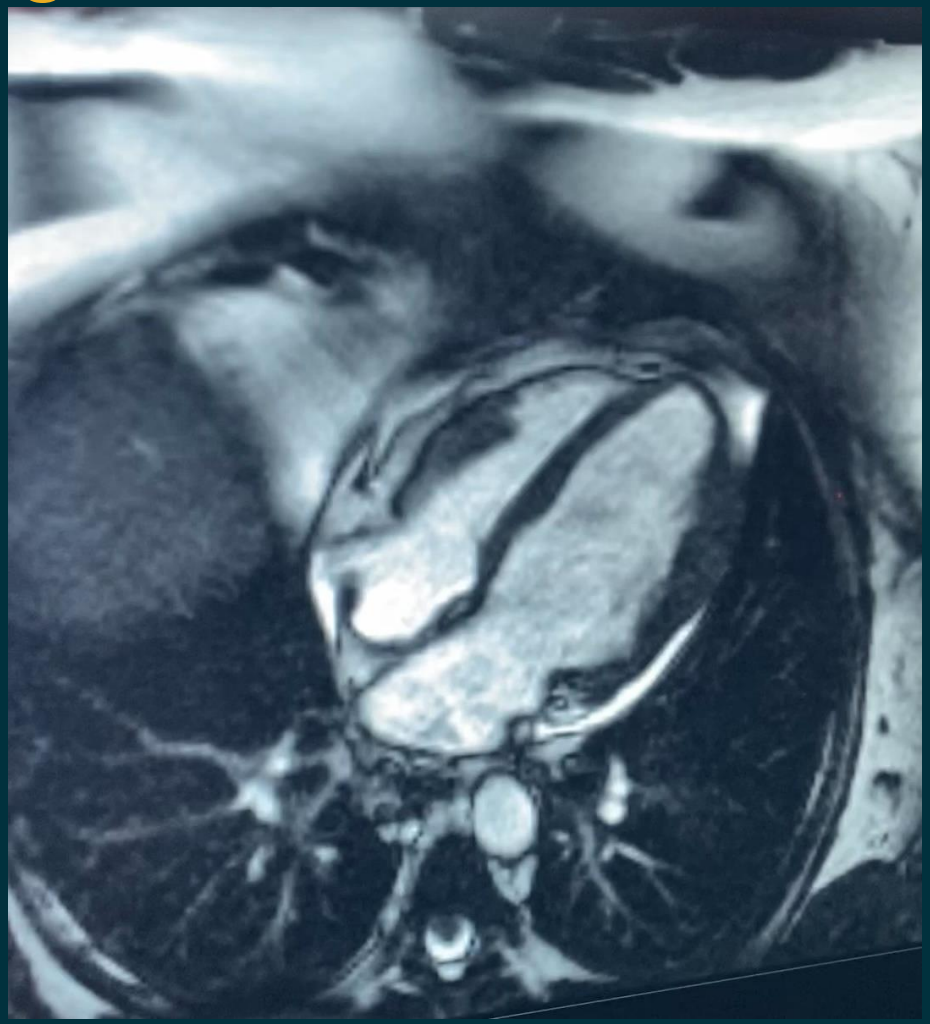
Amyloidosis



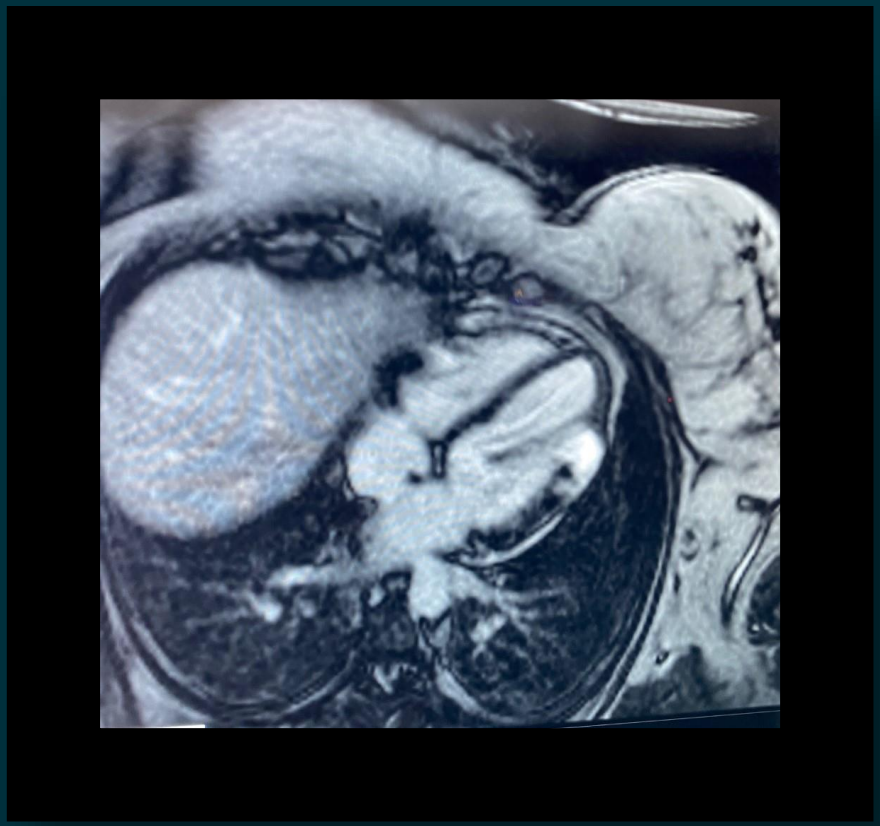
- 49 year old woman with worsening dyspnea with episodes of pre-syncope.

