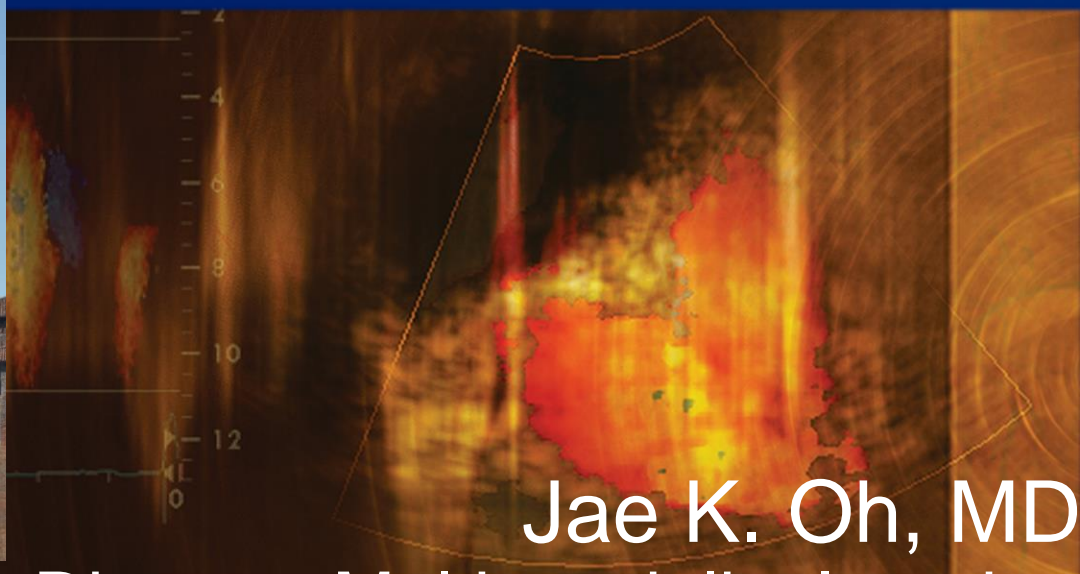




# Multi-modality CV Imaging

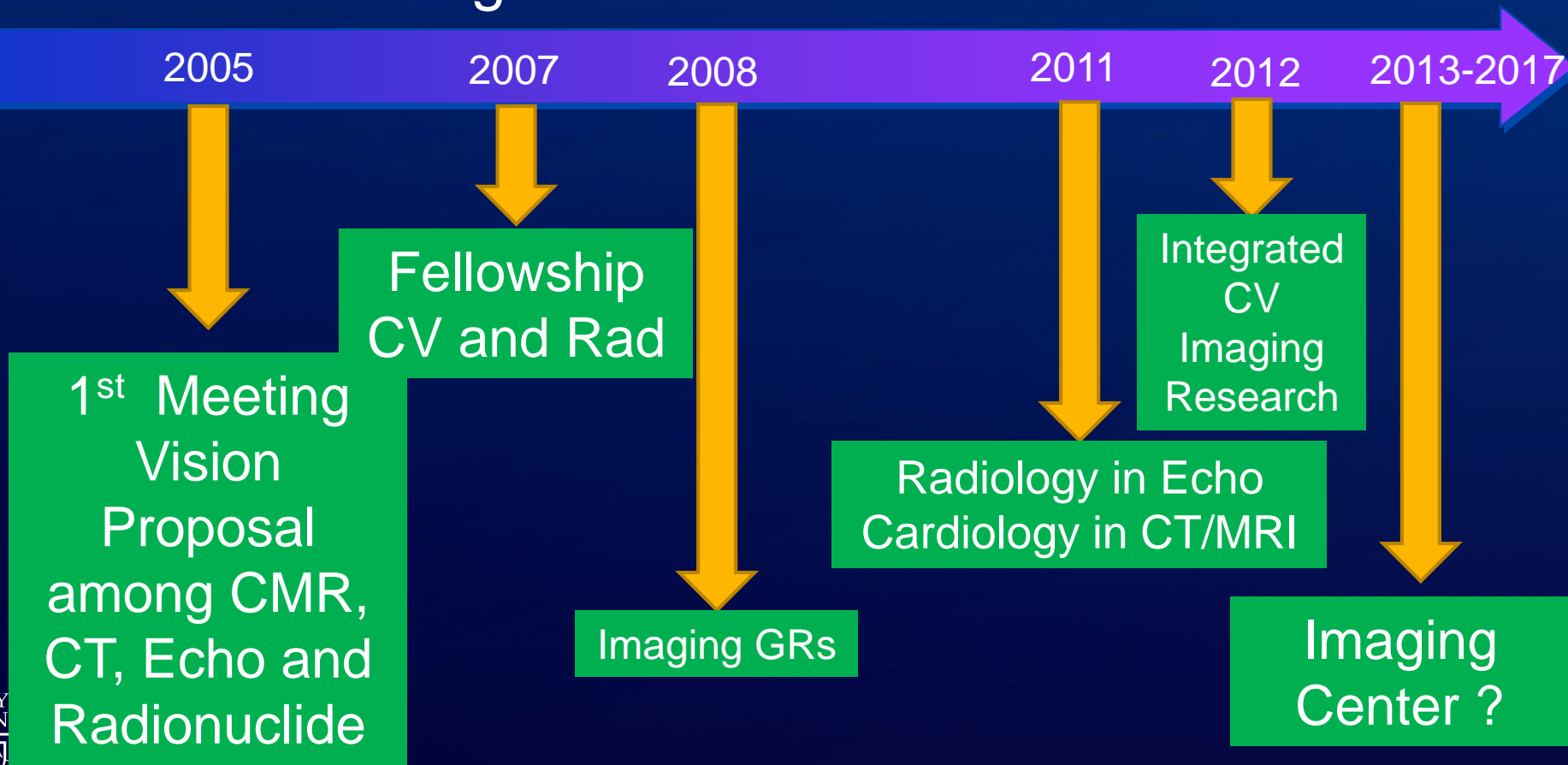
*Practice and Training at Mayo and Samsung MC*



Jae K. Oh, MD  
Co-Director, Multi-modality Imaging  
Director, Samsung Heart Vascular Stroke  
Institute, Korea  
Mantova, Italy 2017

# My Disclosure

- Clinician with a special interest in Echo and cardiac imaging
- Integration of Multi-modality Imaging at Mayo and Samsung MC



Coronary & Cardiac Anatomy

CV Imaging

Echo

Nuclear

CT

MRI

Cath

Inflammation  
metabolism

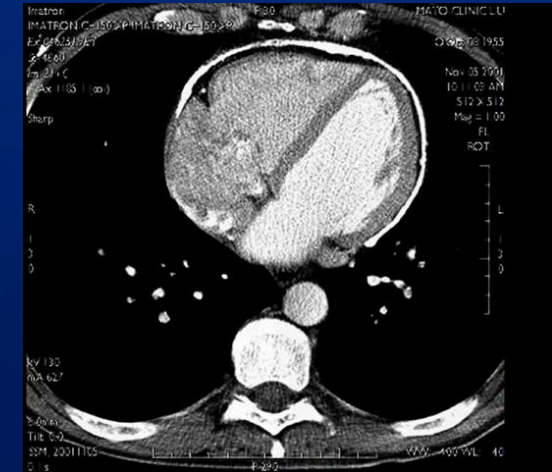
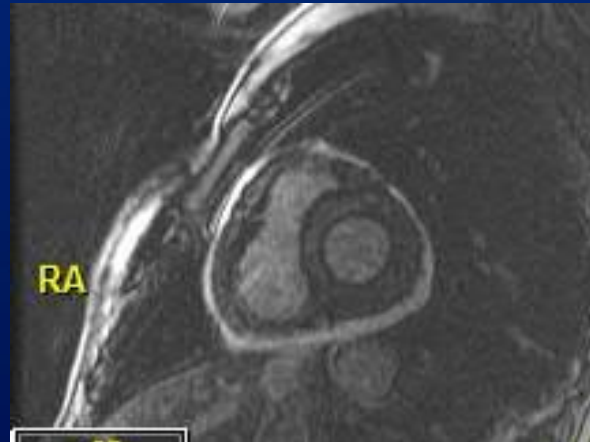
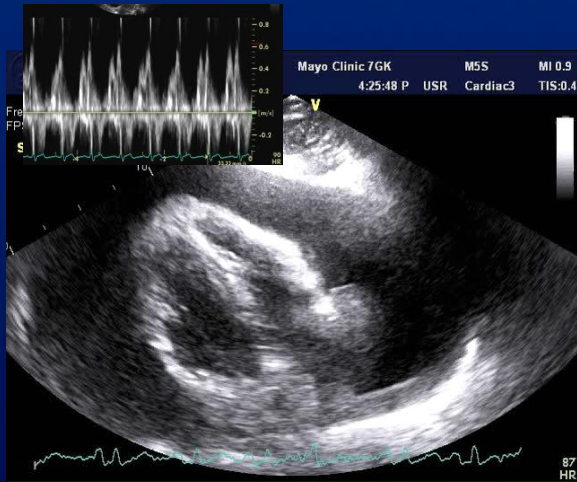
Function  
Ischemia

Hemodynamics

# Established role of imaging modalities

- Echo is usually the initial imaging test
- Echo is usually the diagnostic test of choice for critically ill patients (hemodynamically)
- CT is very good in delineating cardiac structure
- CT provides a good coronary anatomy
- MRI is good in delineation of cardiac structure
- MRI is best in tissue characterization
- Nuclear/PET provide perfusion and metabolism

# Multi-modality imaging *Pericardial Diseases*



- Structure/Function
- Hemodynamics
- Portable
- Structure/Function
- Tissue Characterization
- Inflammation
- Structure/Function
- Calcification

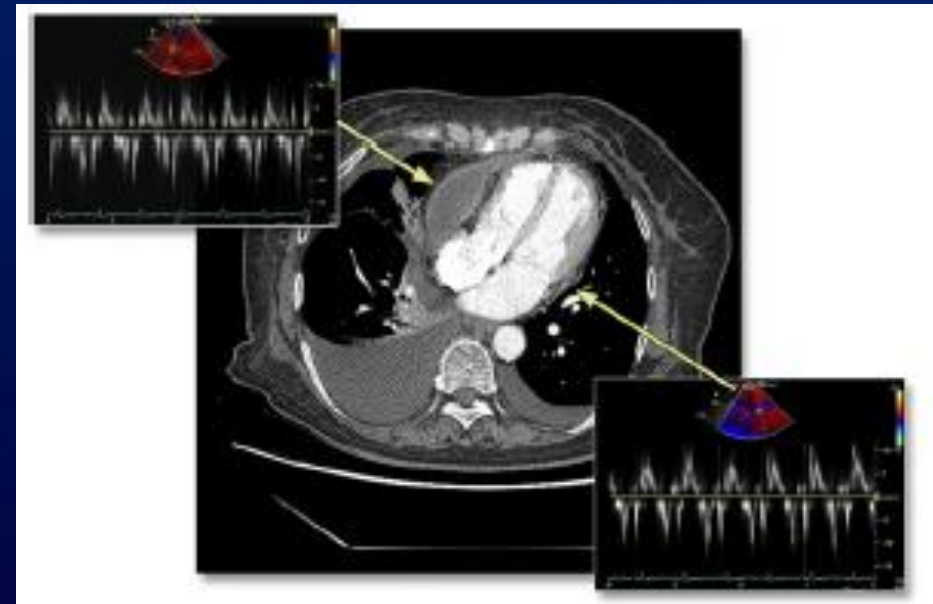
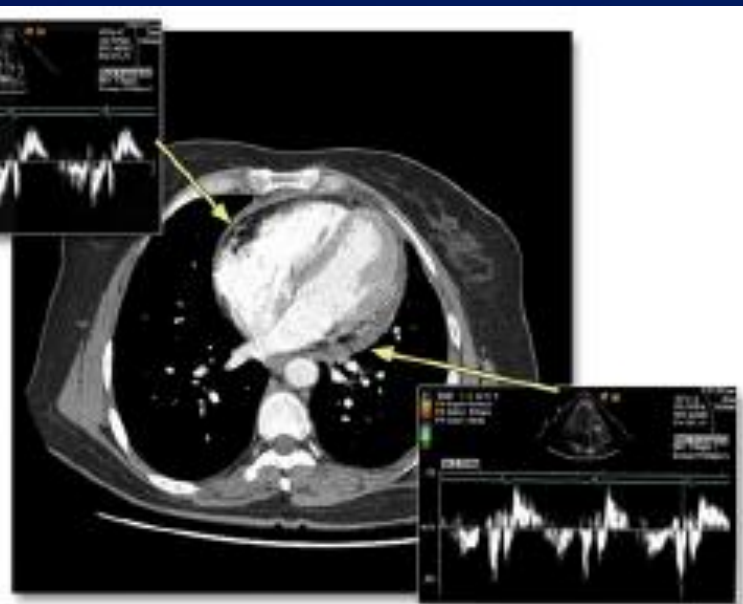
ORIGINAL RESEARCH

