Role of Imaging in Heart Failure Management

HKCC Core Cardiology Certificate Course Module 4

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Imaging in Heart Failure

- Establish the diagnosis
- Assess etiology
- Determine prognosis
- Guide treatment

Imaging in Heart Failure

- Structural abnormalities
- Function (systolic, diastolic, myocardial etc)
- Viability / ischaemia
- Scarring / fibrosis / inflitration

Imaging in Heart Failure

- Echo
- Cardiac MRI
- Nuclear Imaging

Echo

- “Ancient” technique
- Versatility
- Readily available
- Safe
- Lower cost
- But relatively high variability

GUIDELINES AND STANDARDS

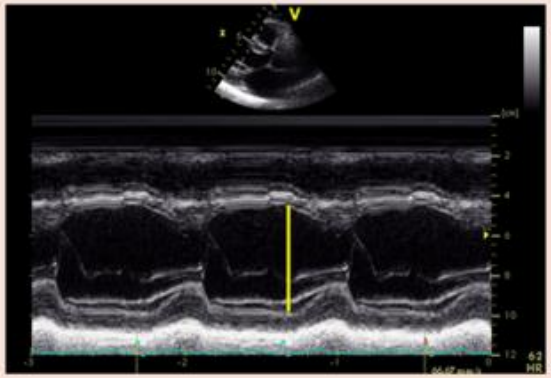
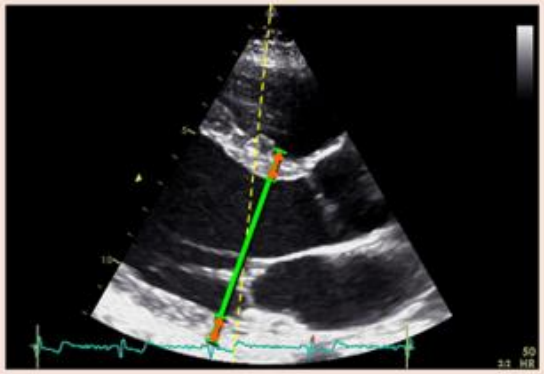
Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Roberto M. Lang, MD, FASE, FESC, Luigi P. Badano, MD, PhD, FESC, Victor Mor-Avi, PhD, FASE, Jonathan Afilalo, MD, MSc, Anderson Armstrong, MD, MSc, Laura Ernande, MD, PhD, Frank A. Flachskampf, MD, FESC, Elyse Foster, MD, FASE, Steven A. Goldstein, MD, Tatiana Kuznetsova, MD, PhD, Patrizio Lancellotti, MD, PhD, FESC, Denisa Muraru, MD, PhD, Michael H. Picard, MD, FASE, Ernst R. Rietzschel, MD, PhD, Lawrence Rudski, MD, FASE, Kirk T. Spencer, MD, FASE, Wendy Tsang, MD, and Jens-Uwe Voigt, MD, PhD, FESC, *Chicago, Illinois; Padua, Italy; Montreal, Quebec and Toronto, Ontario, Canada; Baltimore, Maryland; Créteil, France; Uppsala, Sweden; San Francisco, California; Washington, District of Columbia; Leuven, Liège, and Ghent, Belgium; Boston, Massachusetts*

The rapid technological developments of the past decade and the changes in echocardiographic practice brought about by these developments have resulted in the need for updated recommendations to the previously published guidelines for cardiac chamber quantification, which was the goal of the joint writing group assembled by the American Society of Echocardiography and the European Association of Cardiovascular Imaging. This document provides updated normal values for all four cardiac chambers, including three-dimensional echocardiography and myocardial deformation, when possible, on the basis of considerably larger numbers of normal subjects, compiled from multiple databases. In addition, this document attempts to eliminate several minor discrepancies that existed between previously published guidelines. (J Am Soc Echocardiogr 2015;28:1-39.)

Keywords: Adult echocardiography, Transthoracic echocardiography, Ventricular function, Normal values

M-mode vs 2D

Parameter and method	Technique	Advantages	Limitations
Internal linear dimensions. Linear internal measurements of the LV should be acquired in the parasternal long-axis view carefully obtained perpendicular to the LV long axis, and measured at the level of the mitral valve leaflet tips. Electronic calipers should be positioned on the interface between myocardial wall and cavity and the interface between wall and pericardium (*orange arrows*).	M-mode tracing 	• Reproducible • High temporal resolution • Wealth of published data	• Beam orientation frequently off axis • Single dimension, i.e., representative only in normally shaped ventricles
	2D-guided linear measurements 	• Facilitates orientation perpendicular to the ventricular long axis	• Lower frame rates than M-mode • Single dimension, i.e., representative only in normally shaped ventricles

LV wall thickness and geometry

Table 6 Normal ranges for LV mass indices

	Women	Men
Linear method		
LV mass (g)	67–162	88–224
LV mass/BSA (g/m^2)	***43–95***	***49–115***
Relative wall thickness (cm)	0.22–0.42	0.24–0.42
Septal thickness (cm)	***0.6–0.9***	***0.6–1.0***
Posterior wall thickness (cm)	***0.6–0.9***	***0.6–1.0***
2D method		
LV mass (g)	66–150	96–200
LV mass/BSA (g/m^2)	***44–88***	***50–102***

Bold italic values: recommended and best validated.

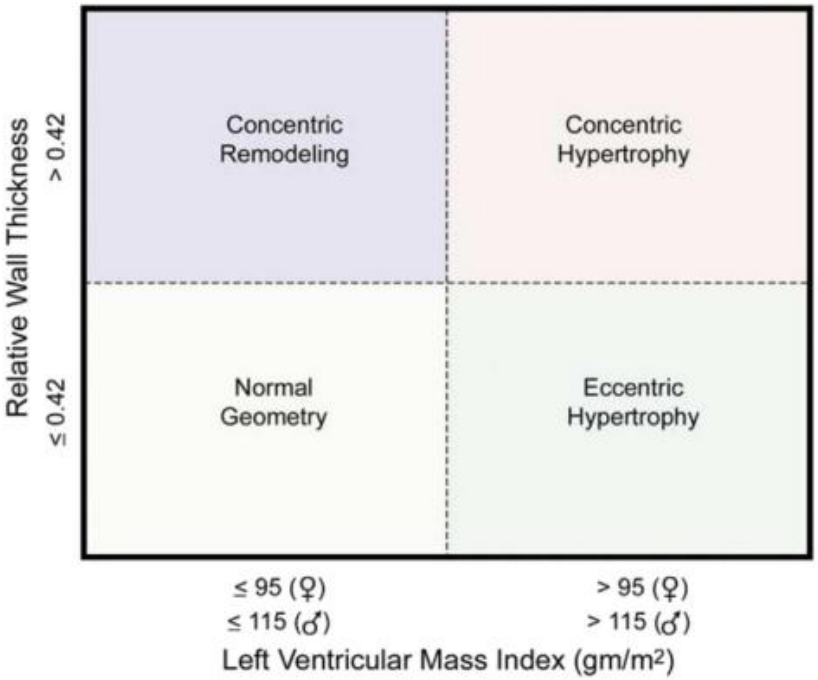


Figure 6 Comparison of RWT. Patients with normal LV mass can have either concentric remodeling (normal LV mass with increased RWT ≥ 0.42) or normal geometry (RWT ≤ 0.42) and normal LV mass. Patients with increased LV mass can have either concentric (RWT ≥ 0.42) or eccentric (RWT ≤ 0.42) hypertrophy. These LV mass measurements are based on linear measurements.

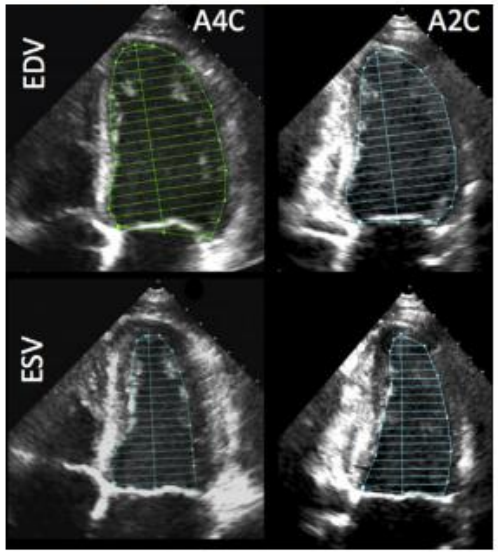
LV EF (ejection fraction)

- Most commonly (and firstly) asked question by both physicians and patients
- A “number” that provides a general impression how “good” or “bad” one’s heart is – “easy to understand”
- Important for cardiologists to determine timing of intervention (e.g. CRT-P/D, valvular surgery in severe lesions)

Volume and EF assessment

Volumes.
Volume measurements are usually based on tracings of the blood-tissue interface in the apical four- and two-chamber views. At the mitral valve level, the contour is closed by connecting the two opposite sections of the mitral ring with a straight line. LV length is defined as the distance between the middle of this line and the most distant point of the LV contour.

Biplane disk summation

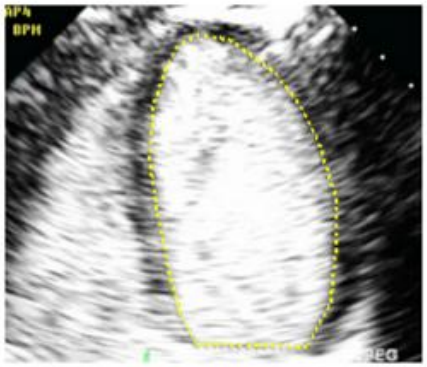


- Corrects for shape distortions
- Less geometrical assumptions compared with linear dimensions

- Apex frequently foreshortened
- Endocardial dropout
- Blind to shape distortions not visualized in the apical two- and four-chamber planes

Volume and EF assessment

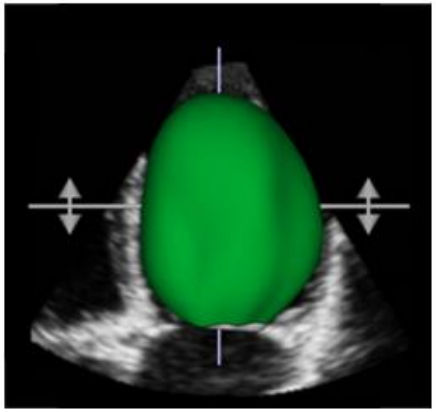
Endocardial border enhancement



- Helpful in patients with suboptimal acoustic window
- Provides volumes that are closer to those measured with cardiac magnetic resonance

- Same limitations as the above non-contrast 2D techniques
- Acoustic shadowing in LV basal segments with excess contrast

3D data sets

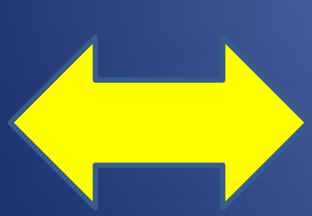


- No geometrical assumption
- Unaffected by foreshortening
- More accurate and reproducible compared to other imaging modalities

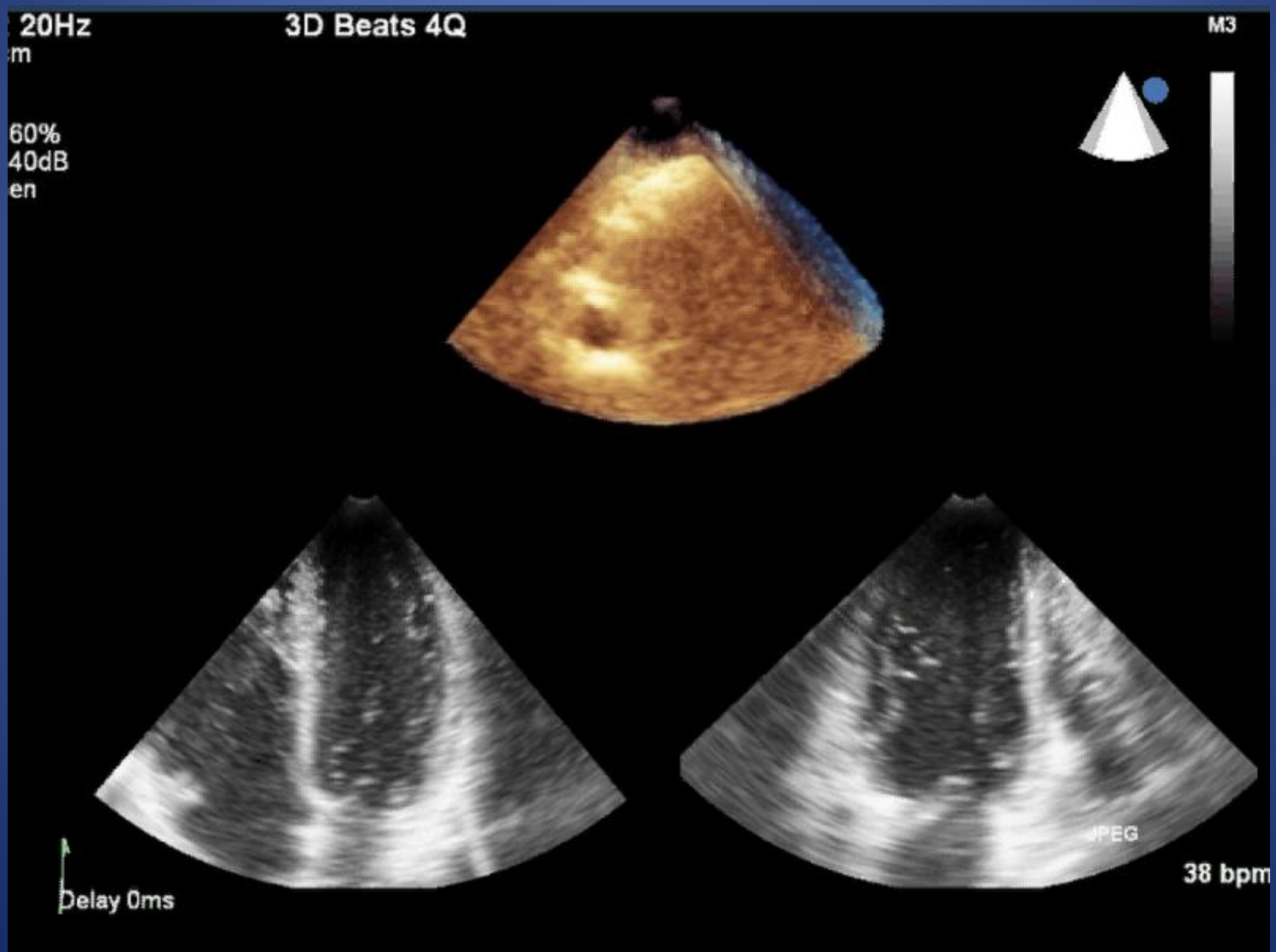
- Lower temporal resolution
- Less published data on normal values
- Image quality dependent

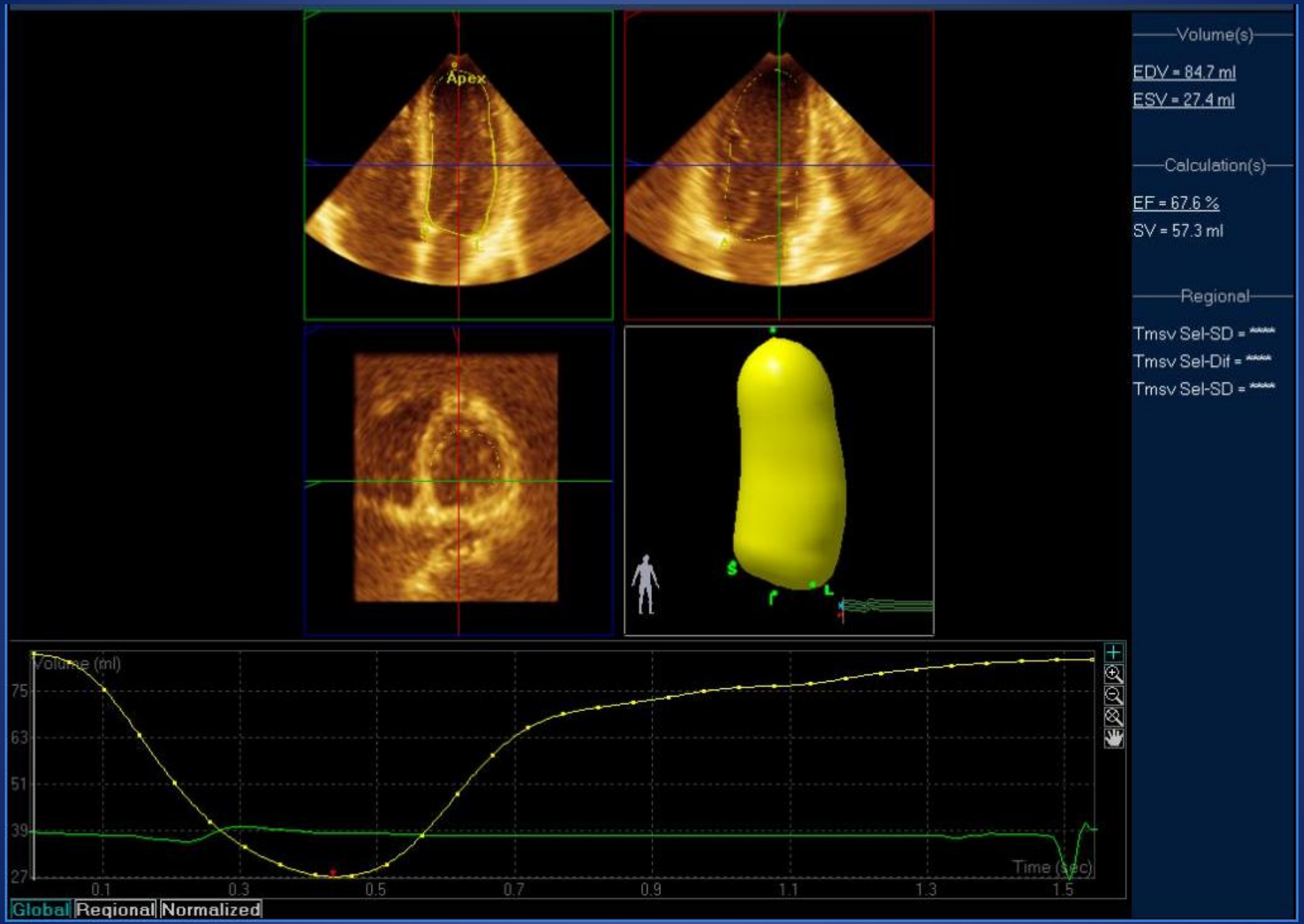
LVEF vs Cardiac Output

- CO = HR x SV
- EF (%) = SV / LV end diastolic volume
- **Assuming that no significant mitral regurgitation**
- **CO = HR x (EF (%) x LV end diastolic volume)**