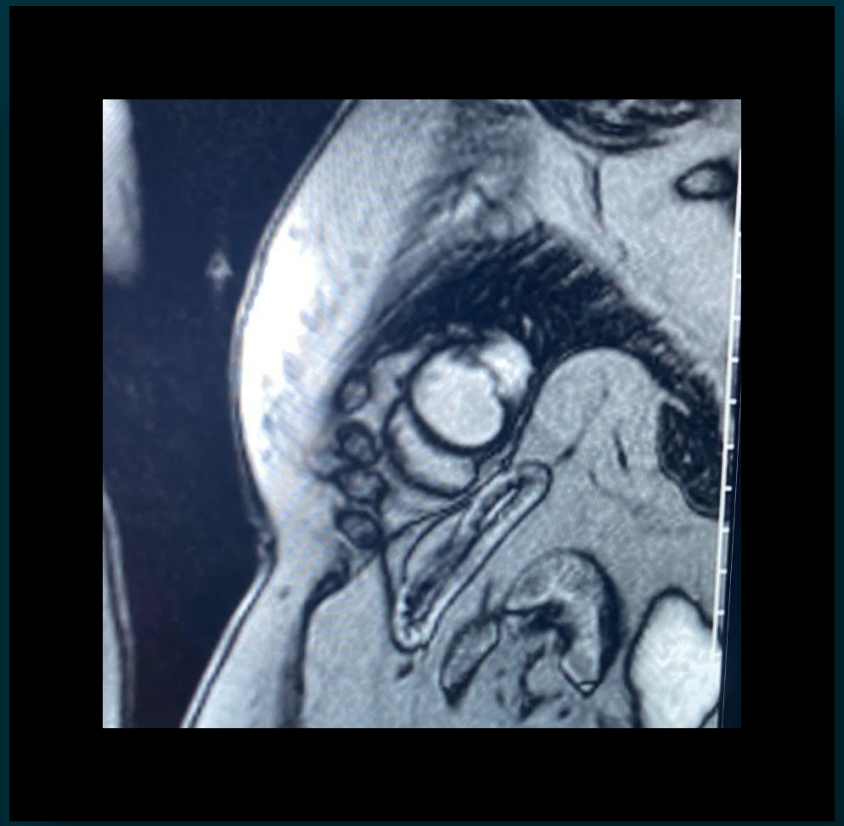


Cine Images

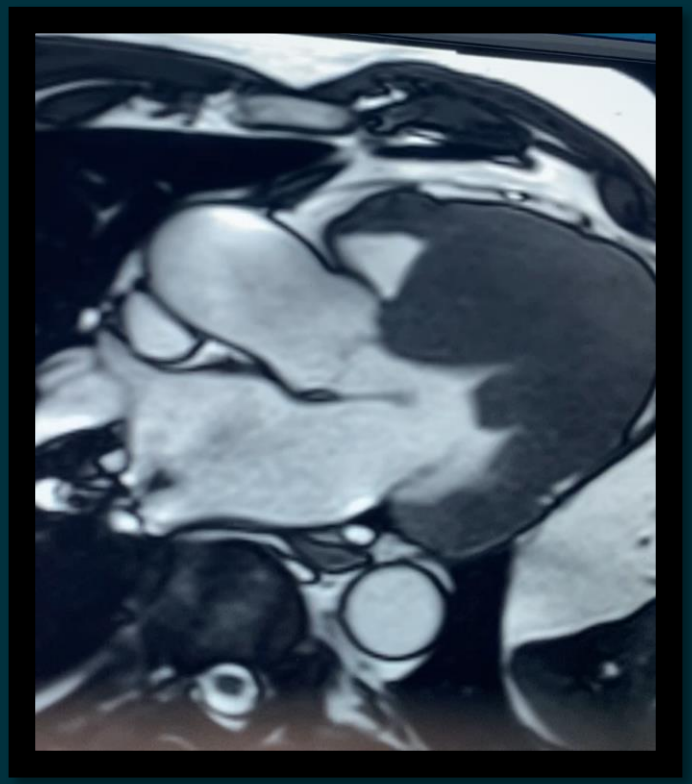


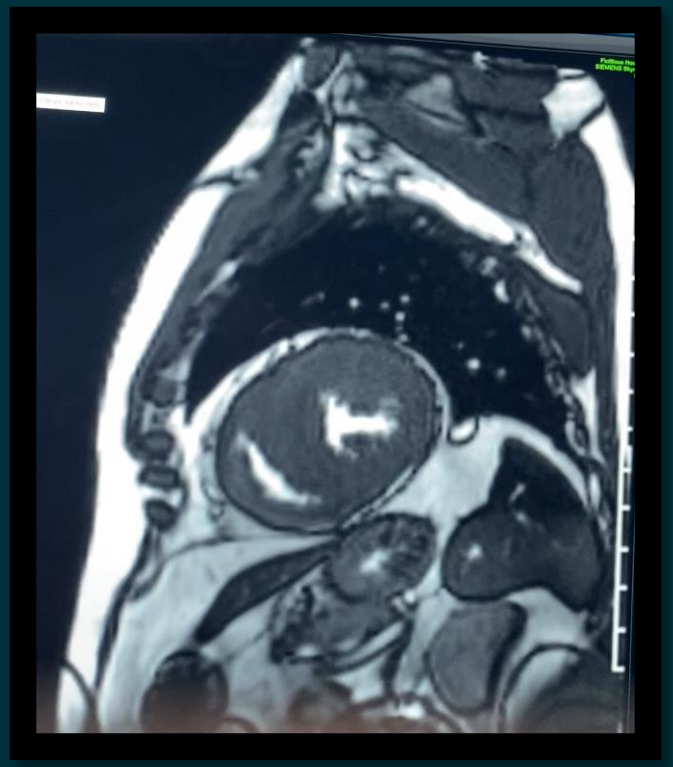
Late Gadolinium Enhancement



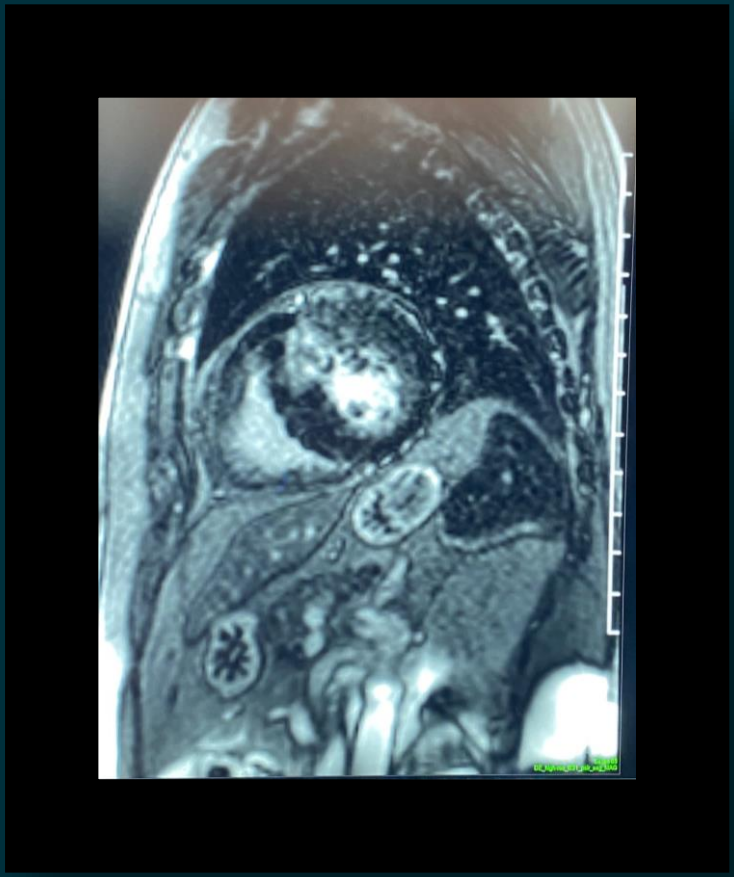


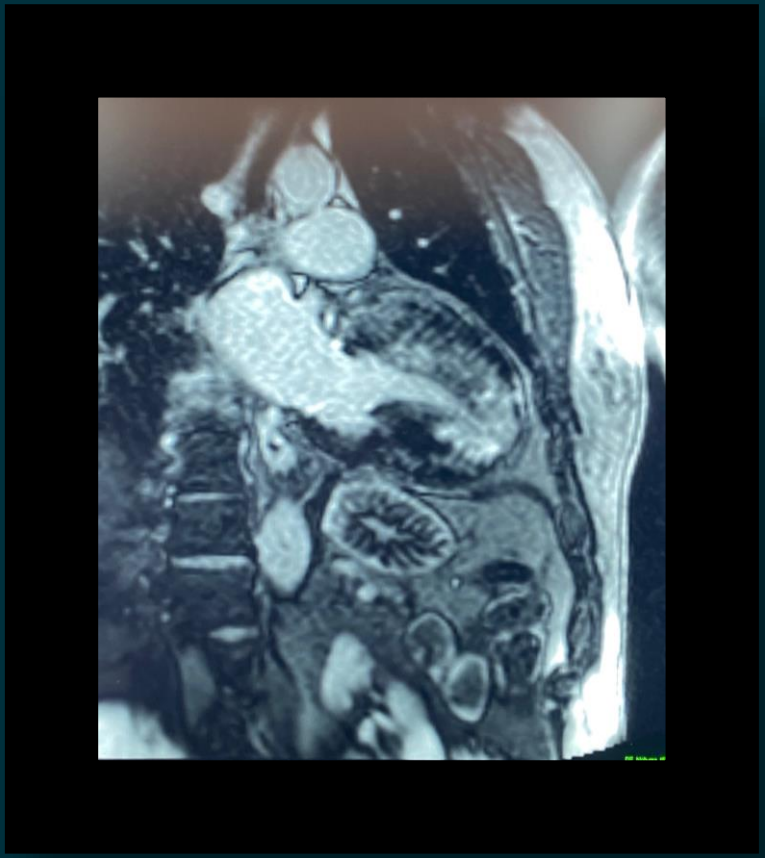
