Physiology of Systole: What are We Really Trying to Measure?

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Research Support/Disclosures:
NIH: R01-HL078610, R01-HL130036, P51-OD011092, R01-135024
NASA: 18-18HCFBP_1_009
GE Healthcare, Lantheus, Philips

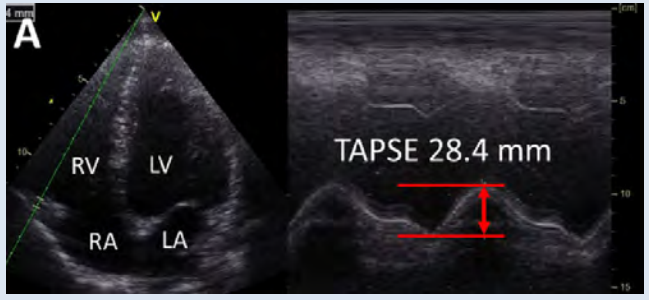
General Ideas on Squeeze and Pump

Left Ventricle

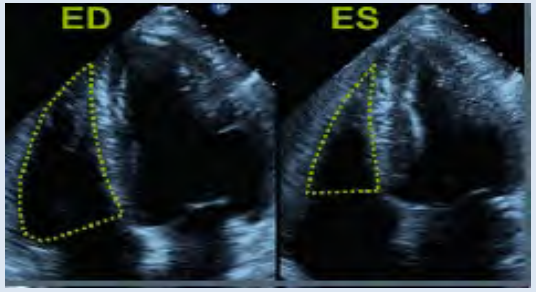
Right Ventricle

Imaging RV Function

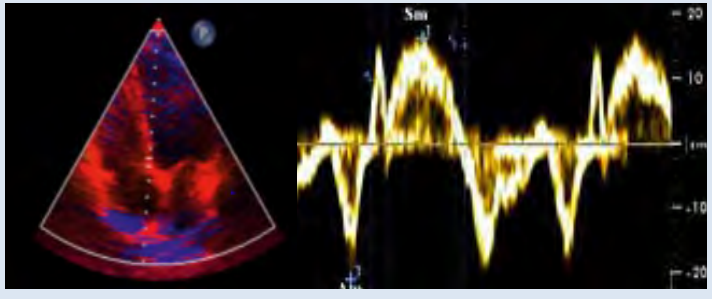
TAPSE



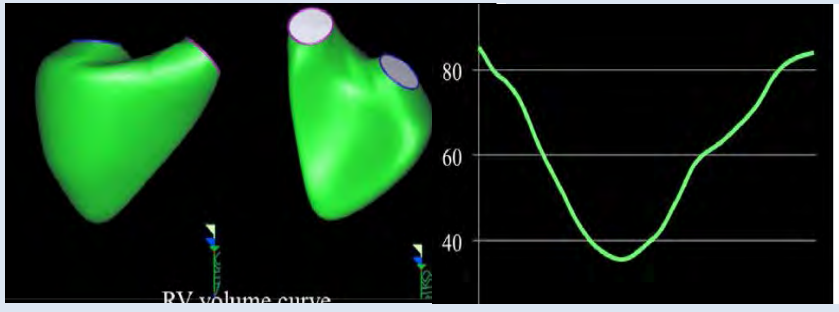
Fractional Area Change



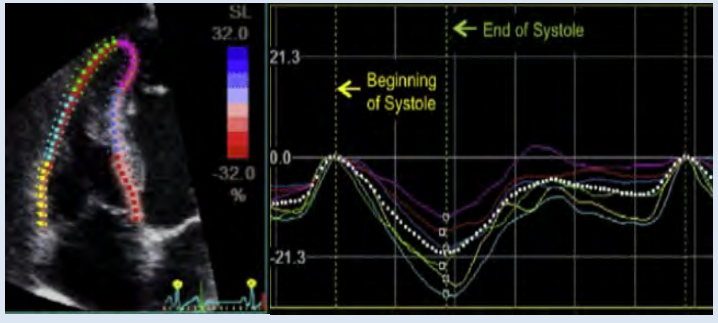
Systolic Velocity



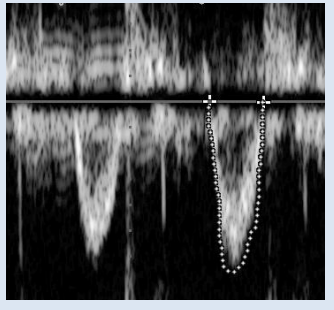
3D RVEF



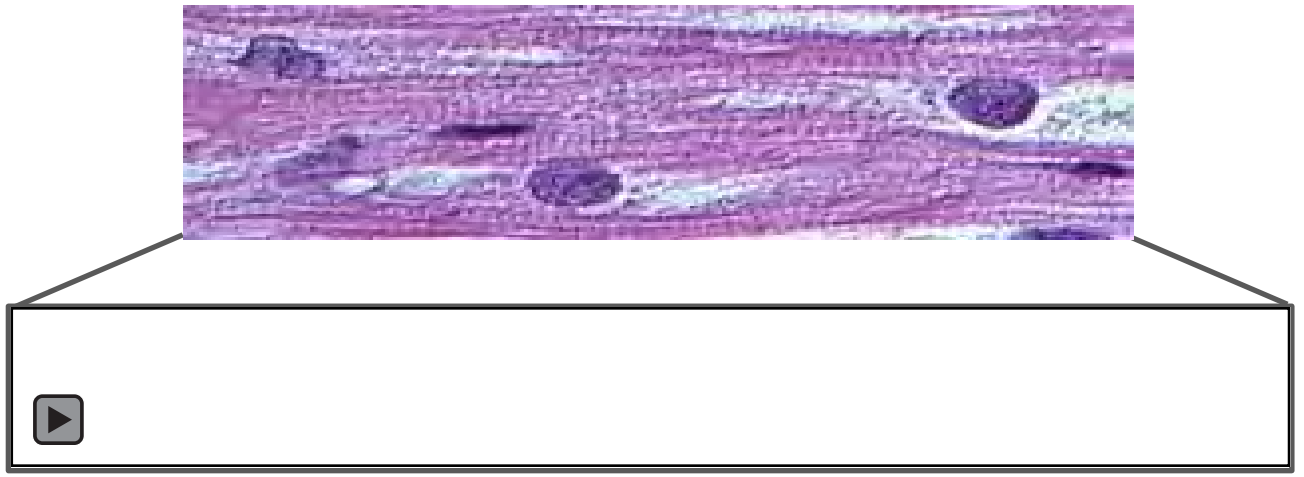
