Diastology 2011

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Disclosures: None

ASE

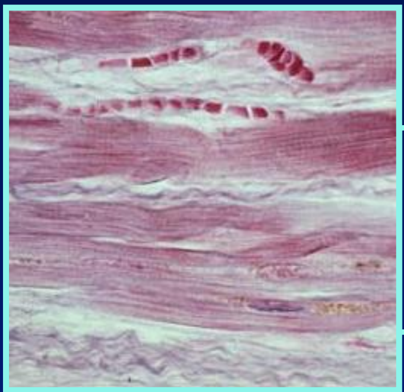
American Society of Echocardiography

Heart & Circulation Ultrasound Specialists

Is *EVERYBODY* a member!?!

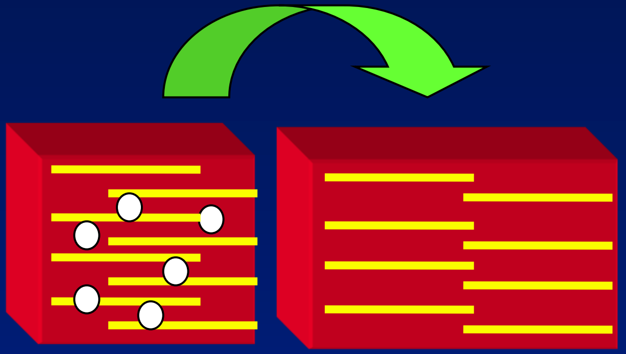
Systolic and Diastolic Function

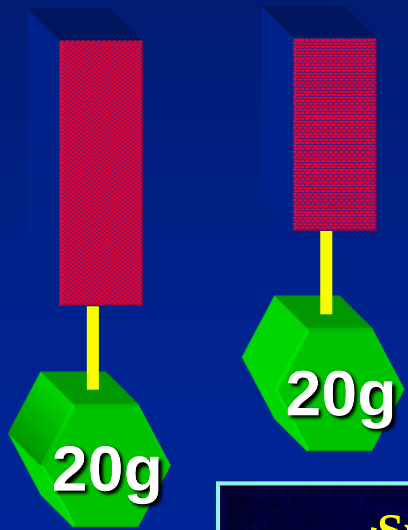
Myocardium to Ventricle



Tissue Elastance

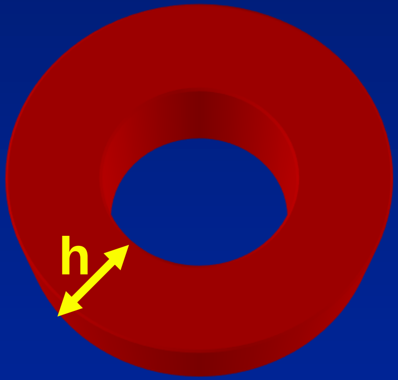
Activation

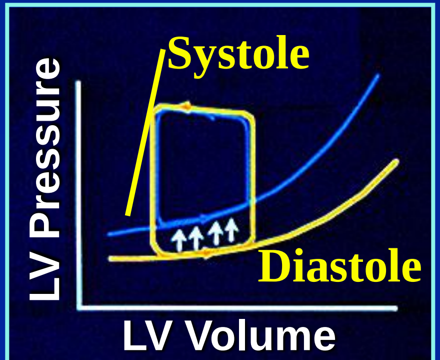




Stress/strain Relationship

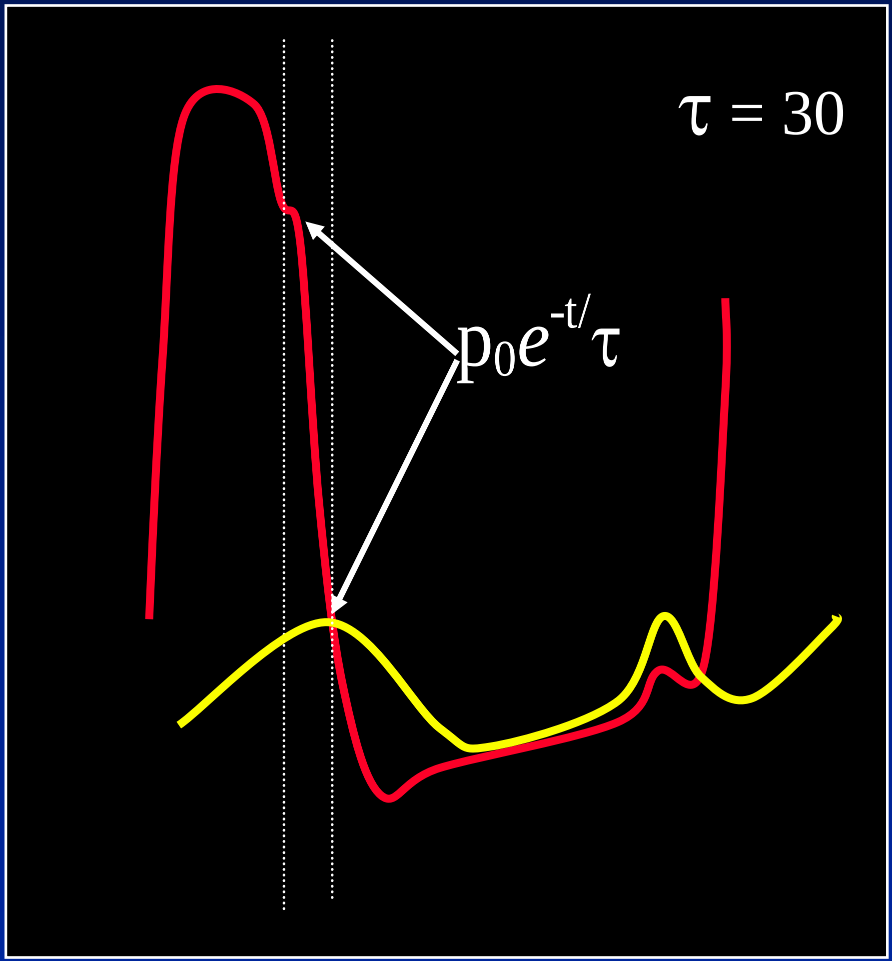
Geometry



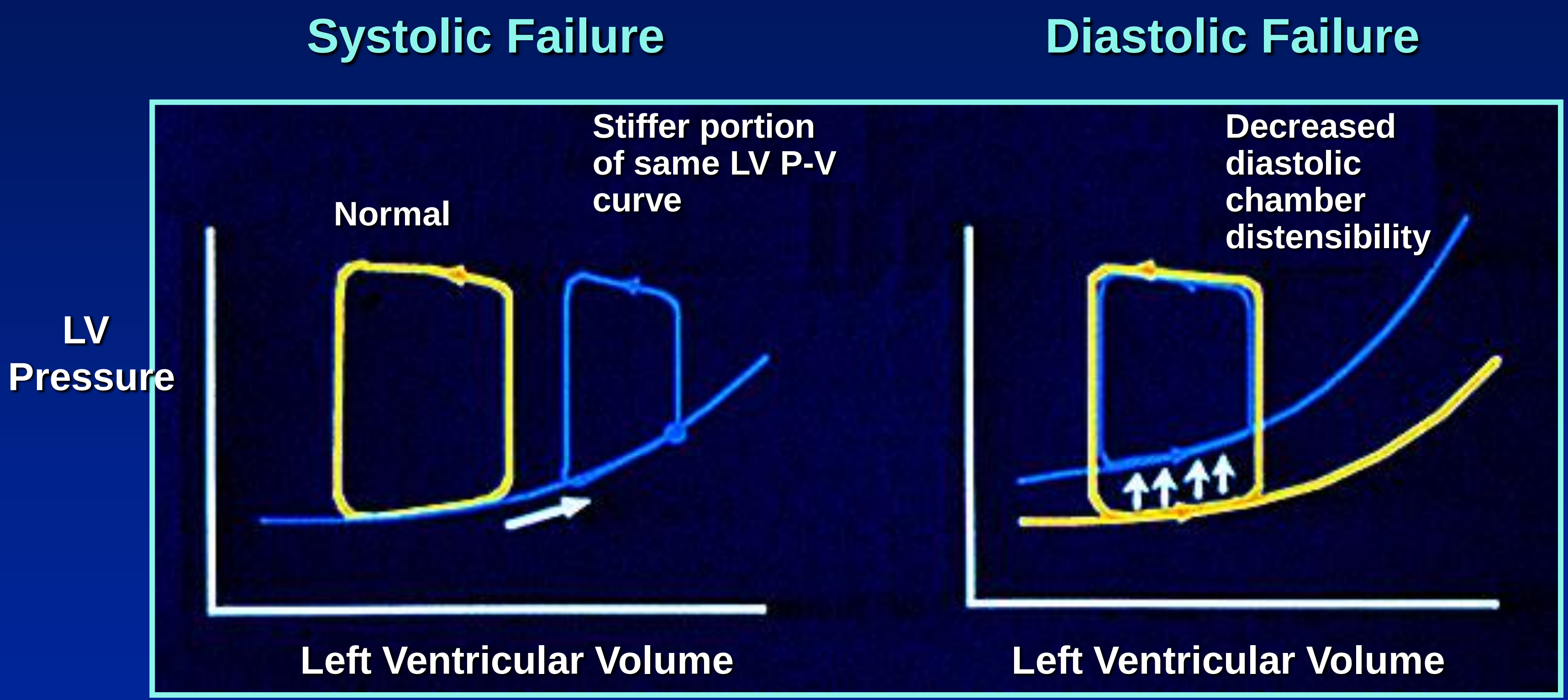


Pressure-Volume Curve

LV Relaxation
Exponential Pressure Decay in IVR



LV Pressures-Volume Curves



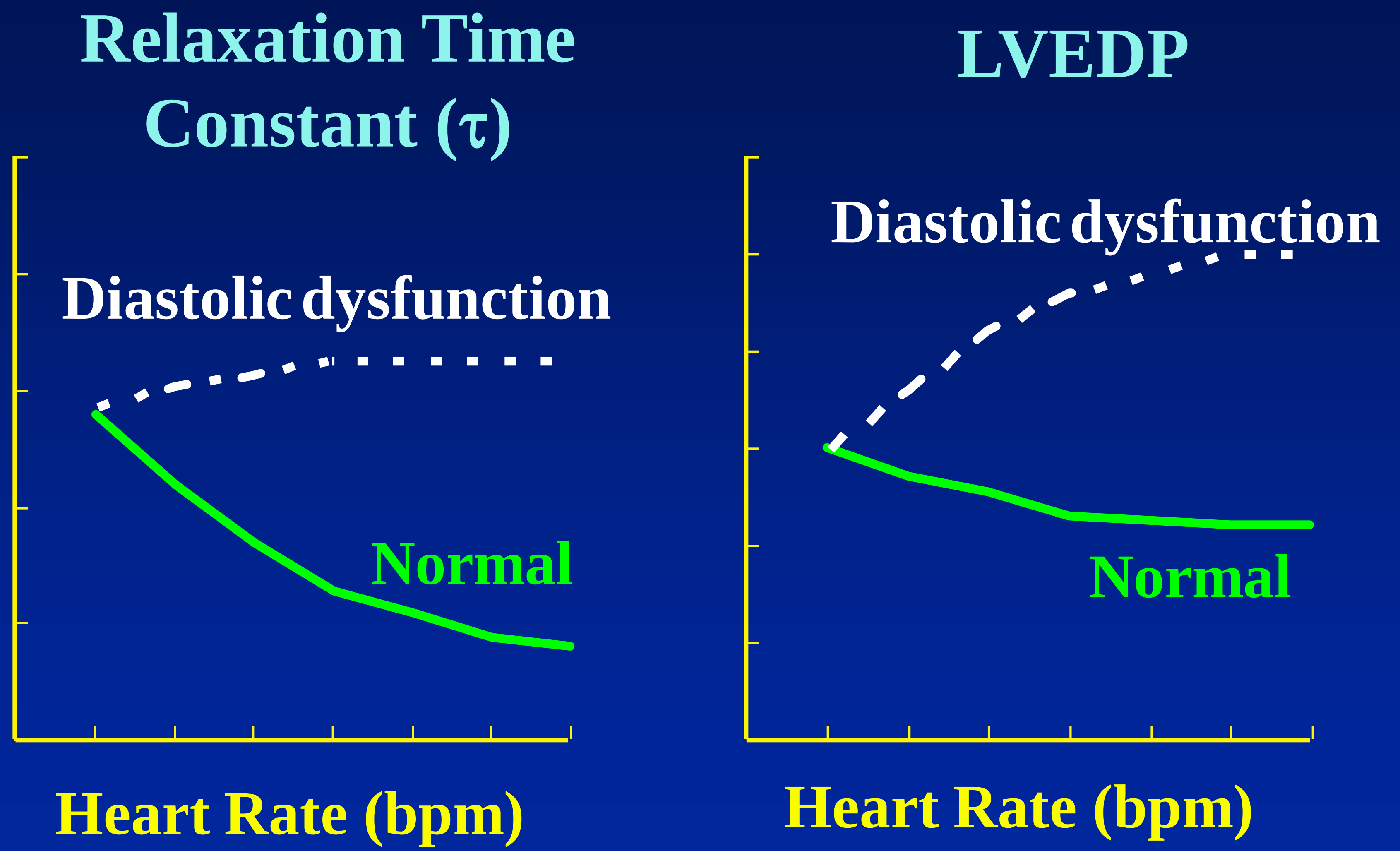
Lorell BH. Ann Rev Med 1991;42:411-37

Passive Elasticity

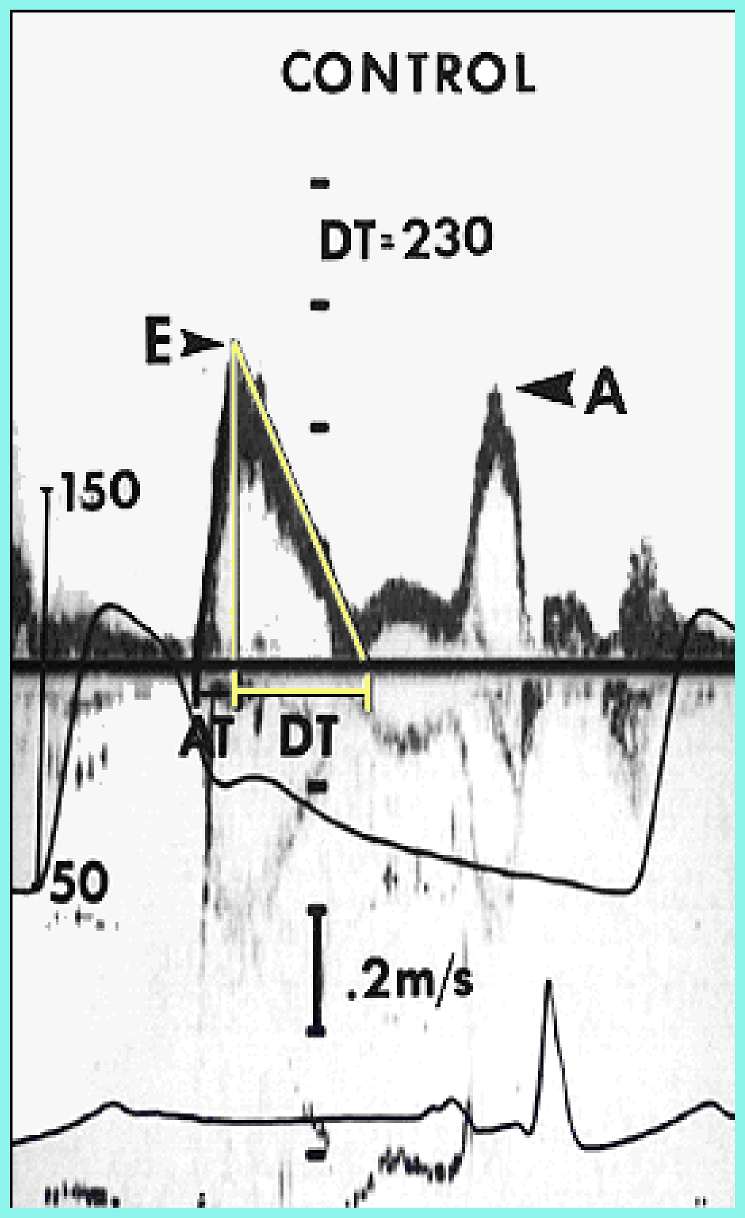
Component	Contribution
Collagen	++++
Titin	++++
Actin	++
Intermediate	+
Microtubules	-

Passive Tension in Cardiac Muscle: Contribution of Collagen, Titin, Microtubules, and Intermediate Filaments
Granzier HL, Irving TC Biophysical Journal 1995; 68: 1027-1044

Exercise Can Unmask Delayed Relaxation



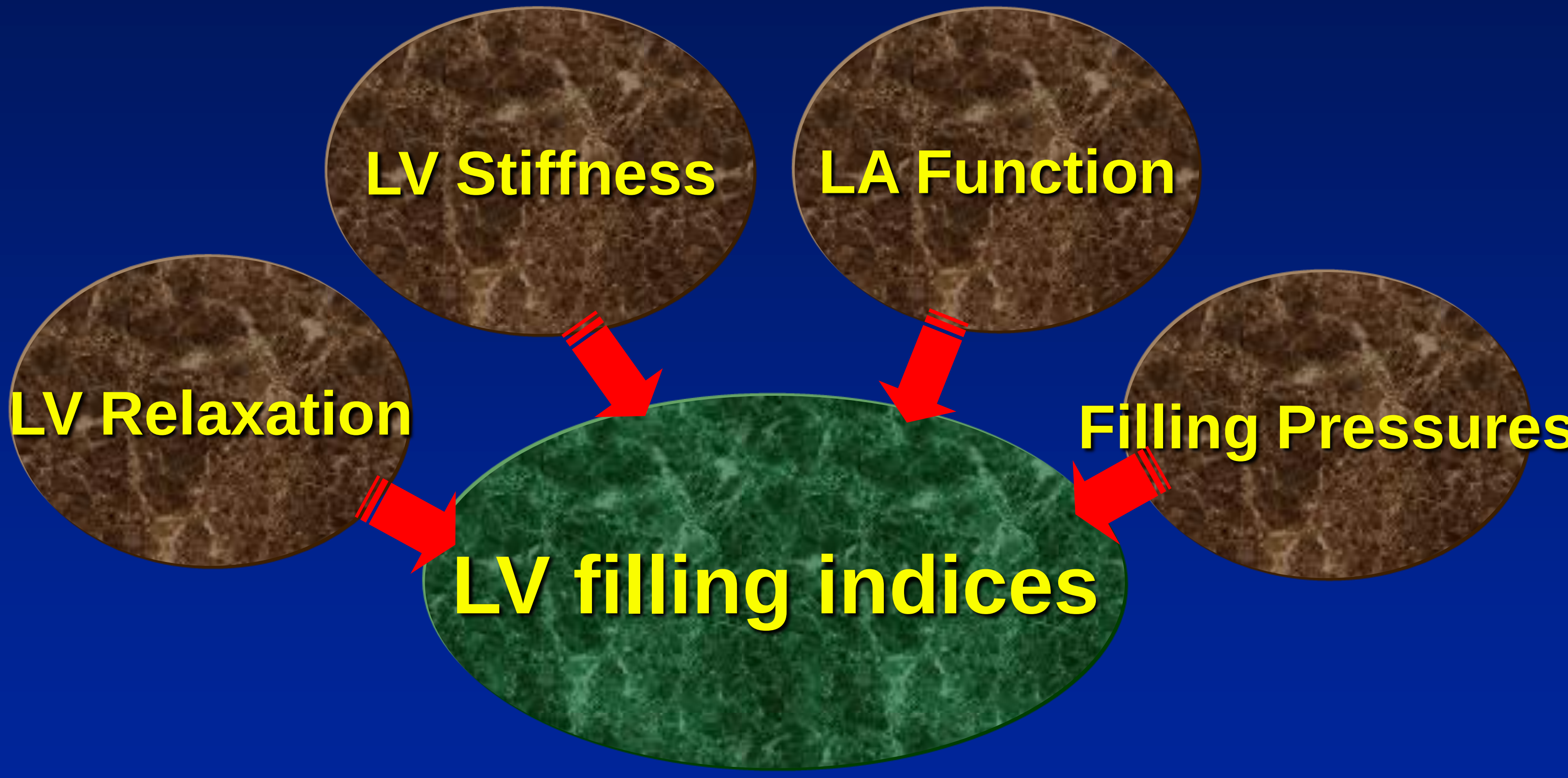
What Determines Transmitral Flow?



