Overview of Myocardial Mechanics

Background and Echocardiographic Assessment

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Conflicts: None

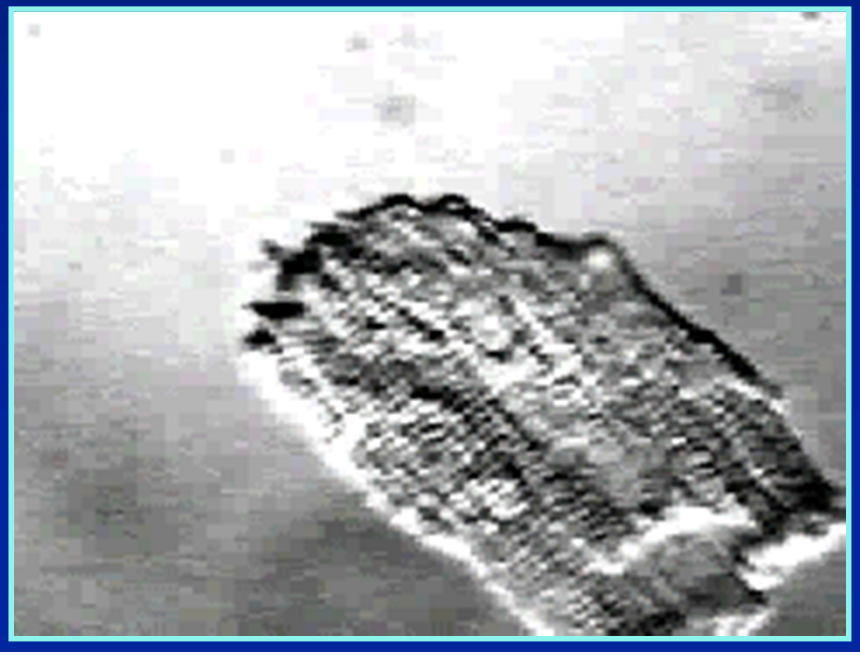
I ALWAYS Have Fun at APCDE!

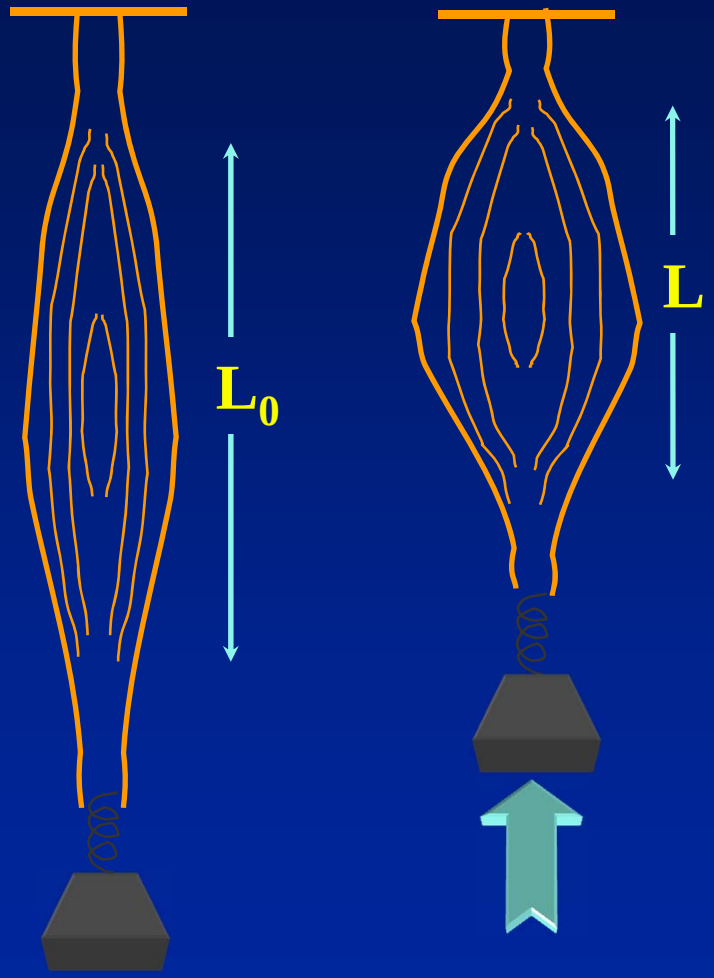
Myocardial Strain: What is It??

Strain: dimensionless index of change in length

Strain (ε) = $L-L_0/ L_0$

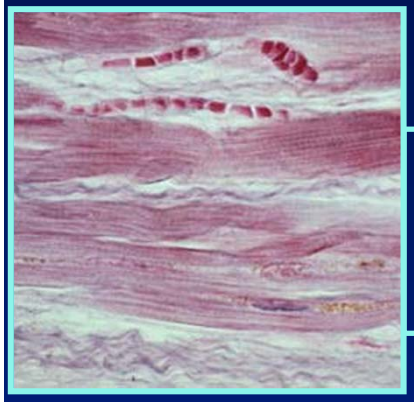
LV strain may offer a pure index of regional LV function but is difficult to measure





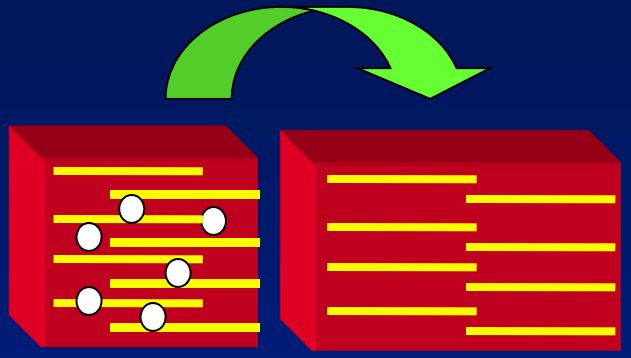
Diastolic Function

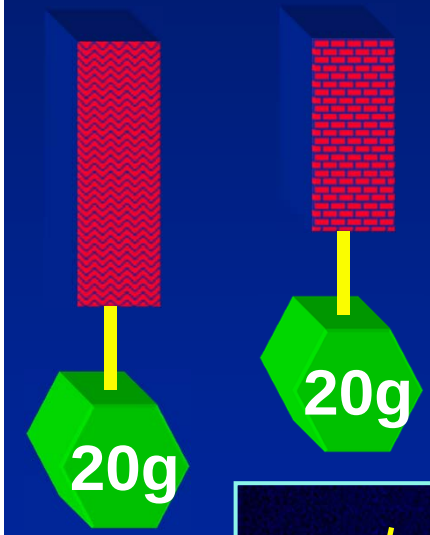
Myocardium to Ventricle



Tissue Elastance

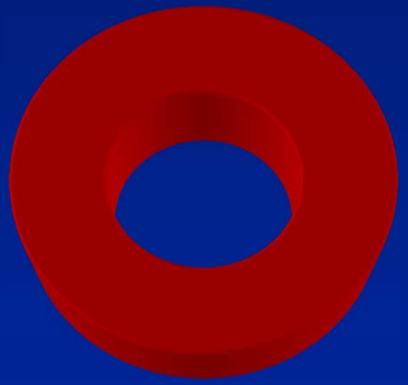
Relaxation

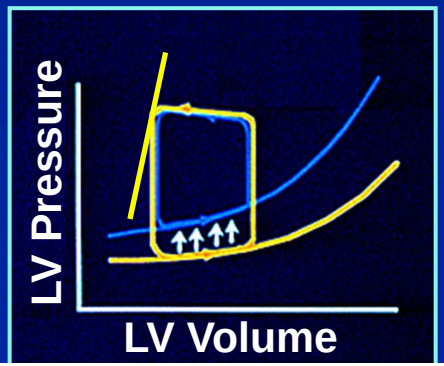




Stress/strain Relationship

Geometry





Pressure-Volume Curve

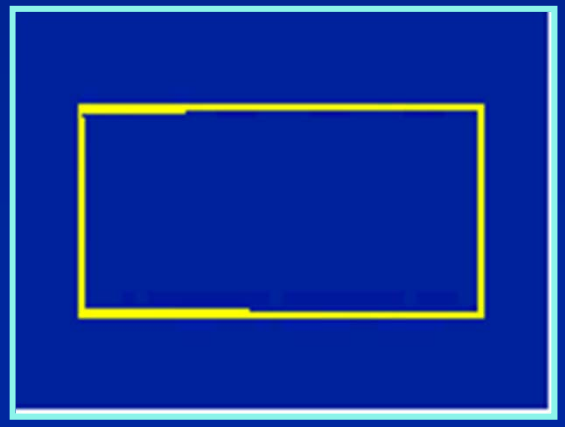
Strain: More Than a Number

3D Tensor with Linear and Shear Components

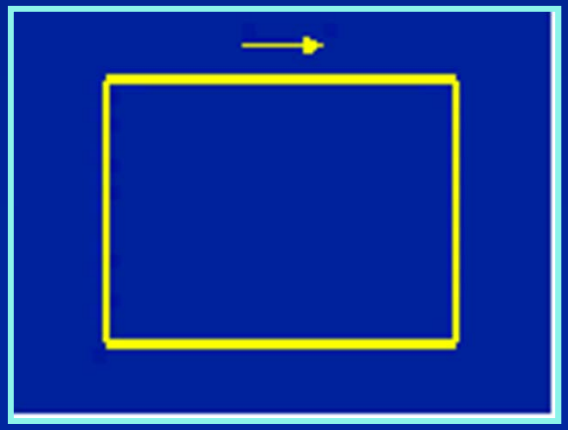
E_{xx}	E_{xy}	E_{xz}
E_{yx}	E_{yy}	E_{yz}
E_{zx}	E_{zy}	E_{zz}

$$E_{ij} = -E_{ji}$$

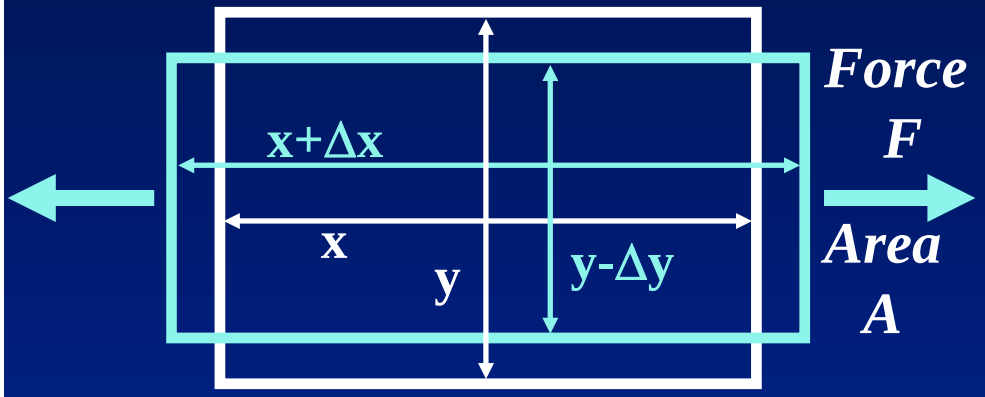
Linear strain



Shear strain



Stress-Strain Relationships

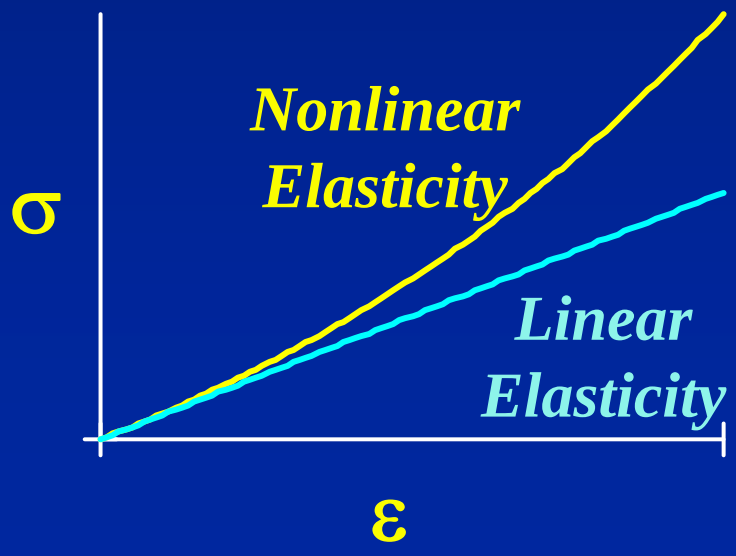


Stress: $\sigma = \frac{F}{A}$ ***Units of Pressure***

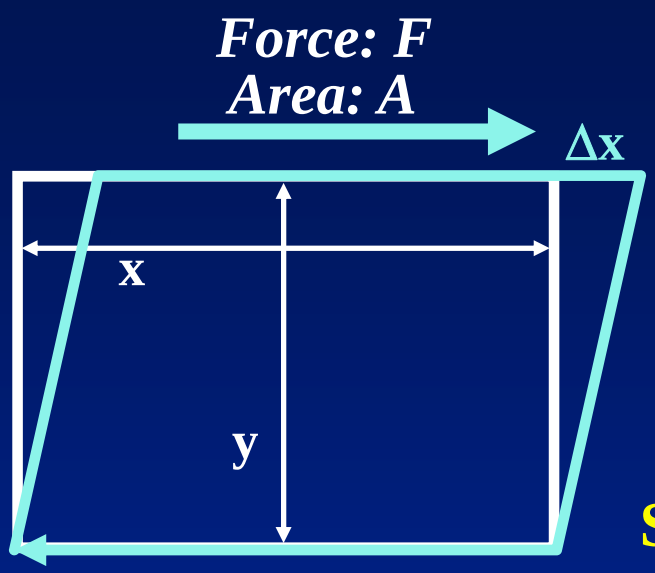
Strain: $\varepsilon = \frac{\Delta x}{x}$ ***Dimensionless***

Young's modulus: $E = \frac{\sigma}{\varepsilon}$ ***Units of Pressure***

Poisson's ratio: $\nu = \frac{\varepsilon_y}{\varepsilon_x}$ ***Dimensionless***



Shear Modulus



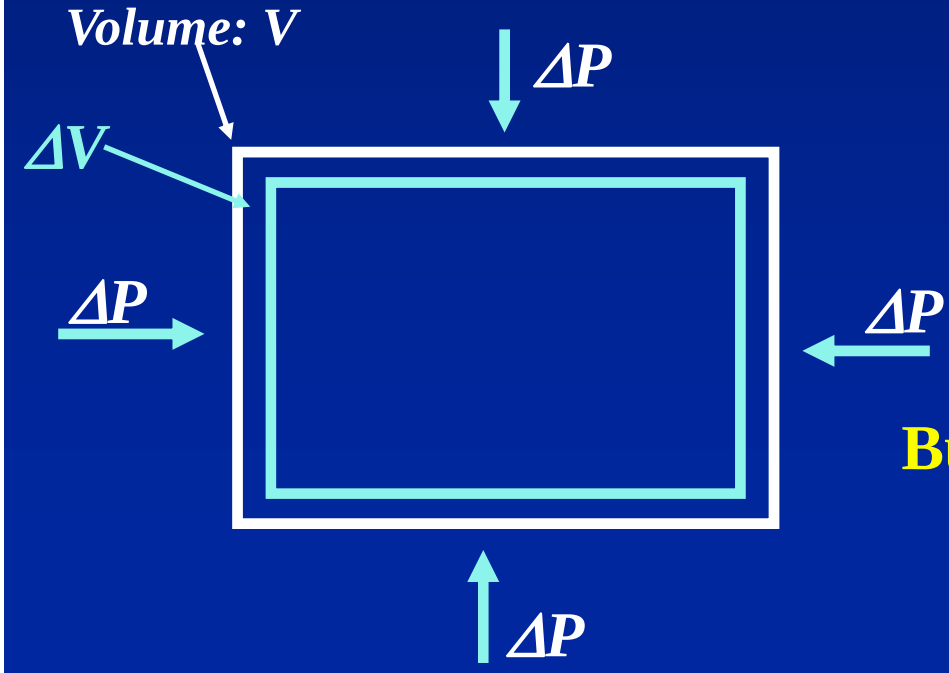
Shear stress: $\tau = \frac{F}{A}$ *Units of Pressure*

Shear strain: $\gamma = \frac{\Delta x}{y}$ *Dimensionless*

Shear modulus: $E = \frac{\tau}{\gamma}$ *Units of Pressure*

Bulk Modulus

(Inverse of compressibility)

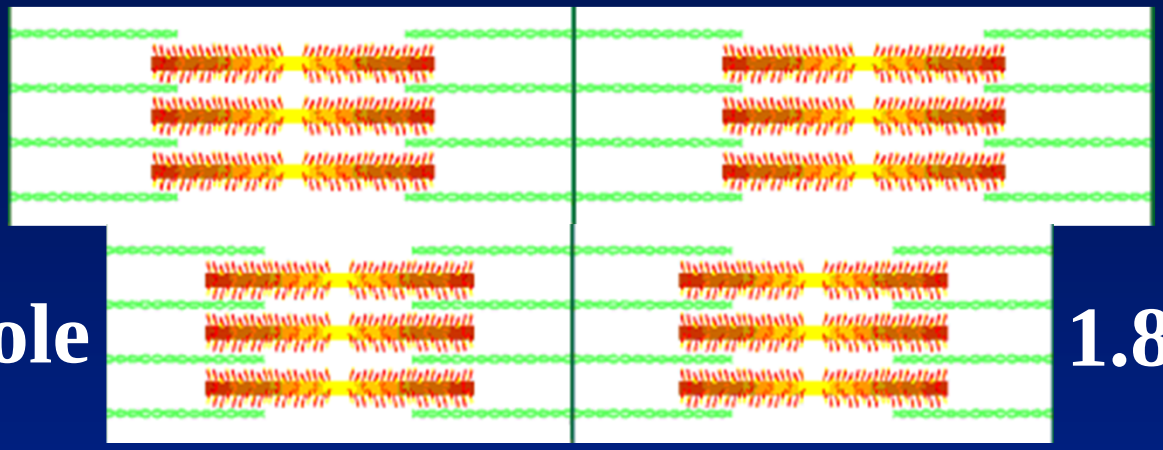


Bulk modulus: $K = \frac{\Delta P}{\Delta V/V}$ *Units of Pressure*

From Sarcomere to Stroke Volume

A Little Goes a Long Way!