RV Strain

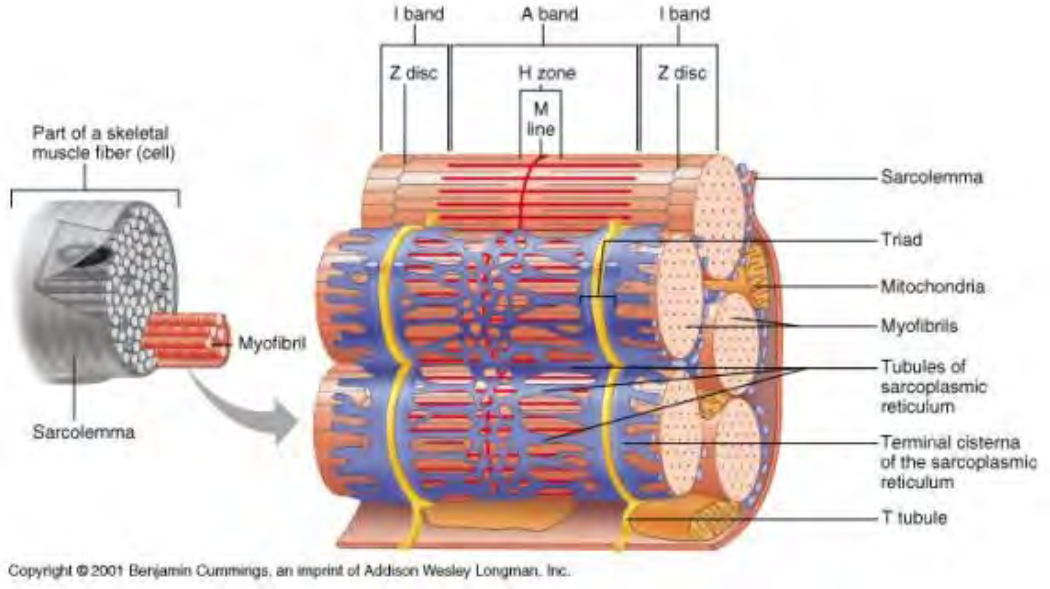


Stroke Volume



The Cardiomyocyte and LV Function





Dynamic Morphometrics

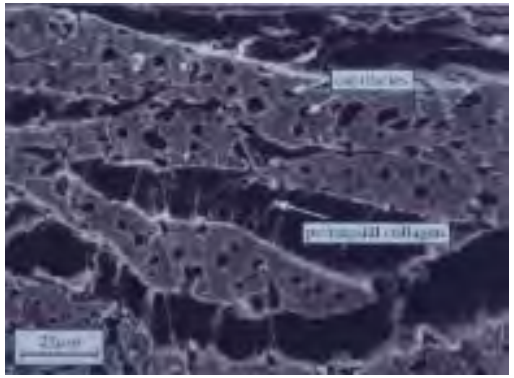
Myocyte shortening: 15%

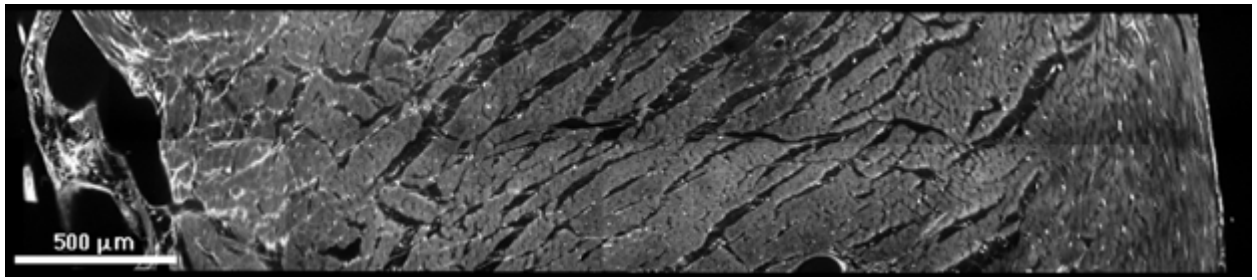
Myocyte thickening: 8%

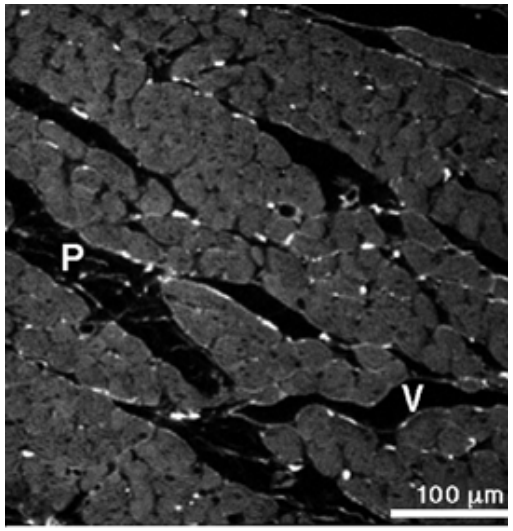
Wall thickening: 40%

Ejection Fraction: 60-70%

Myocardial Sheet Composition

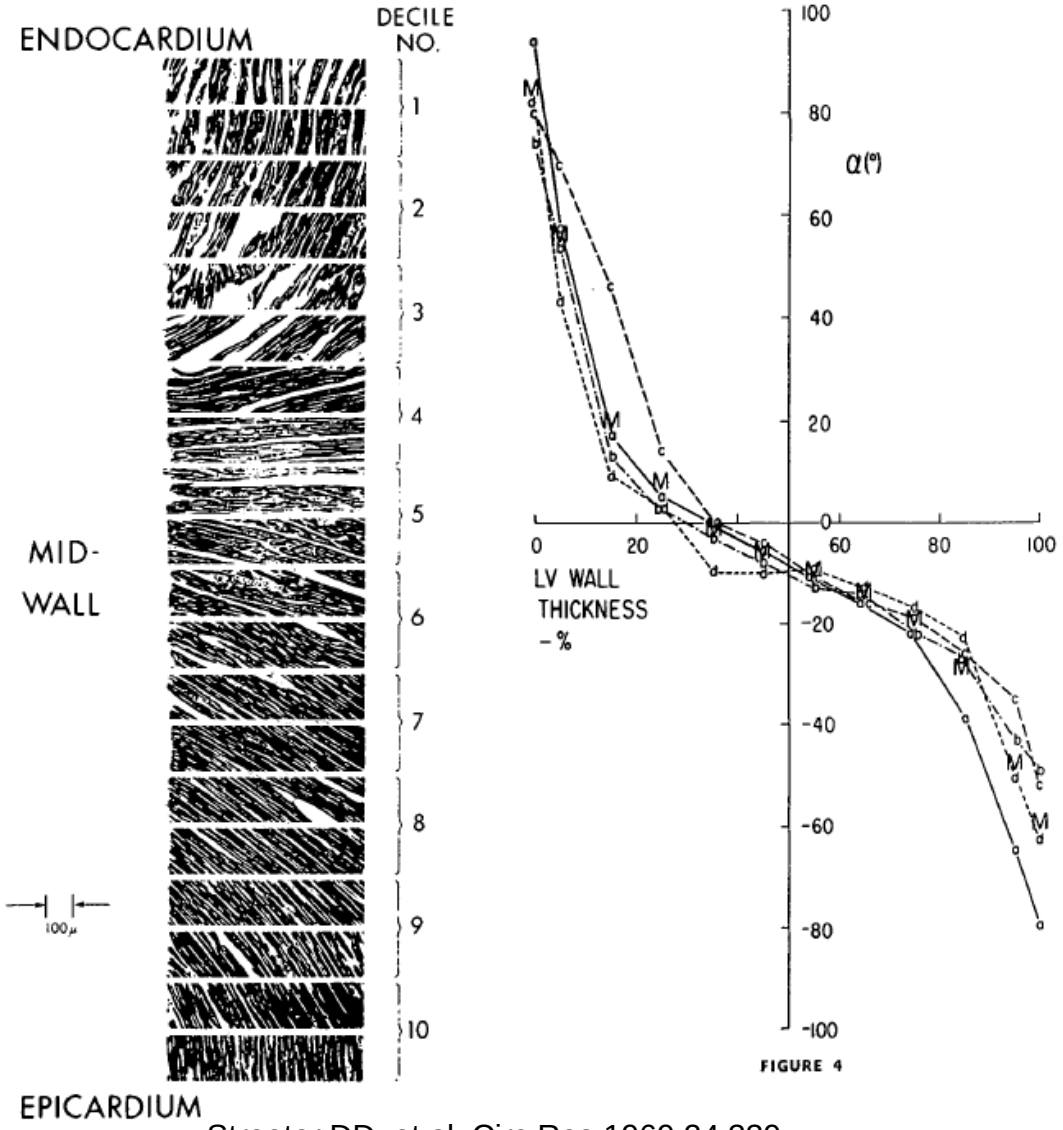






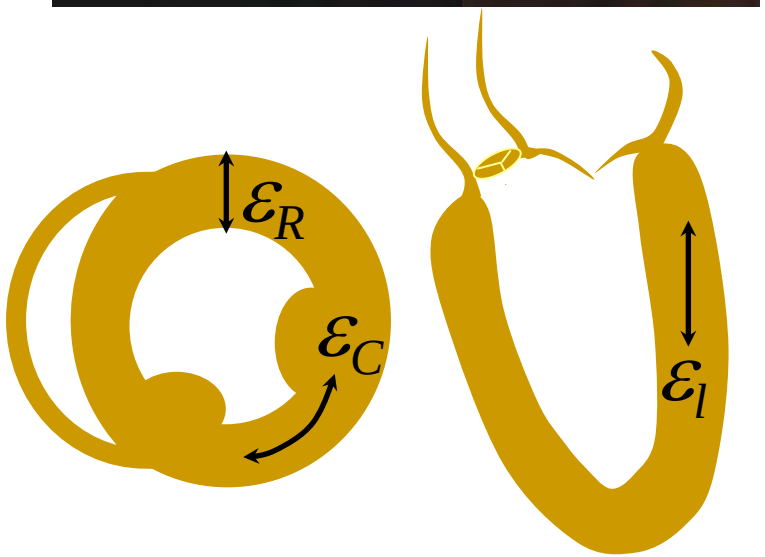
Young AA, et al., J Microsc 1998;191:131

Fiber Orientation and Strain

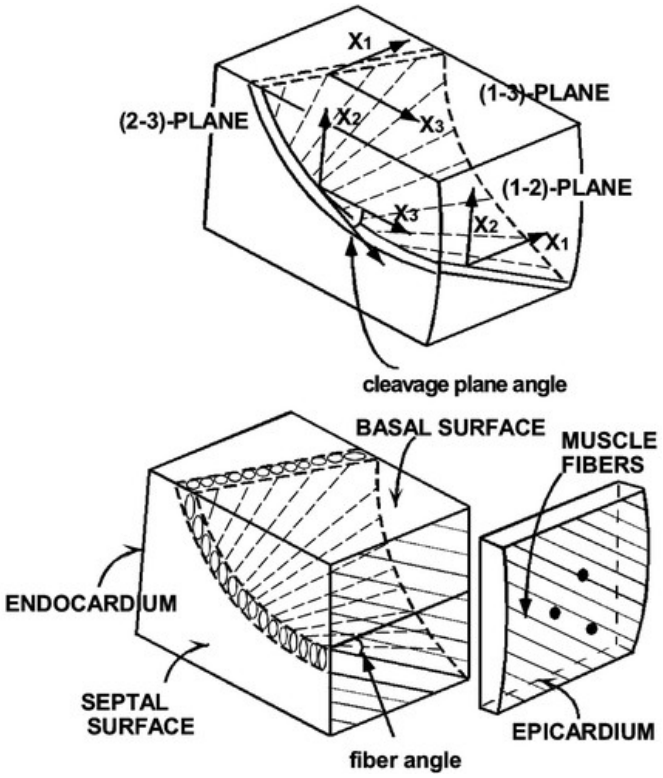


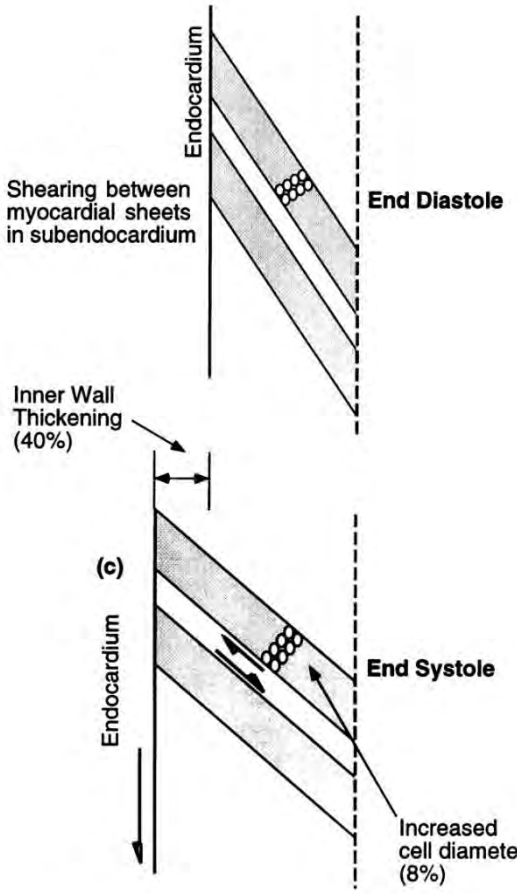
Streeter DD, et al. Circ Res 1969;24:339