Key parameters of the mitral inflow pattern:

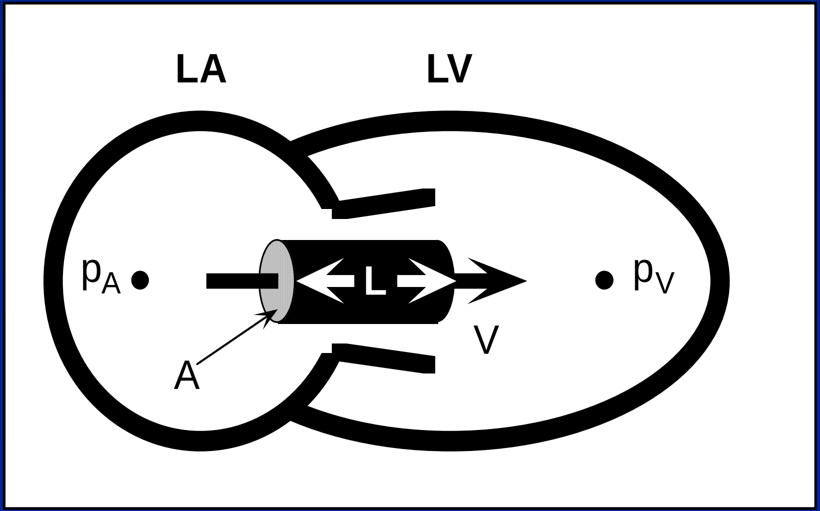
- E
- E VTI
- AT
- DT
- A
- A VTI
- A Duration
- E/A

Determinants of Diastolic Function



Transmitral Flow
Physical Determinants

- *In physical terms, we can only speak of factors that* ***accelerate*** *flow and factors that* ***decelerate*** *flow*
- *Acceleration is governed by the magnitude of the transmitral gradient* $\Rightarrow$ ***relaxation***
- *Deceleration is governed by the equilibration of LA and LV pressure* $\Rightarrow$ ***compliance***



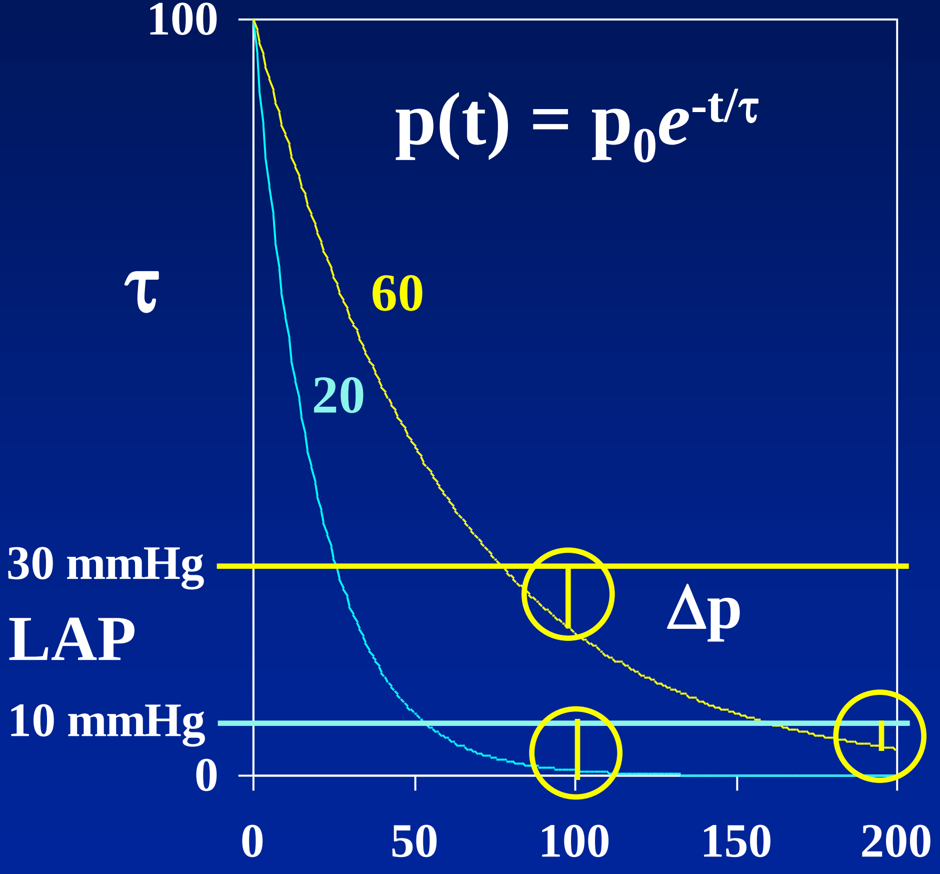
Transmitral Flow

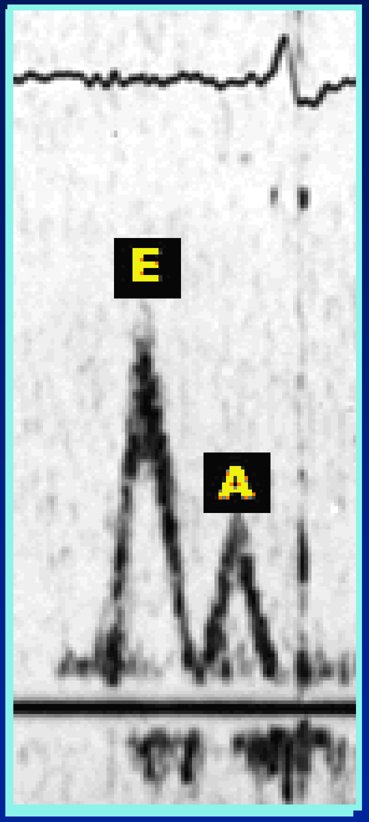
Physical Determinants of Acceleration

- *By Newton's second law, a = F/m*
- *m = mitral inertance, the mass of blood being accelerated across the mitral valve*
  - **≈3 X valve diameter (reduced in mitral stenosis)**
- *F = transmitral pressure difference*
  - **Grows as LV pressure drops exponentially below left atrium**
  - **$p(t) = p_0\ e^{-t/\tau}$**
  - **$dp/dt = -p/\tau = p_{LA}/\tau$**

MV Acceleration

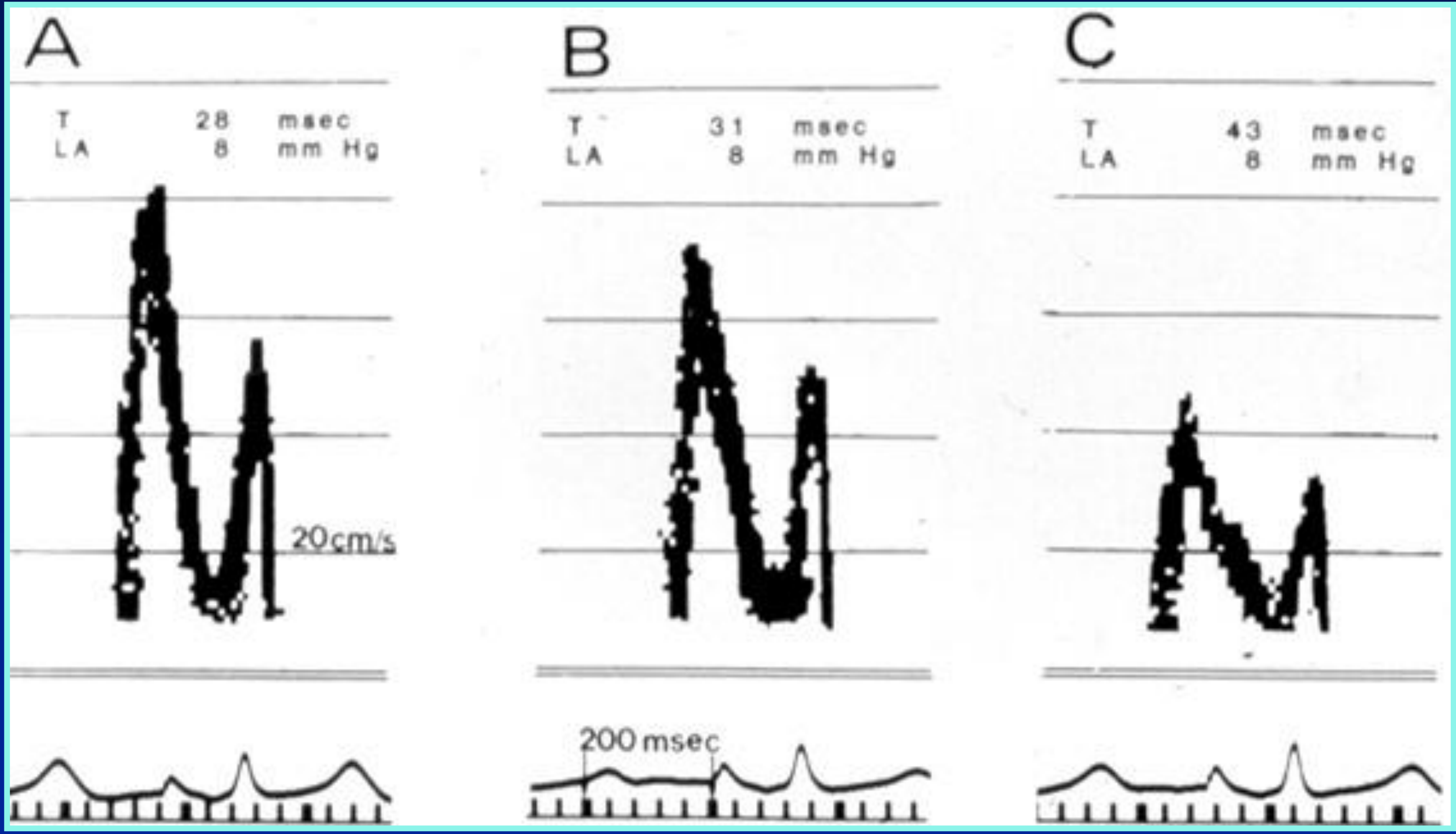
Proportional to p_{LA}/τ





Rate of rise is proportional to growth of transmitral pressure gradient, Δp, and $d\Delta p/dt = LAP/\tau$

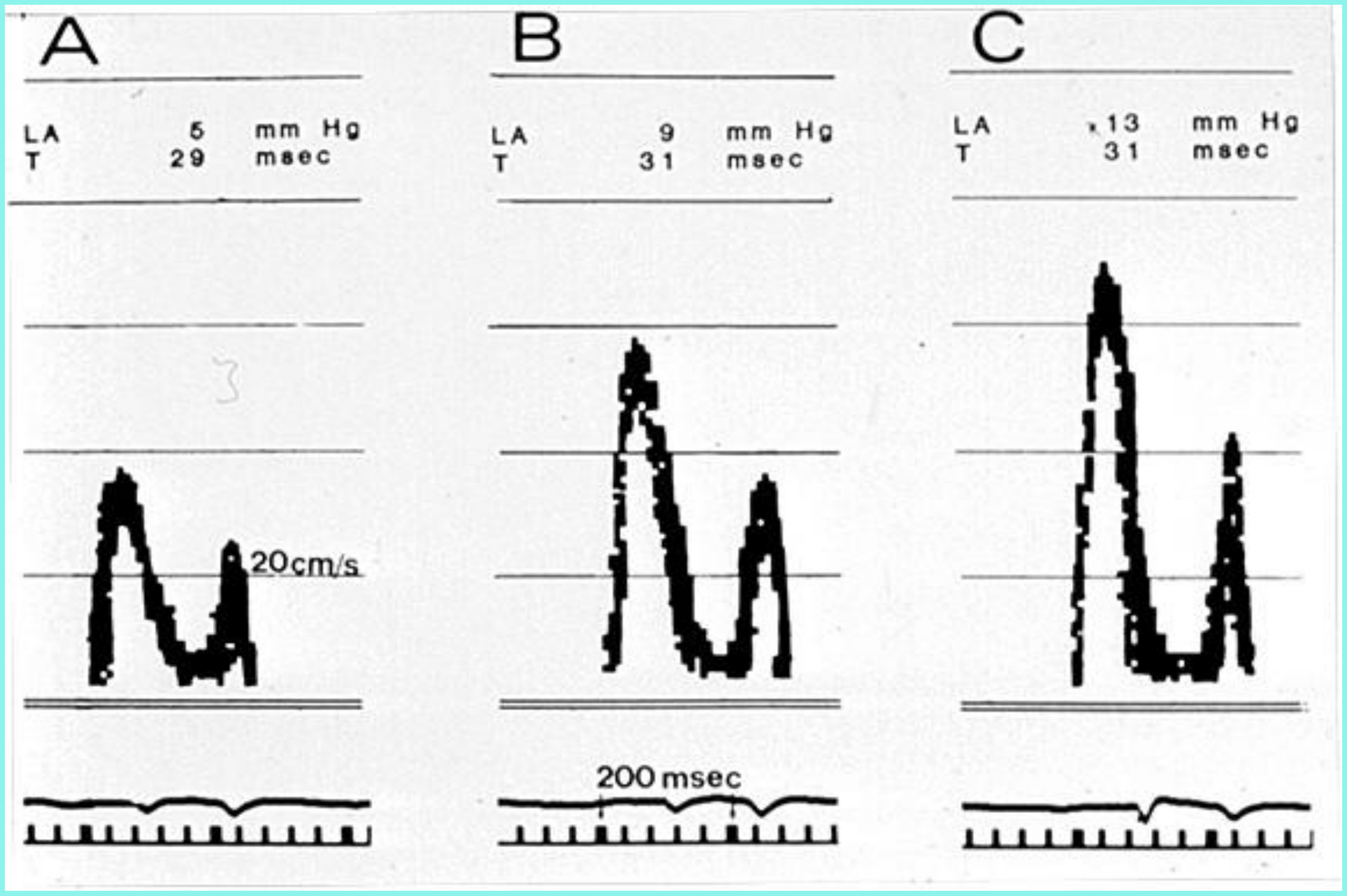
Effect of Relaxation on LV Inflow



With delayed relaxation, acceleration is slowed and E peak is lower.

Choong, et al, Circ 1987

Effect of LAP on LV Inflow

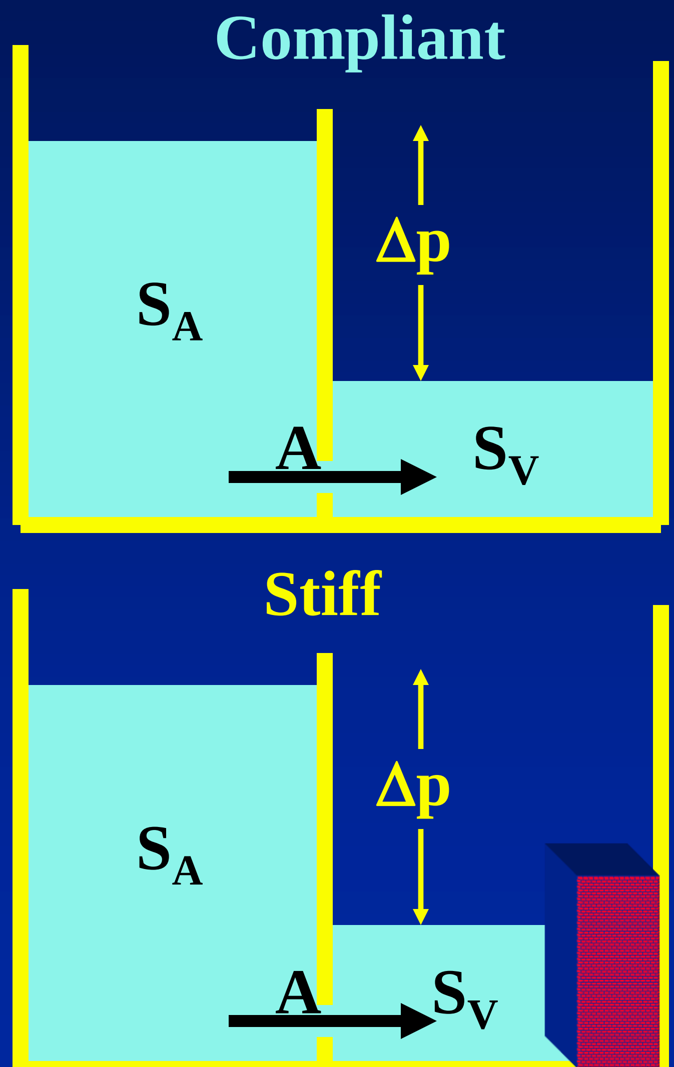


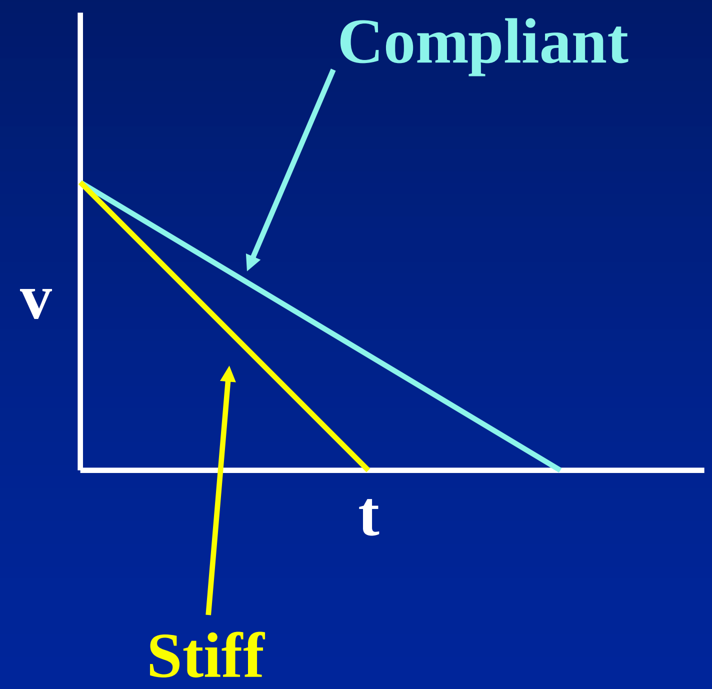
With rising LA pressure, acceleration is faster and E peak is higher.