Cardiomyopathy Case



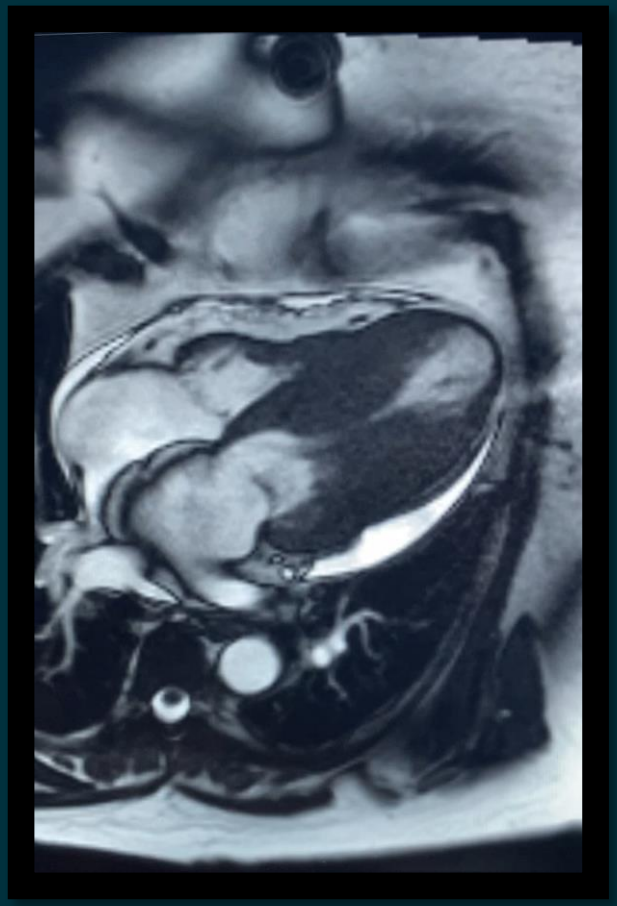


Late Gadolinium Enhancement

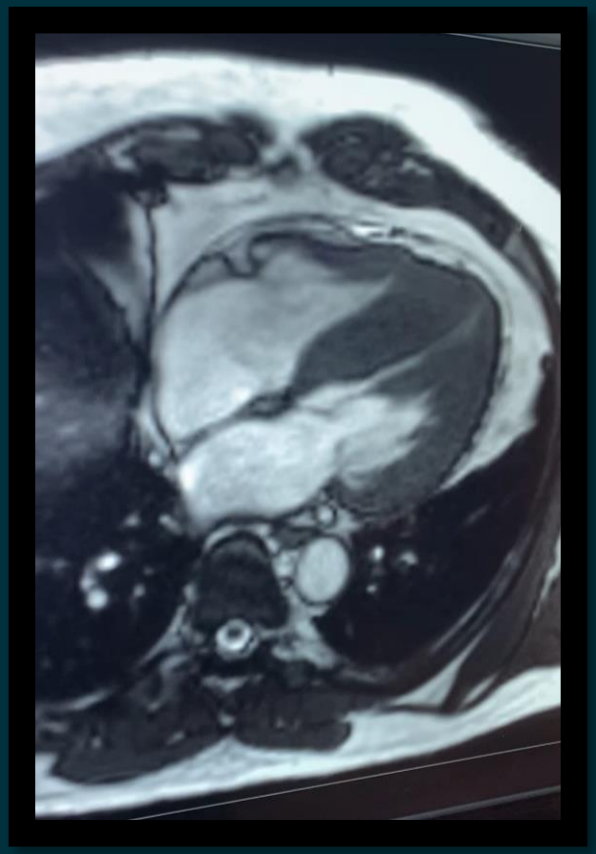


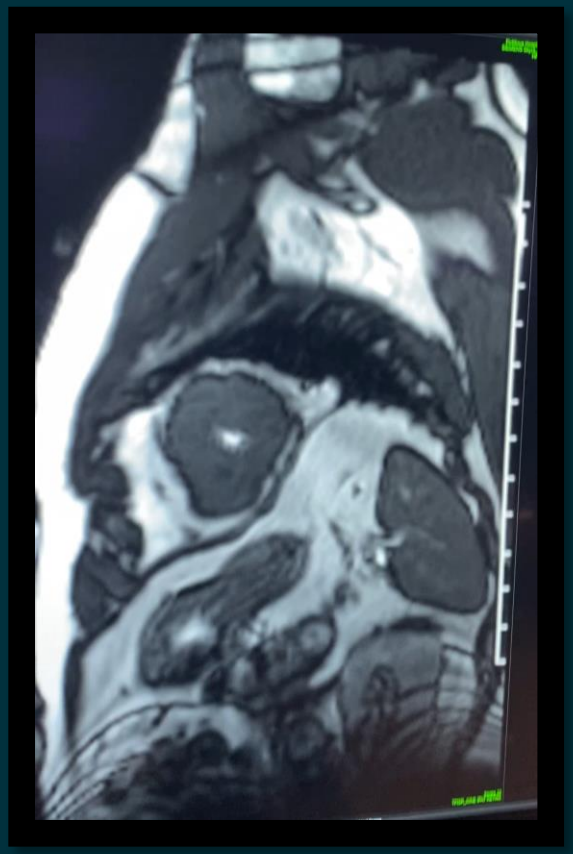


Mid wall HCM

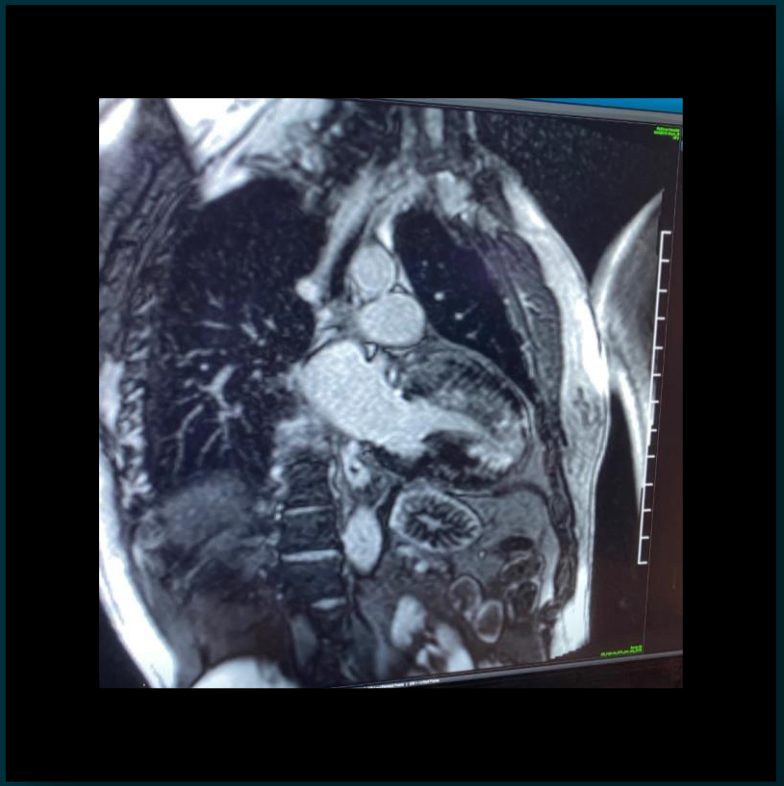


