Myocardial Mechanics: Quantitative Global and Local Myocardial Function For Cardiomyopathies

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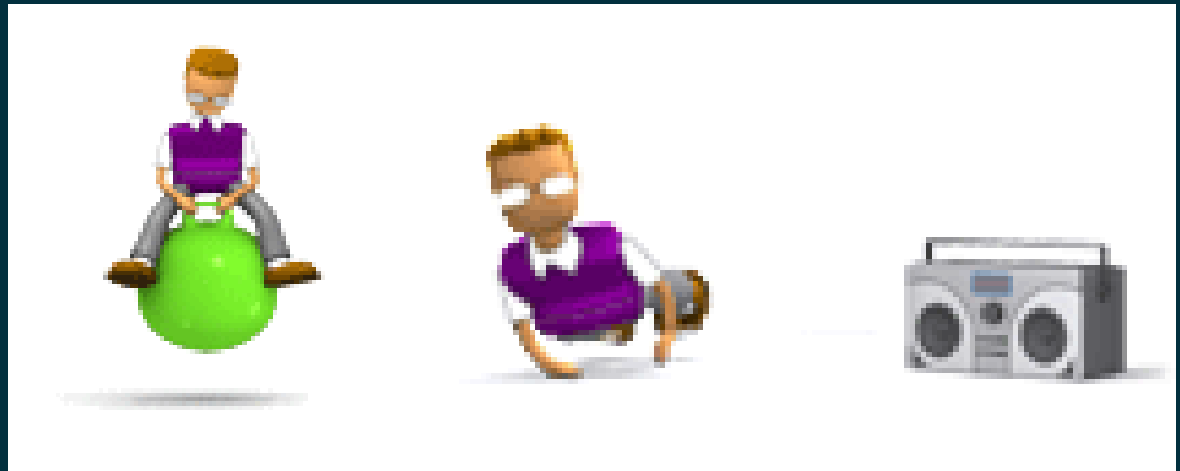
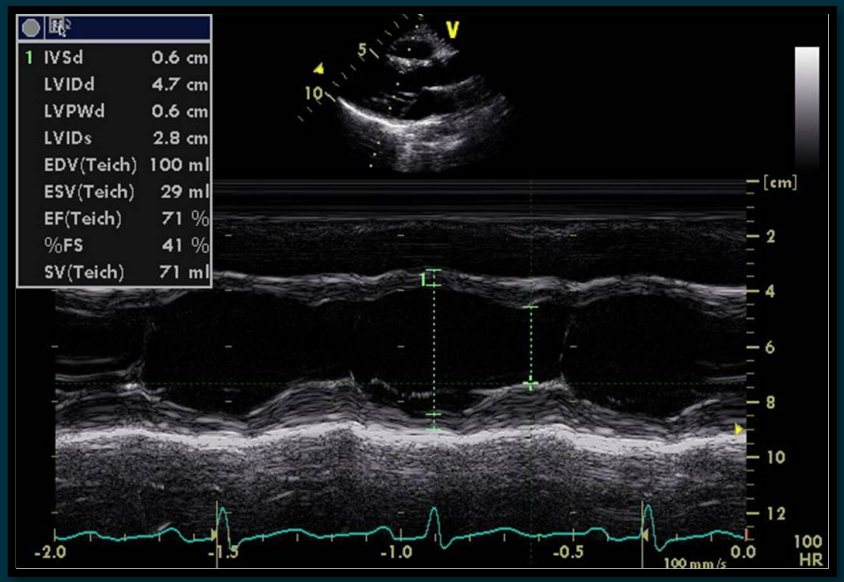
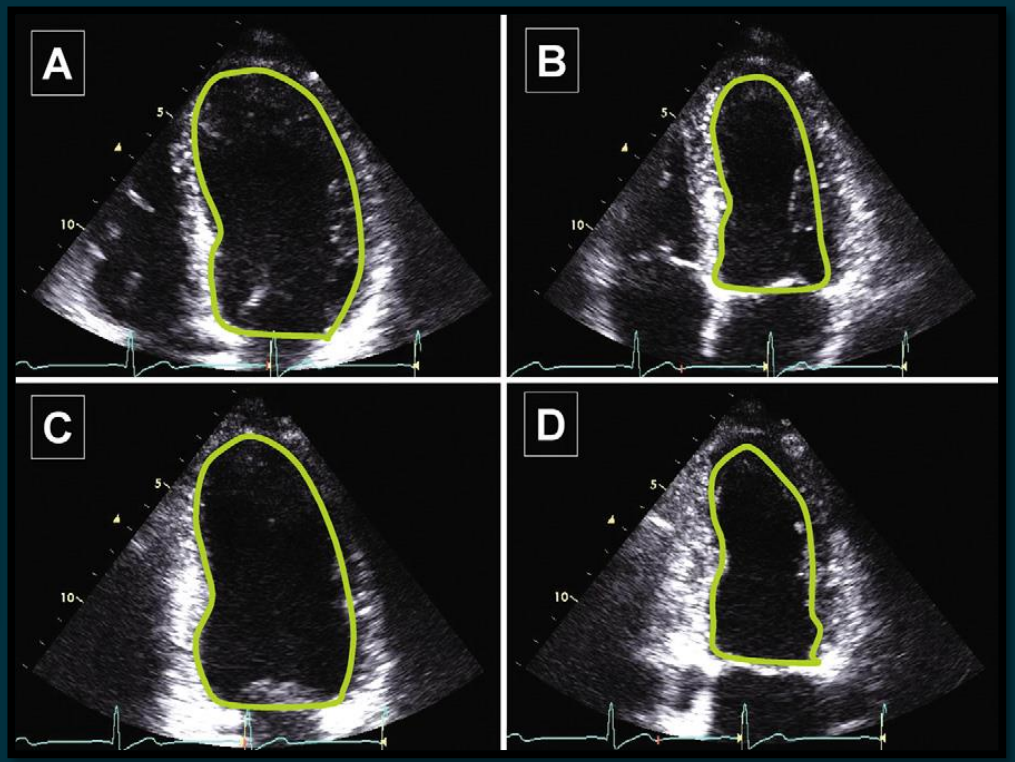


LVEF – most referred parameter

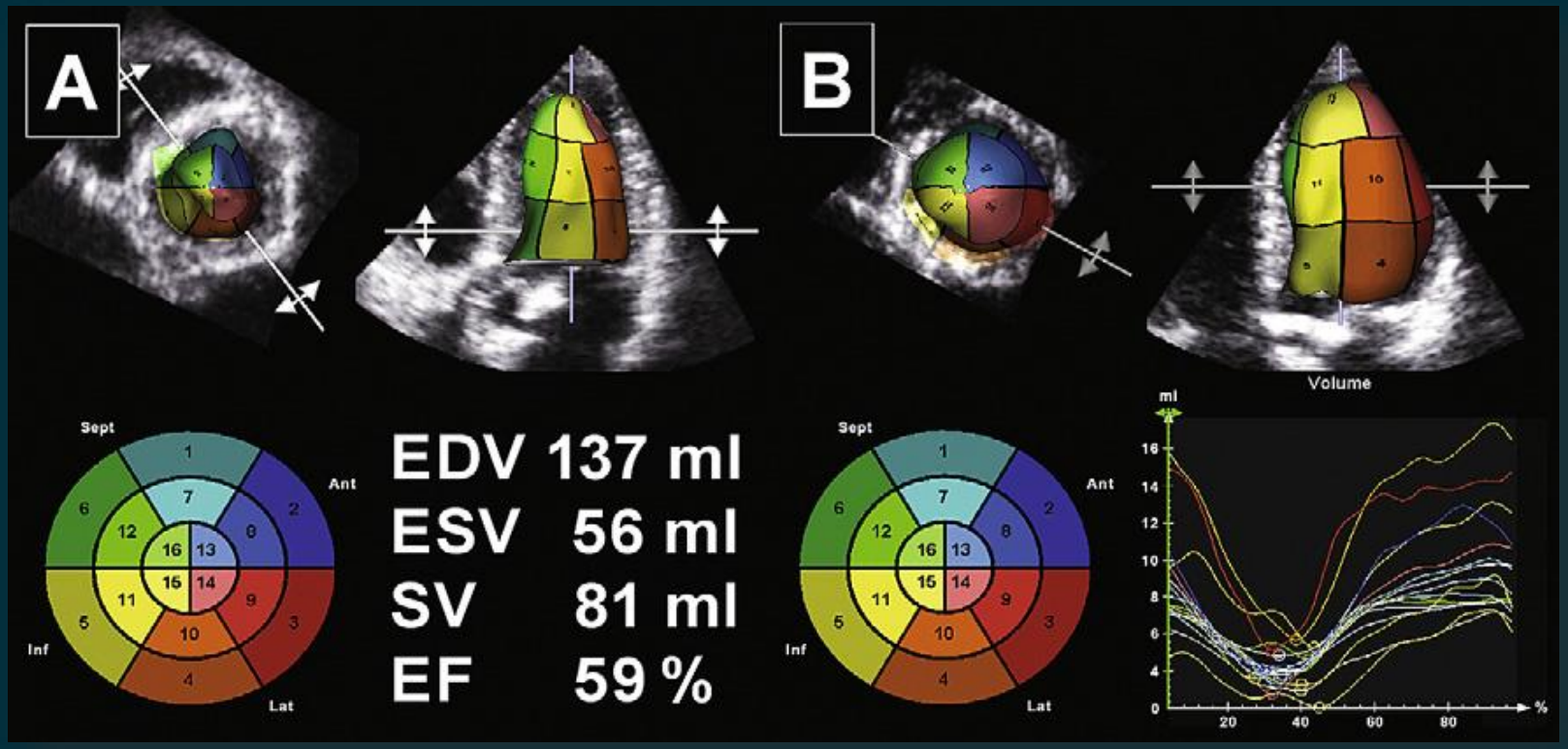
- Visual score: 5-10% increments (~7% variability)
- Teichholz: partial outlook
- Simpson rule: where is the endocardium?





LVEF – most referred parameter

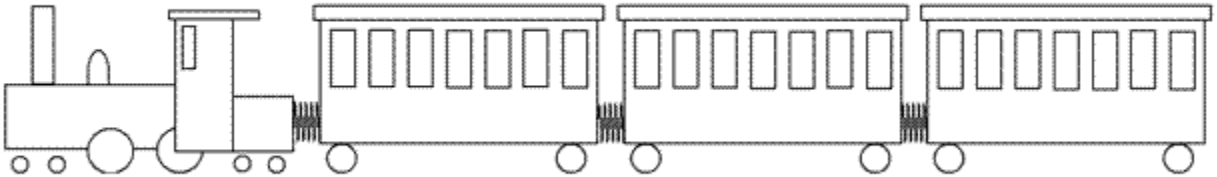
- **3D Echocardiography**
  - **Best correlation with MRI volumes**



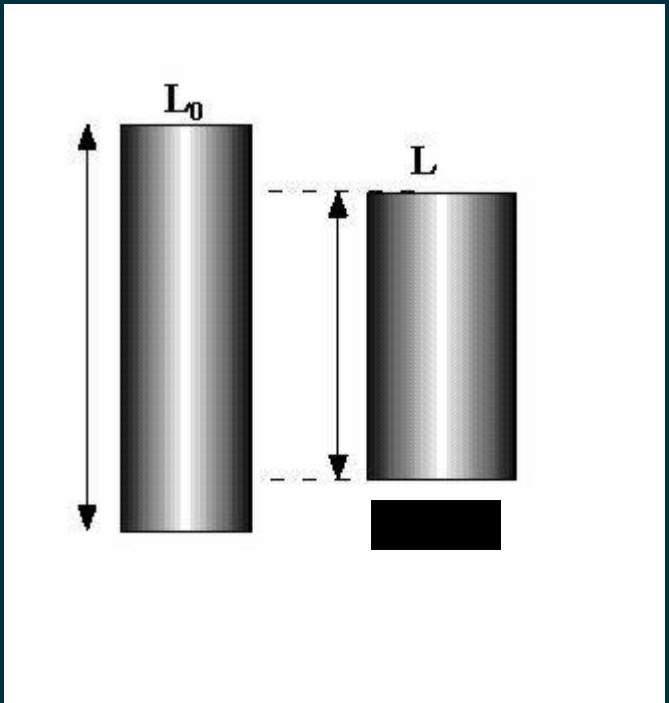
LVEF - Caveats

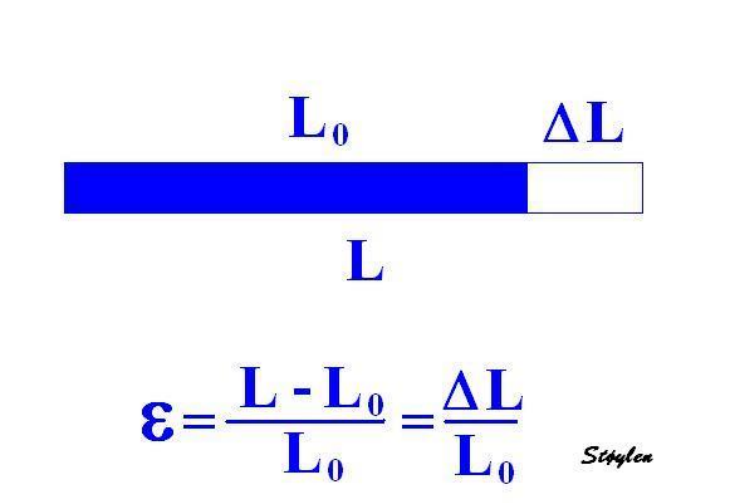
- **Technical:**
  - **LVEF obtained by echocardiography has a 95% confidence interval of ±11%; thus, subtle changes frequently are not detected because of measurement variability**
  - **Depends on image quality**
- **Load dependent (pre-load and afterload)**
- **Heart rate dependent**

Concept: Deformation



Concept: Strain



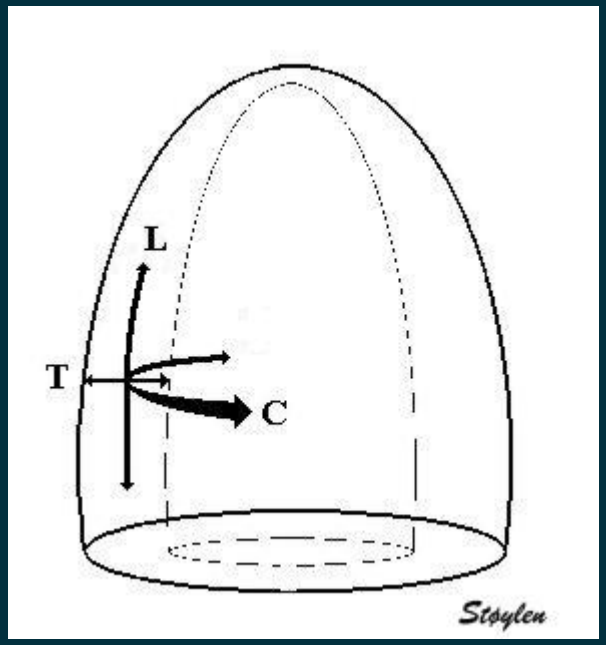


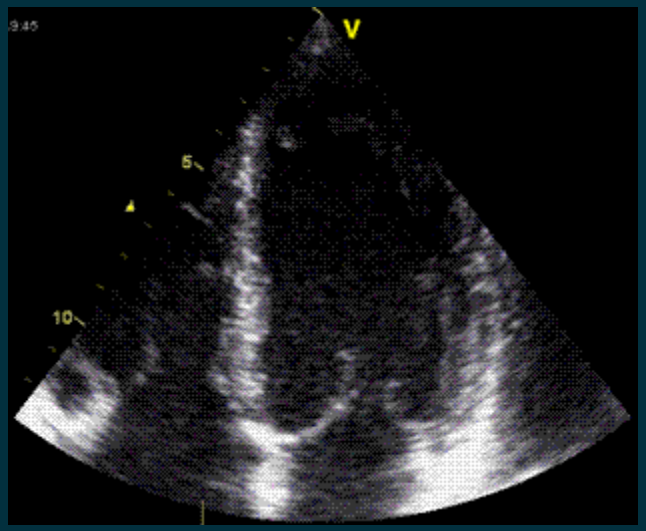
Negative = shortening, expressed as percentage

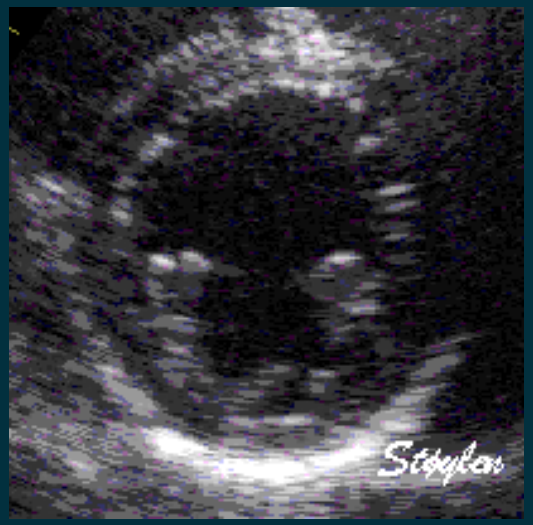
Normal (longitudinal)= -20%

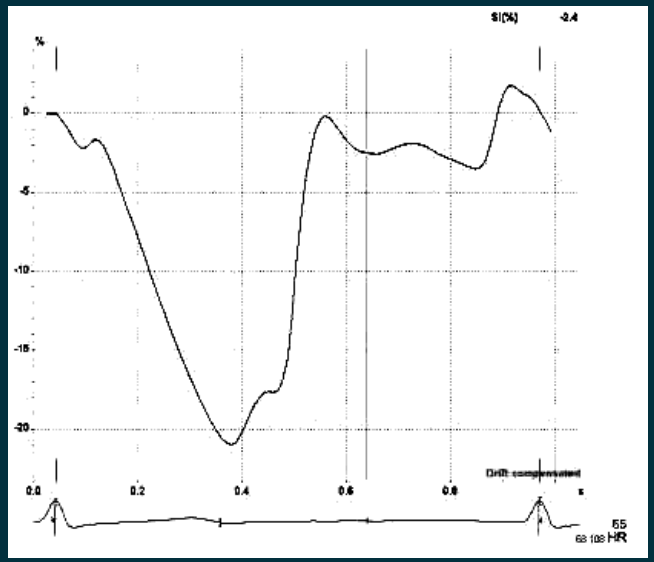
Larger negative number = more shortening, better contraction

Basic echo deformations







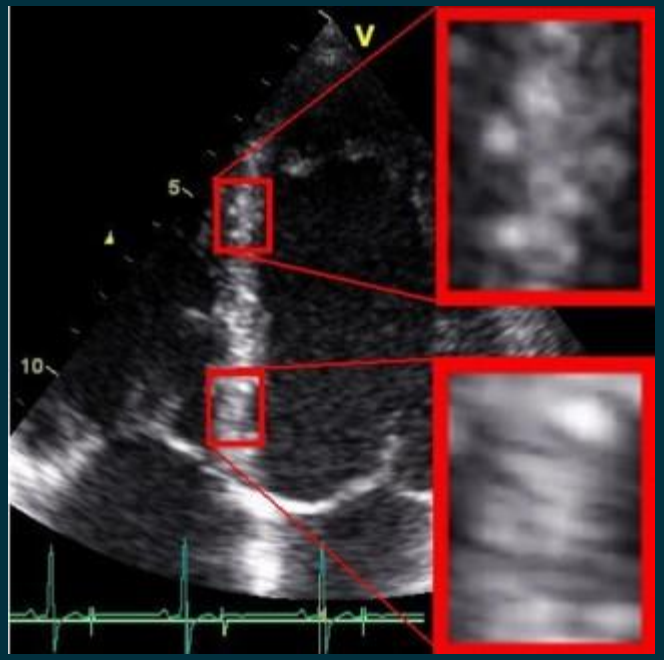


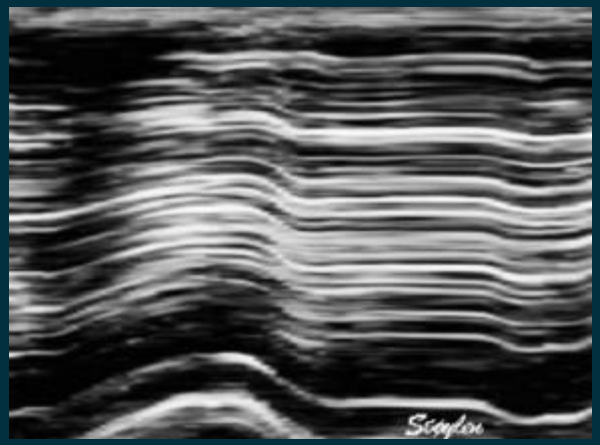
What is Tissue Strain imaging ?