Choong, et al, Circ 1987

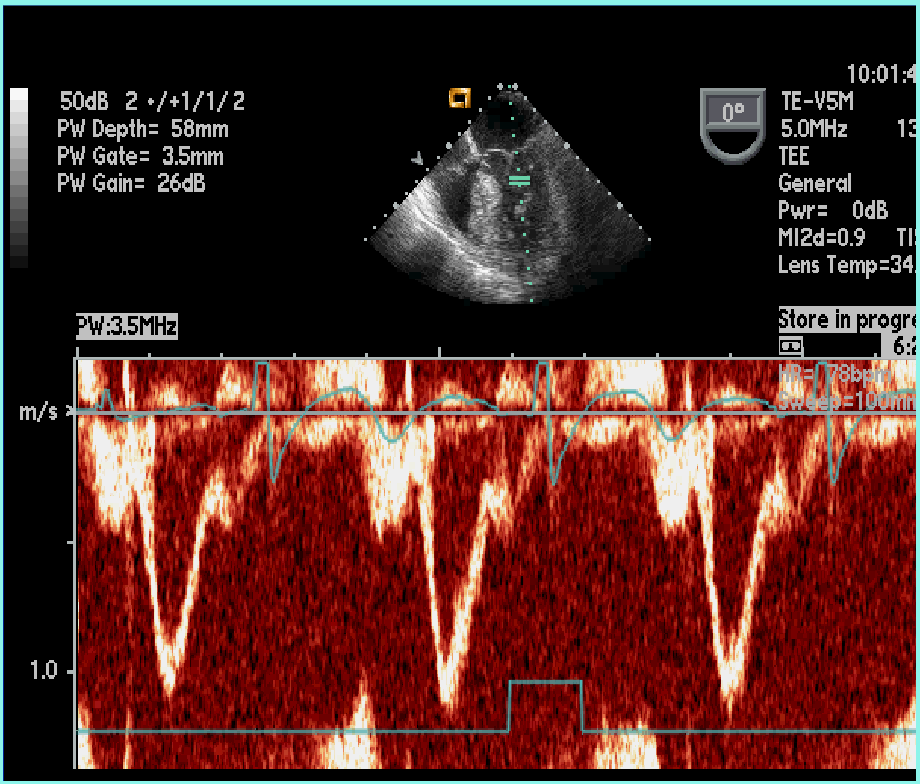
Physical Determinants of Deceleration

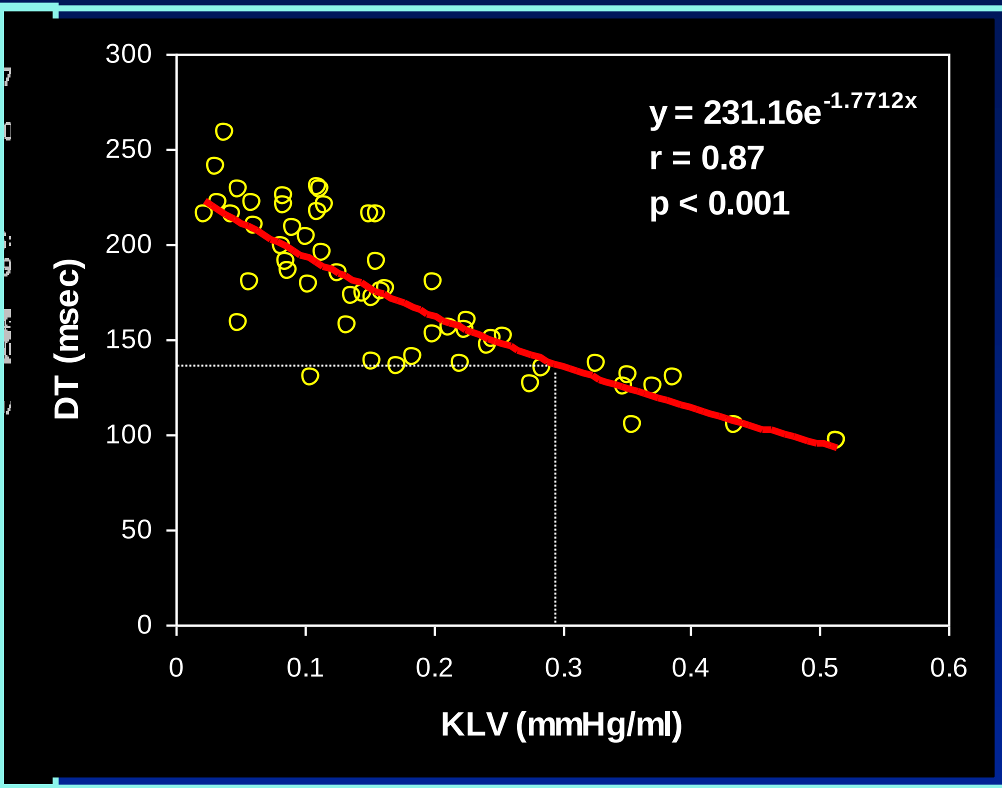
Stiffer Ventricle = Shorter Decel Time





LV stiffness ?





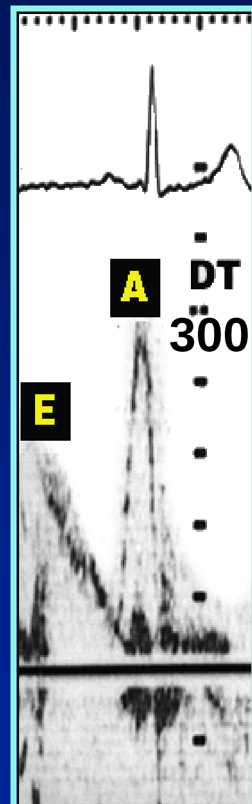
- **DT = 140 msec**

<u>**Answer**</u> = operating stiffness (dp/dV) increased (≅0.30mmHg/ml)

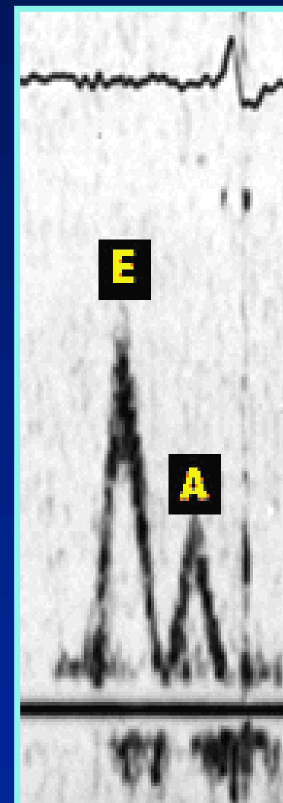
Garcia, Am J Physiol 2001;280:H554

Left Ventricular Filling Patterns

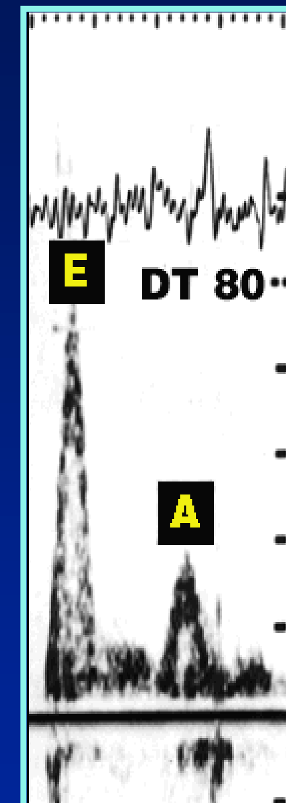
Normal



Delayed relaxation

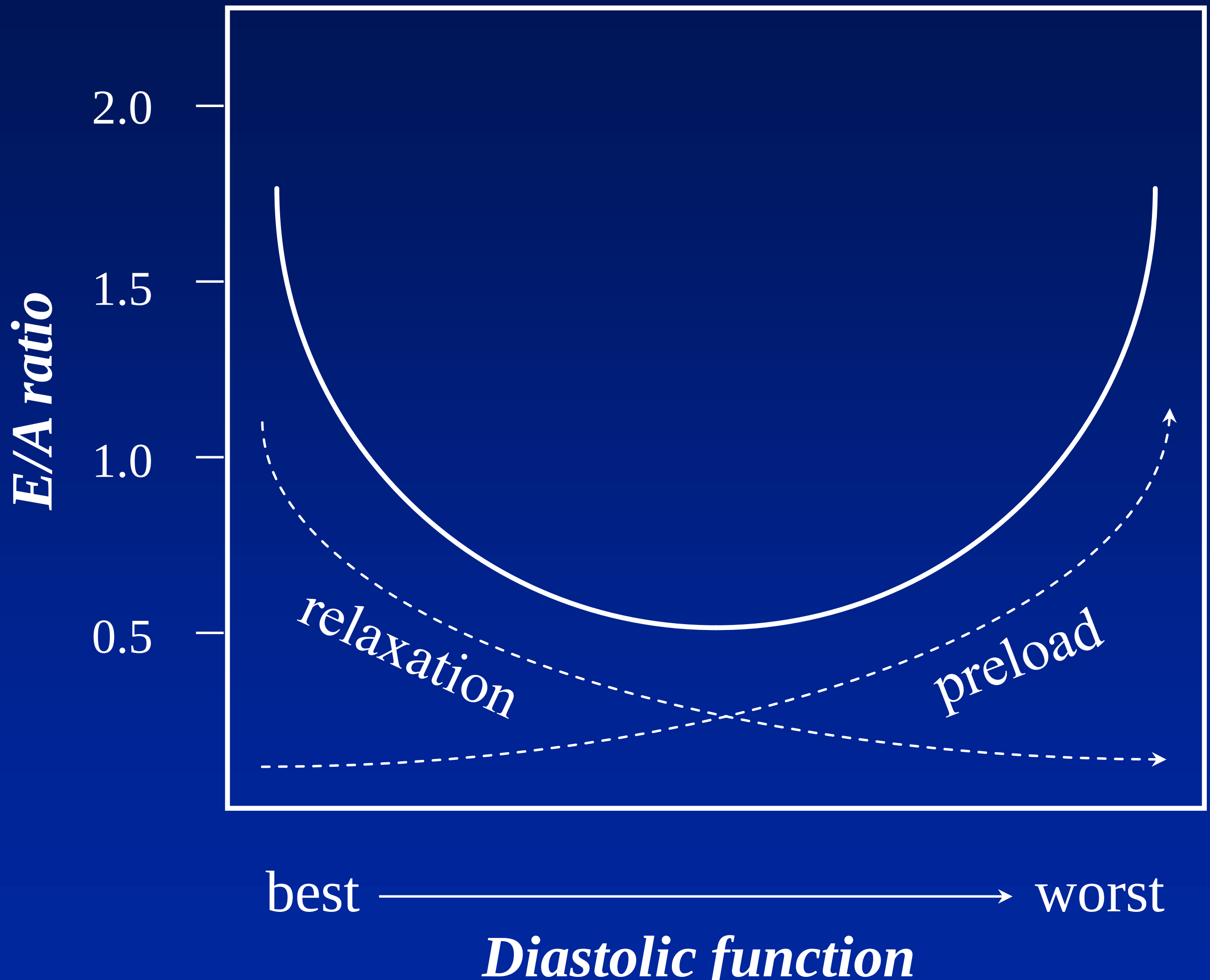


Pseudonormal



Restrictive

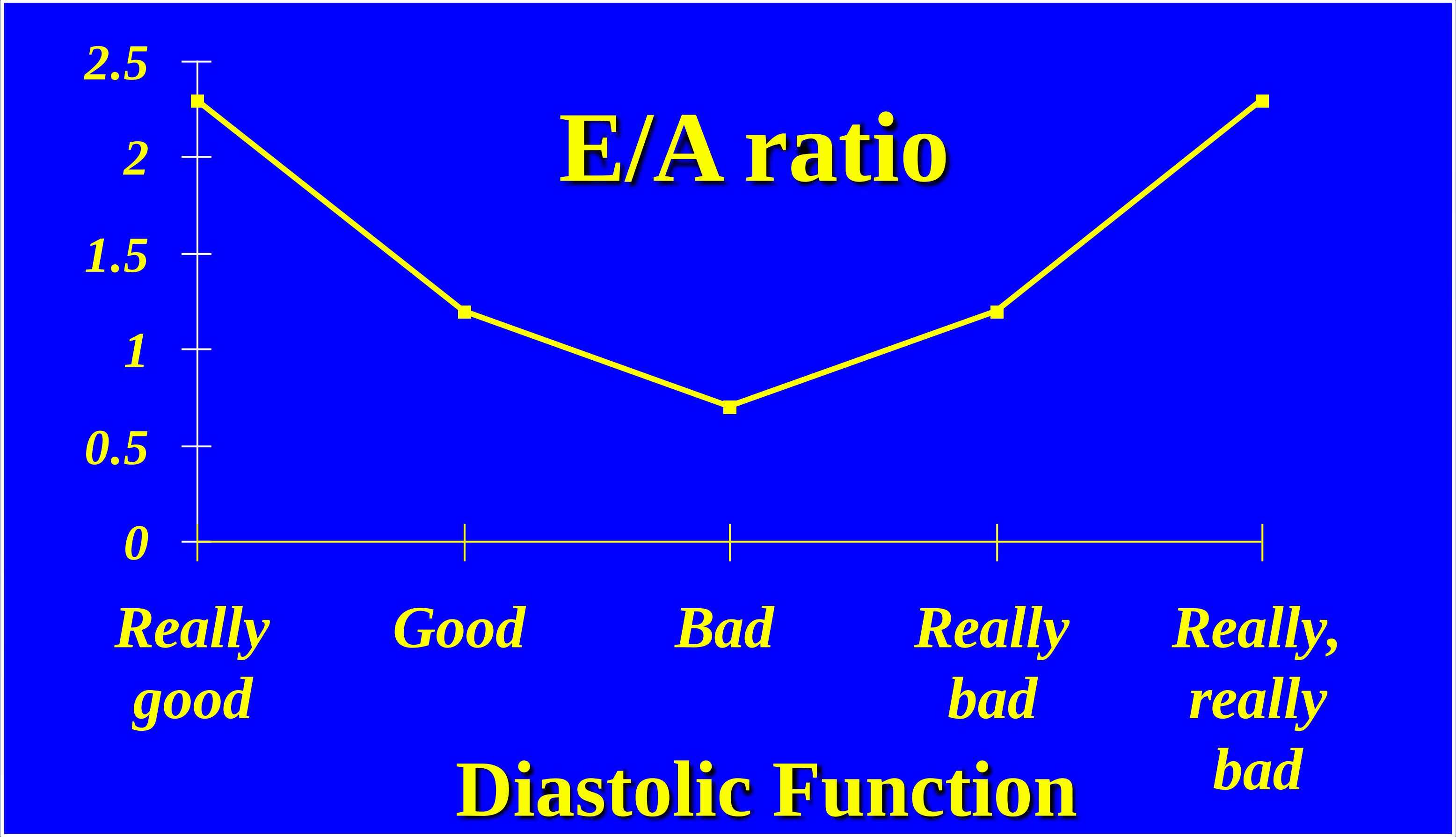
Preload *vs* Relaxation
Confounding Effects