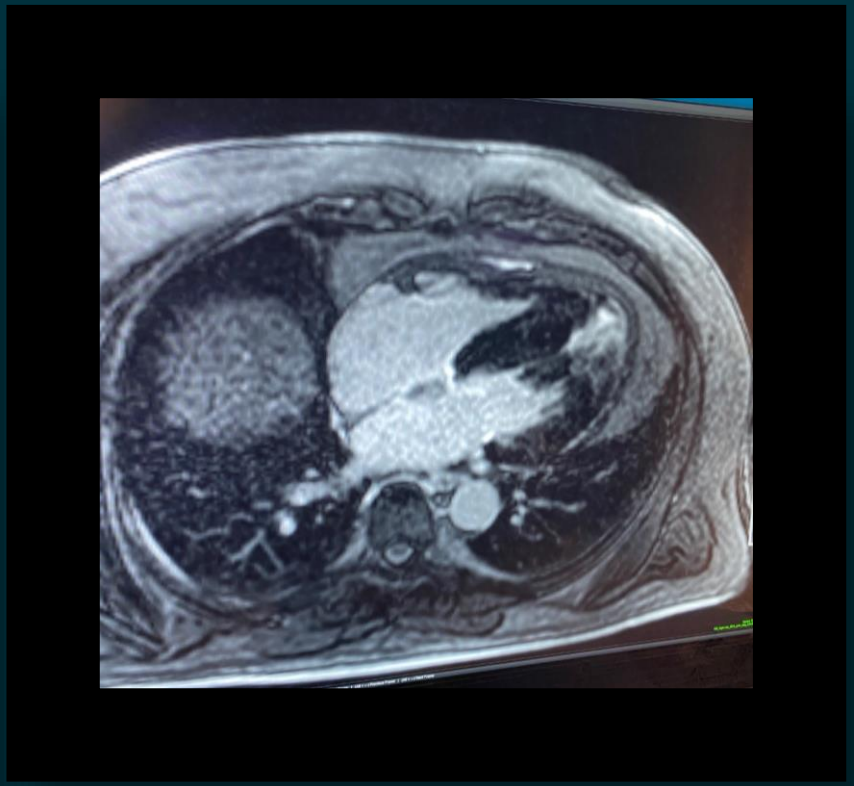
Apical HCM



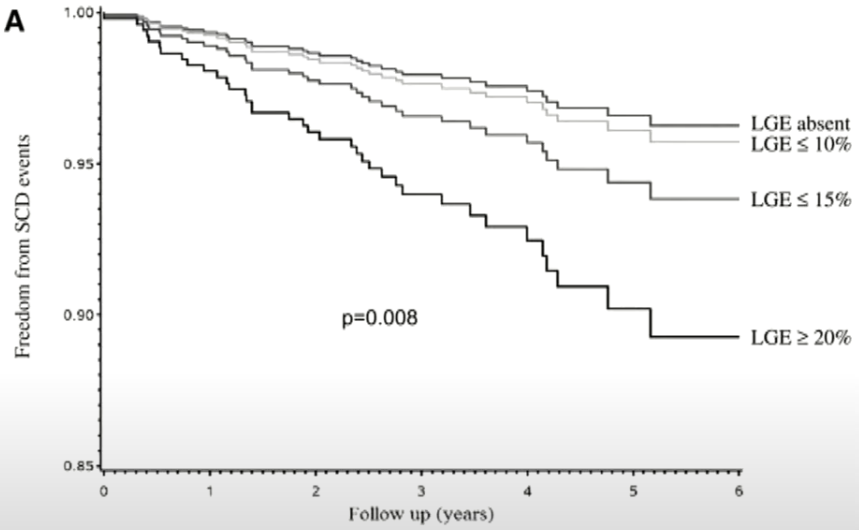


Apical HCM LGE

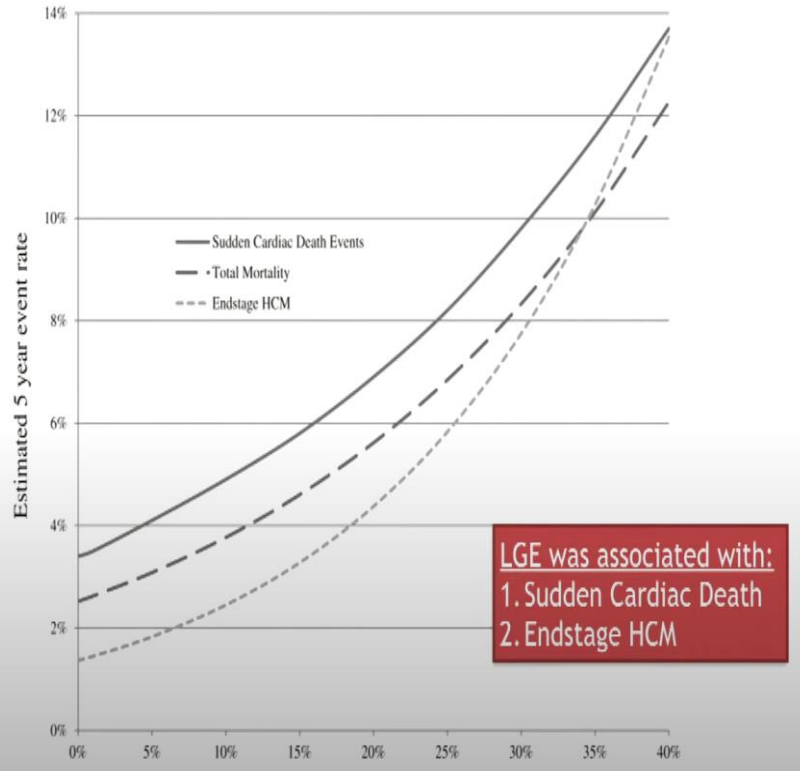




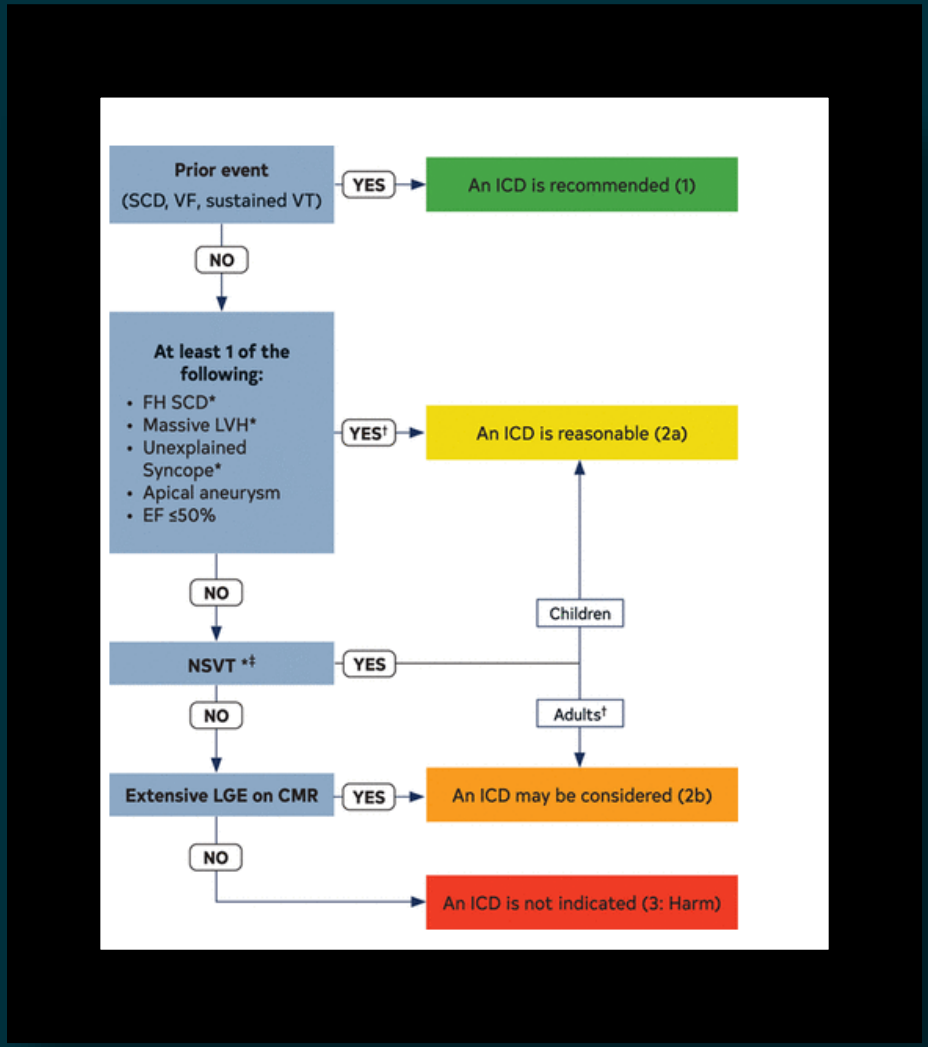
HCM and LGE



Chan et al, Circulation 2014.