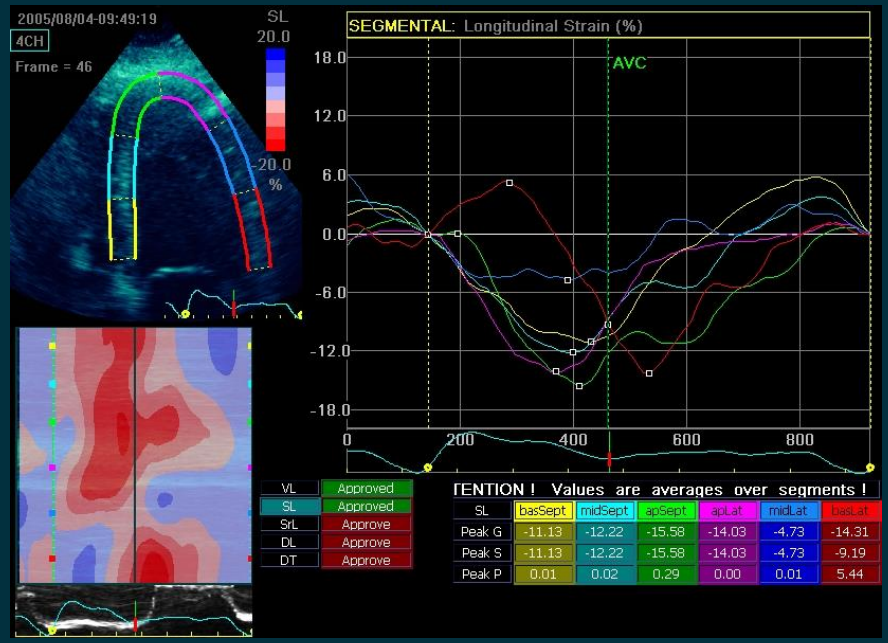
- **Off line analysis of echo clips**
- **Software measures displacement of speckles, using speckle velocities to follow speckles from frame to frame.**
- **Movement measured relative to tracked myocardial border (VVI)**
- **Relative speckle displacement is measured (distance between adjacent speckles/time)**

Software: GE, Siemens (VVI), Philips (QLAB)

Strain: 2D Tissue tracking





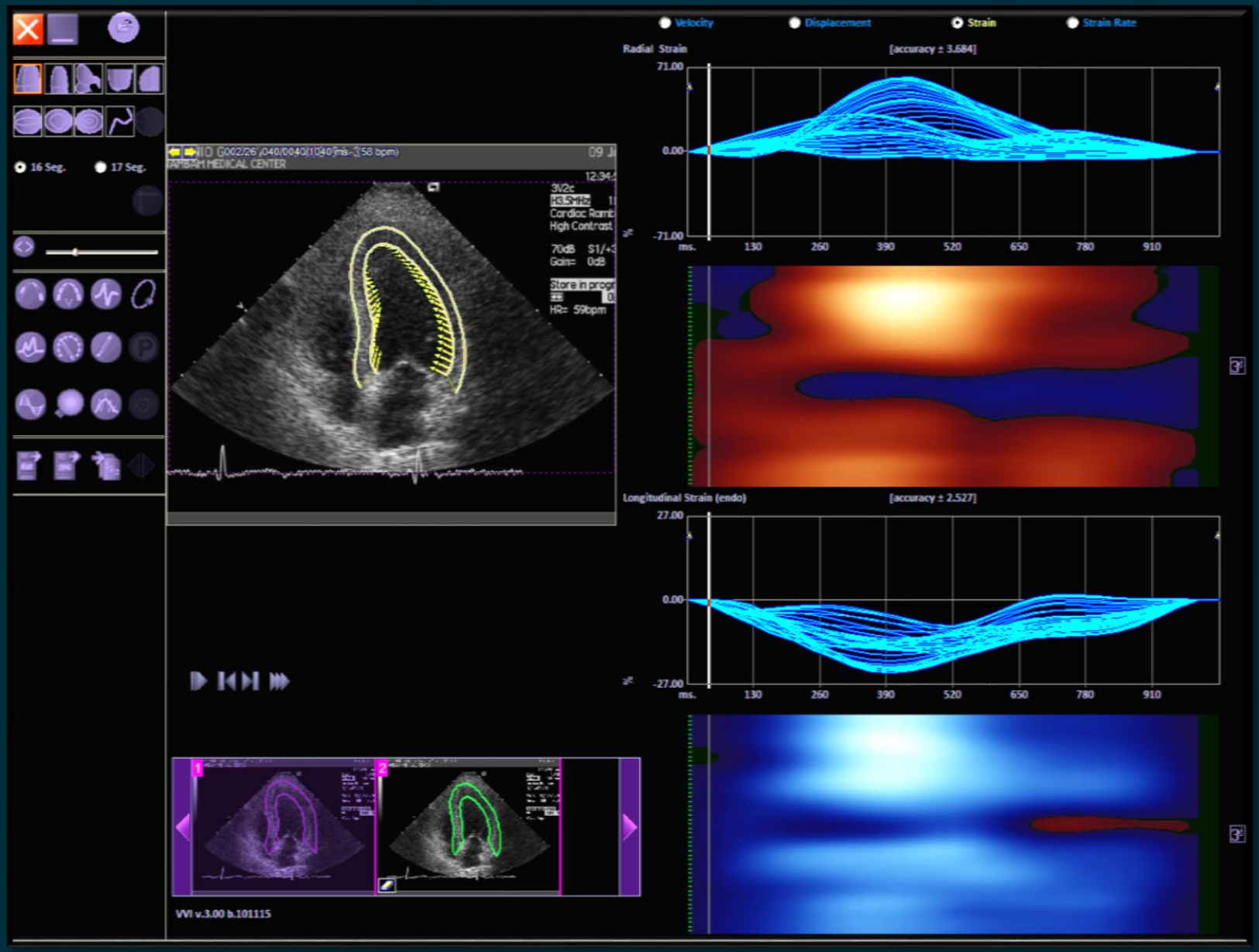


GE's 2DS:

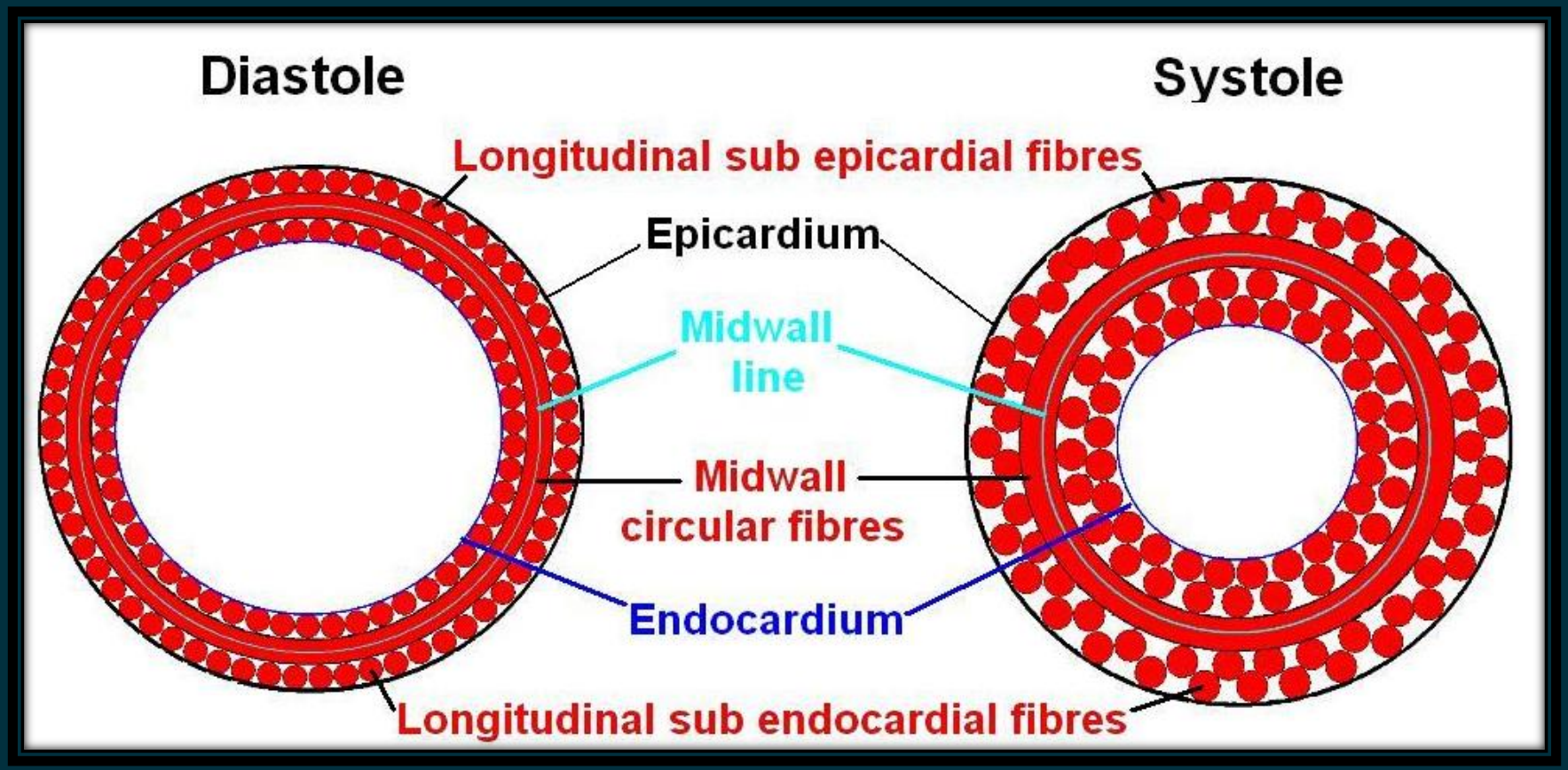
Tirat Ha'Carmel, Israel

By: Peter Lyssyansky and Zvi Friedman

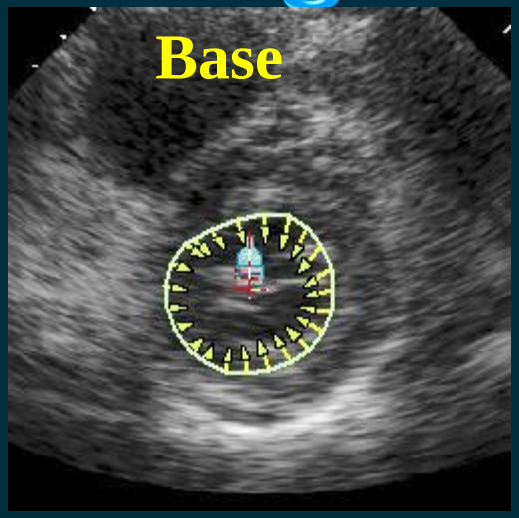
Velocity Vector Imaging

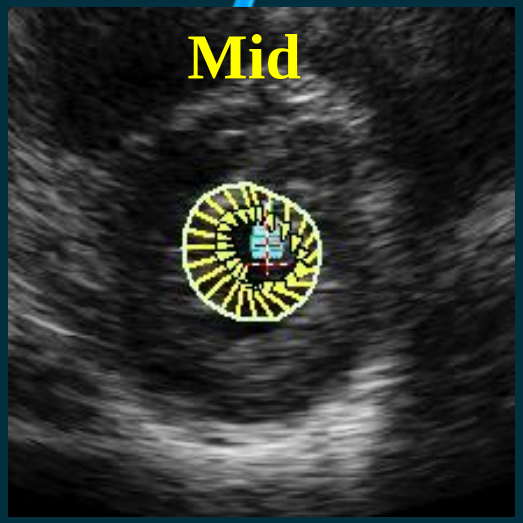


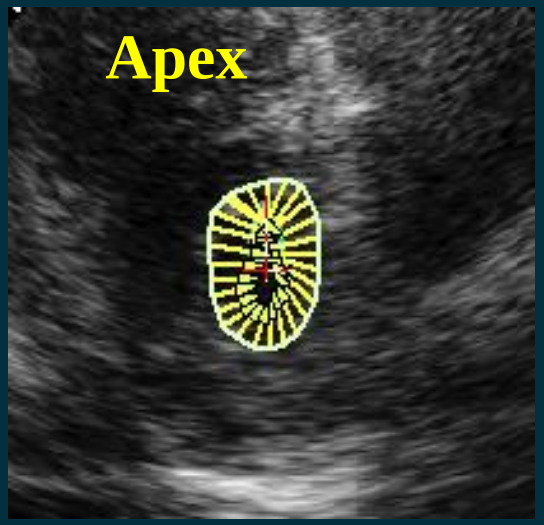
Fiber orientation and deformation

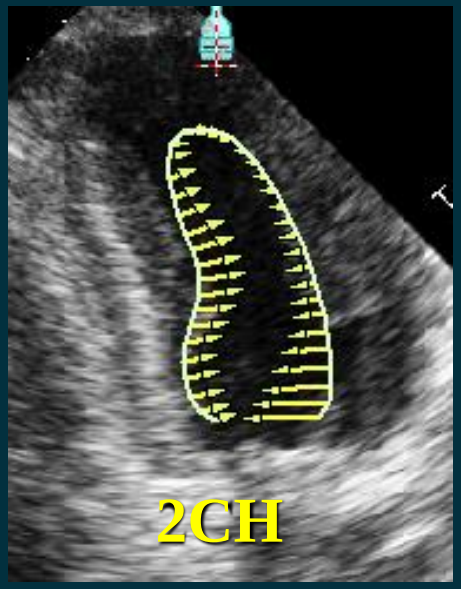


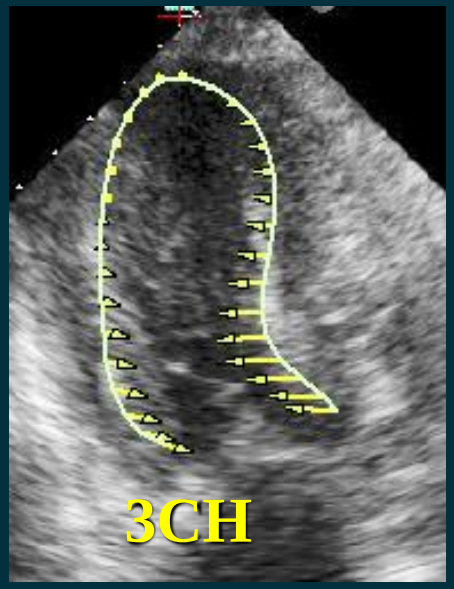
Images Analyzed





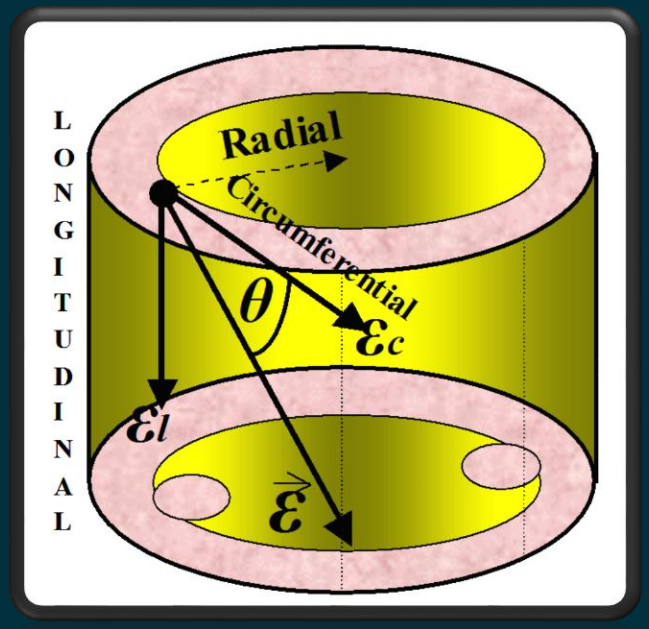




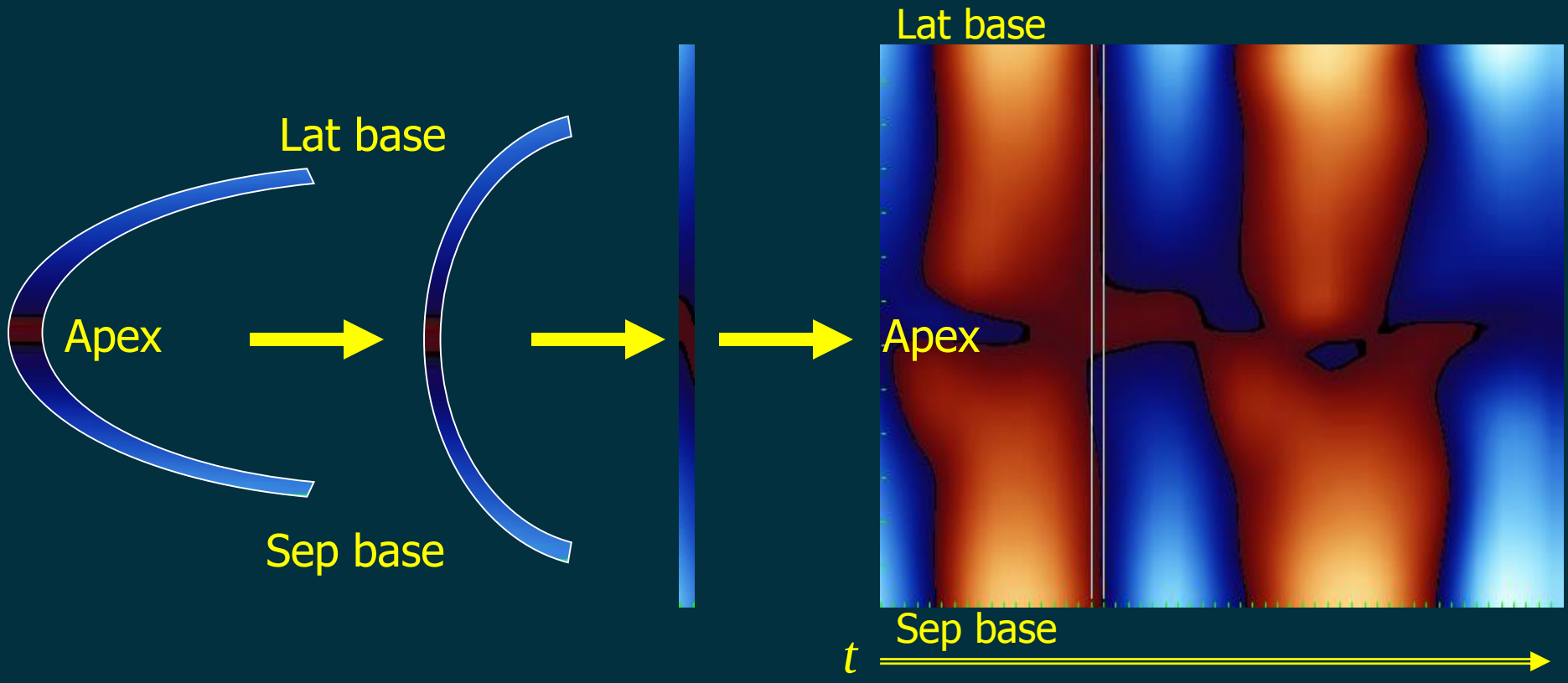


What does it measure?

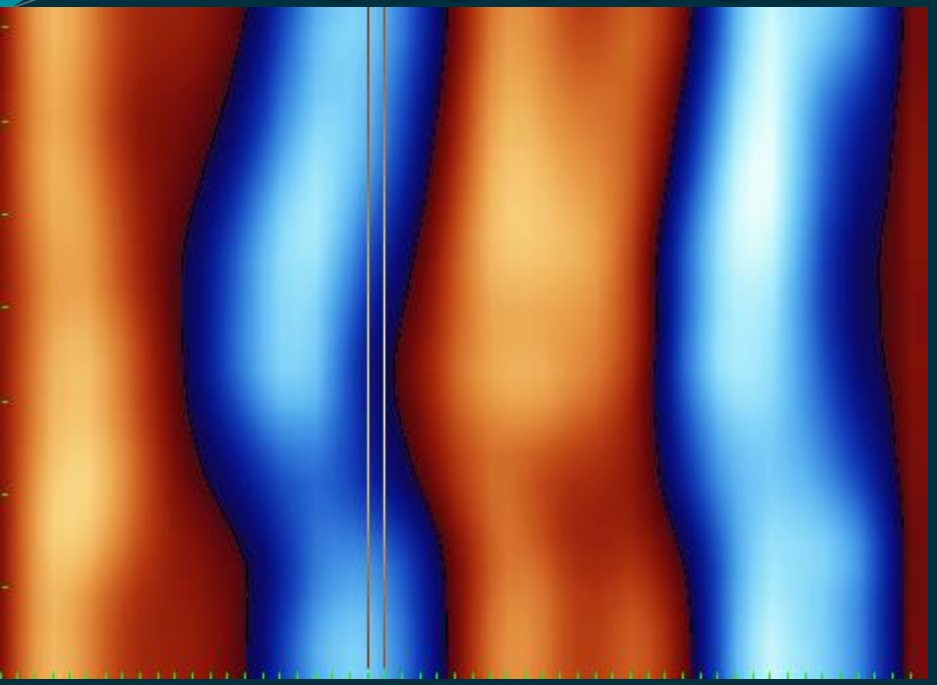
- Displacement
  - Radial
  - Circumferential (rotation)
  - Longitudinal
- Relative displacement (strain)
  - Circumferential
  - Longitudinal
  - Principal (strain vector)
  - Radial
- Time derivative of displacement (strain rate)

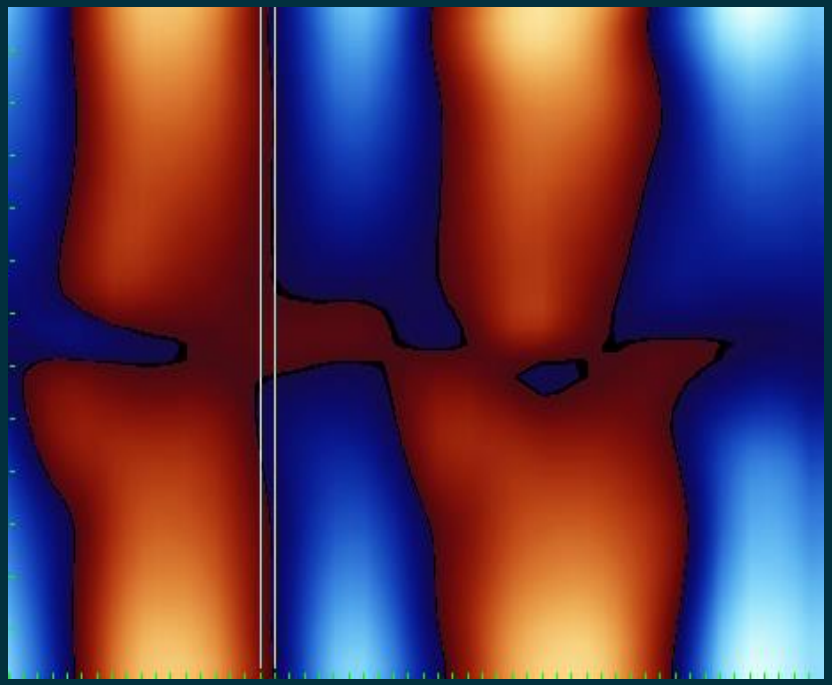


Parametric maps: curved M-mode

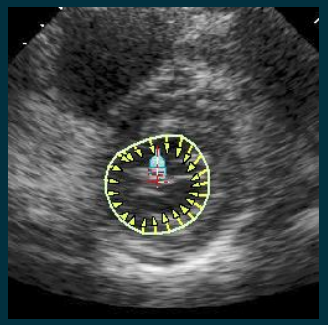


Velocities



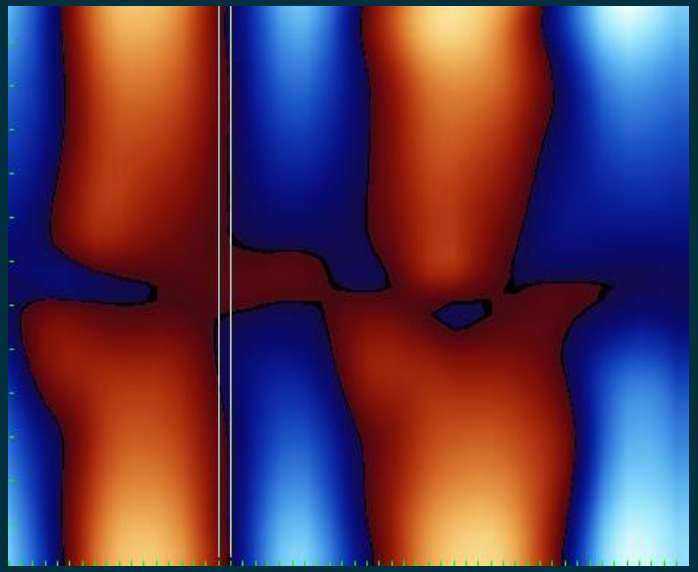


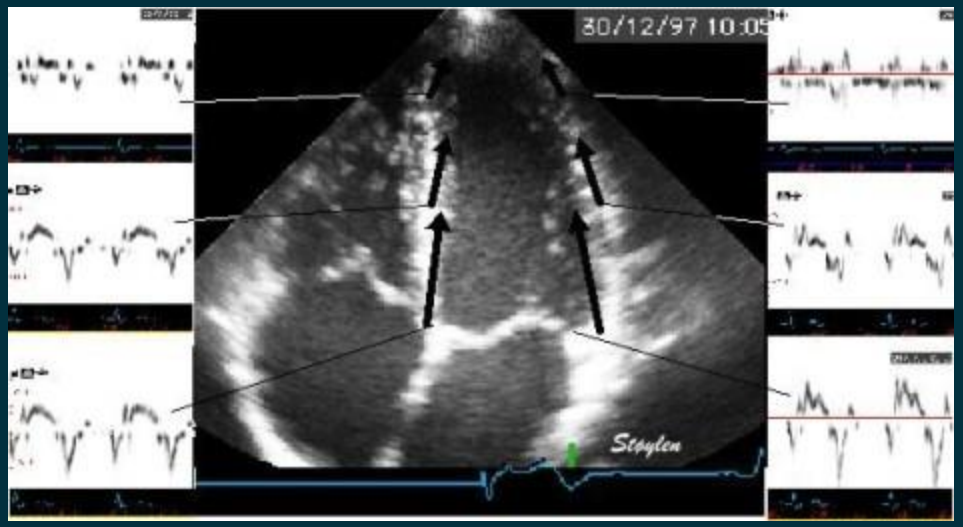
Radial (SAX views)



Longitudinal Apical views

Velocity is NOT synonymous of function !