# Mitral and Tricuspid Annular Velocities in Constrictive Pericarditis and Restrictive Cardiomyopathy

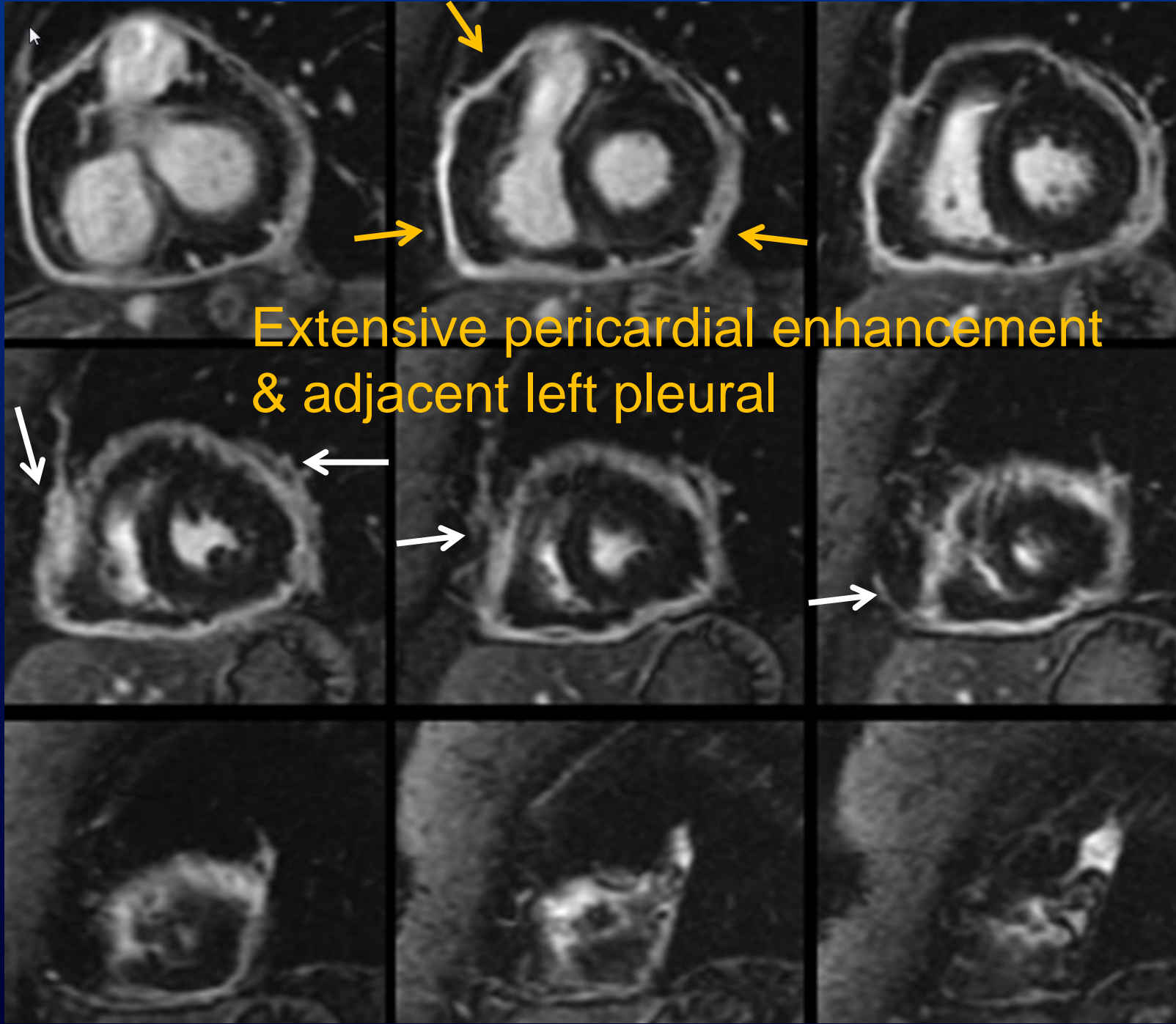
Correlation With Pericardial Thickness on Computed Tomography

Joon Hyouk Choi, MD,\* Jin-Oh Choi, MD,\* Dong Ryeol Ryu, MD,\* Sang-Chol Lee, MD,\*  
Seung Woo Park, MD,\* Yeon Hyeon Choe, MD,† Jae K. Oh, MD\*‡

*Seoul, Korea; and Rochester, Minnesota*



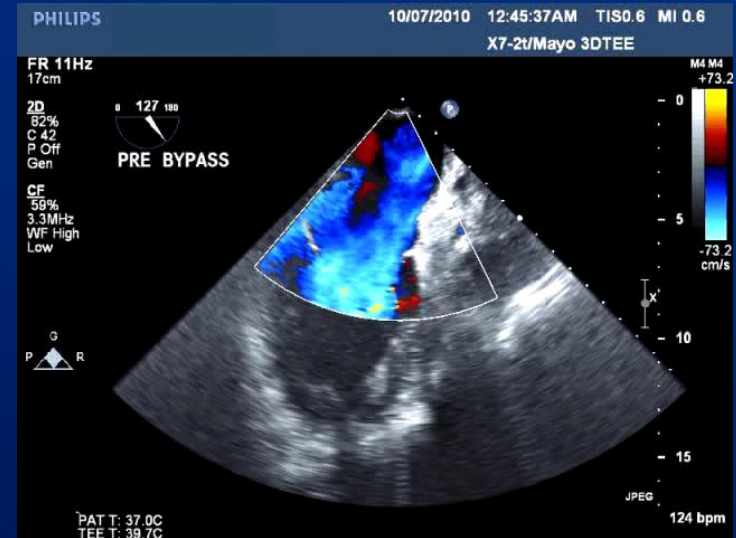
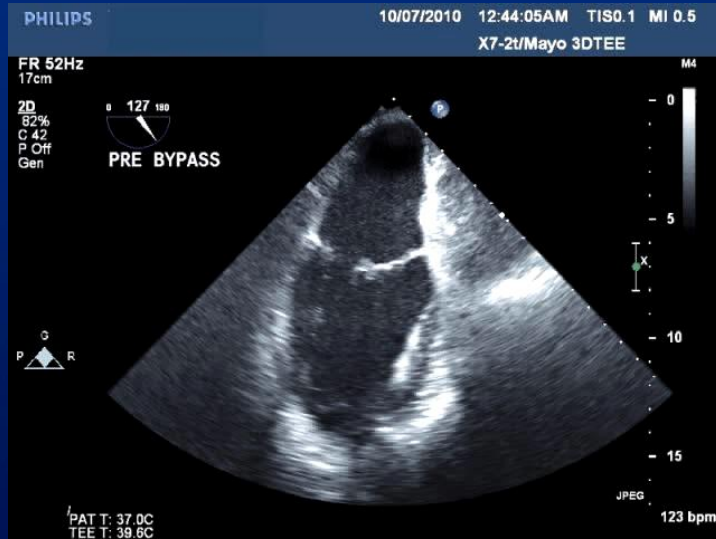