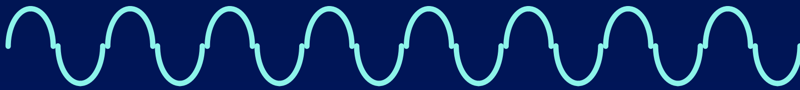
Garcia et al, JACC 1998;32:865

The Problem with Transmitral Doppler Assessment of Diastolic Function

Preload Sensitivity

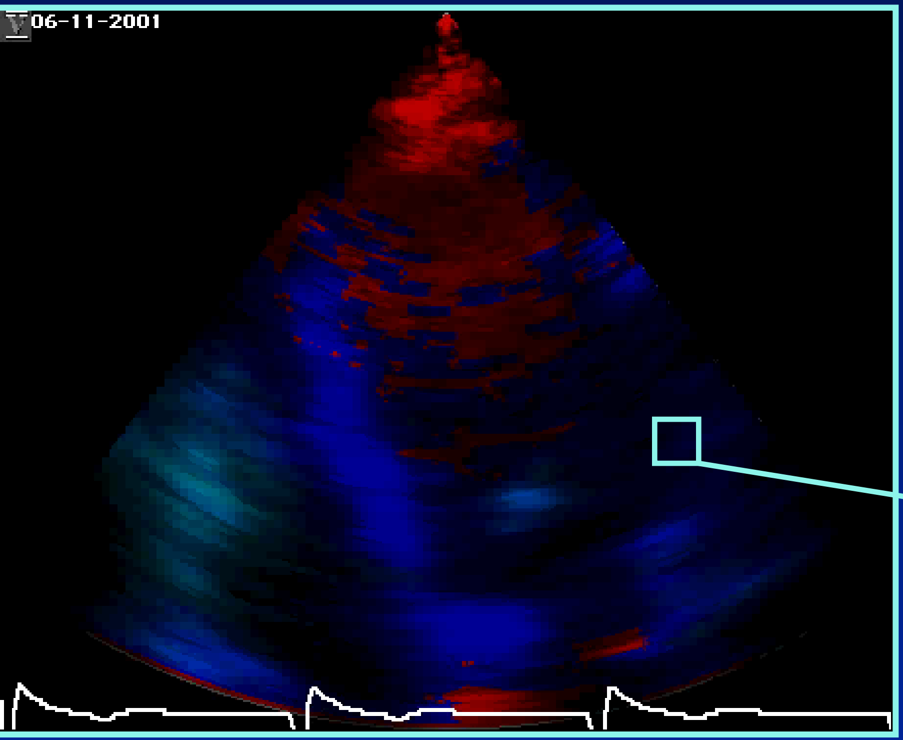


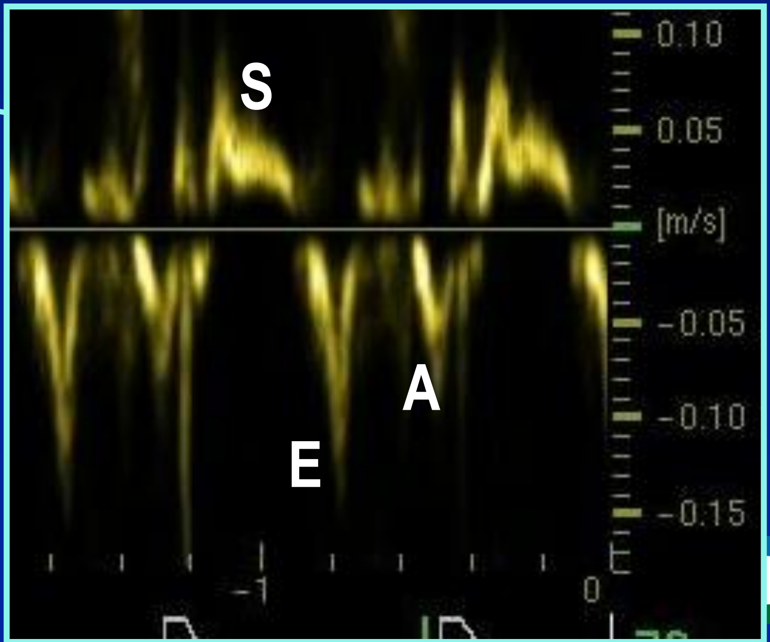
Tissue Doppler Imaging



Blood: High velocity, low amplitude

Tissue: Low velocity, high amplitude

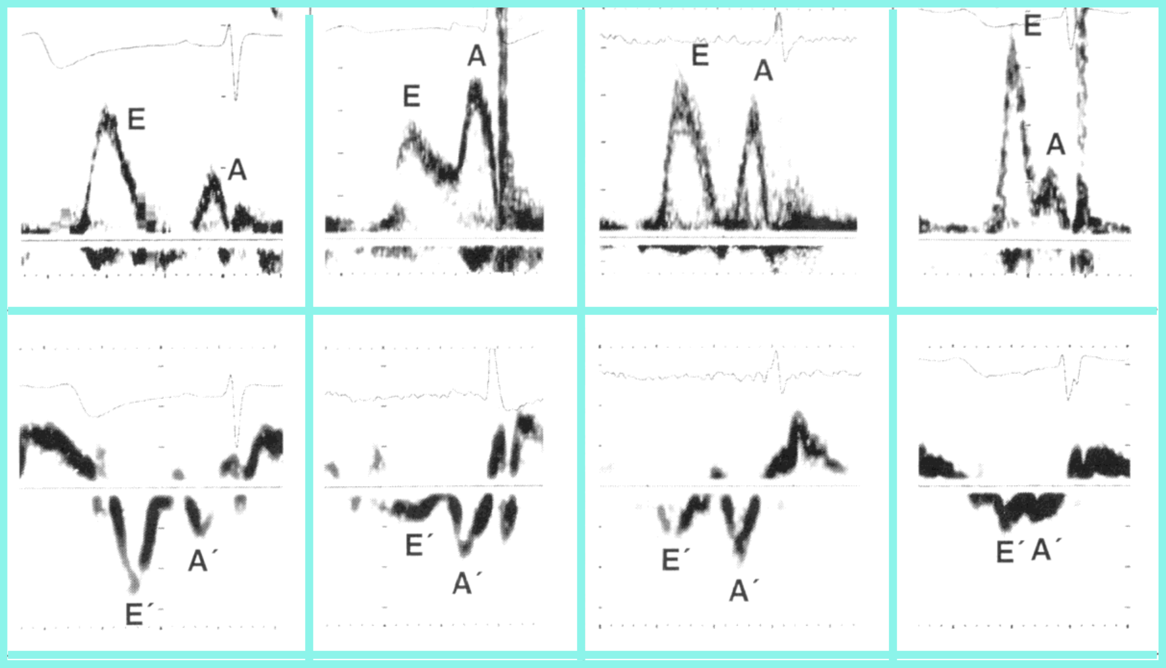




Myocardial Wall Velocities
Independence from Mitral Inflow

Mitral inflow

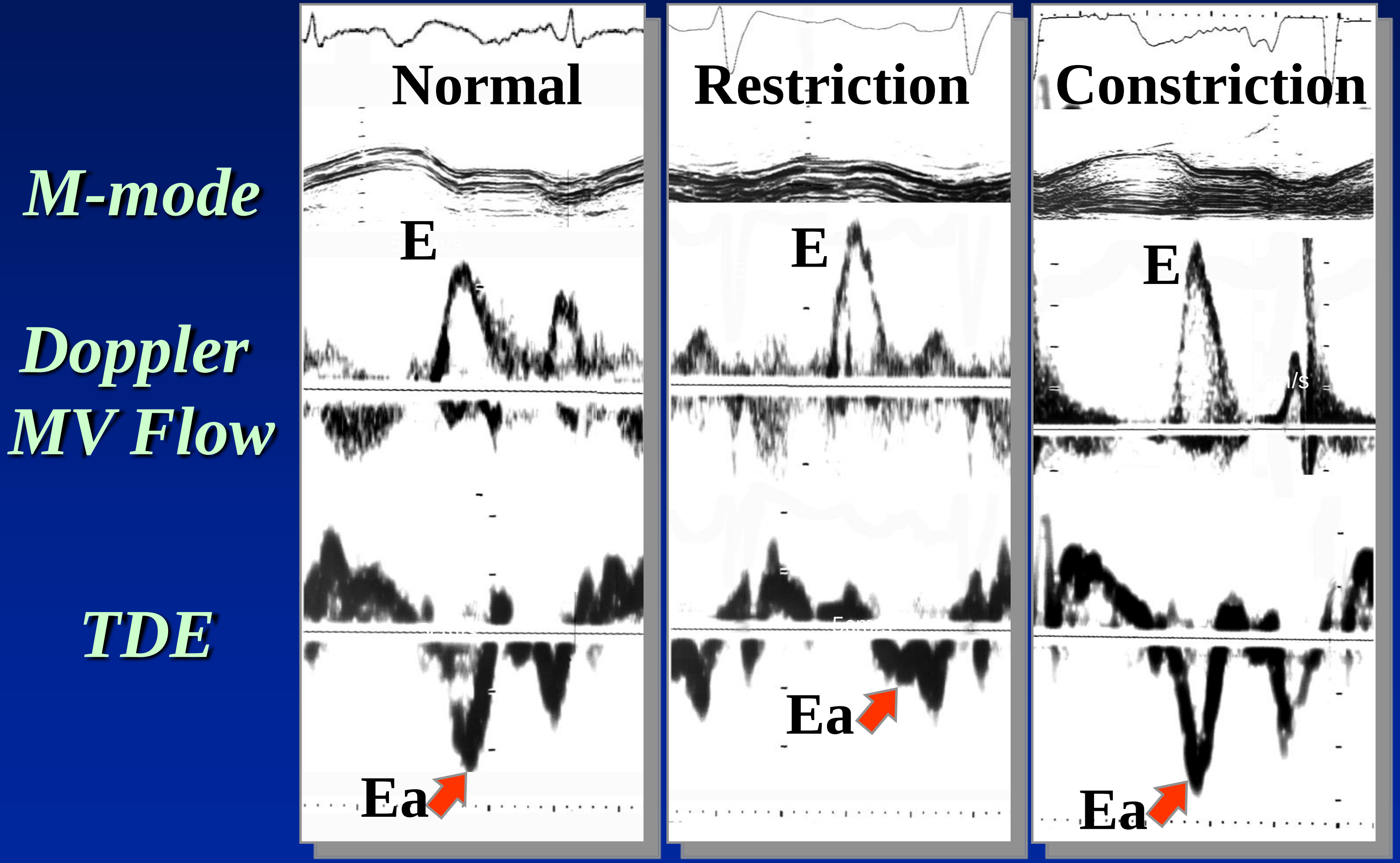
Mitral annulus



Normal | ***Delayed relaxation*** | ***Pseudo-normal*** | ***Restrictive***

Sohn et al., JACC 1997; 30: 474-80

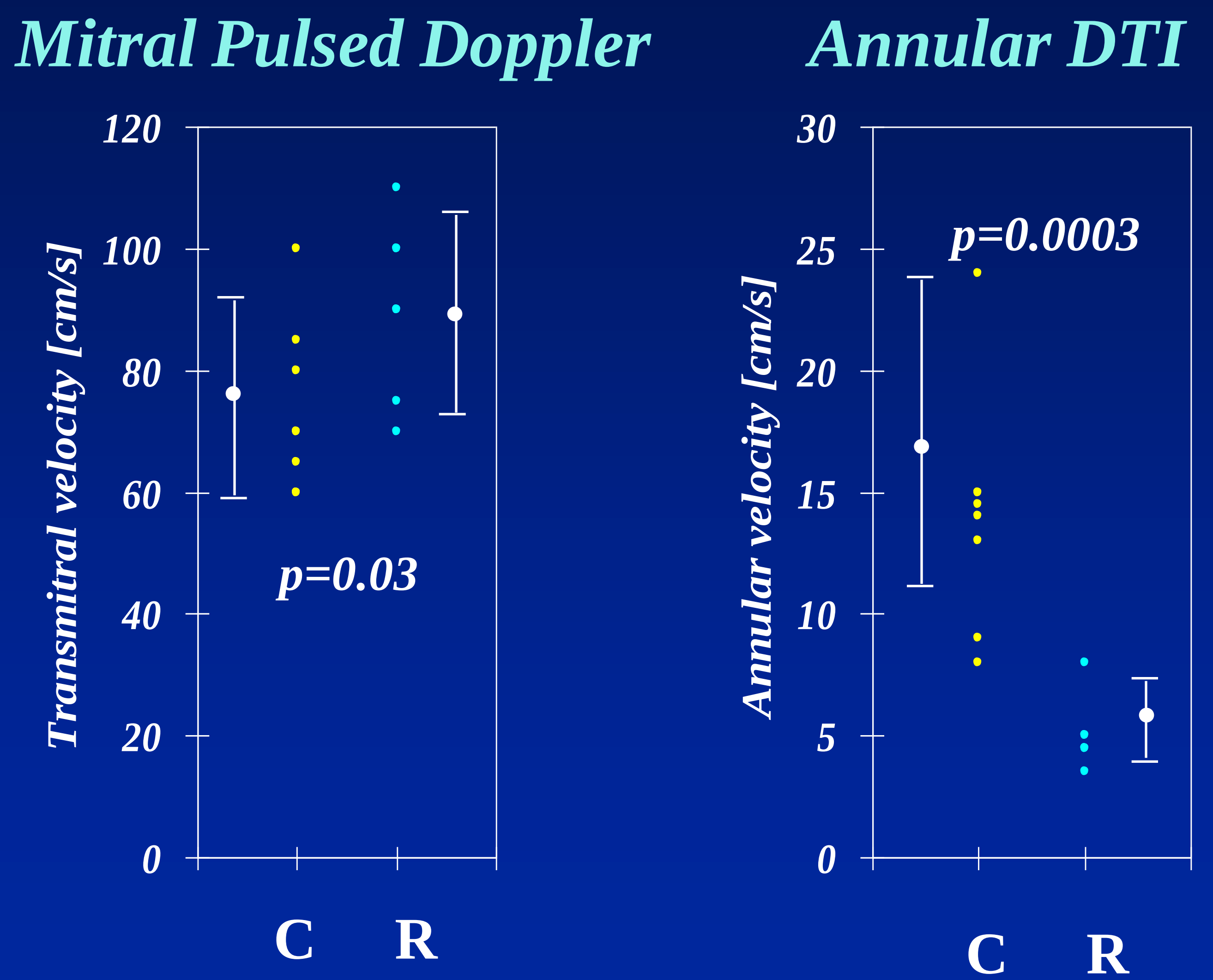
Constriction vs Restriction



Garcia et al., JACC 1996; 27: 108-114

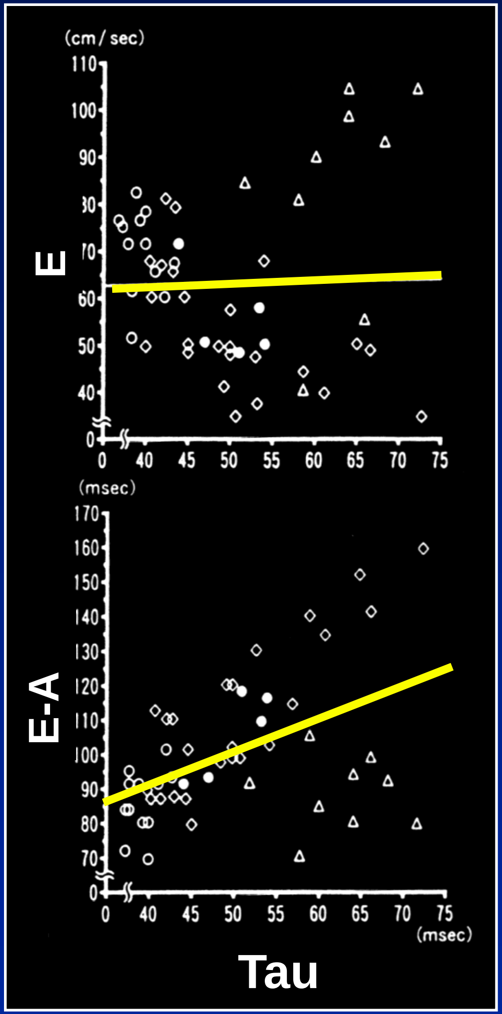
Constriction vs Restriction

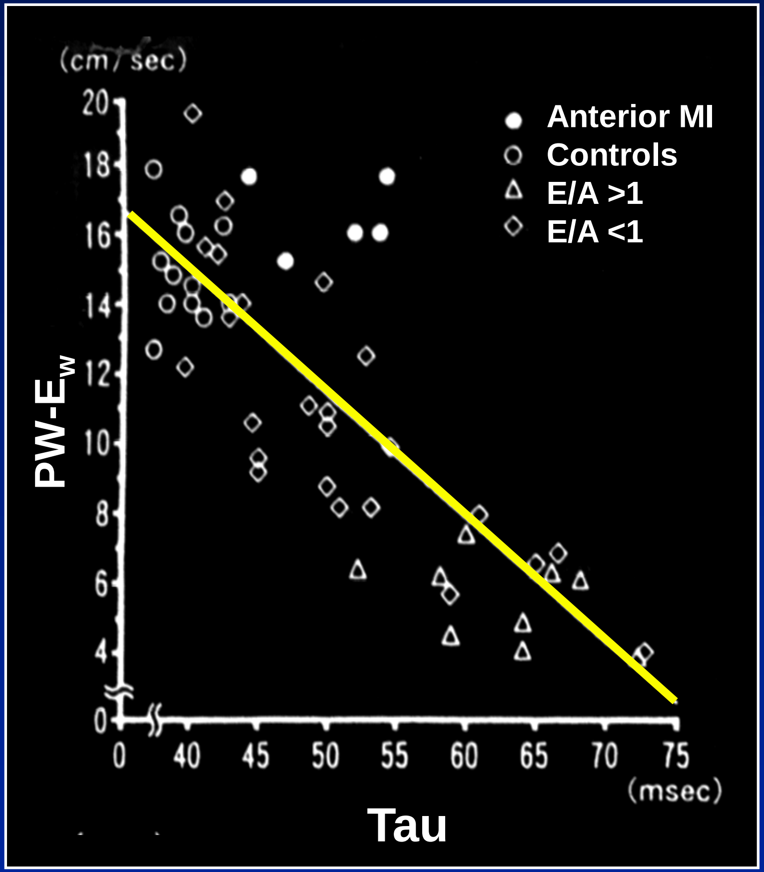
Doppler Differentiation



Garcia et al., JACC 1996; 27: 108-114

Assessment of LV Relaxation
DTE E-wave Inversely Related to τ





Oki et al, Am J Cardiol 1997;79:928

Implication

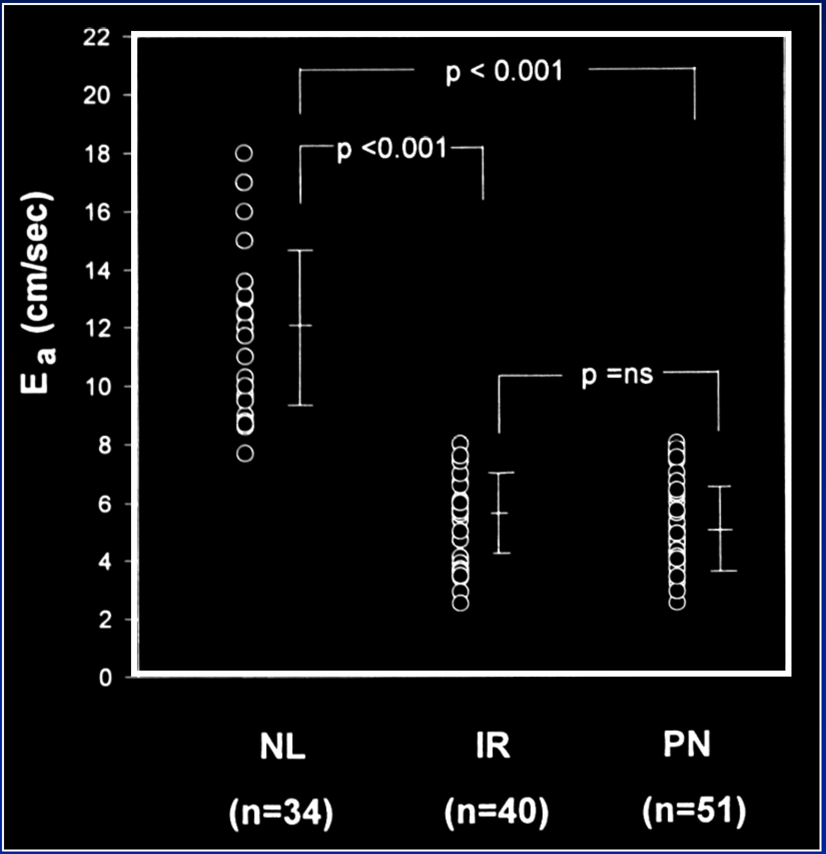
E/Ea Can Predict LA Pressure

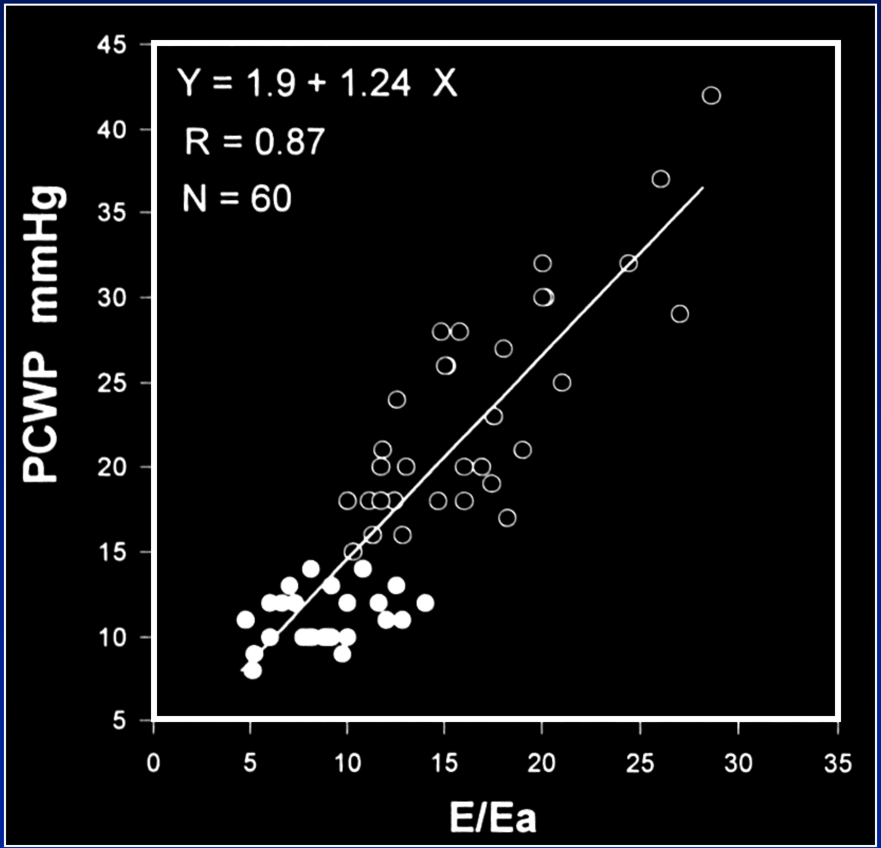
If E $\propto$ LAP/τ

and Ea $\propto$ 1/τ,

then LAP $\propto$ E/Ea

Estimation of P_{LA}



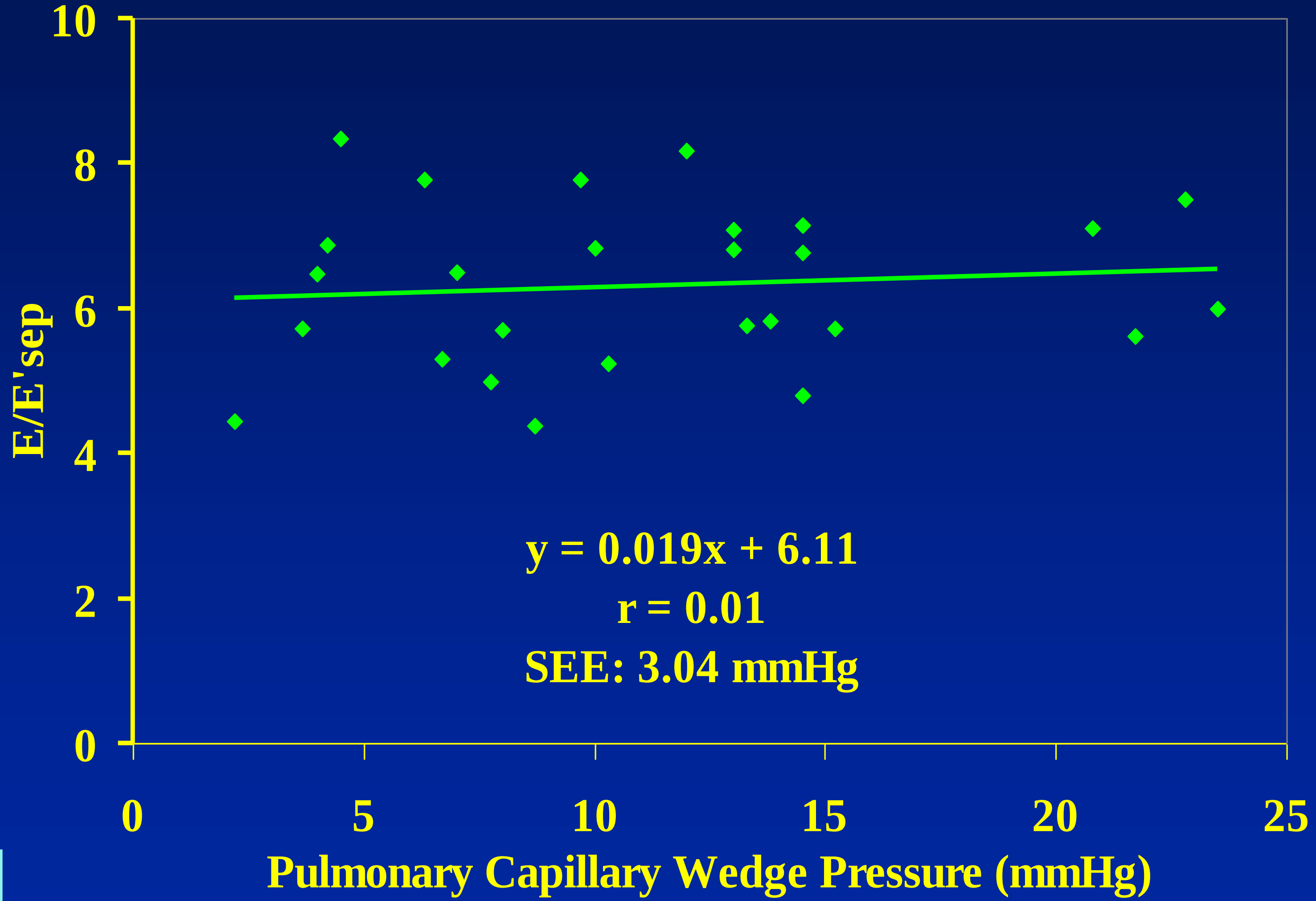


Nagueh et al. JACC 1997;30:1527-33.

Are DTI Velocities Truly Independent of Preload??