Diastole



2.07 μ

Systole

1.81 μ

Diastole

$\Delta SL = 13\%$

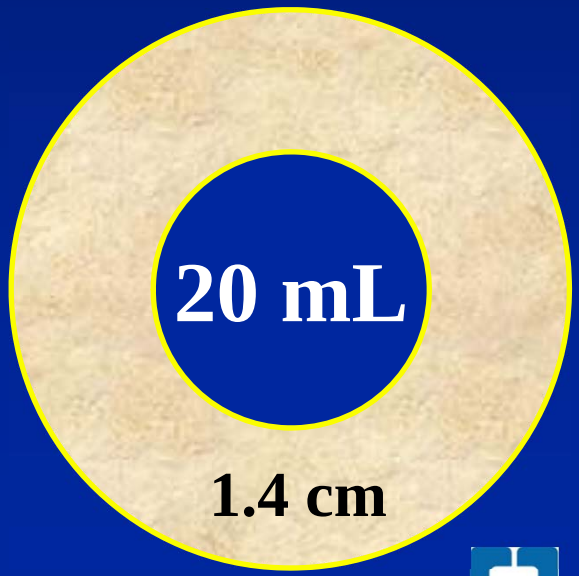
$\varepsilon_{epi} = -7\%$

$\varepsilon_{mid} = -15\%$

$\varepsilon_{endo} = -26\%$

$\varepsilon_{rad} = +37\%$

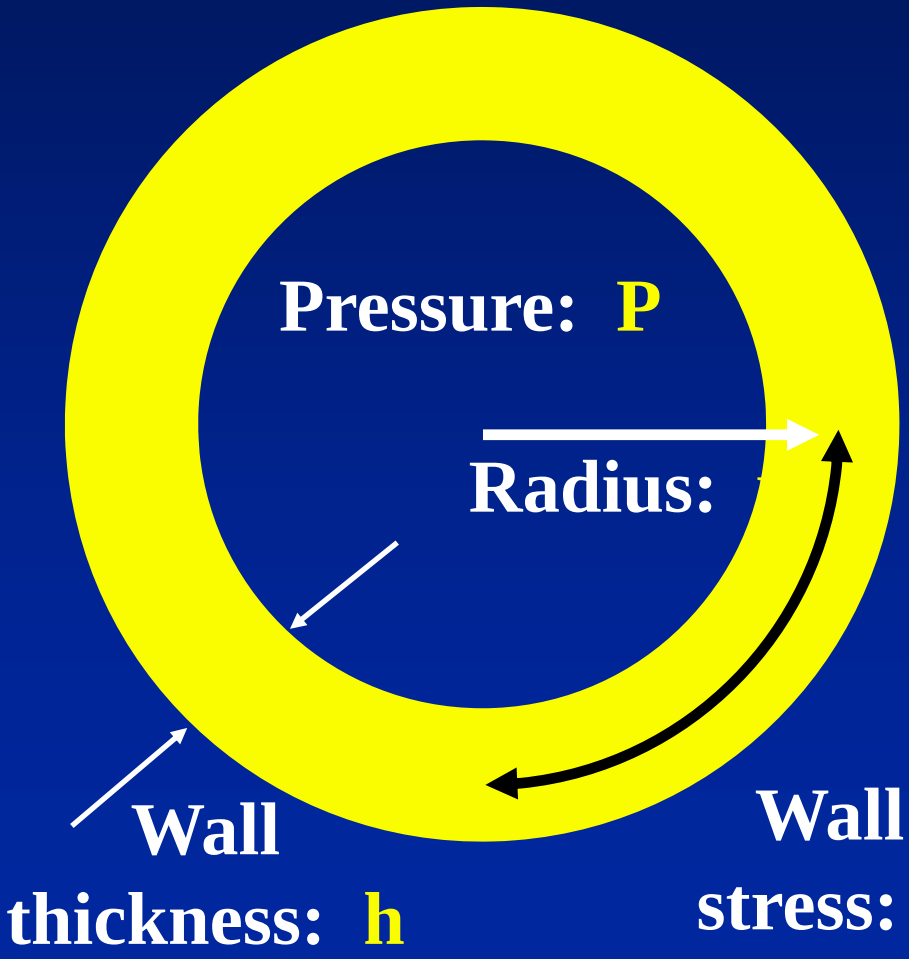
EF = 60%



Systole

Strain11:8

Source of Arterial Pressure
Myocardial Wall Stress



Sphere Approximation
Laplace's Law

$$\sigma = \frac{P \cdot r}{2h}$$

In reality, in 2011, there is NO WAY to directly measure wall stress in vivo

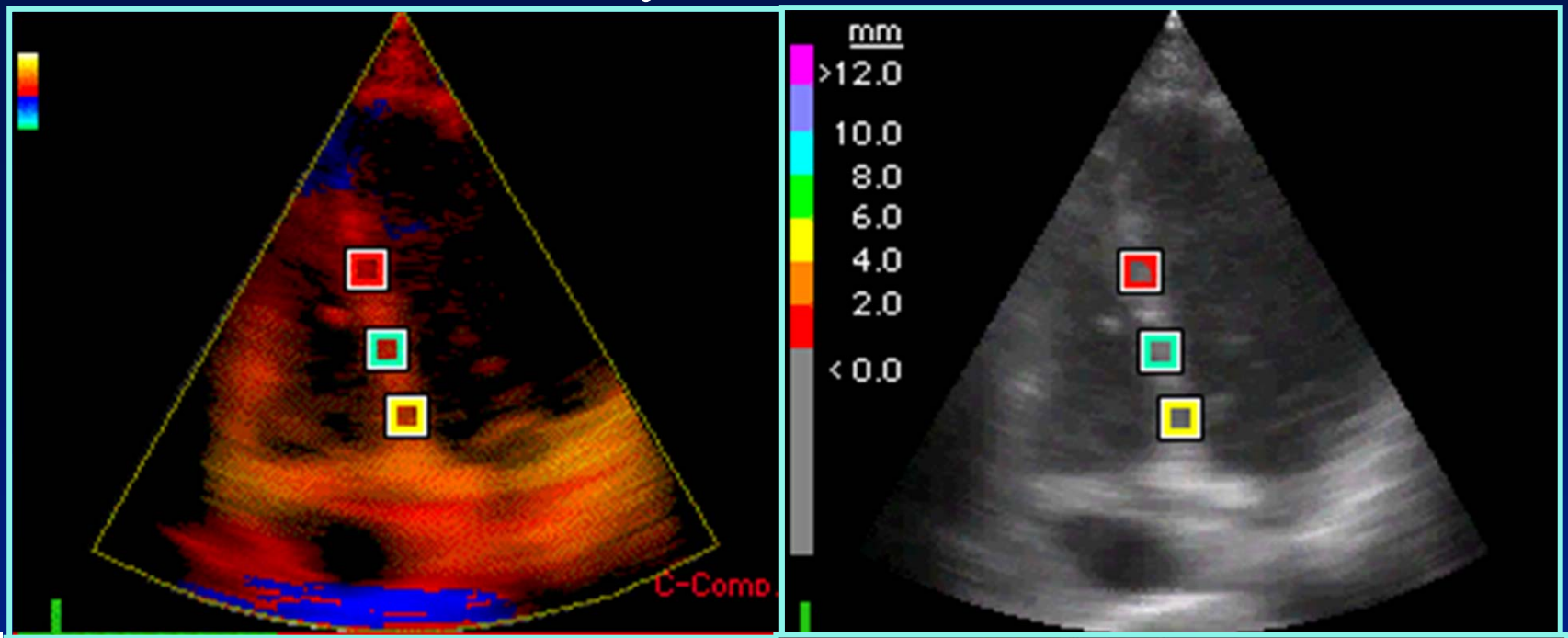
Delighted to be in Korea

Strain11:10

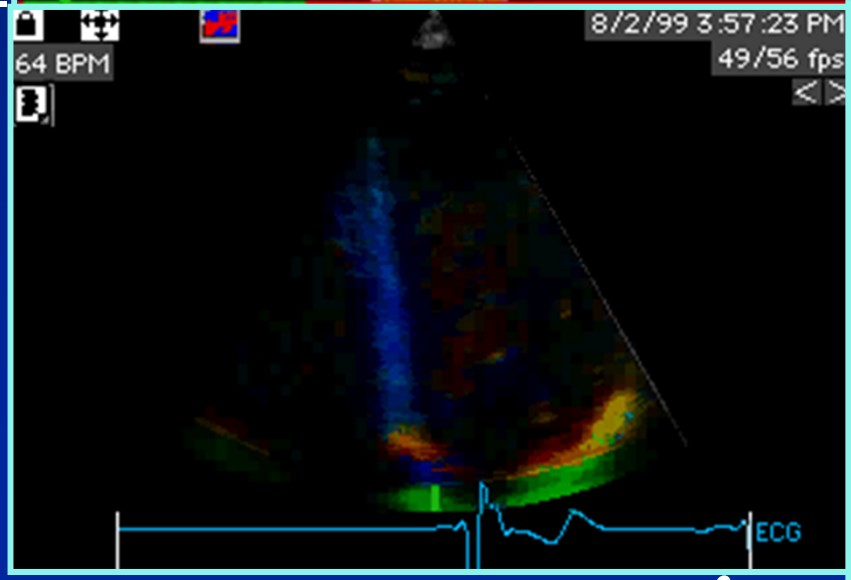
Echocardiographic Methods to Measure Strain

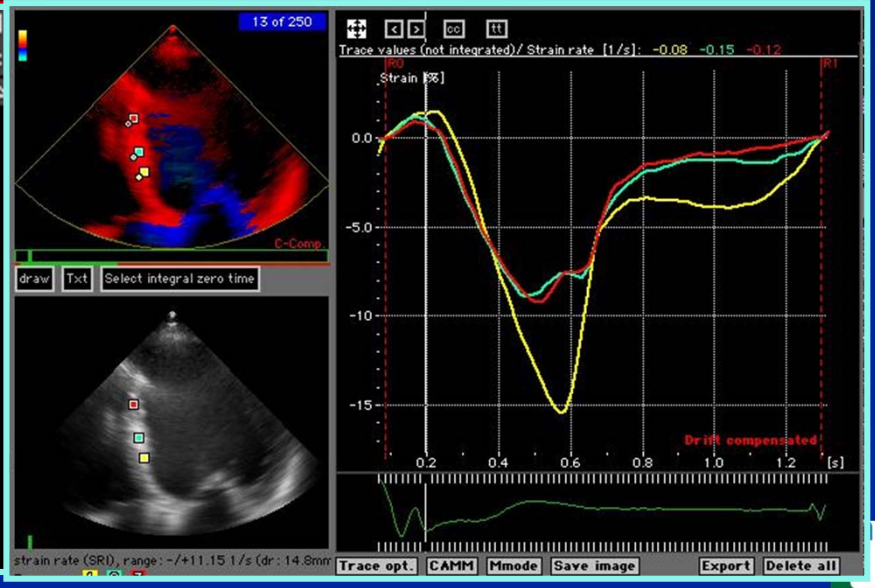
Derived from tissue velocity

Velocity $\int v\,dt \Rightarrow$ Displacement



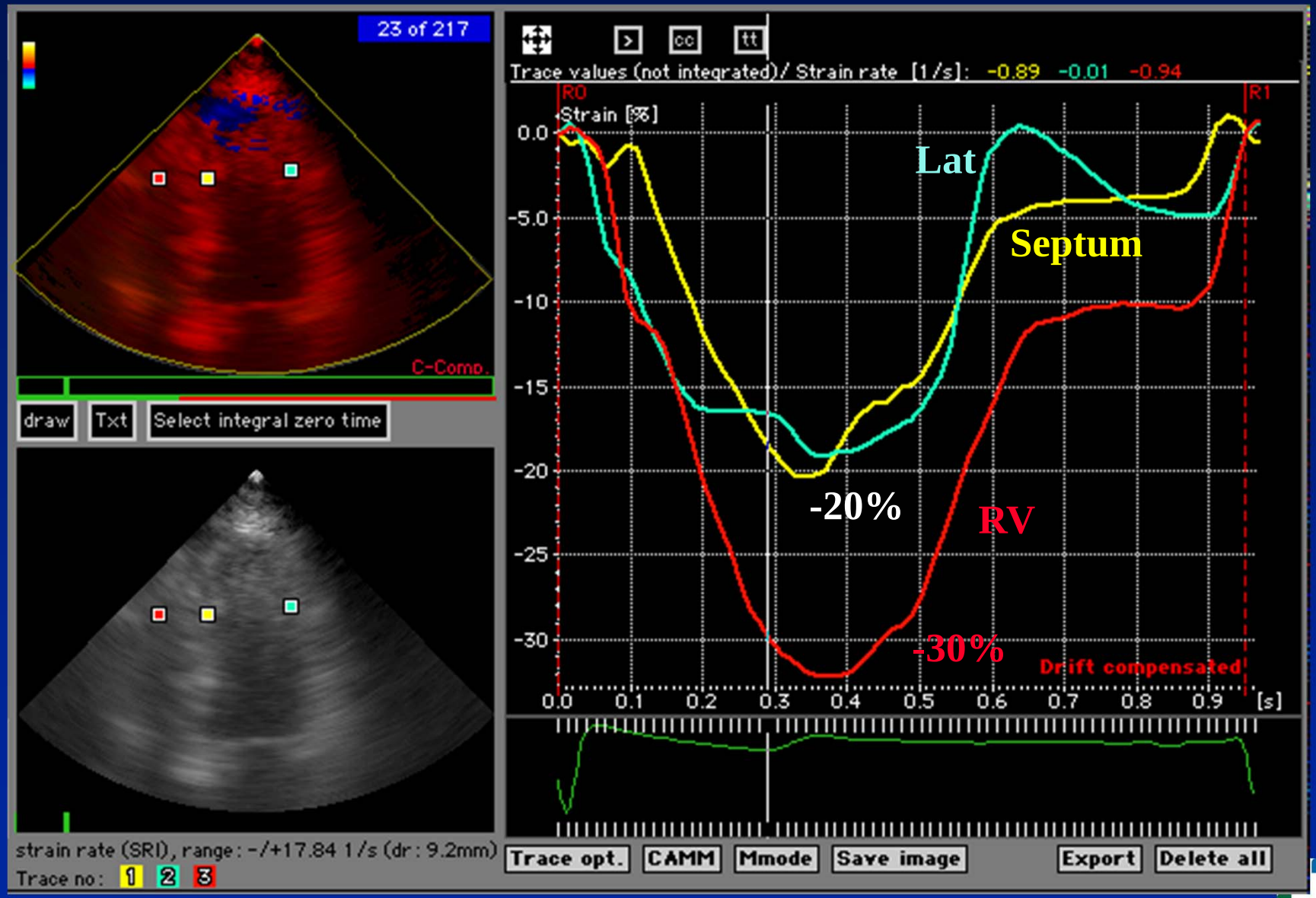
$\frac{\partial v}{\partial s} \Downarrow$