Extensive pericardial enhancement  
& adjacent left pleural

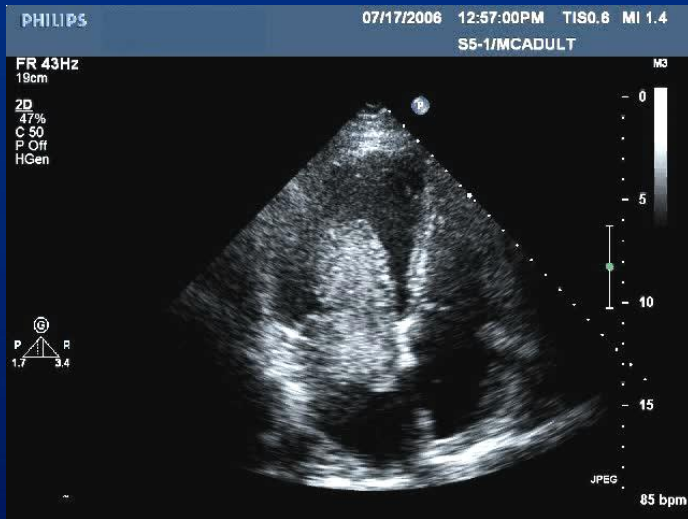
# TEE in 84 year old man with dyspnea

## Partial PM Rupture and Severe MR

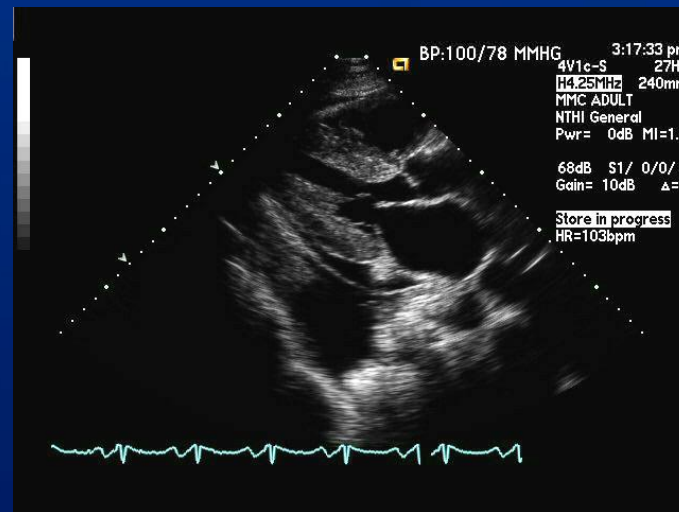




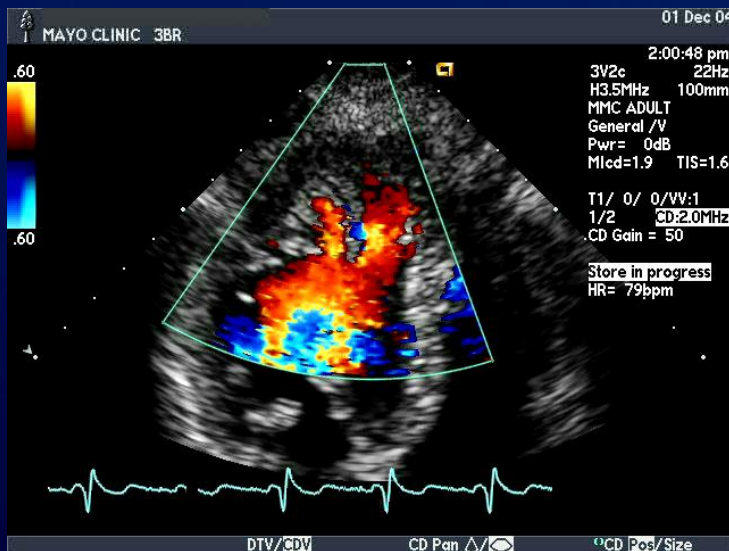
# Structural Abnormalities by Echo



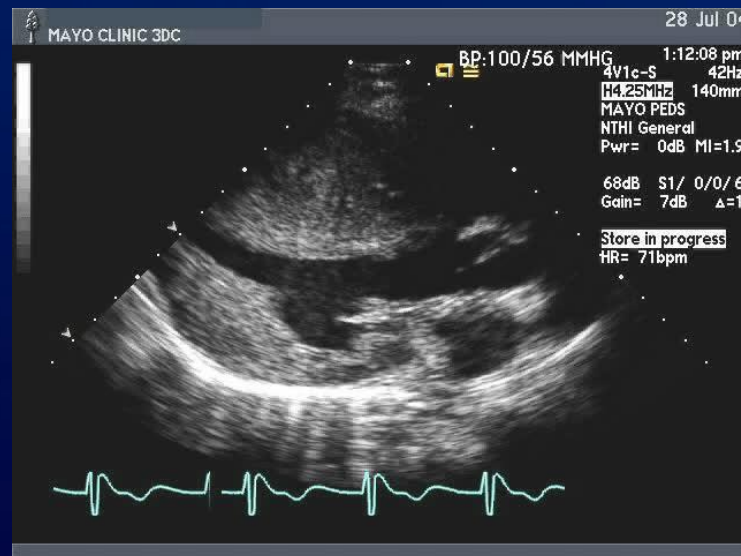
Myxoma



Amyloidosis



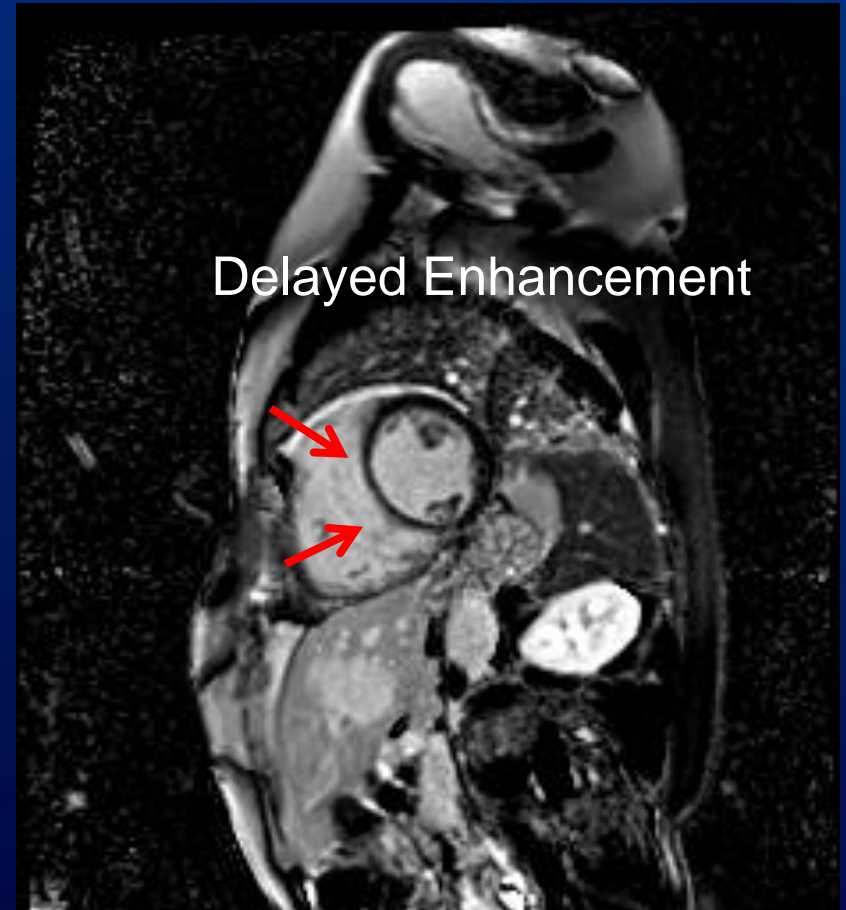
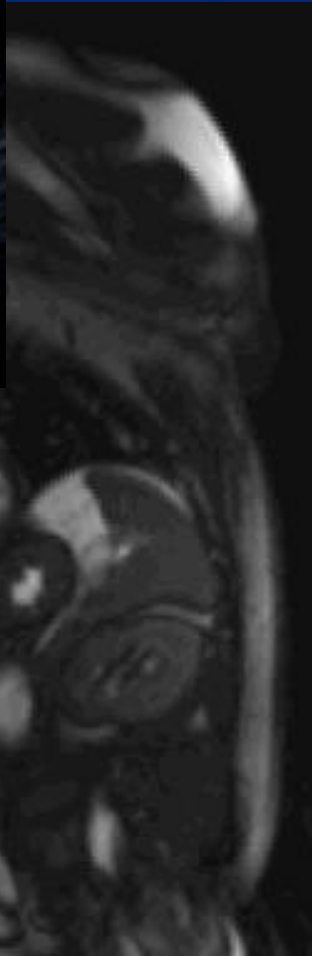
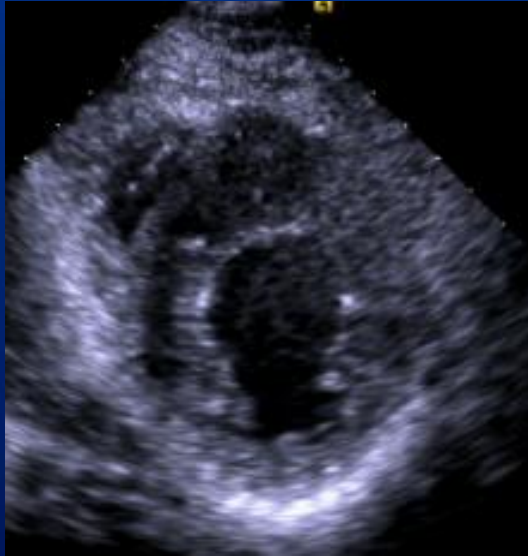
Noncompaction



Hypertrophic CM

# 57 year old with palpitation

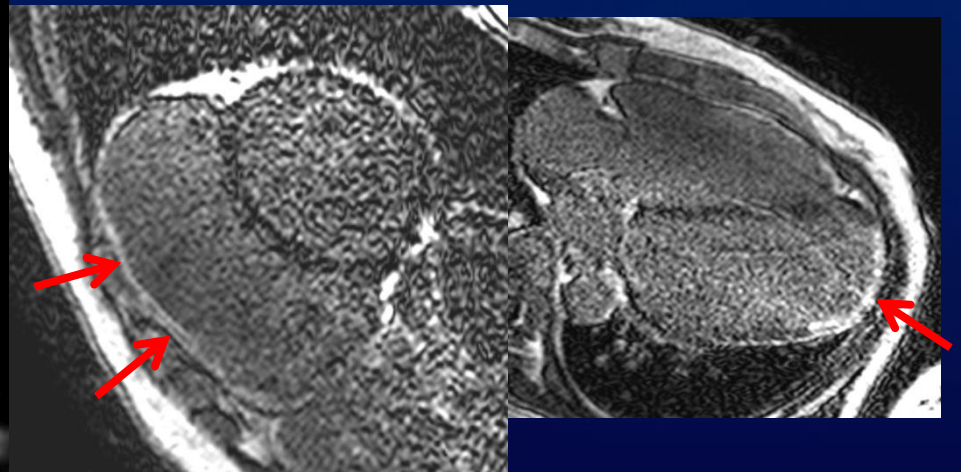
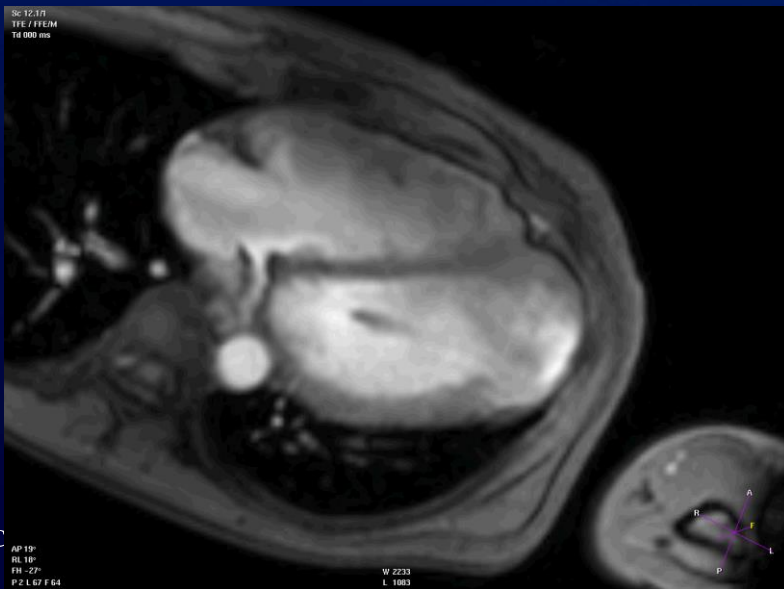
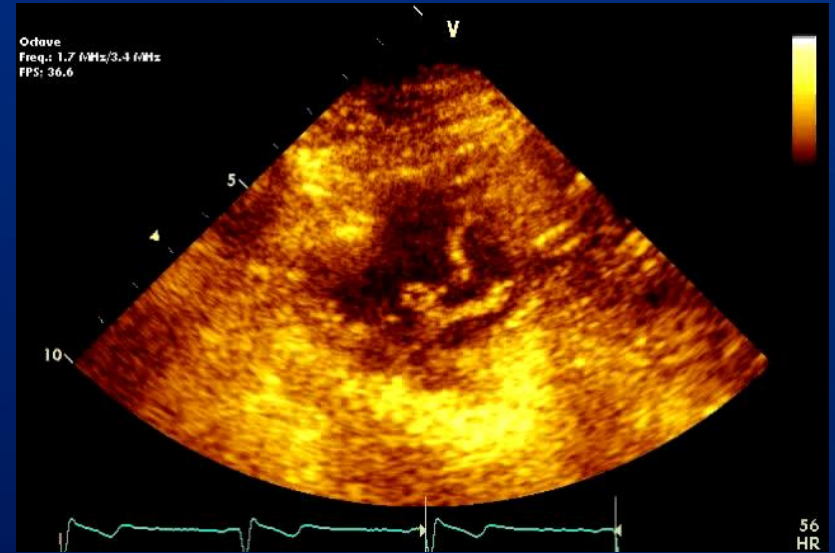
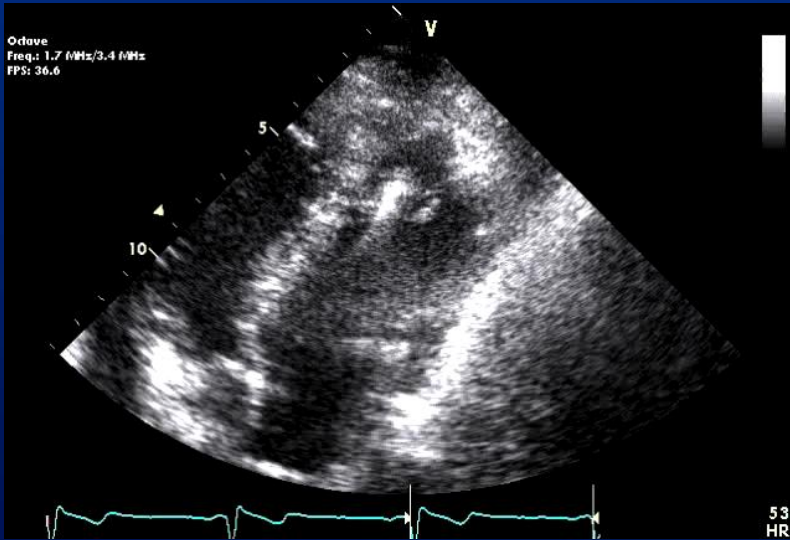
Sarcoidosis



Delayed Enhancement

# Arrhythmogenic RV Dysplasia with LV Fibrosis

## Echo vs MRI “Additional Information”



Late Hyperenhancement

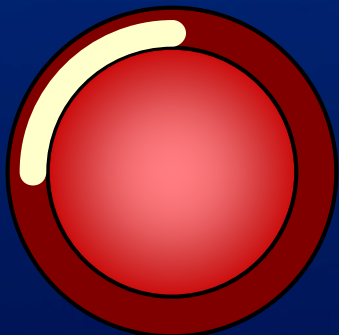


# Cardiac MRI

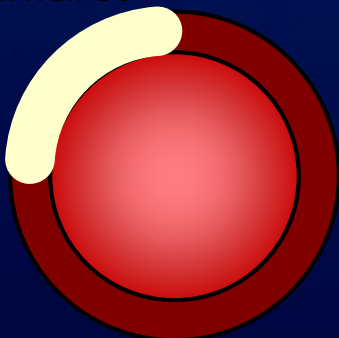
## Hyperenhancement Patterns

### Ischemic

Subendocardial infarct

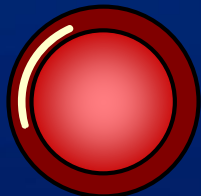


Transmural infarct

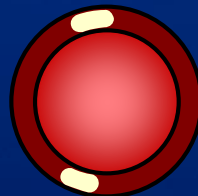


### Nonischemic

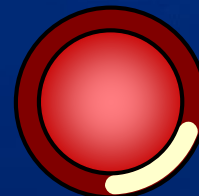
Mid-wall HE



- Idiopathic dilated cardiomyopathy
- Myocarditis

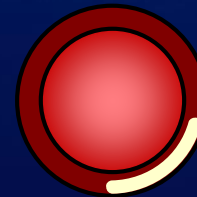
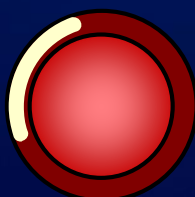


- Hypertrophic cardiomyopathy
- RV pressure overload (eg, congenital heart disease, pulmonary HTN)