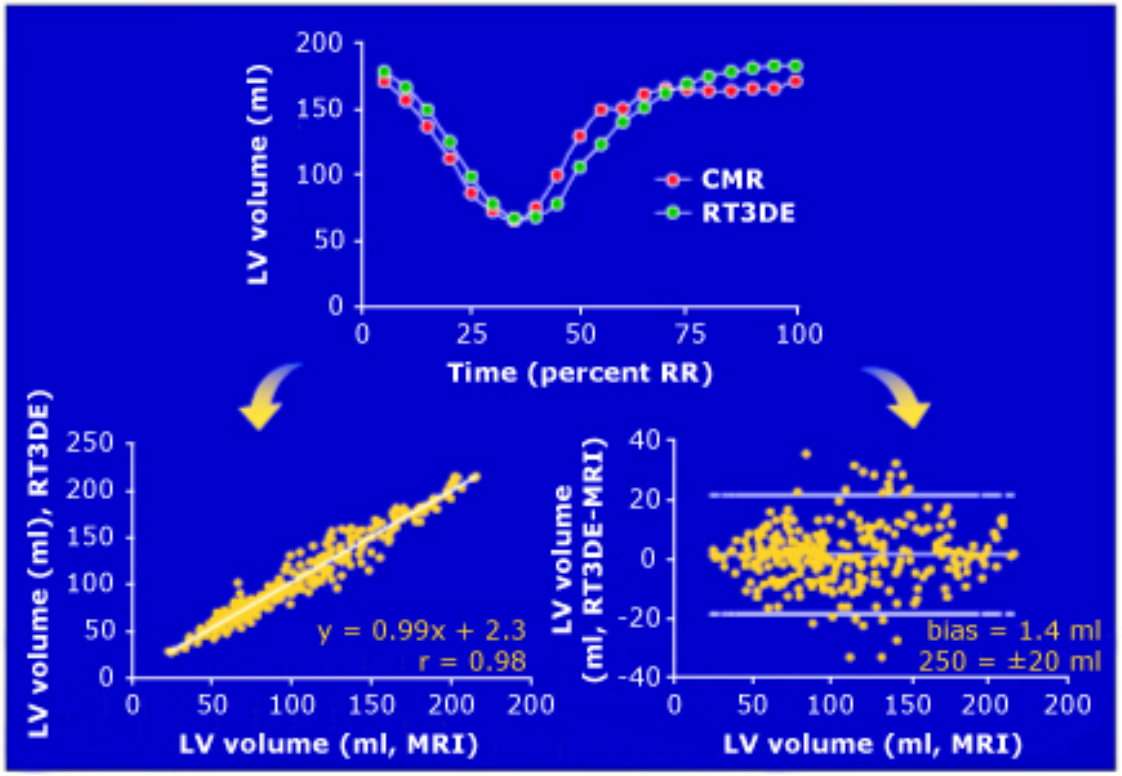


3D full volume acqusition




Apex
Volume(s)
EDV = 84.7 ml
ESV = 27.4 ml
Calculation(s)
EF = 67.6 %
SV = 57.3 ml
Regional
Tmsv Sel-SD =
Tmsv Sel-Dif =
Tmsv Sel-SD =
Volume (ml)
75
63
51
39
27
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
Time (sec)
Global
Regional
Normalized

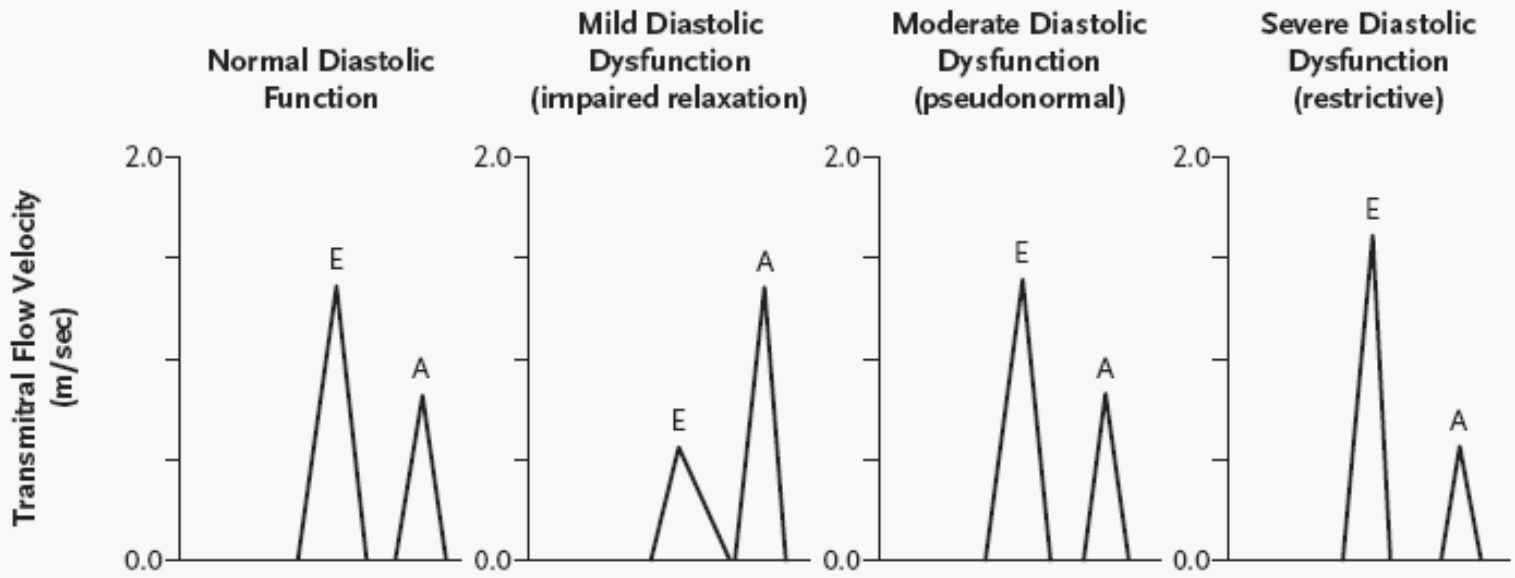
Accuracy of real time three-dimensional echocardiography (RT3DE) measurements of left ventricular (LV) volume



Example of LV volume time curves obtained in one patient from RT3DE and MR images. Results of linear regression (bottom, left) and Bland-Altman (bottom, right) analyses of the point-by-point measurements of LV volume obtained in 16 patients.

Corsi C, Lang RM, Veronesi F, et al. Volumetric quantification of global and regional left ventricular function from real-time three-dimensional echocardiographic images. Circulation 2005; 112:1161.

Diastolic function: Mitral inflow pattern

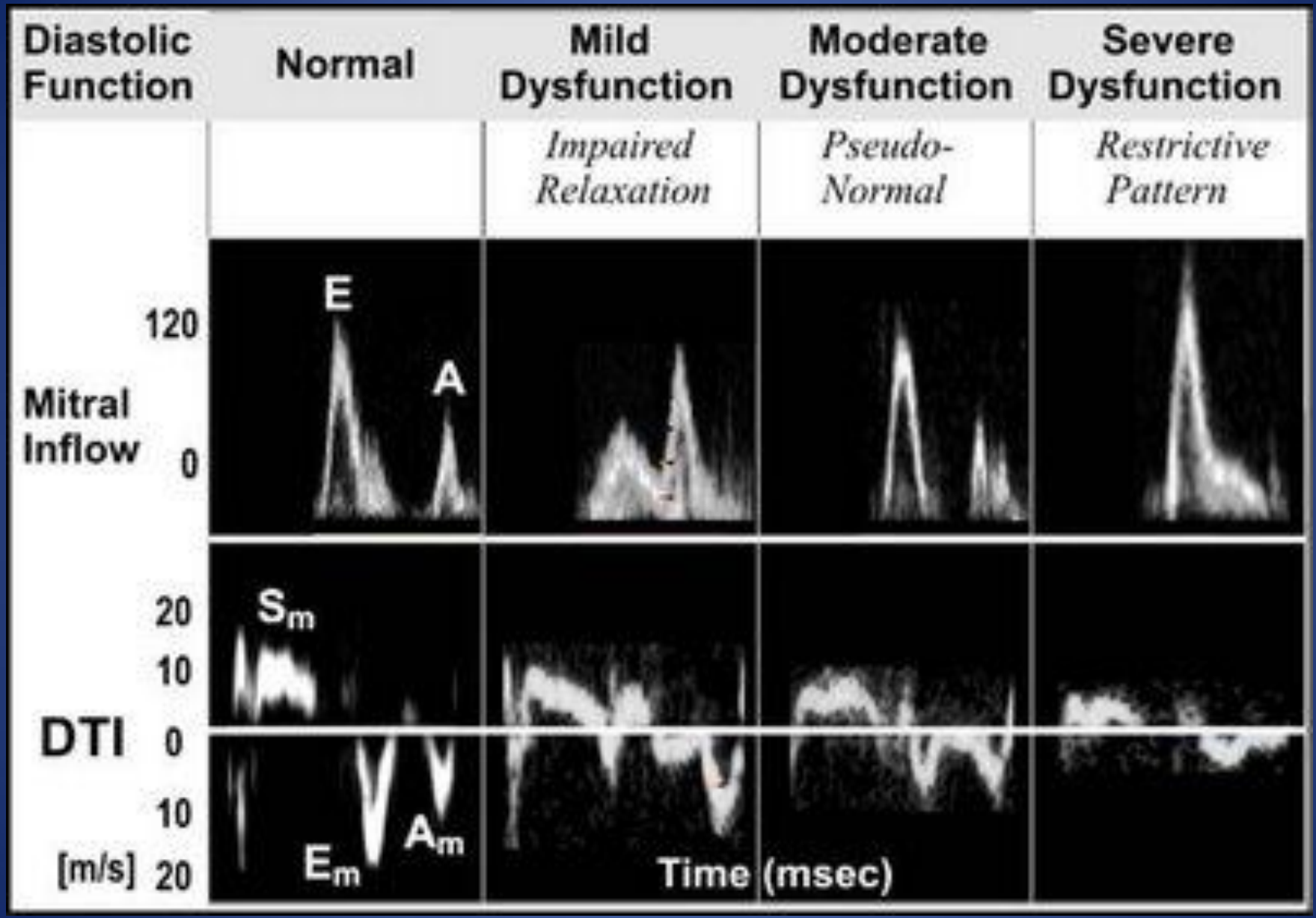


	Normal Diastolic Function	Mild Diastolic Dysfunction (impaired relaxation)	Moderate Diastolic Dysfunction (pseudonormal)	Severe Diastolic Dysfunction (restrictive)
Left Ventricular Relaxation	Normal	Impaired	Impaired	Impaired
Left Ventricular Compliance	Normal	Normal to ↓	↓↓	↓↓↓
Atrial Pressure	Normal	Normal to ↑	↑↑	↑↑↑

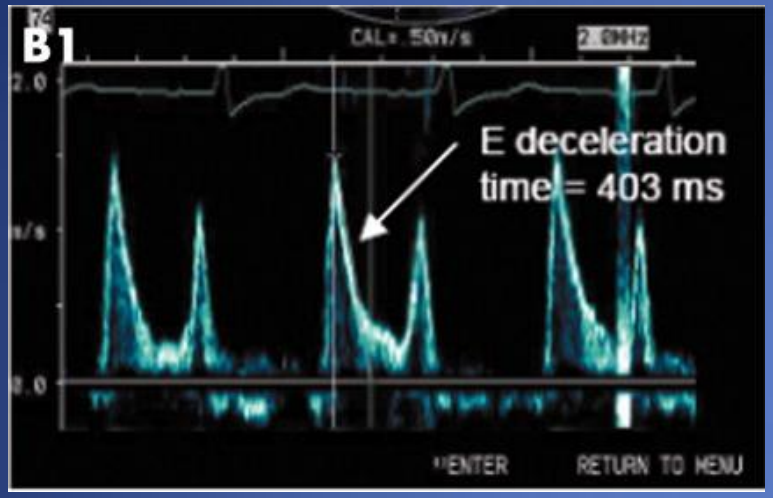
E = early filling

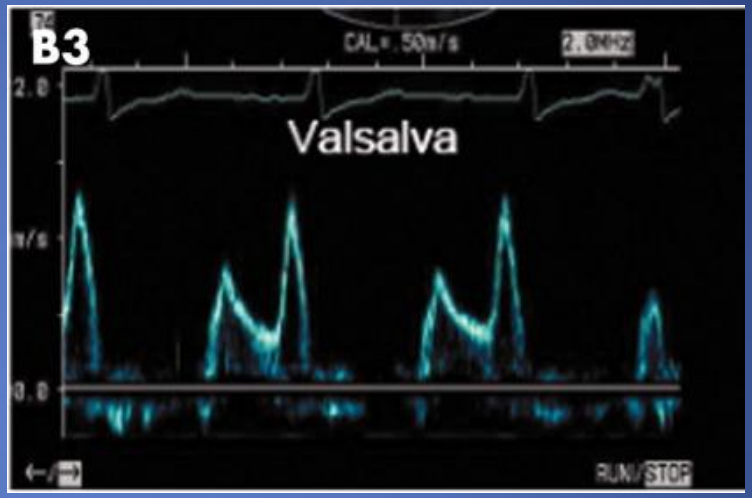
A = atrial contraction

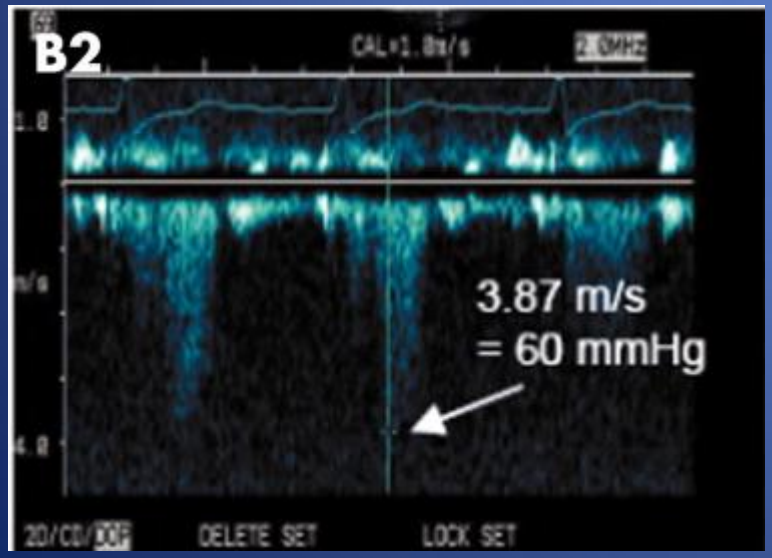
Aurigemma GP. NEJM. 2004;351:1097-105.