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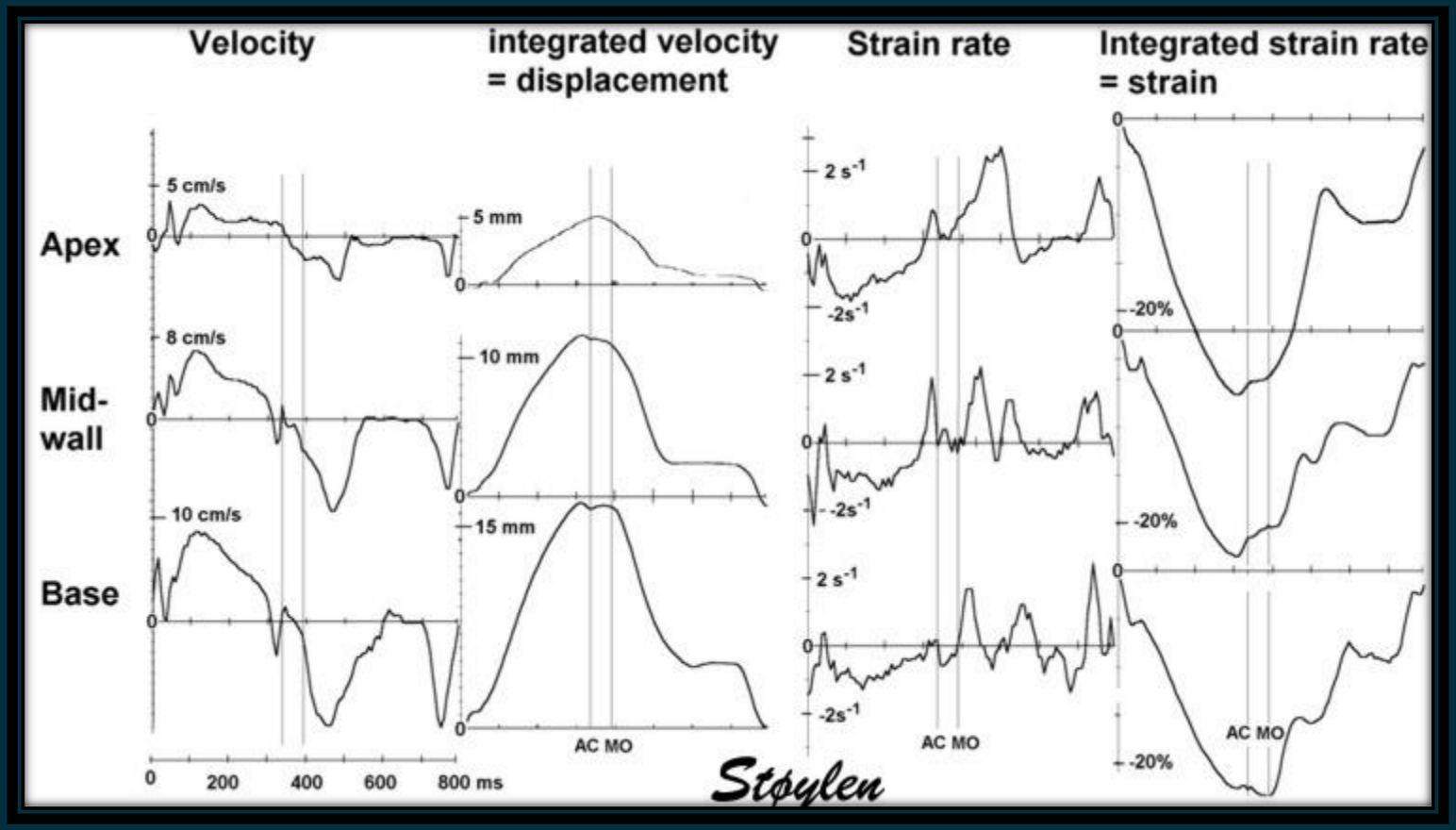
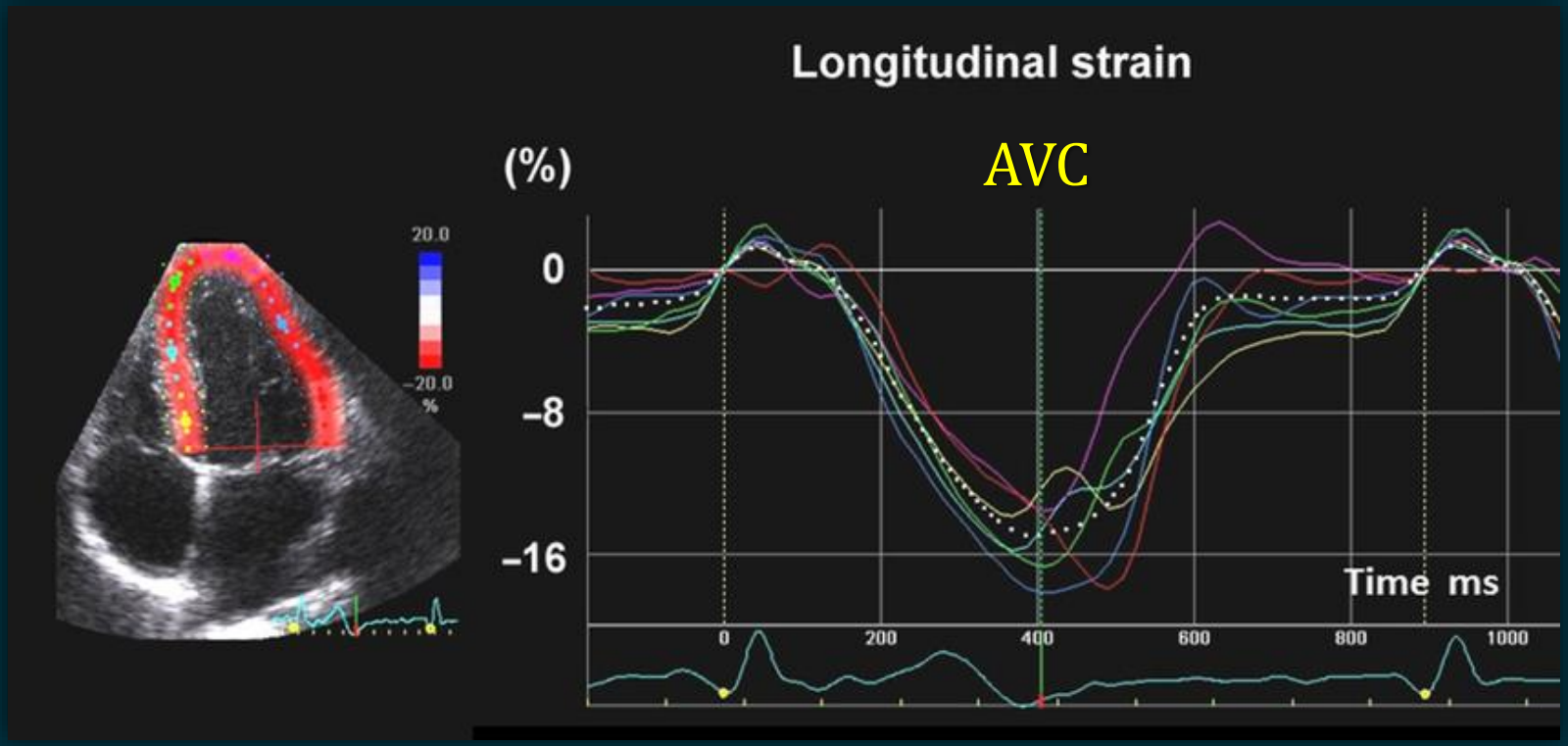
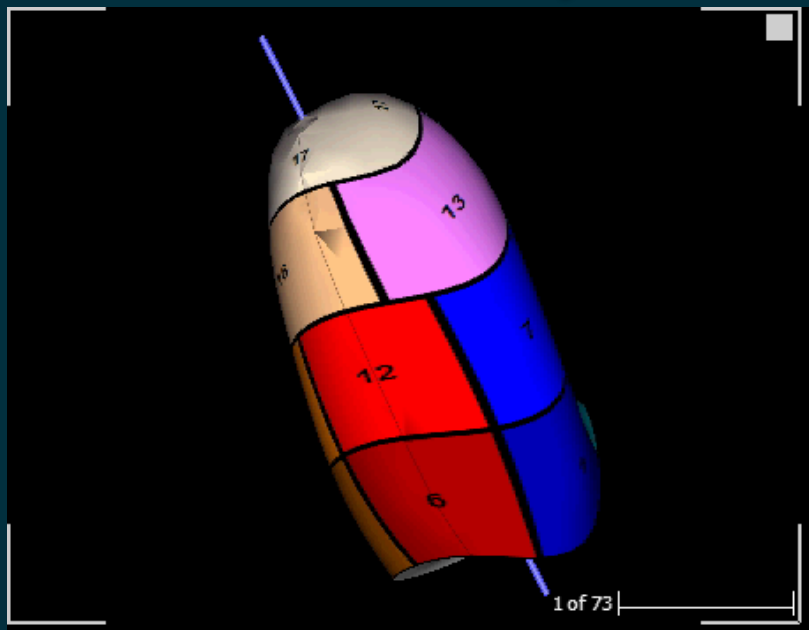


Global longitudinal strain

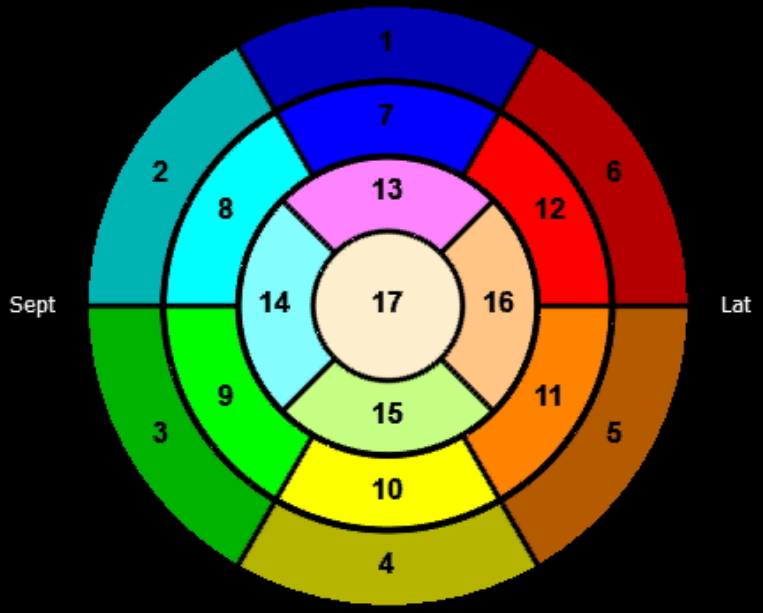
- **Average longitudinal strain at time of Aortic Valve Closure**
- **Peak of the average LV longitudinal segmental strain curve.**

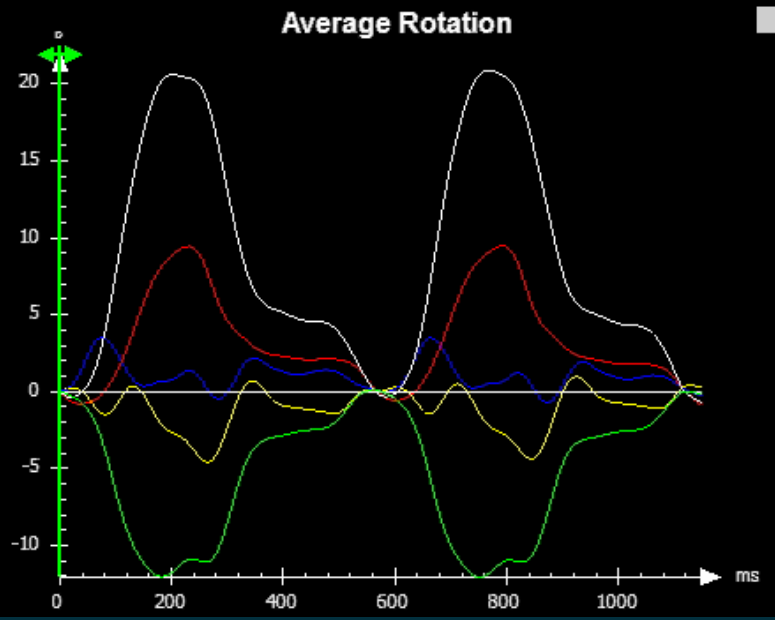


Rotation, Twist and Torsion

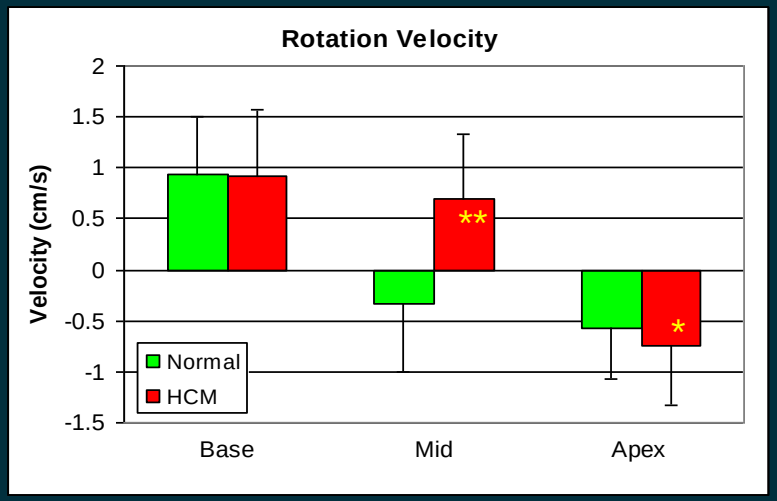


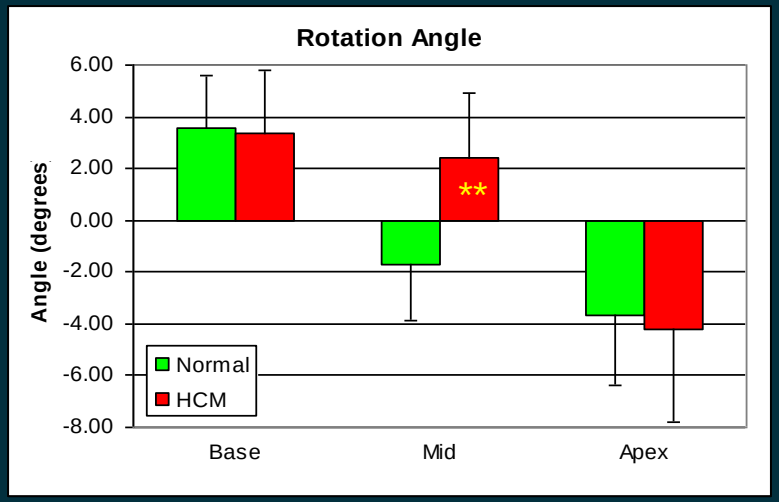
			Peak	Time
Rotation				
Systole	Rotation	Apex	9.4 °	223 ms
	Rotation	Base	-11.99 °	175 ms
	Rotation Rate	Apex	97.9 °/ms	143 ms
	Rotation Rate	Base	-136.3 °/ms	95 ms
Diastole	Unrotation	Apex	0 °	566 ms
	Unrotation	Base	0 °	550 ms
	Unrotation Rate	Apex	-97.21 °/ms	271 ms
	Unrotation Rate	Base	122 °/ms	303 ms
Twist				
Systole	Twist		20.57 °	207 ms
	Twist Rate		202.05 °/ms	111 ms
Diastole	UnTwist		0 °	1125 ms
	UnTwist Rate		-160.33 °/ms	863 ms
Torsion				
	Torsion		4.61 °/cm	