- Sarcoidosis
- Myocarditis
- Anderson-Fabry disease
- Chagas' disease

Epicardial HE



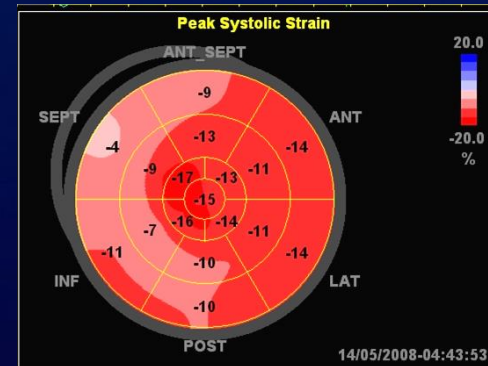
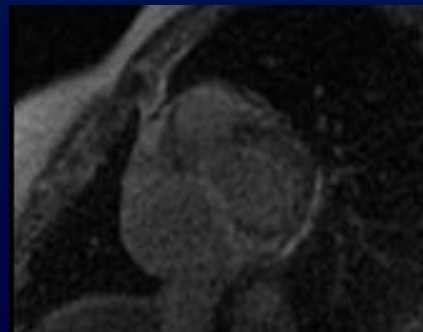
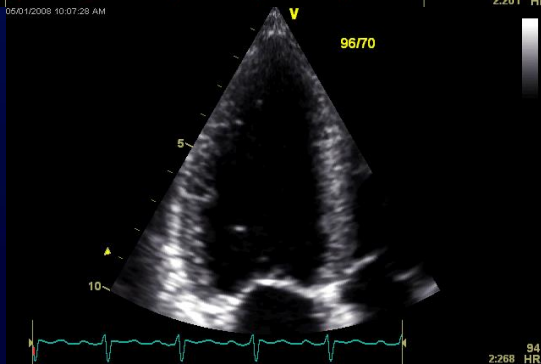
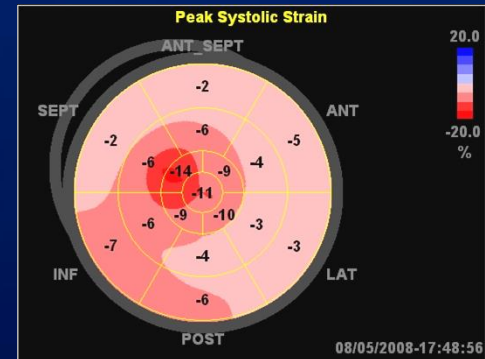
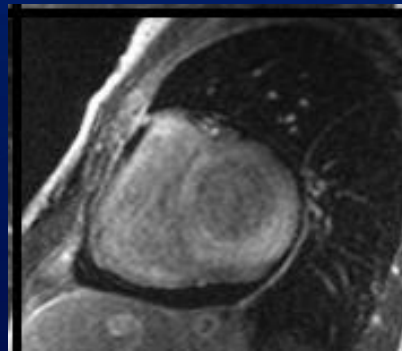
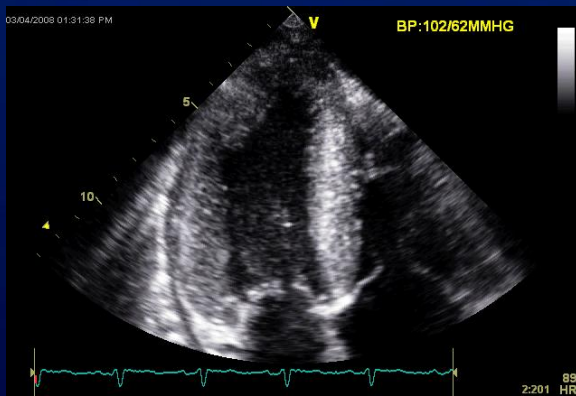
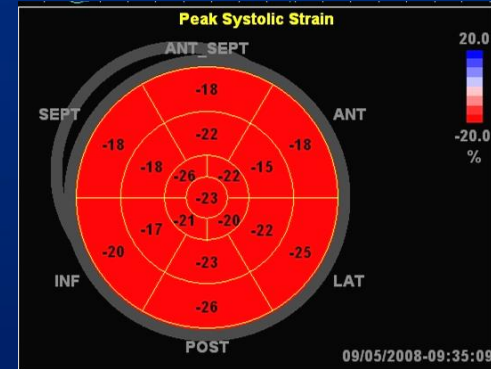
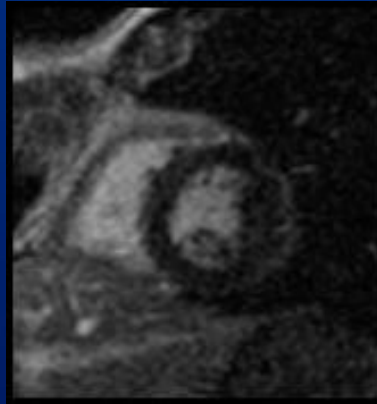
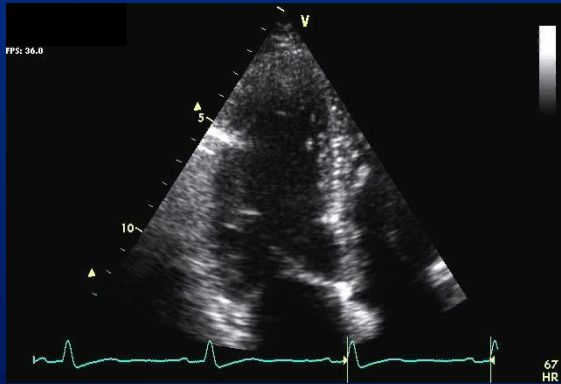
Sarcoidosis, myocarditis,  
Anderson-Fabry disease,  
Chagas' disease

Shah DJ et al: Nat Clin Pract CV  
Med 2(11):597, 2005



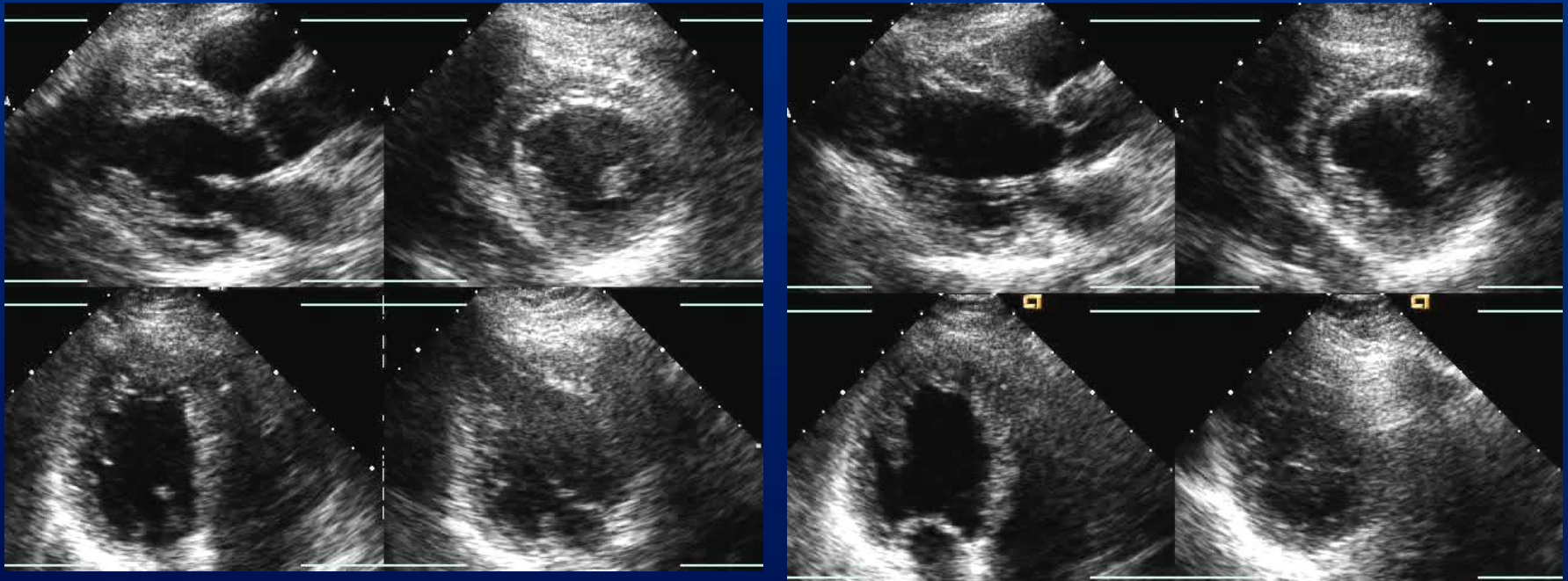
# Cardiac Amyloidosis

## 2-D Echo, MRI, and Strain





# 49 year old woman with chest pain



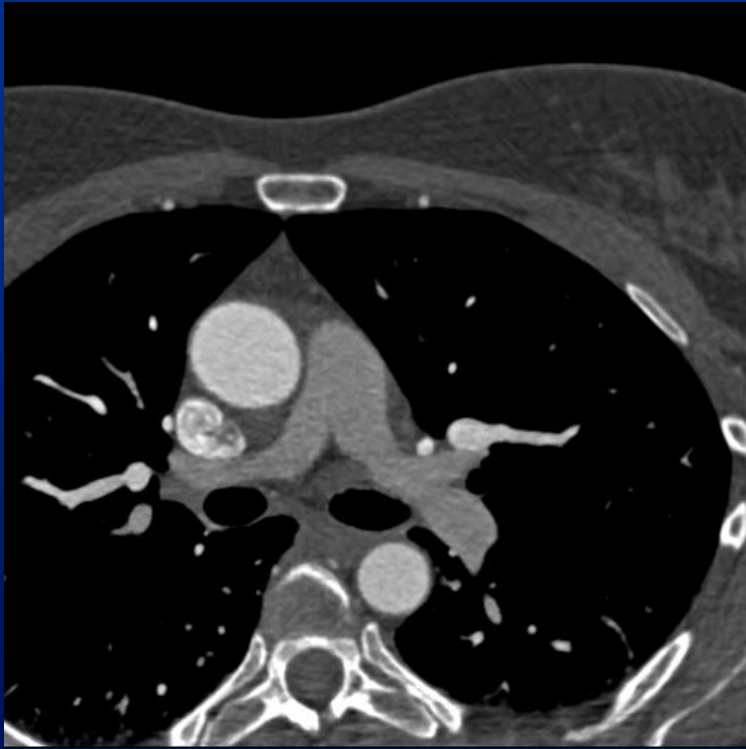
Resting

Exercise

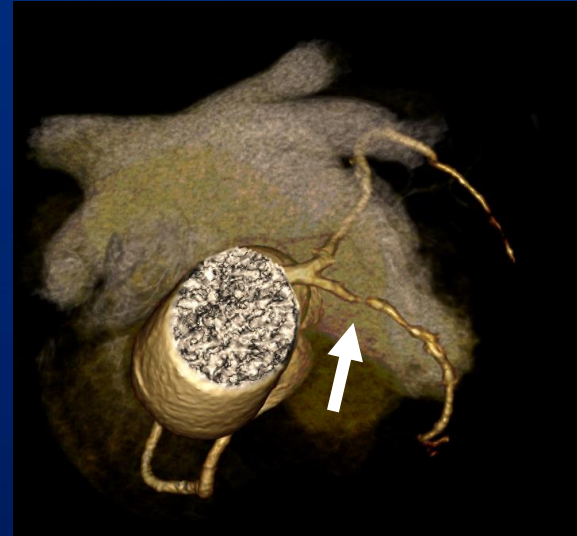
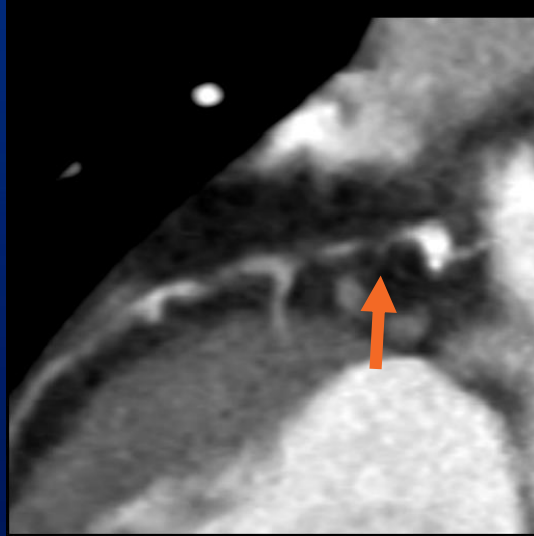
Which Imaging test next ?