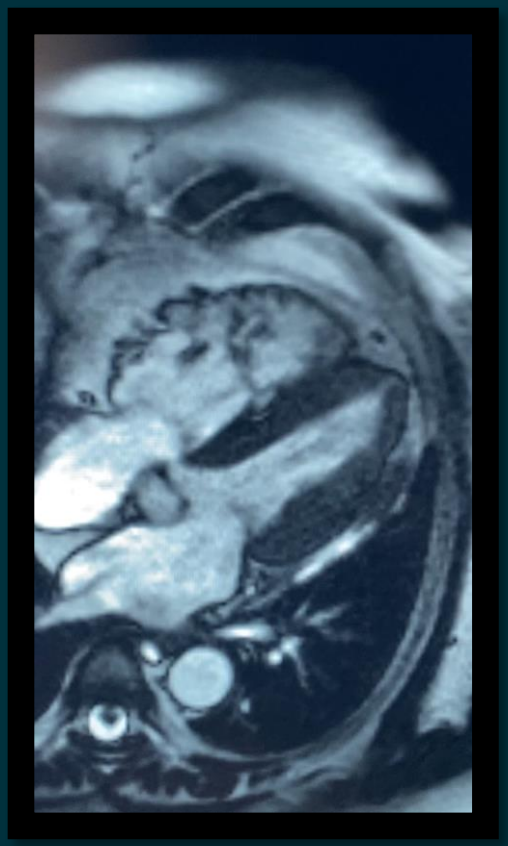


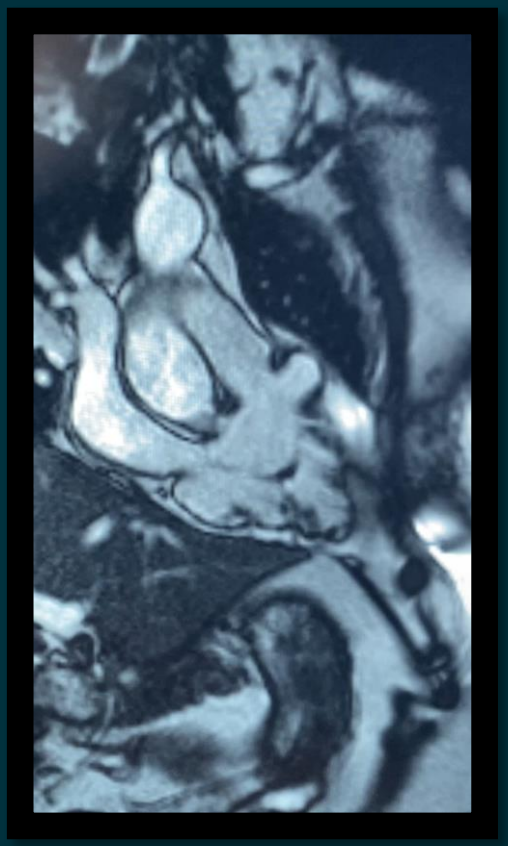
LGE and ICD in HCM



- 42 year old man with episodes of syncope

ARVD





ARVD Criteria

MAJOR CRITERIA

By MRI:

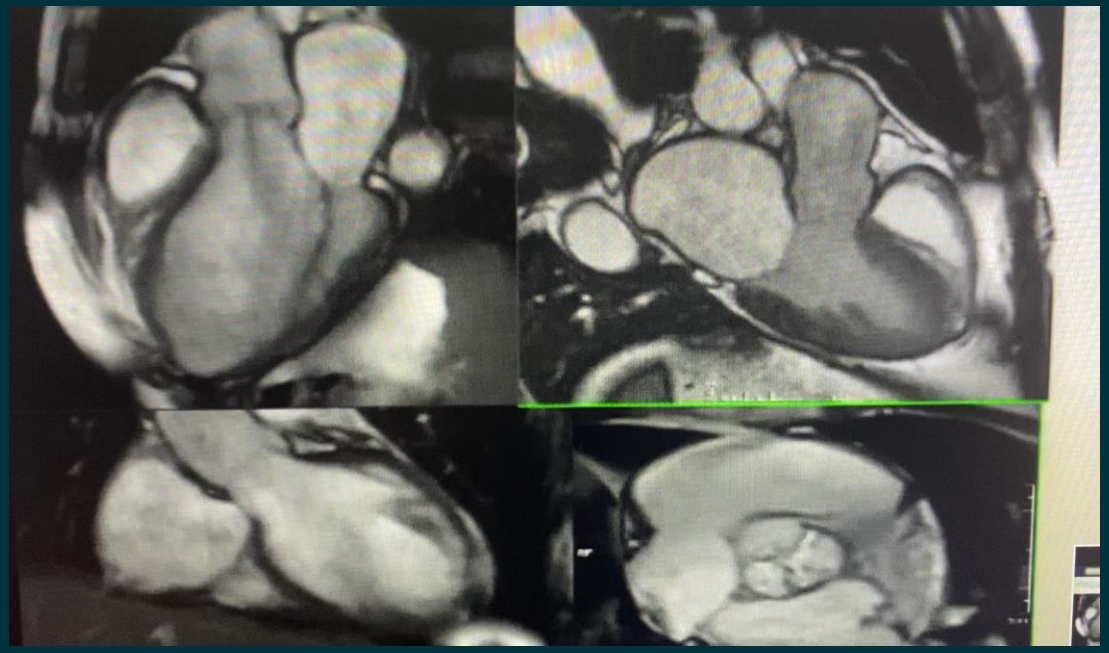
- Regional RV akinesia or dyskinesia or dyssynchronous RV contraction
- *and* 1 of the following:
  - — Ratio of RV end-diastolic volume to BSA ≥110 mL/m^2 (male) or ≥100 mL/m^2 (female)
  - — *or* RV ejection fraction ≤40%

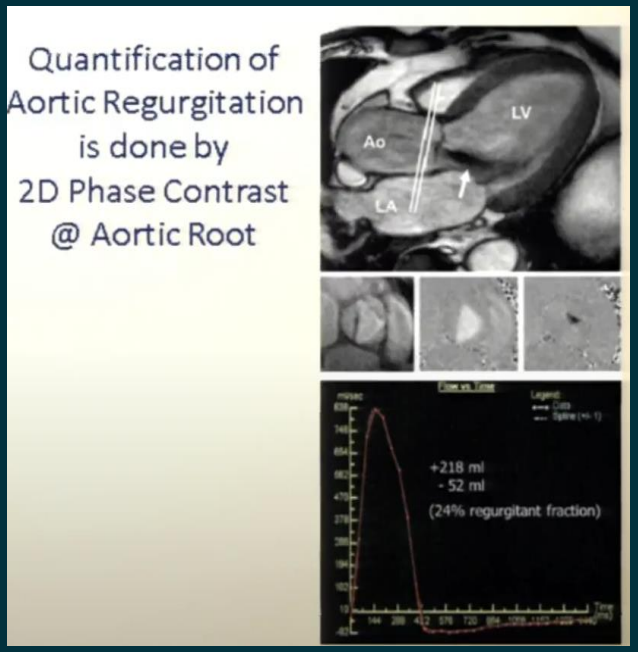
MINOR CRITERIA

By MRI:

- Regional RV akinesia or dyskinesia or dyssynchronous RV contraction
- *and* 1 of the following:
  - — Ratio of RV end-diastolic volume to BSA ≥100 to <110 mL/m^2 (male) or ≥90 to <100 mL/m^2 (female)
  - — *or* RV ejection fraction >40% to ≤45%