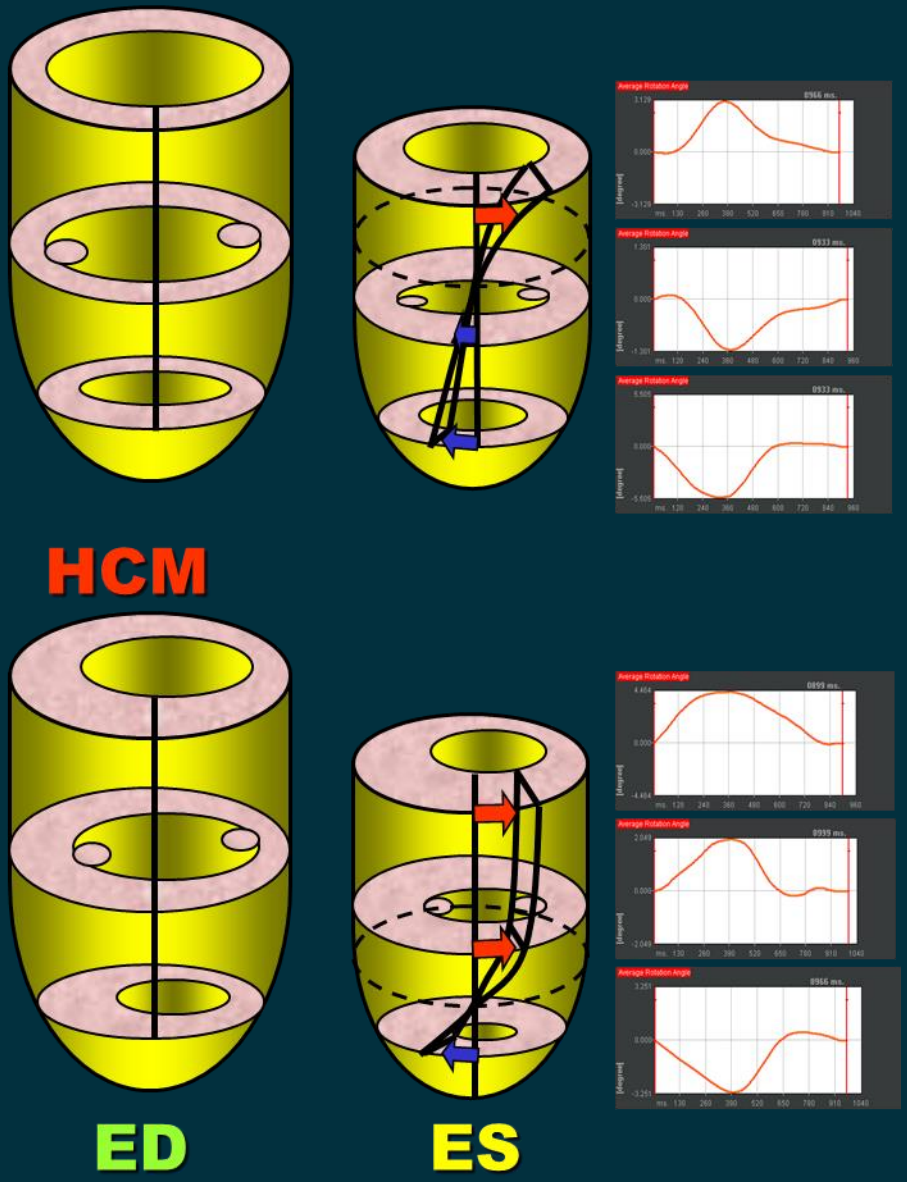




Twist



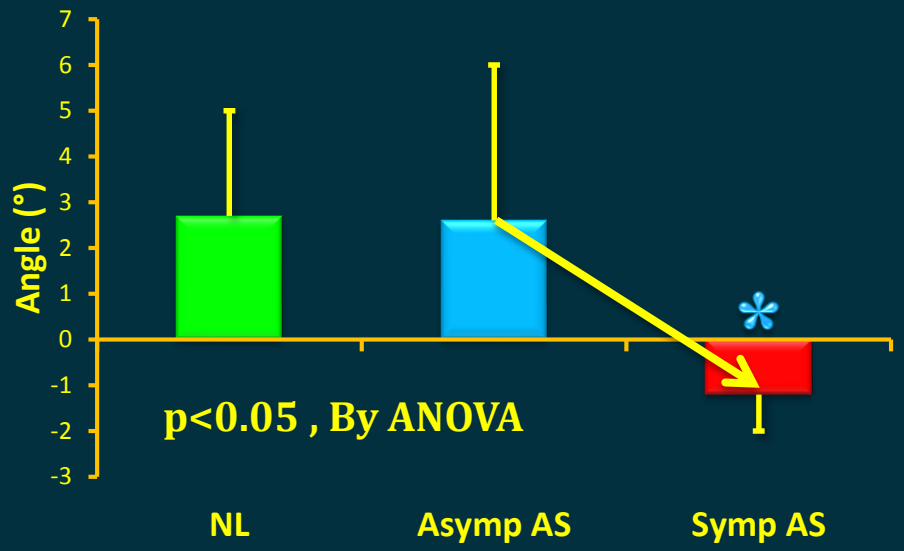




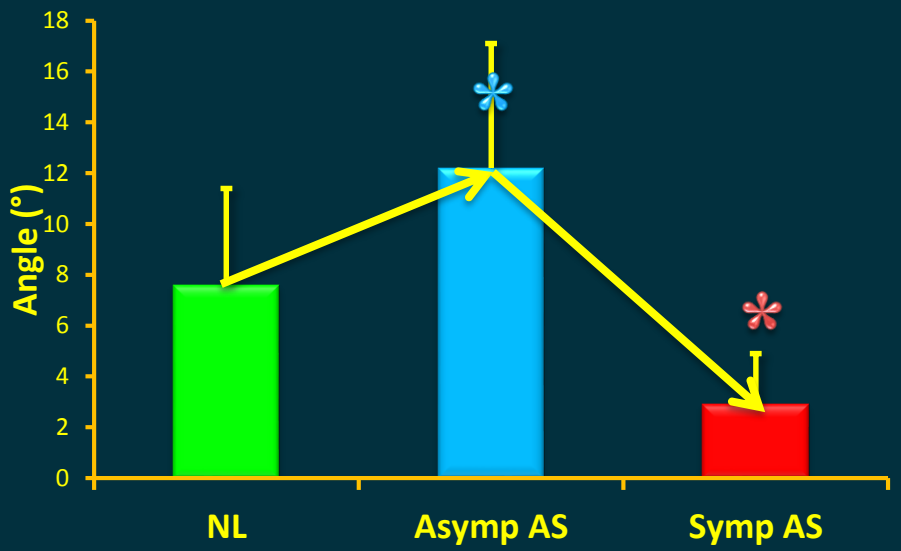
Carasso S, JASE 2008

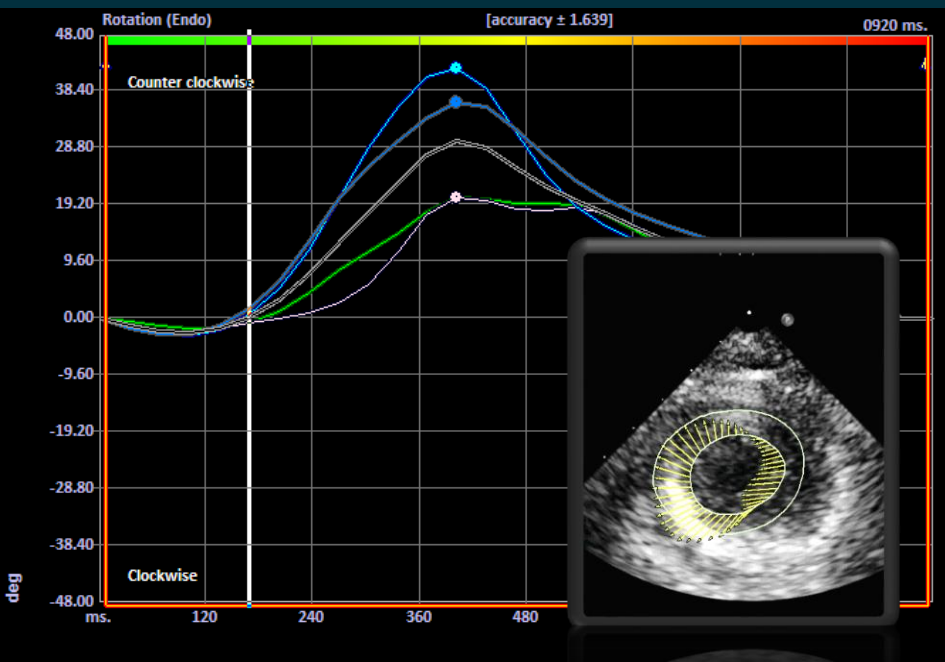
AS – Symptomatic vs. asymptomatic

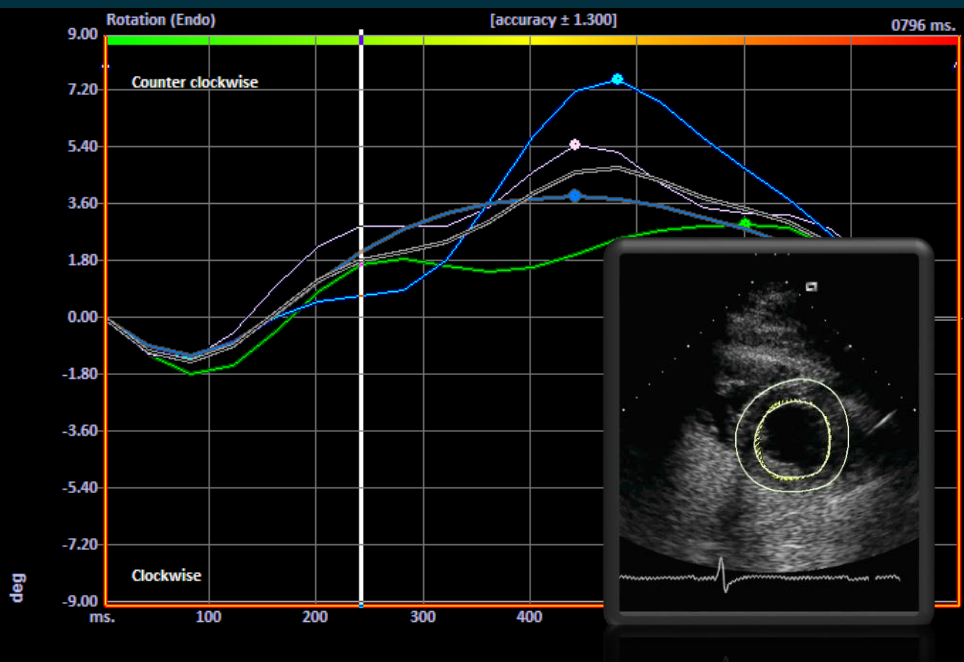
Mid Rotation



Apical Rotation



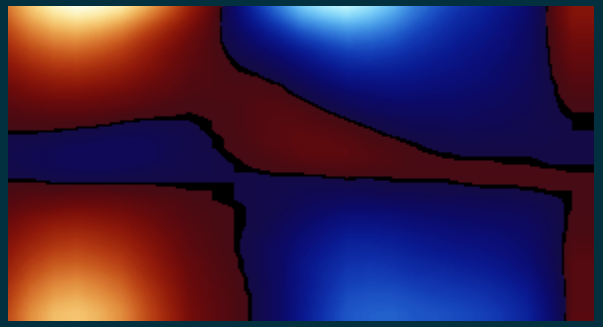


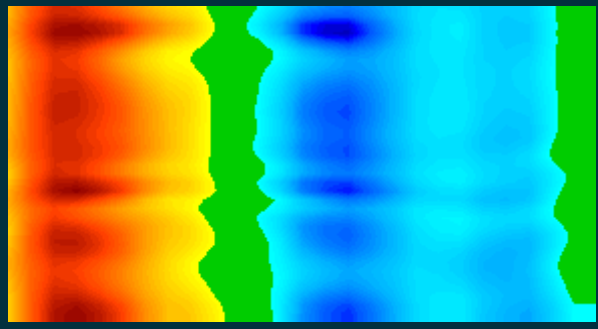
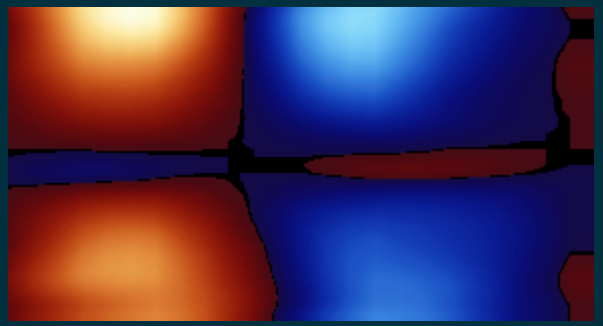
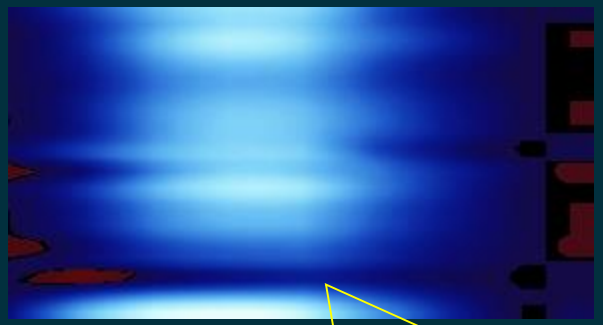
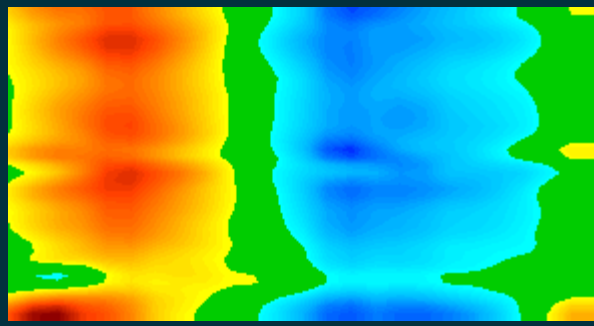


Assessment of LV Systolic Function

Regional function (longitudinal)

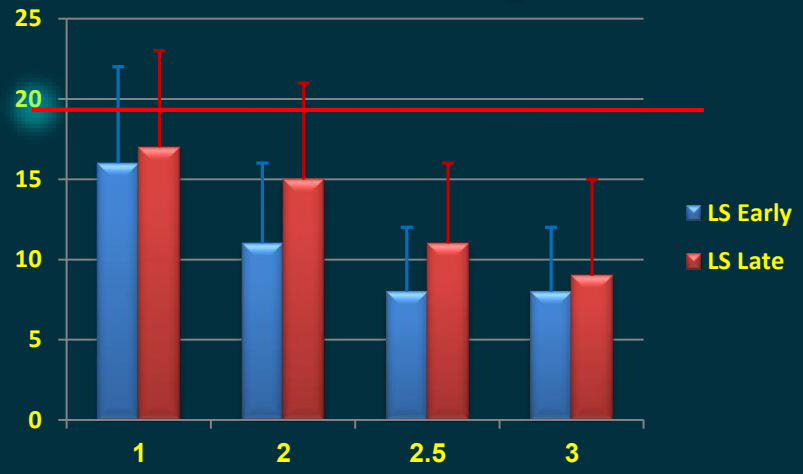
Velocity **Strain** **Strain Rate**

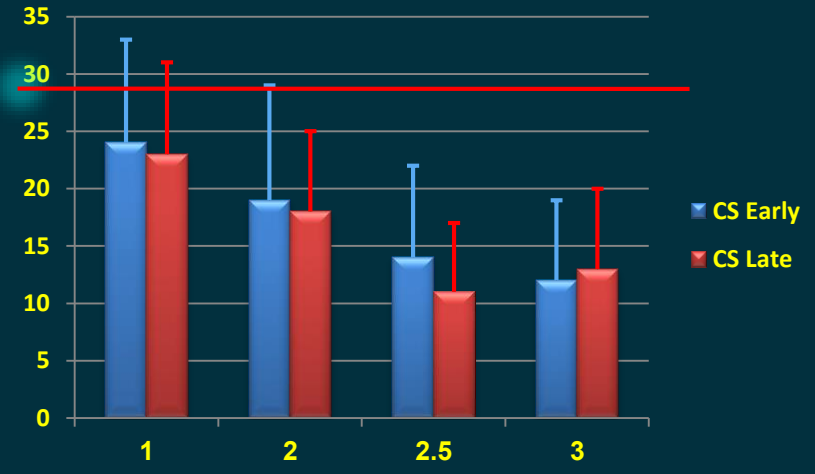


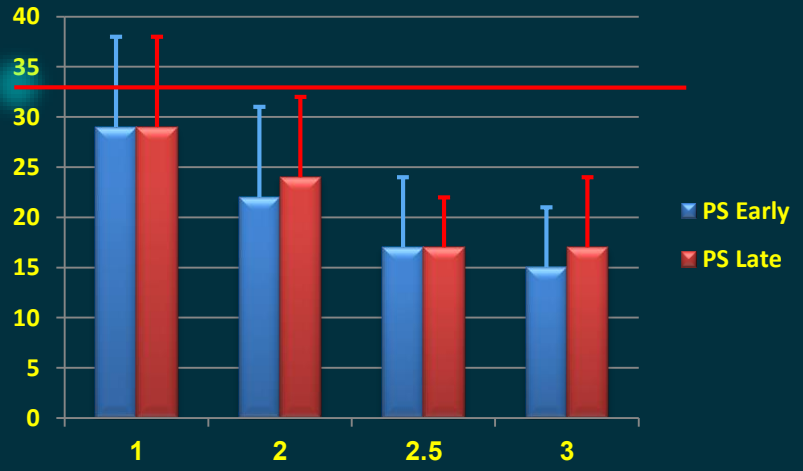





SEA Infarct

Acute myocardial infarction







WMS

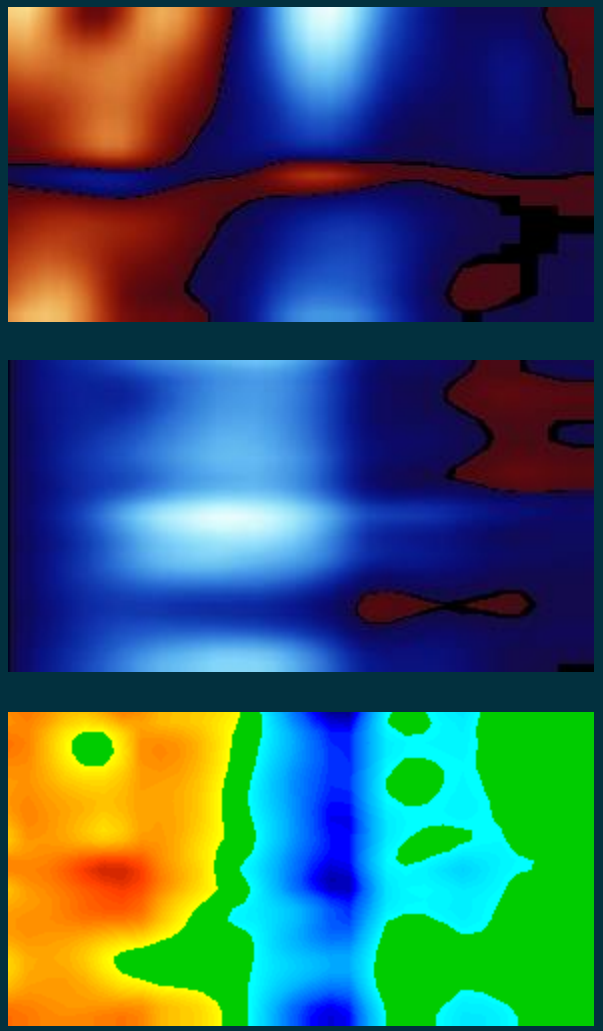
- 1 is less than normal
- 3 is not 0 shortening
- Late LS is higher
- Late CS is lower in hypokinetic segments

What is abnormal strain?

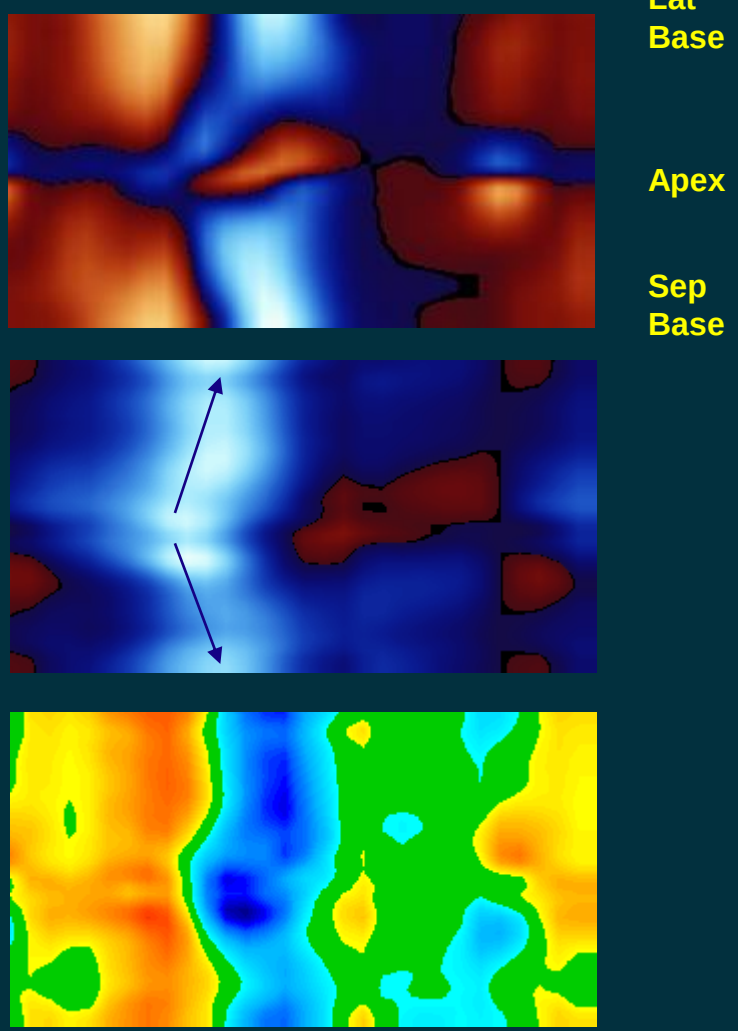
Early Segmental strains	Echo-Score	AUC	Strain Threshold	Sens=Spec
Longitudinal strain	Normal vs. Abnormal	0.83 (0.79-0.88)	-11.7	0.76
	Normal vs. Hypo	0.73 (0.65-0.80)	-12.9	0.69
	Hypokinetic vs. Akinetic	0.71 (0.61-0.80)	-9.2	0.65
Circumferential strain	Normal vs. Abnormal	0.77 (0.72-0.82)	-18.2	0.70
	Normal vs. Hypo	0.65 (0.57-0.74)	-21.0	0.62
	Hypokinetic vs. Akinetic	0.70 (0.60-0.79)	-13.6	0.67
Principal strain	Normal vs. Abnormal	0.83 (0.79-0.88)	22.7	0.76
	Normal vs. Hypo	0.71 (0.63-0.79)	24.9	0.68
	Hypokinetic vs. Akinetic	0.75 (0.66-0.83)	18.3	0.75
Late Segmental strains				
Longitudinal strain	Normal vs. Abnormal	0.74 (0.68-0.79)	-13.9	0.68
	Normal vs. Hypo	0.60 (0.52-0.69)	-15.8	0.56
	Hypokinetic vs. Akinetic	0.73 (0.64-0.82)	-11.8	0.65
Circumferential strain	Normal vs. Abnormal	0.77 (0.72-0.83)	-19.1	0.70
	Normal vs. Hypo	0.66 (0.58-0.75)	-21.5	0.60
	Hypokinetic vs. Akinetic	0.72 (0.63-0.81)	-14.5	0.69
Principal strain	Normal vs. Abnormal	0.80 (0.75-0.85)	23.8	0.75
	Normal vs. Hypo	0.66 (0.57-0.75)	26.2	0.64
	Hypokinetic vs. Akinetic	0.76 (0.67-0.85)	19.9	0.67

Activation pattern: RV pacing

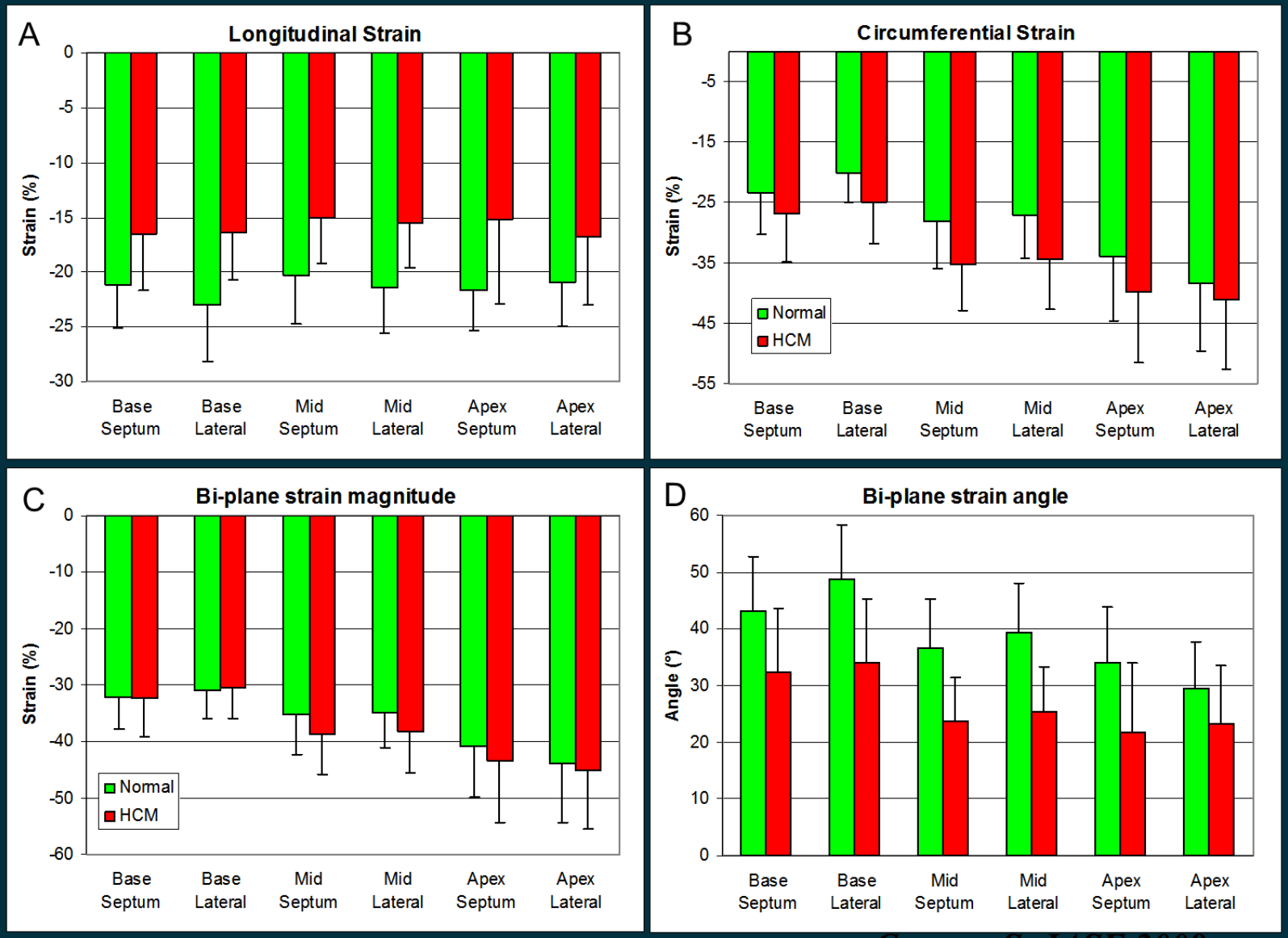
Not Paced



RV Paced



Hypertrophic Cardiomyopathy



Carasso S, JASE 2008

Athlete's Heart

Alteration in left ventricular normal and shear strains evaluated by 2D-strain echocardiography in the athlete's heart