1= None. Medical Tx 2= Chest and cardiac CT  
3= Cardiac MRI 4= Coronary angiogram

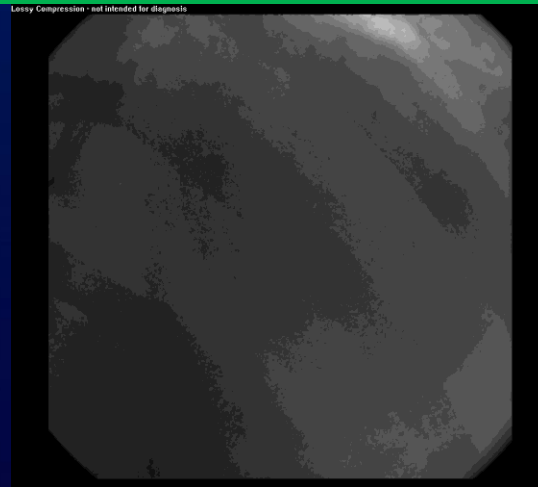
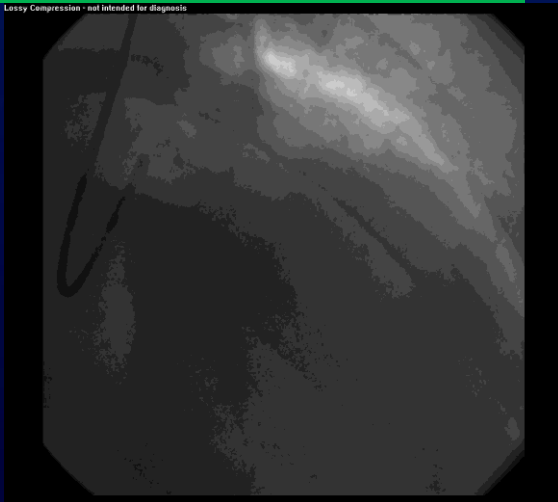
# 49 year old woman with chest pain



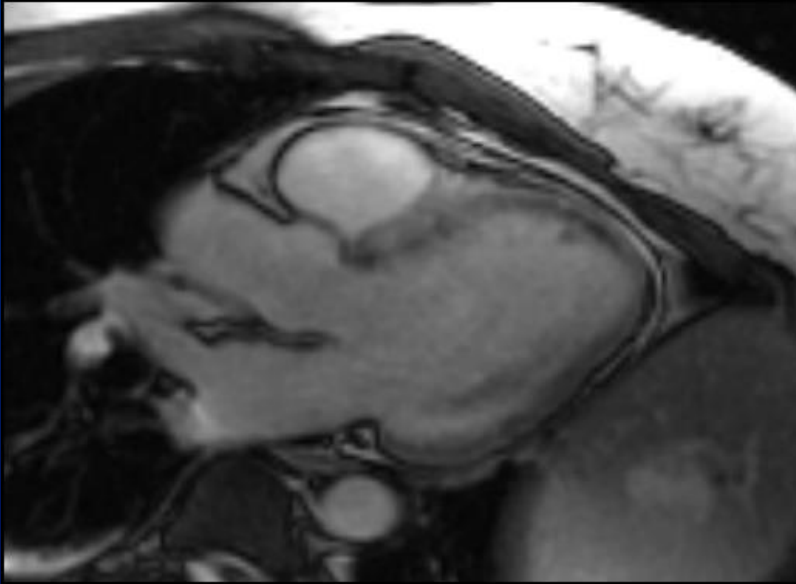
No PE or Dissection



LAD Stenosis



# 49 year old woman with chest pain



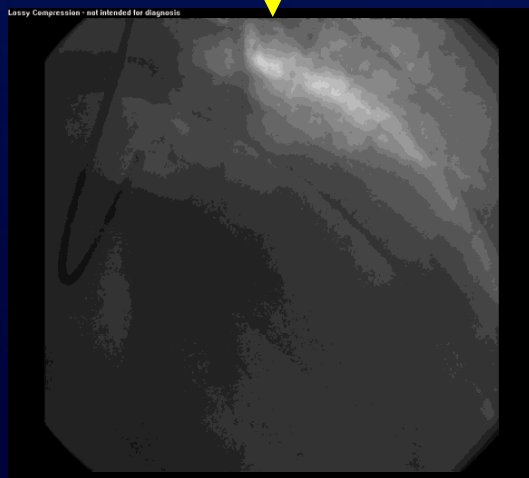
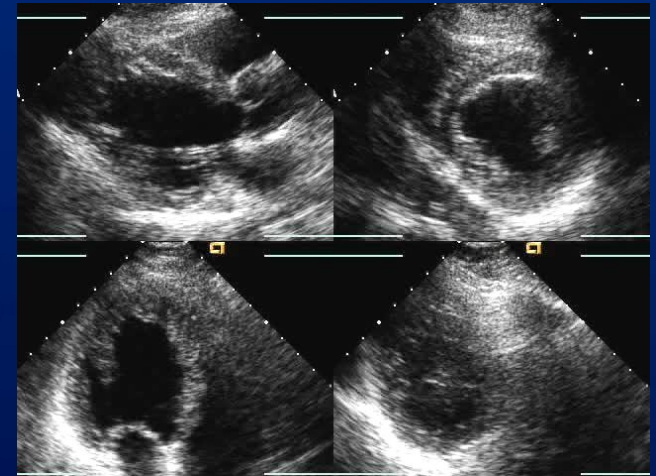
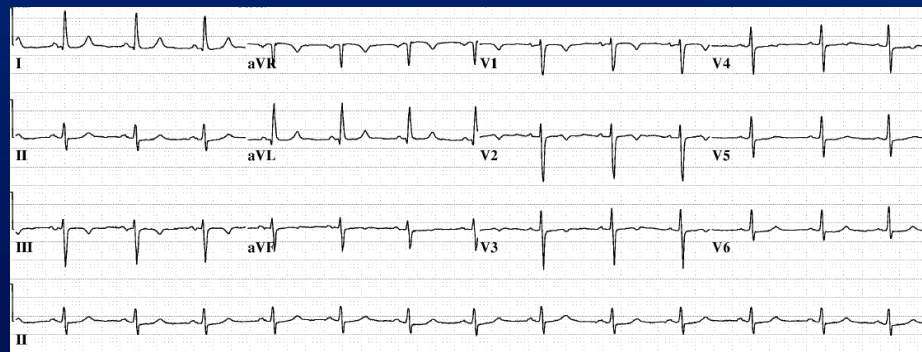
Anterior Hypokinesis



Delayed Enhancement

# 49 year old woman with chest pain

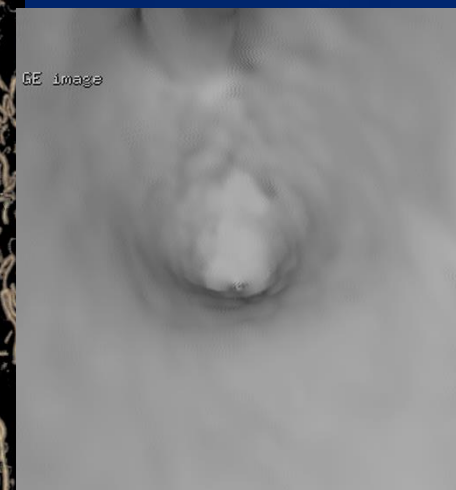
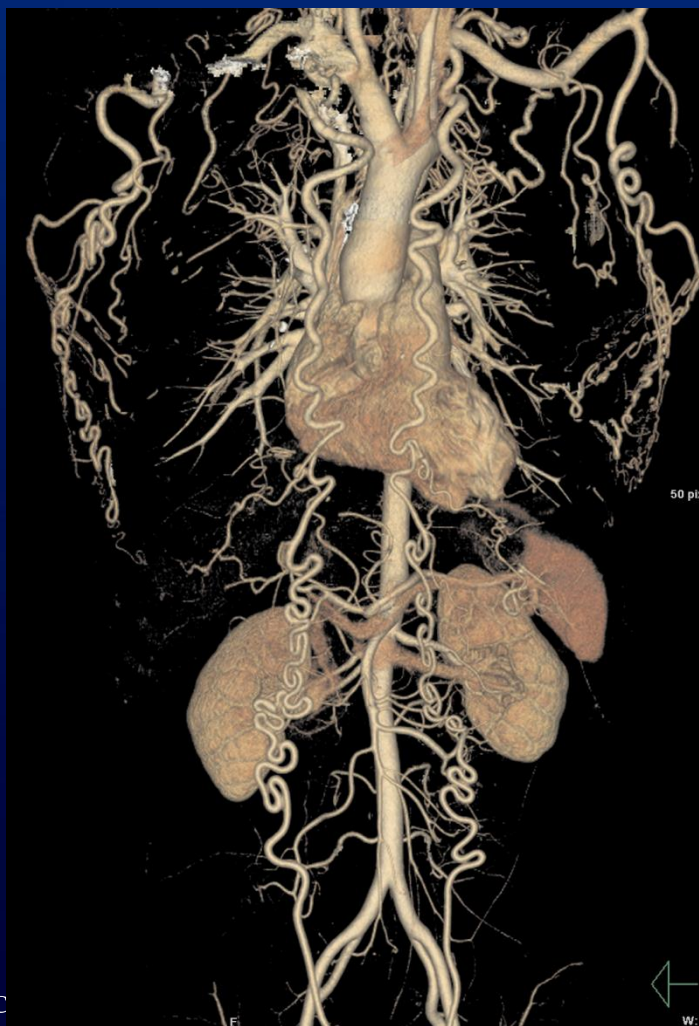
Risk Factors : Hypertension and Hyperlipidemia  
Troponin was not elevated



Retrospectively, CT/MRI did not help in this case



# Coarctation of Aorta by CT

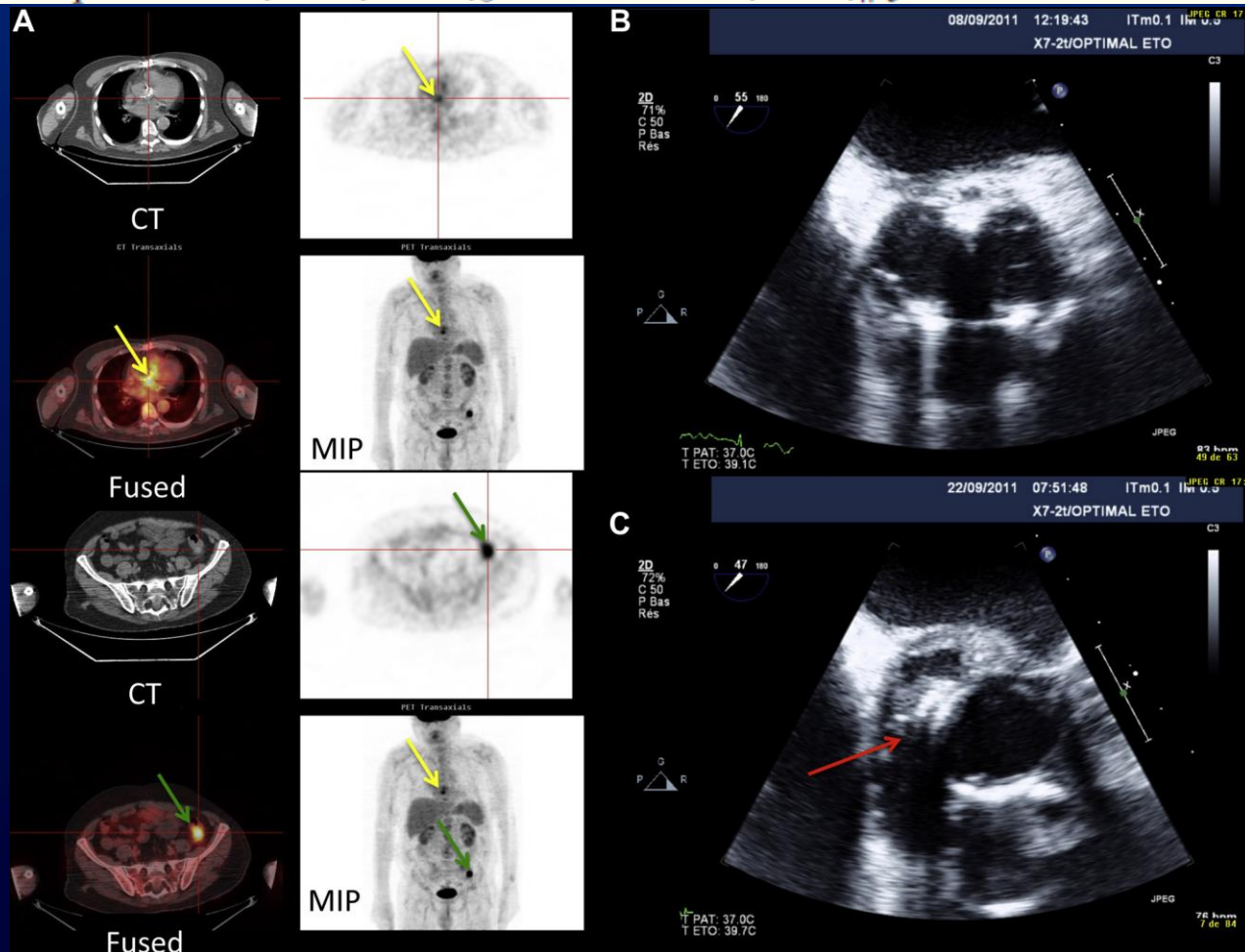




# Positron Emission Tomography/Computed Tomography for Diagnosis of Prosthetic Valve Endocarditis

Increased Valvular  $^{18}\text{F}$ -Fluorodeoxyglucose Uptake as a Novel Major Criterion

Ludivine Saby, MD,\* Olivia Laas, MD,† Gilbert Habib, MD,\* Serge Cammilleri, MD, PhD,† Julien Mancini, MD, PhD,‡ Laetitia Tessonier, MD,† Jean-Paul Casalta, MD,§ Frederique Gouriet, MD, PhD,§ Alberto Riberi, MD,|| Jean-Francois Avierinos, MD,\*



Sensitivity  
increased from  
70% to 97% on  
Prosthetic Valve  
Endocarditis

JACC 2013

# Integrated CV Imaging

- Does not mean more tests
- Should mean “Intelligent” imaging
- Should have incremental clinical value
- Should be used to understand a clinical condition and/or mechanism better
- Should avoid “territorial” dispute

# Multi-modality CV Imaging

- Clinically necessary
- Optimal clinical use requires an imager who understands various modalities
- Not able to afford “single image” specialist
- COCATS (Core Cardiology Training Symposium) 4 Guideline