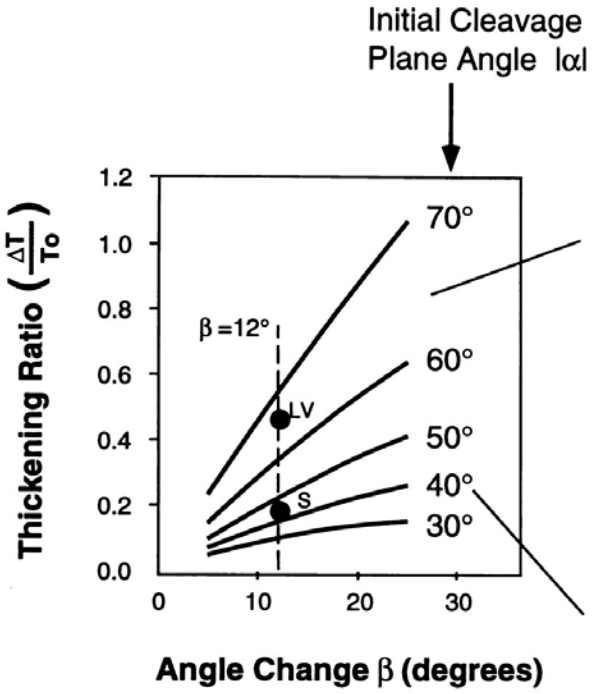
Buckberg G, JTCS 2002:863



Sheet Thickening and Interlaminar Shear







$$\frac{\Delta T}{To} = \frac{\cos(|\alpha| - |\beta|)}{\cos(|\alpha|)} - 1$$

Y Takayama et al. Am J Physiol 2002;282:H1510

IJ LeGrice et al. Circ Res. 1995;77:182

Imaging Assessment of the Periodic Pump

Muscle Squeeze

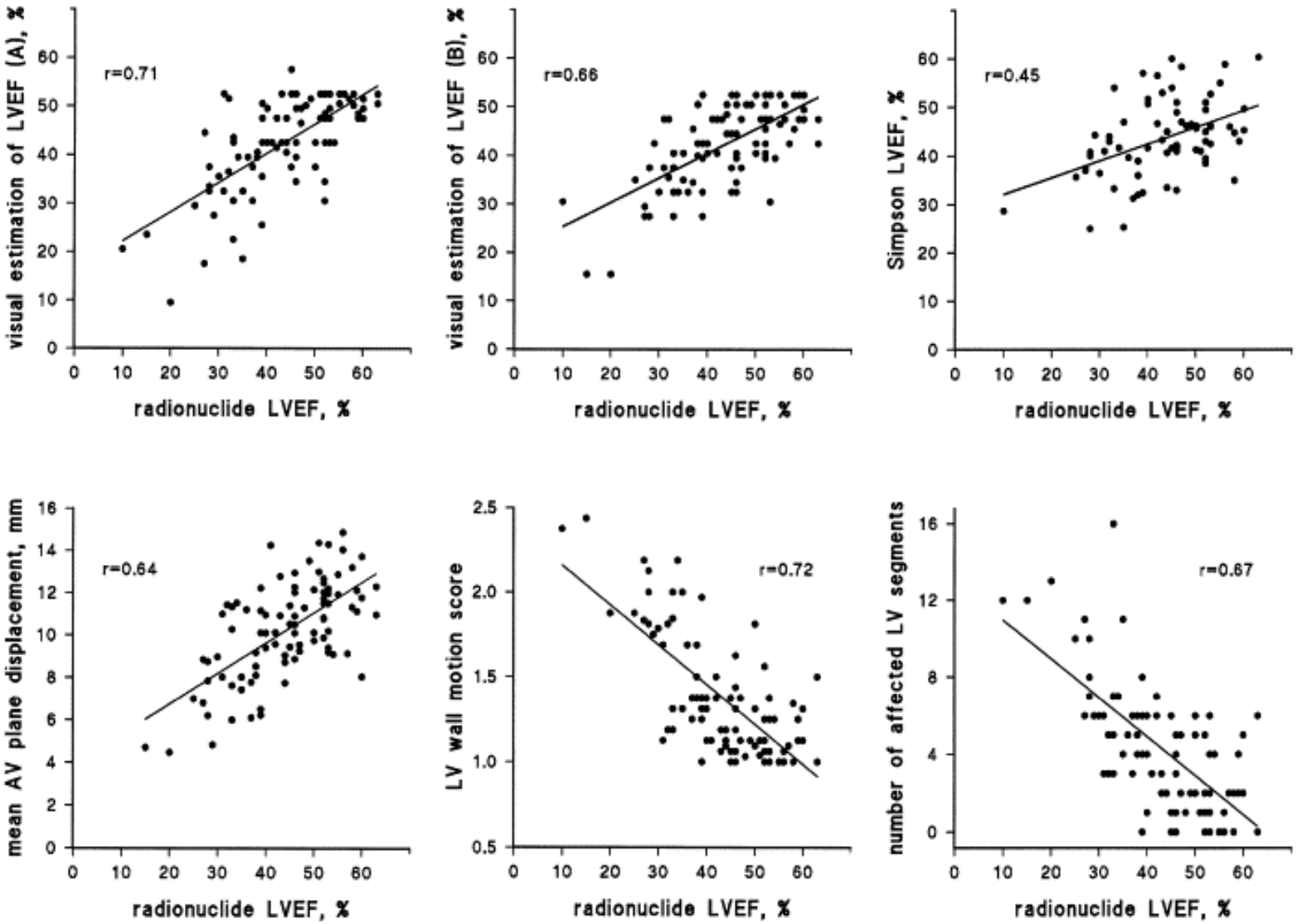
dp/dt
Tissue Doppler
VCF
Strain
Strain rate
Isovolumic acceleration
Torsion
Twist

Volume

LVEF
Shortening Fraction
Stroke volume
Stroke work
(ESV-ESP relation)

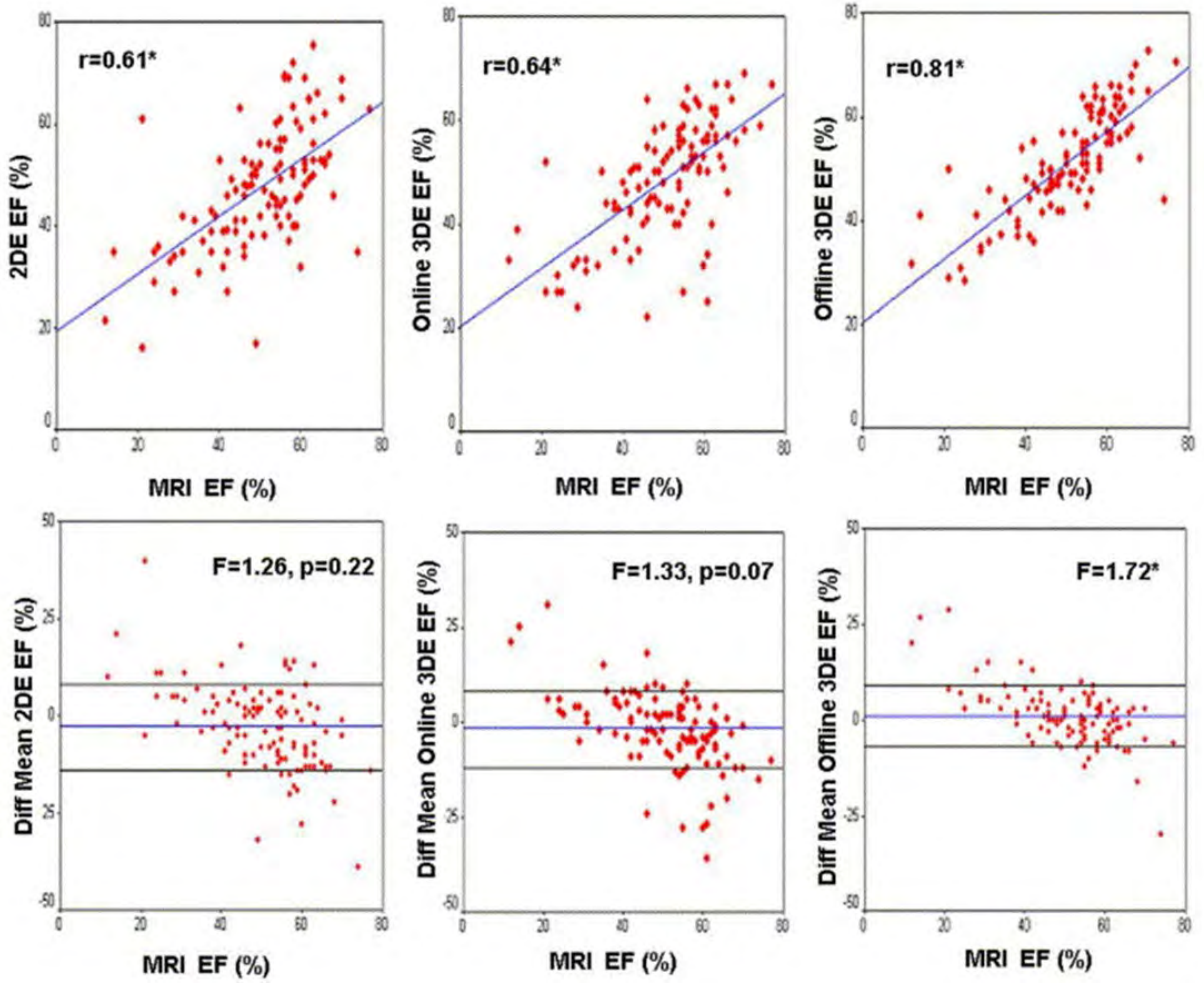
"Myocardial work"

LVEF: A messy business



Jensen-Urstad K, et al. Am J Cardiol 1998;81:538

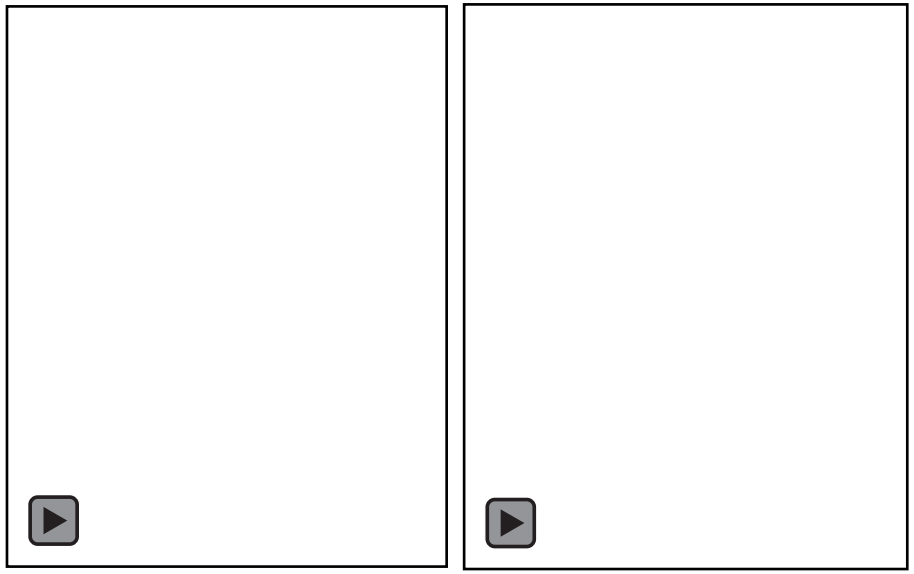
3D LVEF: Even More Messy?



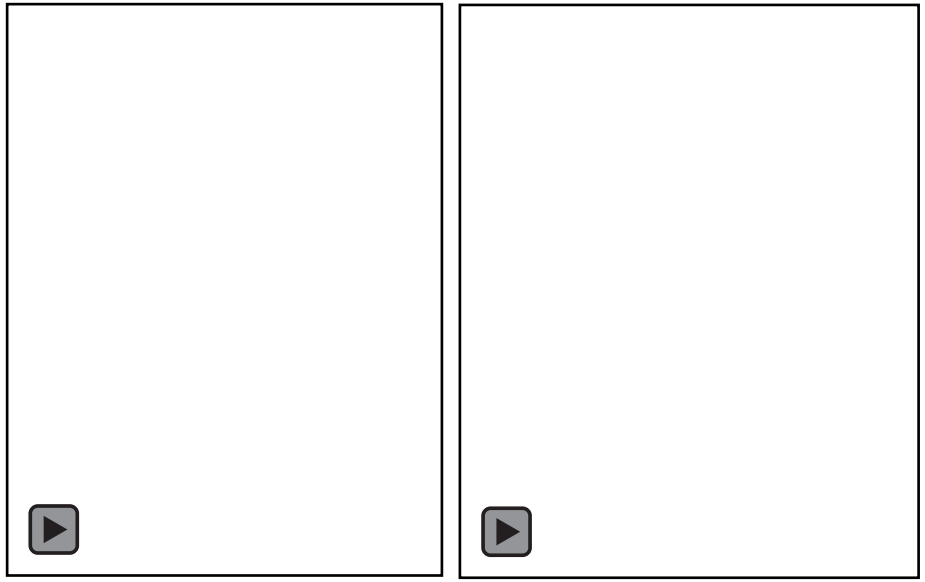
Jenkins C, et al. J Am Soc Echocardiogr 2006;19:1119