Strain rate $\int \varepsilon'\,dt \Rightarrow$ Strain

Strain Derived from Tissue Velocities



Predictors of Tissue Doppler Strain Rate

Relationship to invasive indices during ischemia

Systolic Strain Rates

ε'_{SYS} vs:	r
ES P/V	0.89
$+dP/dt_{max}$	0.86
EF	0.77
ESV	0.57

Diastolic Strain Rates

ε'_{DIAS} vs:	r
EDP	0.82
$-dP/dt_{max}$	0.81
Tau	0.72
EDV	0.60

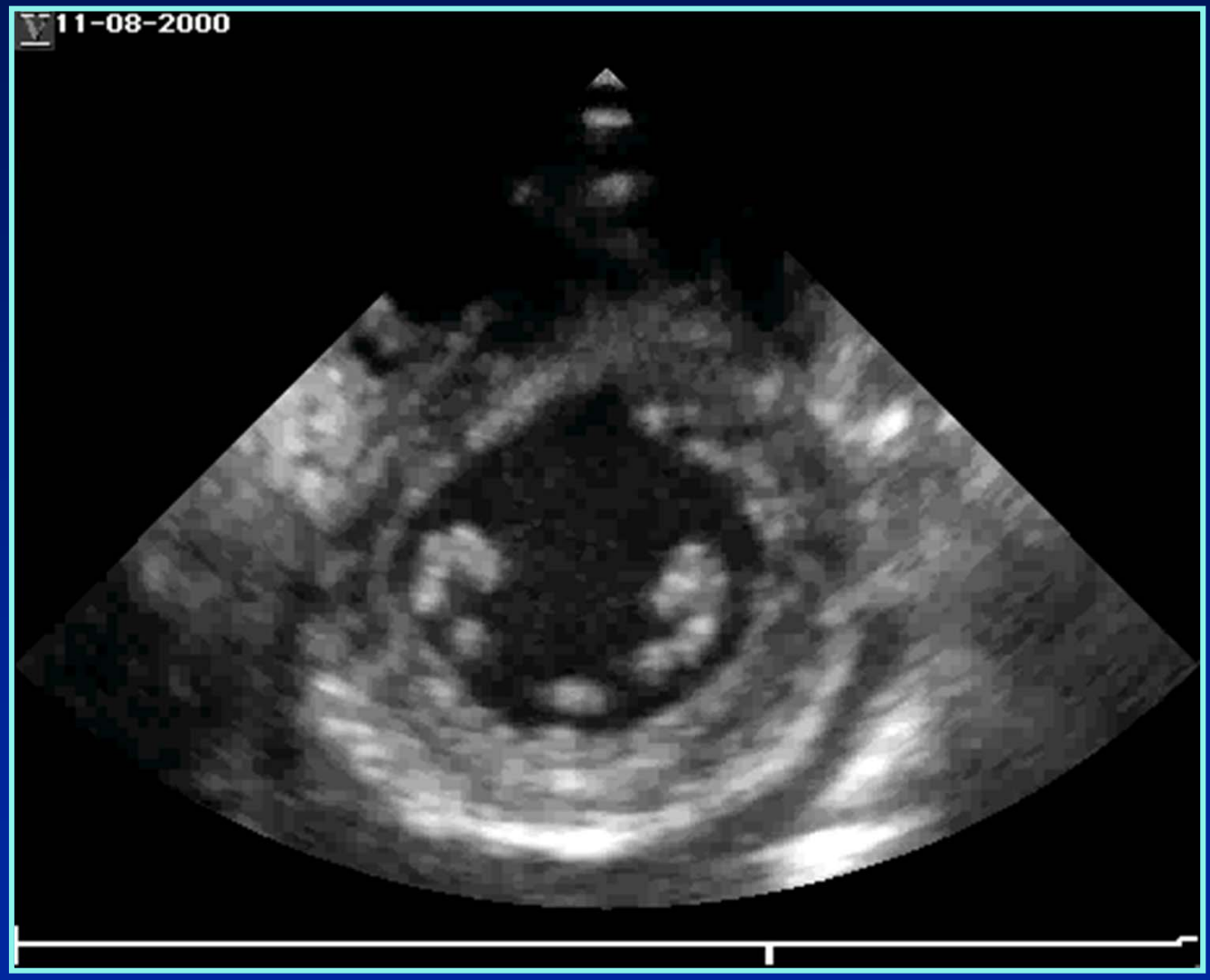
Greenberg et al. Circ 2002; 105:99-105

Limitations of TDI Strain

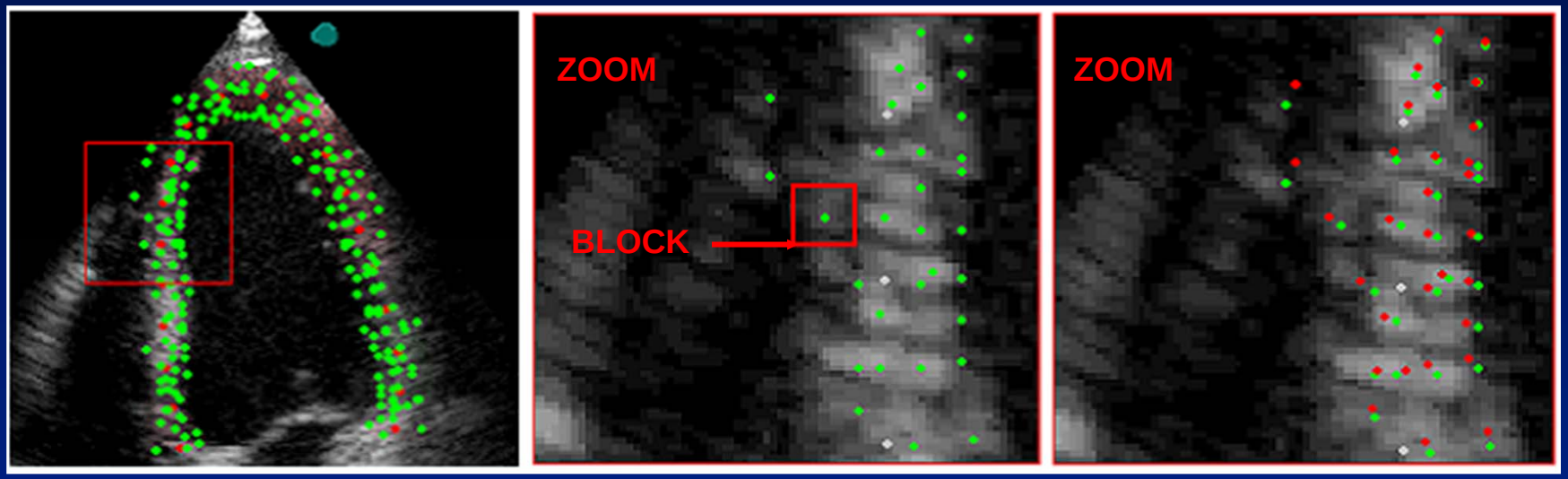
- *Detects only single component of strain*
- *Limited scope of radial (anteroseptum and posterior wall) and circumferential (septum and lateral wall) strain from parasternal window*
- *Subject to noise, particularly strain rate*
- *Very tedious to perform*

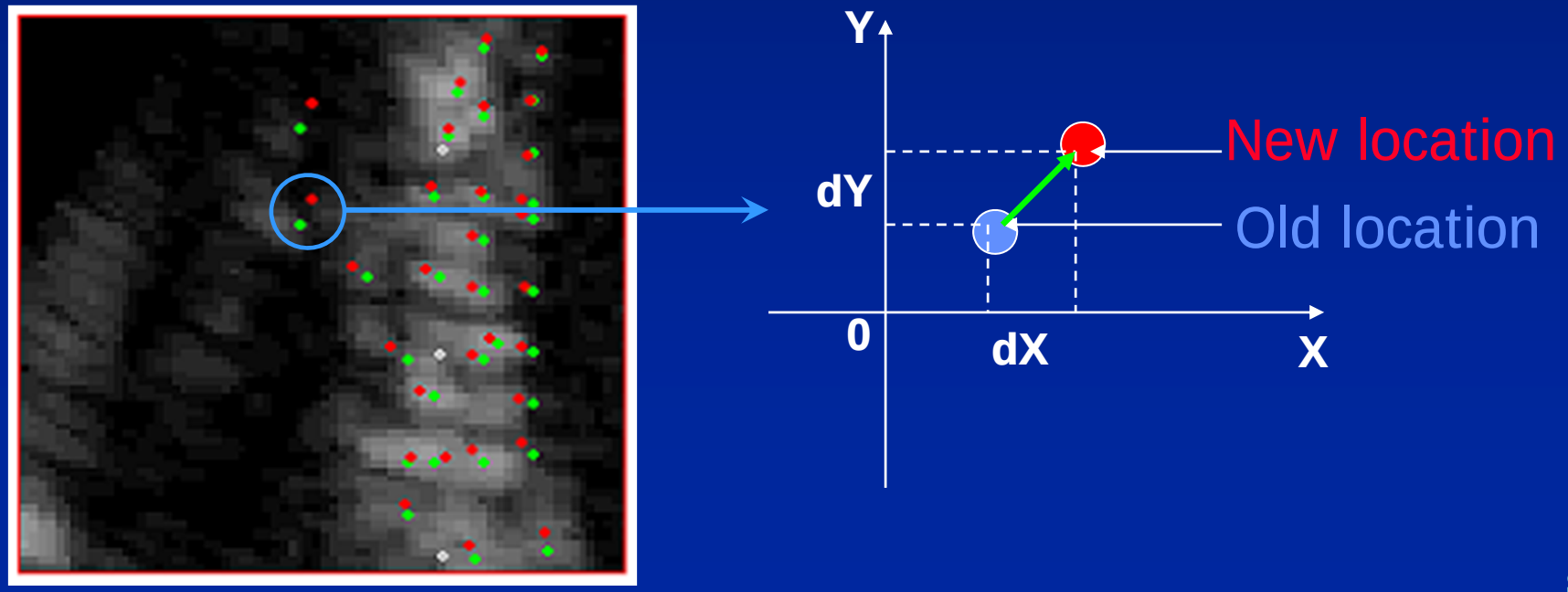
Good tastes in Seoul

Deriving strain directly from the B-mode image



Derivation of 2D Strain by Echo





Not a New Idea, Just Better Implementation

COMPUTERS IN CARDIOLOGY 1988

LOCAL MYOCARDIAL DEFORMATION COMPUTED FROM SPECKLE MOTION

Jean Meunier, Michel Bertrand, Guy E. Mailloux and Robert Petitclerc

Ecole Polytechnique, C.P. 6079, Station "A"
and Institut de Cardiologie, 5000 Belanger E.,
Montreal, H1T 1C8, CANADA

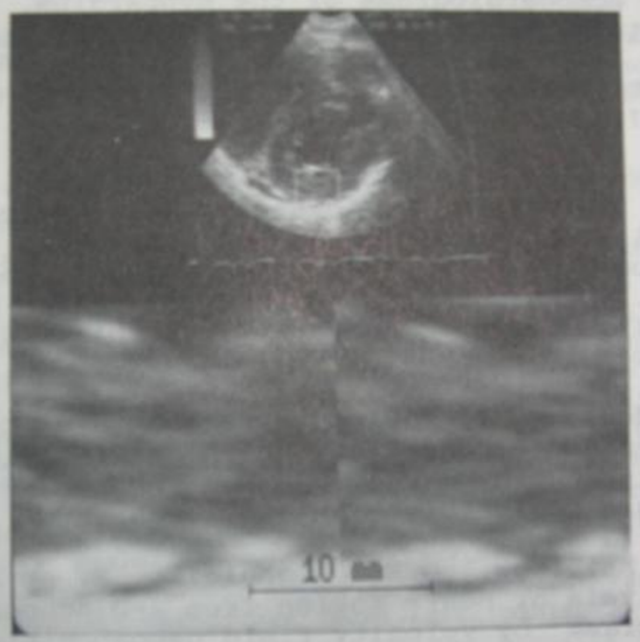


Fig. 2 A typical echocardiographic image (short axis view) and two successive frame ROI after lowpass filtering near end-diastole.

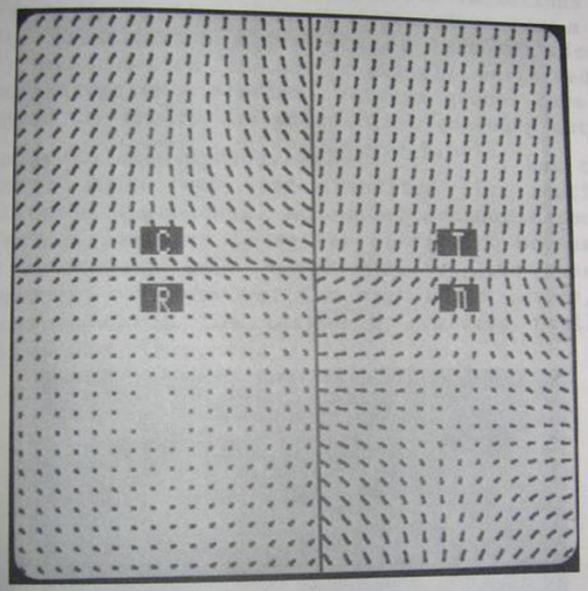
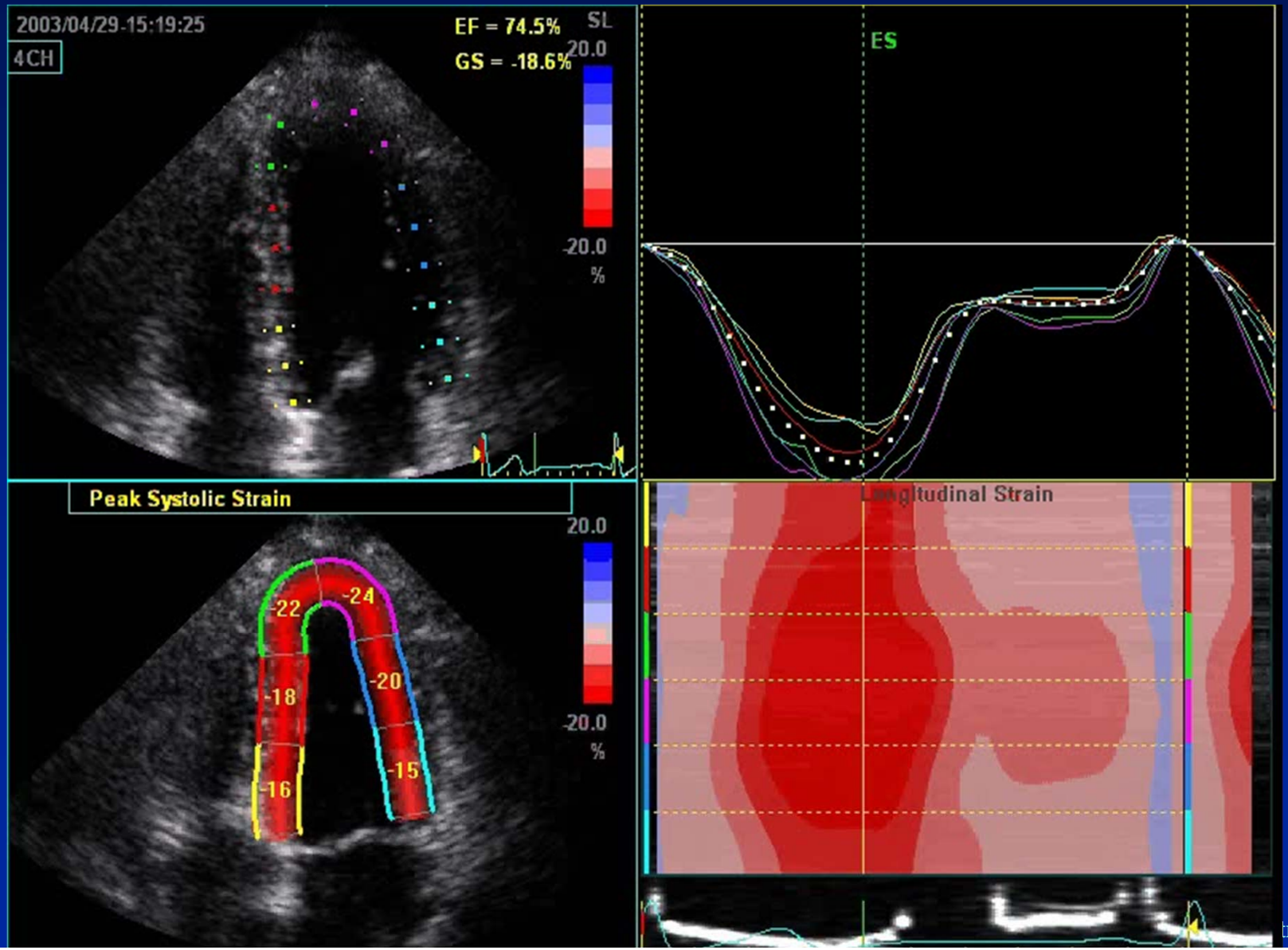


Fig. 3 Velocity (motion) vector fields computed from the two ROI in fig. 2 near end-diatole. The composite (C), translational (T), rotational (R) and deformation (D) fields are represented. The coordinate origin is the ROI center.