# COCATS 4 Task Force

## Core Cardiology Training Symposium Multi-modality Imaging Training

- Level 1
  - Basic requirement for CV training (7 months)
  - Not sufficient for practice in CV imaging
- Level II
  - Additional training after level 1 in  $\geq 1$  imaging area within 3 years of CV training
  - Performs and Interprets imaging trained in
- Level III
  - Lab Directors, training others, specialized imaging research
  - Additional training after 3 years in MMI

# Multi-modality Imaging

- Patient-centric practice based a specific problem
- Most fellows are trained in level II Echo
- For a fellow to achieve level III in all 4 modalities, additional 1-2 years are required
- Cardiology vs Radiology
- Variable practice



# 2017 CV Training Program at Mayo Cardiology

	Mo 1	2	3	4	5	6	7	8	9	10	11	12
Year 1	Cath Level 1-1	Cath Level 1-2	Cath Level 1-3	Cath Level 1-4	Echo Level 1-1 & RMH	Echo Level 1-2	Echo Level 1-3 / CT/CMR Level 1	ECG/ EP Lab	HRS Cons. Level 1-1	Nuclear Level 1-1 & RMH	Nuclear Level 1-2	Stress/ Vascular & RMH
Year 2	Elective Or Cath Level 2-1	Elective Or Cath Level 2-2	Echo Level 2-1	Echo TTE/ST Level 2-2	Echo TEE Level 2-3	CCU 1	CCU 2	SMH CV Cons	IP Hospital/ CVHC_ Rehab/ RMH	HRS Level 1-2	Clin. Elect CF/VAD	Clini. Elec. ACHD
Year 3	Research & Lab 1 day/week & CEC or SC ½ d/wk	RMH (1-2 weeks)	Research (Res)	Res	Res	Res	Res	Res	Res	Res	Res	Res
Year 4	AST*	AST	AST	AST	AST	AST	AST	AST	AST	AST	AST	AST

\*AST = Advanced Subspecialty Training

# Echocardiography Track

**Yr 1**

Echo (12)	Cath (16)	HRS (8)	CVHC Vascular (4)	Nuclear (8)
--------------	--------------	------------	-------------------------	----------------

**Yr 2**

Elec Or Cath Level 2-1	Elec Or Cath Level 2-2	Echo TTE/ CT/ CMR Level 2-1	Echo TTE/ ST Level 2-2	Echo TEE Level 2-3	CCU 1	CCU 2	SMH CV Cons	IPHS/ RMH Cons/ CV Rehab	ECG/ HRS Level 1-2	Clin Elec CF/ LVAD	Clin Elec ACHD
------------------------------------	------------------------------------	--	------------------------------------	-----------------------------	----------	----------	-------------------	--------------------------------------	-----------------------------	-----------------------------	----------------------

**Yr 3**

**Research in Echo**  
Lab 1 d/wk & CEC1/2 d/wk

**Yr 4**

**Echocardiography:** TEE, Stress testing, Independent TTE review, Subspecialty Echo, 3D, Strain, Interventional Echo

# Imaging Track

**Yr 1**

Echo (12)		Cath (16)				HRS (8)	CVHC (4)	Nuclear (8)
-----------	--	-----------	--	--	--	---------	----------	-------------

**Yr 2**

Elec	Elec	Echo TTE/CT/CMR Level 2-1	Echo TTE/ST Level 2-2	Echo TEE Level 2-3	CCU 1	CCU 2	SMH CV Cons	IPHS/RMH Cons/CV Rehab	ECG/HRS Level 1-2	Clin Elec CF/LVAD	Clin Elec ACHD
------	------	---------------------------	-----------------------	--------------------	-------	-------	-------------	------------------------	-------------------	-------------------	----------------

**Yr 3**

**12 mos CT/MR\*  
(Research per Rotation)**

**Yr 4**

**8 months Echo\***

**4 mos Nuclear\***

\*This scheme allows for level III CT/MR and echo and level II Nuclear. Some flexibility is available depending on individual career goals.

# Imaging Track

**Yr 1**

Echo (12)	Cath (16)				HRS (8)	CVHC (4)	Nuclear (8)
--------------	--------------	--	--	--	------------	-------------	----------------

**Yr 2**

Elec	Elec	Echo TTE/ CT/ CMR Level 2-1	Echo TTE/ ST Level 2-2	Echo TEE Level 2-3	CCU 1	CCU 2	SMH CV Cons	IPHS/ RMH Cons/ CV Rehab	ECG/ HRS Level 1-2	Clin Elec CF/ LVAD	Clin Elec ACHD
------	------	--	------------------------------------	-----------------------------	----------	----------	-------------------	--------------------------------------	-----------------------------	-----------------------------	----------------------

**Yr 3**

**12 mos CT/MR\*  
(Research per Rotation)**

**Yr 4**

**8 months Echo\***

**4 mos Nuclear\***

**Yr 5**

Research in MM Imaging



# Hemodynamic Track

**Yr 1**

Echo (12)	Cath (16)	HRS (8)	CVHC Vascular (4)	Nuclear (8)
--------------	--------------	------------	-------------------------	----------------

**Yr 2**

Cath Level 2-1	Cath Level 2-2	Echo TTE/ CT/ CMR Level 2-1	Echo TTE/ ST Level 2-2	Echo TEE Level 2-3	CCU 1	CCU 2	SMH CV Cons	IPHS/ RMH Cons/ CV Rehab	ECG/ HRS Level 1-2	Clin Elec CF/ LVAD	Clin Elec ACHD
----------------------	----------------------	--	------------------------------------	-----------------------------	----------	----------	-------------------	--------------------------------------	-----------------------------	-----------------------------	----------------------

**Yr 3**

Research in Structural HD  
Lab 1 d/wk & CEC1/2 d/wk

**Yr 4**

6 months Echo (Level 3)

6 months Cath (Level 2)

# Ischemic HD – Echo/Nuc Track

**Yr 1**

<b>Echo (12)</b>	<b>Cath (16)</b>				<b>HRS (8)</b>	<b>CVHC Vascular (4)</b>	<b>Nuclear (8)</b>
----------------------	----------------------	--	--	--	--------------------	----------------------------------	------------------------

**Yr 2**

<b>Elec Or Cath Level 2-1</b>	<b>Elec Or Cath Level 2-2</b>	<b>Echo TTE/ CT/ CMR Level 2-1</b>	<b>Echo TTE/ ST Level 2-2</b>	<b>Echo TEE Level 2-3</b>	<b>CCU 1</b>	<b>CCU 2</b>	<b>SMH CV Cons</b>	<b>IPHS/ RMH Cons/ CV Rehab</b>	<b>ECG/ HRS Level 1-2</b>	<b>Clin Elec CF/ LVAD</b>	<b>Clin Elec ACHD</b>
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**Yr 3**

**Research in Echo & Nuclear  
Lab 1 d/wk & CEC1/2 d/wk**

**Yr 4**

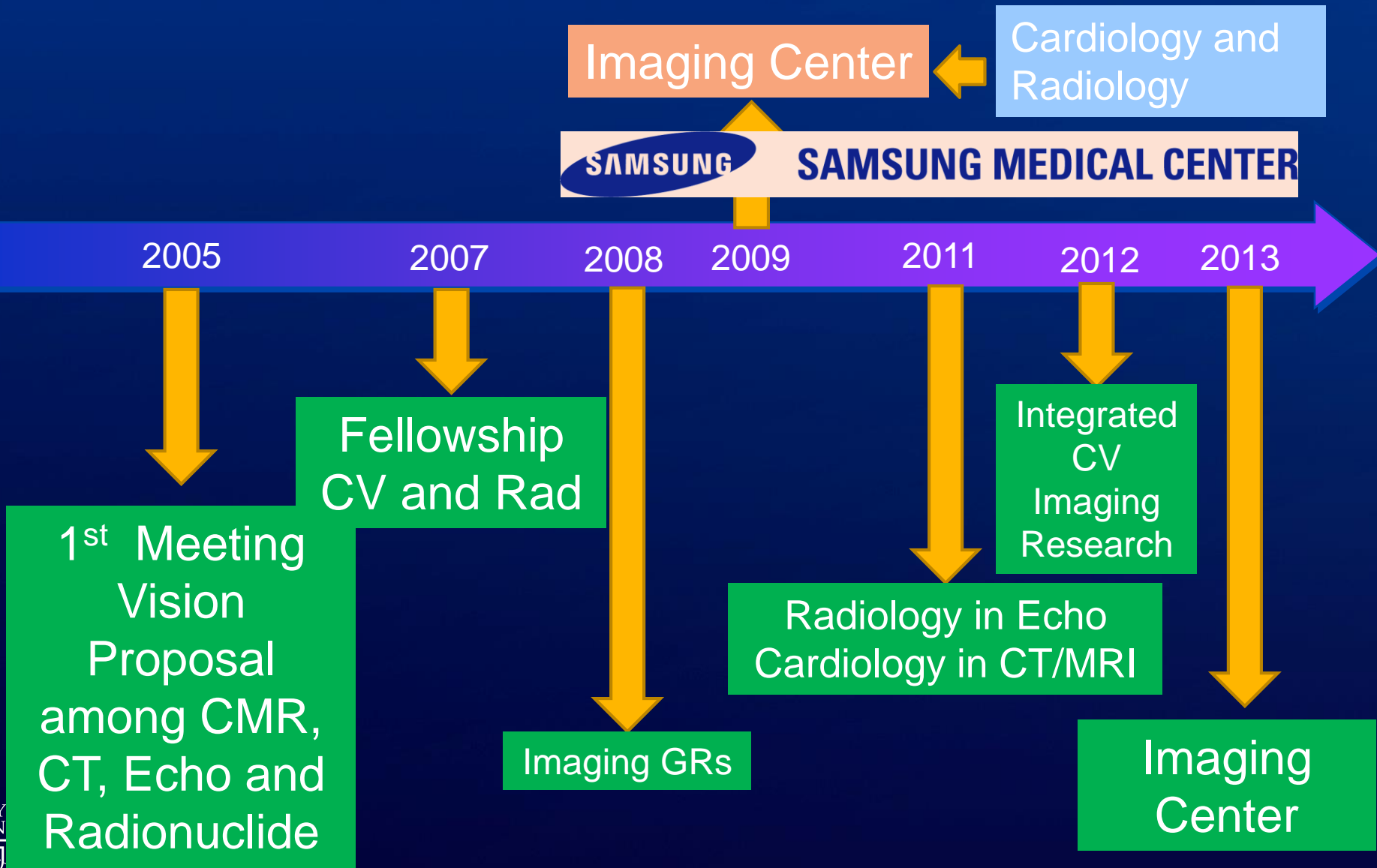
**6 months Echo (Level 3)**

**6 months Nuclear (Level 2)**

# Multi-modality CV Imaging at Mayo

- 2-3 year Fellowship after 2 years of cardiology or Radiology fellowship training
- Cardiology (Anavekar and Bois) and Radiology (Foley) Staff Read 4 Imaging Modalities
- Echo GRs changed to Imaging GRs
- Regular CV Imaging research meeting
- Trying to establish CV Imaging Center