No, not if the heart is normal

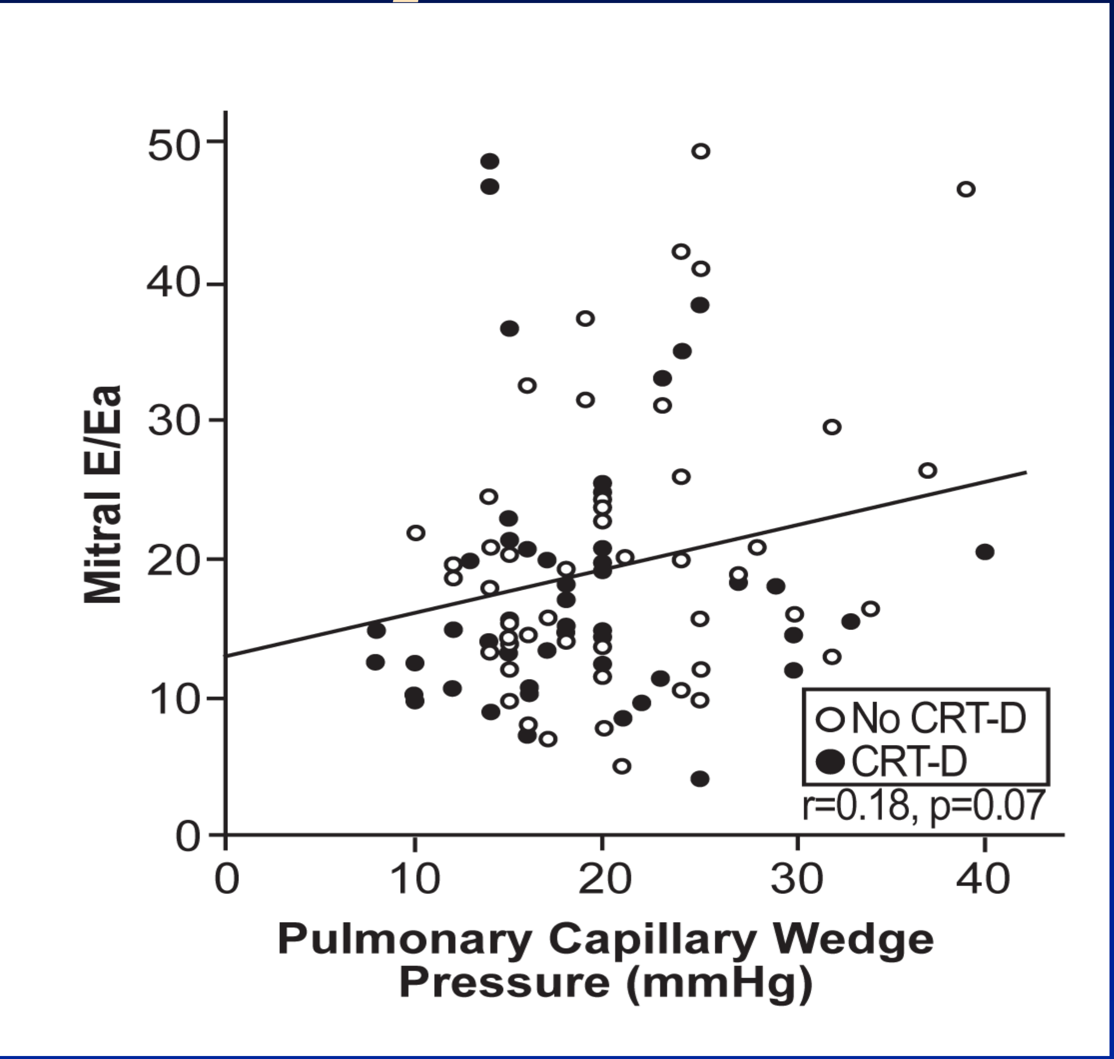
Estimation of Left Atrial Pressure
Subjects without Heart Disease



Firstenberg et al. *J Am Coll Cardiol* 2000; 36: 1664-9.

And Not if the Heart is REALLY Sick

Acute Decompensated Heart Failure



Mullens et al. Circ 2009; 119: 62-70

Tissue Doppler Imaging in the Estimation of Intracardiac Filling Pressure in Decompensated Patients With Advanced Systolic Heart Failure

Wilfried Mullens, MD; Allen G. Borowski, RDCS; Ronan J. Curtin, MD;
James D. Thomas, MD; W.H. Tang, MD

Circ 2009; 119: 62-70

EF = 24%
E = 135 cm/sec
Lateral e' = 2
E/e' = 67
PCW = 14 mmHg

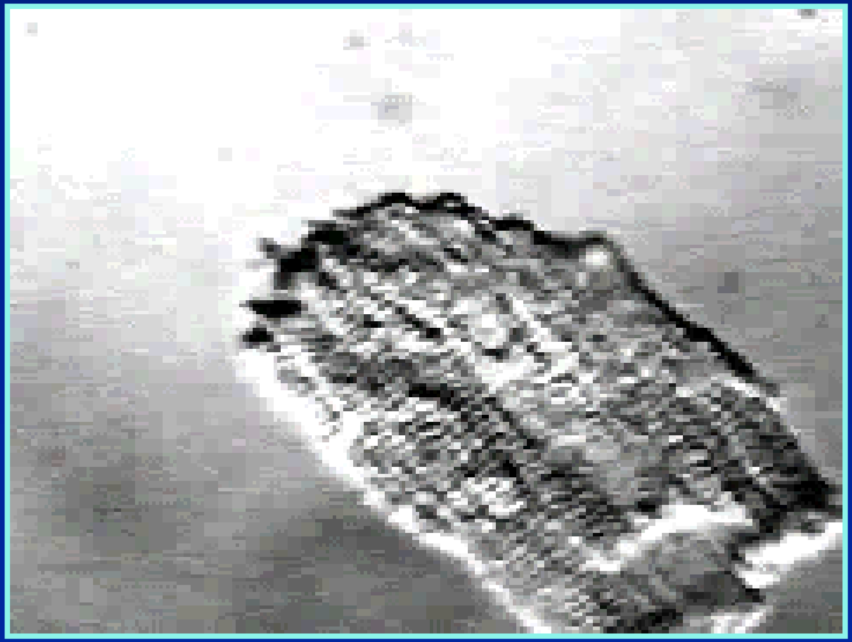
EF = 31%
E = 89 cm/sec
Lateral e' = 6.9
E/e' = 14
PCW = 33 mmHg

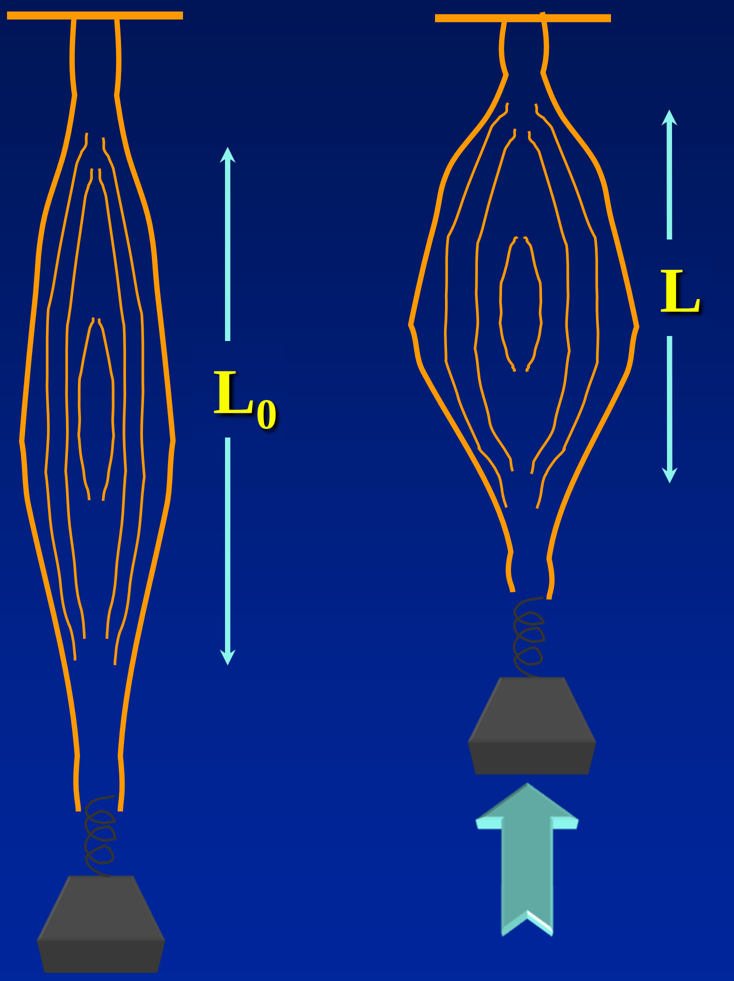
Myocardial Strain: What is It??

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





Predictors of Systolic and Diastolic 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

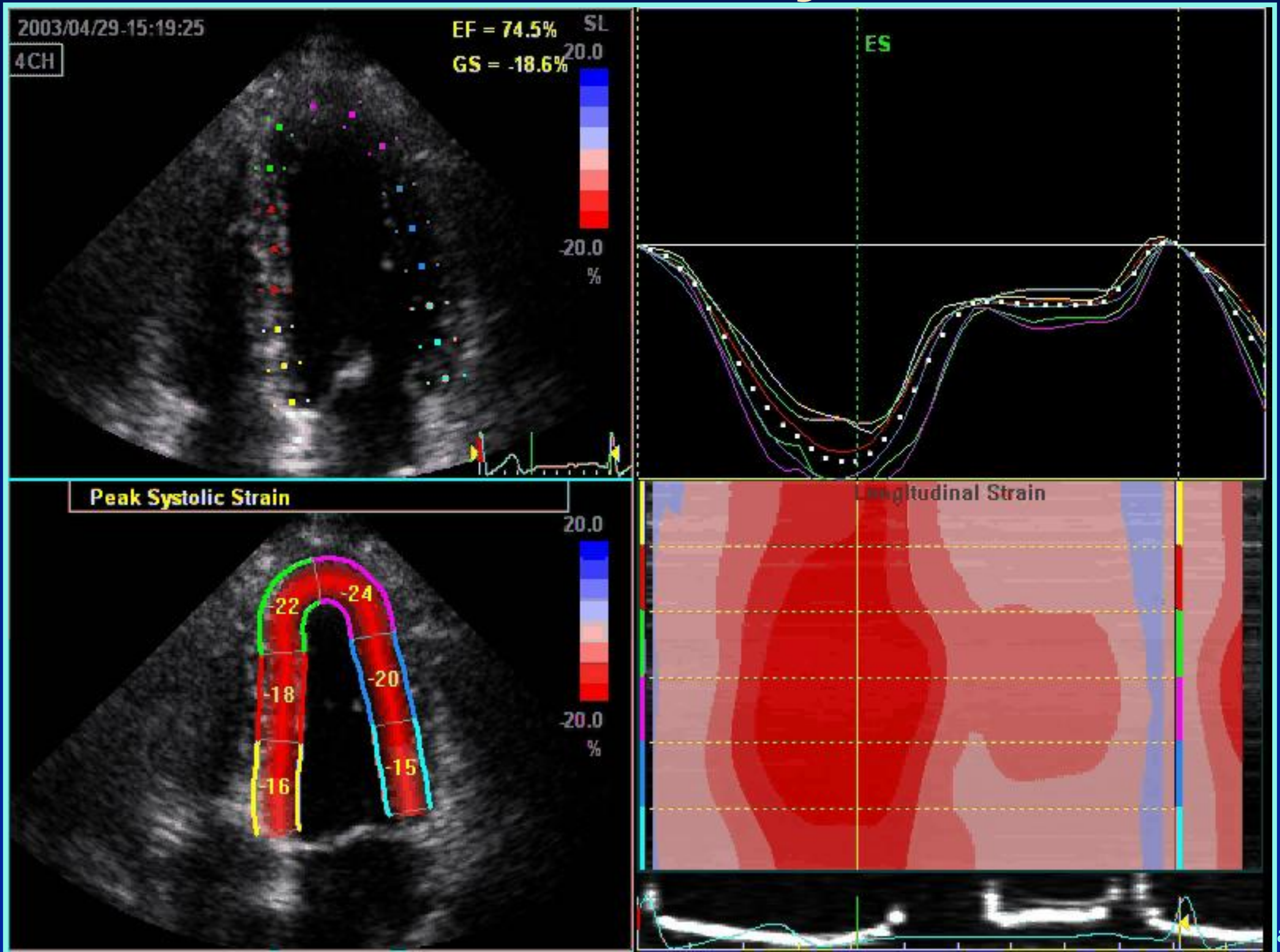
Diastolic Strain Rates

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

Longitudinal Strain from B-Mode Echo

Normal Subject

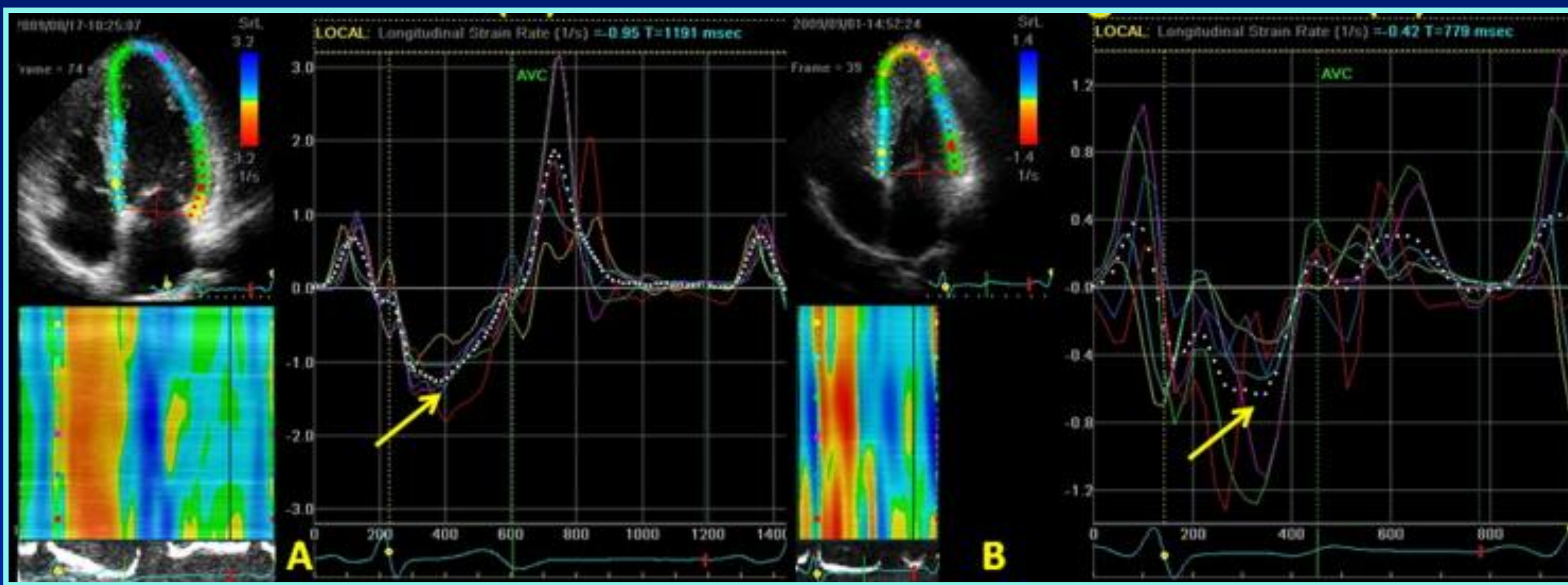


Systolic and Diastolic Myocardial Mechanics in Patients with Cardiac Disease and Preserved Ejection Fraction: Impact of Left Ventricular Filling Pressure