S. Nottin[1], G. Doucende[1], I. Schuster-Beck[2], M. Dauzat[2] and P. Obert[1]

J Physiol 586.19 (2008) pp 4721–4733

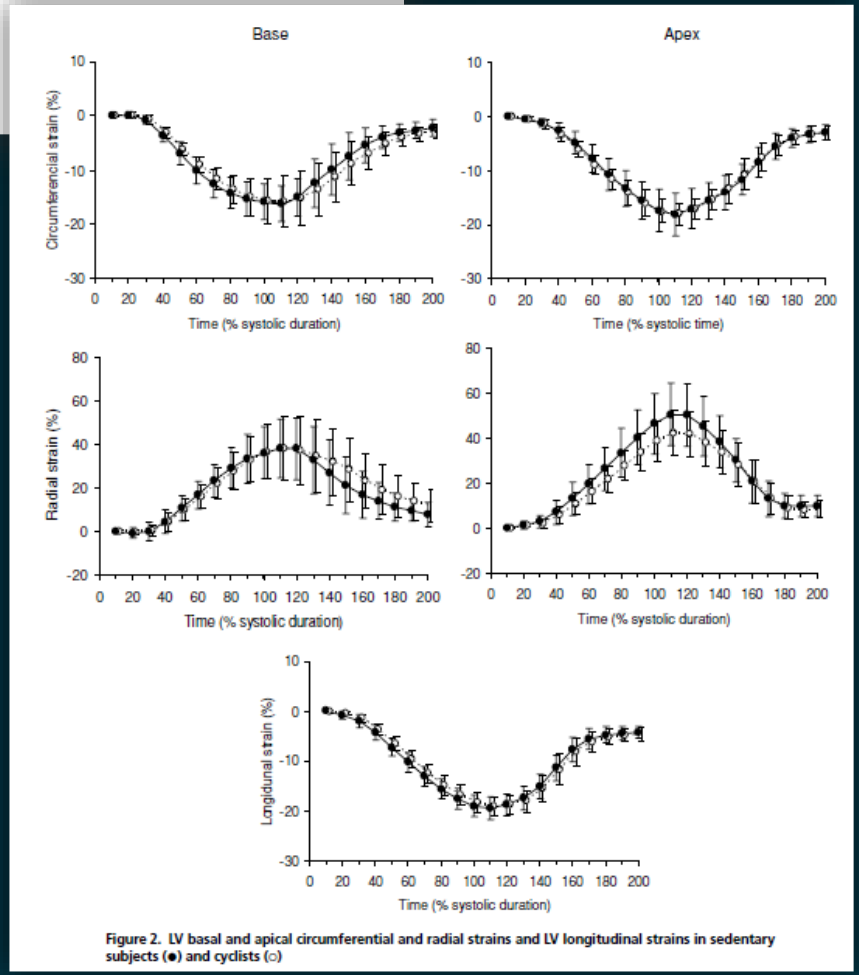
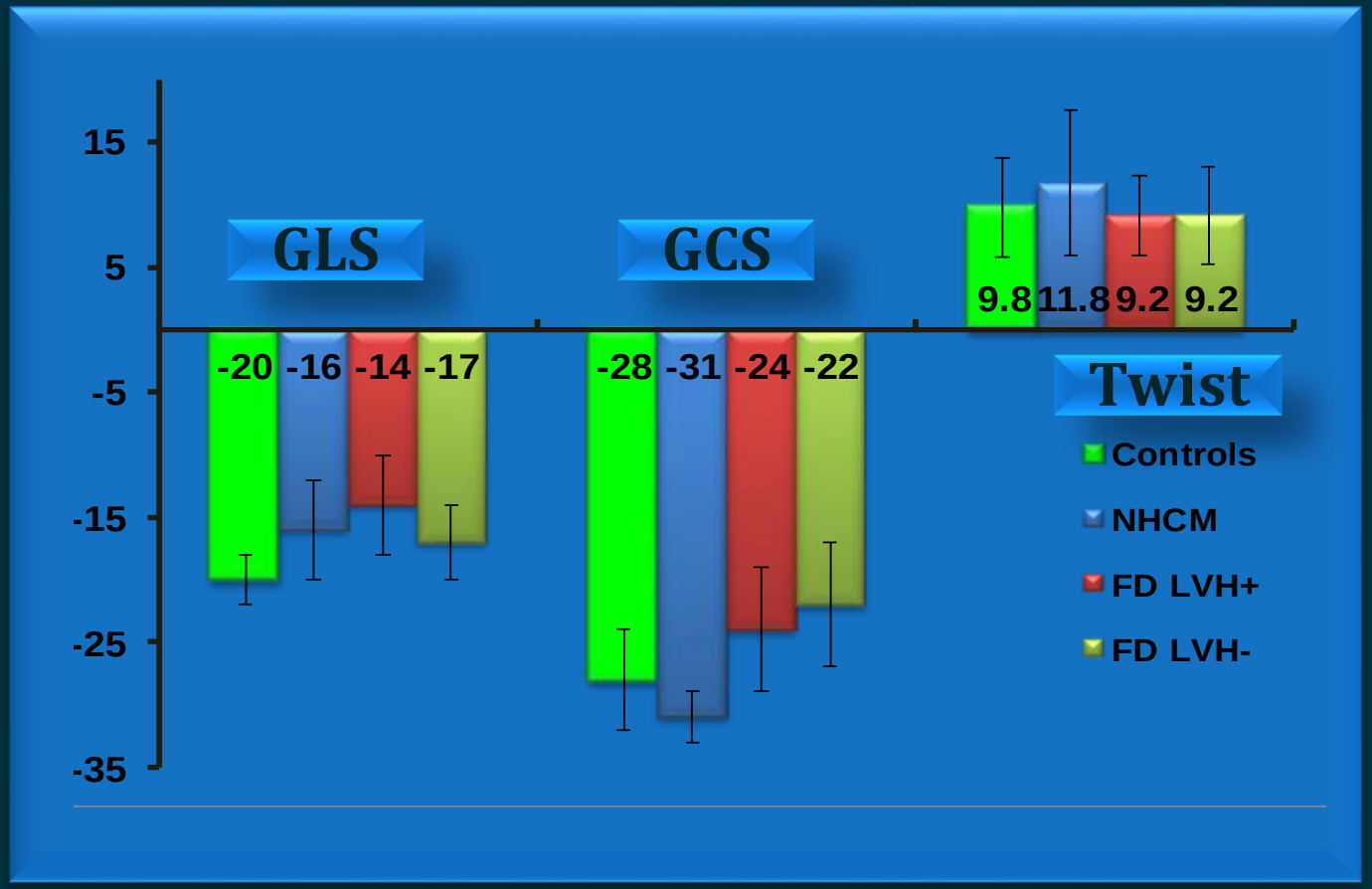


Figure 2. LV basal and apical circumferential and radial strains and LV longitudinal strains in sedentary subjects (●) and cyclists (○)

Anderson Fabry Disease



Amyloidosis

Differentiation of Hypertrophic Cardiomyopathy and Cardiac Amyloidosis from Other Causes of Ventricular Wall Thickening by Two-Dimensional Strain Imaging Echocardiography

Jing Ping Sun, MD[a,*], William J. Stewart, MD[b], Xing Sheng Yang, MD, PhD[a], Robert O. Donnell, MD[a], Angel R. Leon, MD[a], Joel M. Felner, MD[a], James D. Thomas, MD[b], and John D. Merlino, MD[a]

Am J Cardiol 2009

- **Low LS**
- **Low CS**
- **Low apical rotation**

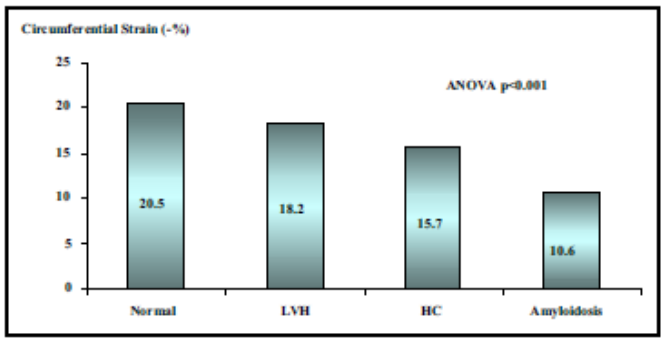
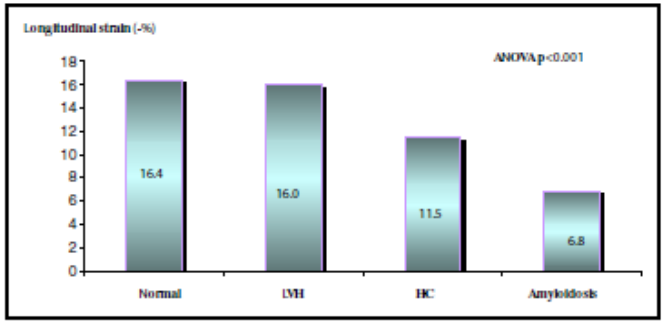
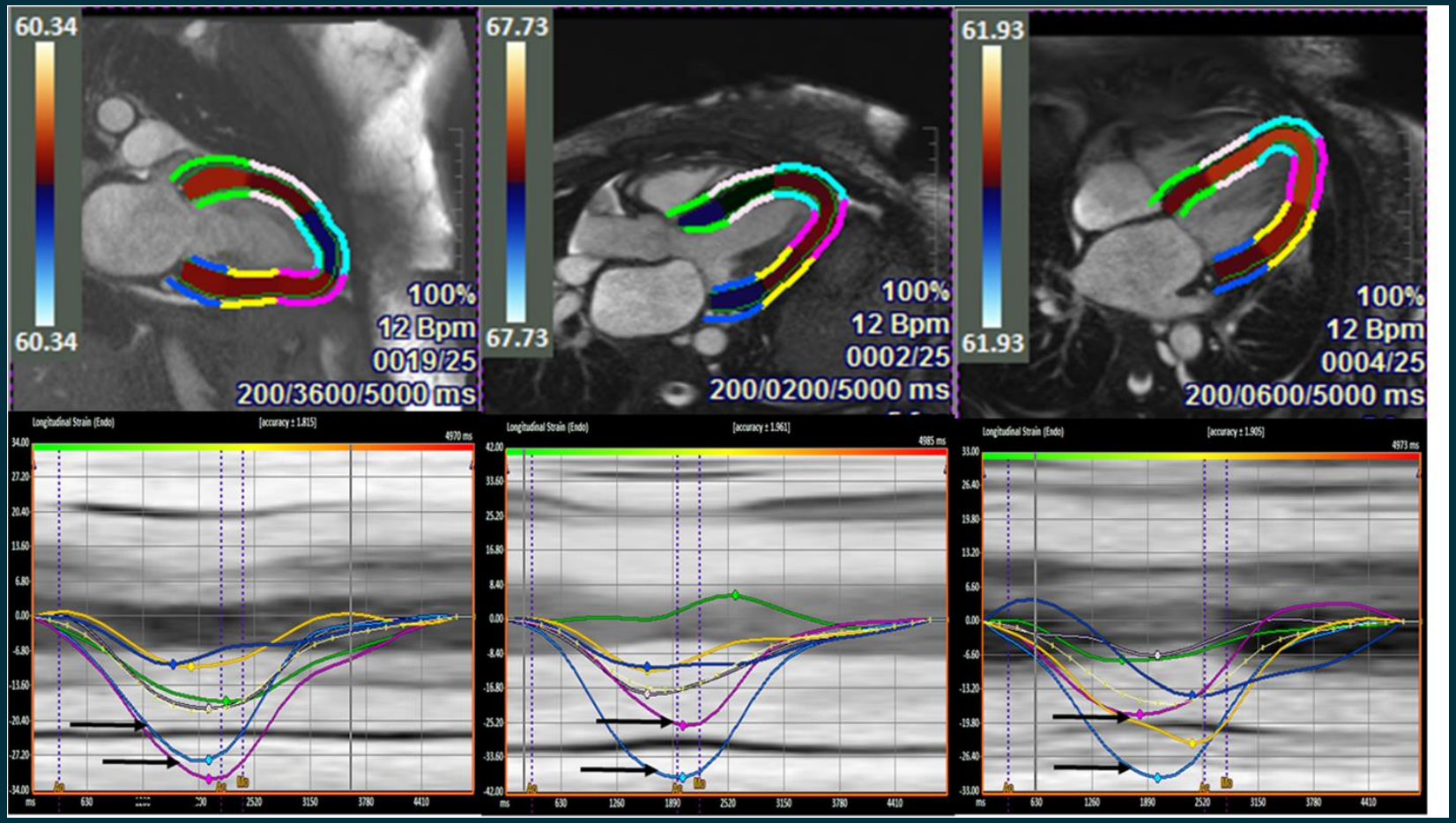


Figure 2. Differences in circumferential strain among the groups. ANOVA = analysis of variance; LVH = LV hypertrophy.



Amyloidosis – apical sparing



STATE-OF-THE-ART PAPERS

Use of Myocardial Strain Imaging by Echocardiography for the Early Detection of Cardiotoxicity in Patients During and After Cancer Chemotherapy

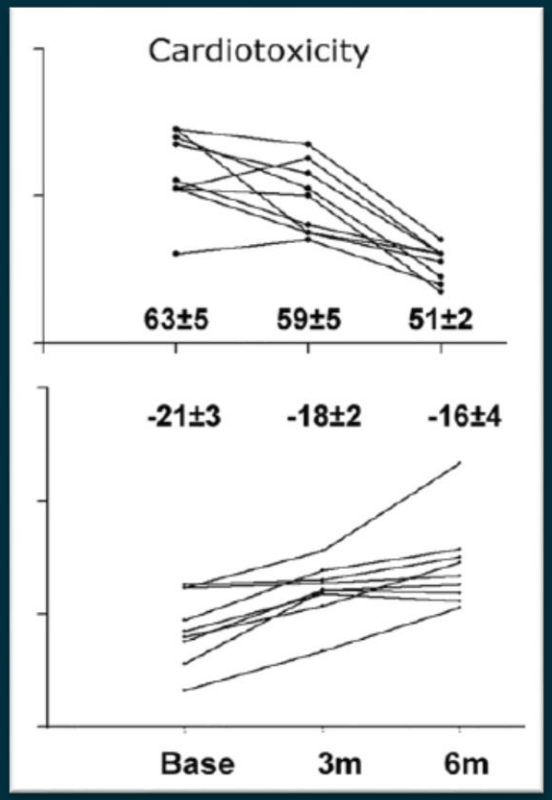
A Systematic Review

Paaladinesh Thavendiranathan, MD,*† Frédéric Poulin, MD,* Ki-Dong Lim, MD,*
Juan Carlos Plana, MD,‡ Anna Woo, MD,* Thomas H. Marwick, MD§

Toronto, Ontario, Canada; Cleveland, Ohio; and Hobart, Australia

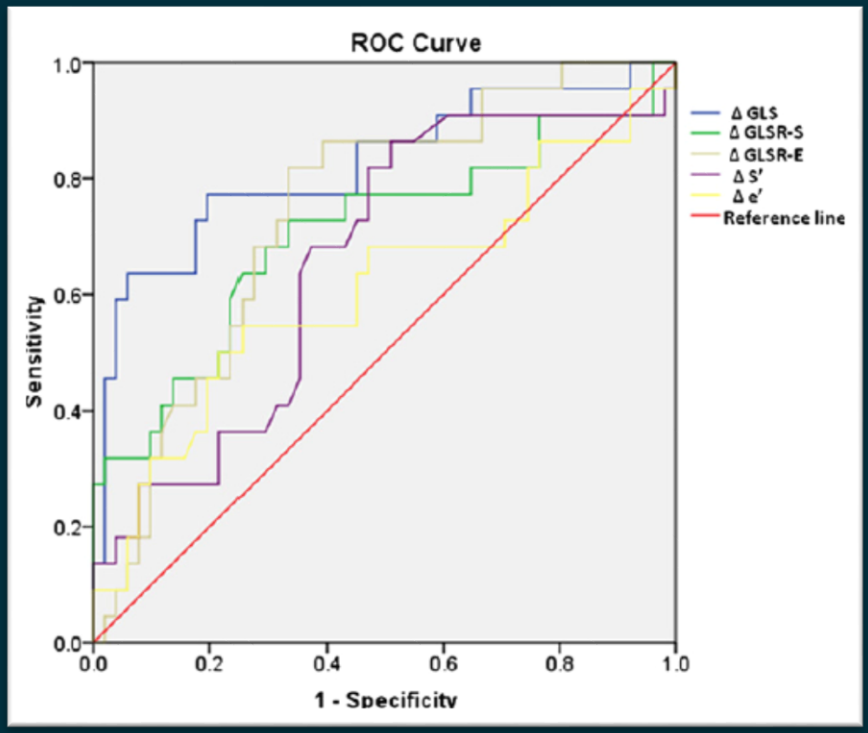
J Am Coll Cardiol 2014;63:2751–68

Early Detection of Myocardial Dysfunction



N=43, 21% CTOX, AC followed by TZM

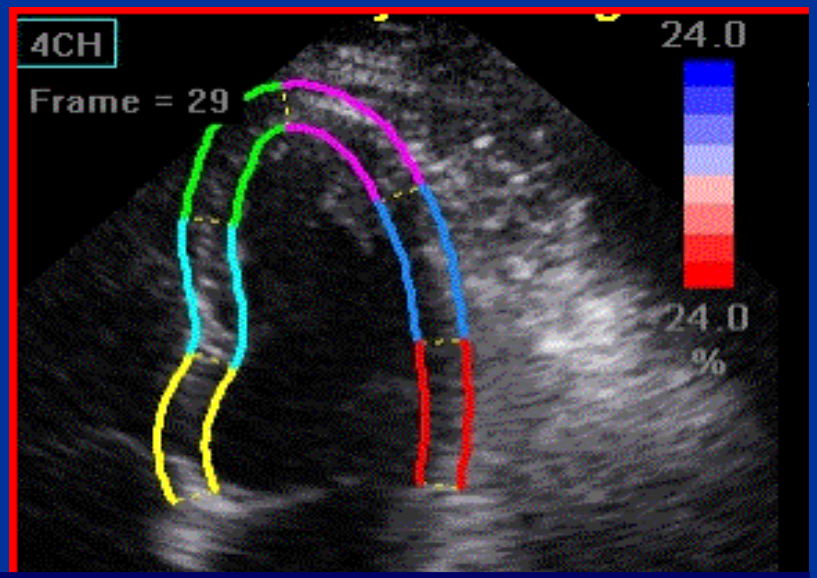
Sawaya H et al. Am J Cardiol 2011;107:1375

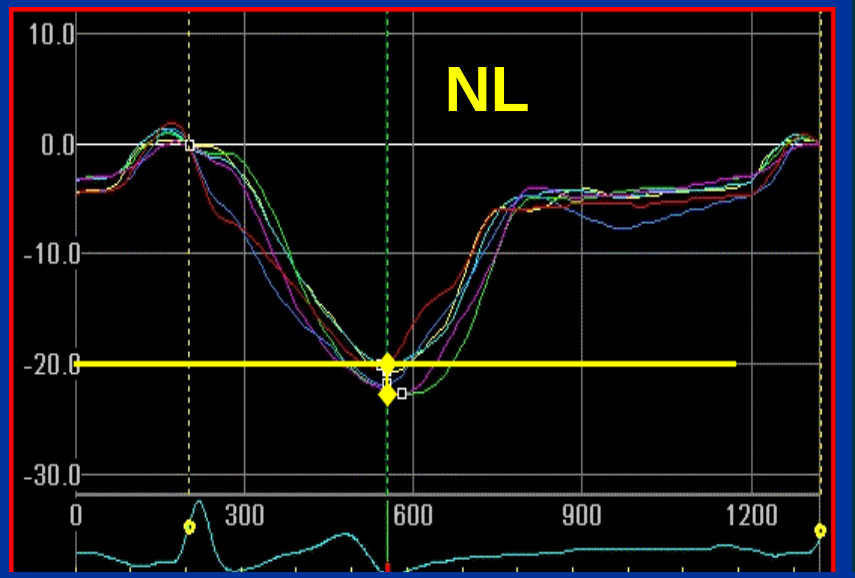


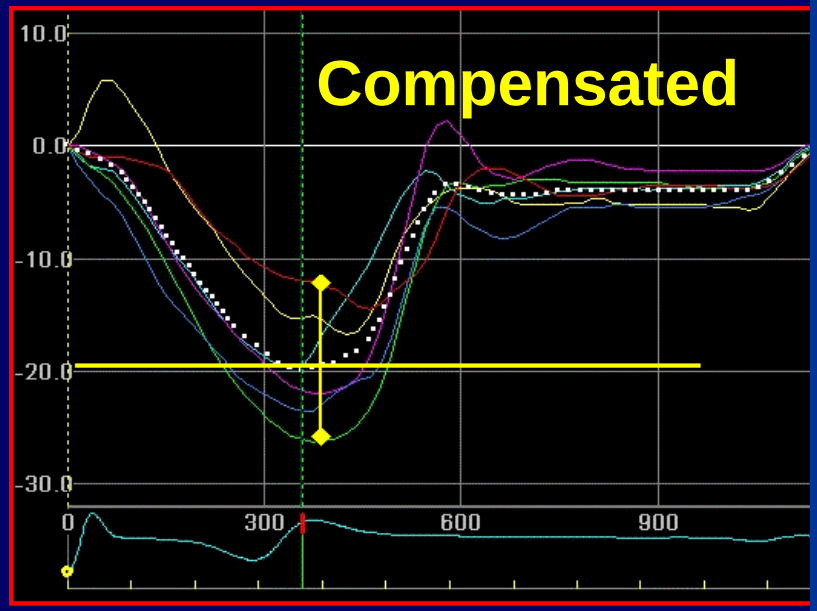
N=81, 30% CTOX, All trastuzumab, 40% A

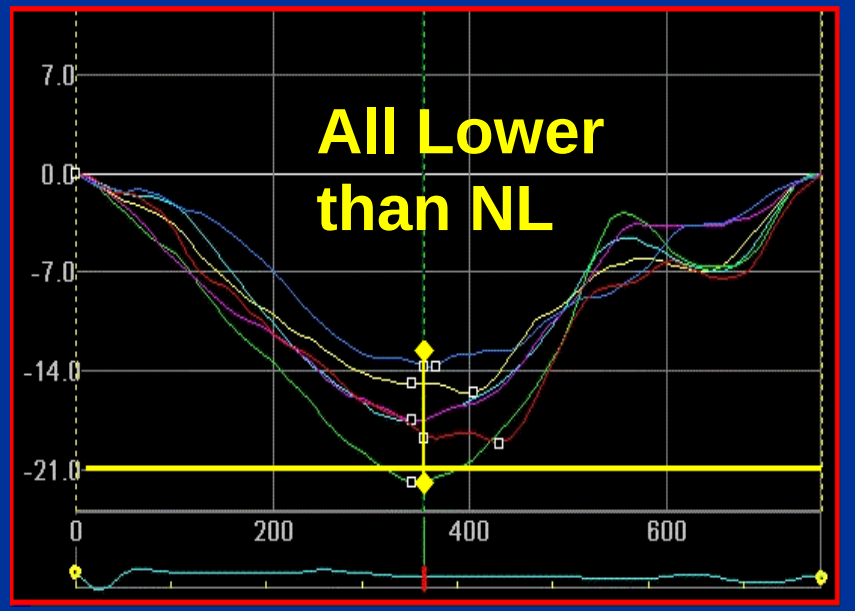
Negishi K et al, JASE 2013, 26: 493-8

Toxic Cardiomyopathy: stages









Adoption of method in guidelines

European Heart Journal (2016) **37**, 2768–2801
doi:10.1093/eurheartj/ehw211

ESC CPG POSITION PAPER

2016 ESC Position Paper on cancer treatments and cardiovascular toxicity developed under the auspices of the ESC Committee for Practice Guidelines