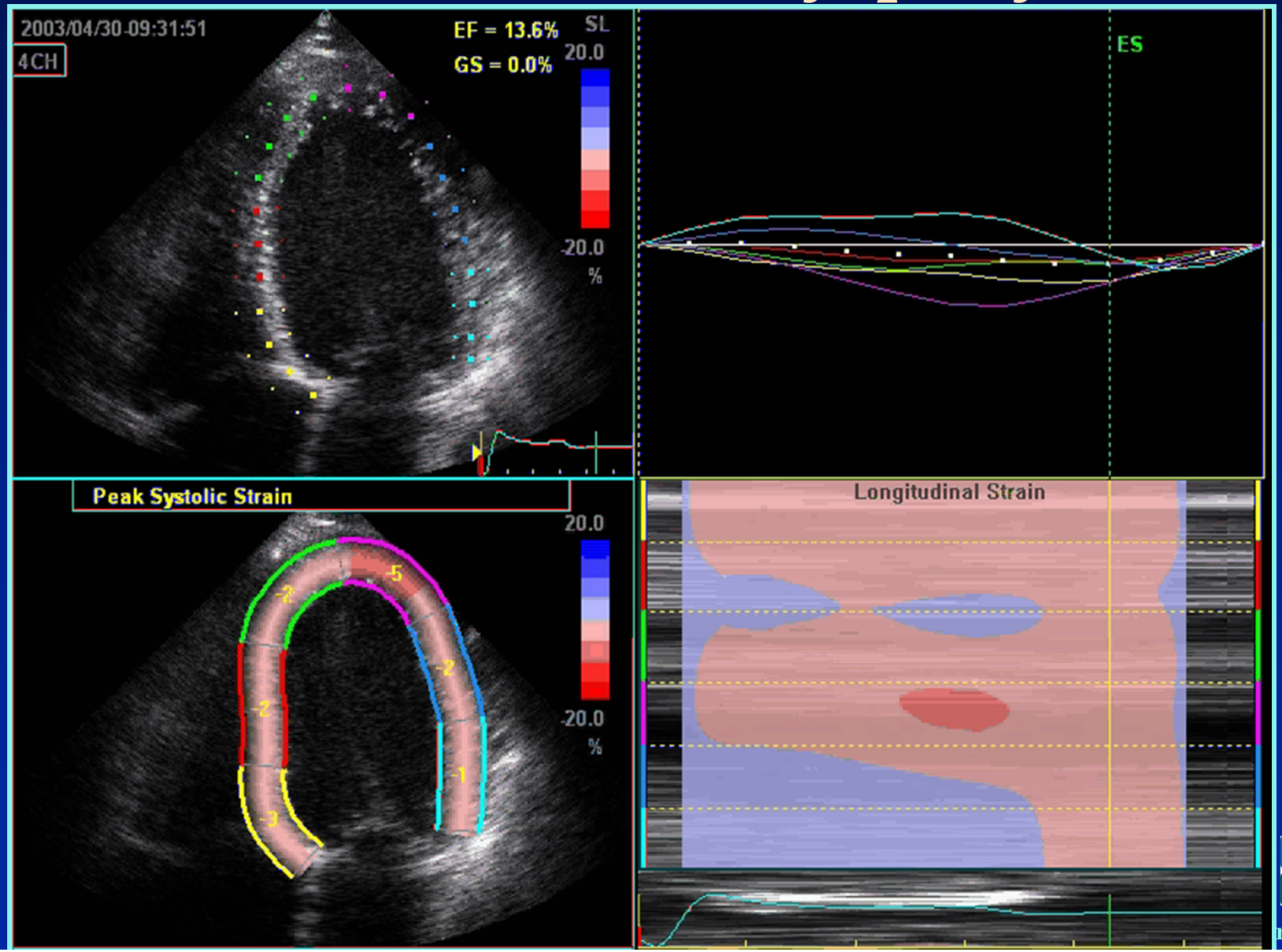
Longitudinal Strain from B-Mode Echo

Normal Subject



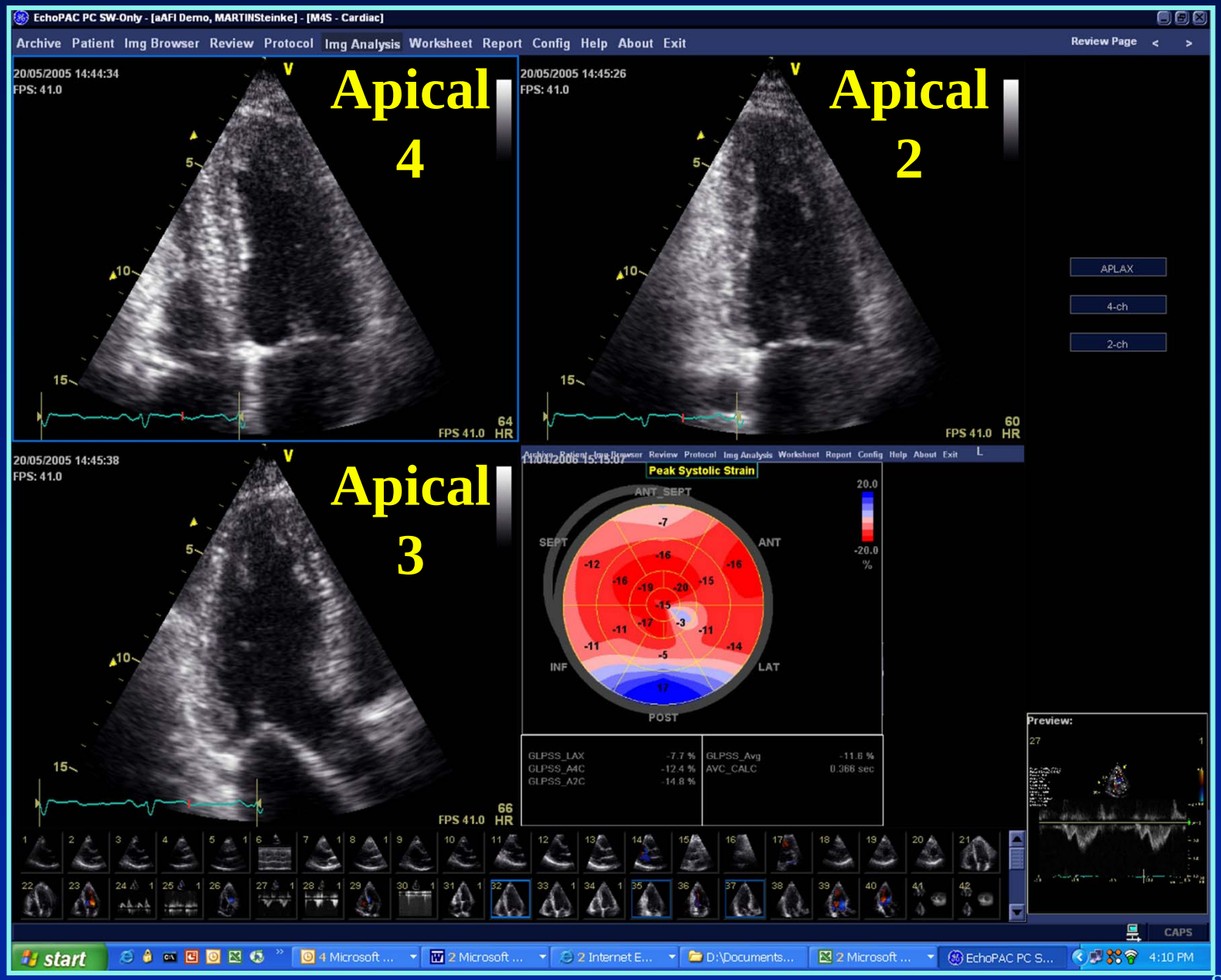
Longitudinal Strain

Dilated Cardiomyopathy



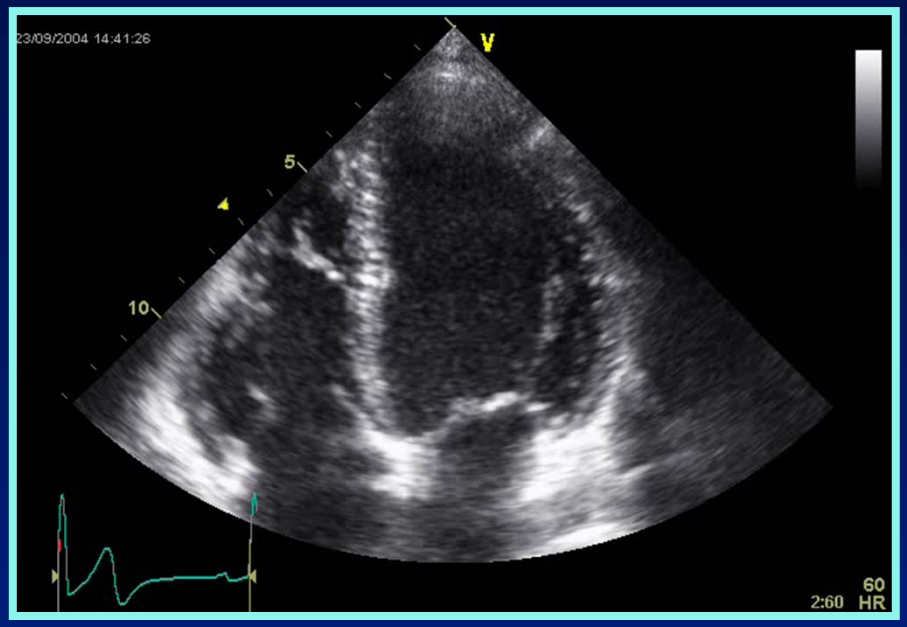
rain11:21

Bull's-eye Plot from 3 Apical Views

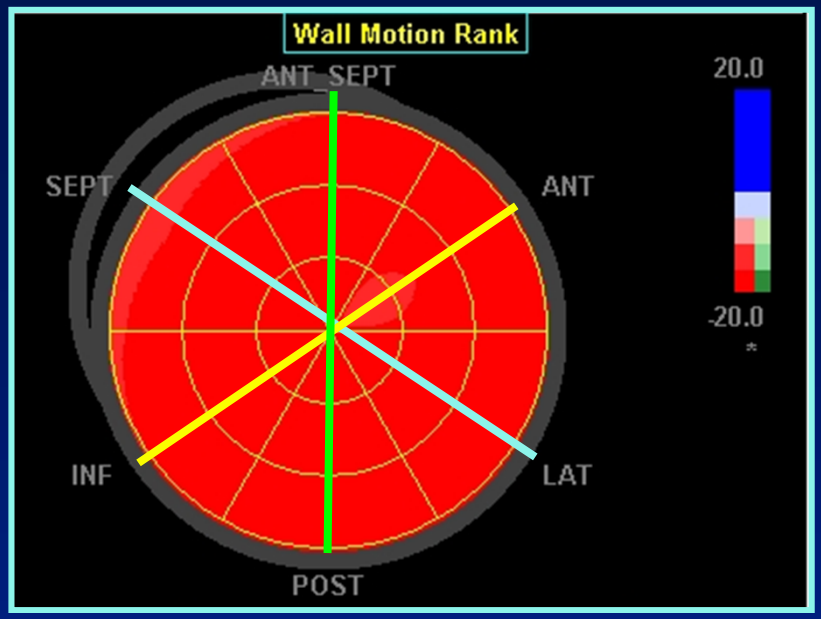


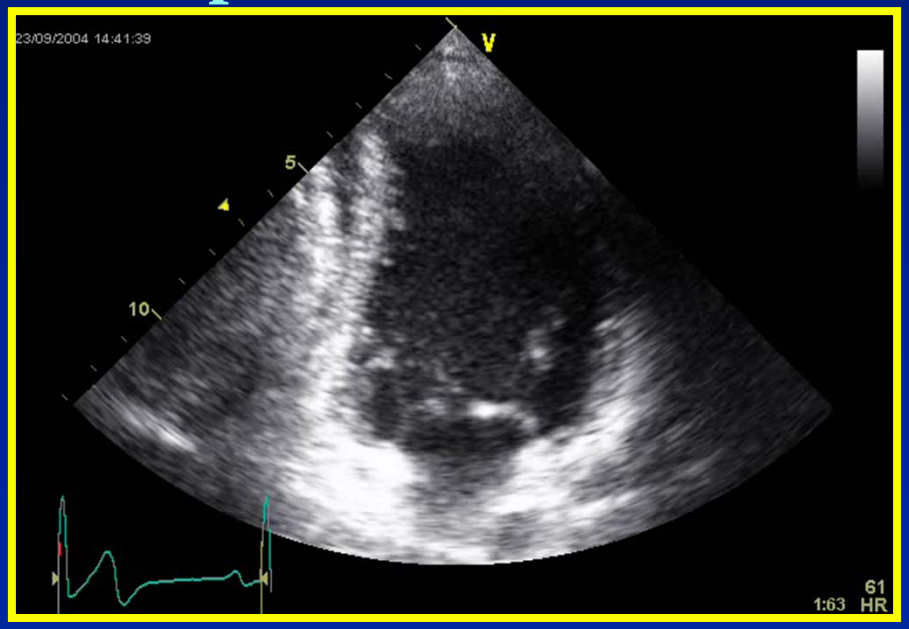
Strain11:22

Normal

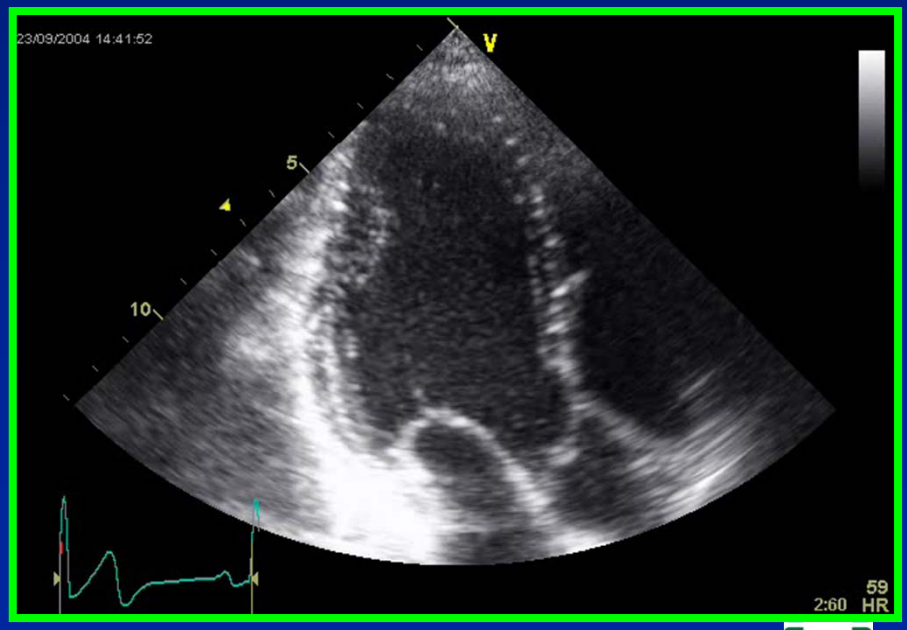


Apical 4 Chamber





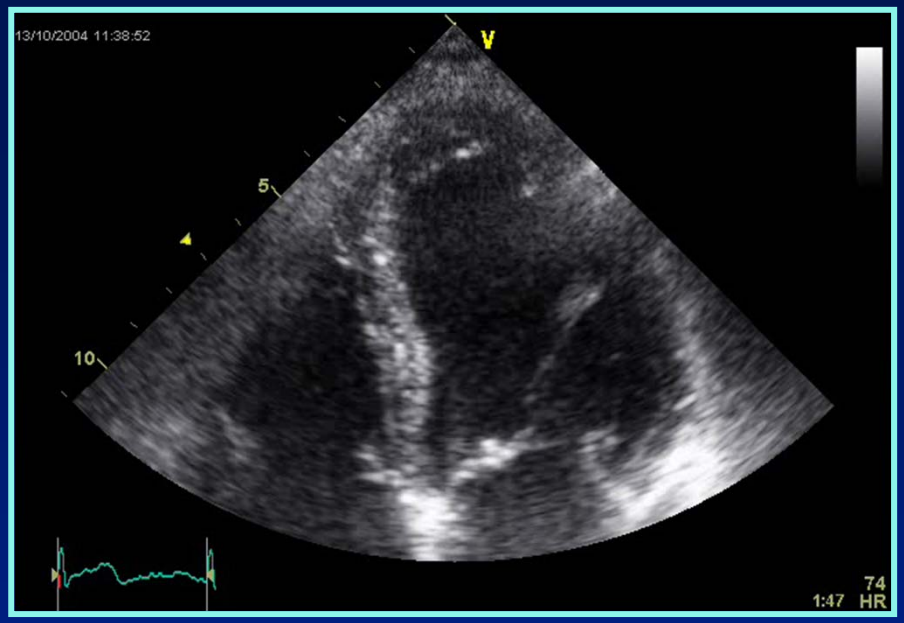
Apical 2 Chamber

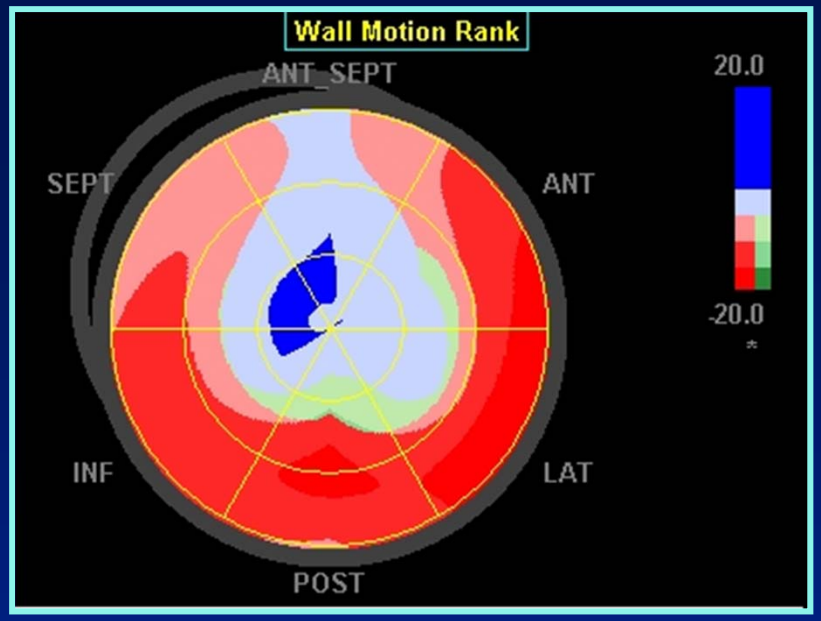


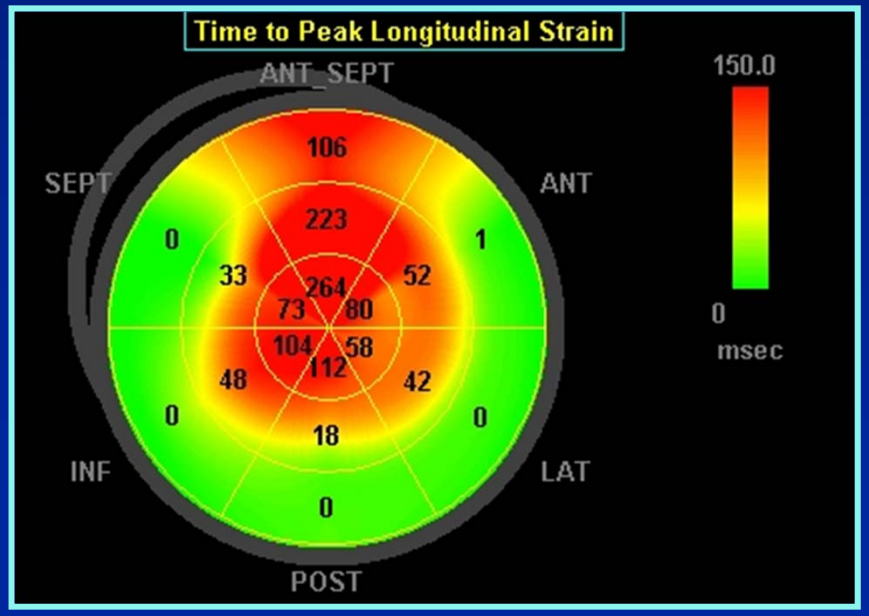
Apical Long-Axis

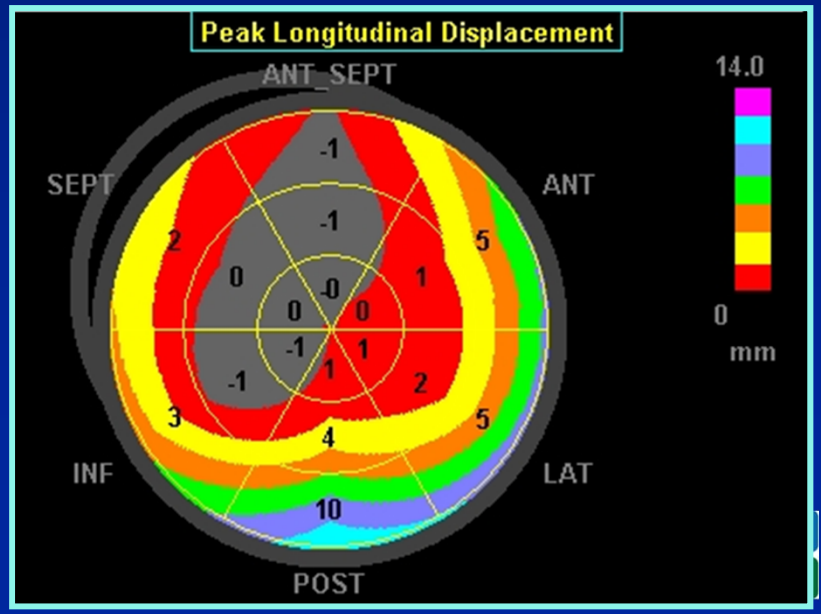
Strain11:23

LAD Infarct



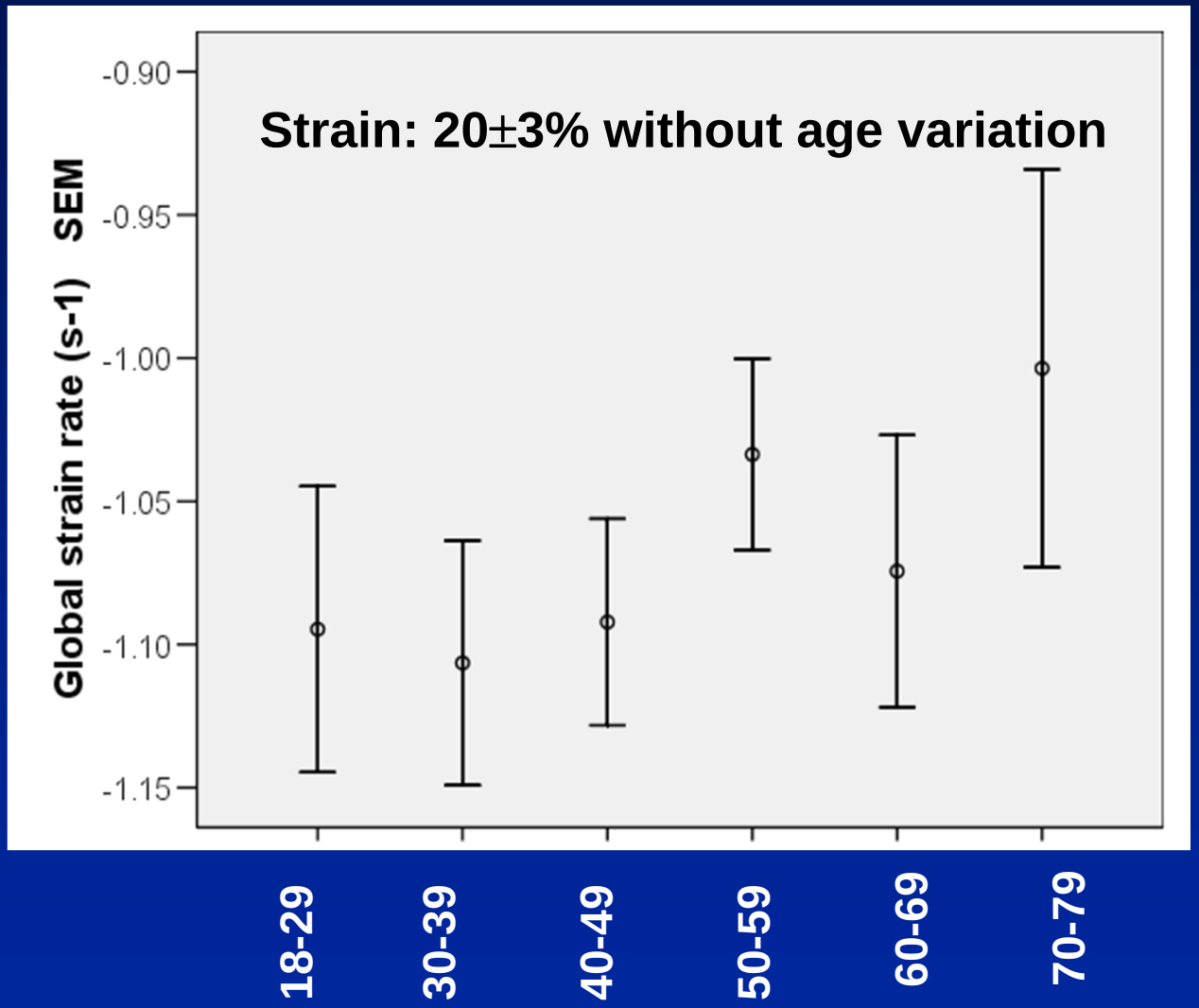






Strain11:24

Normal Global Strain and Strain Rate by Age

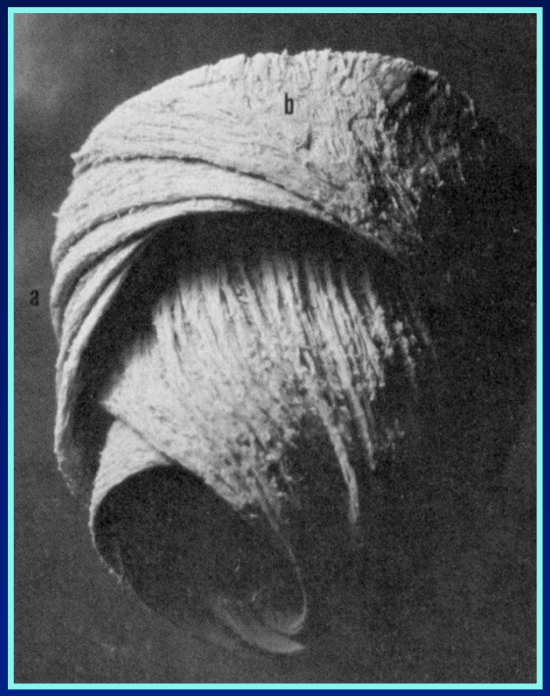