John S. Nguyen, MD, Nasser M. Lakkis, MD, Jaromir Bobek, RCIS, Rajiv Goswami, MD, and Hisham Dokainish, MD, *Dallas, Texas; Hamilton, Ontario, Canada*

60 pts w/ EF>50%, 30 w/ pre-A LVEDP<15 mmHg, 30 over 15 mmHg

Normal EDP **Elevated EDP**

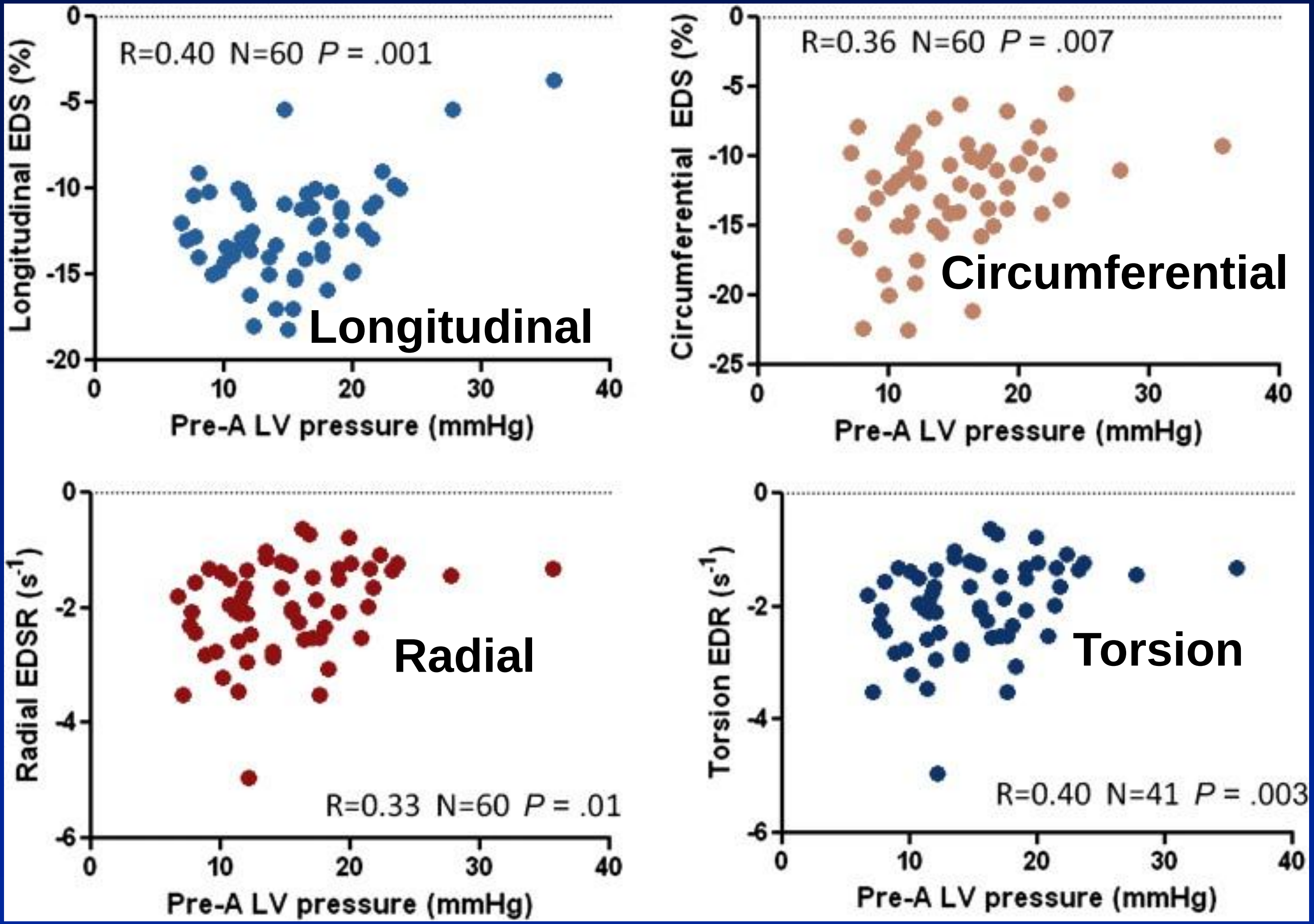


Higher LVEDP ⇒ lower systolic and diastolic strain rate

Nguyen et al. JASE 2010; 23: 1273-80

Diastolic Strain vs LVEDP

Lower values ⇒ higher EDP

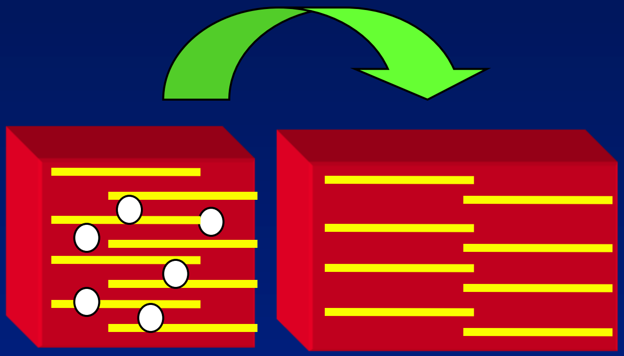


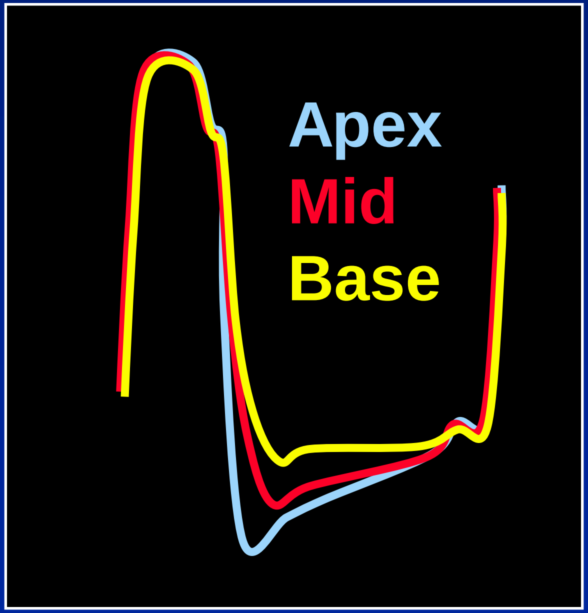
But r^2 only 0.11 to 0.16

Nguyen et al. JASE 2010; 23: 1273-80

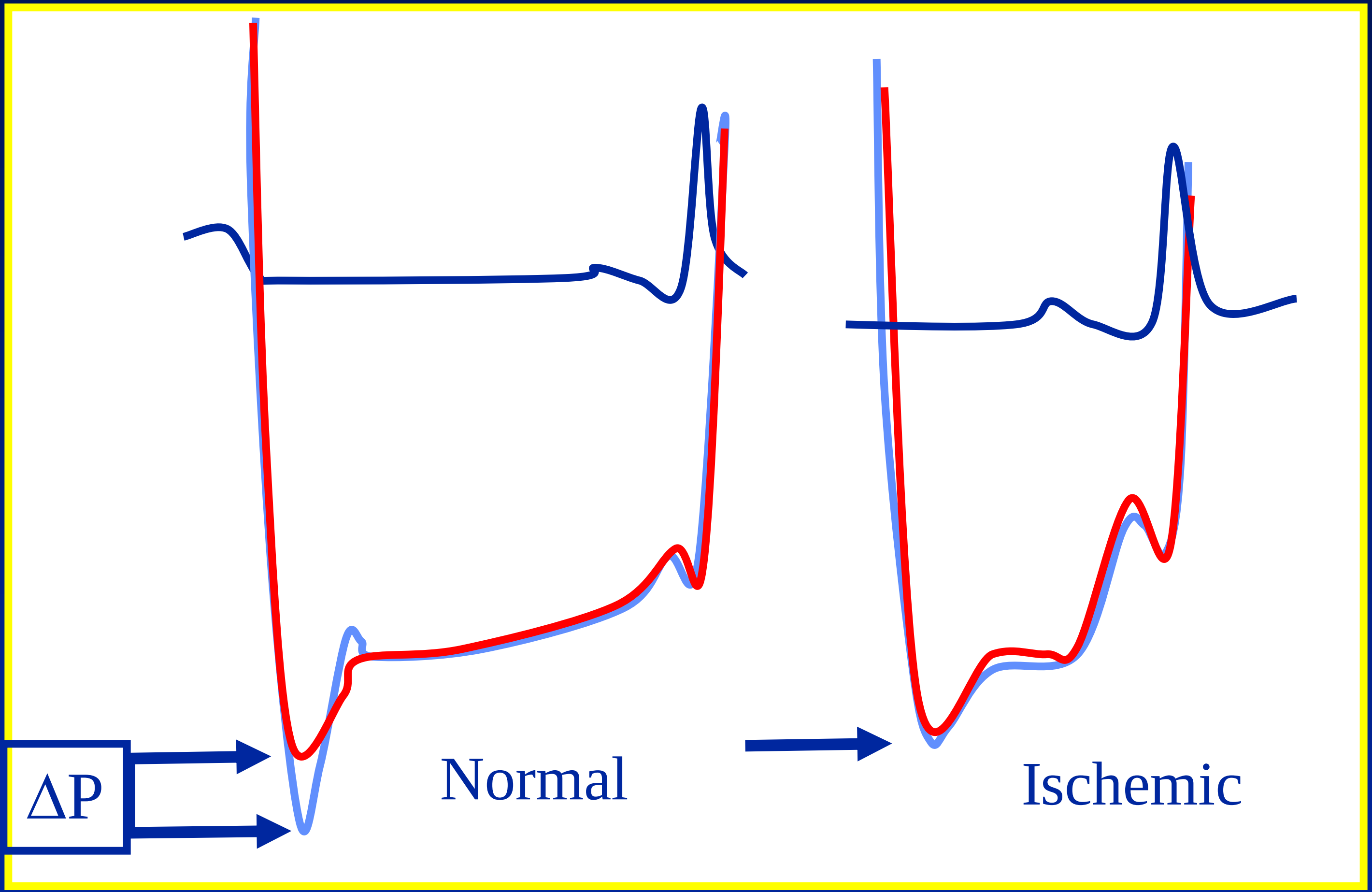
LV Relaxation and Intraventricular Pressure Gradients

- Active relaxation, occurring earlier and more rapidly at the LV apex generates small (1-2 mmHg) intraventricular pressure gradients in the normal heart.
- These intraventricular pressure gradients assist in the low pressure filling of the heart
- Critically impacted by delayed relaxation and dyssynchrony





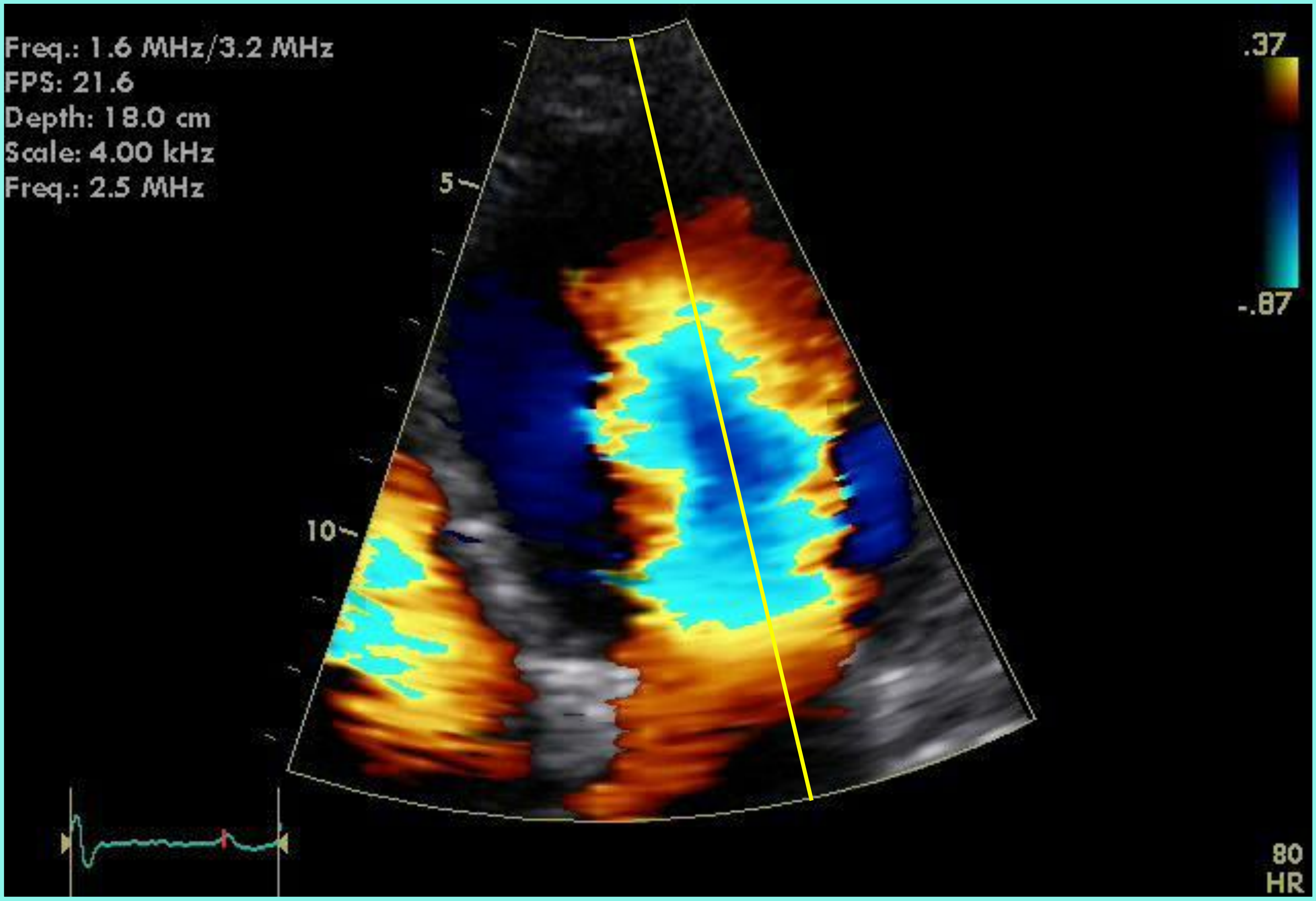
Importance of Diastolic Suction



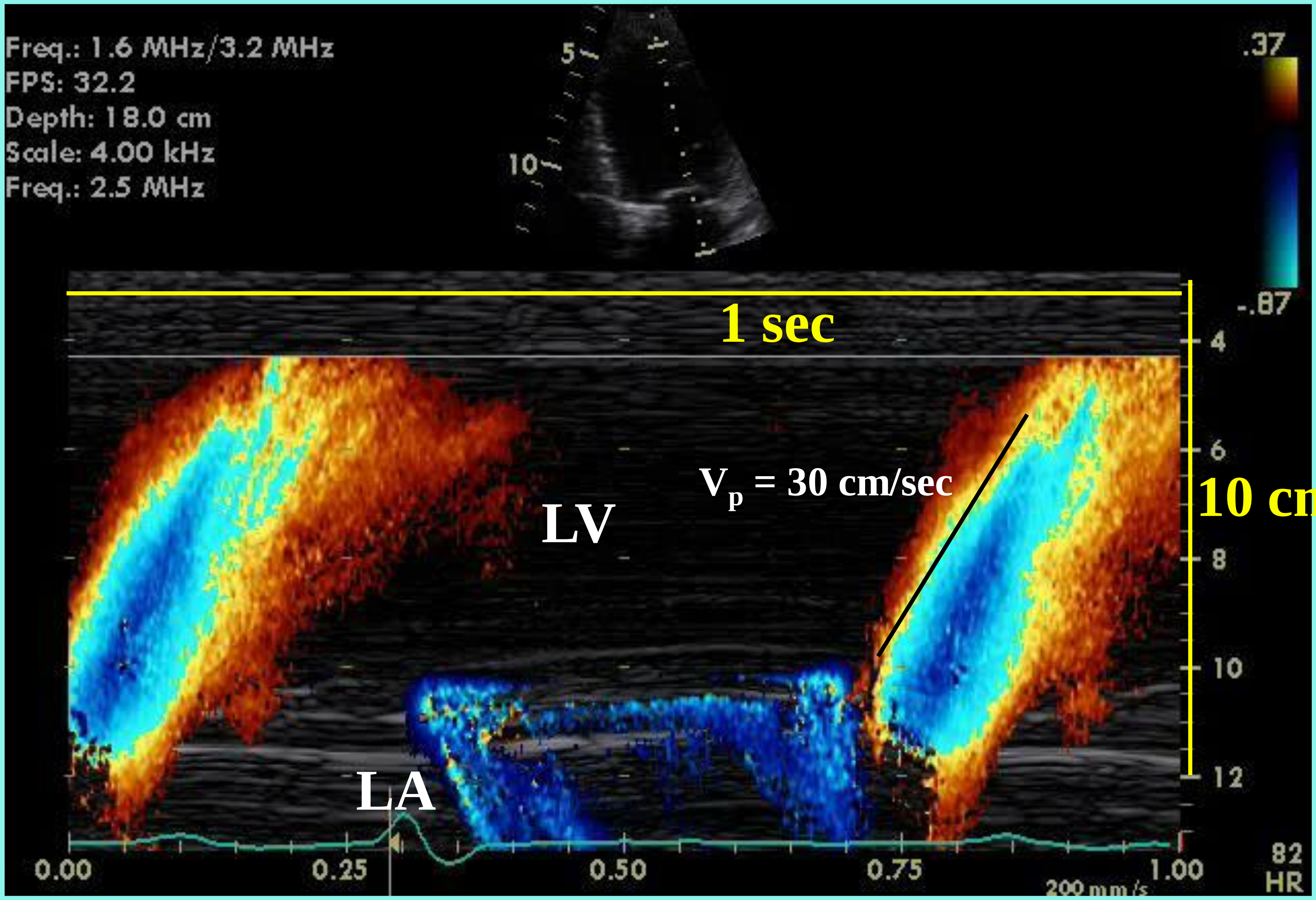
Almost impossible to measure invasively……