Diastolic Function
Normal
Mild Dysfunction
Moderate Dysfunction
Severe Dysfunction
Impaired Relaxation
Pseudo-Normal
Restrictive Pattern
E
A
120
Mitral Inflow
0
20
S_m
10
DTI
0
10
[m/s]
20
E_m
A_m
Time (msec)

Pseudonormal (grade 2) vs Normal



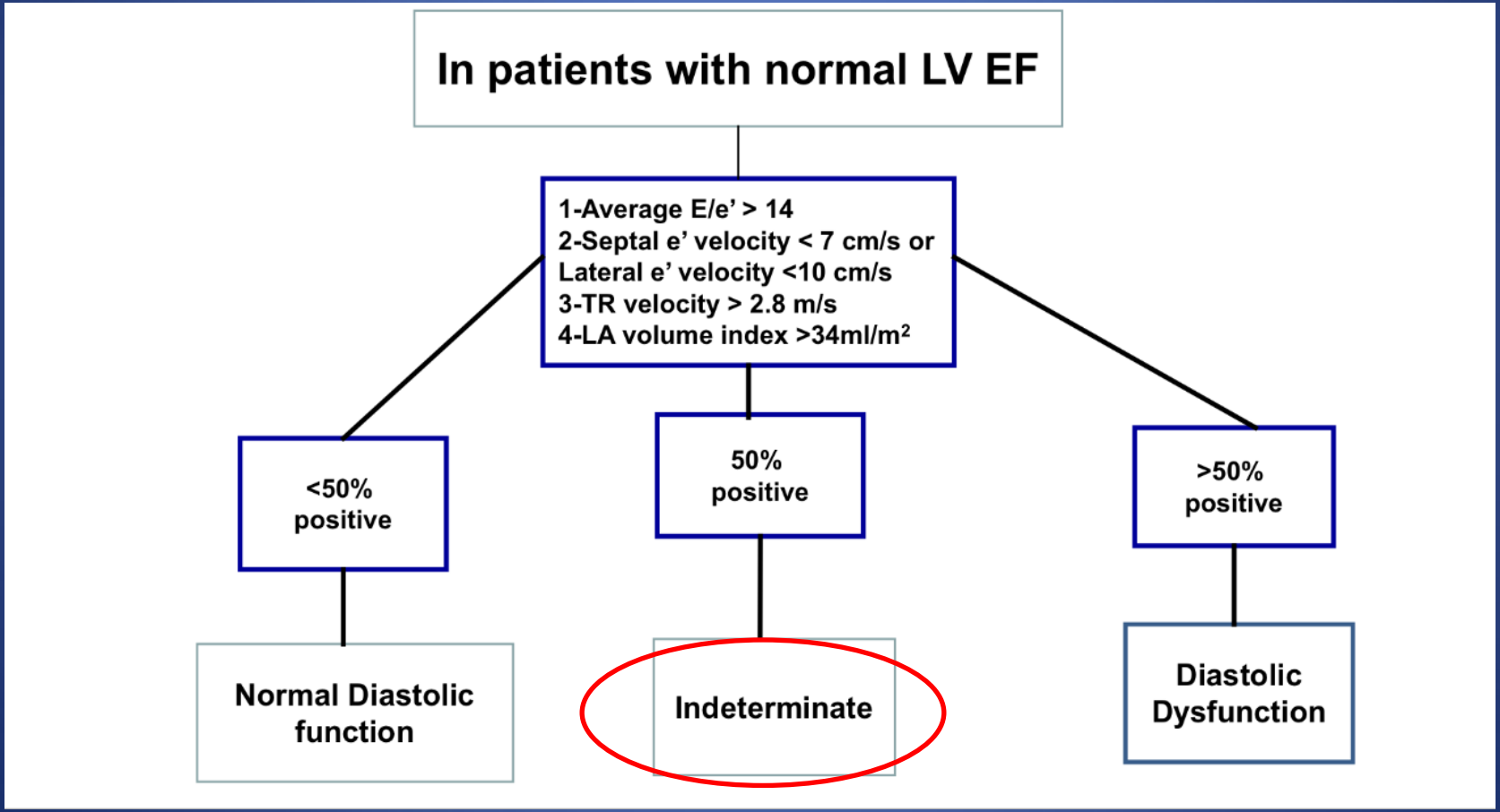




Valsalva – decrease preload and convert the mitral inflow into "abnormal relaxation pattern"

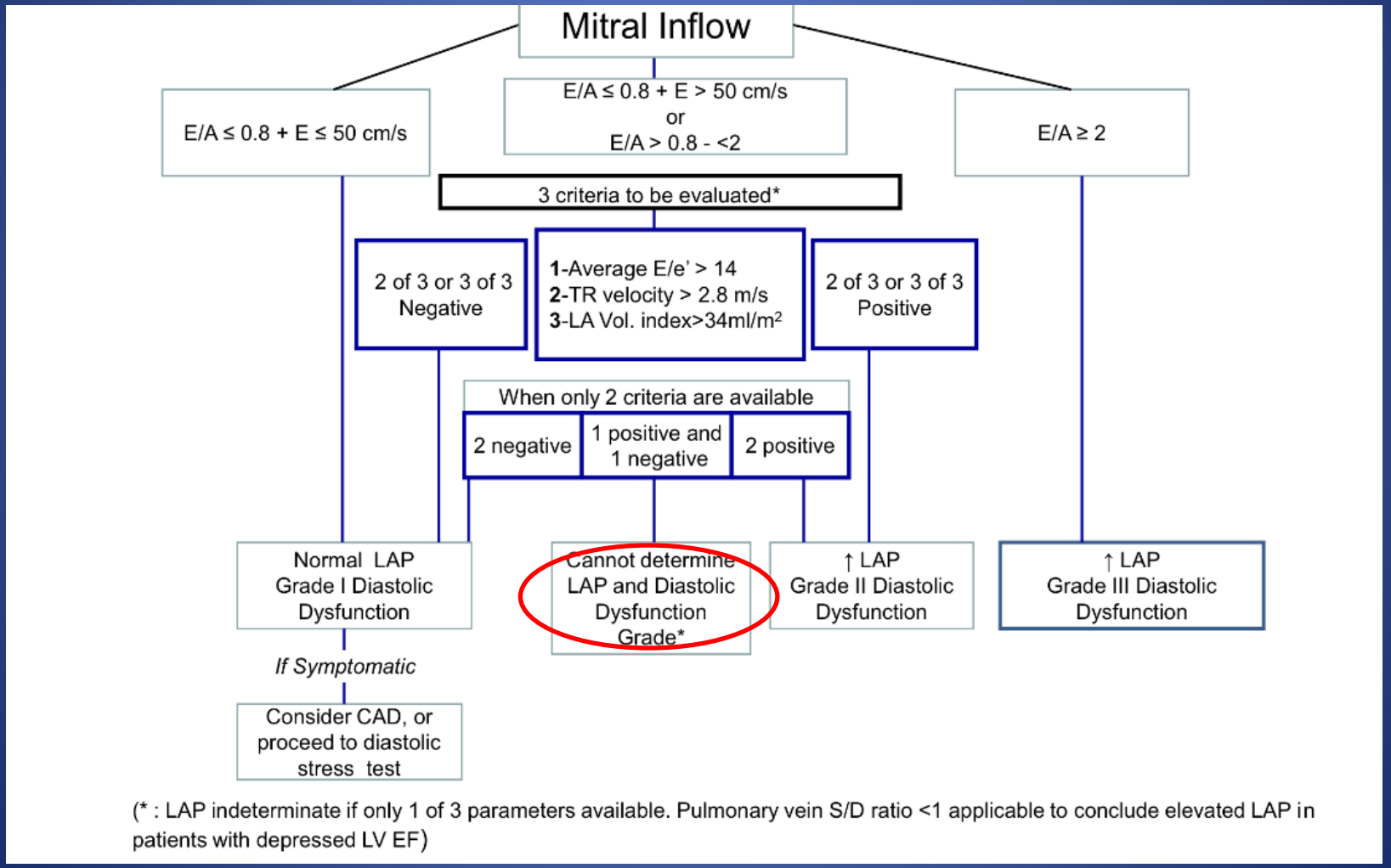
Pulmonary hypertension usually present

Diagnosis of LV diastolic dysfunction in patients with normal LV EF



J Am Soc Echocardiogr 2016;29:277-314

Estimation of LV filling pressure/diastolic function grading in patient with depressed LVEF or myocardial disease

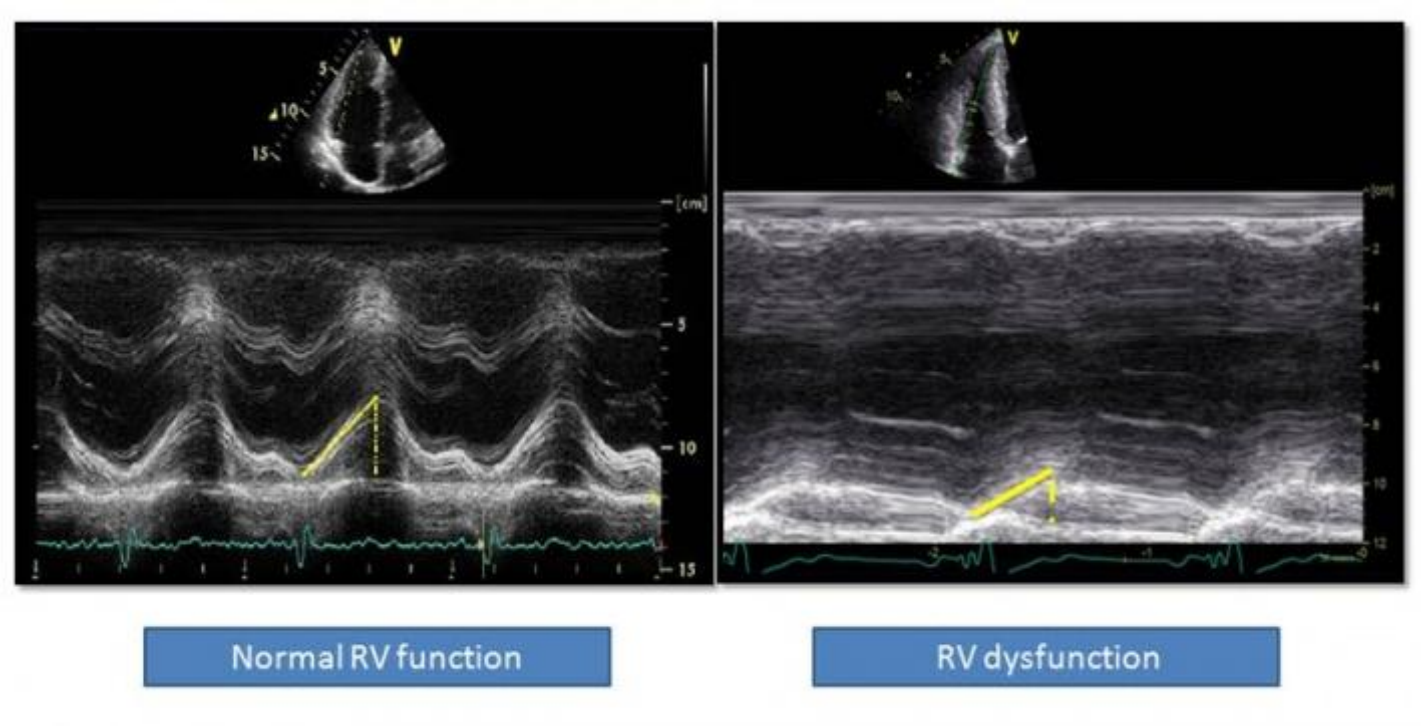


J Am Soc Echocardiogr 2016;29:277-314

RV Geometry

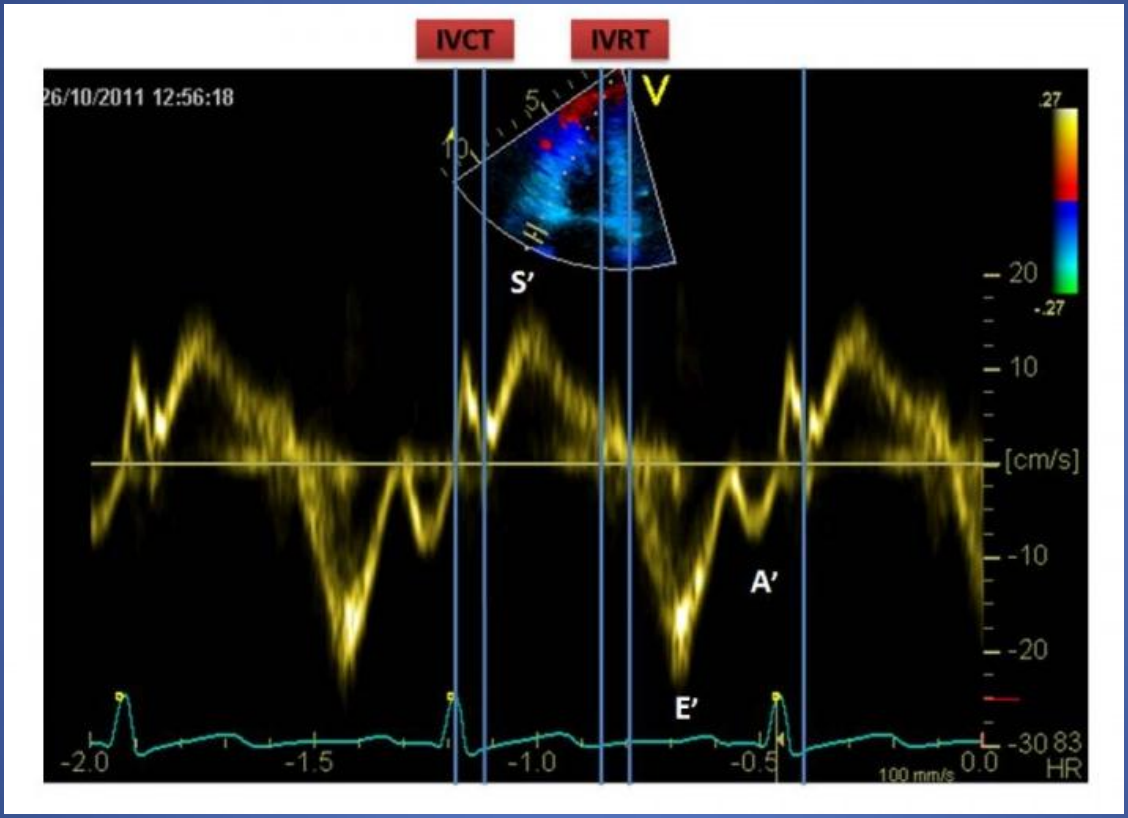
- The shape of the right ventricle is complex
- In contrast to the ellipsoidal shape of the left ventricle, the right ventricle is triangular when viewed longitudinally and is crescent shaped when viewed transversally.
- Its complex shape is difficult to model geometrically as opposed to the left ventricle, which explains the difficulty to assess right ventricular volumes and function by echocardiography

Tricuspid Annular Plane Systolic Excursion (TAPSE)



- M-mode cursor passed through the tricuspid lateral annulus in a four-chamber view and measuring the amount of longitudinal displacement of the annulus at peak-systole
- Abnormal < 16 mm

Systolic Excursion velocity (S')



- Utilize Tissue Doppler Imaging of tricuspid annulus movement during systole
- Abnormal < 10 cm/sec

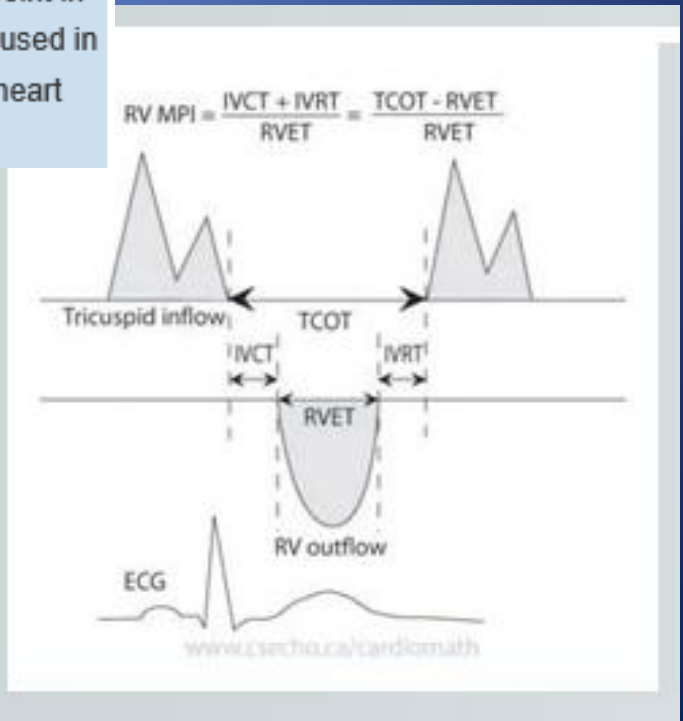
RV Myocardial Performance Index

RV MPI Abnormal Values

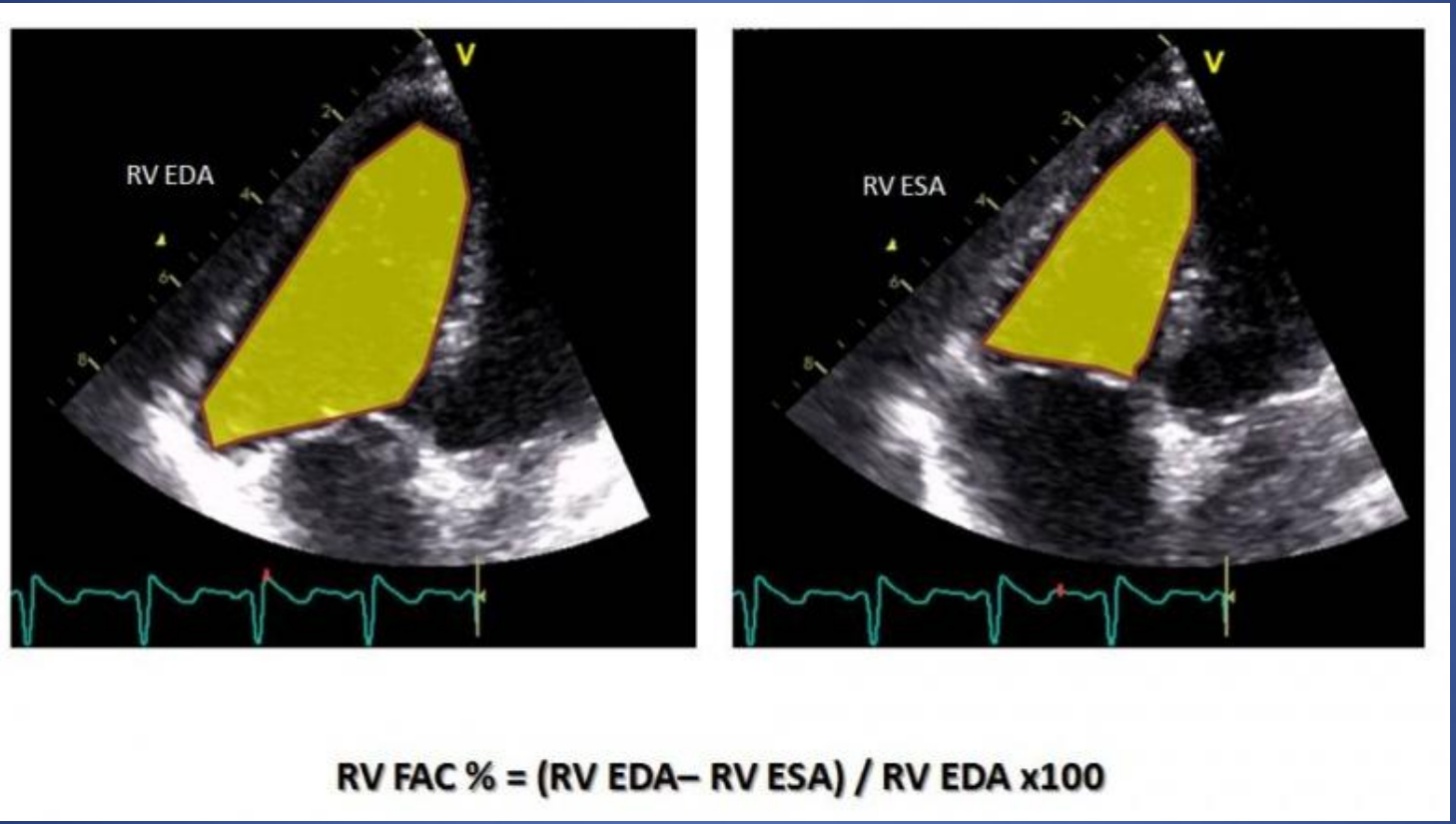
	Abnormal
Pulsed Doppler RV MPI	>0.40
Tissue Doppler RV MPI	>0.55