UEAs, LV Volumes, and LVEF

Bad → Good

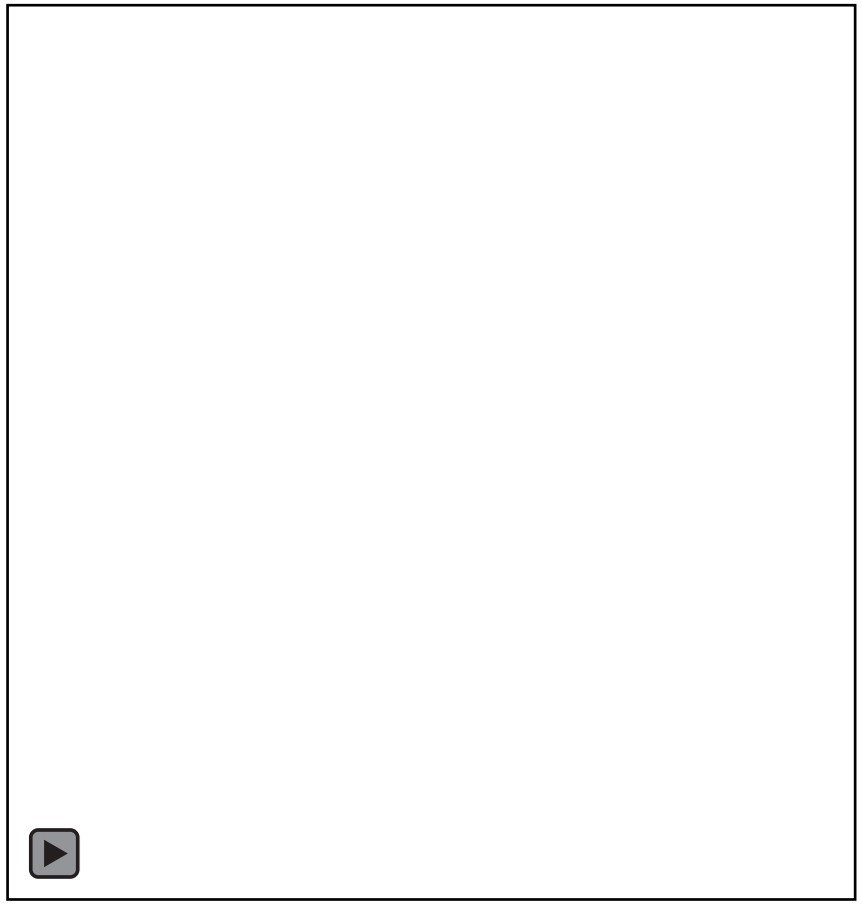


Mediocre → Great

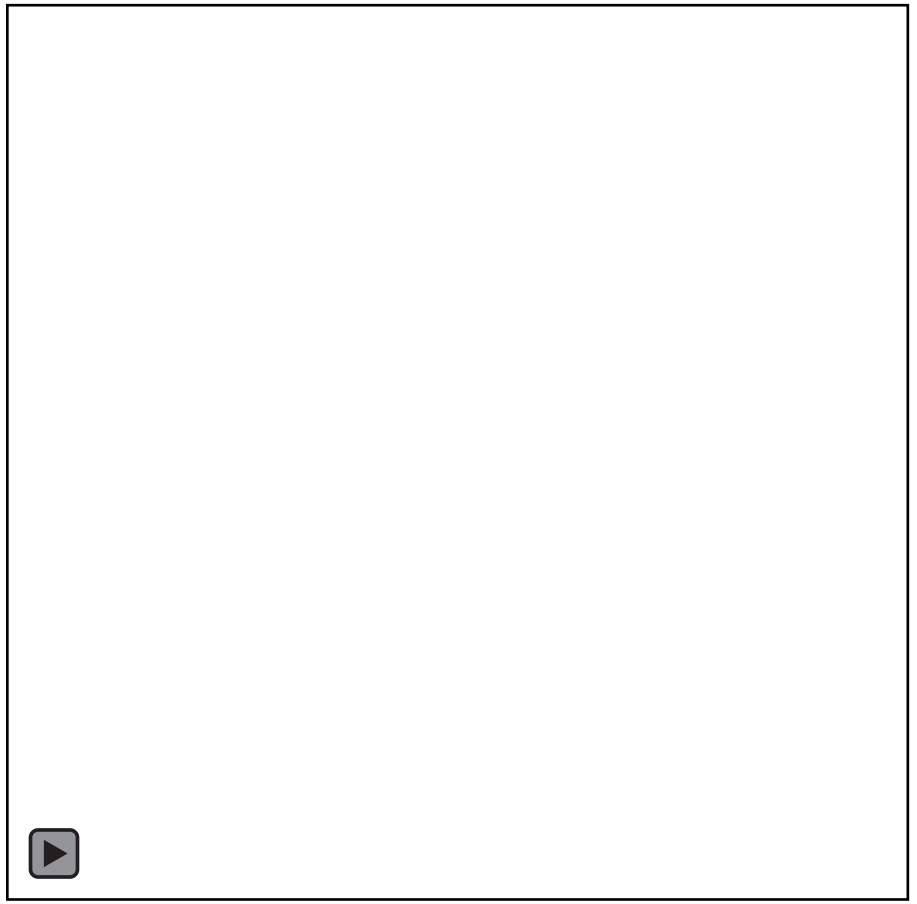


Speckle-tracking Strain Echocardiography

Strain



Strain Rate

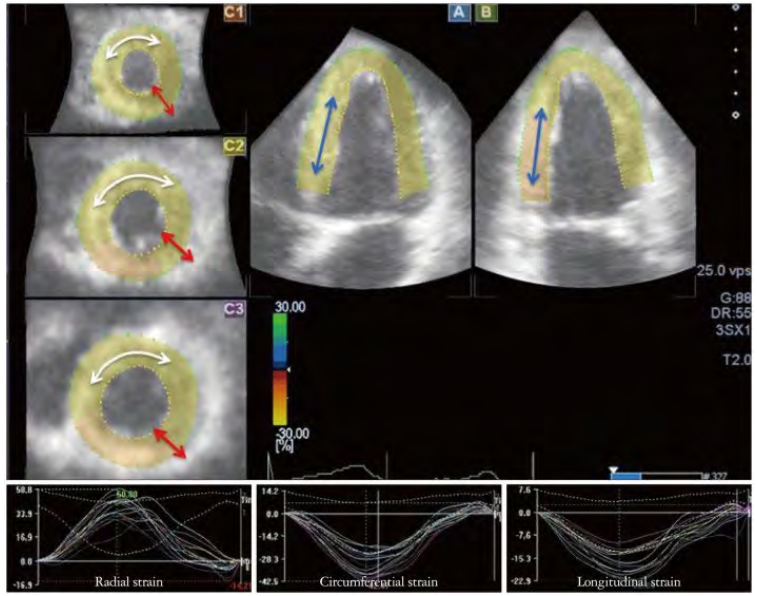


Jenkins C, et al. J Am Soc Echocardiogr 2006;19:1119

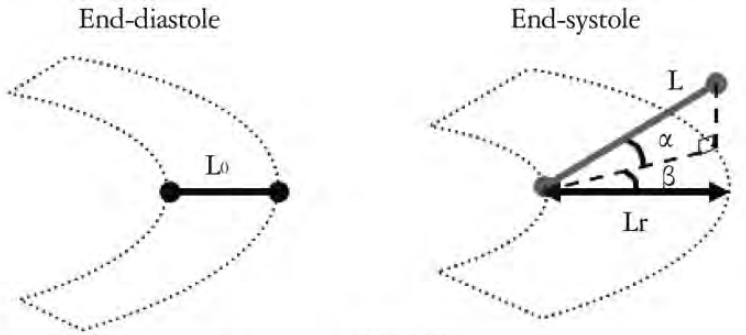
Jenkins C, et al. J Am Soc Echocardiogr 2006;19:1119

Advanced Strain

Component Strain (Lagrangian)



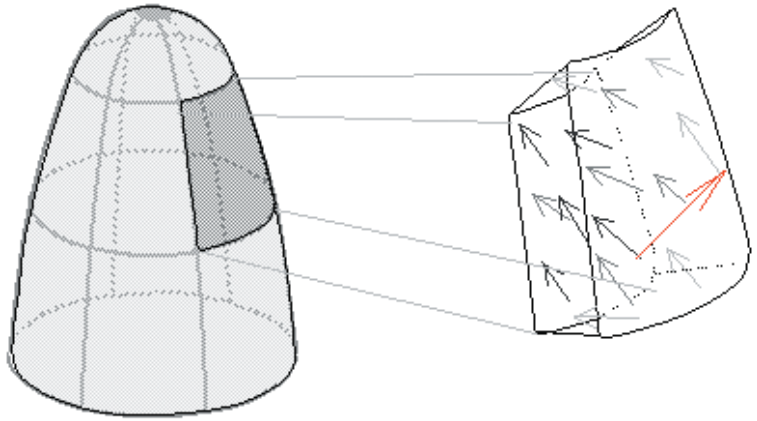
Shear Strain



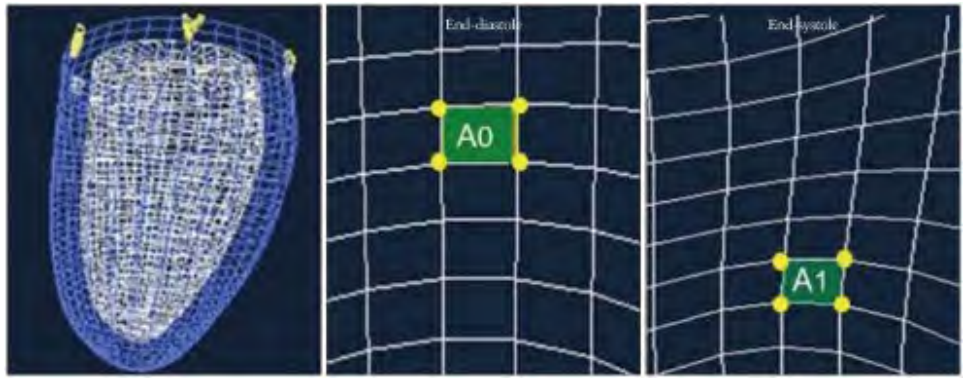
$$\text{Radial strain} = \frac{(Lr - L_0)}{L_0} \times 100\ (\%)$$