# Integration of CV Imaging at Mayo Clinic and Samsung MC





Strong  
Heart



Clean  
Blood vessel



Happy  
Brain



**SAMSUNG**

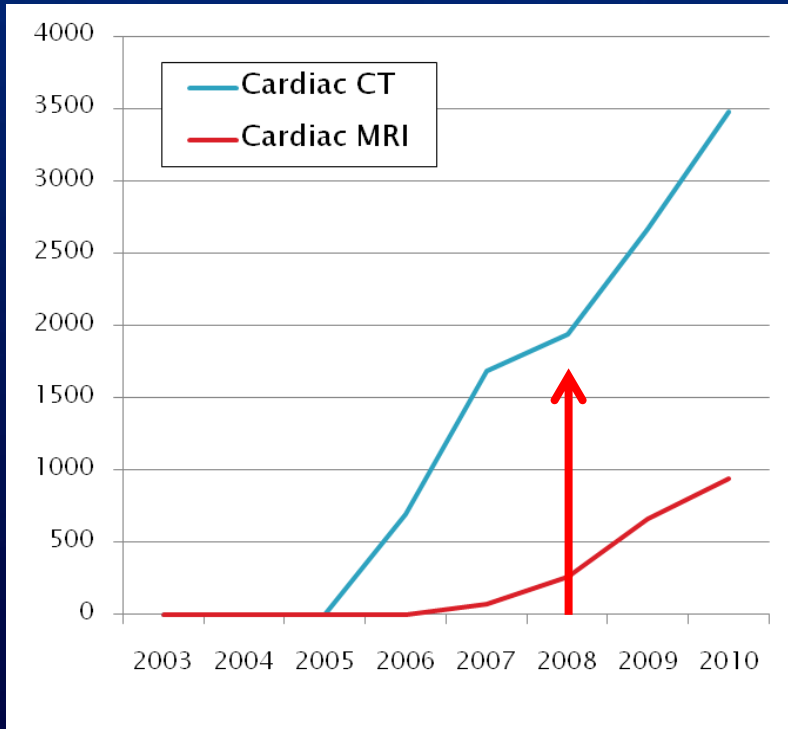
## SAMSUNG MEDICAL CENTER



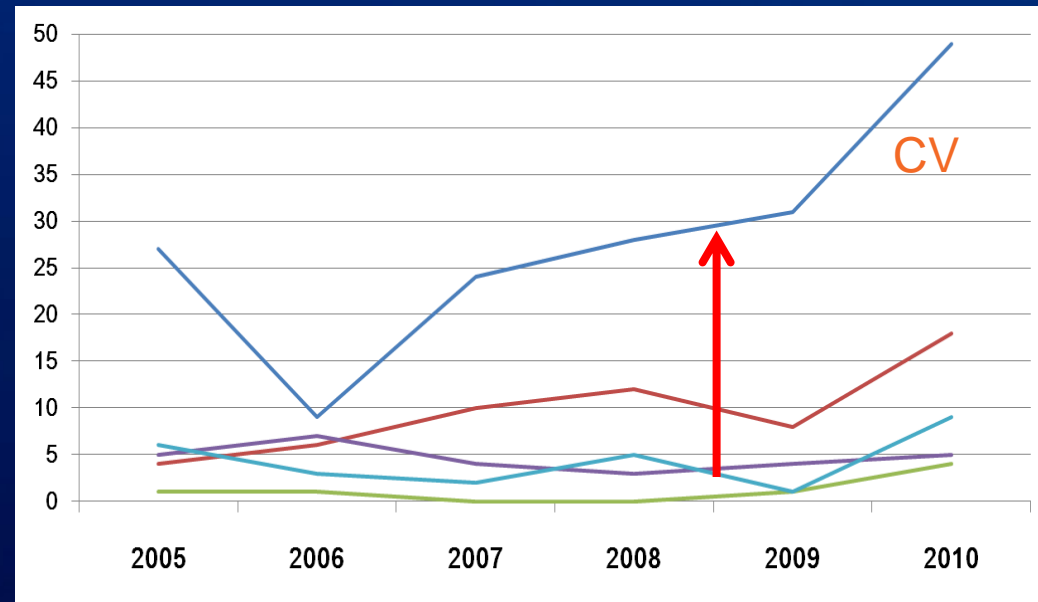
# Multi-modality CV and Stroke Imaging at Samsung MC in Korea

- Echo Lab and MRI Lab side by side
- A joint Work-room for Echo, CT, MRI
- Heart Vascular Stroke Institute...Stroke Imaging was added
- Imaging Center Director...Cardiology or Radiology
- Increased Publications in Collaborative Research

# Integrated CV Imaging Result



Cases



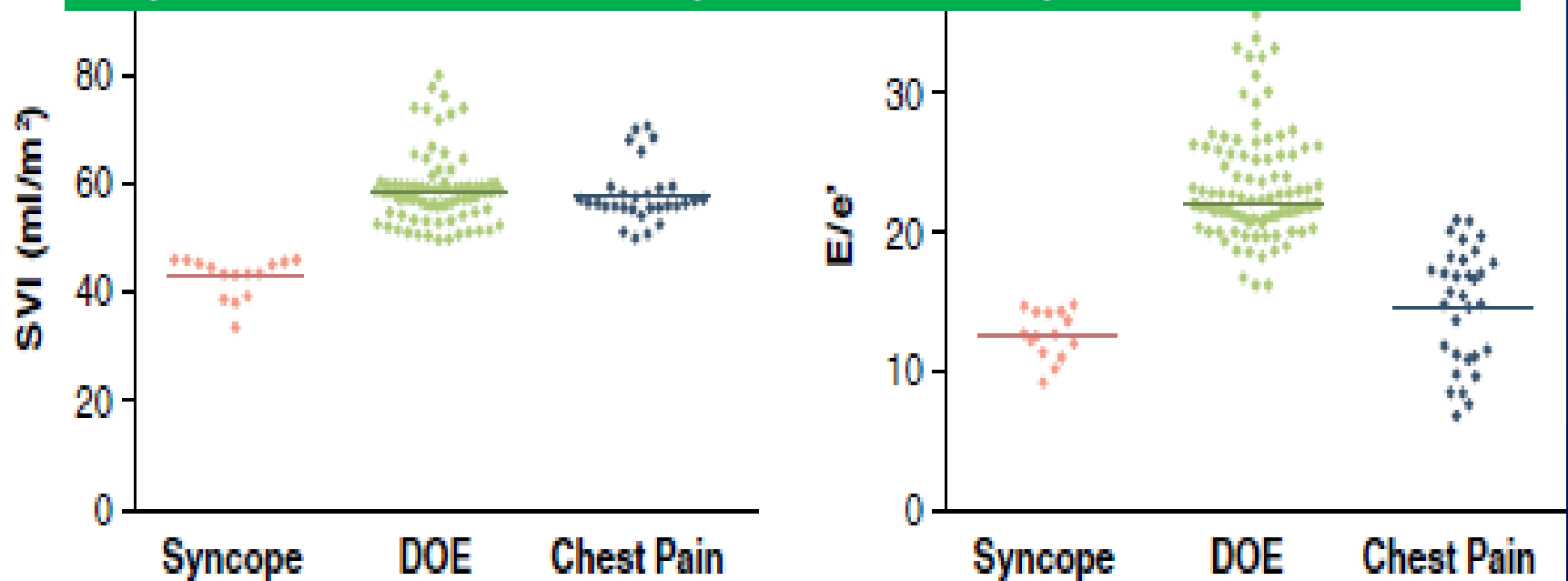
Publications

# Hemodynamic Patterns for Symptomatic Presentations of Severe Aortic Stenosis

Sung-Ji Park, MD, PhD,\* Maurice Enriquez-Sarano, MD,† Sung-A Chang, MD, PhD,\* Jin-Oh Choi, MD, PhD,\* Sang-Chol Lee, MD, PhD,\* Seung Woo Park, MD, PhD,\* Duk-Kyung Kim, MD, PhD,\* Eun-Seok Jeon, MD, PhD,\* Jae K. Oh, MD\*†

Seoul, Korea; and Rochester, Minnesota

All groups had the same mean gradient (56 mmHg) and AVA (0.79 cm<sup>2</sup>)

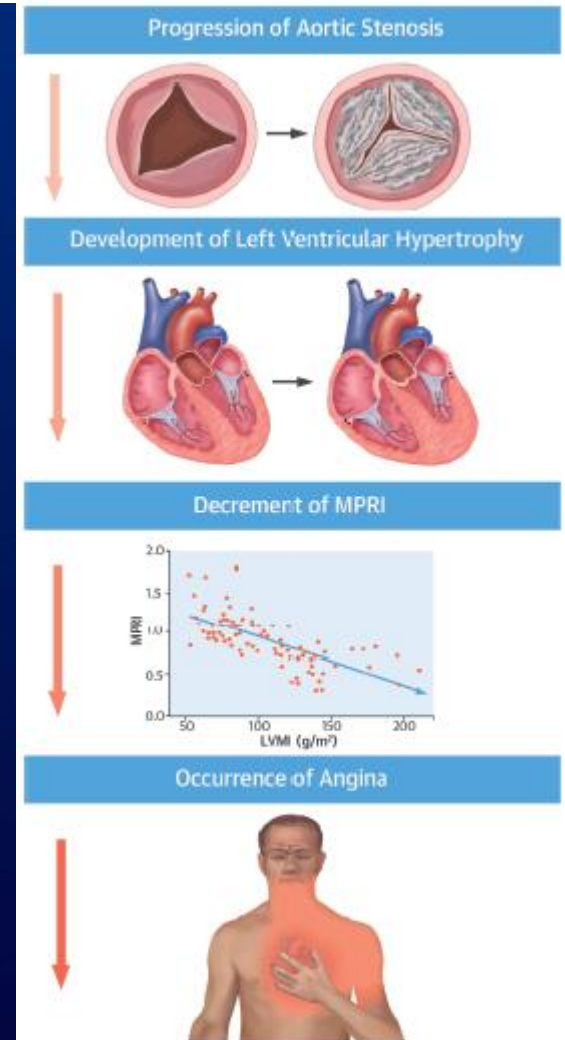
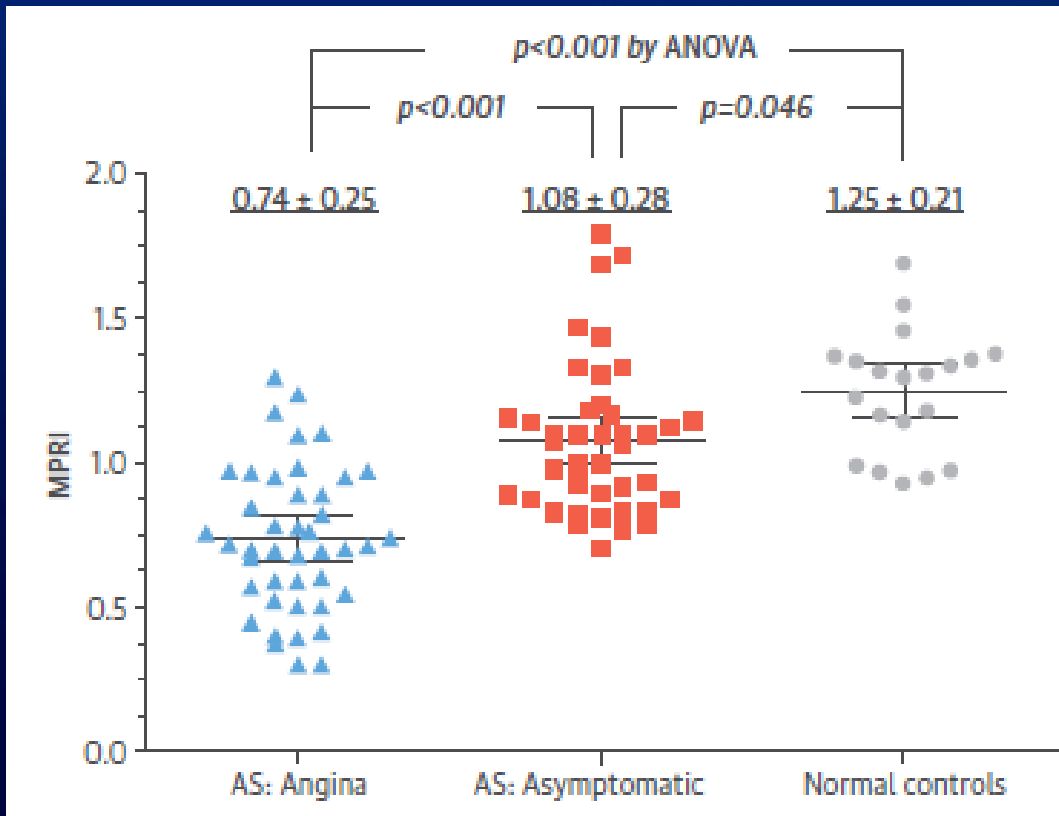


# Coronary Microvascular Dysfunction as a Mechanism of Angina in Severe AS

## Prospective Adenosine-Stress CMR Study



Jong-Hwa Ahn, MD,<sup>a</sup> Sung Mok Kim, MD,<sup>b</sup> Sung-Ji Park, MD, PhD,<sup>a</sup> Dong Seop Jeong, MD, PhD,<sup>c</sup> Min-Ah Woo, MS,<sup>d</sup> Sin-Ho Jung, PhD,<sup>d</sup> Sang-Chol Lee, MD, PhD,<sup>a</sup> Seung Woo Park, MD, PhD,<sup>a</sup> Yeon Hyeon Choe, MD, PhD,<sup>b</sup> Pyo Won Park, MD, PhD,<sup>c</sup> Jae K. Oh, MD<sup>a,e</sup>





## 2 Tier Training for MM CV Imaging

- Lower level tier training :Basic Front Line Imaging
  - Level 2 training in all imaging modalities
  - Takes care of day to day imaging needs
  - In 3 year CV training program
- Higher level tier training :Imaging Expertise
  - Level 3 training in 1 or more imaging modalities
  - Imaging Lab director, investigator
  - Requires additional year of training

# Multi-modality CV Imaging Challenges

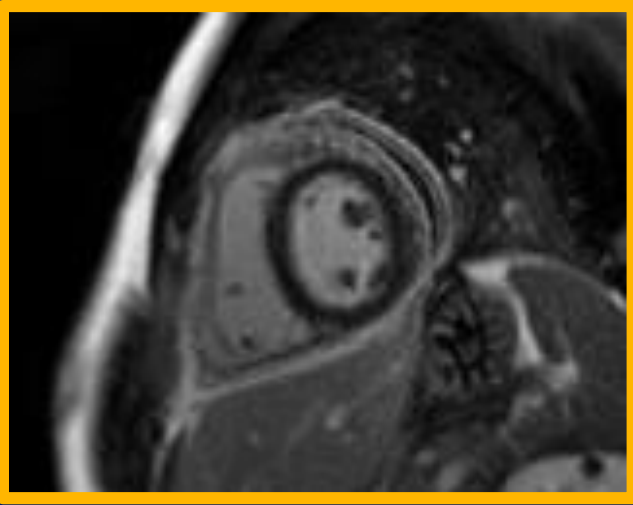
- Developed independently
- Ownership varies...Cardiology vs Radiology
- Training takes a long time and nor coordinated
- “the application of a given modality should be dictated by the needs of a particular patient rather than the expertise of a particular cardiologist” (Zoghbi and Narula 2009 JACC)