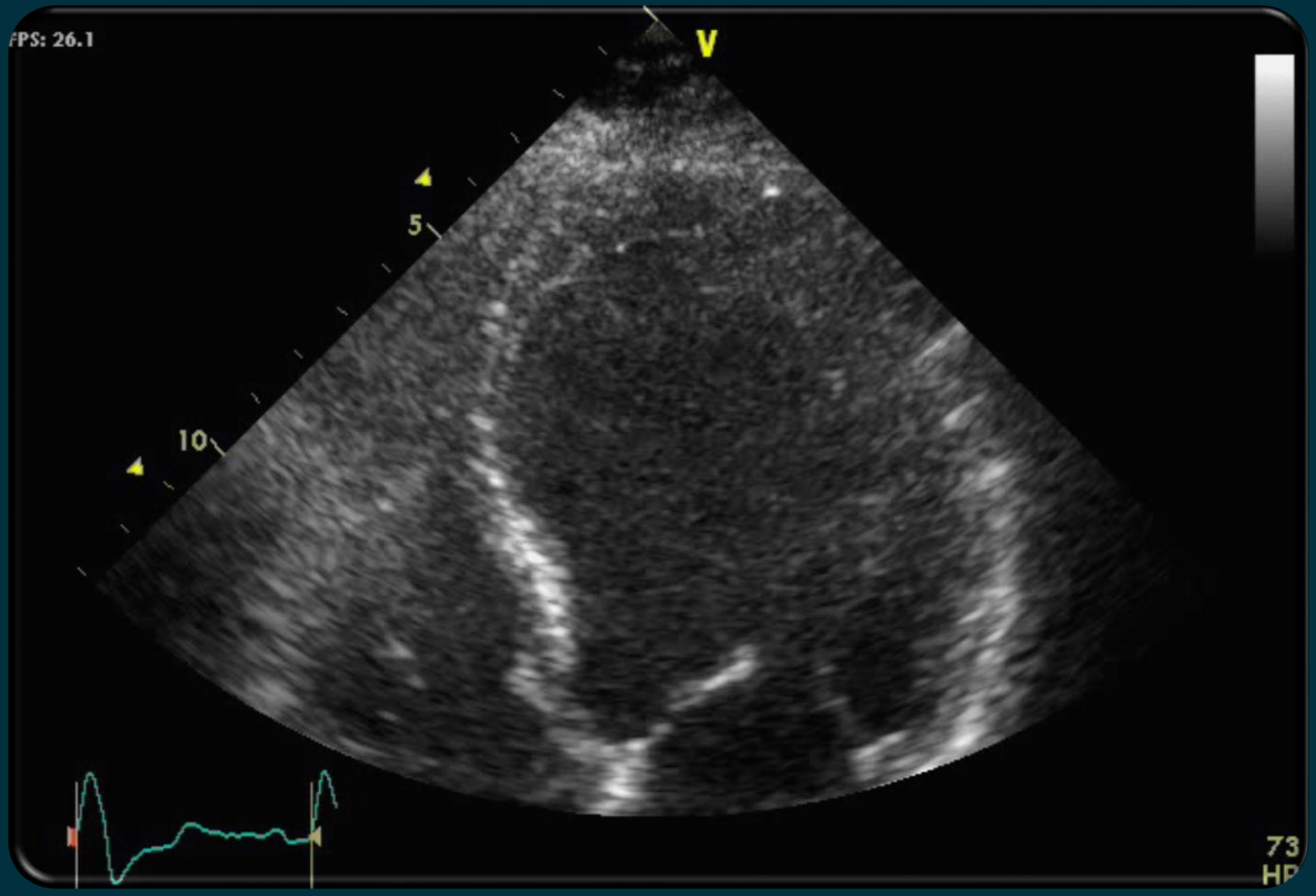
Baseline and follow-up

Table 6 Proposed diagnostic tools for the detection of cardiotoxicity

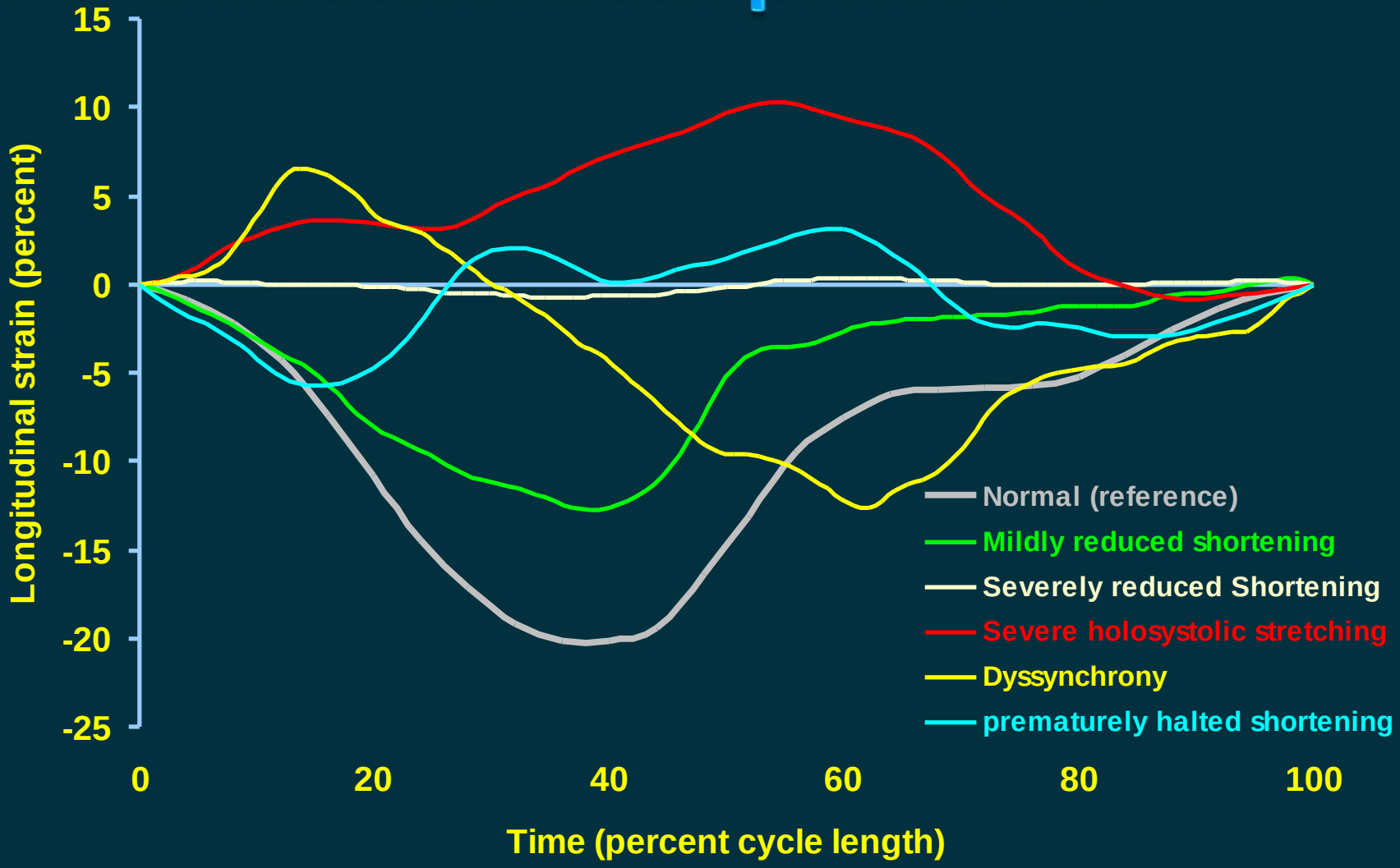
Technique	Currently available diagnostic criteria	Advantages	Major limitations
Echocardiography: **- 3D-based LVEF** **- 2D Simpson's LVEF** **- GLS**	• LVEF: >10 percentage points decrease to a value below the LLN suggests cardiotoxicity. • GLS: >15% relative percentage reduction from baseline may suggest risk of cardiotoxicity.	• Wide availability. • Lack of radiation. • Assessment of haemodynamics and other cardiac structures.	• Inter-observer variability. • Image quality. • GLS: inter-vendor variability, technical requirements.
Nuclear cardiac imaging (MUGA)	• >10 percentage points decrease in LVEF with a value <50% identifies patients with cardiotoxicity.	• Reproducibility.	• Cumulative radiation exposure. • Limited structural and functional information on other cardiac structures.
Cardiac magnetic resonance	• Typically used if other techniques are non-diagnostic or to confirm the presence of LV dysfunction if LVEF is borderlines.	• Accuracy, reproducibility. • Detection of diffuse myocardial fibrosis using T1/T2 mapping and ECVF evaluation.	• Limited availability. • Patient's adaptation (claustrophobia, breath hold, long acquisition times).
Cardiac biomarkers: **- Troponin I** **- High-sensitivity Troponin I** **- BNP** **- NT-proBNP**	• A rise identifies patients receiving anthracyclines who may benefit from ACE-Is. • Routine role of BNP and NT-proBNP in surveillance of high-risk patient needs futher investigation.	• Accuracy, reproducibility. • Wide availability. • High-sensitivity.	• Insufficient evidence to establish the significance of subtle rises. • Variations with different assays. • Role for routine surveillance not clearly established.

ACE-Is = angiotensin converting enzyme inhibitors; BNP = B-type natriuretic peptide; ECVF = extacellular volume fraction; GLS = global longitudinal strain; LV = left ventricular; LLN = lower limit of normality; LVEF = left ventricular ejection fraction; MUGA = multigated radionuclide angiography; NT-proBNP = N-terminal fragment B-type natriuretic peptide.

Dilated Cardiomyopathy



DCM mechanical patterns



Visual Statistics: non responders

Apical 4 Chamber | Apical 2 Chamber

Strain Pattern											
basSept	midSept	apSept	apLat	midLat	basLat	basInf	midInf	apInf	apAnt	midAnt	basAnt
1	2	2	-2	1	1	3	4	0	1	-2	-4
3	0	4	4	0	-4	-2	1	2	4	2	1
-4	4	1	4	4	1	4	4	1	3	-2	-4
3	3	4	0	-2	1	0	-2	4	0	0	4
3	4	3	1	-4	-4	4	4	1	1	1	0
3	-2	2	4	-4	-4	4	3	1	1	1	4
-4	2	2	1	0	1	0	0	4	1	1	1
1	1	1	3	4	-4	4	-2	1	2	2	-4
-4	-4	2	4	4	1	1	1	3	1	1	1
4	4	2	0	0	-2	4	4	-2	1	3	1
-4	-2	4	2	1	1	0	3	-2	1	4	3
4	4	1	1	-4	-4	2	-2	0	-2	0	4
-2	-4	0	0	3	3	4	2	0	0	2	1
2	-2	4	4	-2	1	2	2	1	-4	2	-4
0	0	1	3	1	-4	0	0	1	0	3	-2
-2	-2	2	2	3	4	4	3	1	3	0	-4
2	2	4	1	-4	-4	0	0	0	0	0	2
3	3	?	2	1	-4	3	0	0	-2	4	1
4	4	0	3	0	-4	4	4	-4	-4	4	4
3	4	4	0	-4	-2	3	4	3	-2	1	1

3-4	Mildly Hypokinetic
2	Pseudo Dyssynchrony
1	Dyssynchronous
0	Akinetic
-2	Mildly Dyskinetic
-4	Severly Dyskinetic

Visual Statistics: responders

Apical 4 Chamber | Apical 2 Chamber

Strain Pattern											
basSept	midSept	apSept	apLat	midLat	basLat	basInf	midInf	apInf	apAnt	midAnt	basAnt
0	2	3	1	4	1	2	0	2	2	1	1
2	2	4	4	0	-2	4	2	1	-2	0	4
4	4	-2	1	4	0	0	2	-2	1	0	4
4	4	1	1	1	1	4	4	3	0	1	-2
2	0	?	0	1	1	1	1	4	4	1	0
3	2	2	0	1	1	1	3	0	0	3	1
4	4	4	1	1	1	4	4	4	1	1	4
2	2	1	2	1	1	0	2	4	1	1	1
-2	-2	0	4	4	1	4	4	0	0	2	1
2	2	1	0	3	1	1	0	3	2	0	0
4	4	0	0	2	1	4	3	0	0	0	-2
4	4	4	3	1	1	4	2	4	1	1	1
4	2	?	3	4	1	4	2	?	3	2	2
2	2	3	0	1	1	1	1	4	4	1	1
4	3	2	1	1	1	4	4	2	2	1	1
2	2	2	1	1	1	4	4	1	1	0	1
2	2	0	0	4	1	1	4	0	0	4	3
4	4	4	1	1	1	1	4	4	1	1	1
4	2	2	2	1	1	4	2	2	4	3	1
3	3	0	0	1	1	3	3	2	2	1	1

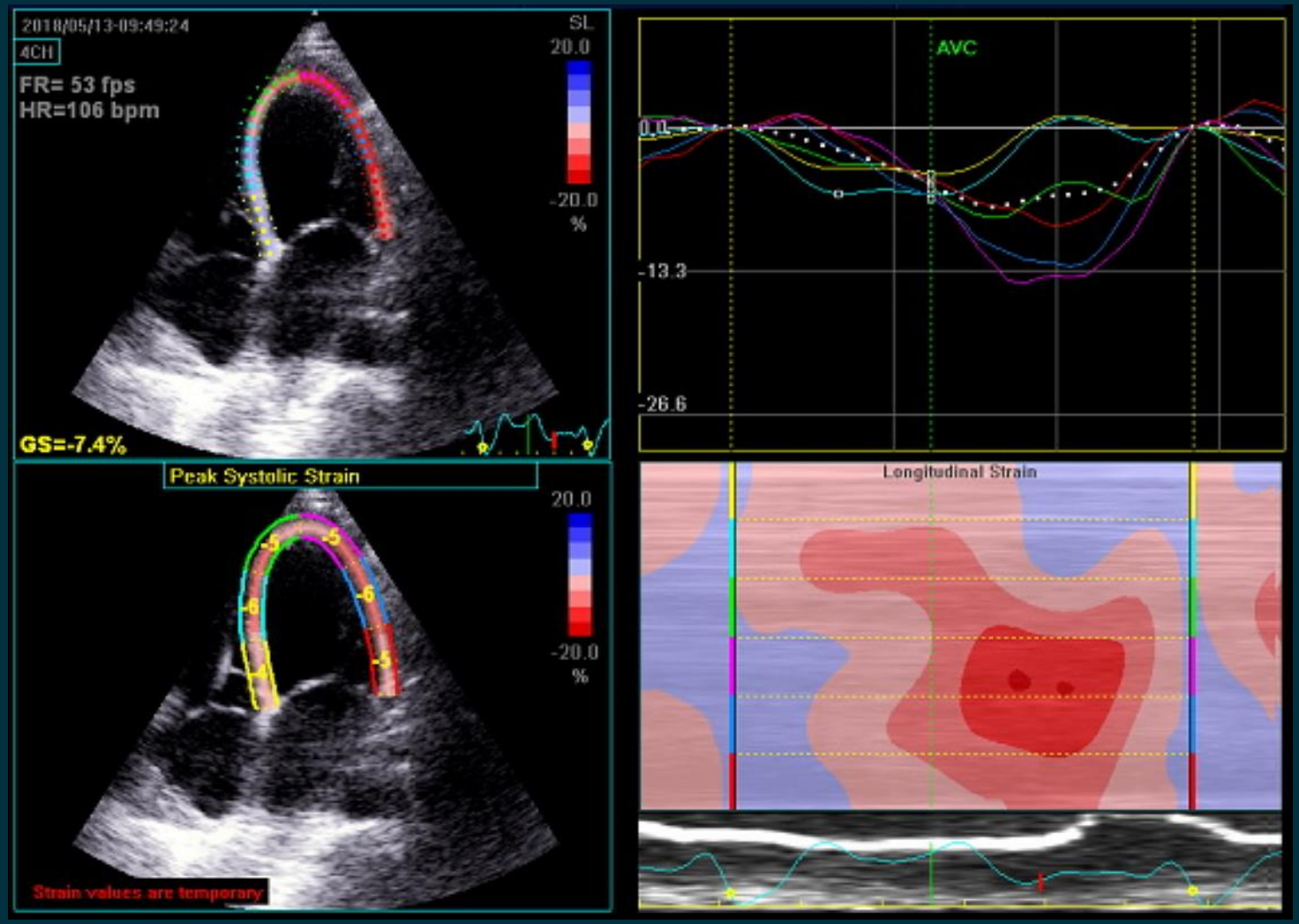
Septal pseudodyssynchrony…

Anterolateral dyssynchrony…

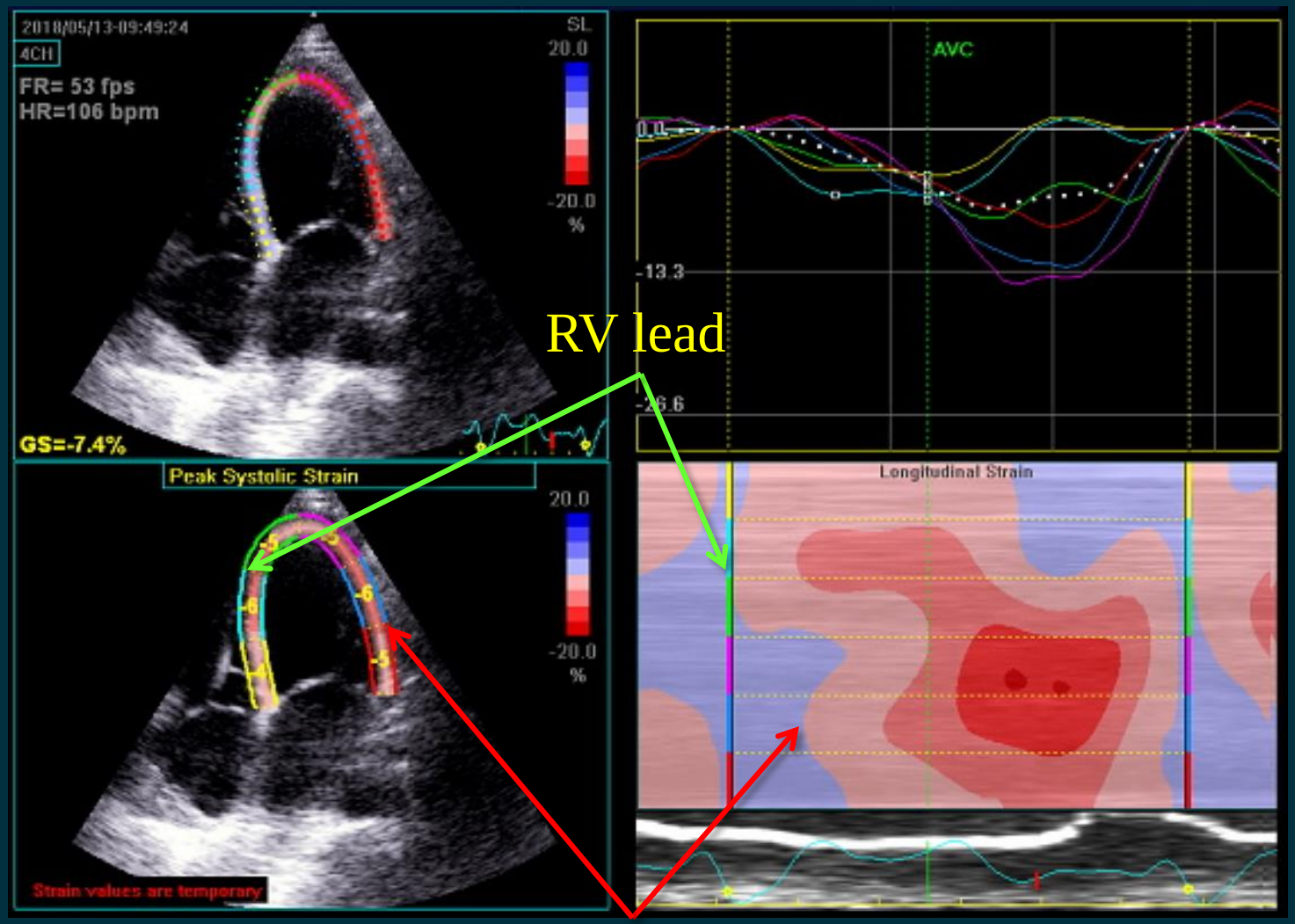
… and No severely dyskinetic Segments

3-4	Mildly Hypokinetic
2	Pseudo Dyssynchrony
1	Dyssynchronous
0	Akinetic
-2	Mildly Dyskinetic
-4	Severly Dyskinetic