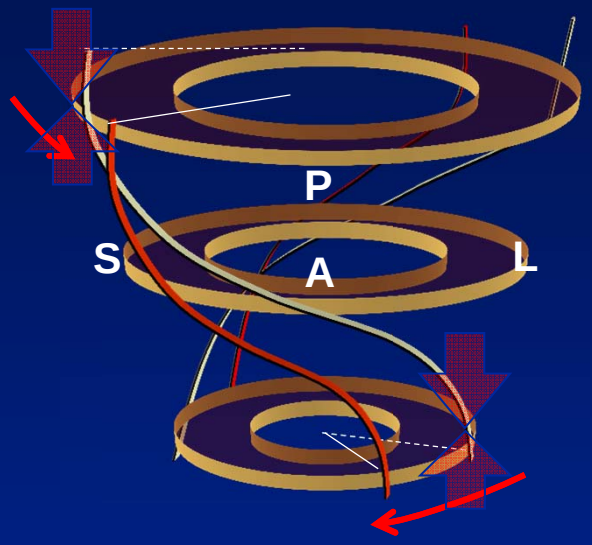
Marwick et al. JACC Imaging 2009; 2: 80-84

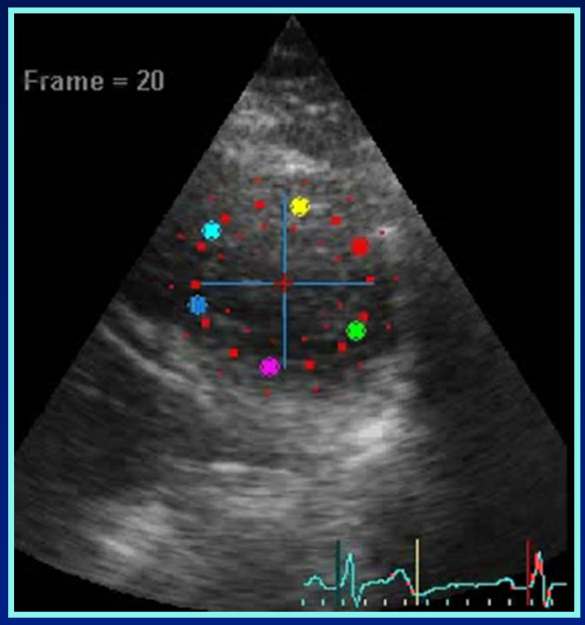
Scenes from Seoul

Strain11:26

What About Torsion?



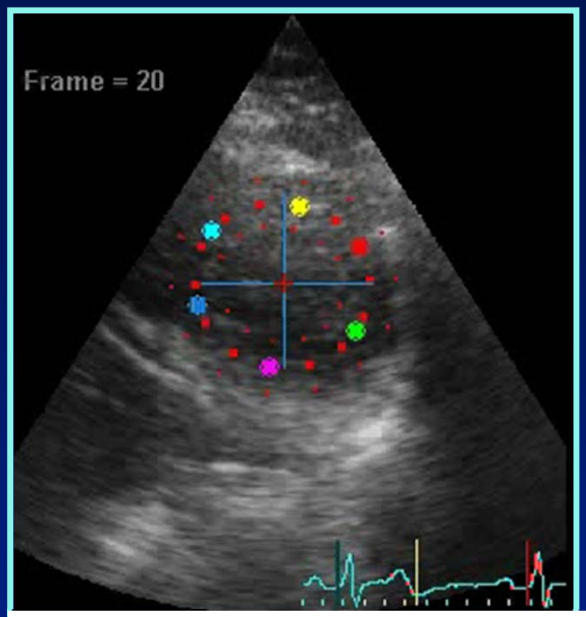


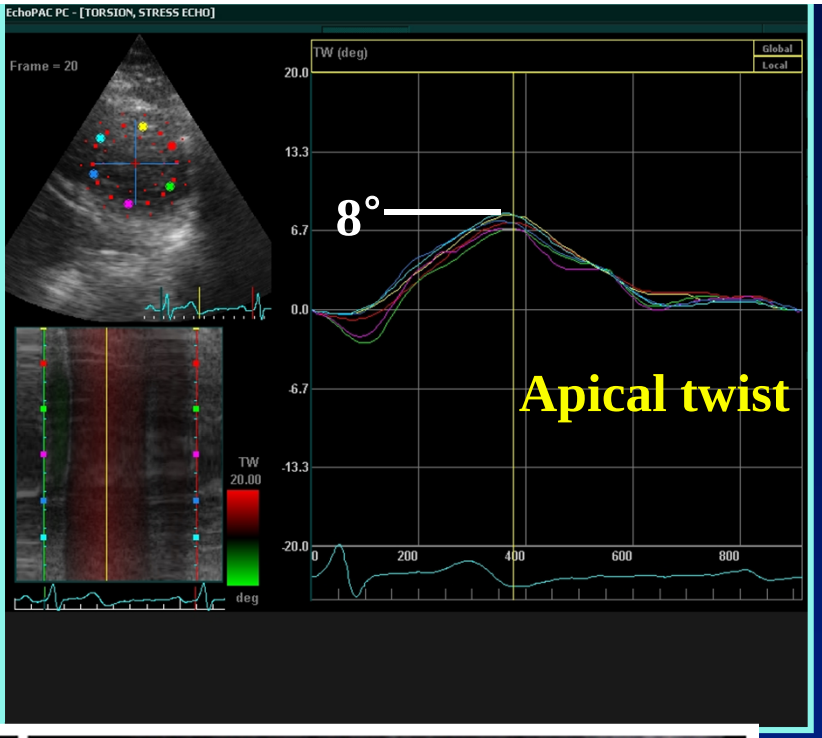


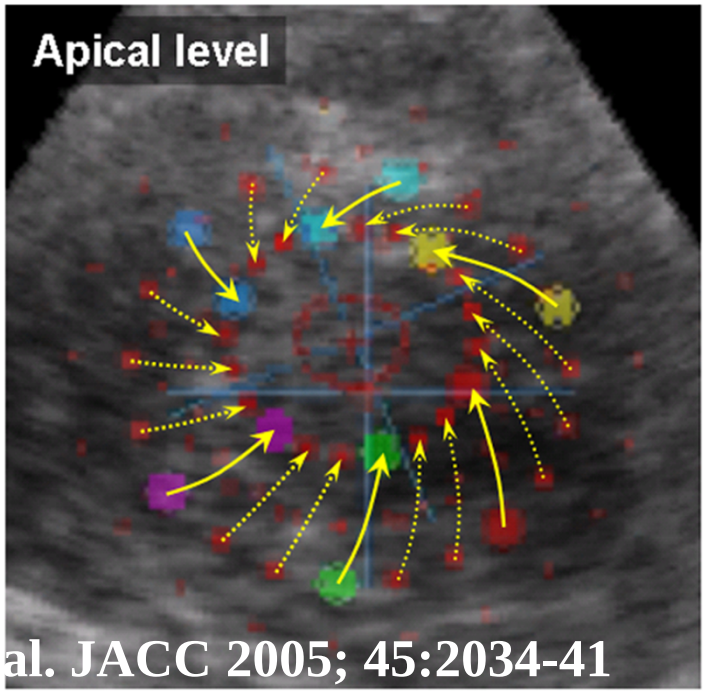
E_{ll}	E_{lc}	E_{lr}
E_{cl}	E_{cc}	E_{cr}
E_{rl}	E_{rc}	E_{rr}

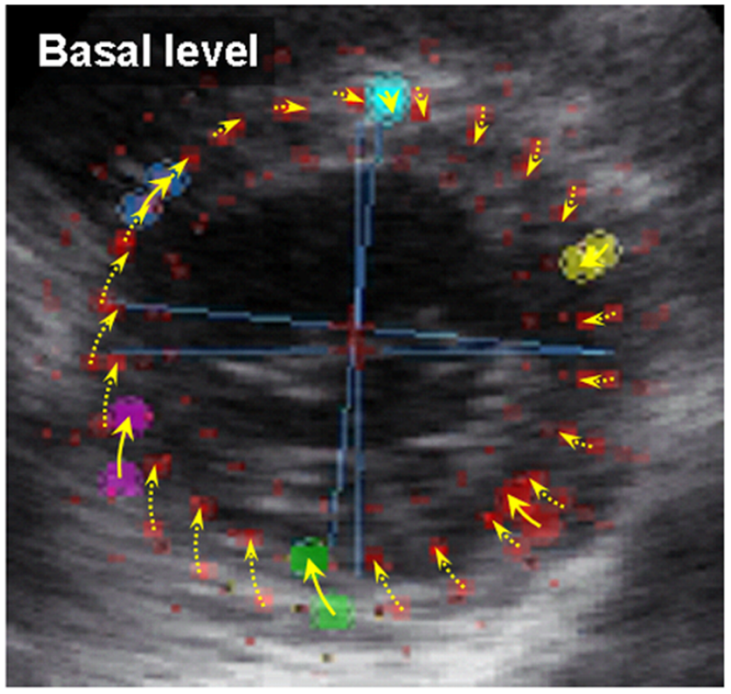
- **Torsion is the longitudinal-circumferential shear component of strain**

Torsion from 2D Echo







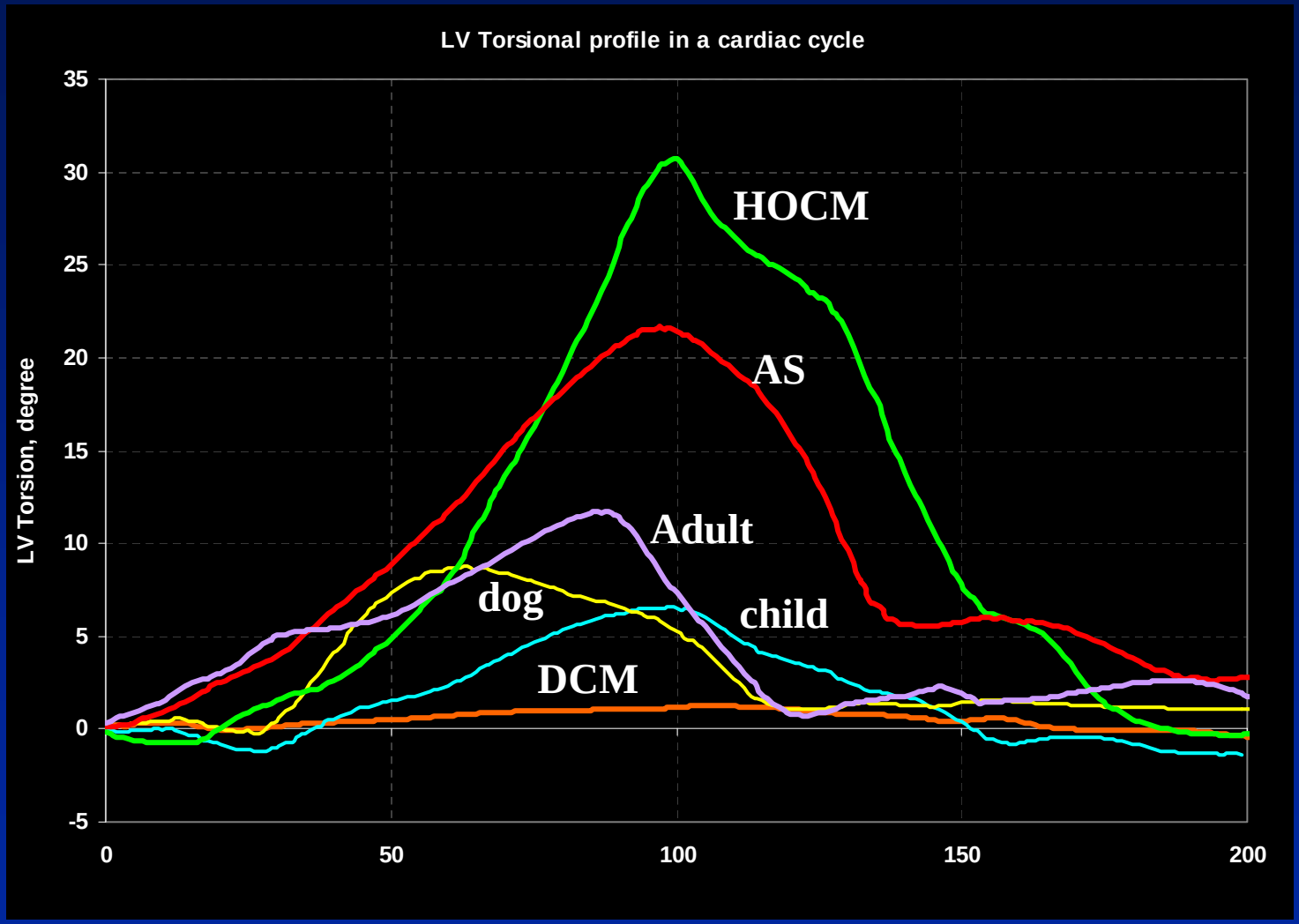


Notomi et al. JACC 2005; 45:2034-41

Strain11:28

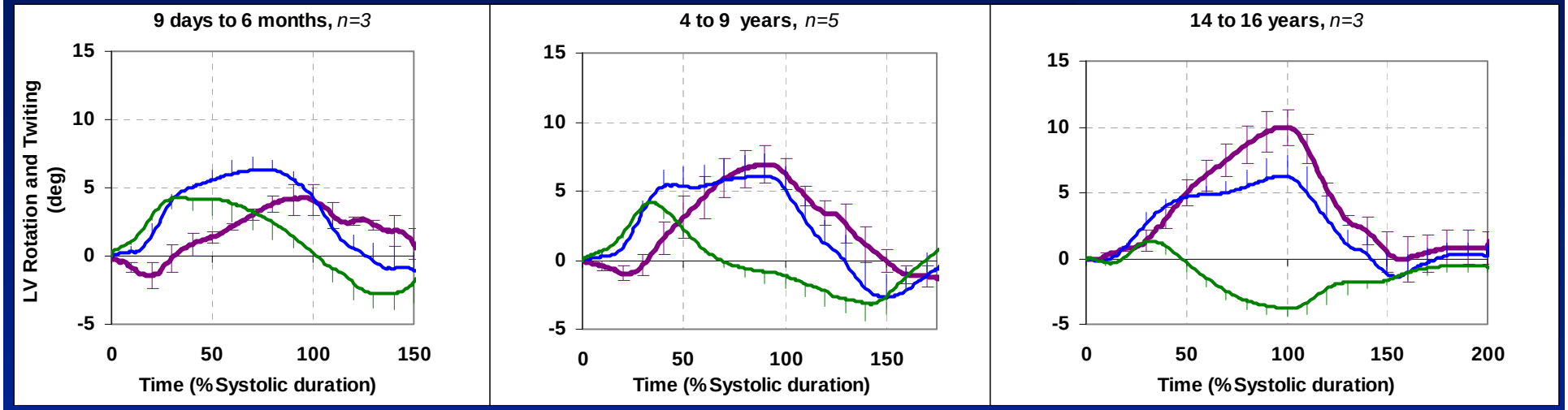
Measurement of LV Torsion

by Doppler tissue imaging



Alteration of LV Torsion in Childhood
No Twist as Infant, Develops by Adolescence