$$\text{3D strain} = \frac{(L - L_0)}{L_0} \times 100\ (\%)$$

Principal

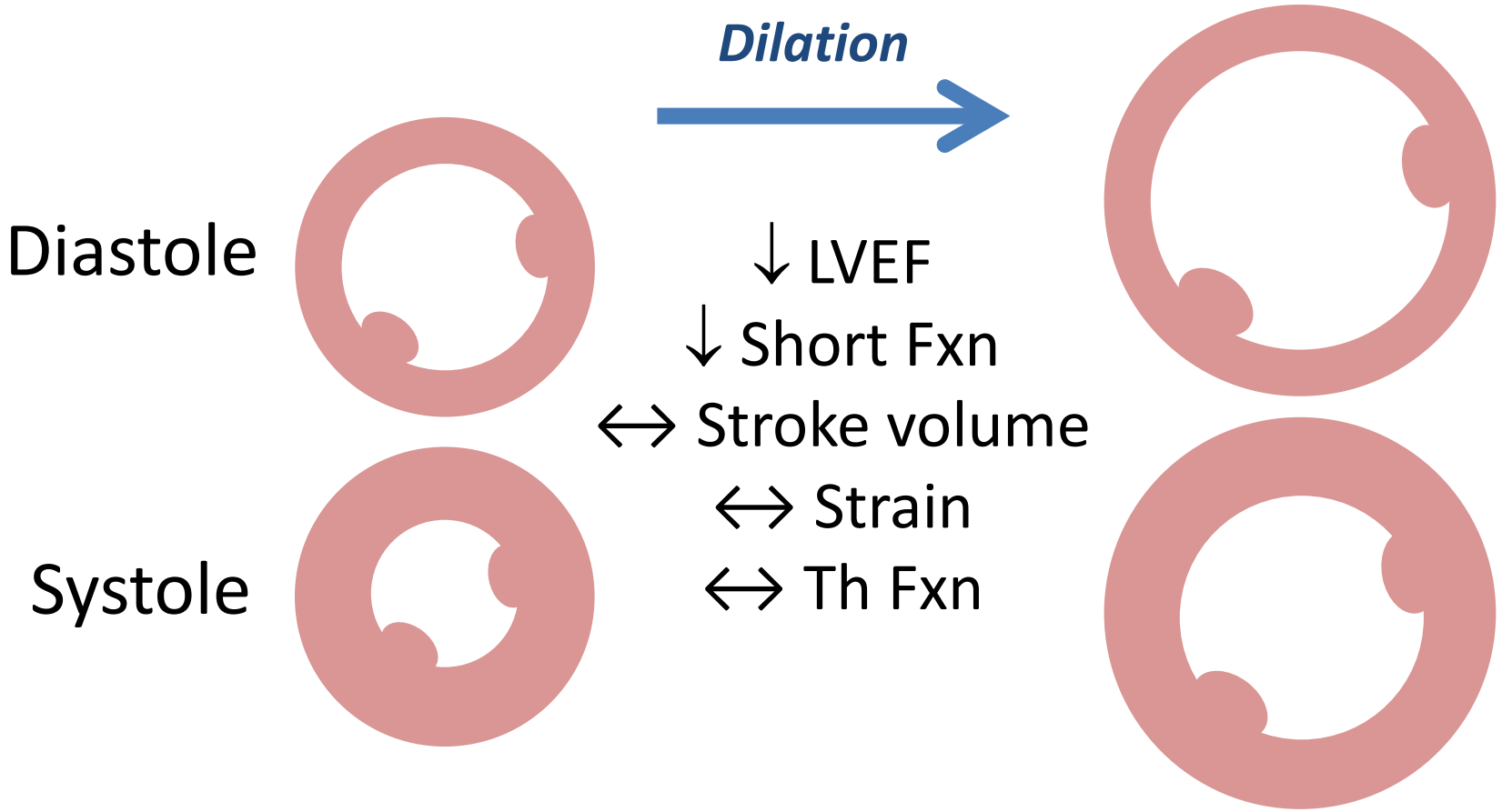


Area Strain



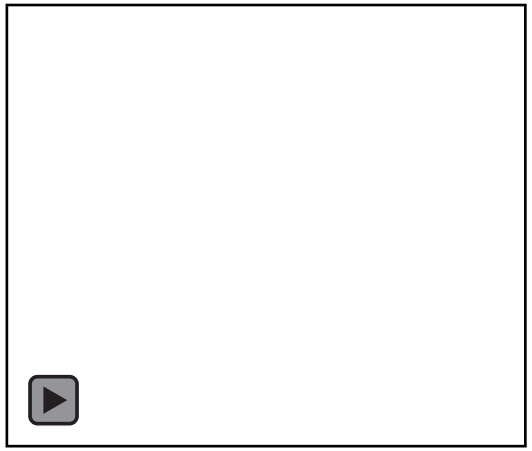
Seo Y, et al., J Cardiovasc Ultrasound 2014;22:490