RV MPI

Also known as RIMP or Tei index. It is an index that incorporates both systolic and diastolic time intervals in expressing global systolic and diastolic ventricular function. The RV MPI has prognostic value among pulmonary hypertension patients at a single point in time and changes in this index correlate with change in clinical status. It also been used in studying patients with RV infarction, hypertrophic cardiomyopathy, and congenital heart disease, etc.



Fractional Area Change



- Resemble “Simpons method” for LVEF
- Abnormal: < 35% change in area

Table 9 Recommendations for the echocardiographic assessment of RV function

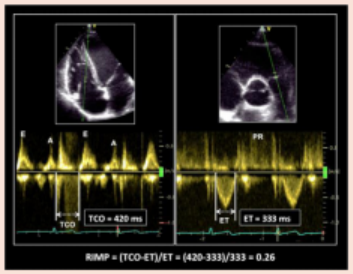
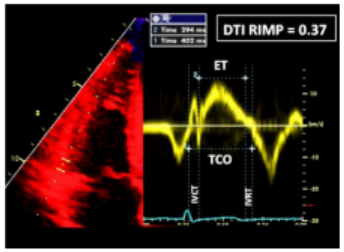
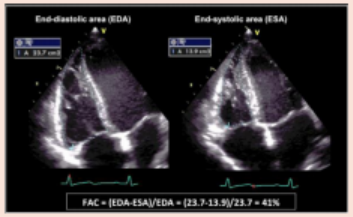
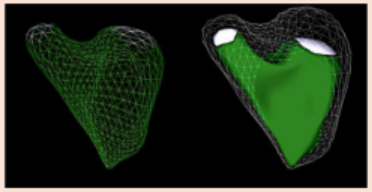
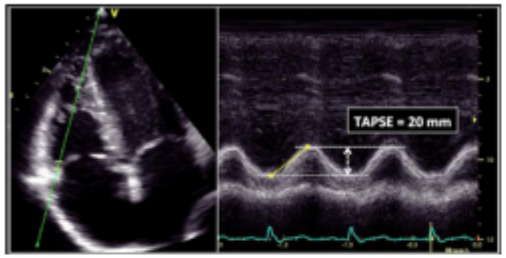
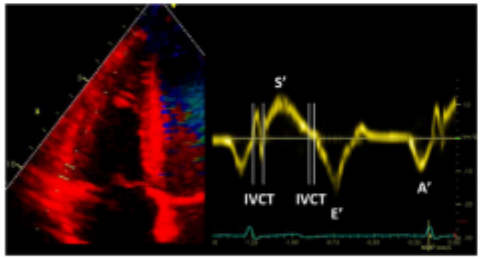
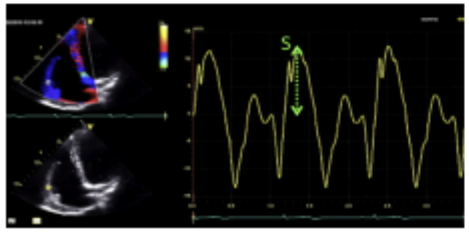
Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV global function Pulsed Doppler RIMP 	RIMP (Tei index) by pulsed Doppler: RIMP = (TCO − ET)/ET	• Prognostic value • Less affected by heart rate	• Requires matching for R-R intervals when measurements are performed on separate recordings • Unreliable when RA pressure is elevated
Tissue Doppler RIMP 	RIMP by tissue Doppler: RIMP = (IVRT + IVCT)/ET = (TCO − ET)/ET	• Less affected by heart rate • Single-beat recording with no need for R-R interval matching	• Unreliable when RA pressure is elevated
RV global systolic function FAC 	RV FAC in RV-focused apical four-chamber view: RV FAC (%) = 100 × (EDA − ESA)/EDA	• Established prognostic value • Reflects both longitudinal and radial components of RV contraction • Correlates with RV EF by CMR	• Neglects the contribution of RV outflow tract to overall systolic function • Only fair inter-observer reproducibility
EF 	Fractional RV volume change by 3D TTE: RV EF (%) = 100 × (EDV − ESV)/EDV	• Includes RV outflow tract contribution to overall function • Correlates with RV EF by CMR	• Dependent on adequate image quality • Load dependency • Requires offline analysis and experience • Prognostic value not established

Table 9 (*Continued*)

Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV longitudinal systolic function TAPSE 	• Tricuspid annular longitudinal excursion by M-mode (mm), measured between end-diastole and peak systole • Proper alignment of M-mode cursor with the direction of RV longitudinal excursion should be achieved from the apical approach.	• Established prognostic value • Validated against radionuclide EF	• Angle dependency • Partially representative of RV global function*
Pulsed tissue Doppler S wave 	• Peak systolic velocity of tricuspid annulus by pulsed-wave DTI (cm/sec), obtained from the apical approach, in the view that achieves parallel alignment of Doppler beam with RV free wall longitudinal excursion	• Easy to perform • Reproducible • Validated against radionuclide EF • Established prognostic value	• Angle dependent • Not fully representative of RV global function, particularly after thoracotomy, pulmonary thromboendarterectomy or heart transplantation
Color tissue Doppler S wave 	• Peak systolic velocity of tricuspid annulus by color DTI (cm/sec)	• Sampling is performed after image acquisition • Allows multisite sampling on the same beat	• Angle dependent • Not fully representative of RV global function, particularly after thoracotomy, pulmonary thrombendarterectomy or heart transplantation • Lower absolute values and reference ranges than pulsed DTI S′ wave

Pitfalls

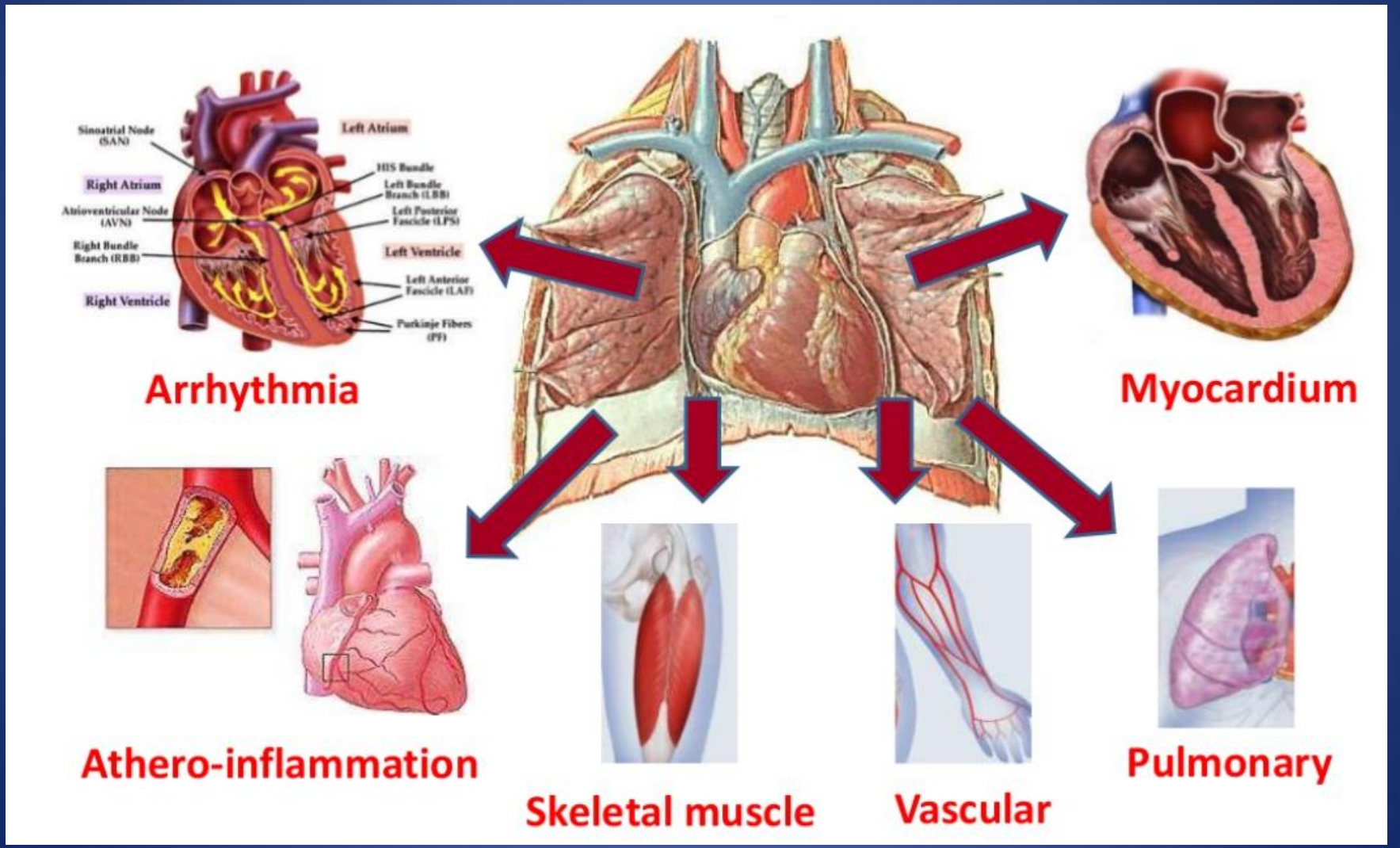
- However, all the above method only provide indirect clues to estimate RV systolic function
- RV ejection fraction is difficult to be estimated from 2D Echo due to its complex geometry
- 3D Echo may provide new insight on volumetric assessment of RV

Stage A HF – can we detect subclinical abnormalities?

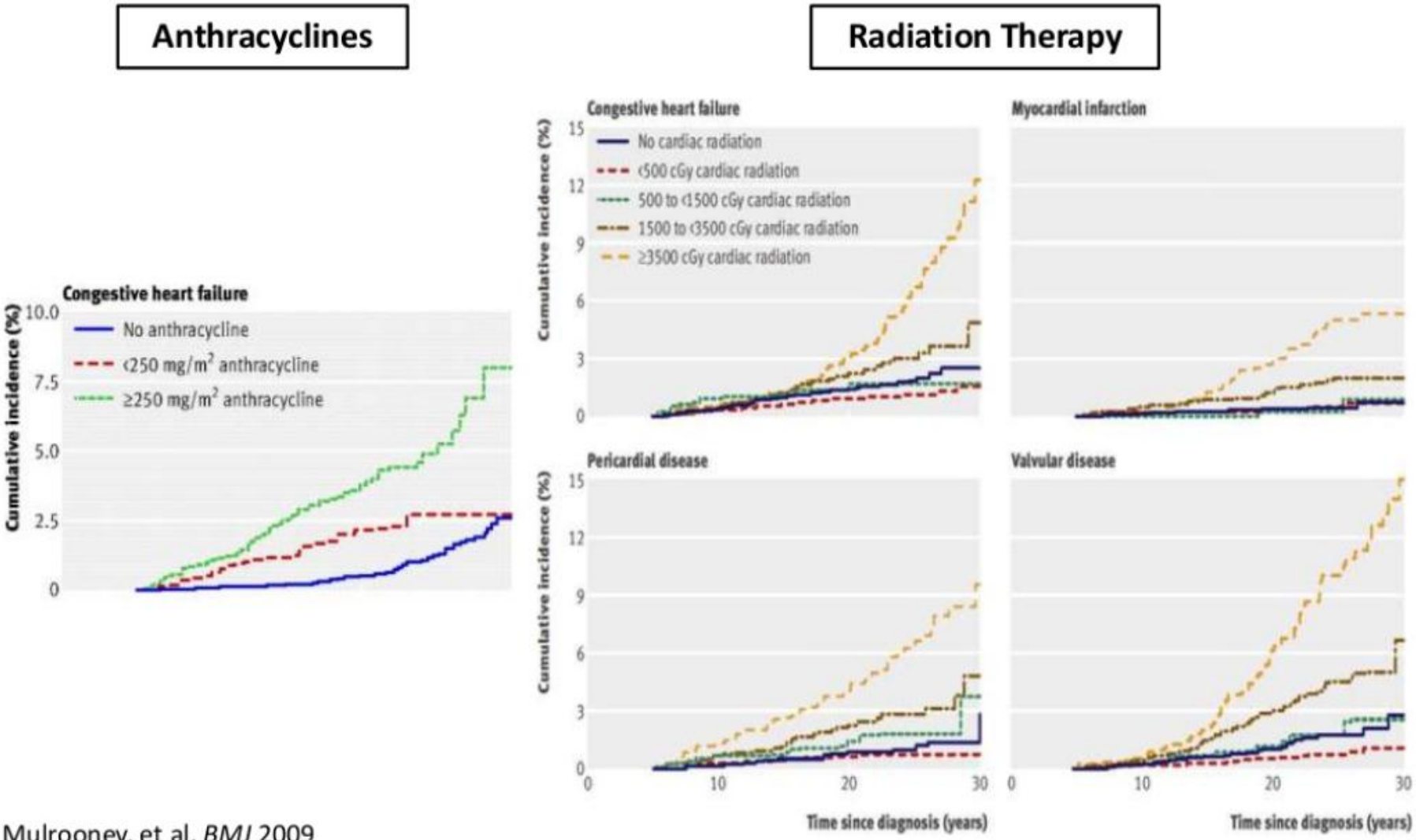
Classification	Severity (Low → High)			
ACC/AHA heart failure stage	**Stage A**	**Stage B**	**Stage C**	**Stage D**
	At risk (e.g., patients receiving cardiotoxins) but without structural heart disease or symptoms	Structural heart disease (hypertrophy, low EF, valve disease) but without signs or symptoms	Structural heart disease with prior or current symptoms	Refractory HF requiring specialized interventions
NYHA symptom classification	**Grade I**		**Grade II** / **Grade III**	**Grade IV**
	No limitation of activity		Mild limitation of activity / Marked limitation of activity	Confined to bed or chair