Courtois et al. Circulation 1990;81:1688-96

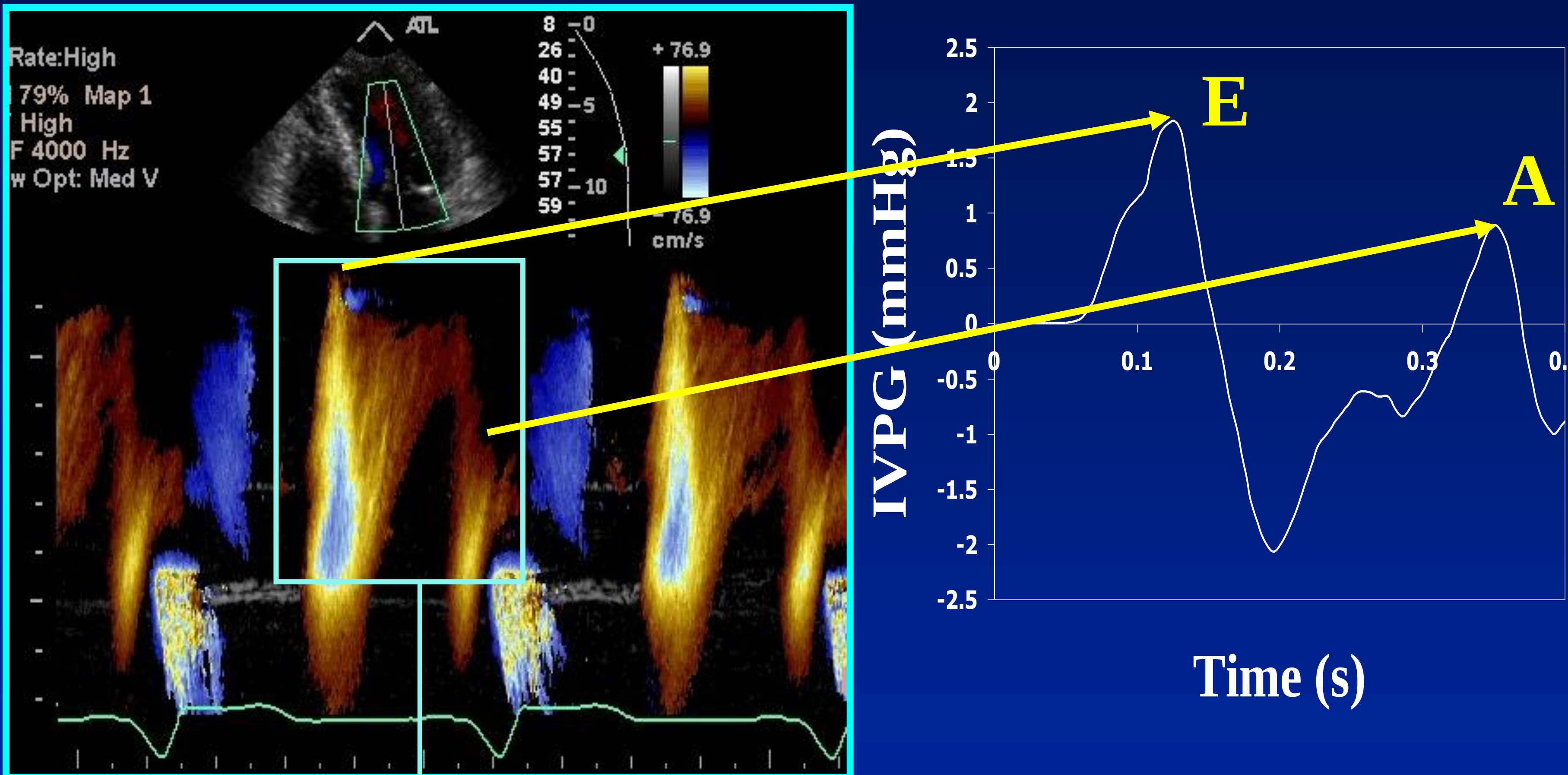
Color M-Mode Methodology



Measurement of Propagation Velocity



CMM Calculation of IVPG

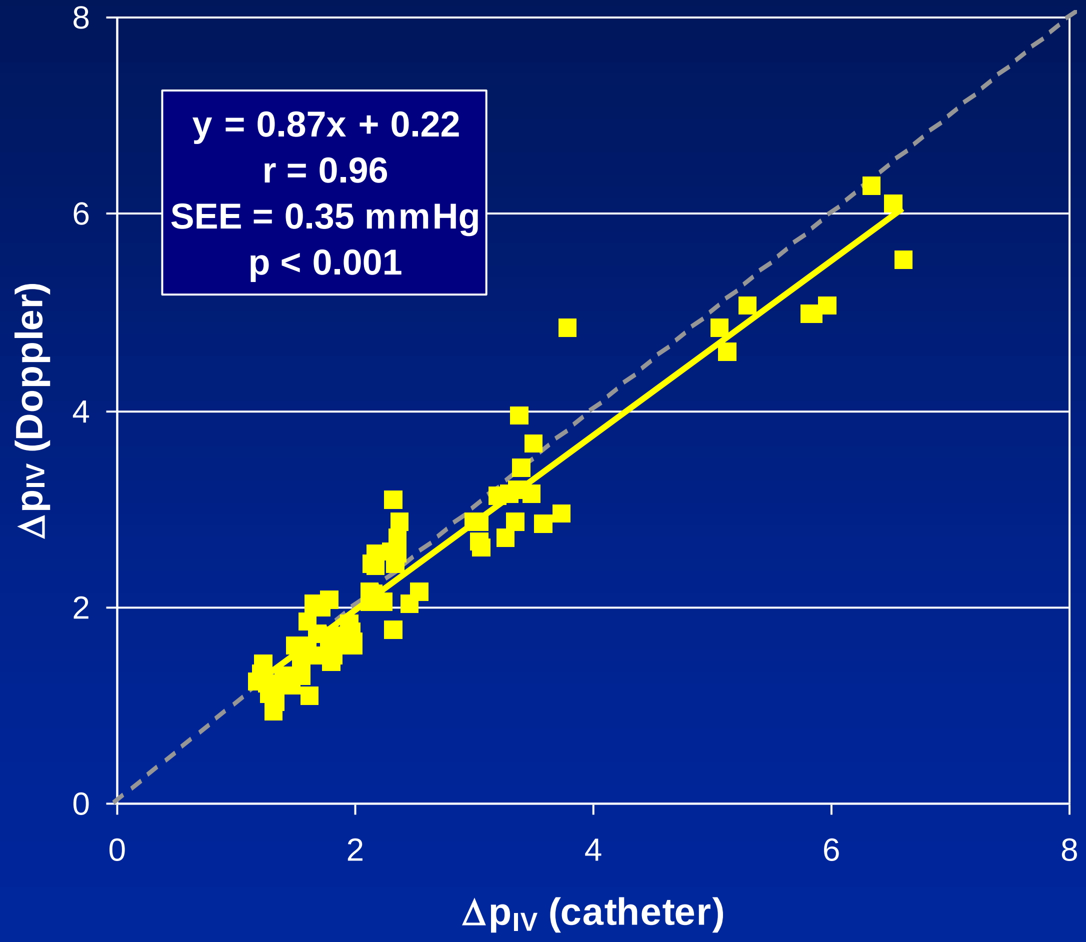


$$\Delta P = -\rho \int_{LV\,base}^{LV\,apex} \left(\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial s} \right) \partial s$$

Euler equation

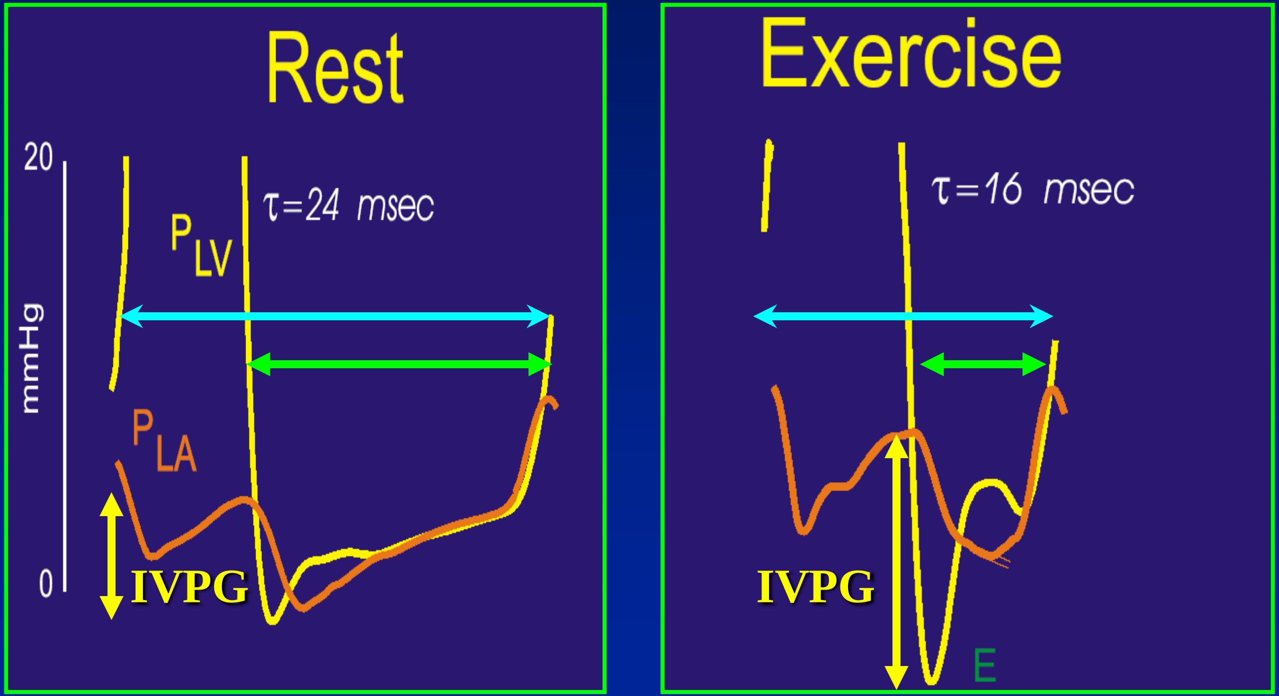
Greenberg et al. Am J Physiol 2001;280:H2507-15

Intraventricular Pressure Gradient



Greenberg et al: Am J Physiol 2001; 280; H2507-H2515

IVPG are Critical During Exercise
Diastole Disproportionately Shortened

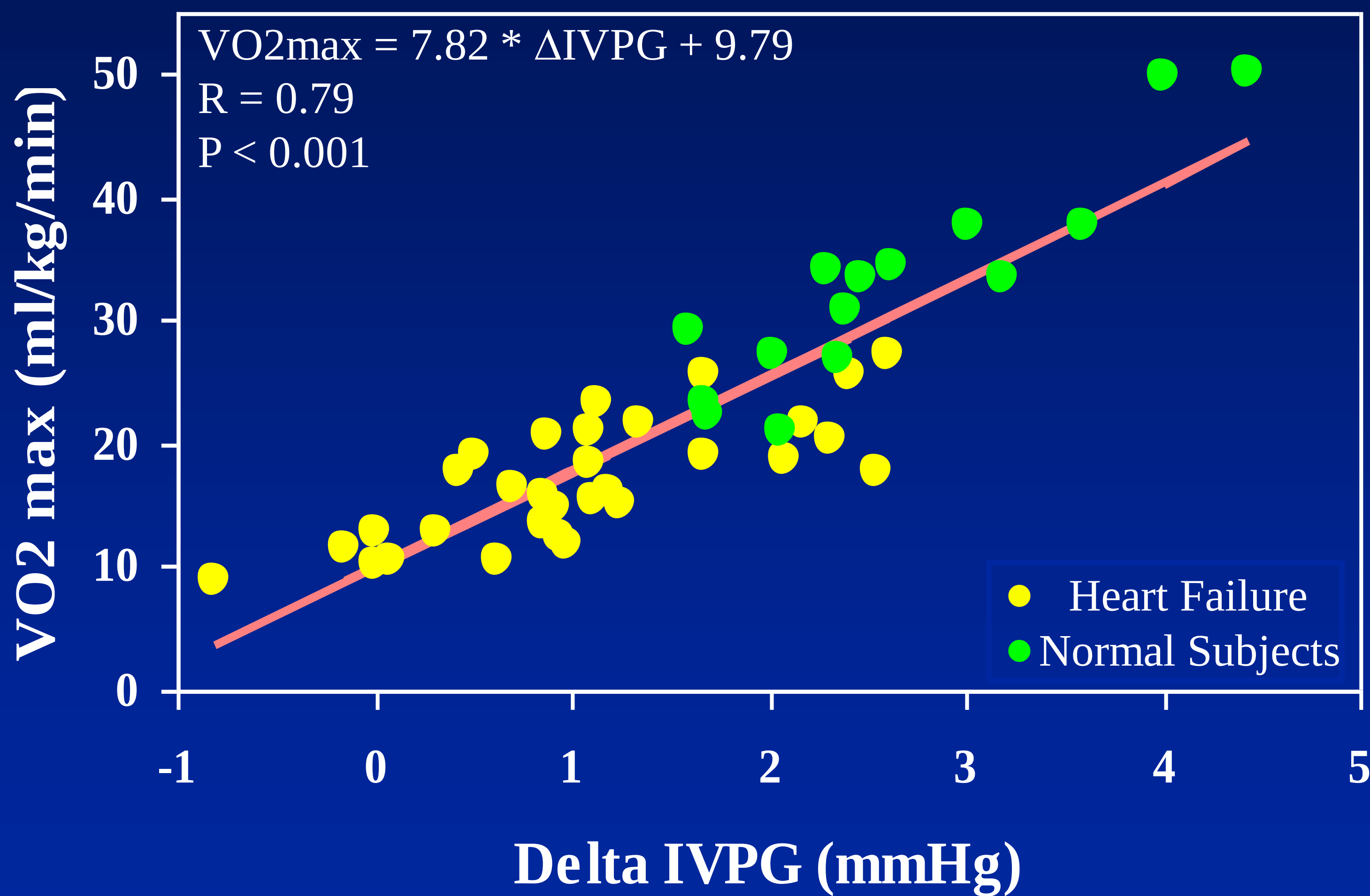


Diastolic Filling Time

Full Cardiac Cycle

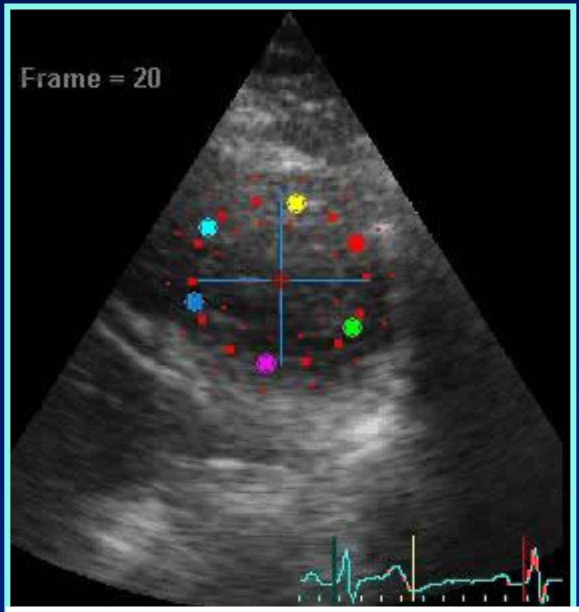
Cheng, Circ Res 1992;70:9-19

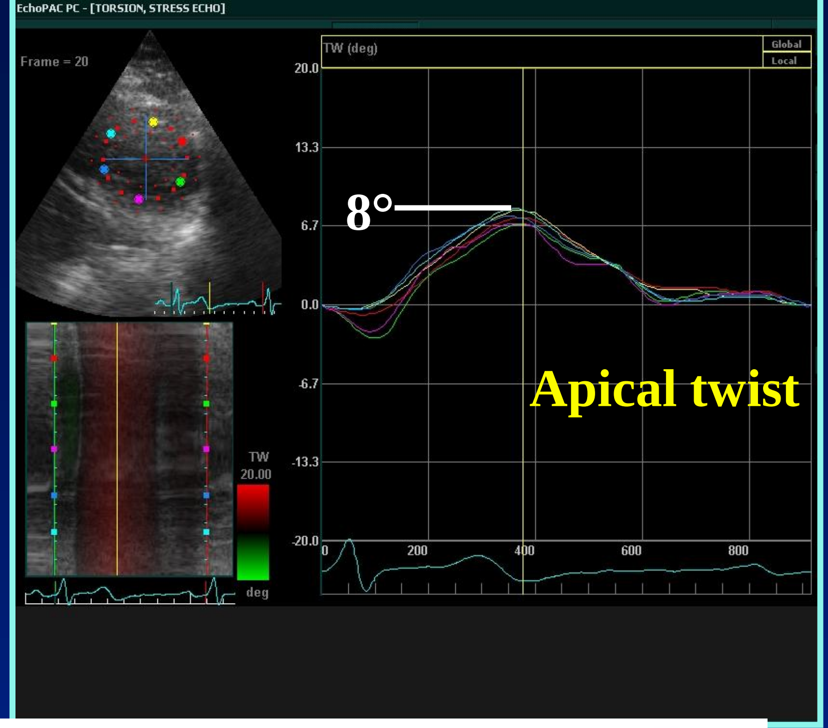
Augmentation of Diastolic Suction Predicts Exercise Capacity