Regurgitant Jet Assessment and Quantification

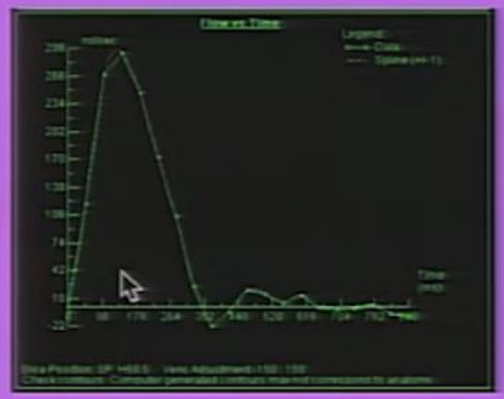




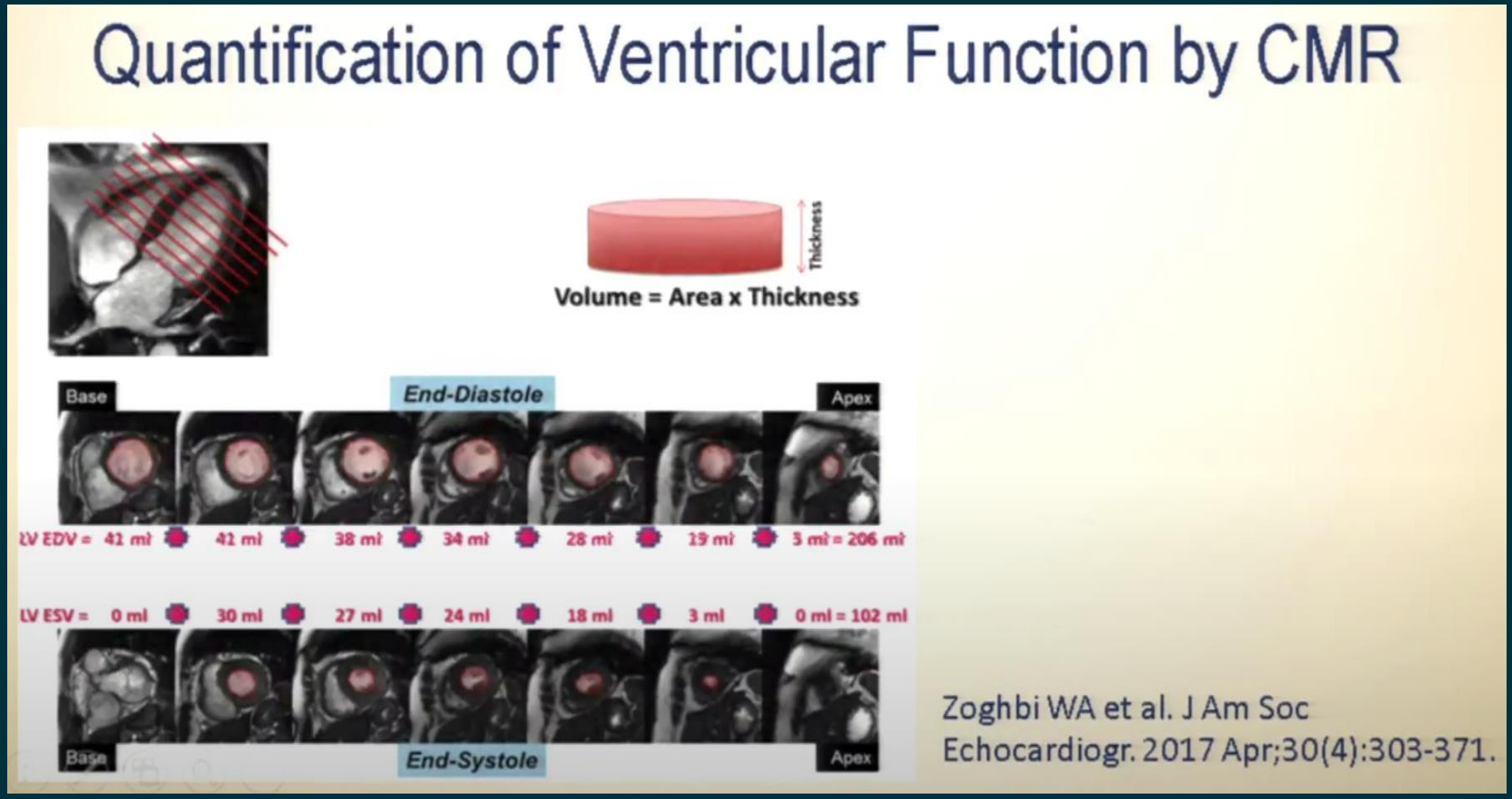
Phase Contrast CMR

- Strong correlation
  - In-vivo
    - LV SV in subjects w/out MR
    - SV by Fick & thermodilution
    - Doppler
  - In-vitro
    - Flow phantoms

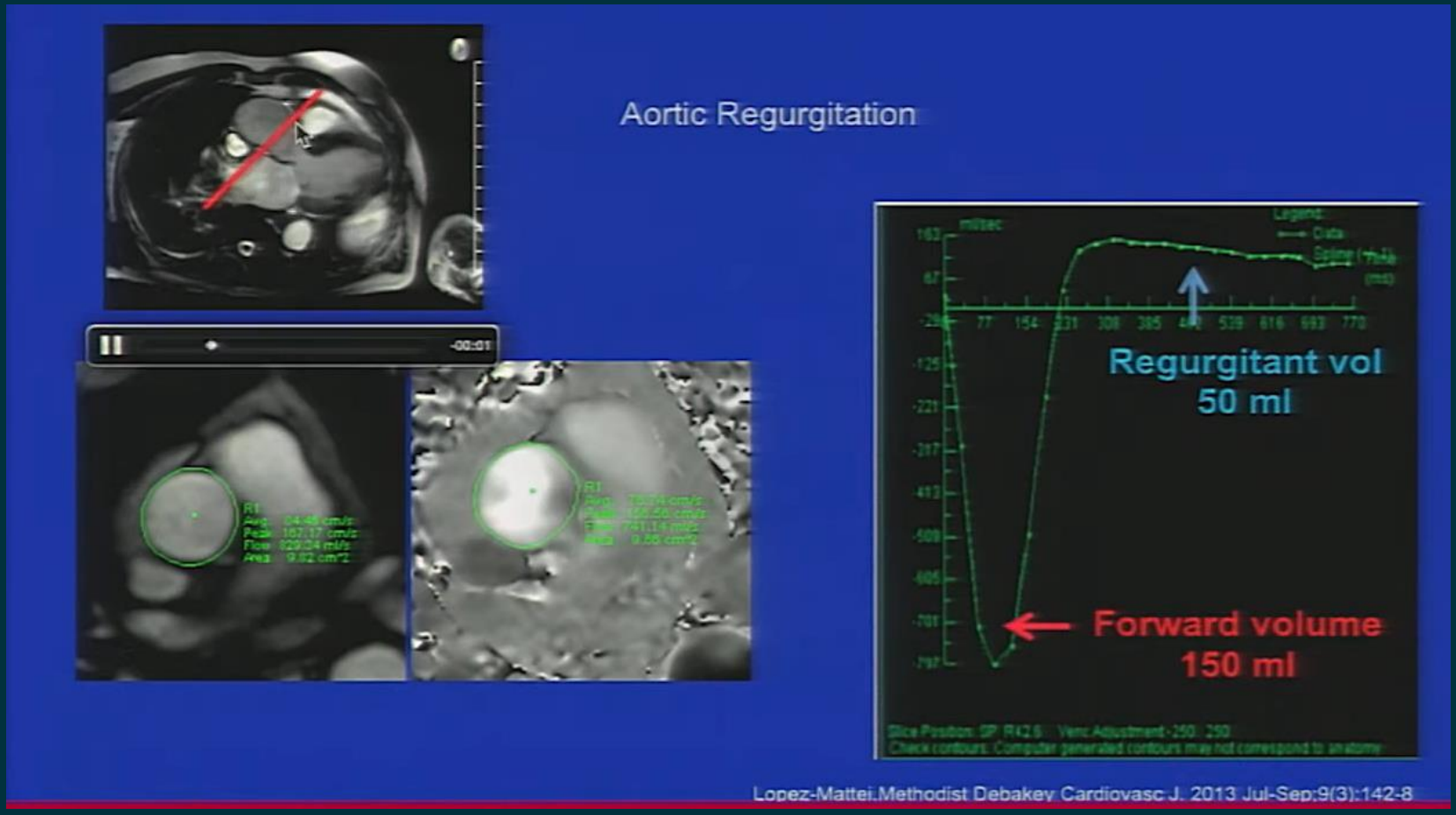
Hundley WG. *Am J Cardiol*.1995;75:1250–1255.
Bogren HG. *Am Heart J*. 1989;117:1214–1222.
Chatzimavroudis GP. *J Cardiovasc Magn Reson*. 2001;3:11–19.
Van Rossum AC. *Eur Heart J*. 1991;12:117–126.
Kondo C. *AJR Am J Roentgenol*. 1991;157:9–16.



Quantification



Flow Mapping: Direct quantification Antegrade & Retrograde Volumes across Semilunar Valves



MR Assessment

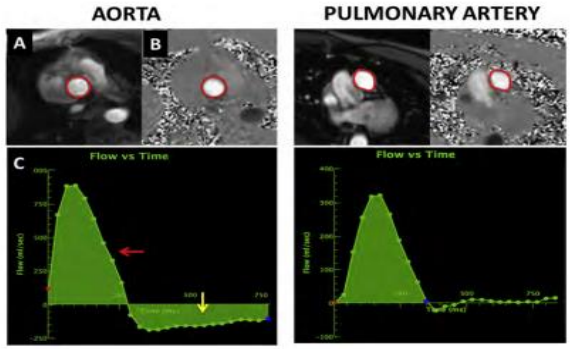


Figure 7 CMR technique for assessment of great vessel forward and retrograde flow. Left side of the figure demonstrates a phase-contrast acquisition performed in the aortic root. This produces a set of two cine images at matched anatomic locations that provide differing information: a magnitude image that provides anatomic reference (**A**) and velocity or phase map with pixel values linearly related to velocity and direction of flow (**B**). On postprocessing, via drawing a region of interest around the aortic root (*red circles*), a flow versus time graph is generated (**C**), which can be used to compute forward (*red arrow*) and reverse flow (*yellow arrow*). In this example of AR, the reverse flow represents the directly measured volume of AR. The right side of the figure demonstrates the same, performed at the PA trunk to derive PA flow.