Khouri, et al. *Circulation* 2012

Example: Oncology treatment side effects on CV system

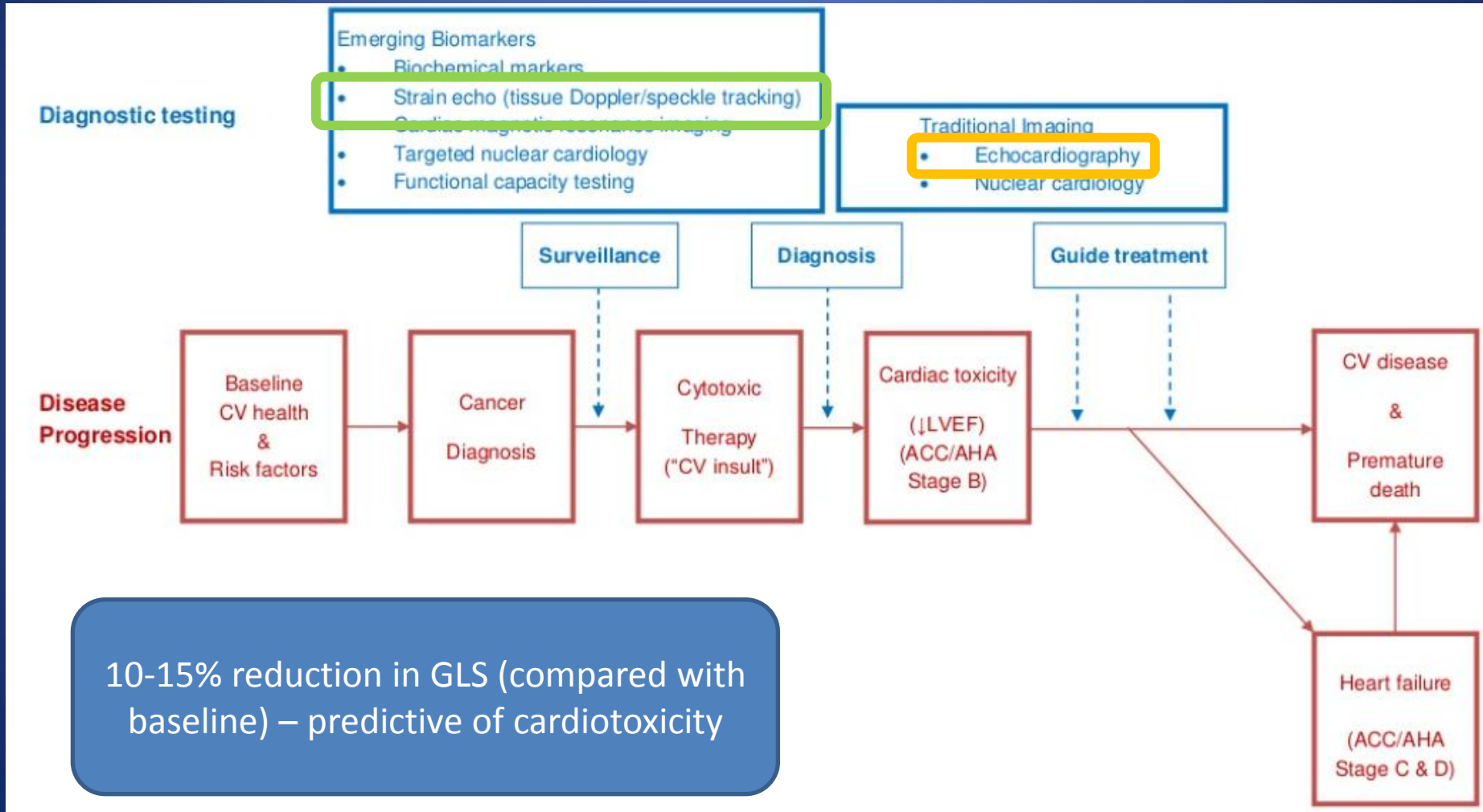


Long term incidence of CV disease in treated patients



Mulrooney, et al. *BMJ* 2009

Early detection



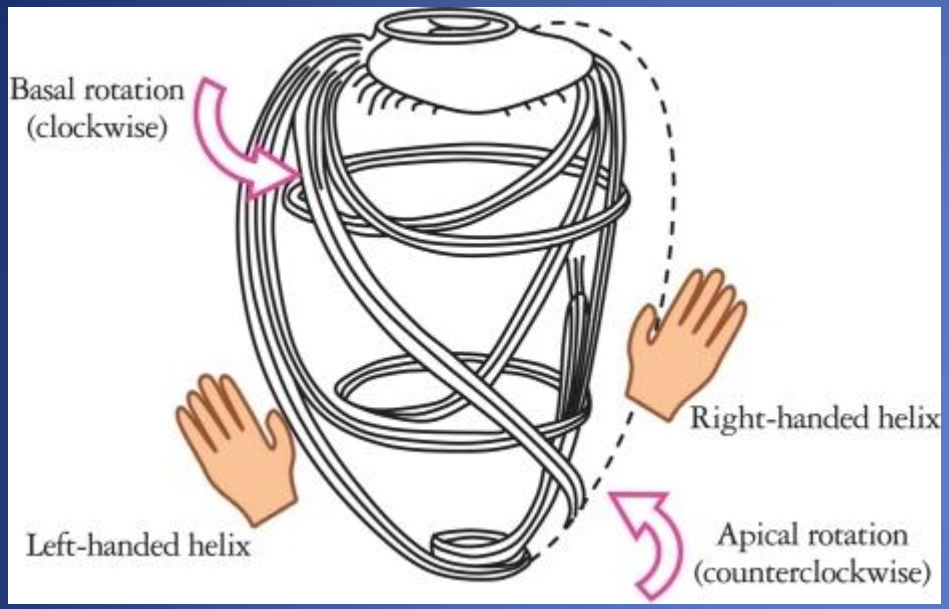
10-15% reduction in GLS (compared with baseline) – predictive of cardiotoxicity

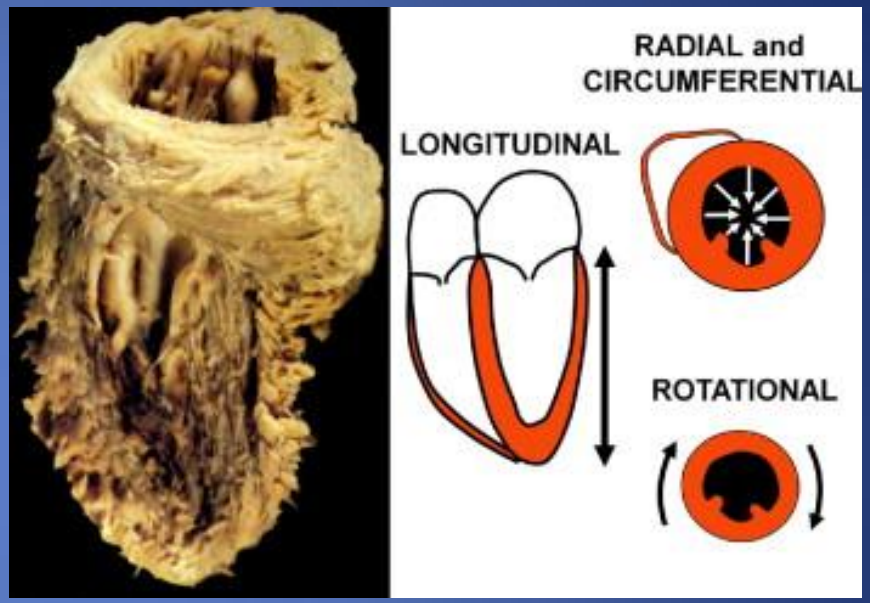
Khouri, et al. *Circulation* 2012

Limitation of traditional 2D Echo

- LVEF
  - only tells you the “change of cavity” as end result
  - no information regarding the myocardial fiber contractile function
- Wall motion assessment
  - effect of “tethering” by adjacent normal segment
  - Appeared akinetic on 2D with 25% - 100% thickness myocardial injury / infarct

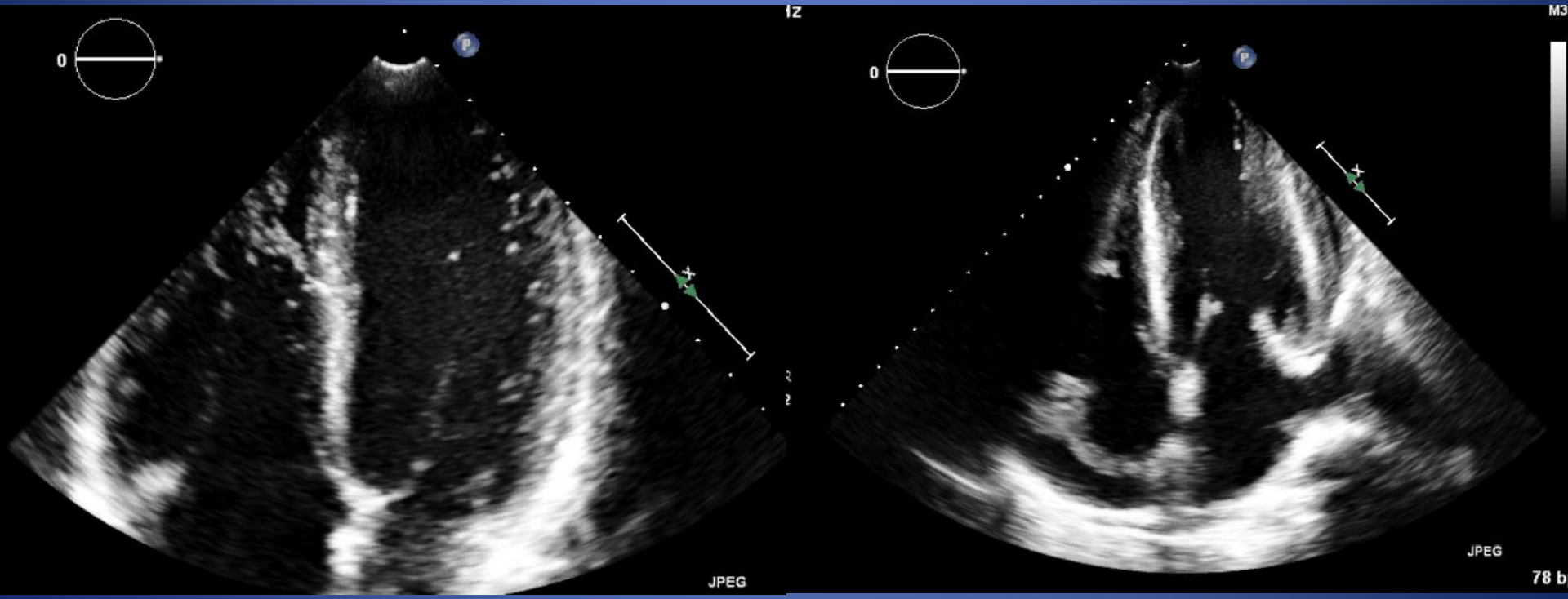
Myocardial Deformation



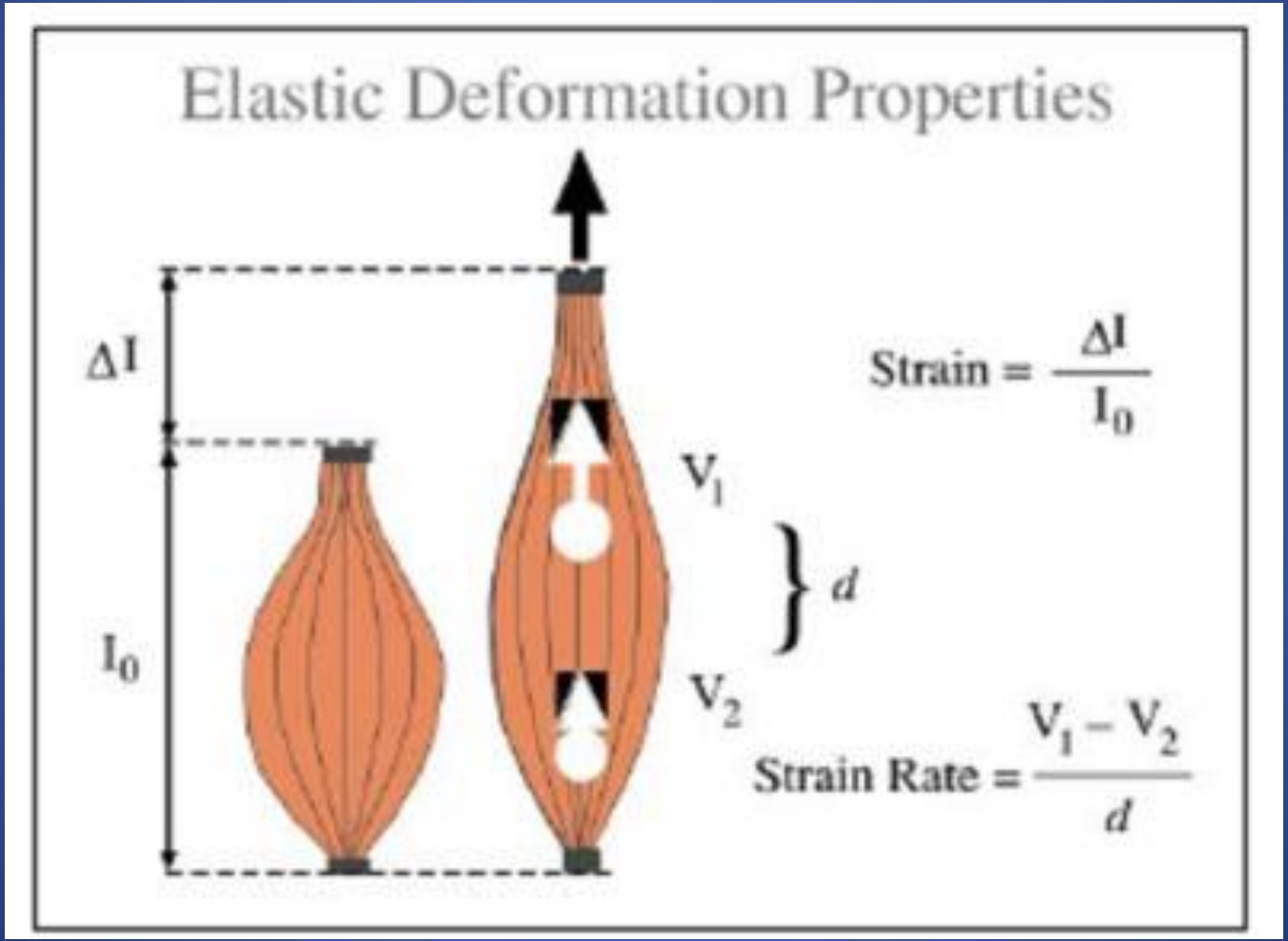


Subepicardium : helically left-handed direction
Mid layer: run circumferentially
Subendocardium: helically right-handed direction

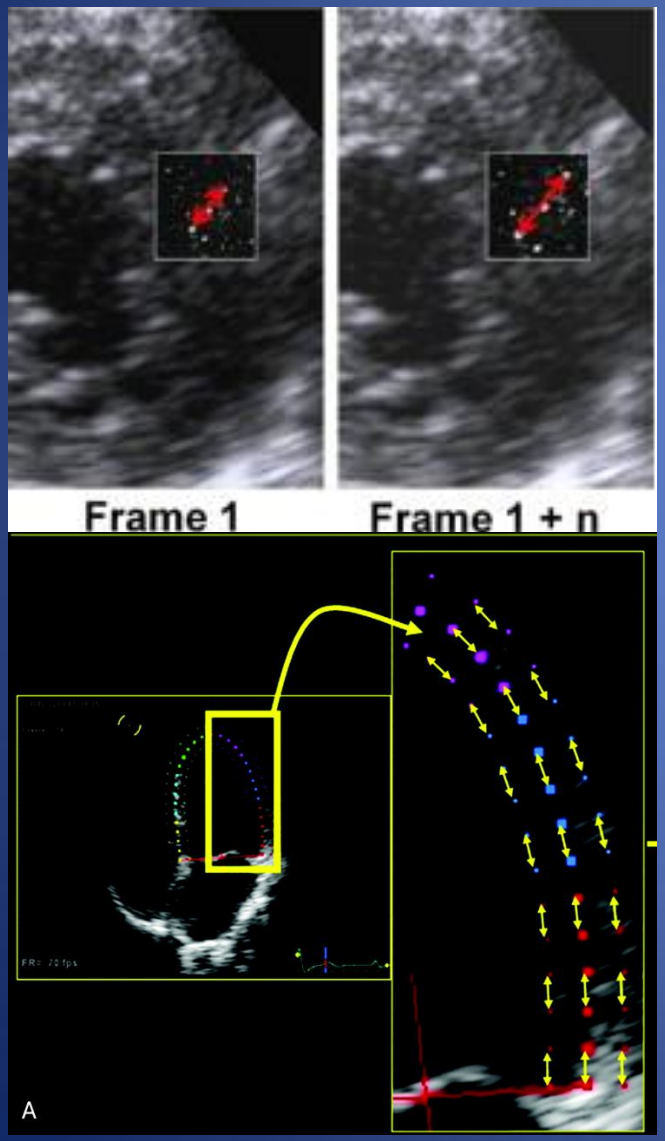
Same LVEF, looks different?