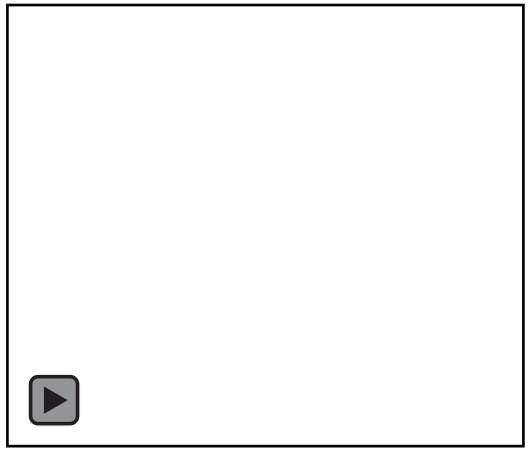
Expect Incongruent Data with Echo Data



Concentric Remodeling

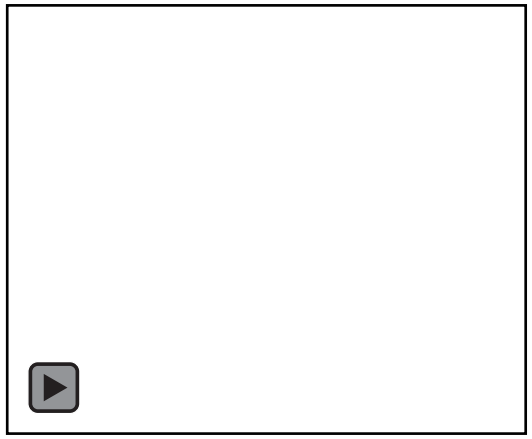
Normal

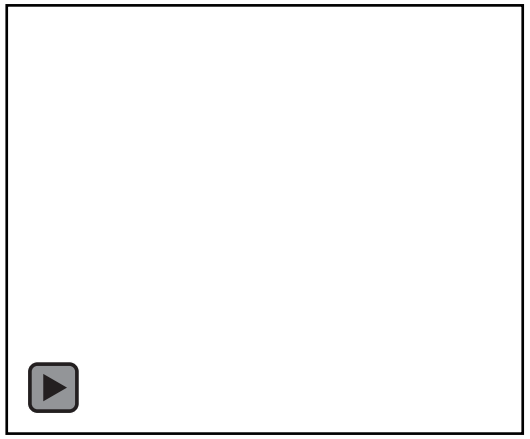


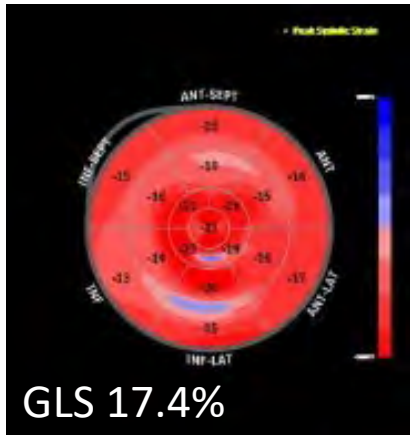


LVEF 66%
SV=81 mL

Concentrically remodeled

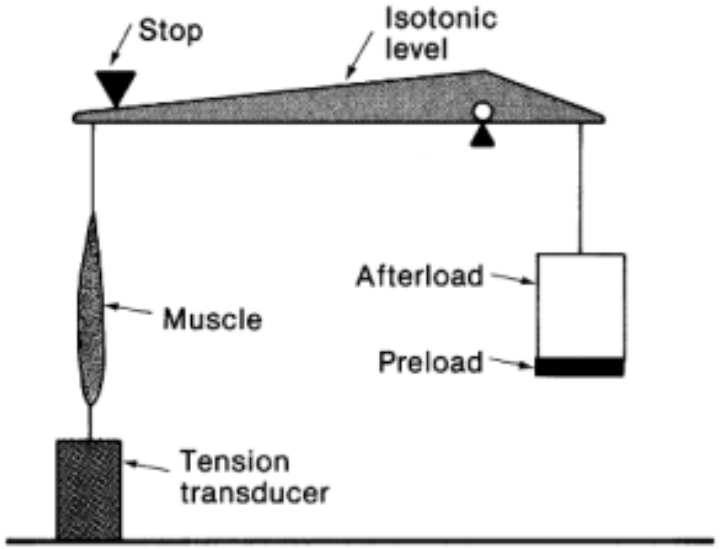


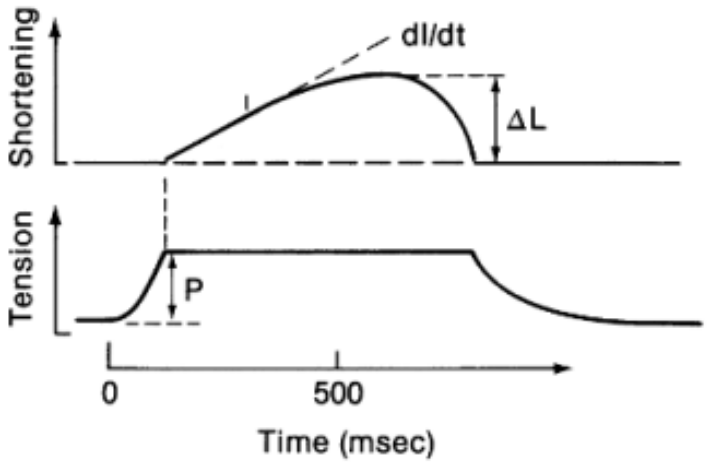




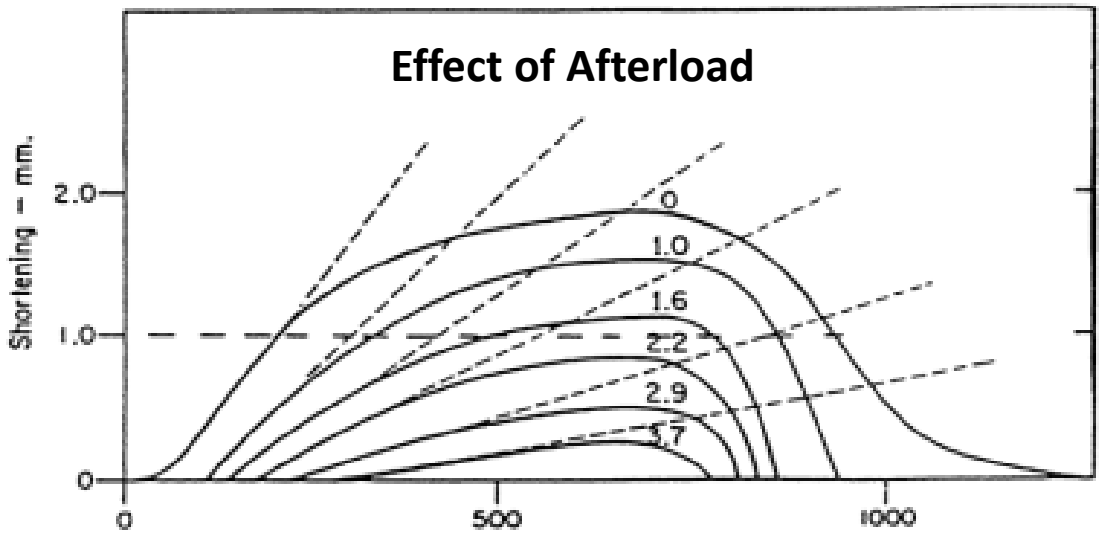
LVEF 69%
SV =51 mL

Afterload and Force-velocity Relations

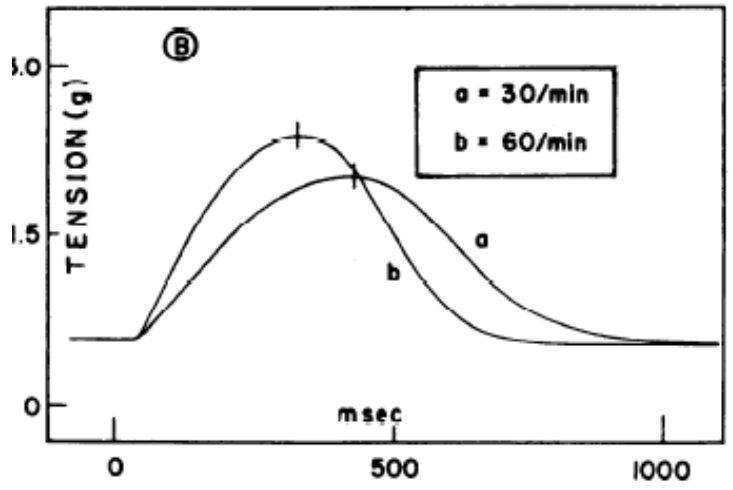




Effect of Afterload

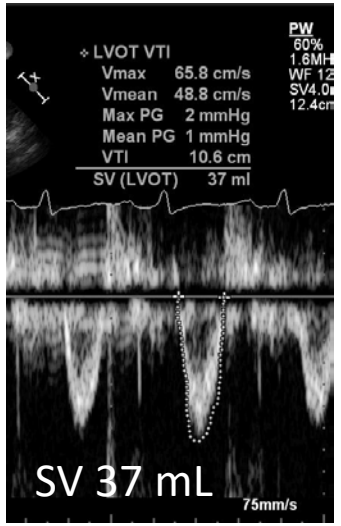


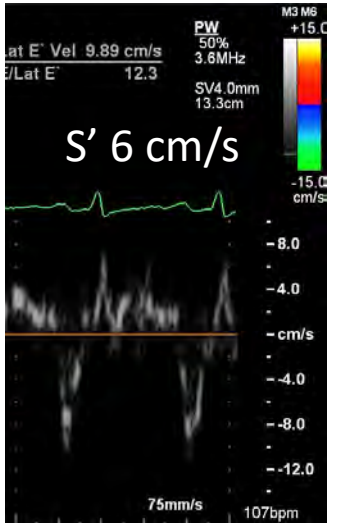
Effect of Beat Frequency



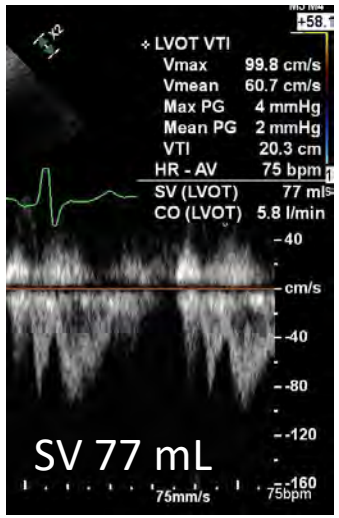
Sonnenblick EH, et al. Am J Physiol 1962;205:931
Sonnenblick EH, et al. Circ Res 1966;19:980