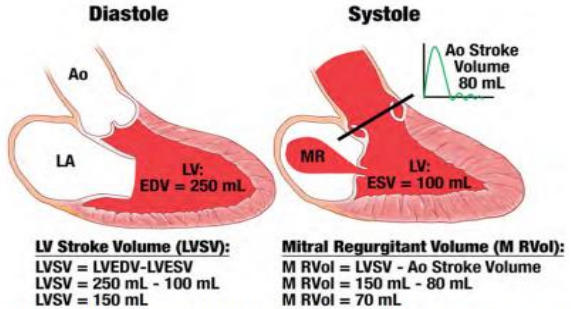
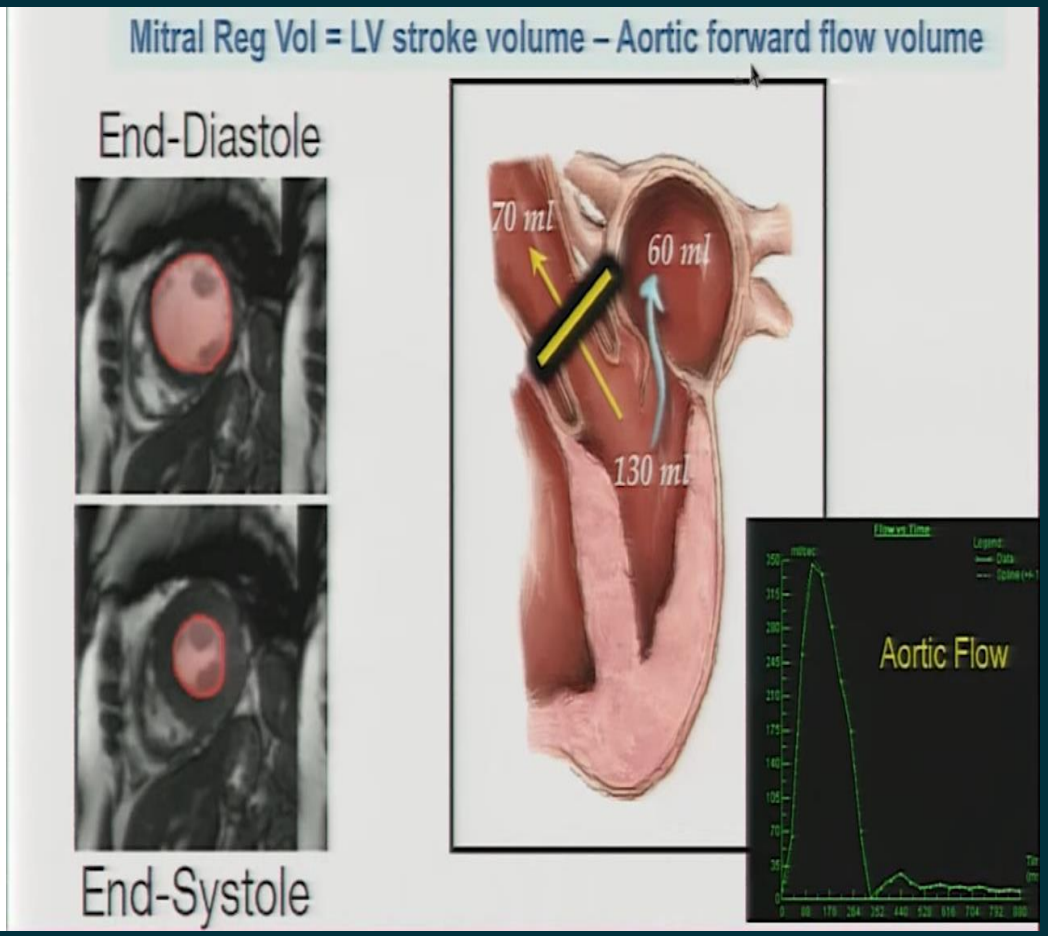
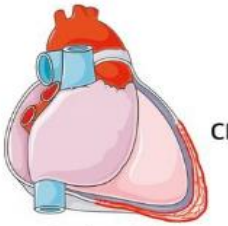


Figure 8 Example CMR method for quantification of MR. The volume of the LV is calculated during end-diastole (LVEDV) and during end-systole (LVESV) via the methodology demonstrated in Figure 6. The total volume of blood ejected from the LV, LV SV, is computed as the difference between LV end-diastolic volume and LV end-systolic volume. In this example LV SV is 150 mL. The volume of blood crossing the aortic (AO) valve is measured by performance of a phase-contrast acquisition in the aorta (as detailed in Figure 6); in this example, 80 mL. The mitral RVol (M RVol) is computed as the difference between the LV SV and aortic forward SV; in this example, 70 mL.

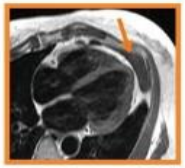
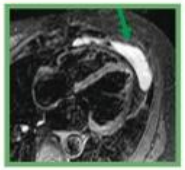
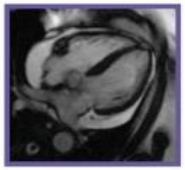
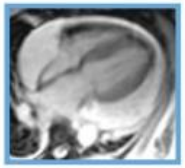
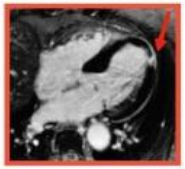