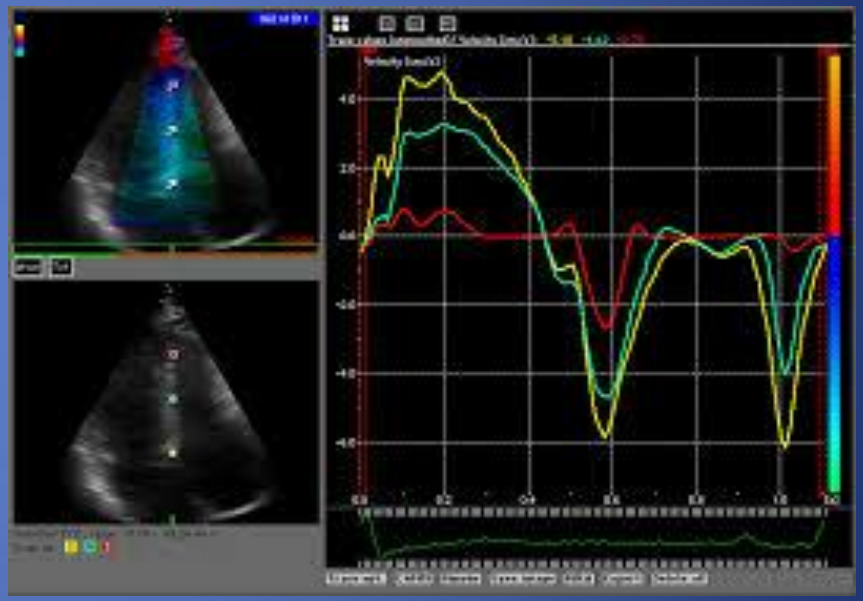
Strain and Strain Rate

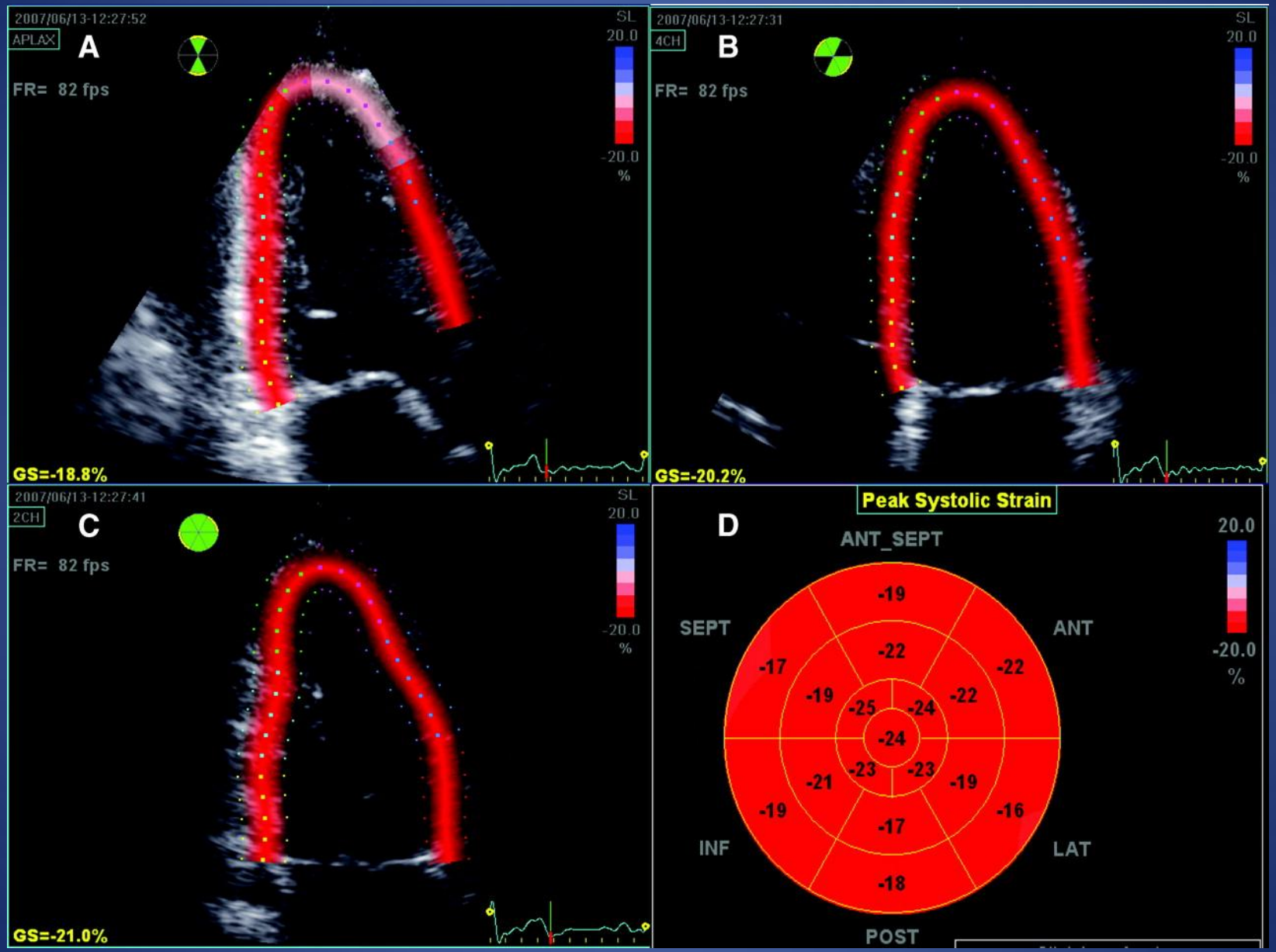


Speckle Tracking



Tissue doppler derived




2007/06/13-12:27:52
APLAX
A
FR= 82 fps
SL
20.0
-20.0
%
GS=-18.8%
2007/06/13-12:27:31
4CH
B
FR= 82 fps
SL
20.0
-20.0
%
GS=-20.2%
2007/06/13-12:27:41
2CH
C
FR= 82 fps
SL
20.0
-20.0
%
GS=-21.0%
D
Peak Systolic Strain
ANT_SEPT
SEPT
ANT
INF
LAT
POST
20.0
-20.0
%
-19
-22
-17
-22
-19
-22
-25
-24
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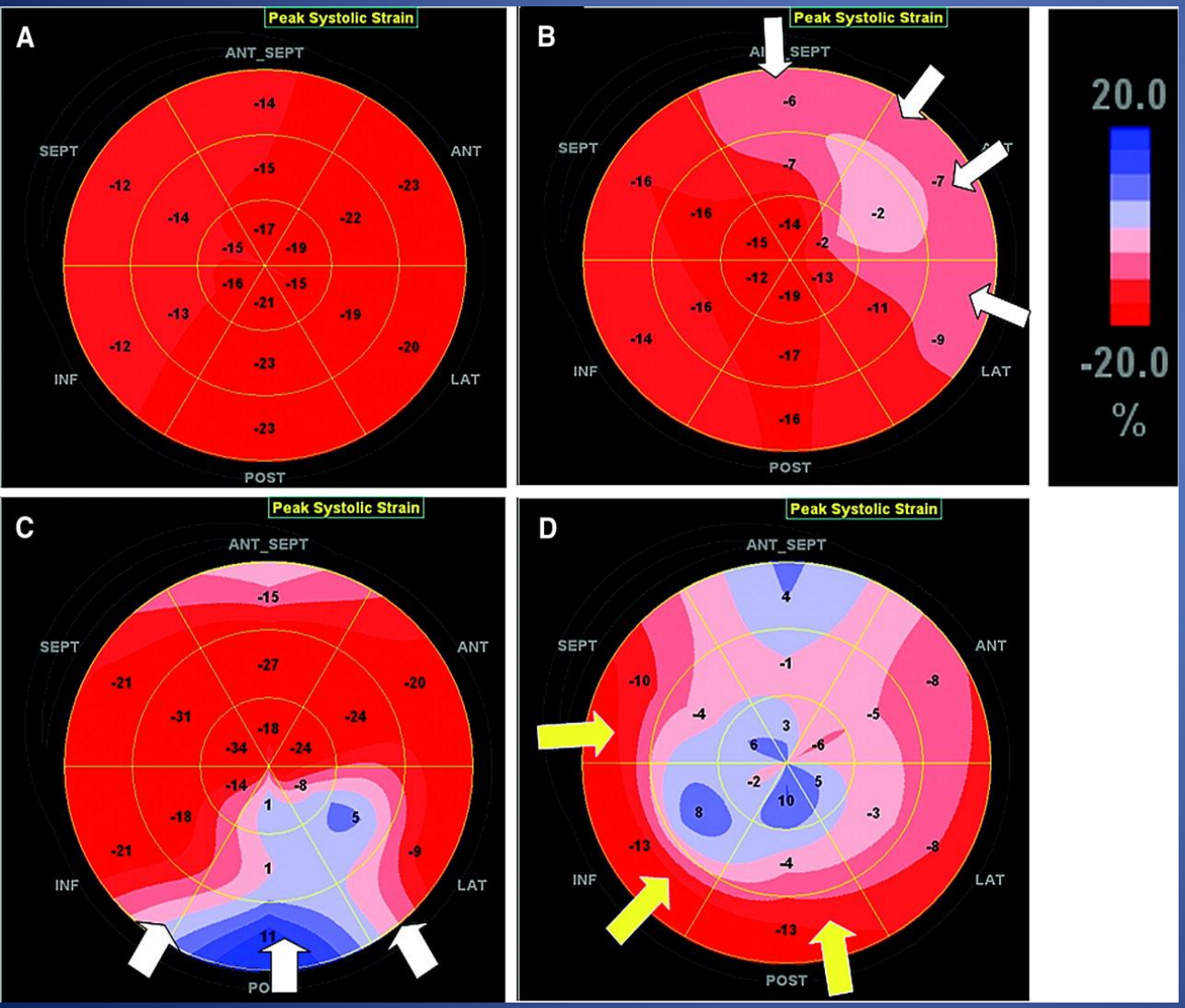
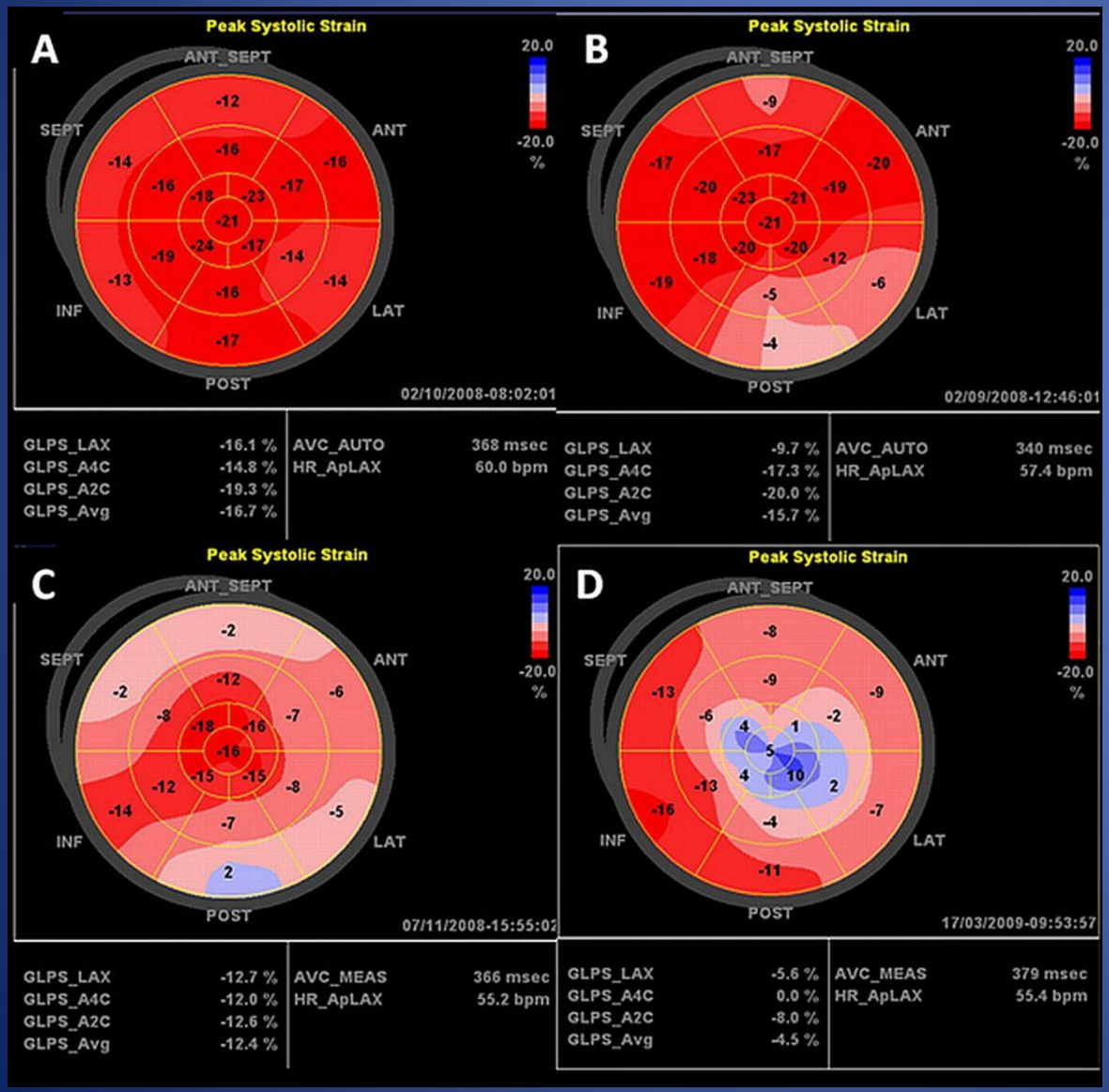
-23
-23
-21
-19
-19
-16
-17
-18

Myocardial infaction



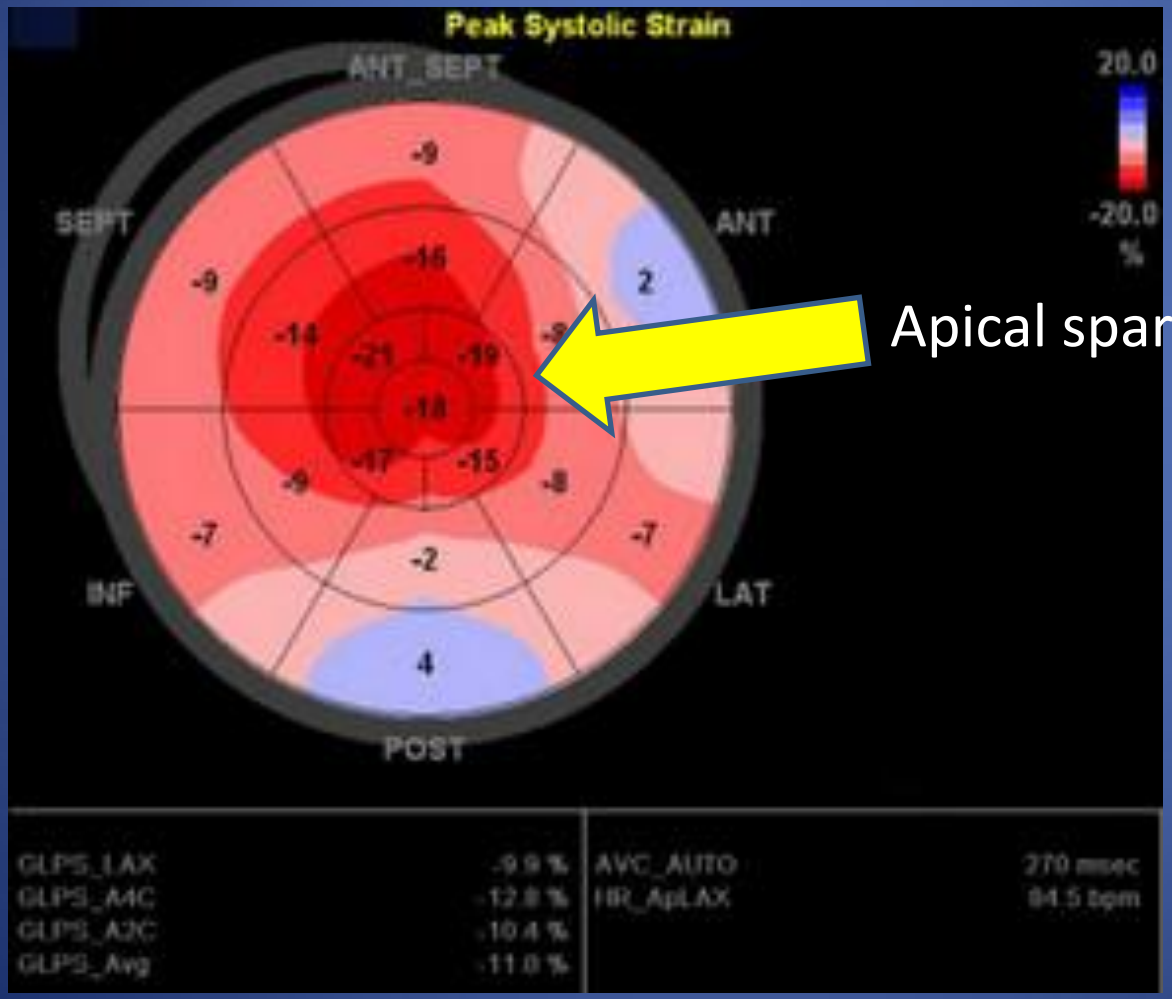
A. Normal
B. LAD infarct
C. LCx infarct
D. Non-ischaemic CMP

Cardiomyopathies



A. Normal athlete
B. Hypertensive heart
C. Hypertrophic cardiomyopathy
D. Apical variant HCM

Amyloid heart disease



Apical sparing pattern

Ischaemic CMP

- Perfusion abnormalities
- Viability
- Guide decision on revascularization

Exercise vs pharmacological stress Echo

	Advantages	Disadvantages
Treadmill	Widely available High workload	Post stress images Mild ischemia may revert
Upright bicycle	Imaging during exercise	Technically difficult
Supine bicycle	Imaging during exercise Dopplers readily available	Low workload
Dobutamine	Continuous imaging	Side effects
Dipyridamole	Continuous imaging	Side effects

Stress Echo Interpretation

Interpretation	Rest / Baseline	Low dose stress	Peak & post stress
Normal	Normal	Normal	Hyper dynamic
Ischemic	Normal	Normal / severe ischemia – new RWMA	Decreased
Scar	WMA	No change	No change
Hibernating	WMA	Improved	Worsens
Stunned	WMA	Improved	Improved