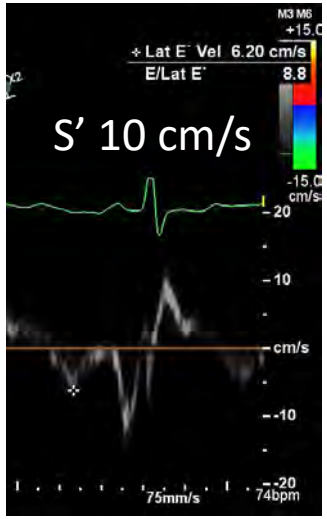
BP 220/114





BP 132/84

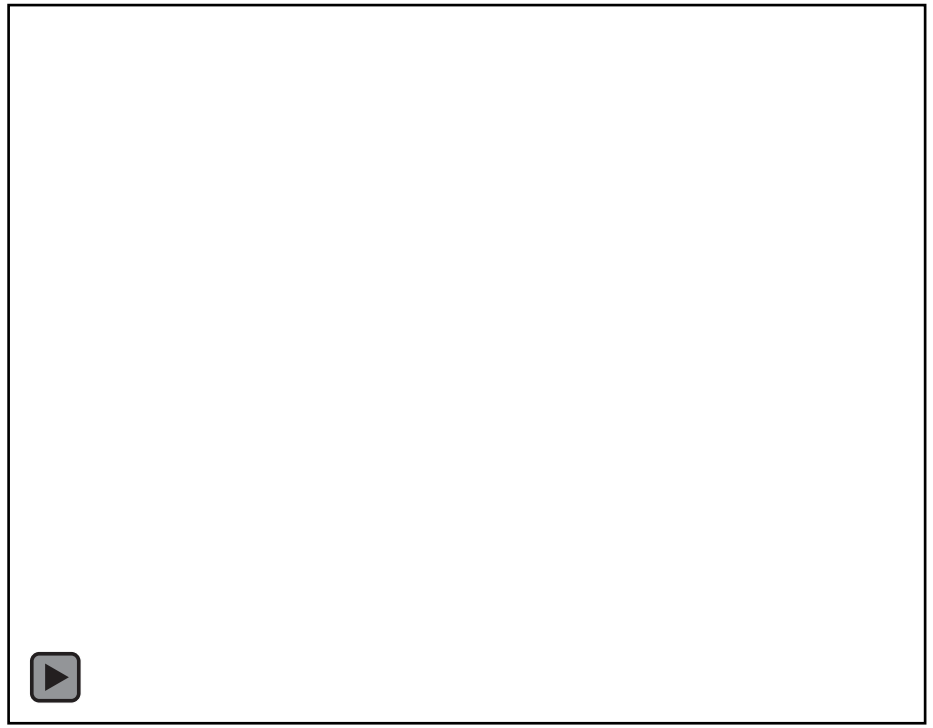




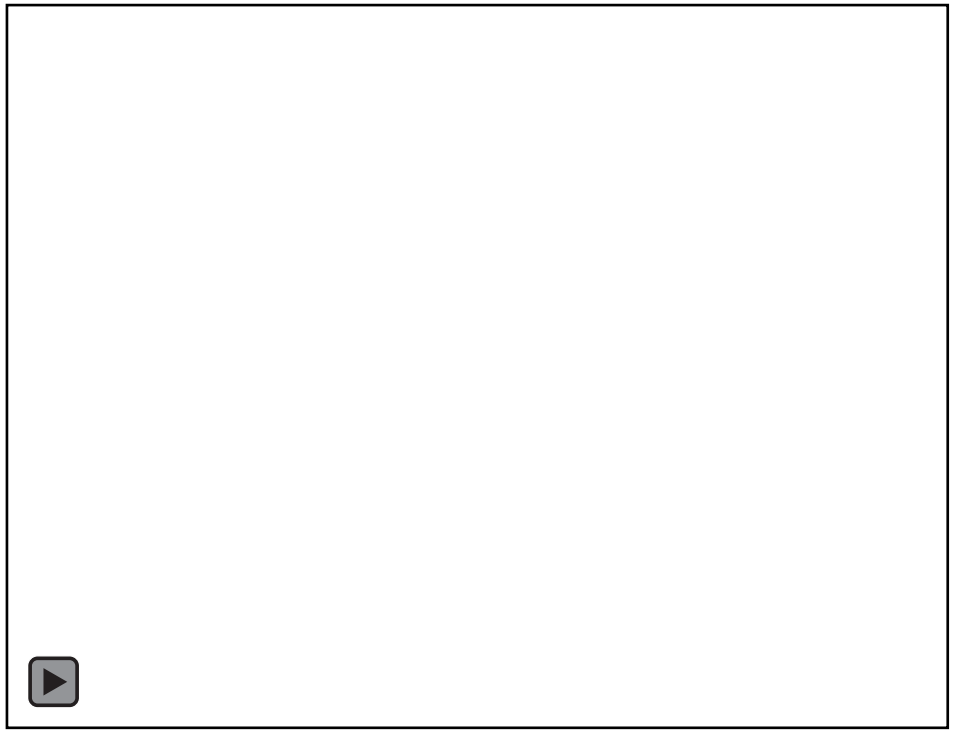
Effect of Afterload During Stress Echo

Hypertensive Response to Exercise
Systolic BP at Peak 218/74

PSAX

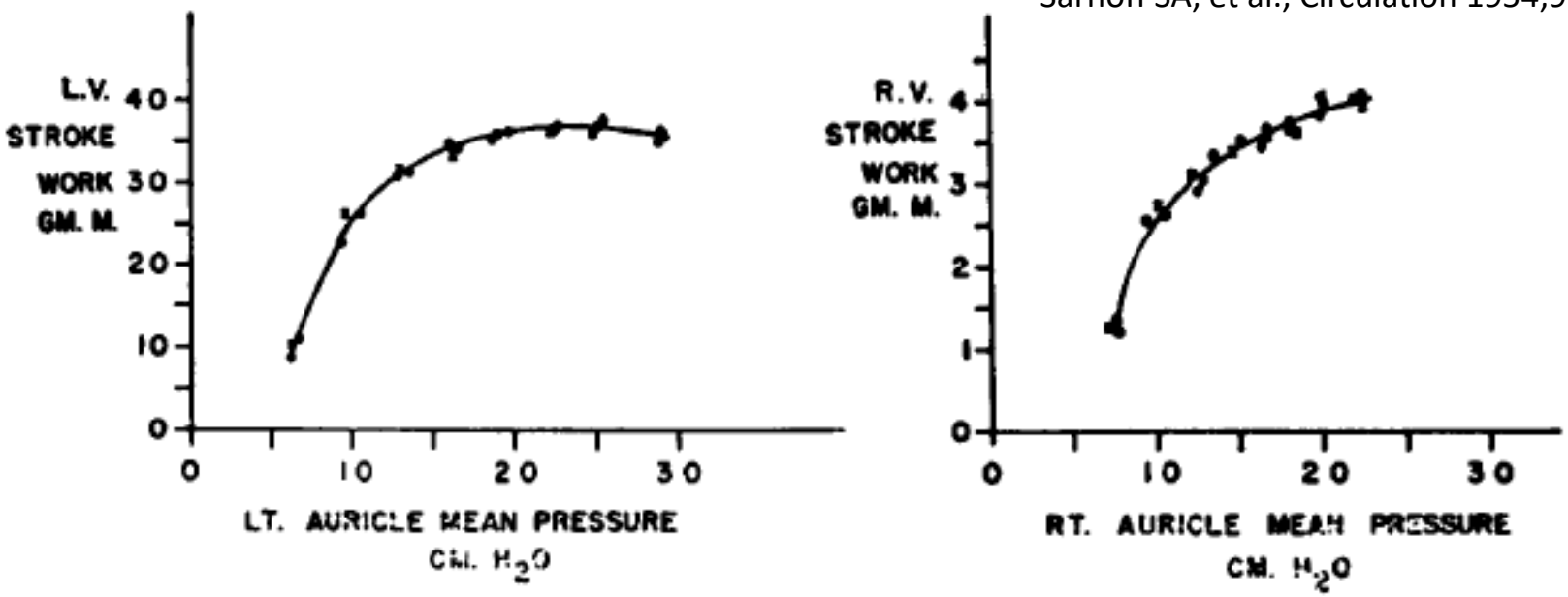


Ap 2 Ch



Frank-Starling Principles

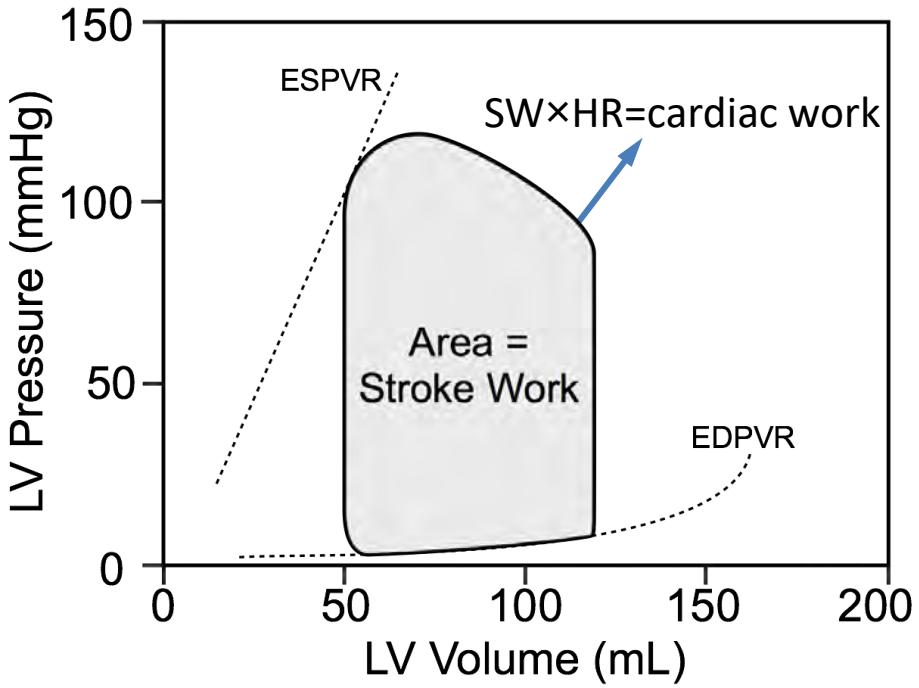
Sarnoff SA, et al., Circulation 1954;9:706



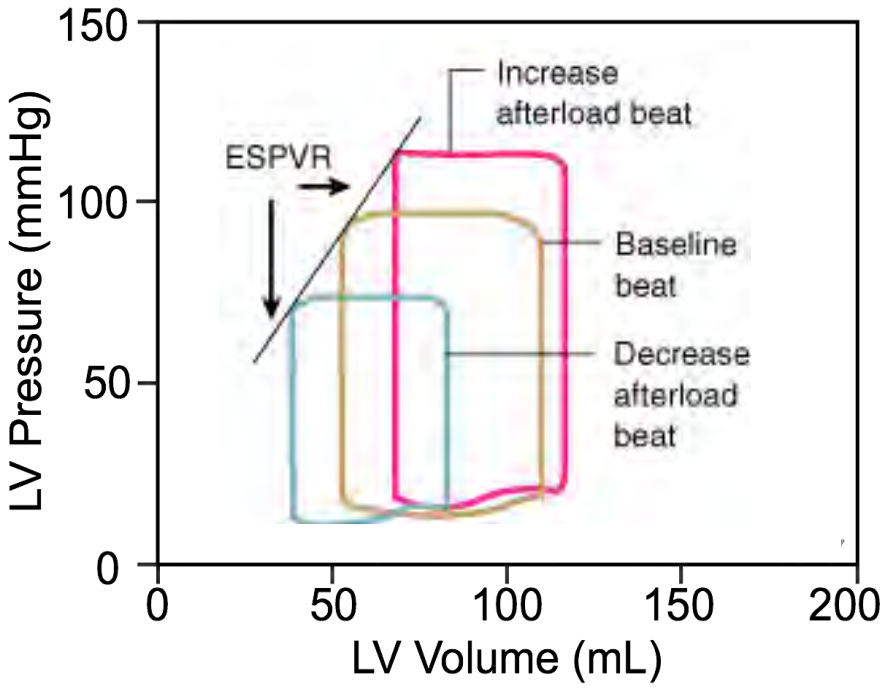
Intravascular volume status
Mitral/tricuspid stenosis
Tamponade physiology
Tachycardia
PEEP
RV infarct/Pulmonary embolus

Contractility and Myocardial Work

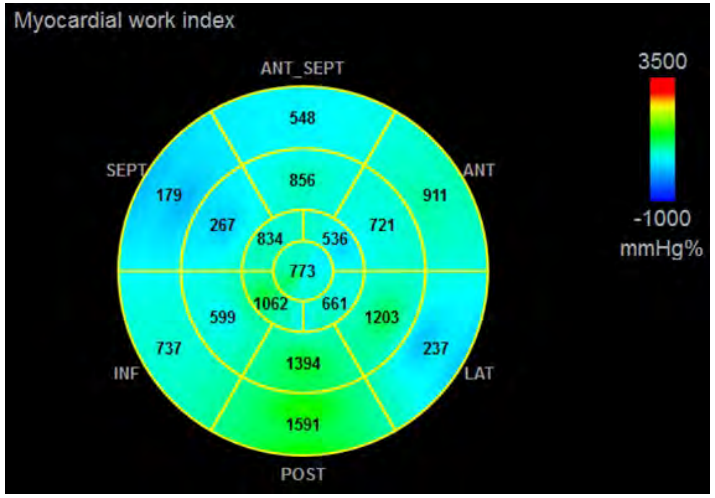
Work

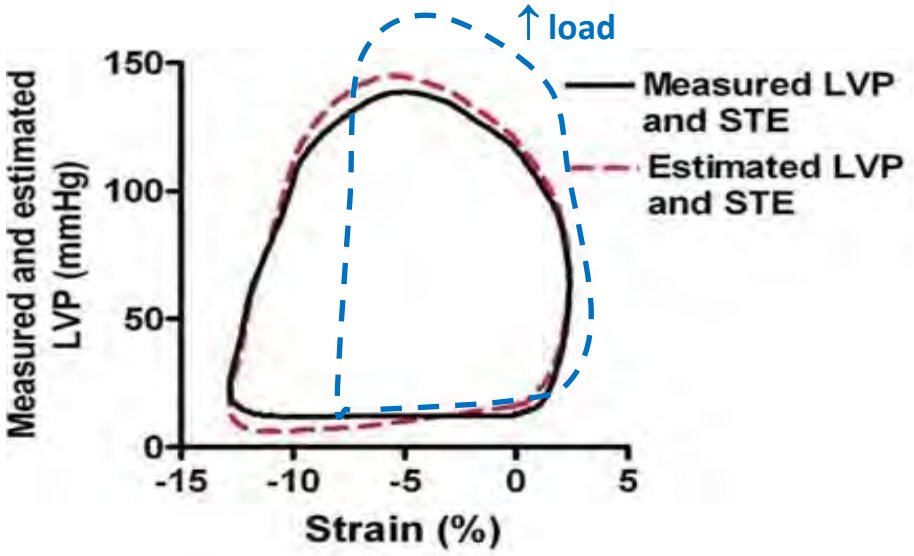


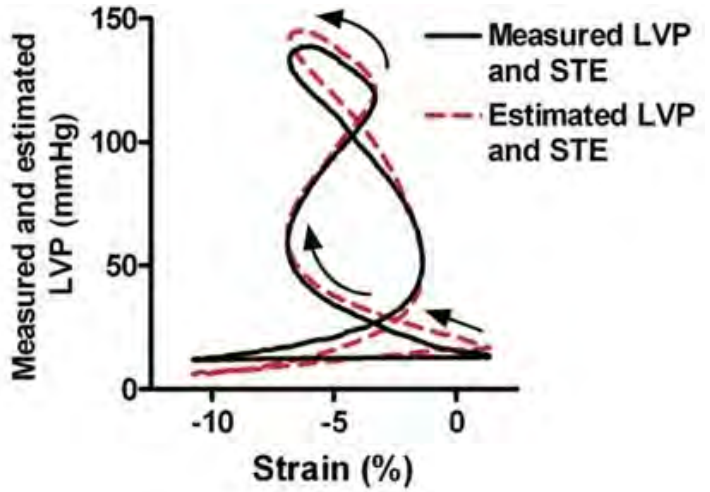
Contractility



Myocardial “Work”