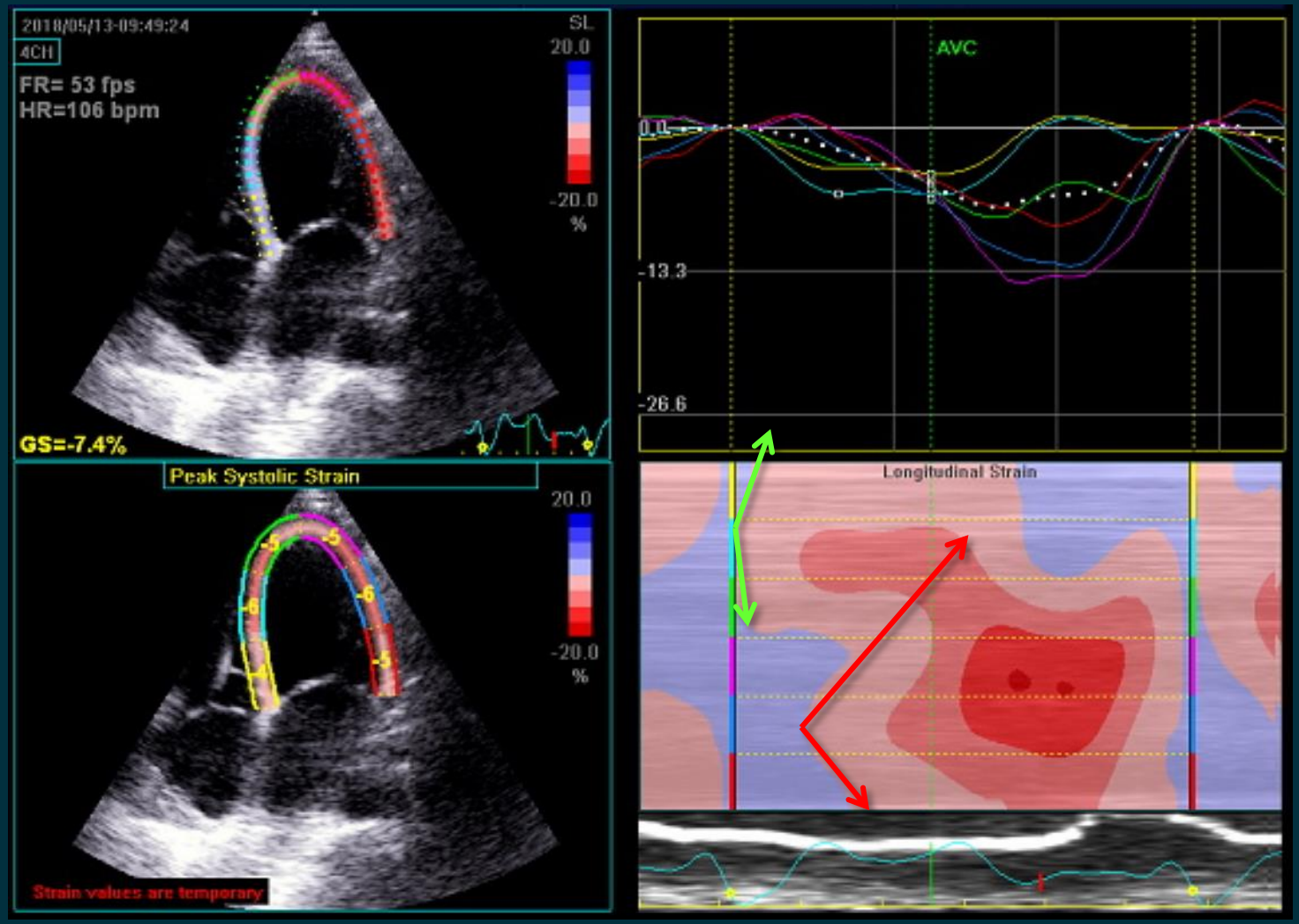
Pacing and Conduction velocities



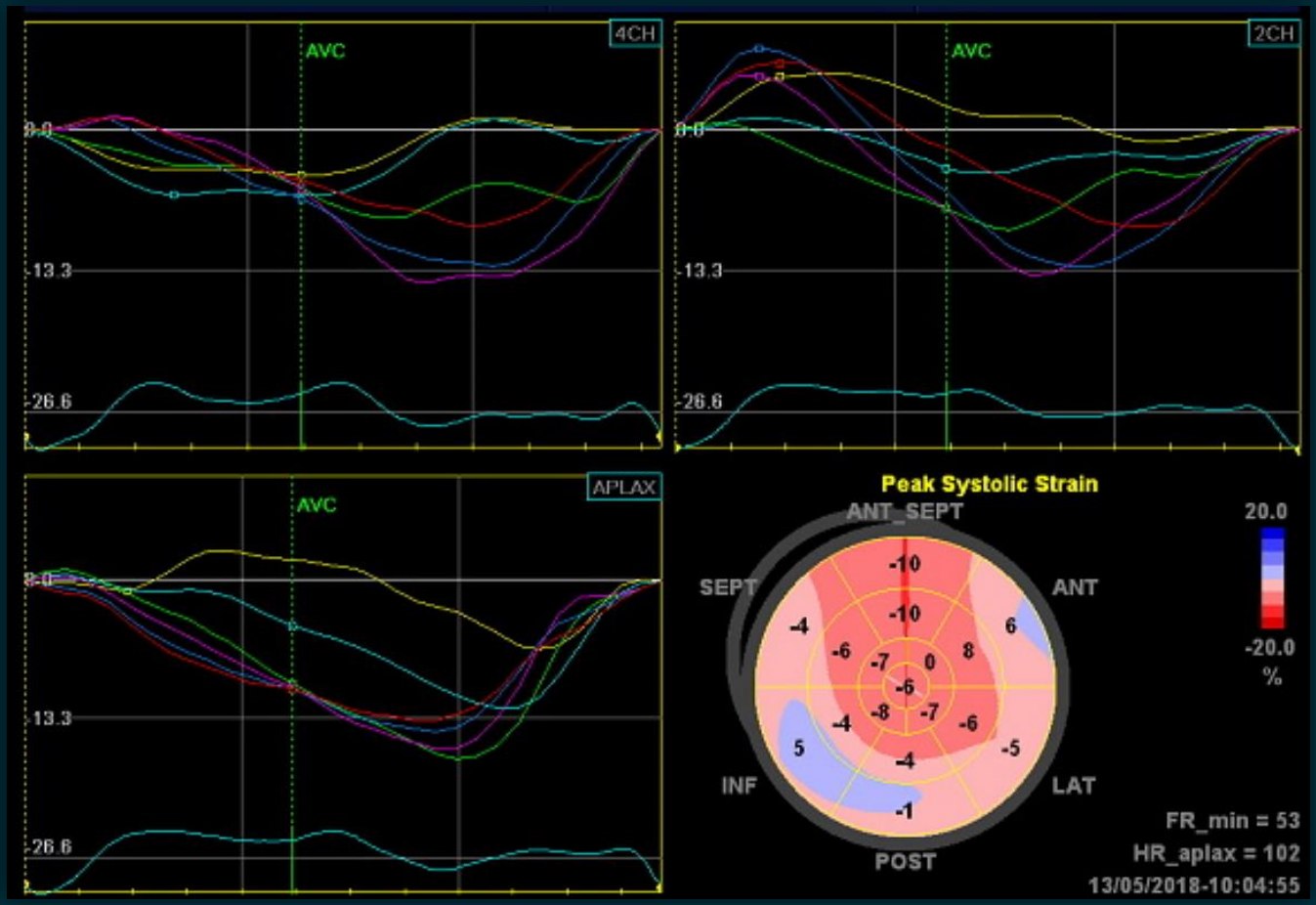
CRT - Pacing Focus



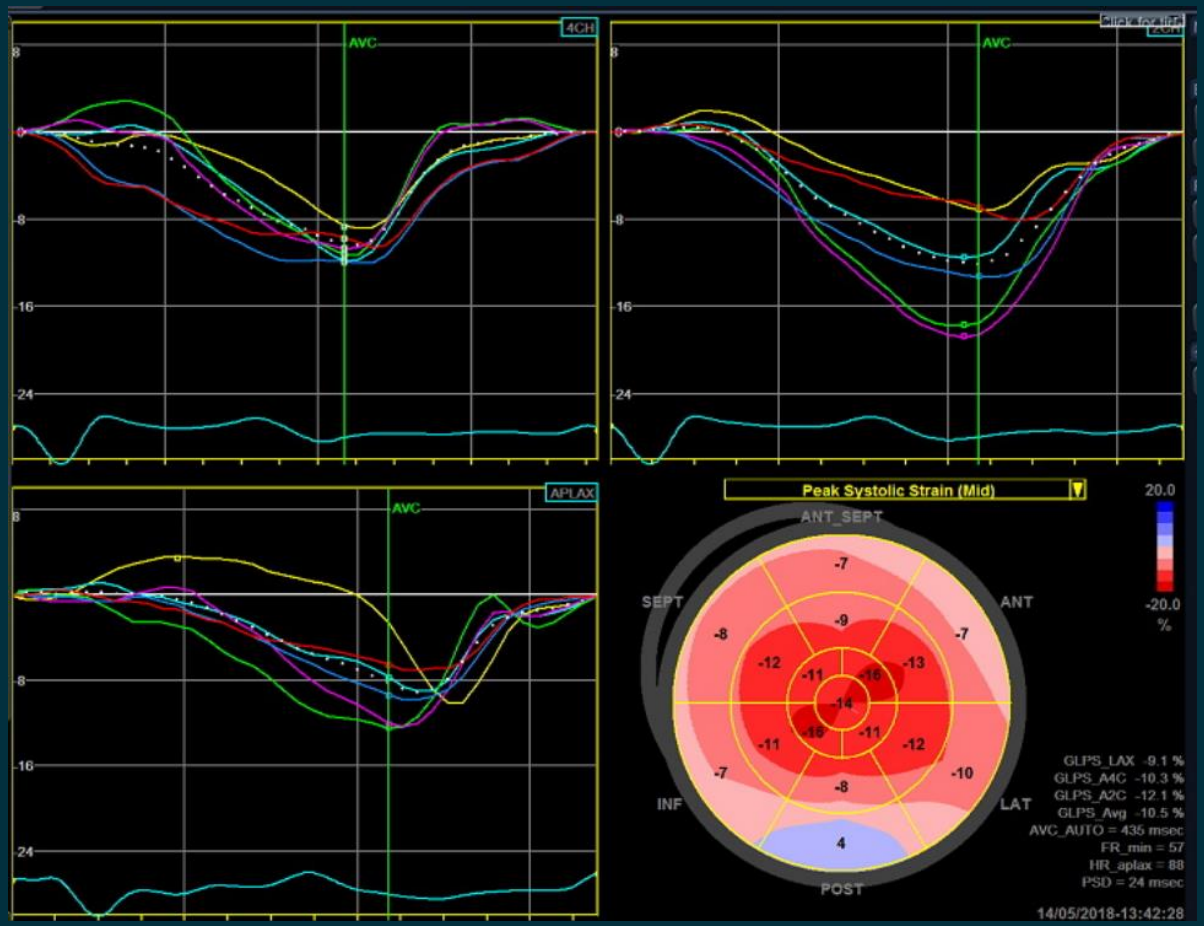
CRT - Myocardial conduction



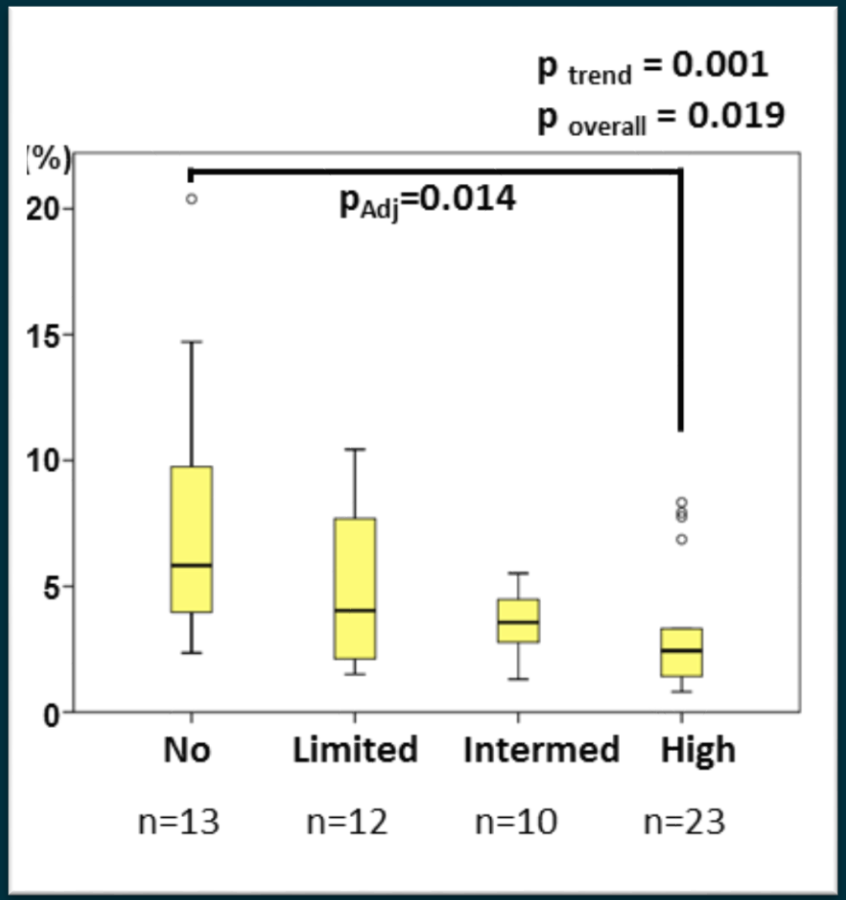
CRT – not optimized



CRT – Optimization, LV pacing.



Influence of experience on reproducibility



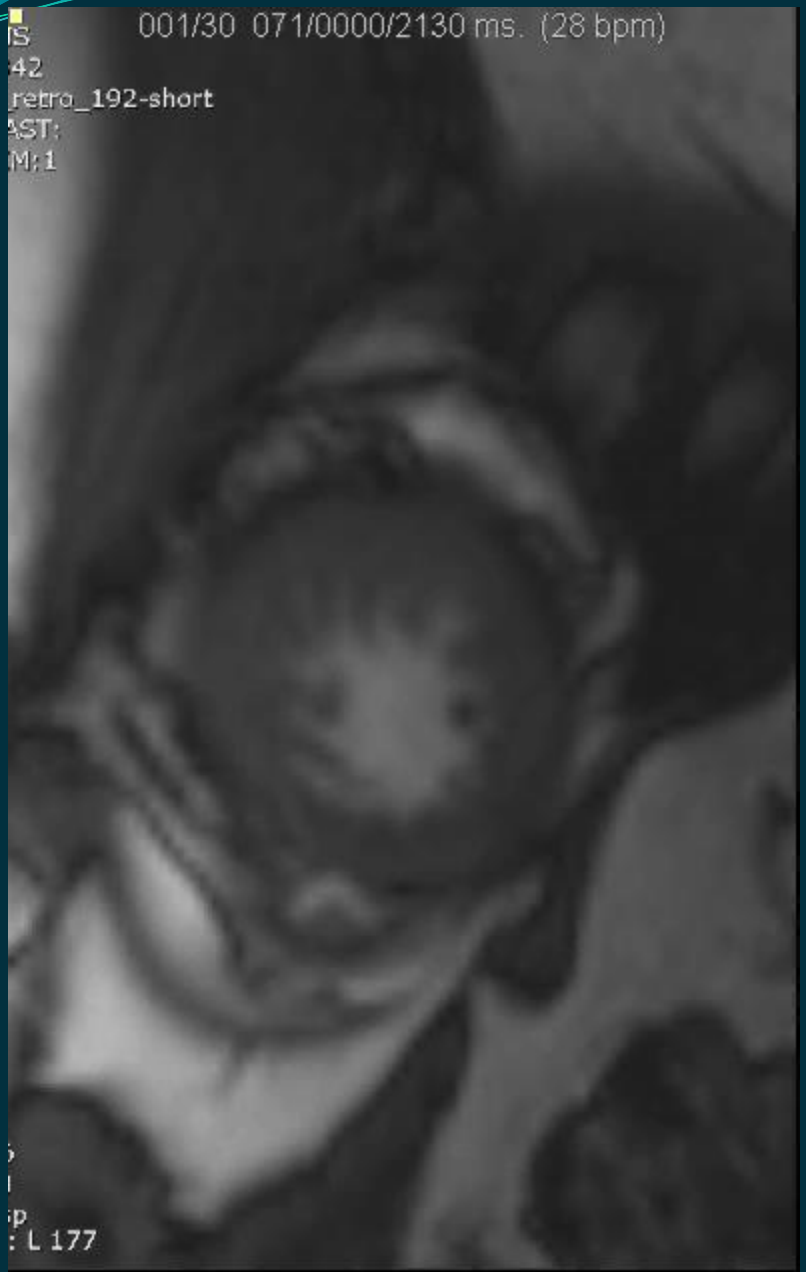
No = 0 cases
Limited = 1-20
Intermediate = 21-100
High >100 cases
Expert > 1000 cases

Negishi T et al, JACC CV Imaging, 2016, Oct 6
58 Readers from North America, Europe, Asia and Oceania

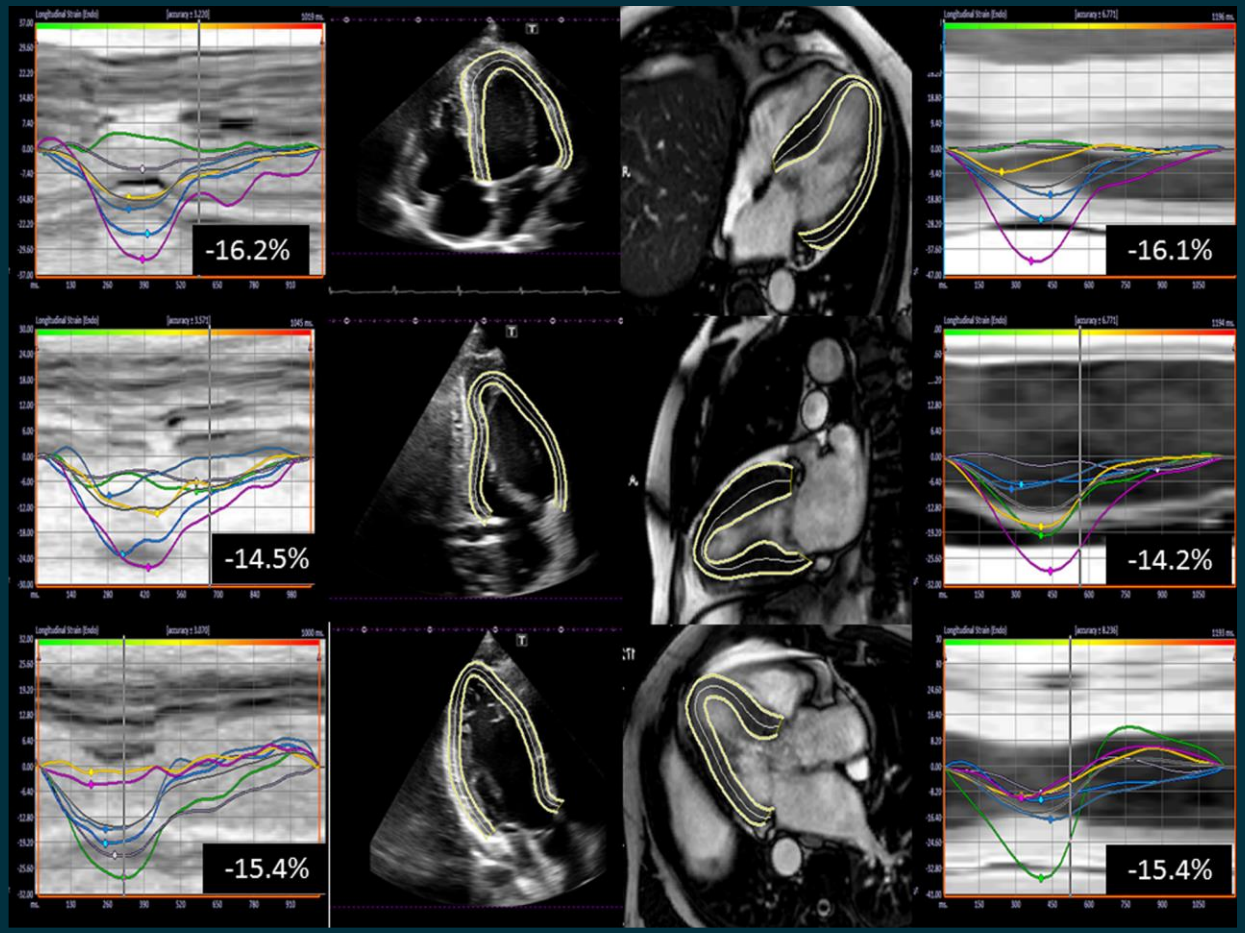
Systolic summary

- What is normal LV systolic function?
  - Merely normal LVEF or:
    - Normal bi-plane strain: LS and CS
    - Normal strain gradients (Apex-base, Endo-Epi)
    - Normal Rotation (magnitude, orientation)
    - Normal segmental and global strain

MRI … and Echo Strain

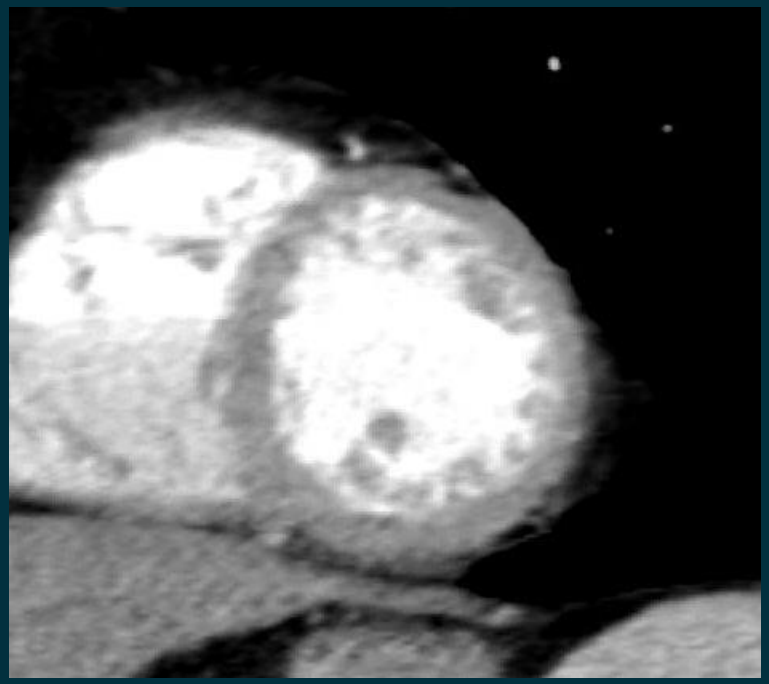


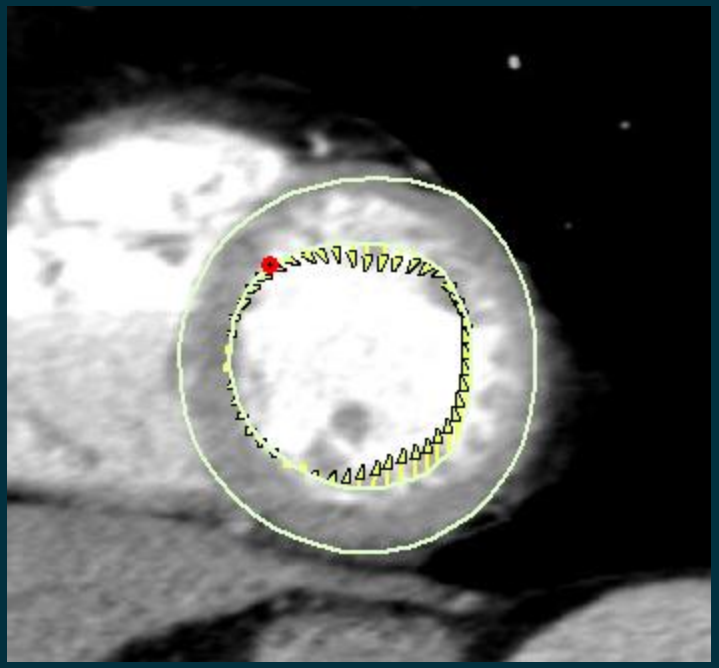
MRI vs. ECHO - longitudinal



(J Am Soc Echocardiogr 2013;26:1153-62.)