< 6 months: 4° **4 to 9 years : 7°** **14 to 16 years : 11°**

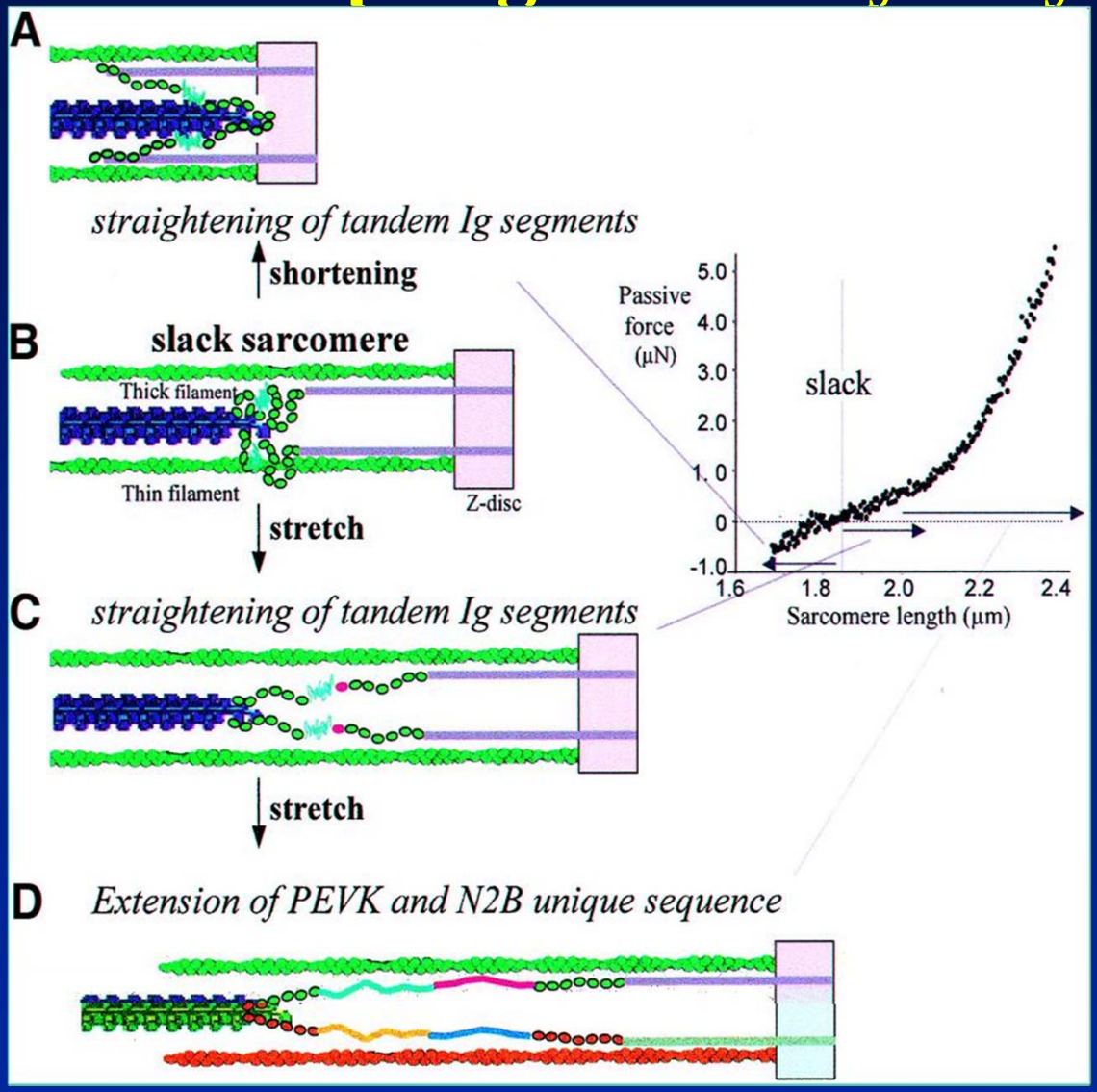


Apex Base Twist

Notomi et al. Circulation 2006; 113: 2534-2541

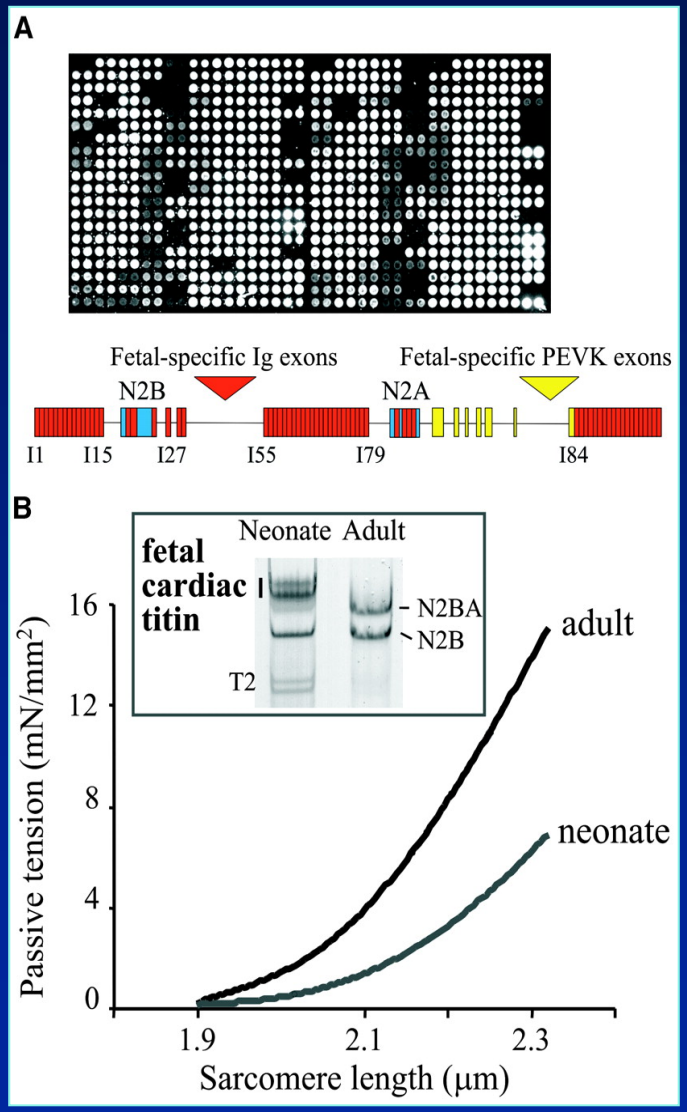
Strain11:30

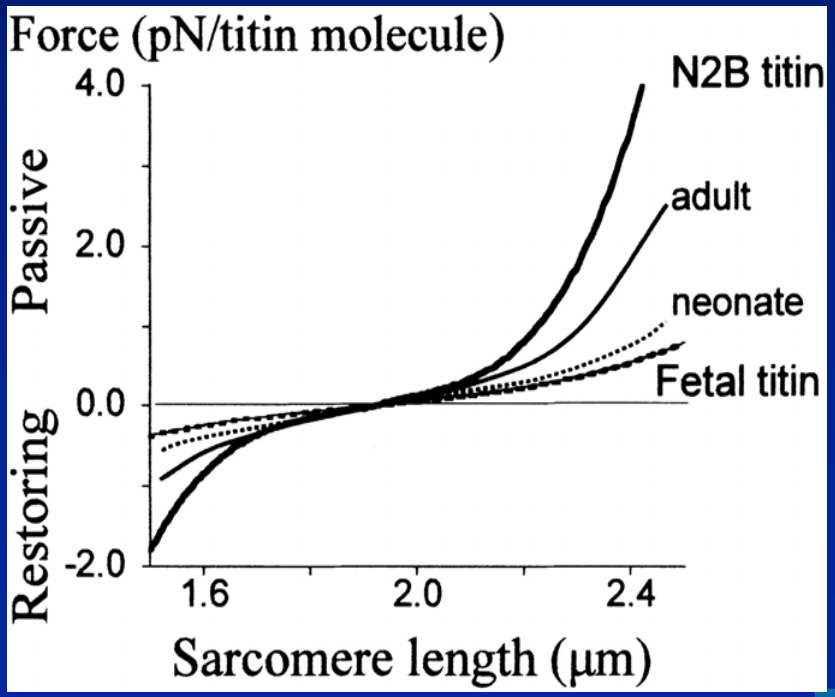
The Molecular Spring Titin May Play a Role



Grenzier and Labeit Circ Res 2004; 94: 284-295

Titin is Stiffer in Adults Than Children

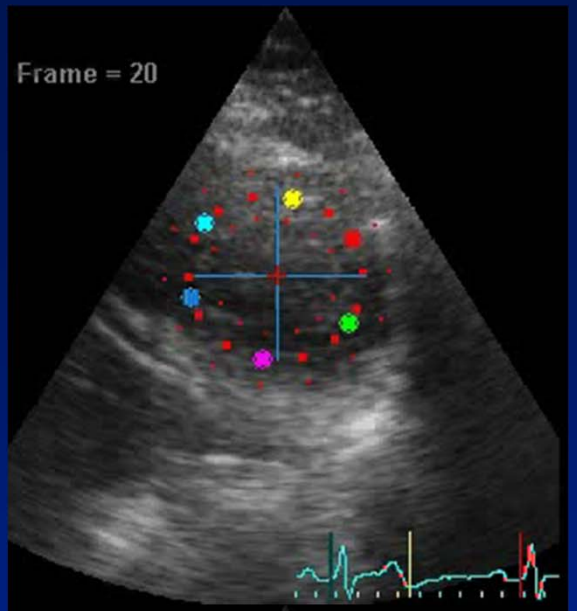




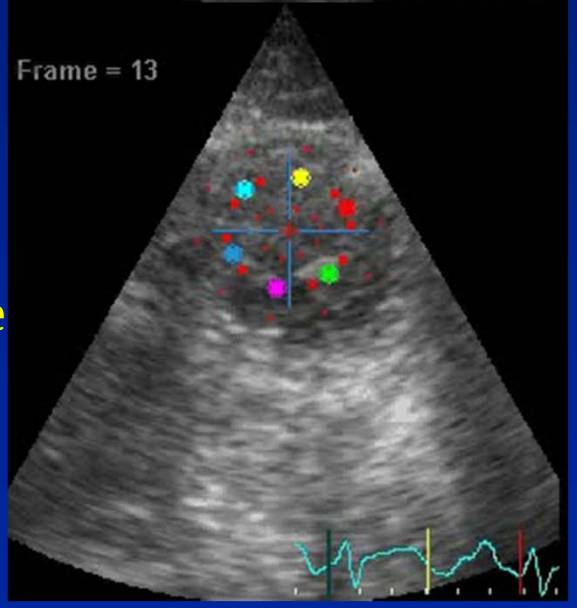
Lahmers et al. Circ Res 2004; 94: 505-13