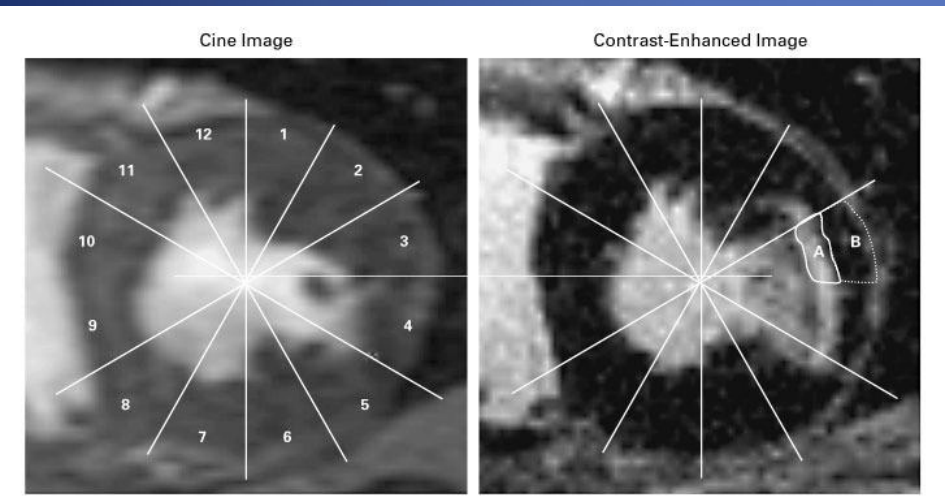
Stress Echo – other parameters

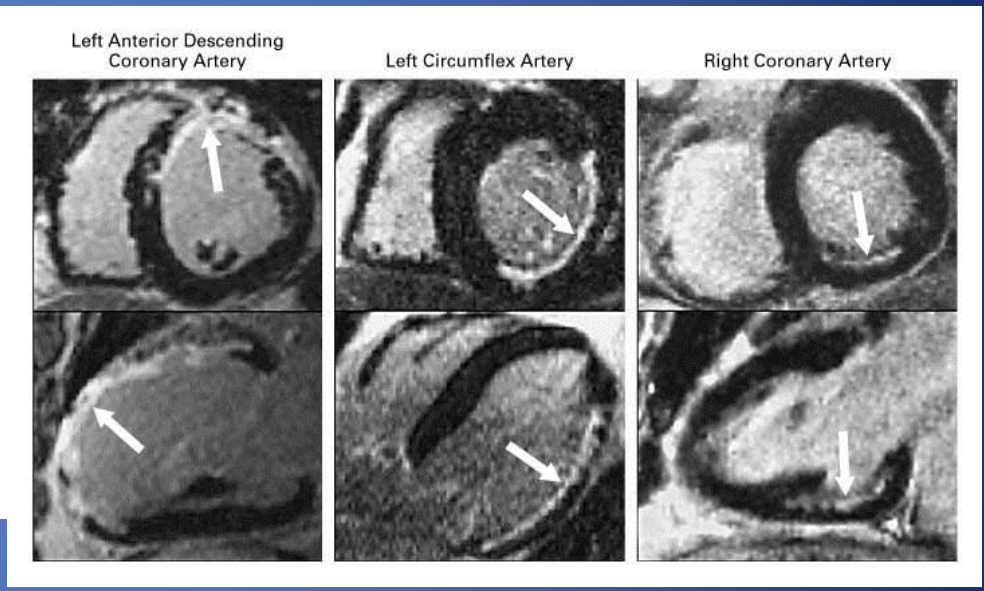
- Change in diastolic function
- Change in RSVP
- Change in LV chamber size
- Change in haemodynamics in valvular disease
  - "mild MS" at rest with exertional symptoms
  - "LFLG severe AS"

Cardiac MRI

- Structure and function assessment
- Stress perfusion for ischameia
- Late Gandolinium Enhancement (LGE)
  - Differentating ischaemic vs non-ischaemic cause
  - Ischaemic – almost always involvement subendocardium or even transmural, corresponding to coronary artery territory

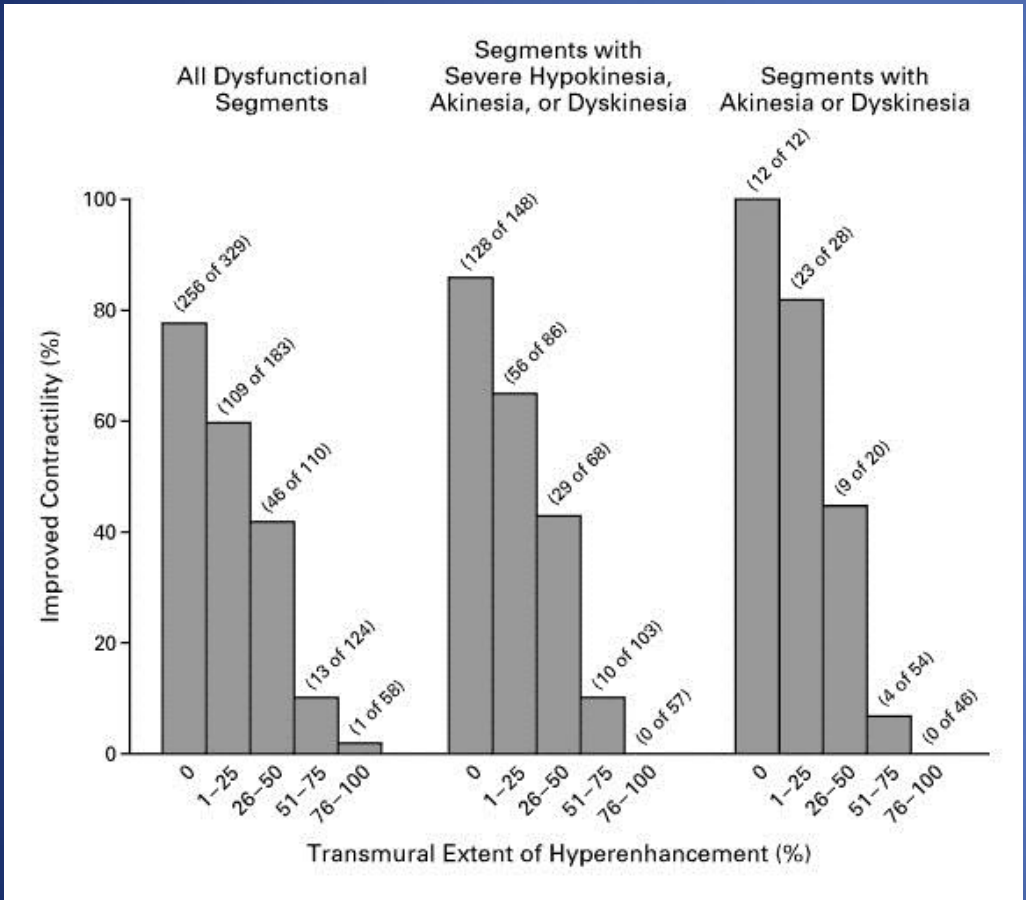
LGE – transmural extent of infarct





Kim, Raymond J., et al. "The use of contrast-enhanced magnetic resonance imaging to identify reversible myocardial dysfunction." New England Journal of Medicine 343.20 (2000): 1445-1453.

LGE – transmural extent of infarct



Can be used to predict whether or not regions of myocardial dysfunction will improve after revascularization.

Kim, Raymond J., et al. "The use of contrast-enhanced magnetic resonance imaging to identify reversible myocardial dysfunction." New England Journal of Medicine 343.20 (2000): 1445-1453.

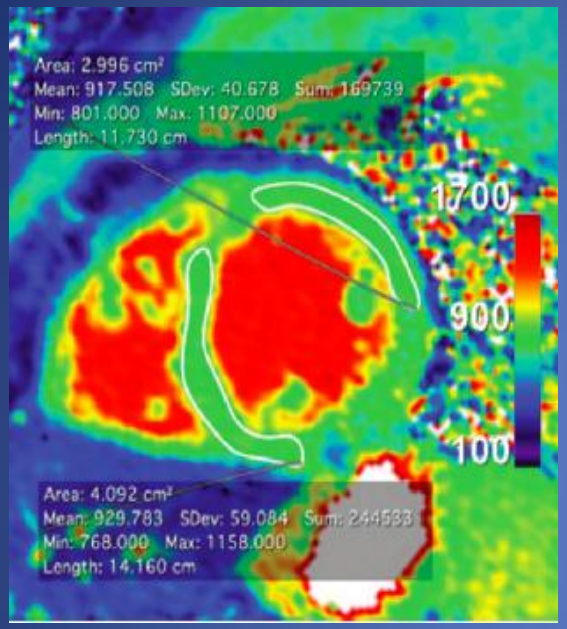
LGE

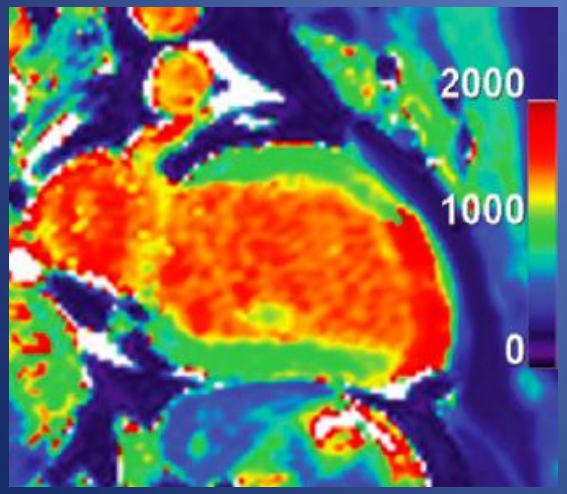
- Predict response to CRT – transmural necrosis at inferolateral wall may do worse
- Predict arrhythima risk base on extent of scarring

Tissue characterization

- Native T1 – non-contrast
- Extracellular volume (ECV)
- T2: acute inflammation, edema, infarct
- T2*

Native T1 mapping

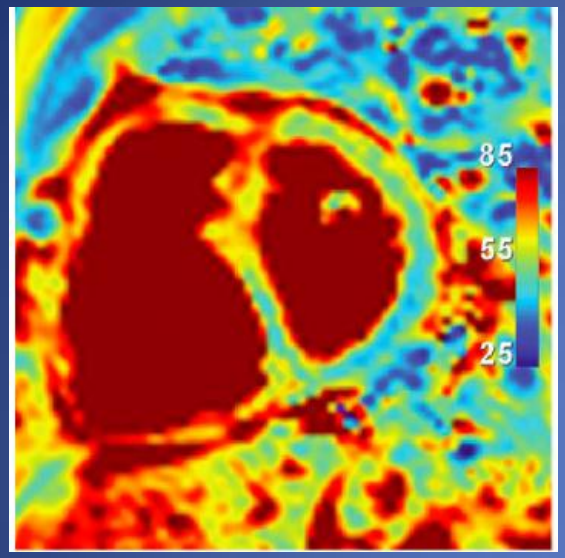


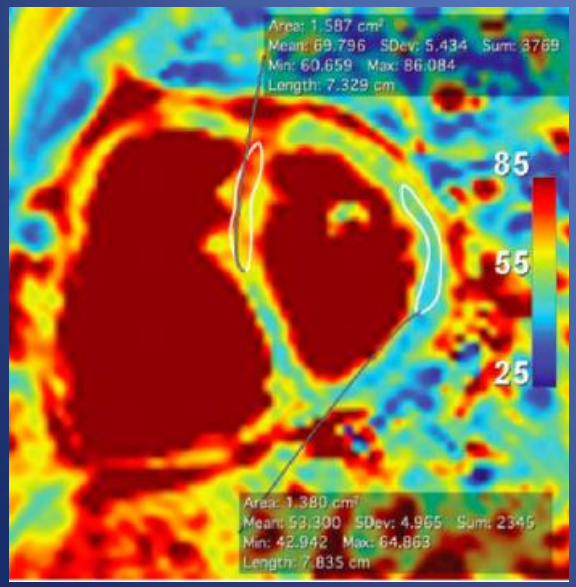


- Parametric mapping
- A more recent development in myocardial tissue characterisation

- Diffuse myocardial fibrosis - ↑ T1 values
- Non-specific
  - any pathology resulting in edema/fibrosis/other depositional disease
- Values applicable to local setup only

T2 mapping





- Similar principle to T1 mapping
- T2 relaxation time altered by water content
- Detect myocardial edema in different diseases
- “Area-at-risk” myocardium

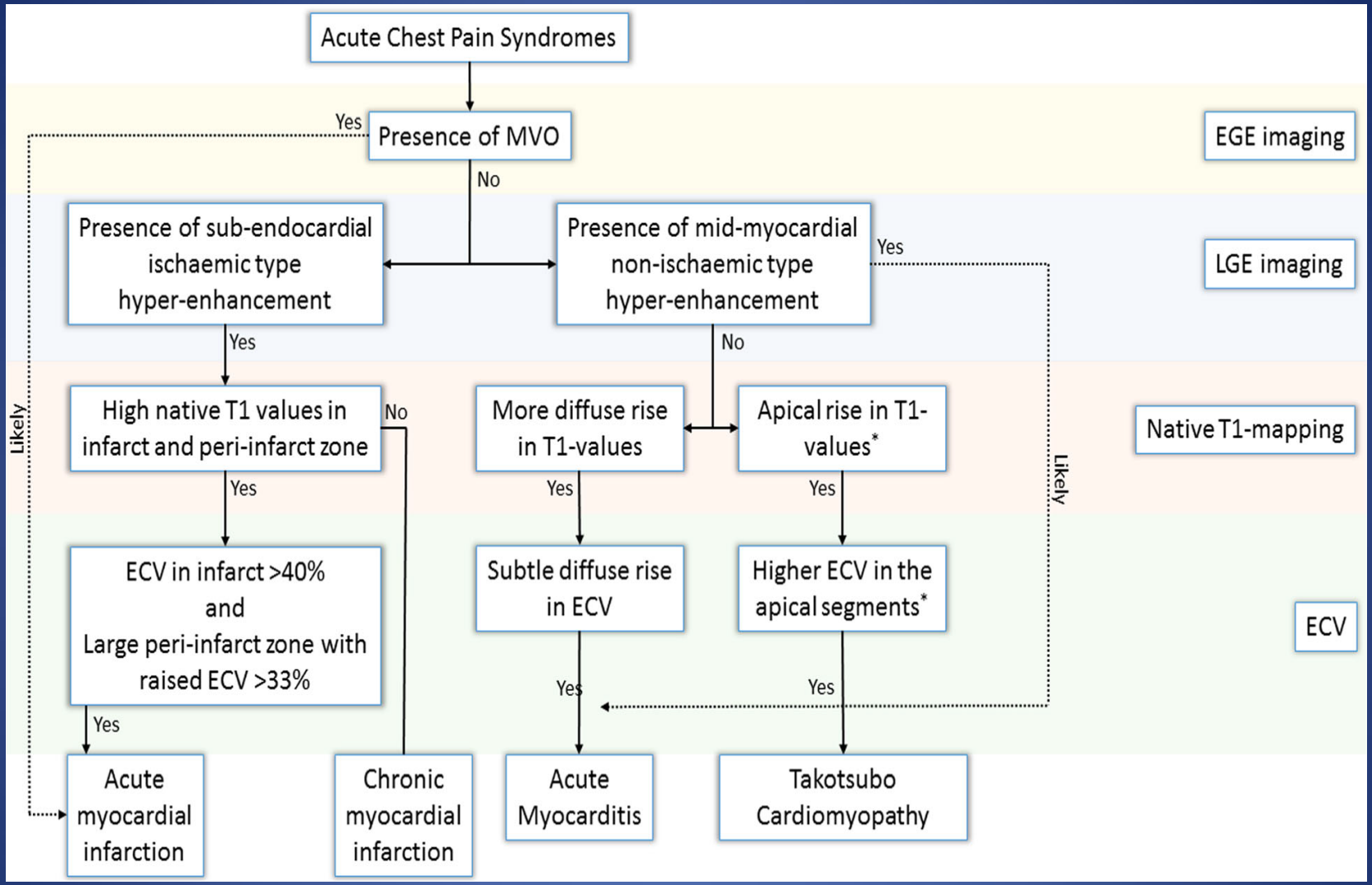
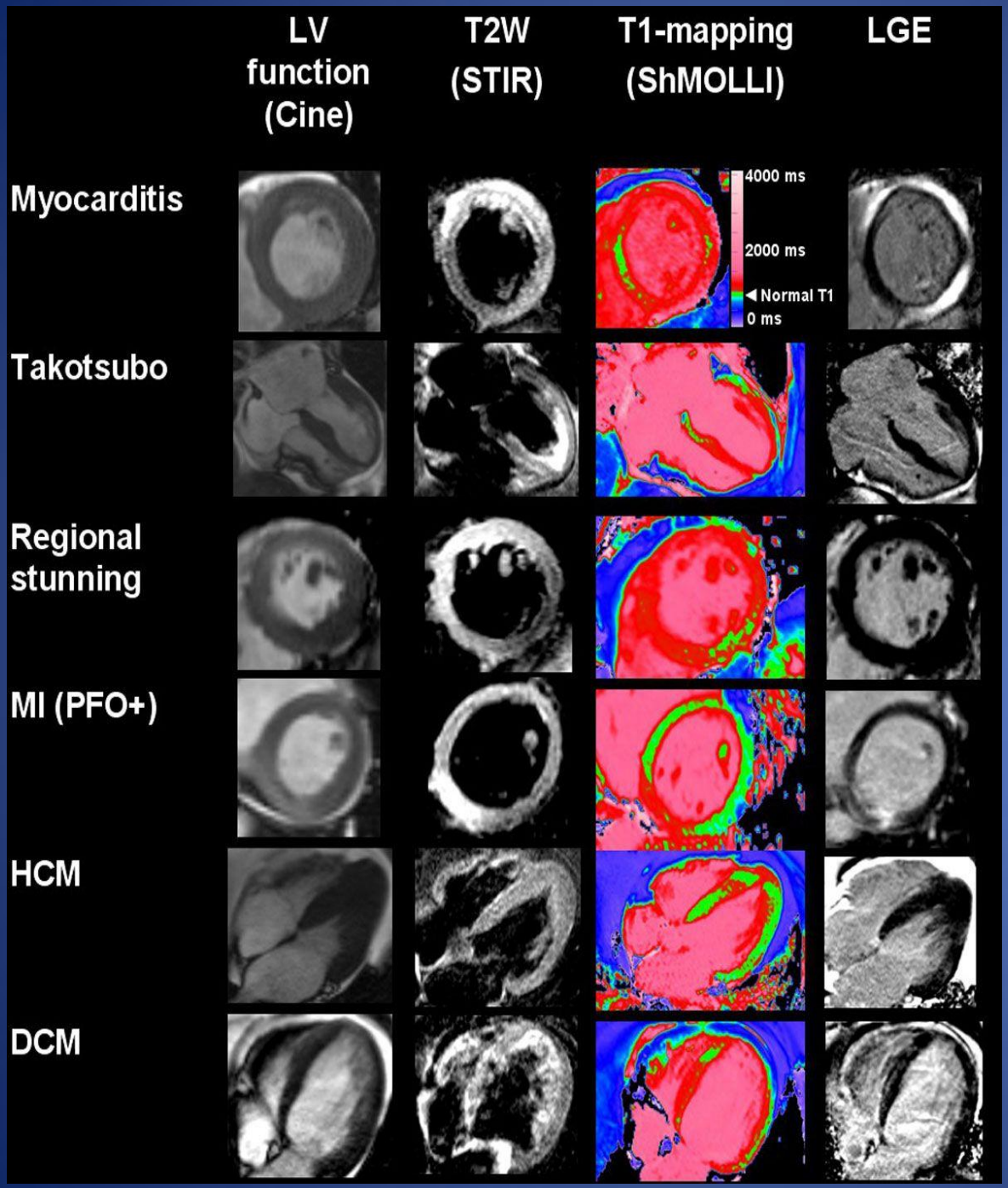