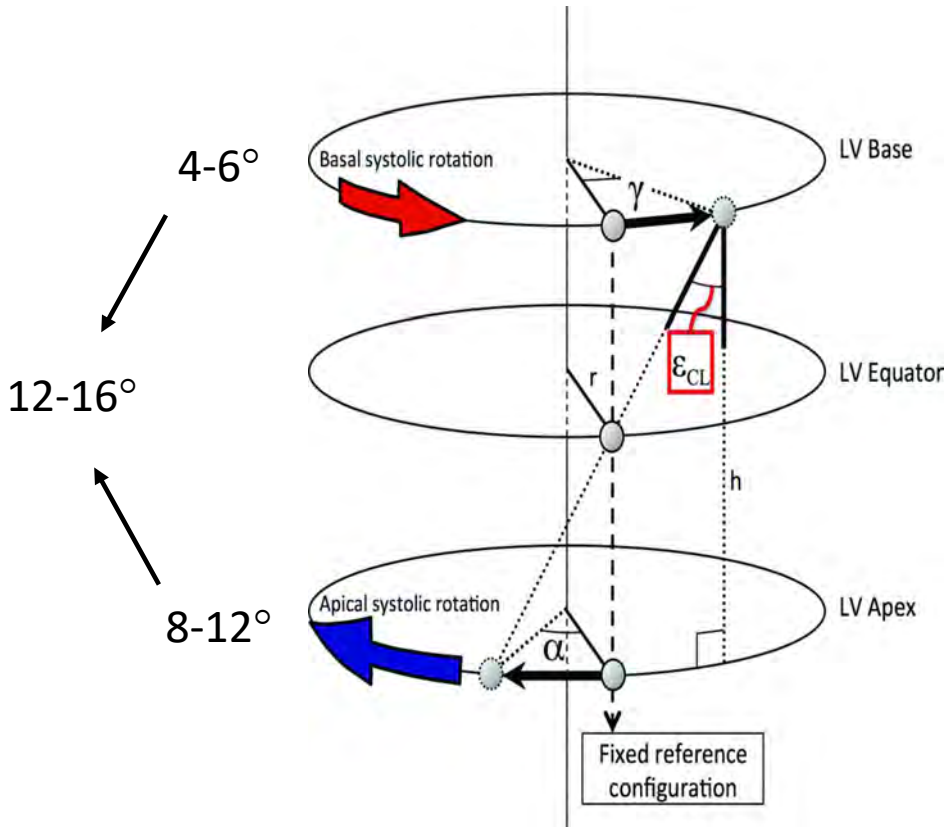




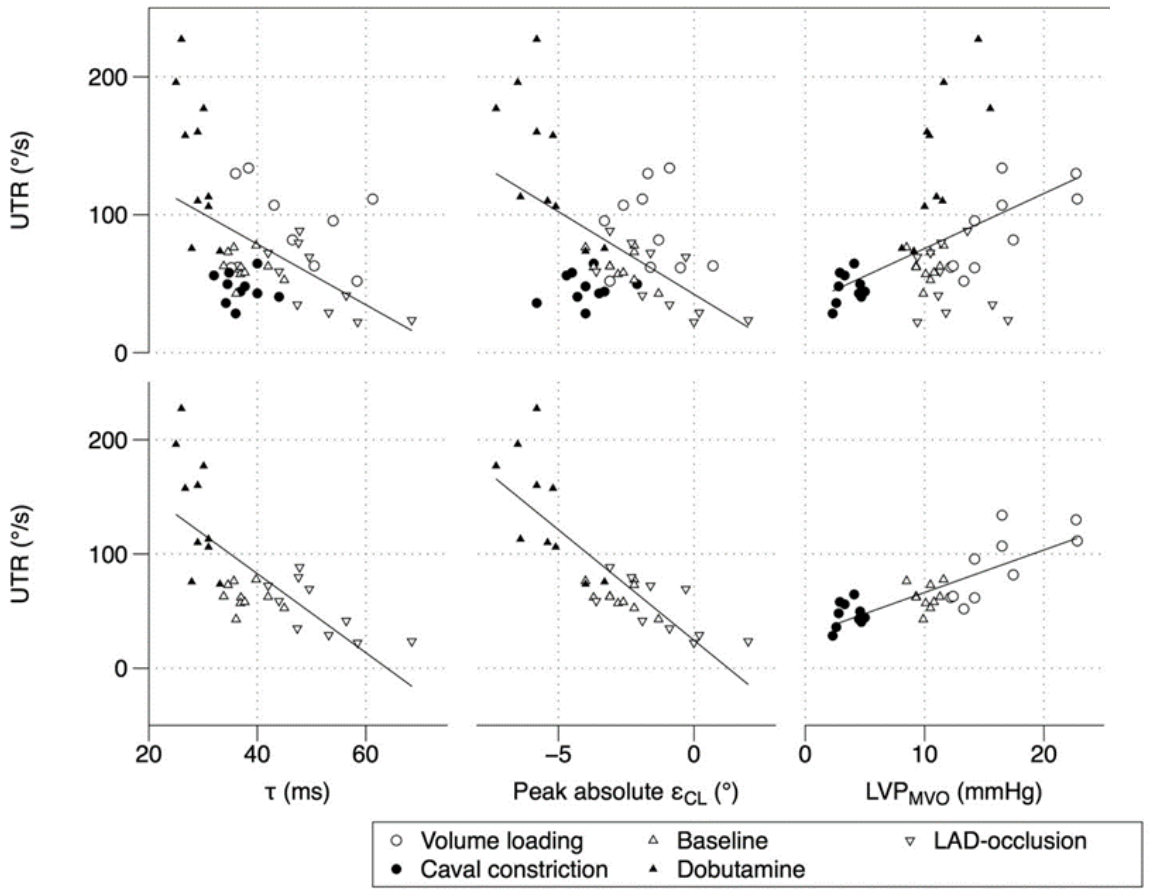


Russell, et al. Am J Physiol 2013;305:H996

Untwisting and LV suction (-dp/dt)

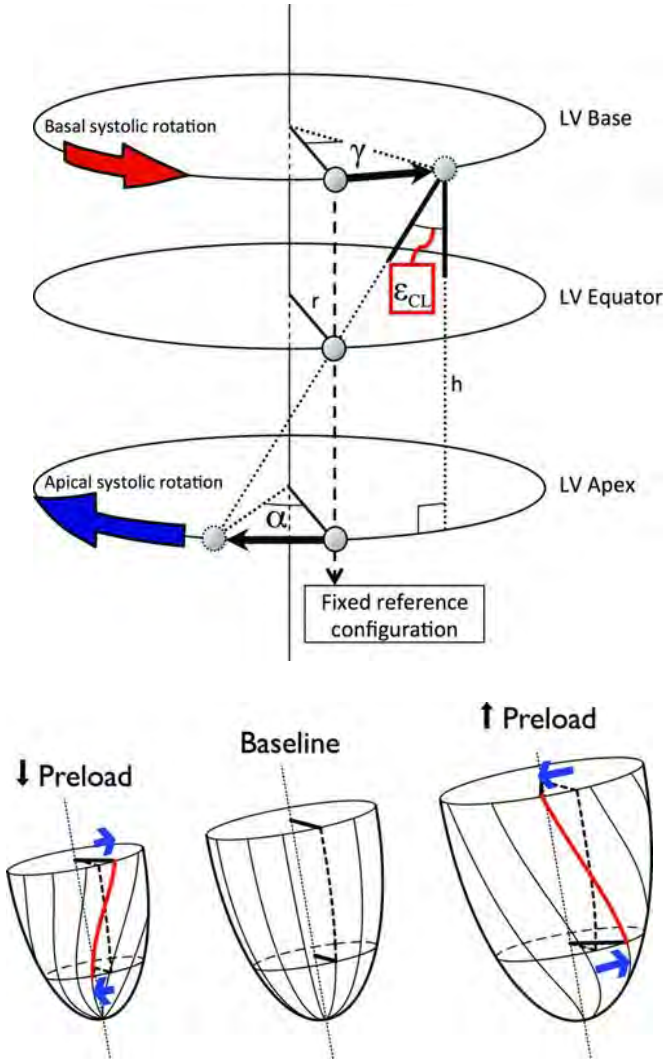


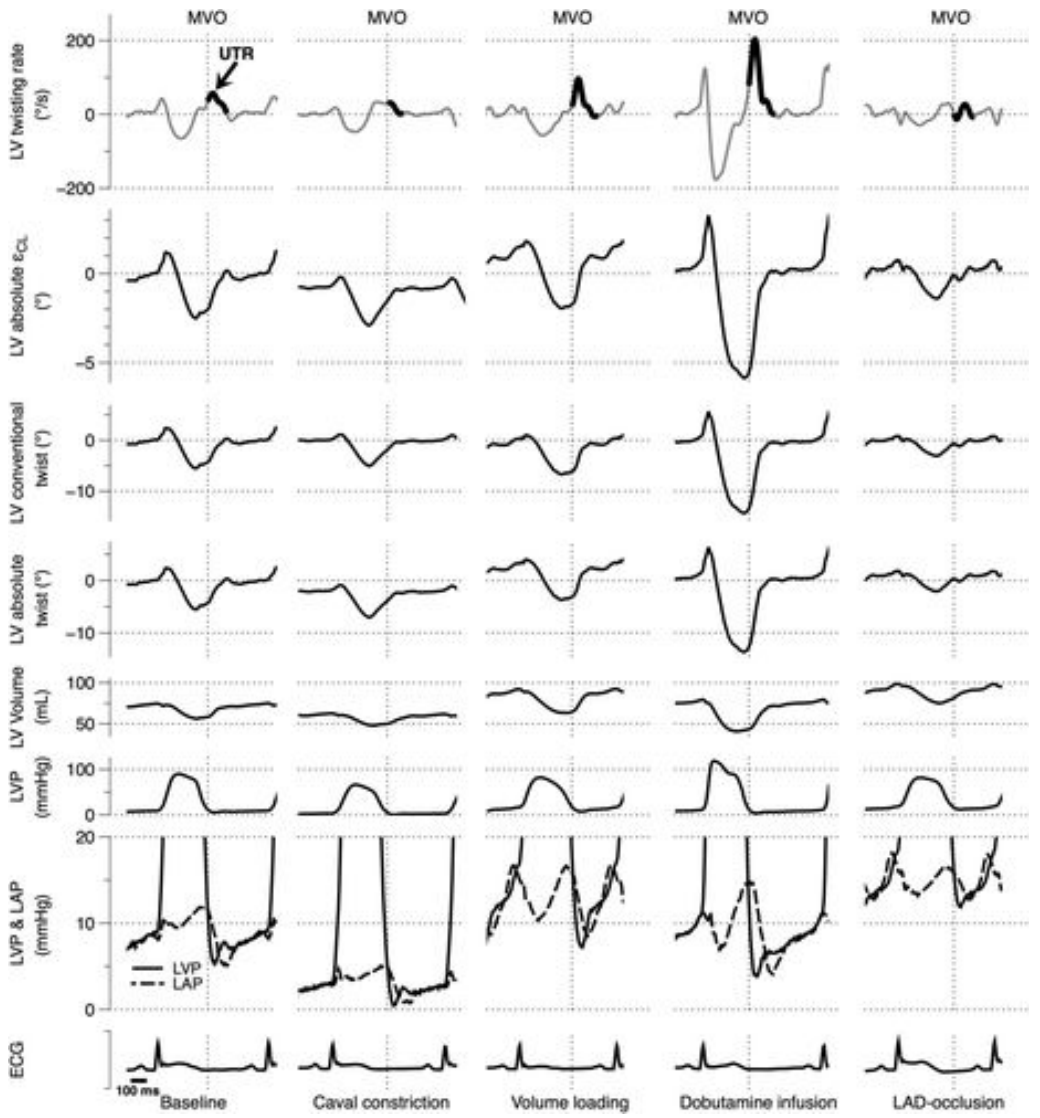
Torsion 1.6-2.4°cm^{-1}



Opdahl A, et al. Circulation 2012;126:1441

Conditional Determinants of Twist/Untwist

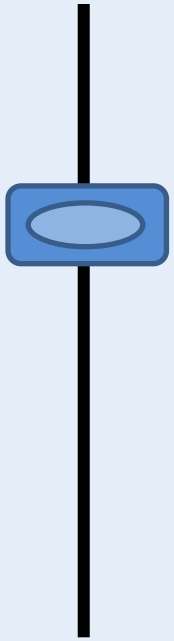




Opdahl A, et al. Circulation 2012;126:1441

Summary

Expert



Competent

Understands applications *and* limitations of new echo technology and the physiologic influences of function

Knowledge and reporting of new technologies 2D/3D strain, dp/dt

Knowledge, reporting, and problem solving for LVEF, SV, and TDI