# Who is an optimal MM CV Imager?

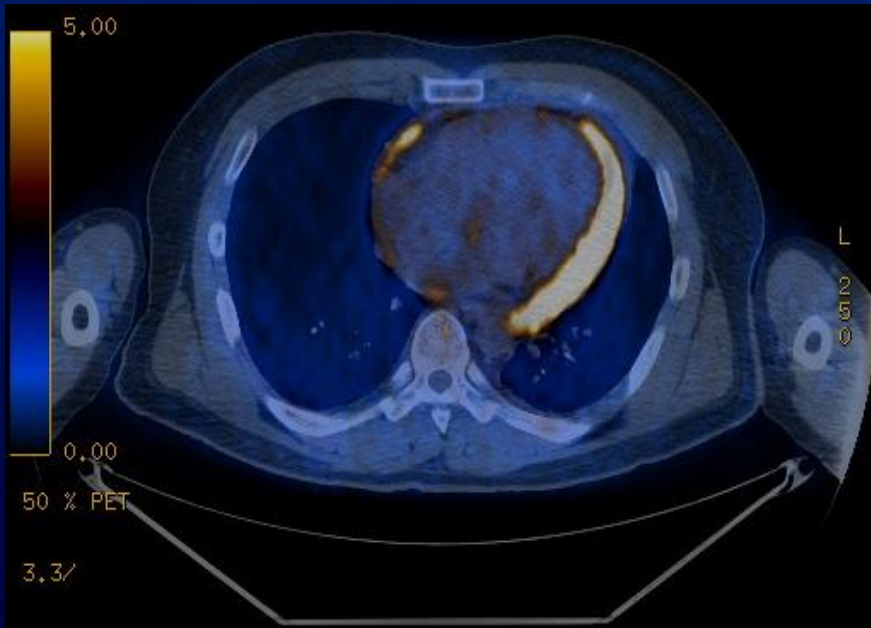
- Good clinical cardiology/cardiac radiology training
- Ideally, level II in all imaging modalities
- Level III training in at least 1, preferably in  $\geq 2$
- Select the most suitable image for a given patient and/or disease
- Able to coordinate “Bundled” imaging



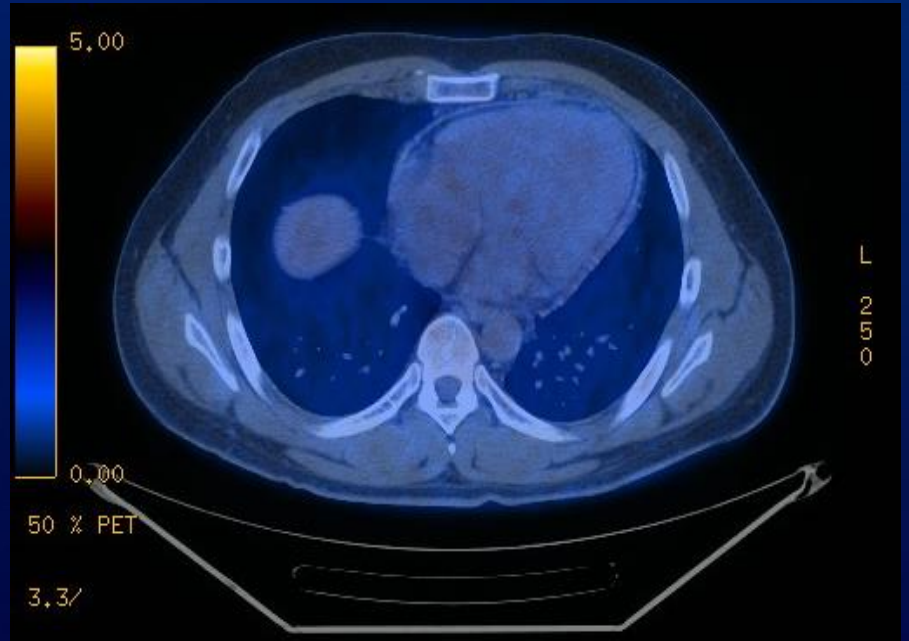
Thanks for listening!  
oh.jae@mayo.edu



# 31 year old man with Acute Pericarditis Treated with NSAID



**Baseline**



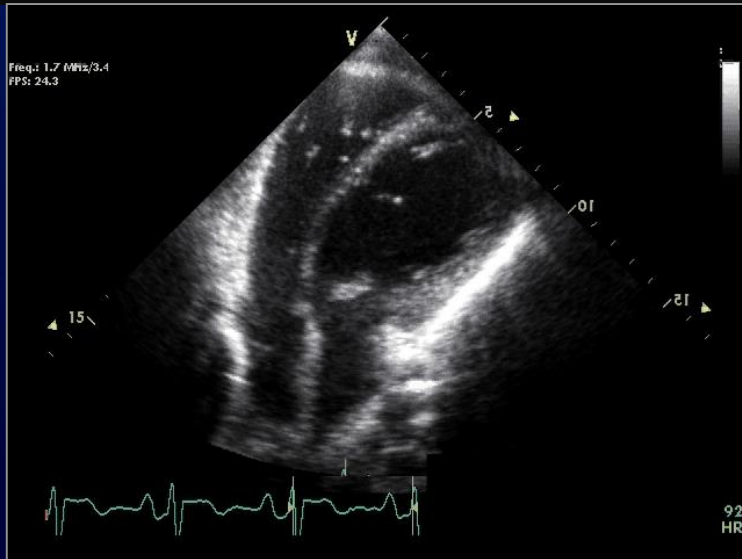
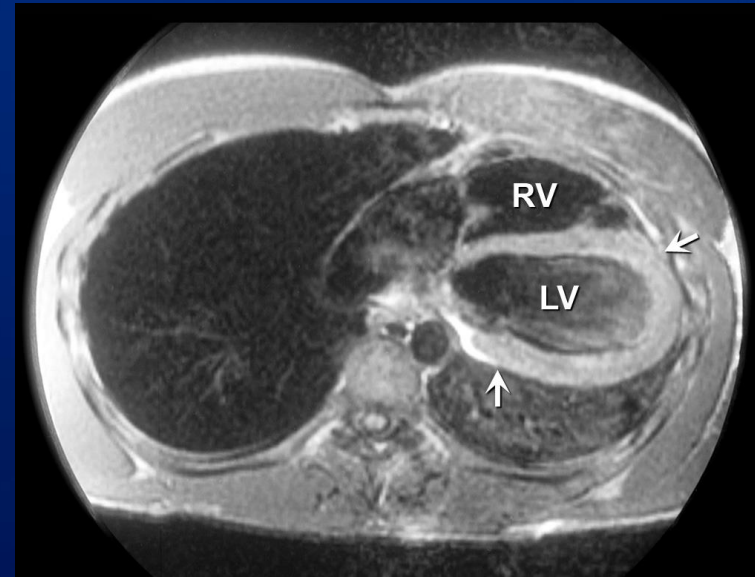
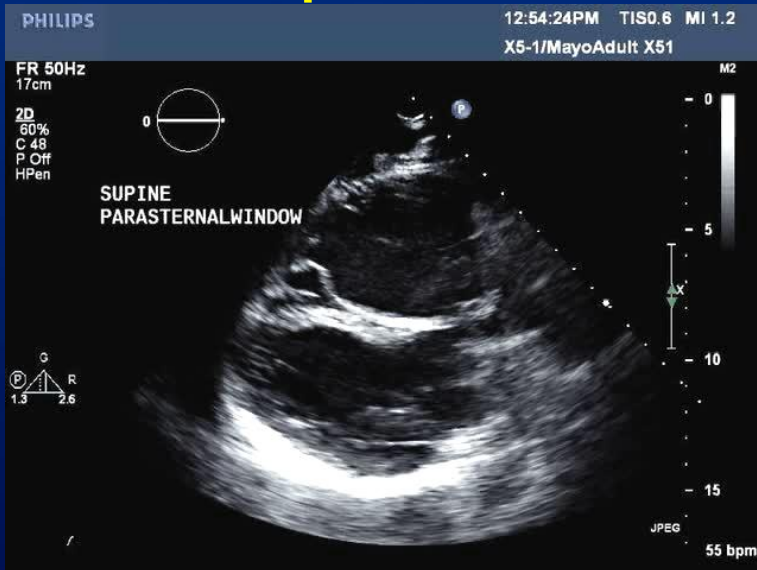
**3month later**

# FDG-PET



# 47 year old man with chest pain

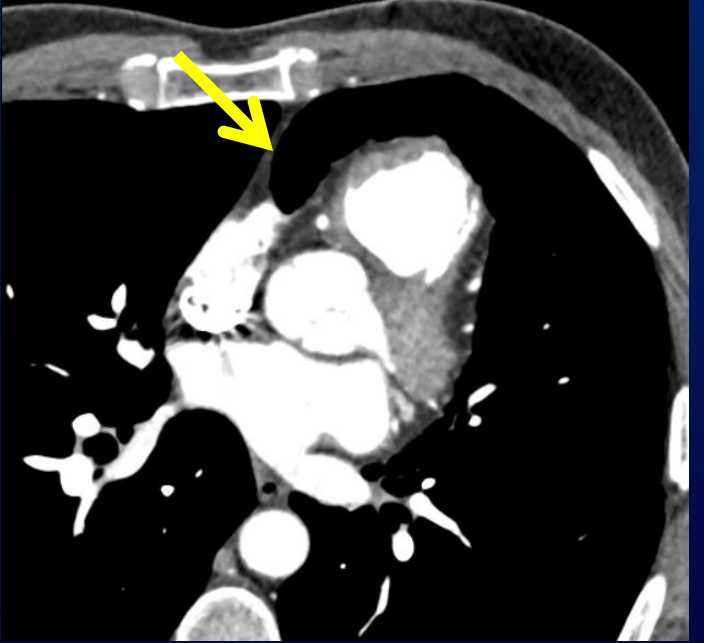
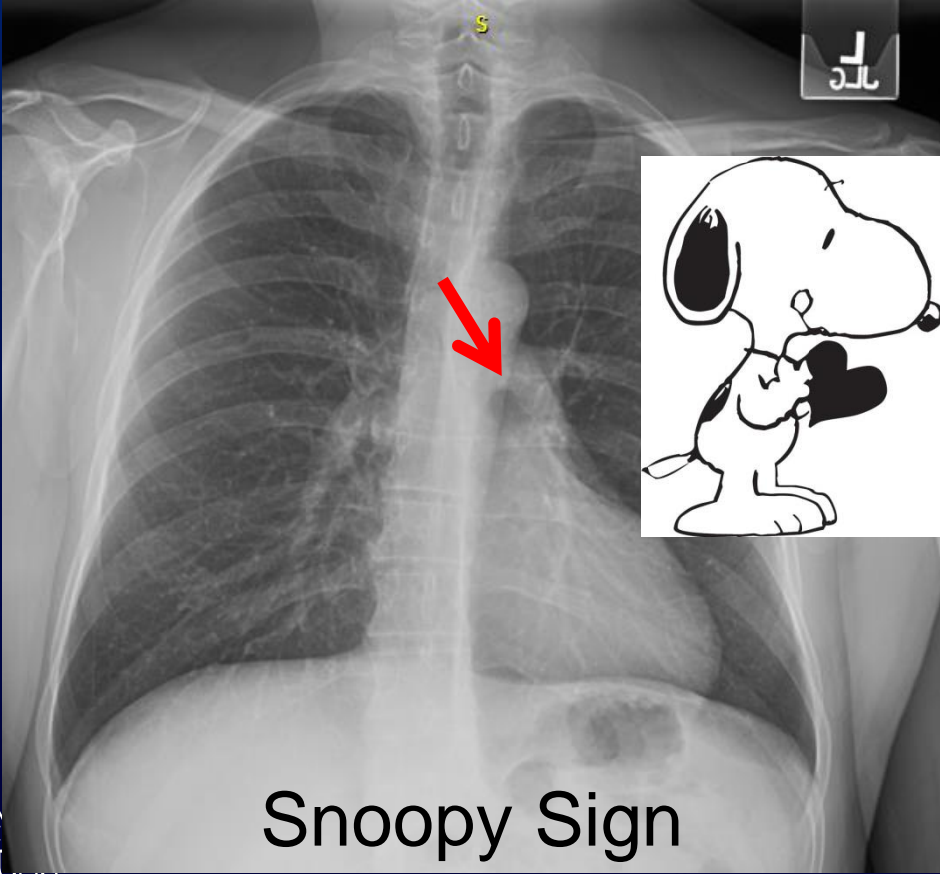
## Absent pericardium



- Usually left side
- Heart shifted to left
- Mostly asymptomatic
- Strangulation can happen



# Congenital Absence of the Pericardium



# CT Coronary Angiogram