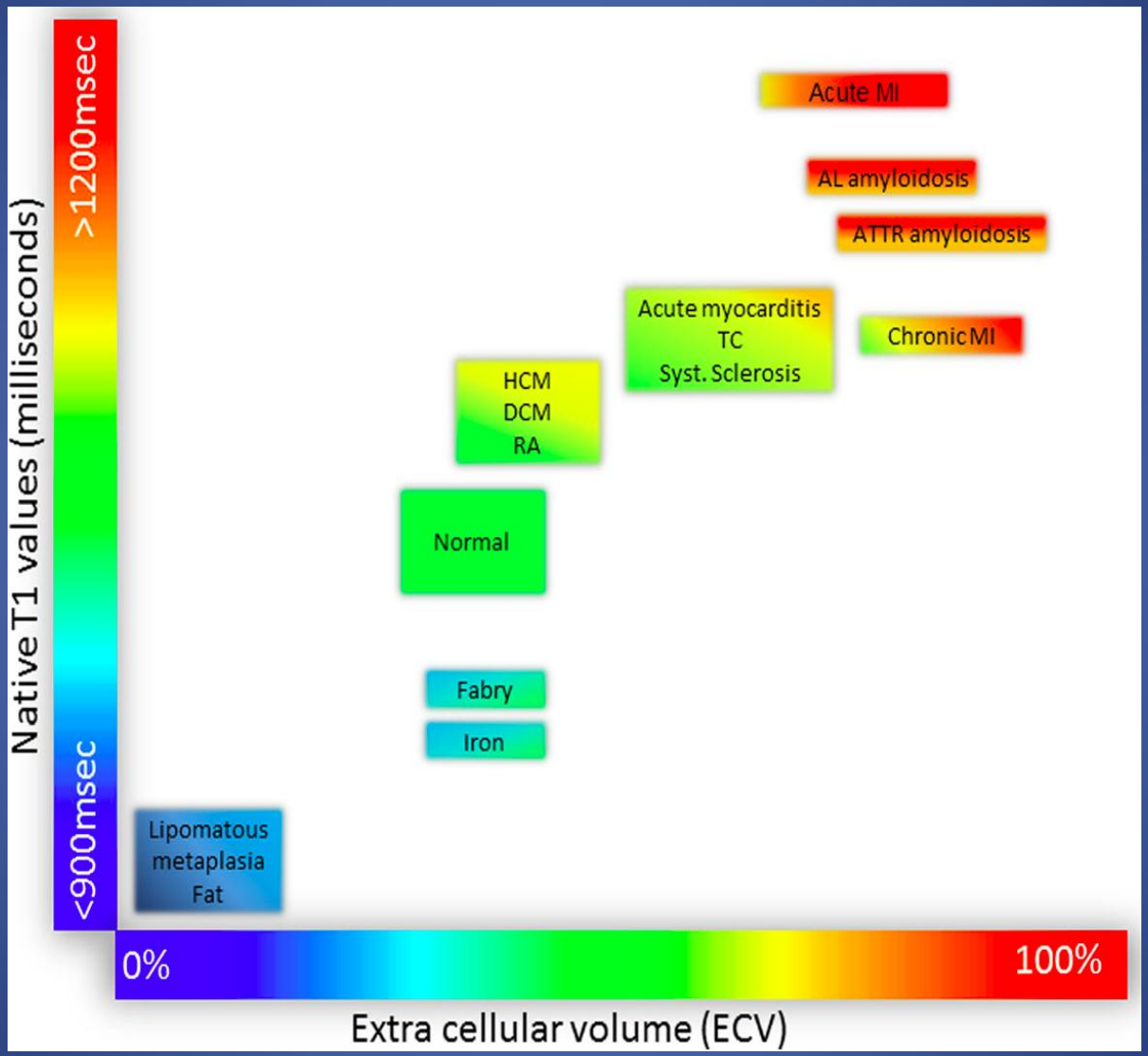
Fig. 3 Acute chest pain syndromes algorithm using multi-parametric tissue characterisation. ECV denotes extra-cellular volume, LGE Late Gadolinium Enhancement, and MVO microvascular obstruction. .
*This holds true for classical type 1 Takotsubo Cardiomyopathy

Haaf et al. Journal of Cardiovascular Magnetic Resonance (2016) 18:89



Ferreira et al. Journal of Cardiovascular Magnetic Resonance 2014 16 (Suppl 1) :P215

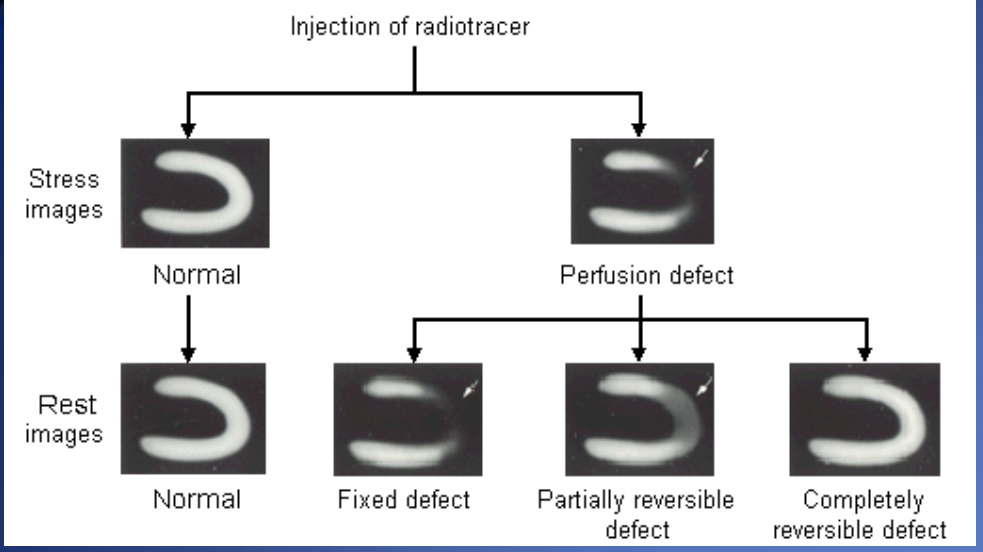
T1 mapping and ECV in clinical practice

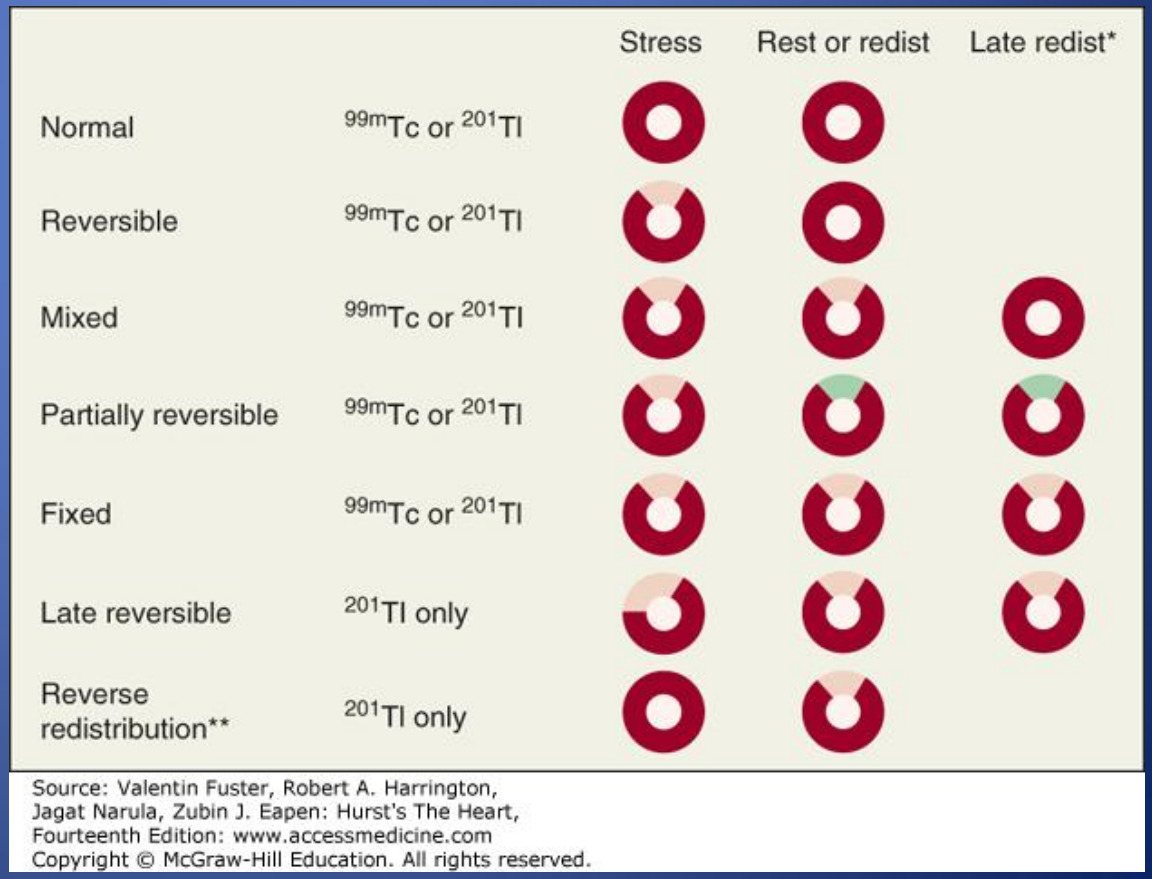


Haaf et al. Journal of Cardiovascular Magnetic Resonance (2016) 18:89

Nuclear imaging for ischaemia

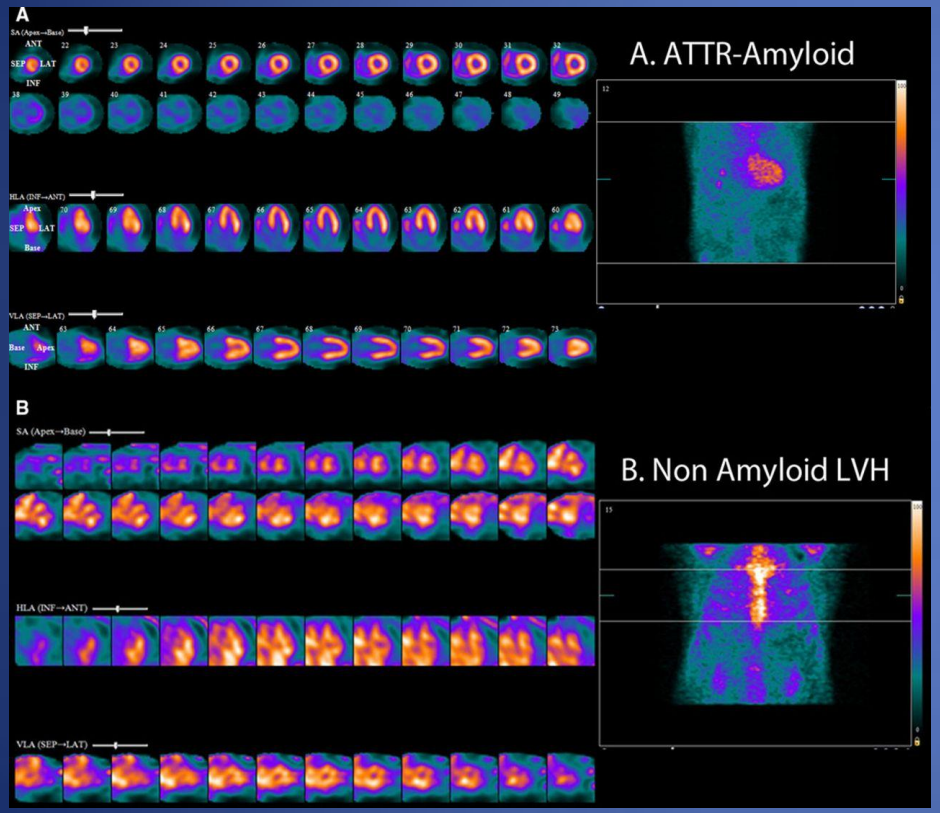
- Thallium-201 or technietium-99m
- Exercise or pharmacological stress
- Evaluate ischaemia, infarction and viability
- Prior studies suggest excellent negative predictive values but poor positive predictive values
- Ischaemic CMP shows more extensive, diffuse and severe perfusion defects than NICM, but a noteworthy degree of overlap exists





Source: Valentin Fuster, Robert A. Harrington, Jagat Narula, Zubin J. Eapen: Hurst's The Heart, Fourteenth Edition: www.accessmedicine.com

Nuclear imaging for cardiac amyloidosis



- direct amyloid imaging agents (I-123–labeled serum amyloid P component),
- bone imaging agents (Tc-99m pyrophosphate or Tc-99m 3,3-diphosphono-1,2-propanodicarboxylic acid [DPD])
- agents to image cardiac sympathetic innervation (I-123 metaiodobenzylguanidine)

How to Image Cardiac Amyloidosis, Volume: 7, Issue: 3, Pages: 552-562, DOI: (10.1161/CIRCIMAGING.113.001396)

Table 1: Main Indications and Applications for Each One of the Available Imaging Modalities in the Assessment of Heart Failure Patients

	2D ECO	3DE	Strain	Cardiovascular Magnetic Resonance	Nuclear	Computed Tomography
LV/RV volumes	RU	AI		AI (GS)		AI
LV systolic function	RU	AI	AI	AI (GS)		
LV diastolic function	RU (GS)		AI	AI		
RV function	RU	AI	AI	AI (GS)		
Ischaemia	RU		AI	AI (GS)	AI (GS)	
Viability	RU		AI	AI (GS)	AI (GS)	
Cardiomyopathies and other heart failure aetiologies	RU		AI	AI (GS)		AI
Risk assessment (arrhythmia)						
Therapy guidance (cardiac resynchronisation therapy)						
Follow-up	RU					

Green: best performance of the technique for this indication; yellow: the technique could provide useful information for this indication; red: no/little use for this indication. AI = provides additional information to that obtained with 2D echocardiogram; GS = gold standard; RU = routinely used for this indication. LV = left ventricular; RV = right ventricular.

Cardiac Failure Review, 2016;2(1):27–34

Imaging in Heart Failure

- Echo continues to be the method of choice for its availability, cost and usefulness, it provides most of the information required for the management and follow up of HF patients and it has been enhanced with the development of 3DE and strain.
- Cardiac MRI and nuclear imaging are alternative for ischaemia or viability assessment
- Cardiac MRI is excellent in tissue characterization to differentiate different types of cardiomyopathies