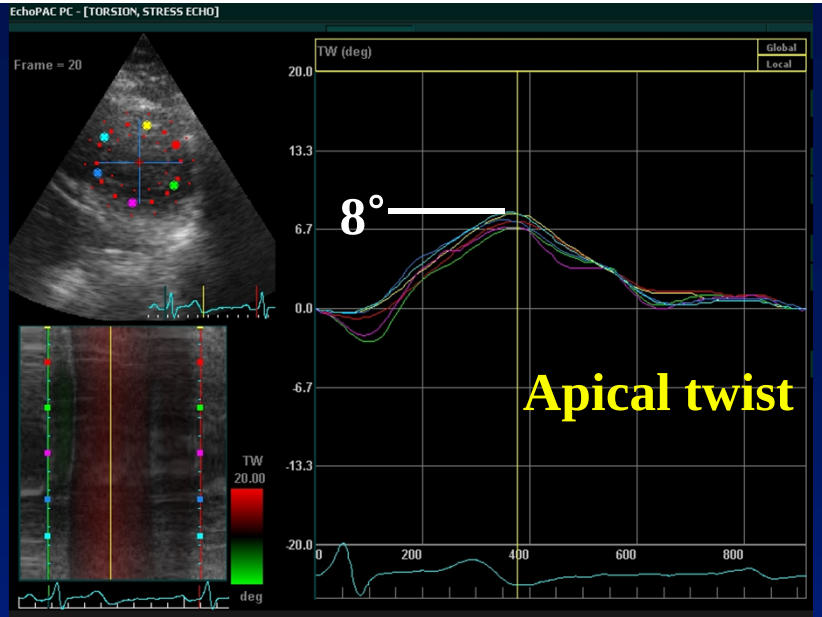
Torsion During Exercise

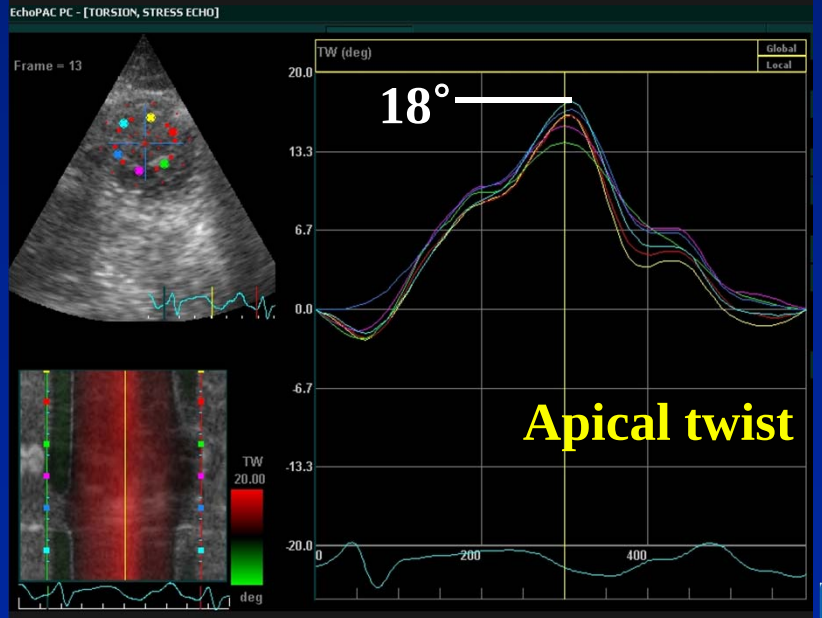
Rest



Exercise



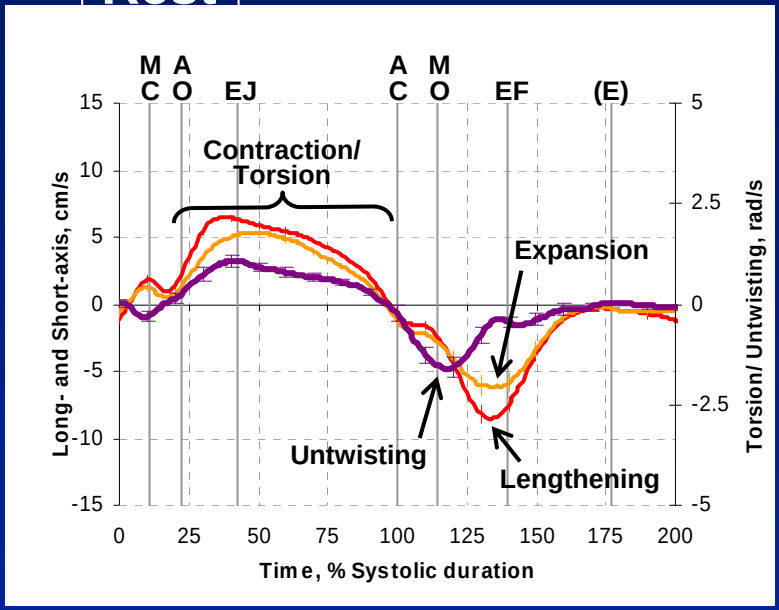




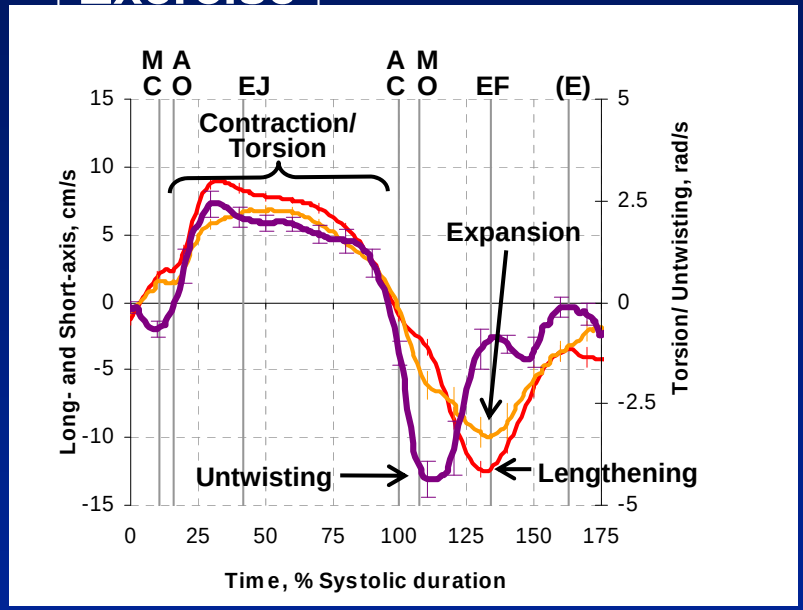
Notomi et al. Circ 2006; 113: 2524-2533

Timing and Magnitude of LV Mechanics
Impact of Exercise

Rest



Exercise



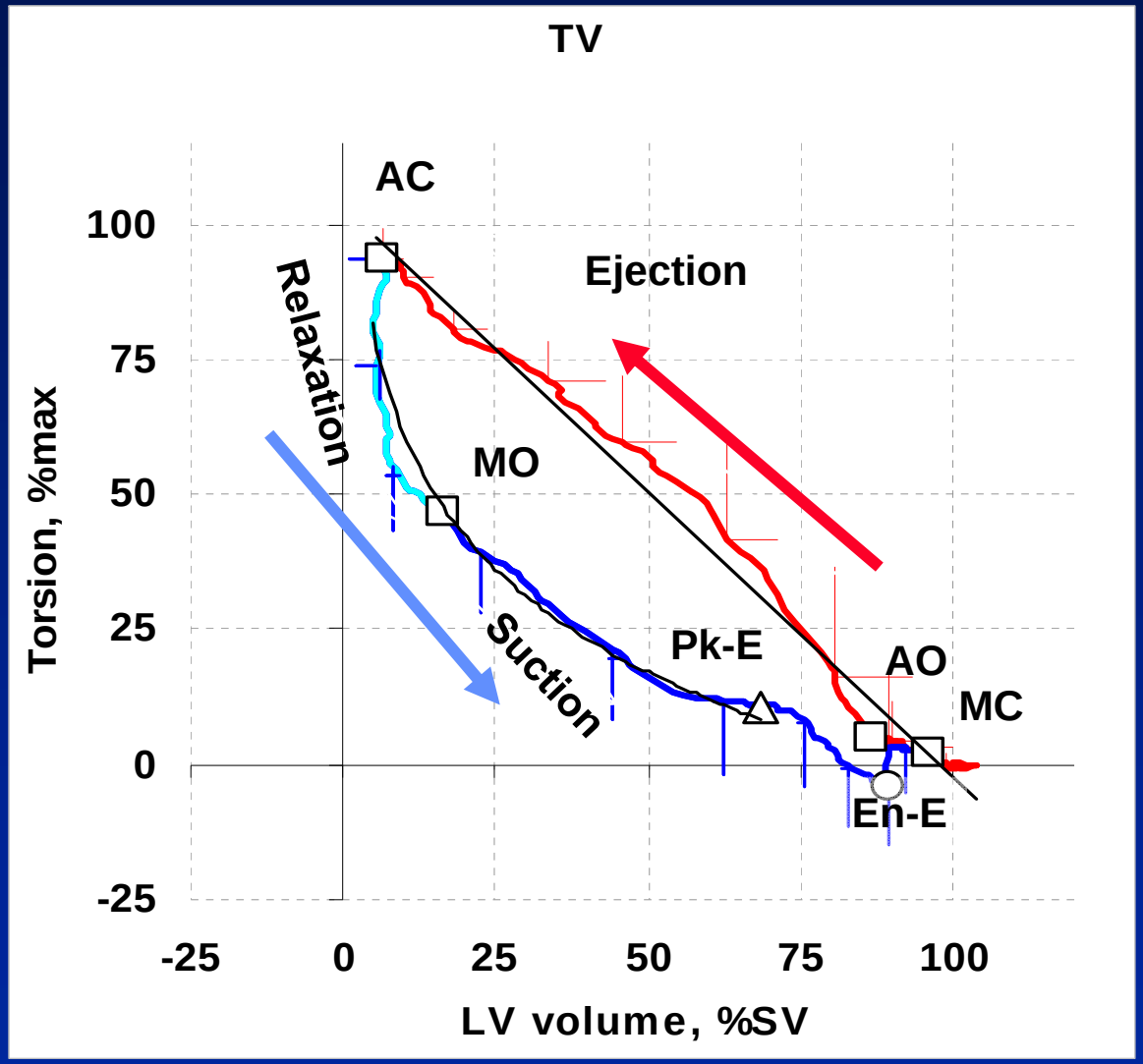
Long axis motion

Radial motion

Torsion

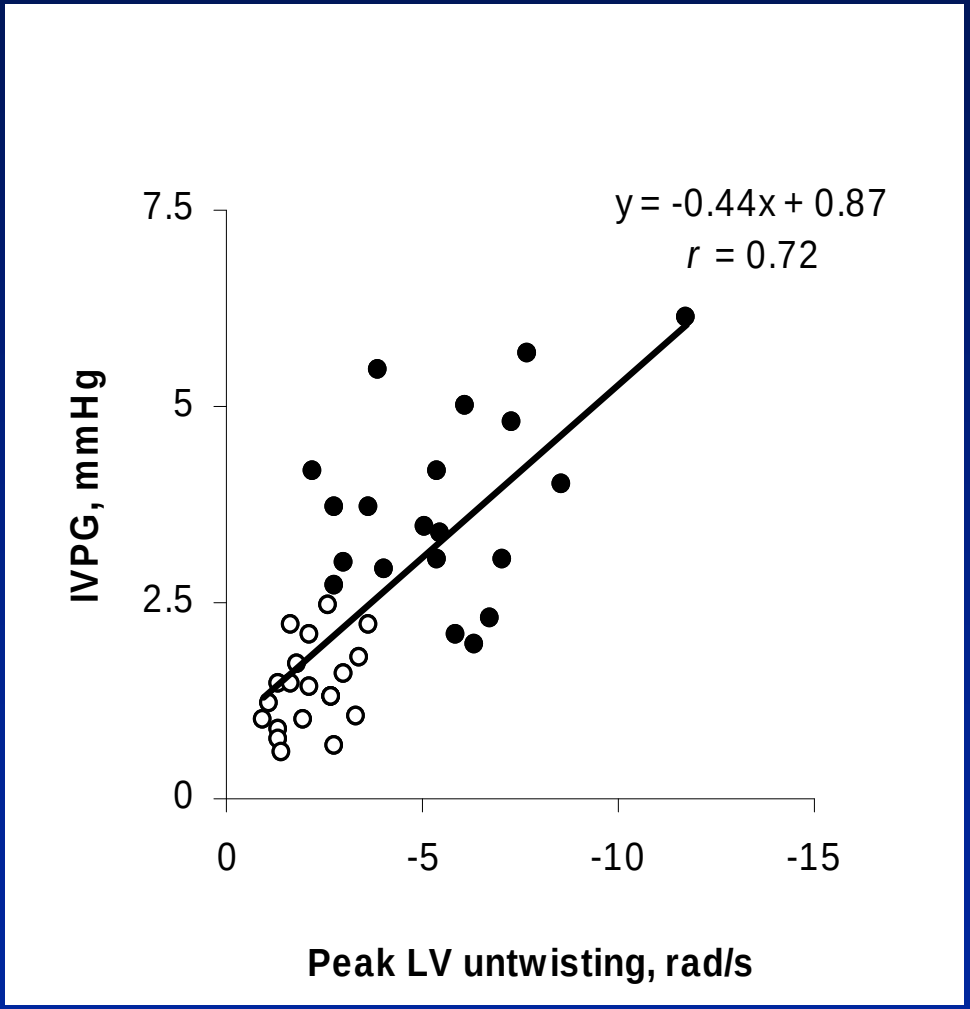
Notomi et al. Circ 2006; 113: 2524-2533

Torsion-Volume Loop



Notomi et al. Circ 2006; 113: 2524-2533

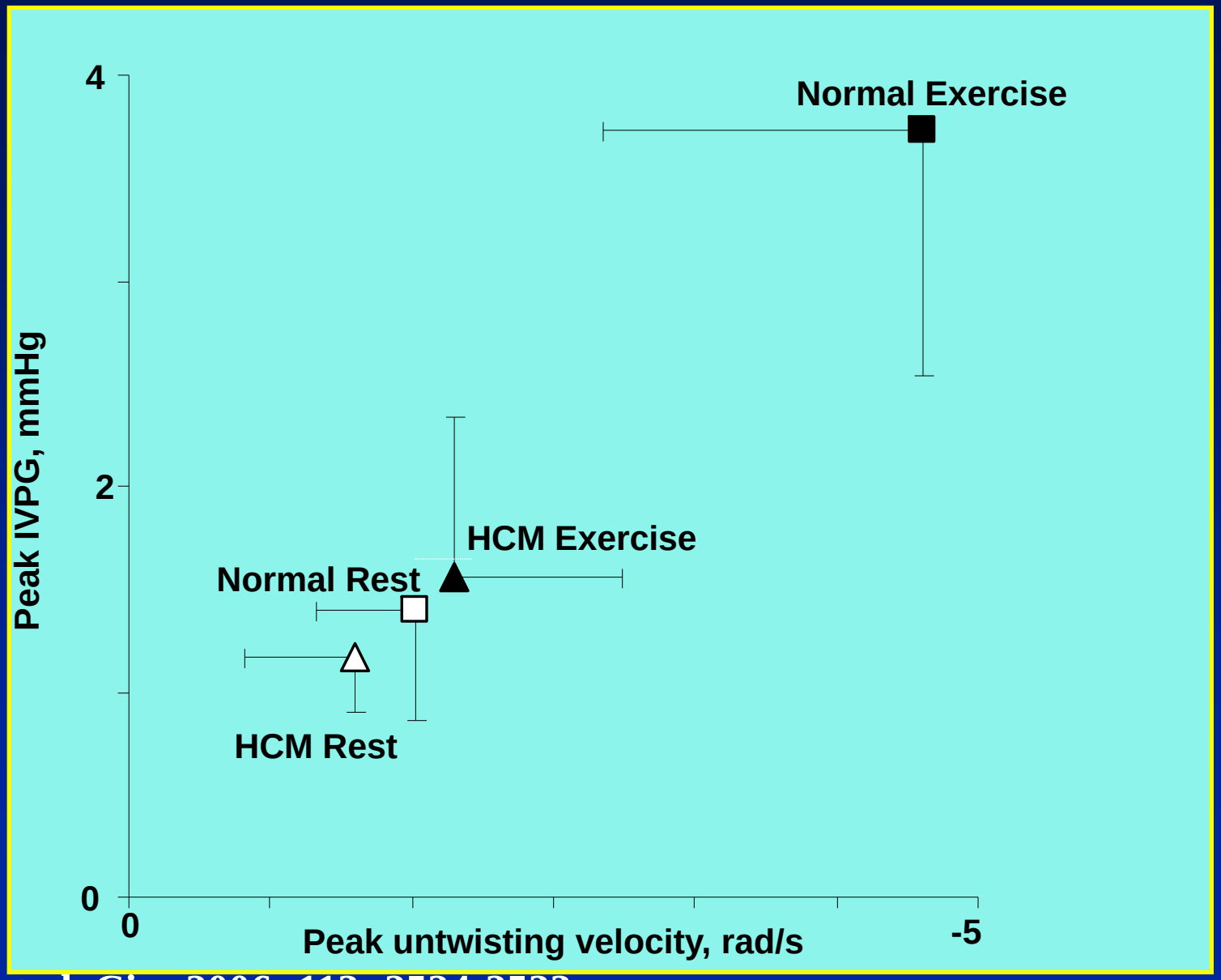
LV Untwisting Predicts IVPG



Notomi et al. Circ 2006; 113: 2524-2533

Strain11:36

Untwisting/IVPG Relationship Holds for Normals and HCM



Notomi et al. Circ 2006; 113: 2524-2533

Putting It All Together

- *During systole, a significant amount of elastic energy is stored in the myocyte and the interstitum as torsion*
- *The earliest mechanical manifestation of diastole is an abrupt untwisting that is largely completed before the mitral valve opens*
- *This untwisting helps to establish a base-to-apex intraventricular pressure gradient in early diastole that assists in the low pressure filling of the heart*
- *Modulation of this mechanism allows the heart to augment its function many-fold during exercise*

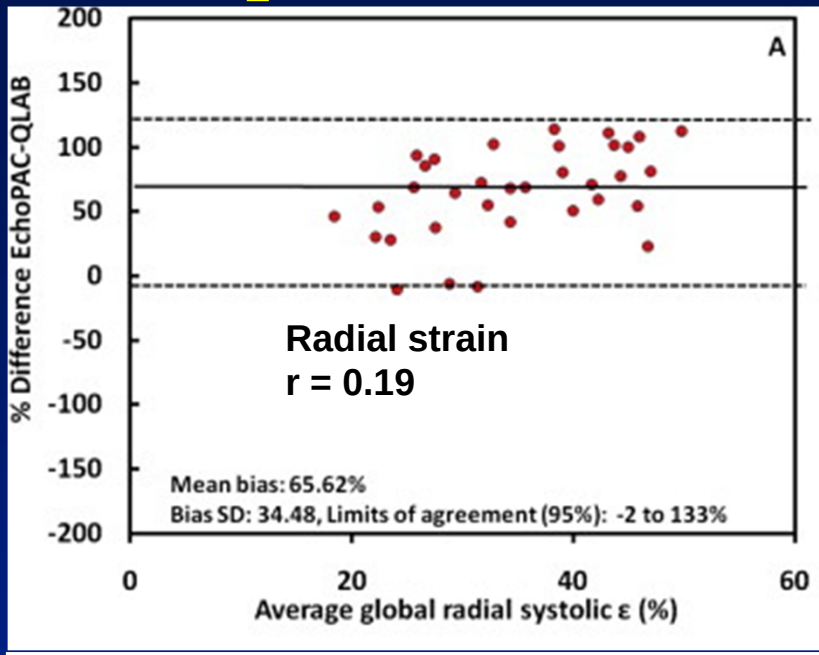
Good tastes in Korea

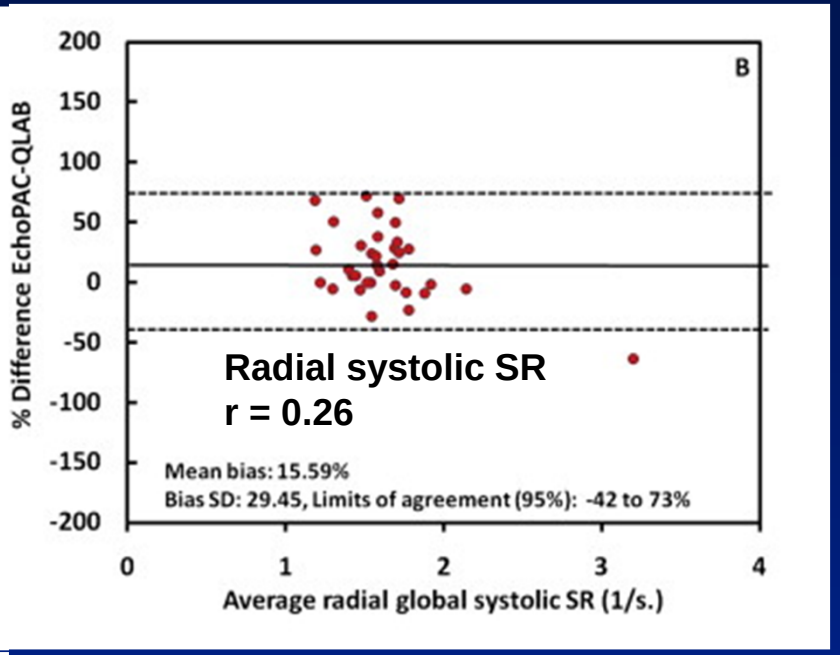
Strain11:39

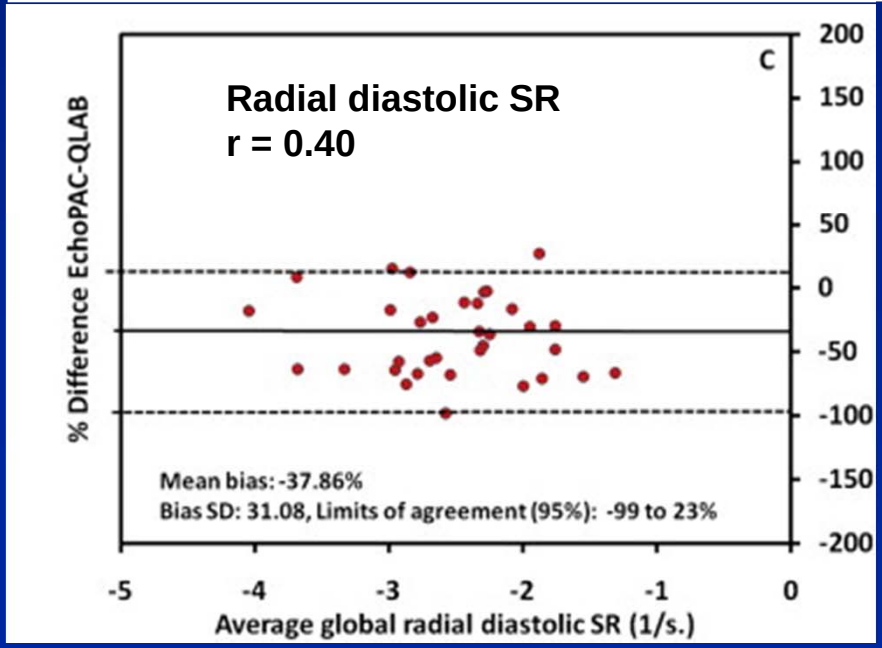
Why Has Strain/Torsion Not Become Mainstream?