…or even CT





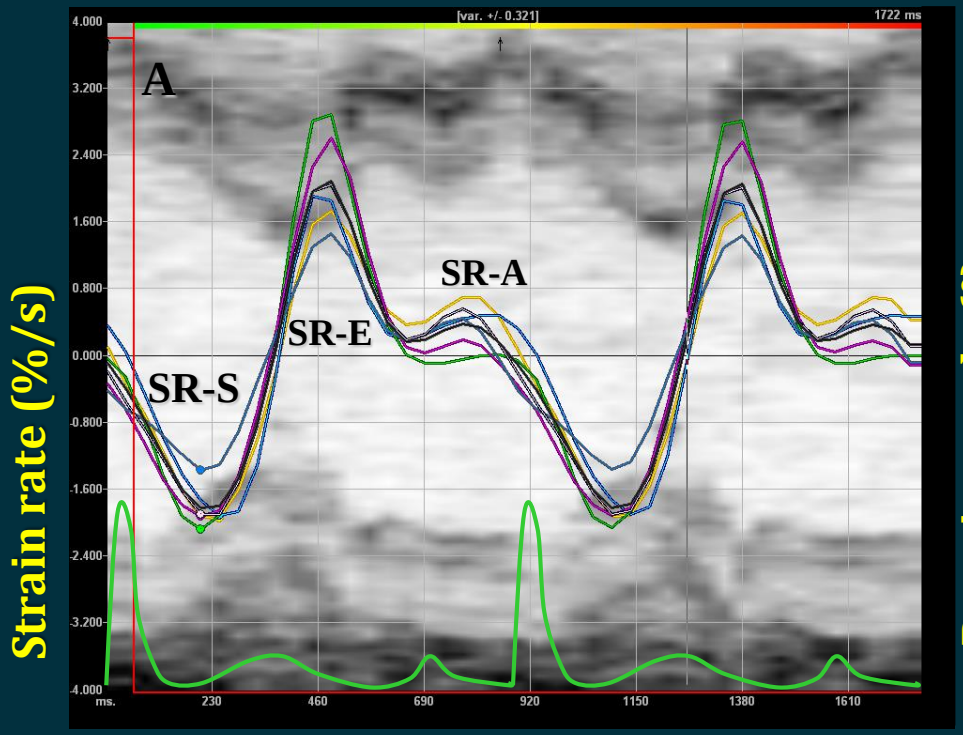
Thank You

…Discussion:

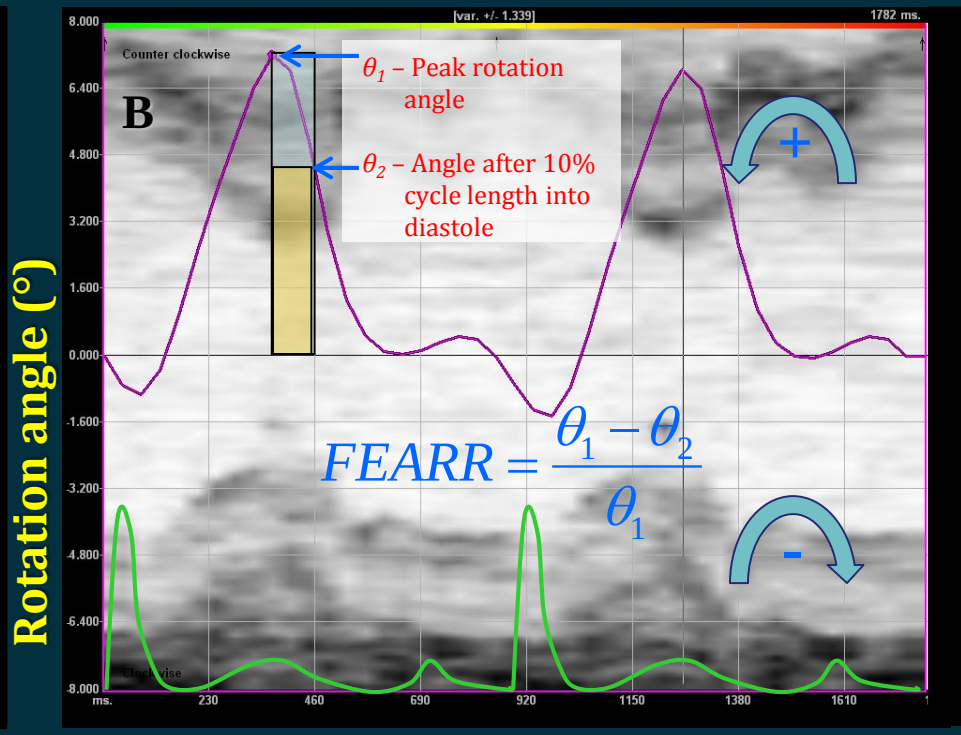
Assessment of LV Diastolic Function

… When conventional 2D Doppler echo fails

Strain rate and reverse rotation

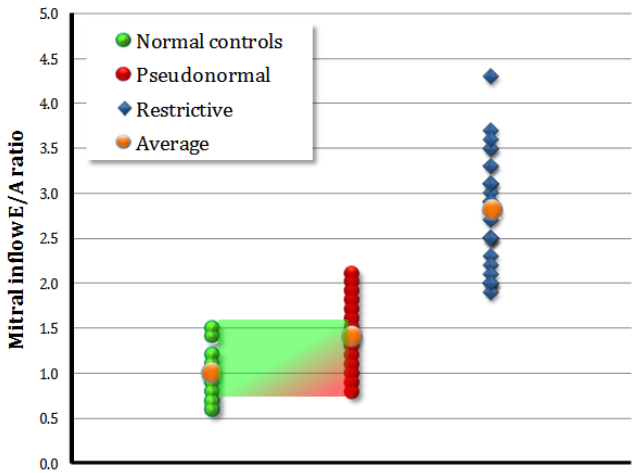


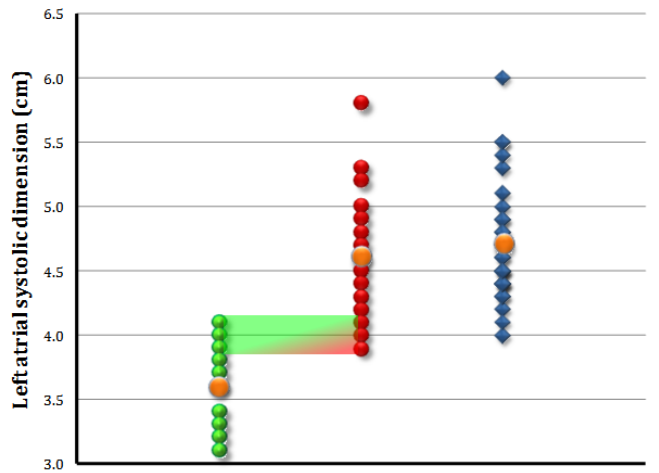
Strain rate

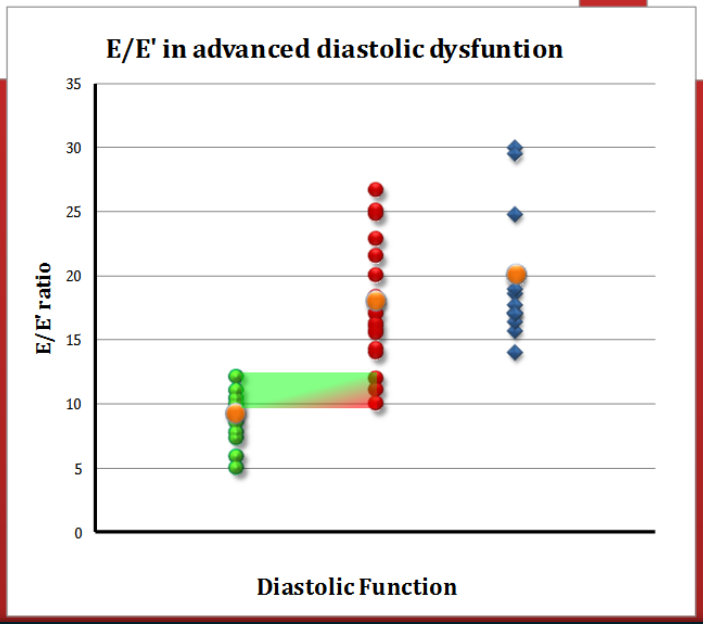


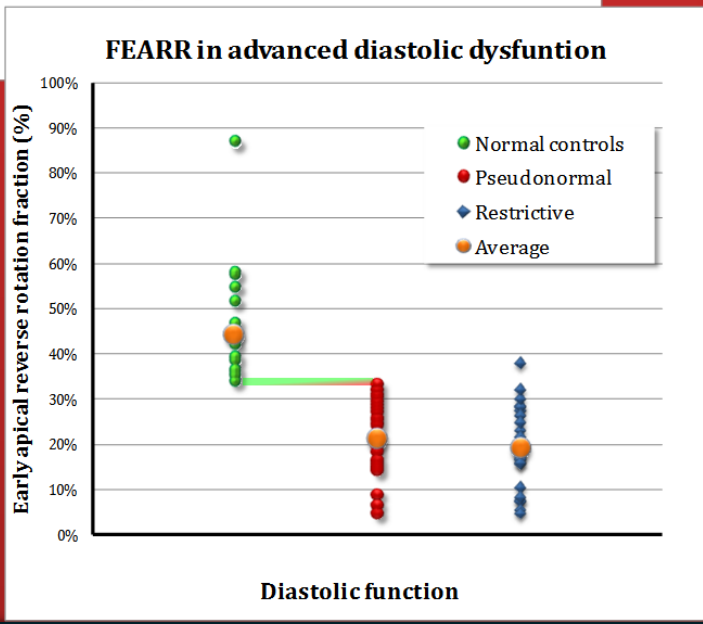
Apical Rotation

Symptomatic NLEF ADDFx

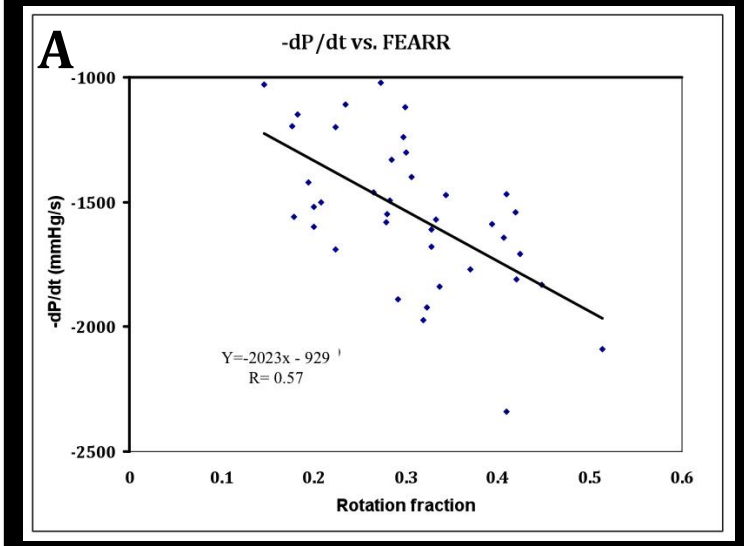


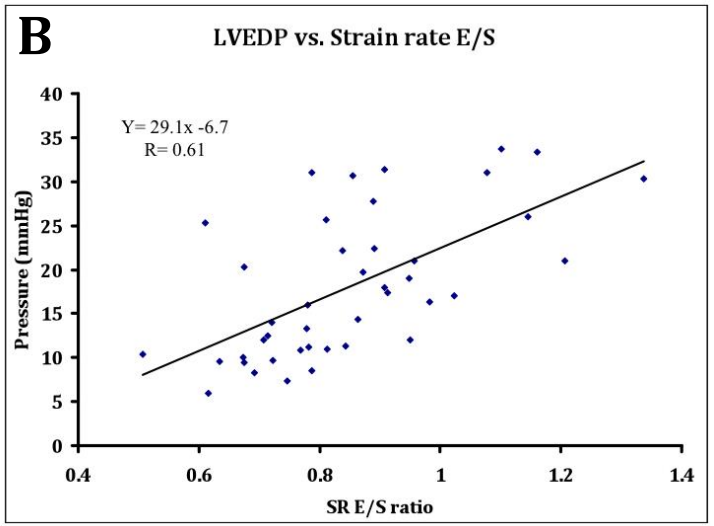


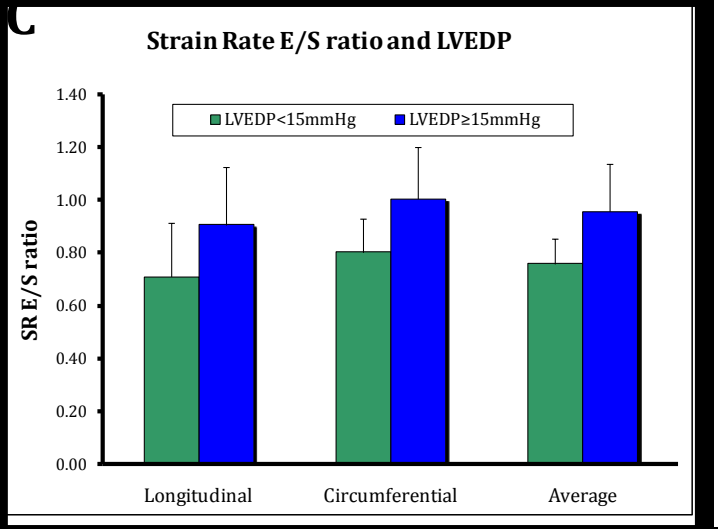


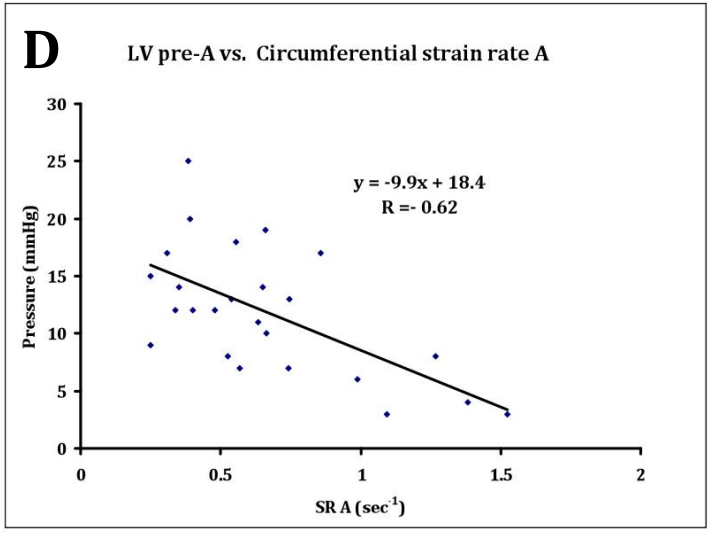


Hemodynamic correlations

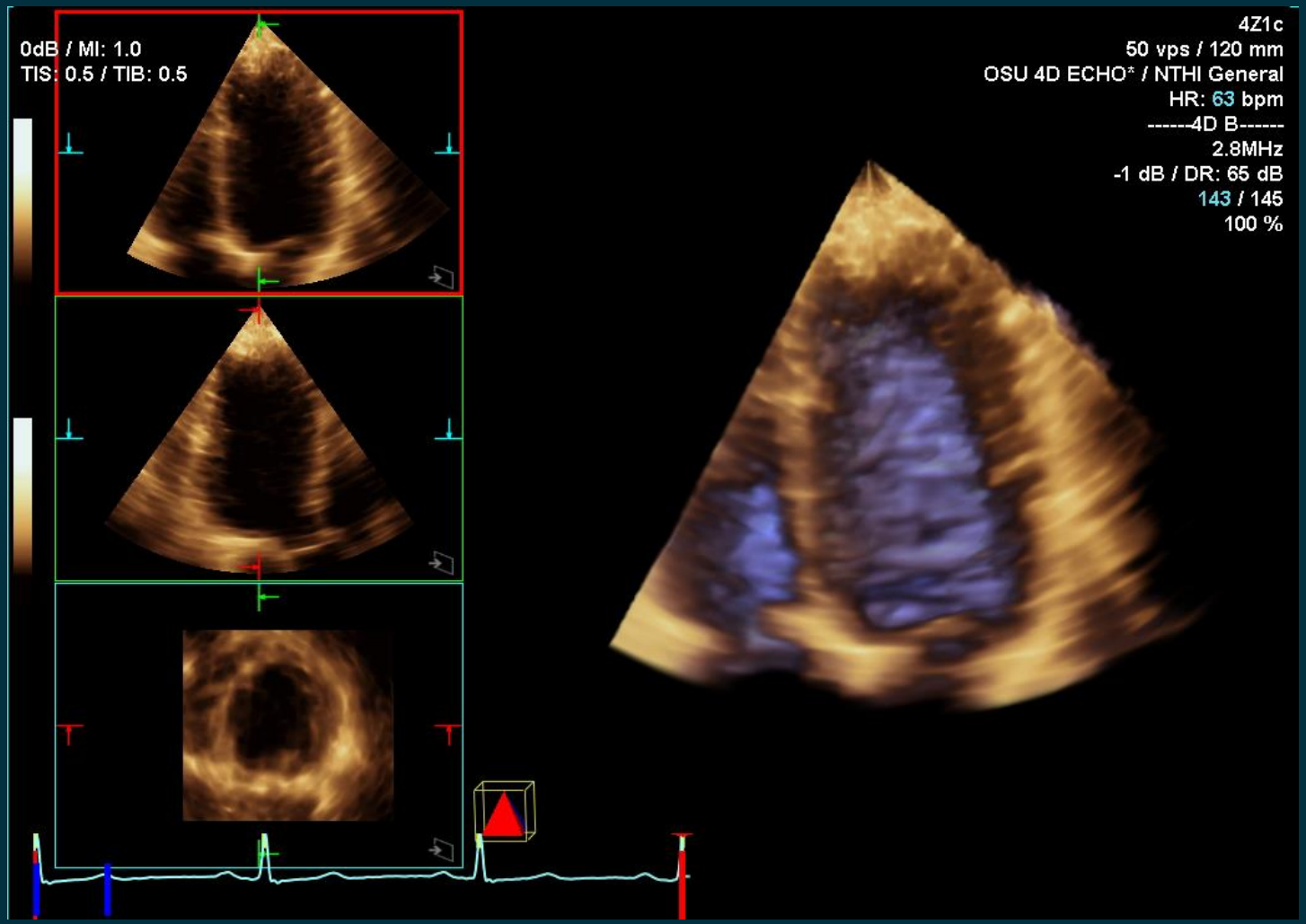


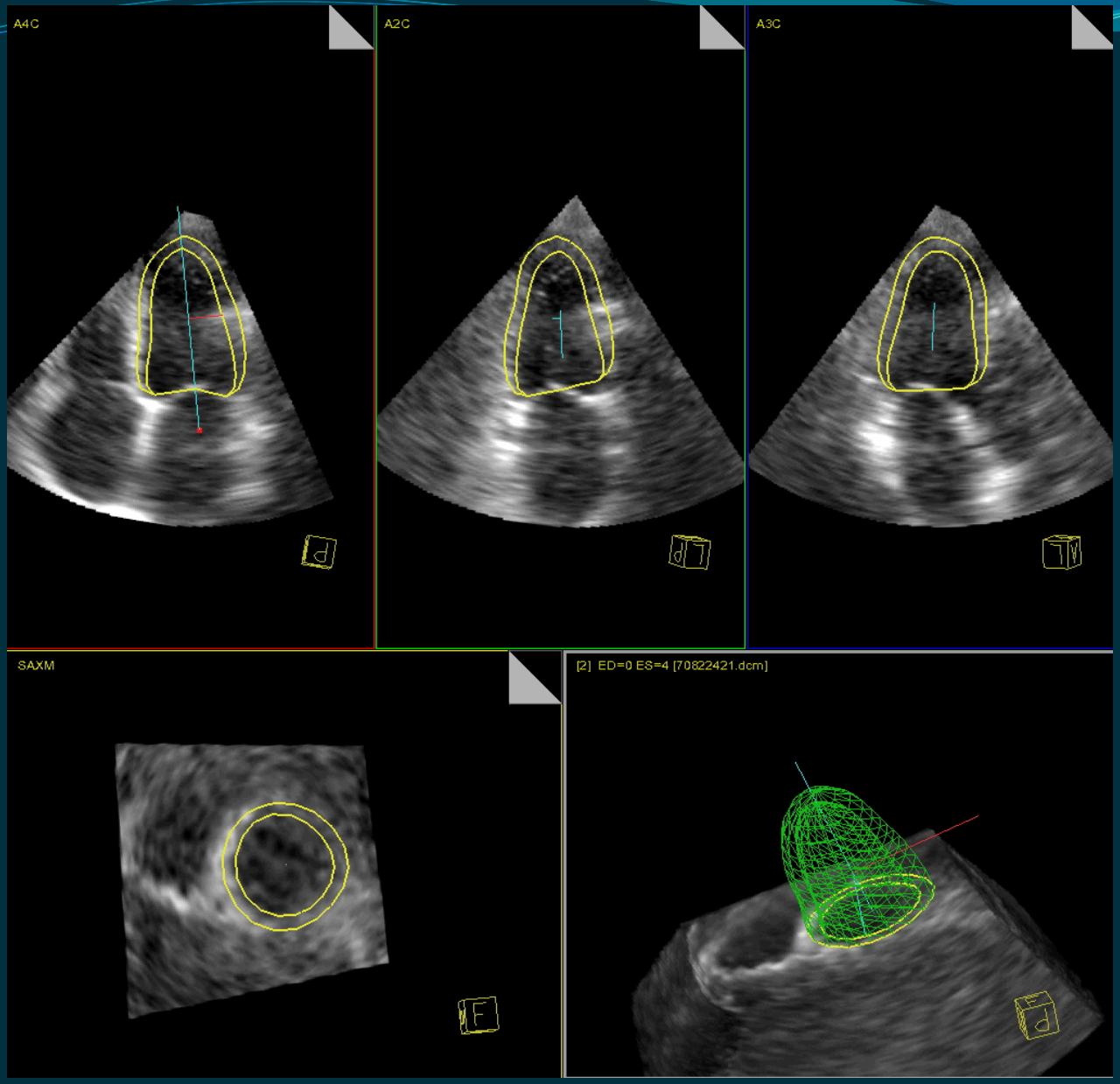






New in Echo: 3D strain




A4C
A2C
A3C
SAXM
[2] ED=0 ES=4 [70822421.dcm]

Advantages of 3D strain

- Same cycle
- Automated contour detection
- LS and CS segmental registration
  - Relative longitudinal motion correction
- More strains:
  - Principal strain and angle
  - Shear strains