Pericardial Disease

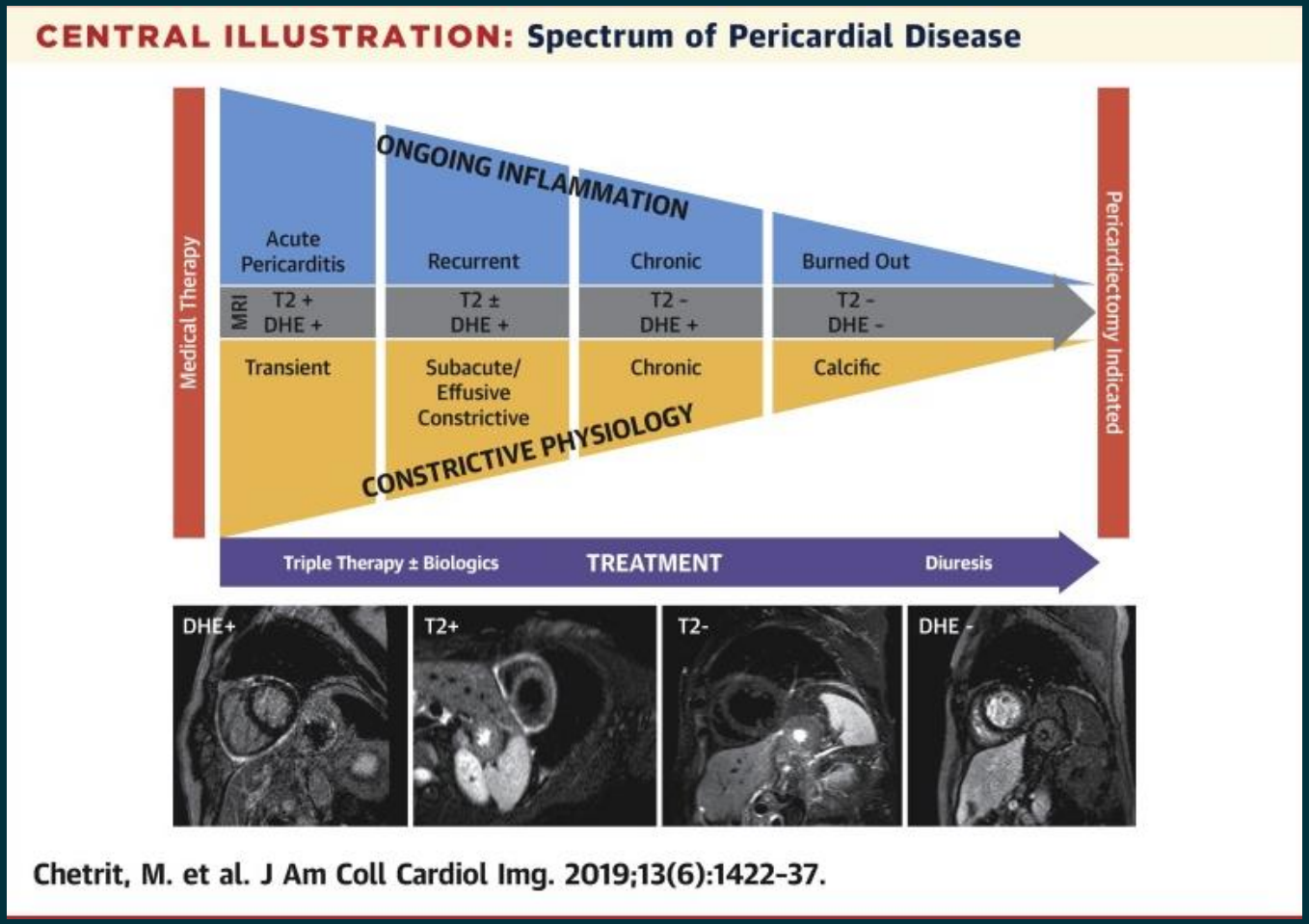


Pericarditis

CMR

Sequence		Main findings
T_1-weighted fast spin echo		**Morphological assessment of the pericardium** • Thickened pericardium • Pericardial effusion Signal intensity inversely correlated to inflammation chronicity *The arrow indicates pericardial cyst as a low signal structure*
T_2-weighted fast spin echo		**Fluid-rich structures** • pericardial effusion • pericardial edema • myocardial edema → myocardial involvement *The arrow indicates pericardial cyst as a high signal structure*
HR SSFP cine imaging		**Accurate quantification of cardiac chamber size and function** *including pathological effects such as RV/RA collapse*
Real-time cine imaging		**Dynamic physiological effects of pericardial disease** • ventricular interdependence *Fast but lower resolution imaging*
LGE imaging		**Active pericardial inflammation** • focal myocardial and adjacent pericardial enhancement (arrow)

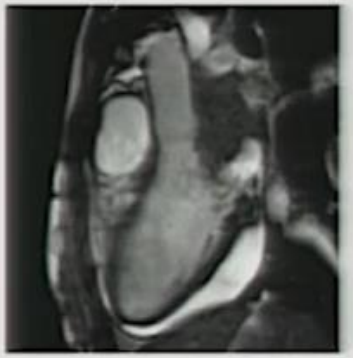
Pericardial Disease

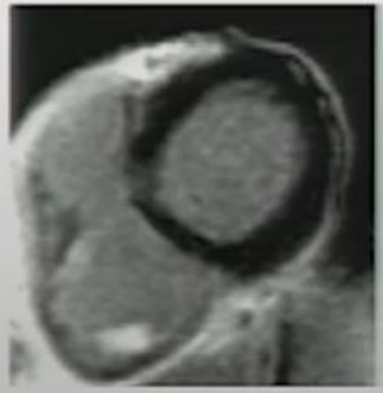


Chetrit, M. et al. J Am Coll Cardiol Img. 2019;13(6):1422-37.

Role of CMR in Cardiac Mass Evaluation

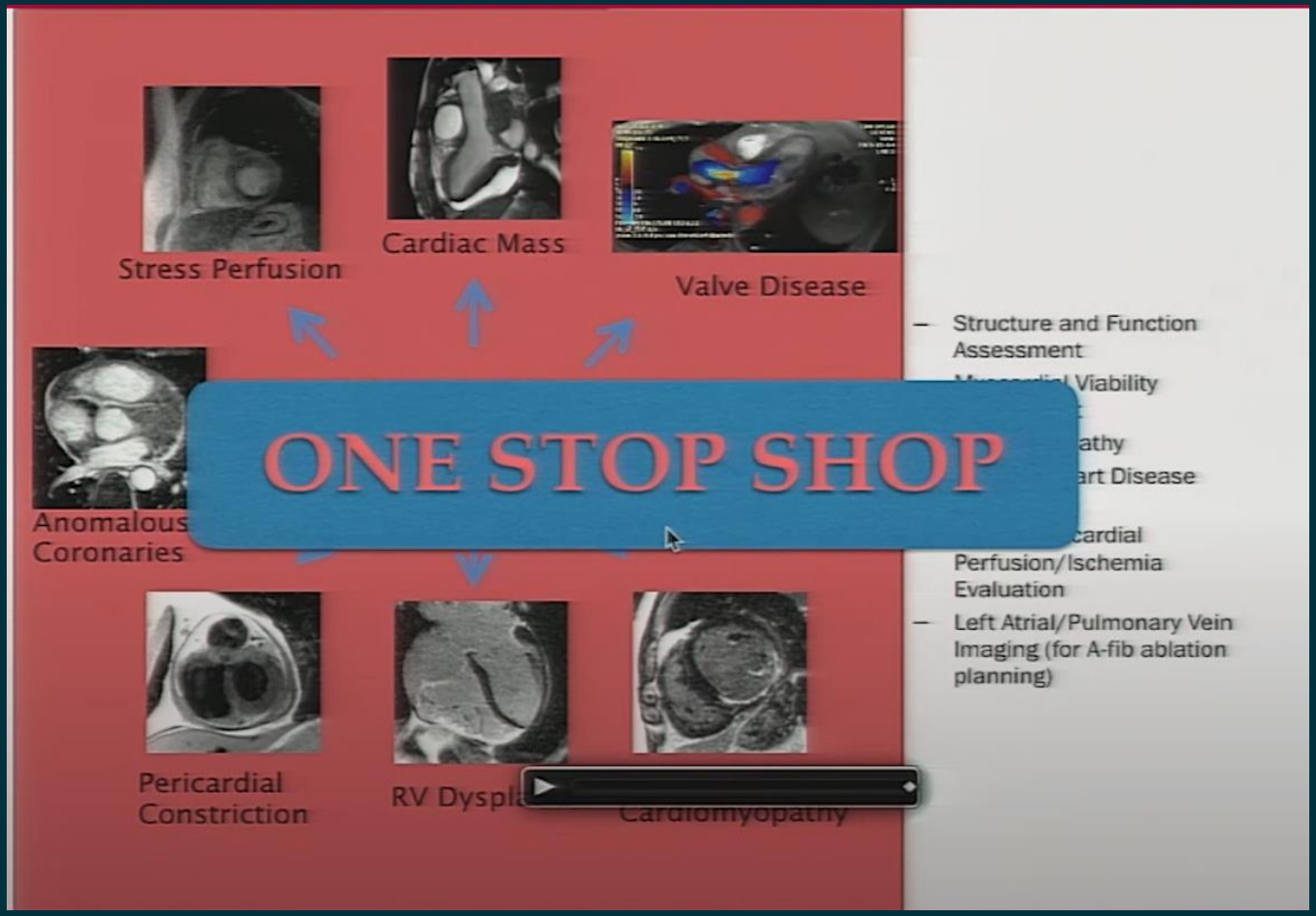
Cardiac Masses





	T1-weighted	T2-weighted	Post Contrast
Myxoma	Isointense, heterogeneous	Hyperintense, heterogeneous	Heterogeneous enhancement
Papillary fibroelastoma	Isointense	Hyperintense	Hyperintense
Rhabdomyoma	Iso- or hyperintense	Slightly hyperintense	Hyperintense
Fibroma	Iso- or hyperintense	Hypointense	Hyperintense
Hemangioma	Isointense	Hyperintense, heterogeneous	Hyperintense or heterogeneous
Paraganglioma	Iso- or hypointense	Hyperintense	Hyperintense
Intravenous leiomyomatosis	Isointense	Isointense	Heterogeneous
Bronchogenic cyst	Hypointense	Hyperintense	None
Angiosarcoma	Isointense, with hyperintense areas	Iso- or hyperintense	Hyperintense
Undifferentiated sarcoma	Isointense	Isointense	Nonspecific
Rhabdomyosarcoma	Isointense	Isointense, heterogeneous	Central nonenhancing areas
Osteosarcoma	Hyperintense	Hyperintense	Nonspecific
Malignant fibrous histiocytoma	Isointense	Hyperintense, heterogeneous	Nonspecific
Leiomyosarcoma	Isointense	Hyperintense	Nonspecific
Fibrosarcoma	Isointense, heterogeneous	Hyperintense	Central nonenhancing areas
Lymphoma	Hypo- or isointense	Hyperintense	Variable

Summary


Stress Perfusion
Cardiac Mass
Valve Disease
ONE STOP SHOP
Anomalous Coronaries
Pericardial Constriction
RV Dysp
Cardiomyopathy
– Structure and Function Assessment
Viability
athy
art Disease
cardial
Perfusion/Ischemia Evaluation
– Left Atrial/Pulmonary Vein Imaging (for A-fib ablation planning)