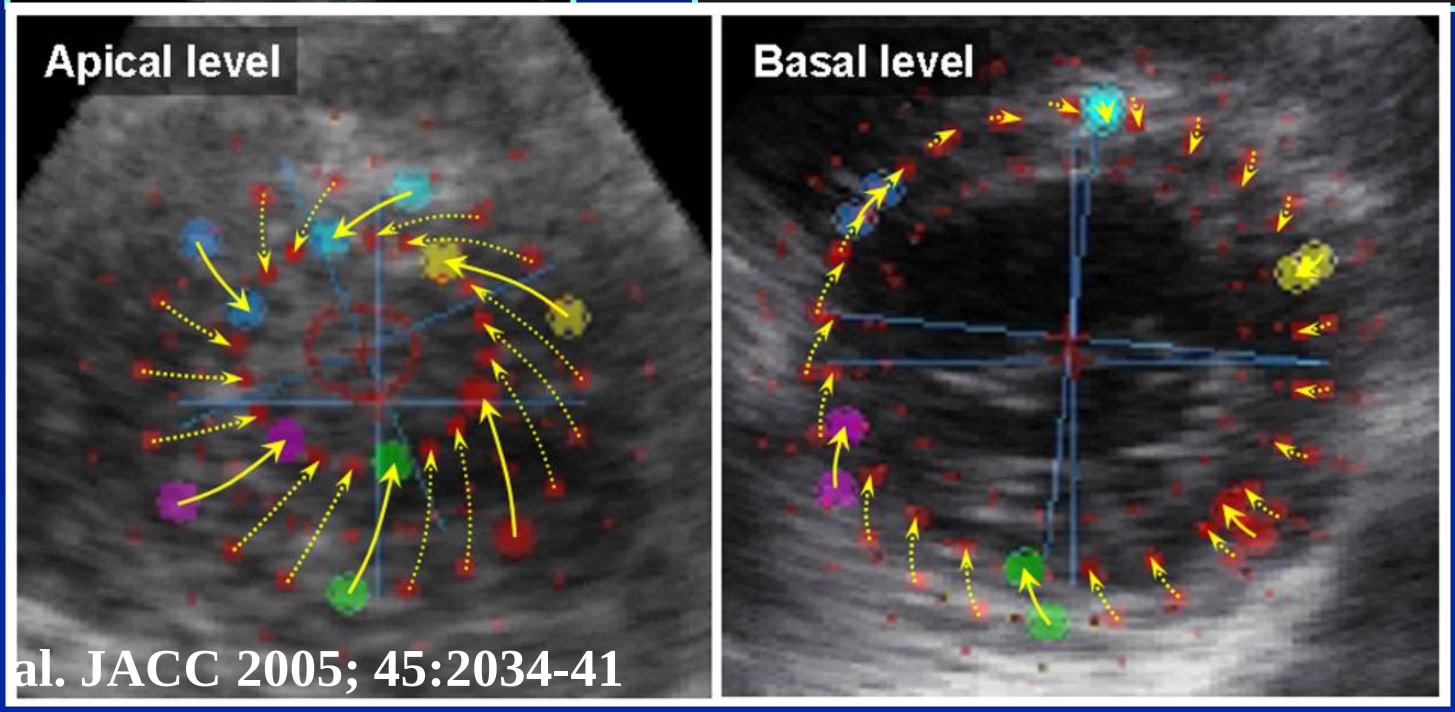


Rovner et al. Am J Physiol 2005; 289: H2081-8

Torsion from 2D Echo





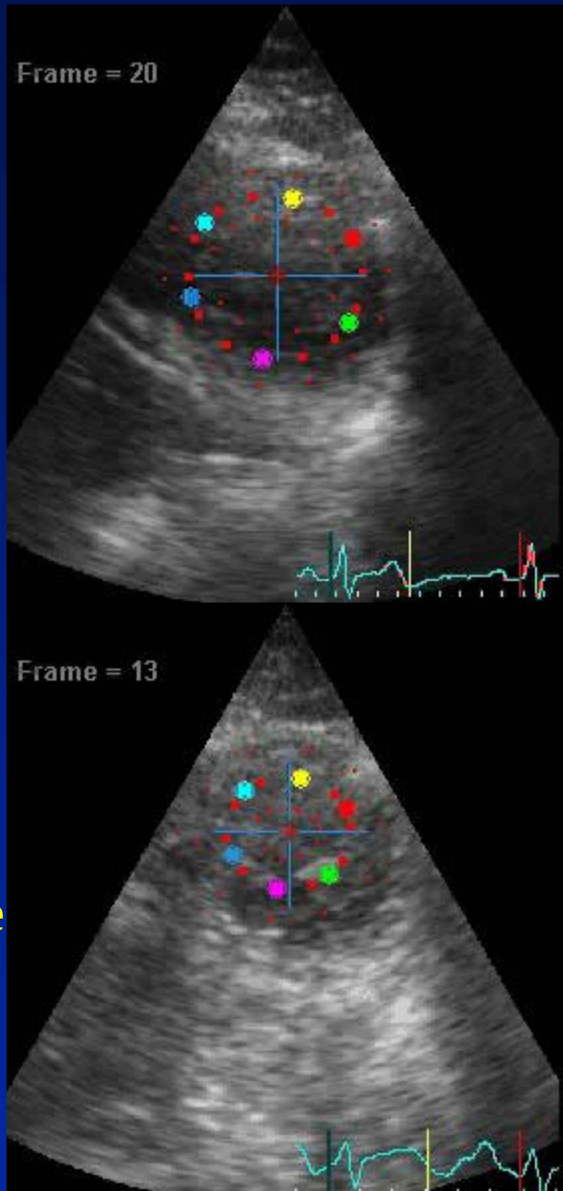


Notomi et al. JACC 2005; 45:2034-41

Torsion During Exercise

Rest

Exercise

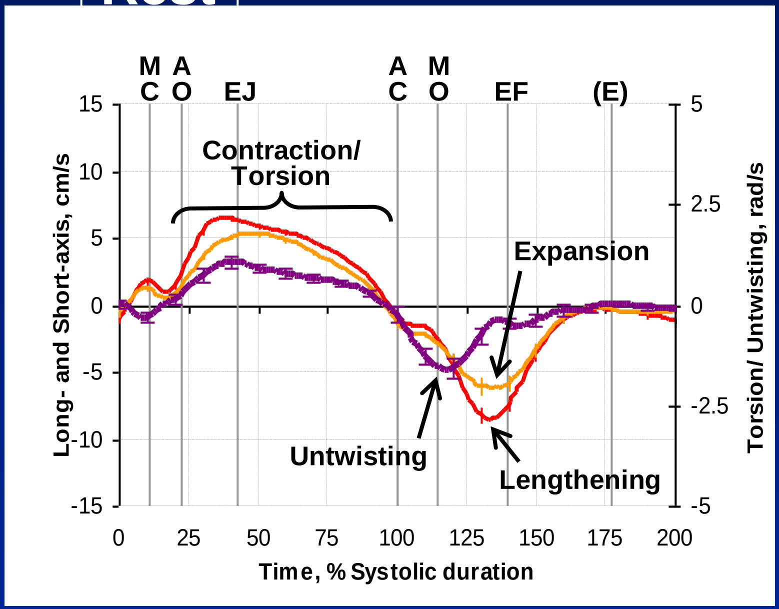


Notomi et al. Circ 2006; 113: 2524-2533

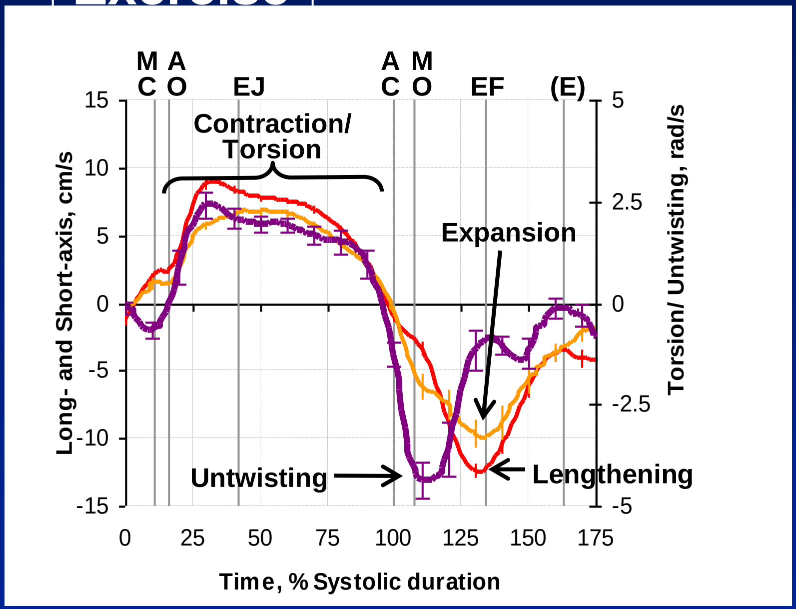
Timing and Magnitude of LV Mechanics

Untwisting is the First Event of Diastole

Rest



Exercise



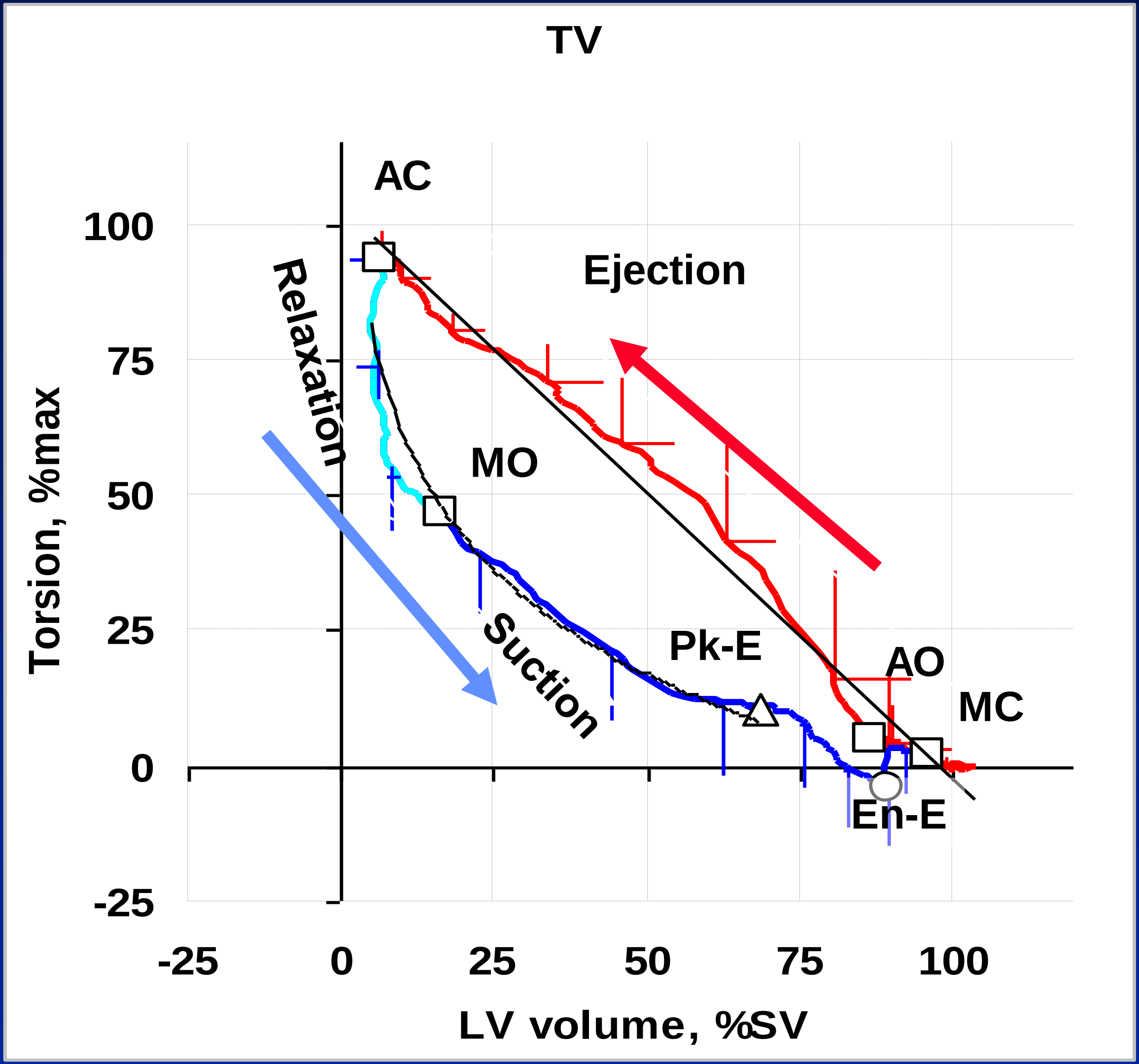
Long axis motion

Radial motion

Torsion

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

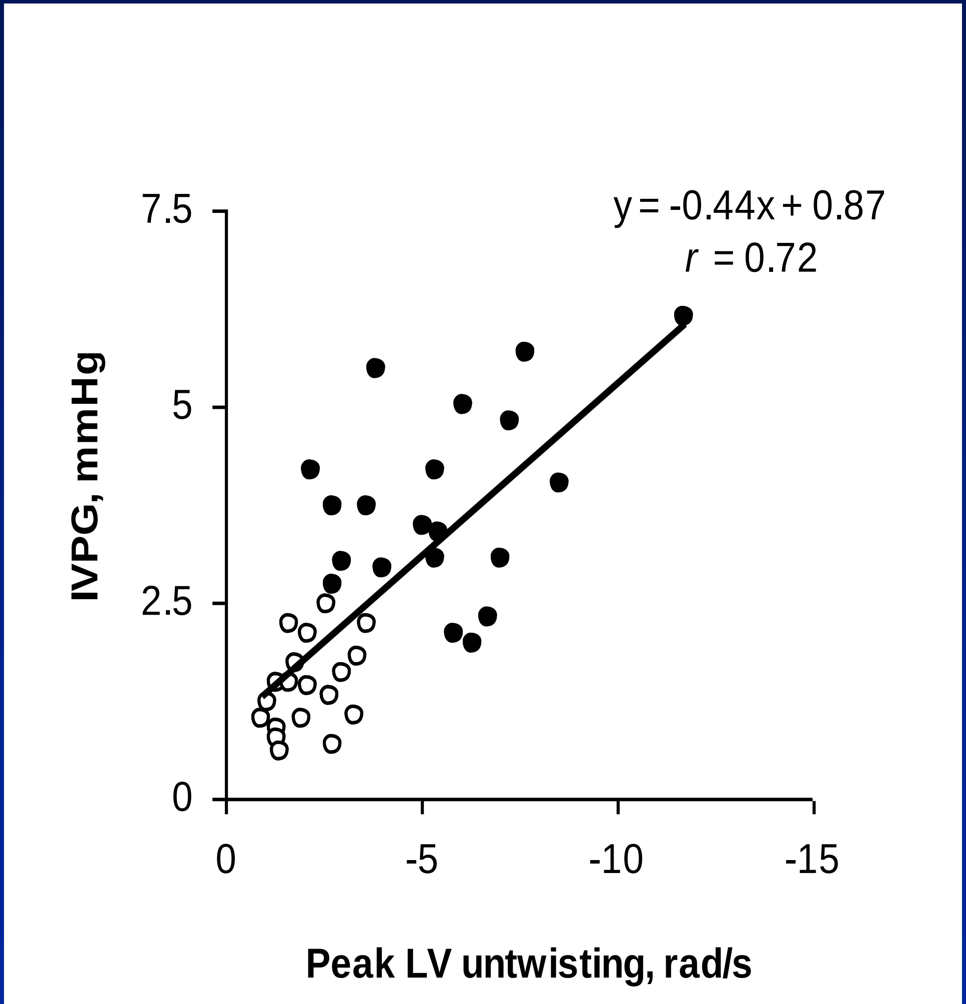
Torsion-Volume Loop



Half of torsion is released before MV opens

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

LV Untwisting Predicts IVPG

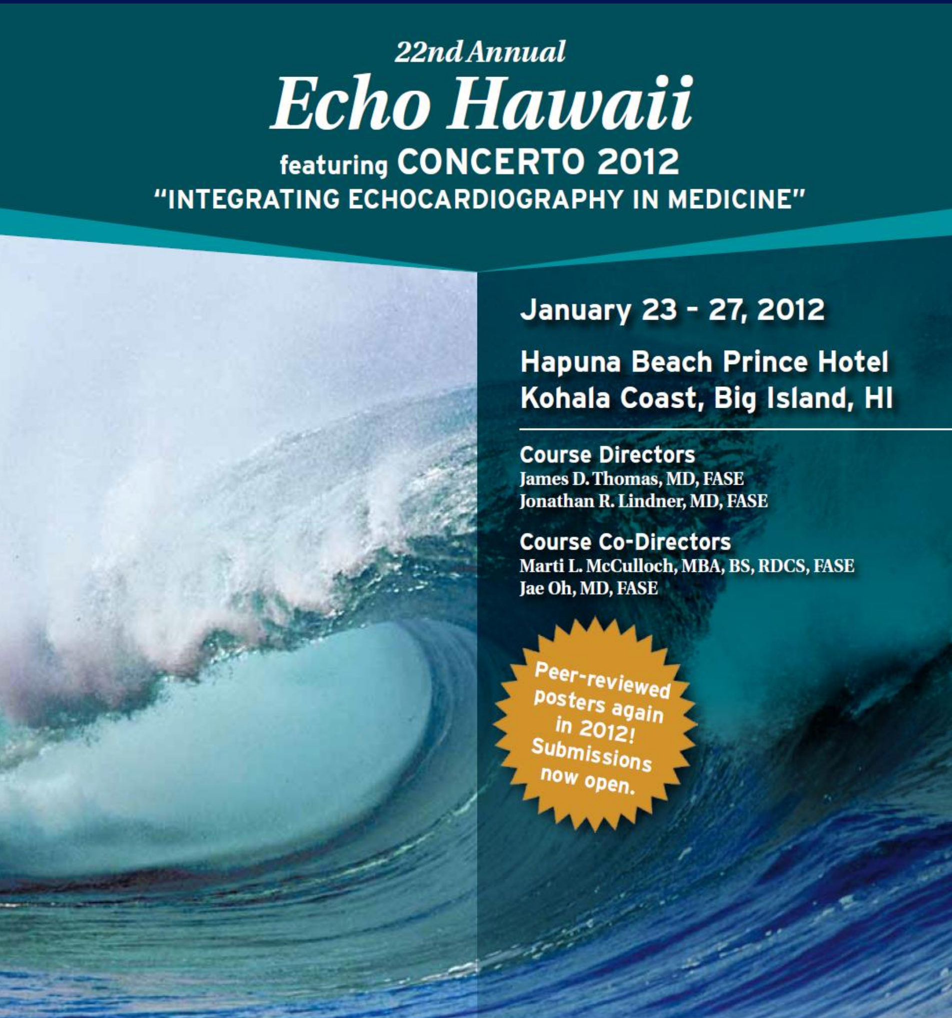


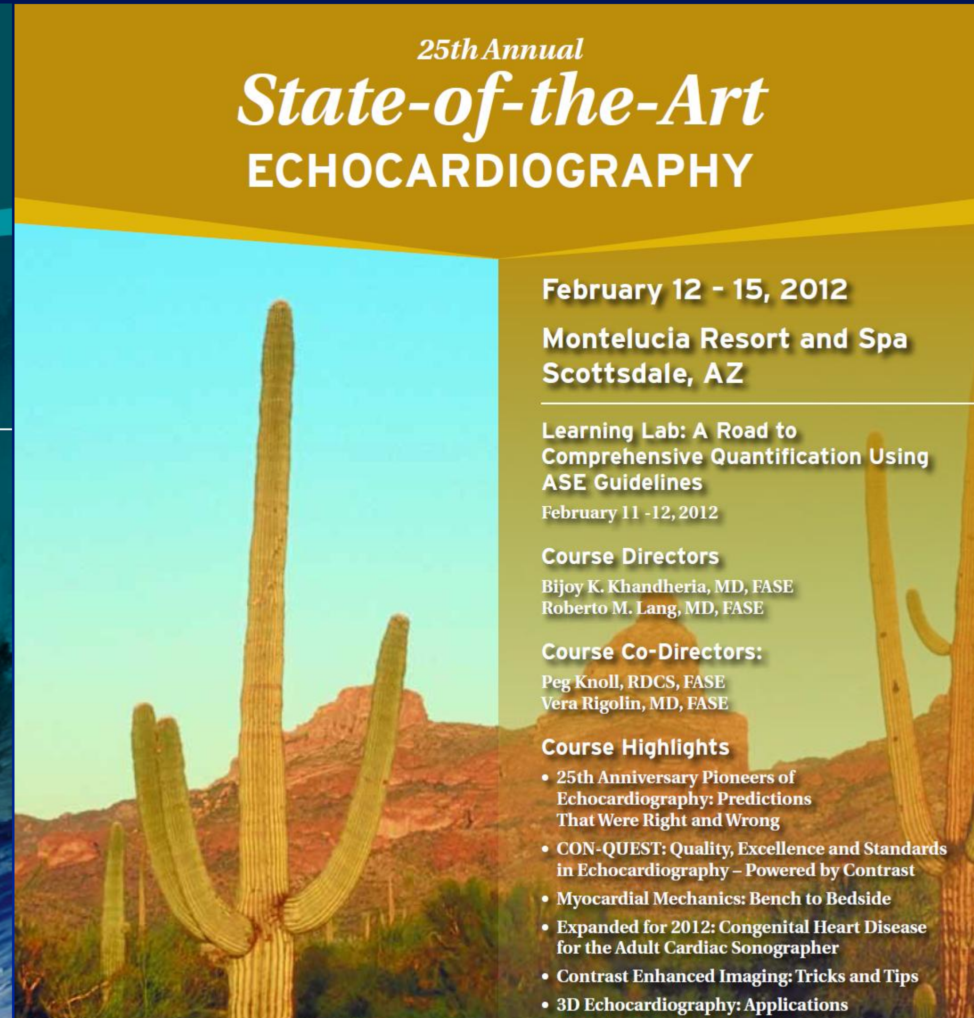
Notomi et al. Circ 2006; 113: 2524-2533

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*

Echo Education This Winter!





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Hope to see you there!

It’s Your Choice!!