- *In 2011 very few clinical reports have any advanced mechanics*
- *No interoperability*
  - **Each company has proprietary format**
  - **No DICOM scan line format**
  - **Different results with different equipment**
- *No standardization*
- *Changing workflow requirements*
  - **On-line or off-line?**
  - **Need for separate review software**
- *Too many parameters!*
  - **And what do they mean???**
- *No reimbursement*

Comparison of Radial Strain Measurements







- 34 children imaged with Philips and GE
- Strain analyzed on QLab and EchoPAC
- Very poor correlation ($r^2 < 0.2$)
- GE almost 2x Philips
- Impossible to compare on serial studies

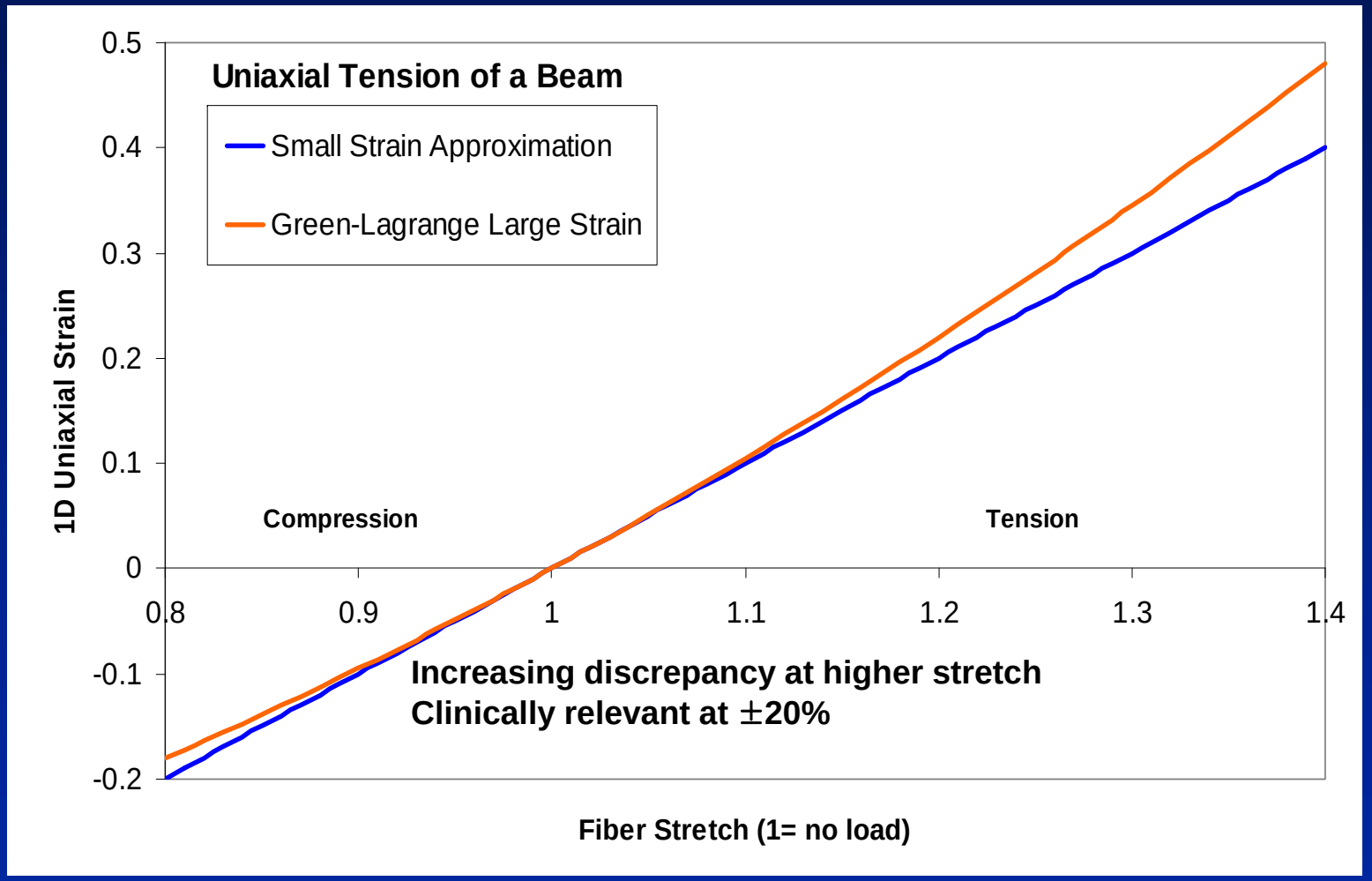
Koopman et al. JASE 2011; 23: 919-28

Strain Can Be Defined in Many Ways

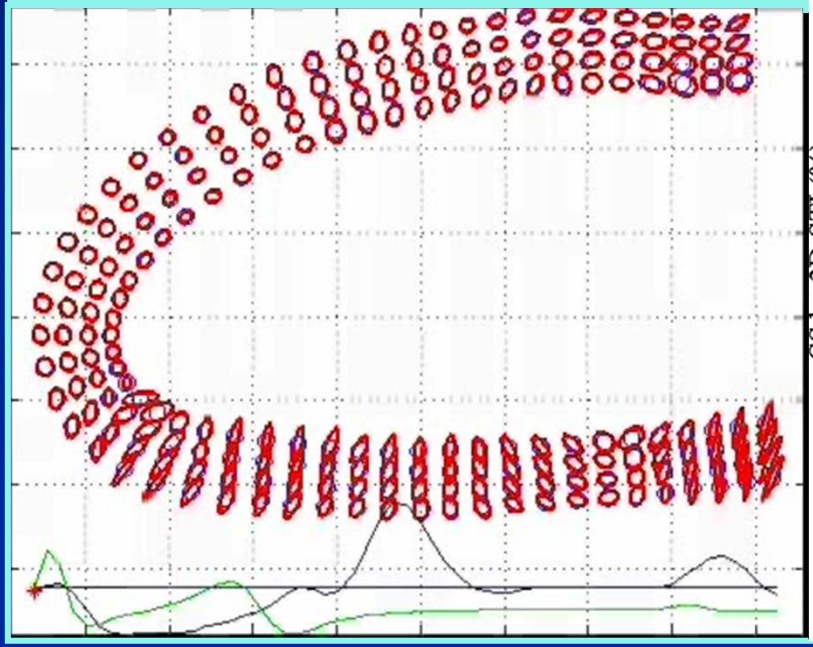
Some 1D Strain Definitions

- Small Strain $$e_0 = \frac{l - l_0}{l_0}$$
- Green Lagrange Strain $$\varepsilon = \frac{1}{2}\frac{l^2 - l_0^2}{l_0^2}$$
- Almansi Strain $$\varepsilon_a = \frac{1}{2}\frac{l^2 - l_0^2}{l^2}$$
- Logarithmic Strain $$e = \ln\frac{l}{l_0} = \int_{l_0}^{l}\frac{dl}{l}$$

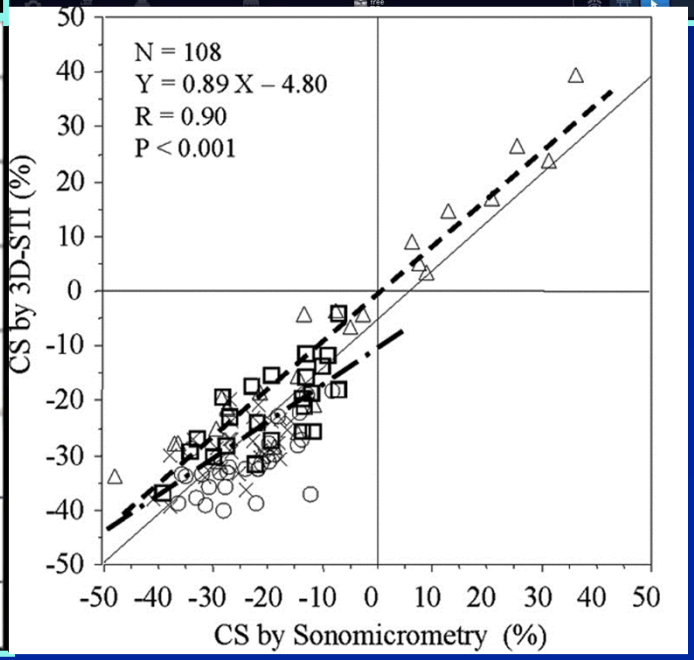
Small Strain or Large Strain?
Manufacturers Do Not Specify their Approach



Transmural strain

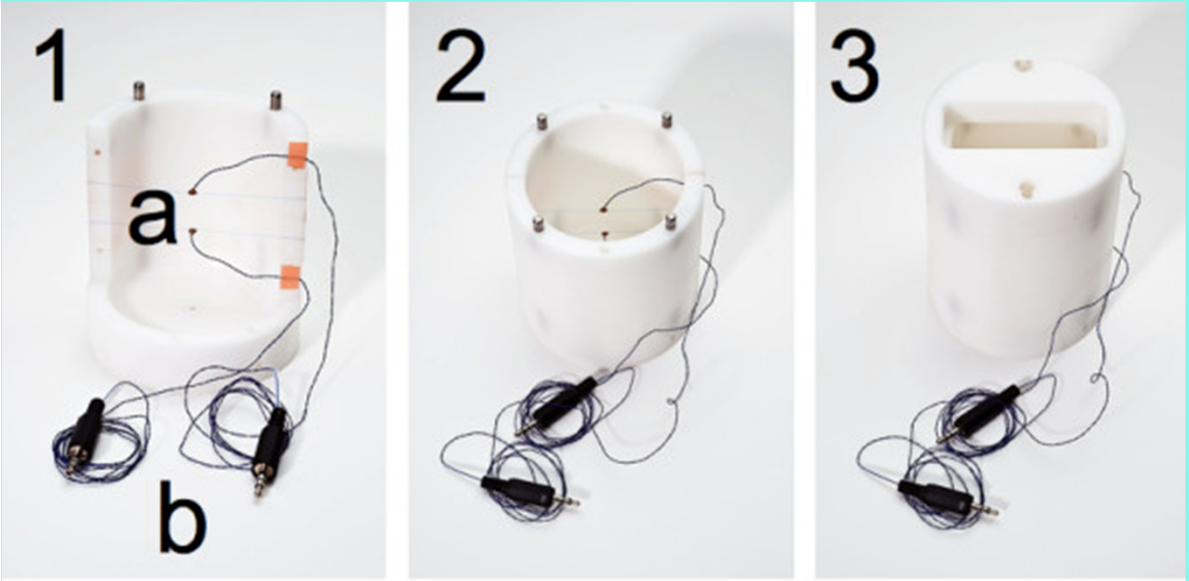


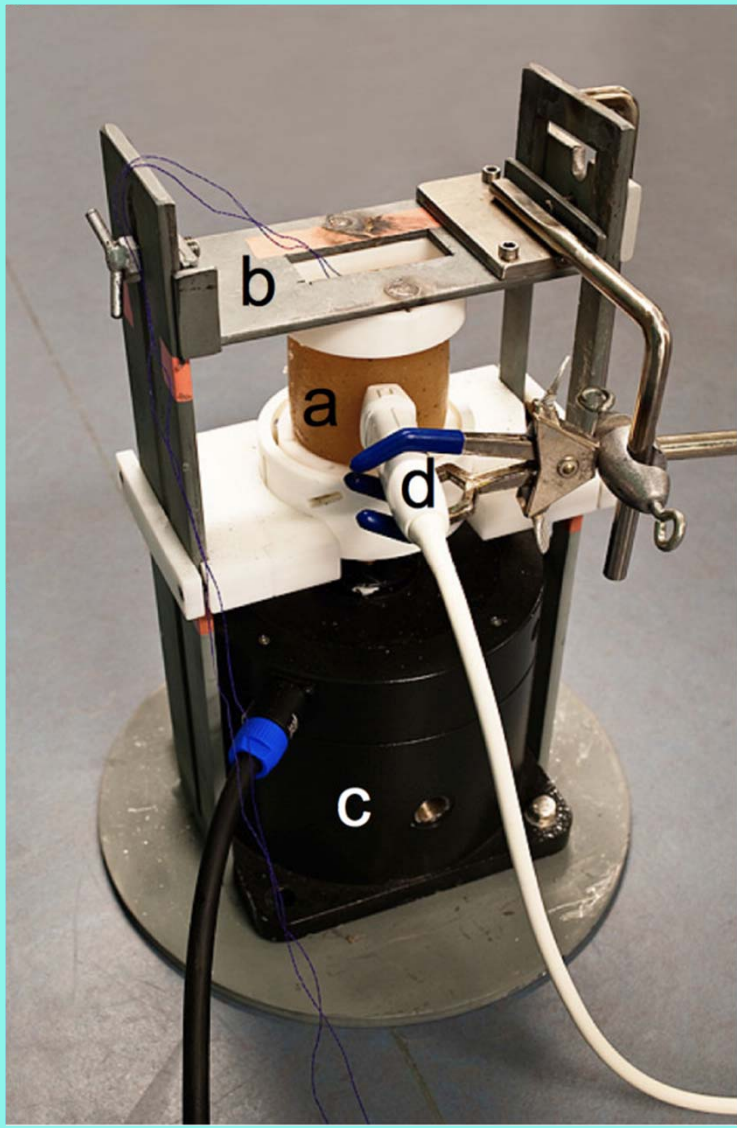
3D strain



Seo et al. Circ Img 2009; 2: 451-9 Strain11:44

Approaches to Standardization
In vitro strain phantom??





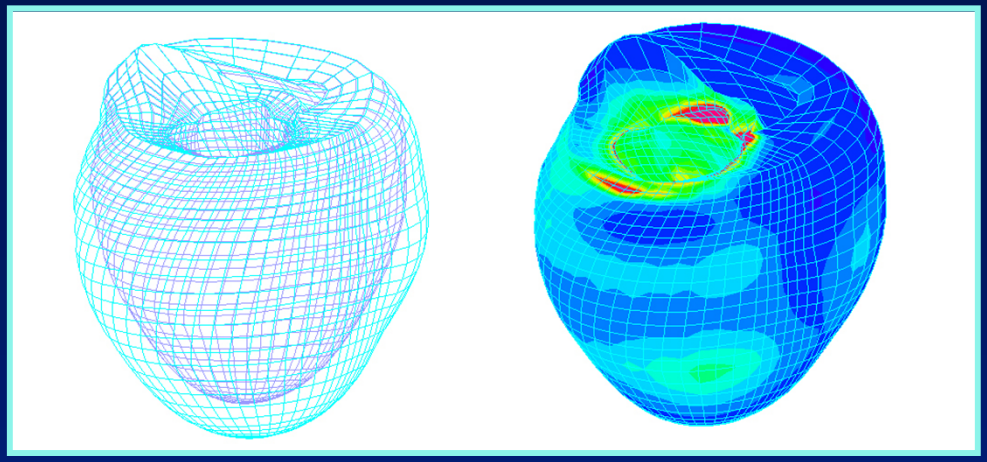
- Agar gel with reflectors formed inside a mold
- Sonomicrometer crystals imbedded within
- Rhythmic deformation applied to gel
- Can only validate 1D strain
- Agar dehydrates so phantom rapidly deteriorates

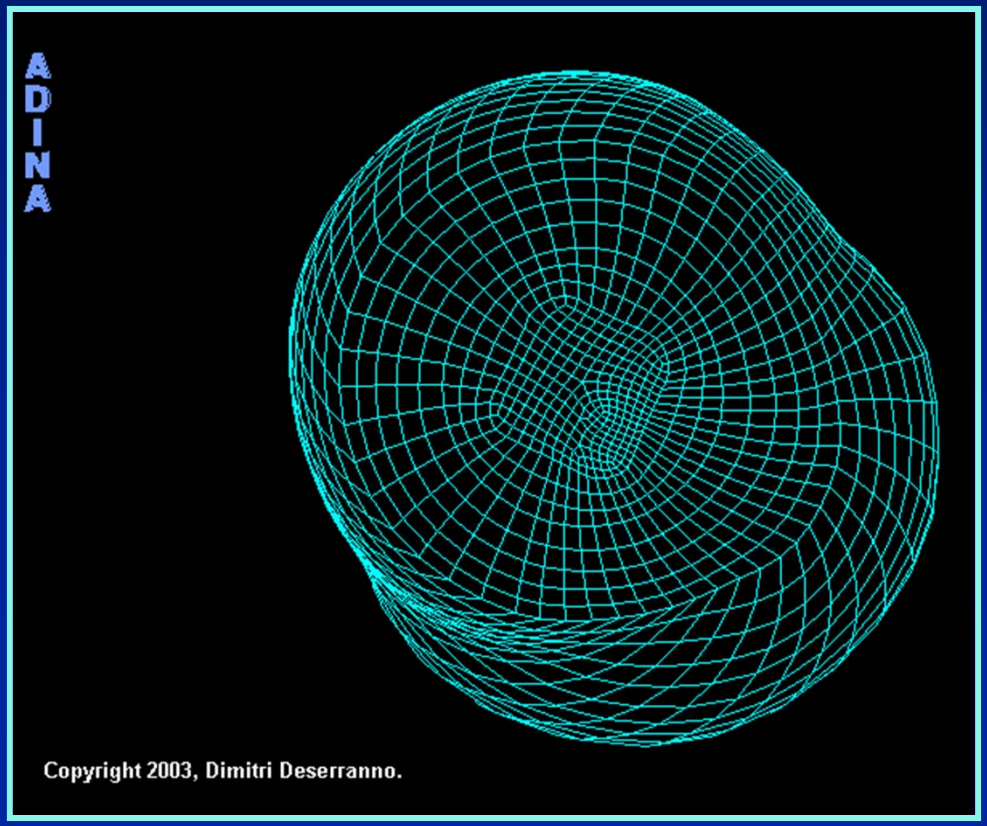
Stigo et al, Cardiovasc Ultrasound 2010; 8: 40

Possible Approaches

- *Improved interoperability*
  - Can we develop a DICOM scan line format
  - Barring that would individual companies provide a way for others to work with their data
  - ASE and EAE have formed task force with industry
- *Standardization*
  - Develop a strain phantom?
- *Changing workflow requirements*
  - On-line or off-line must give the same values!
- *Too many parameters!*
  - Need for comparative studies
- *Approach to reimbursement*
  - Can we prove the value of this without devaluing the rest of echo

LV Mechanics: Present State of the Art





We now have the echocardiographic tools available to let us assess LV contraction, relaxation, compliance, suction, and filling pressure.

3D Modelling of LV Torsion

Strange tastes in Korea

“Tuna’s tears”

Strain11:48