Ventricular-arterial coupling

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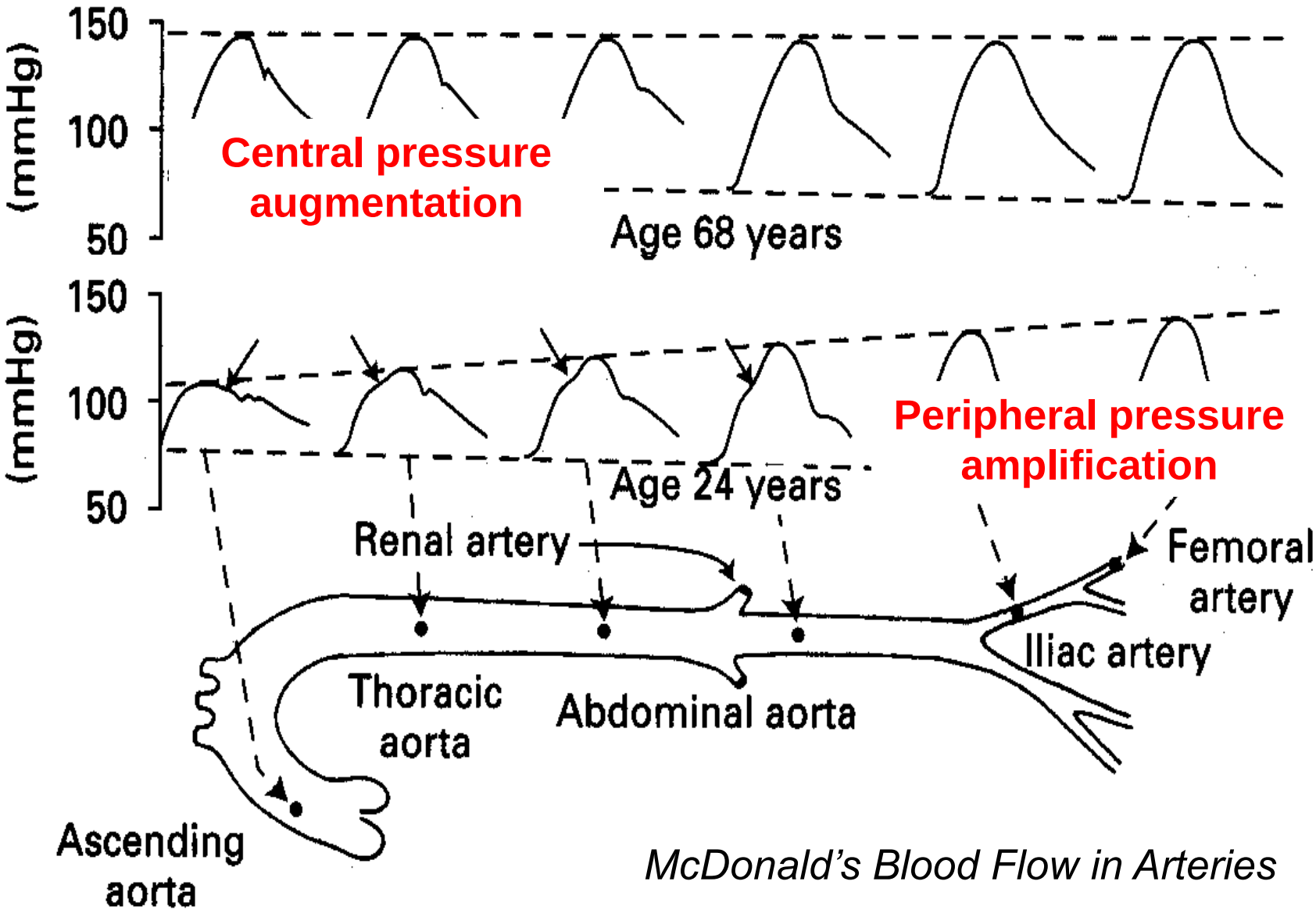
Cardiff University

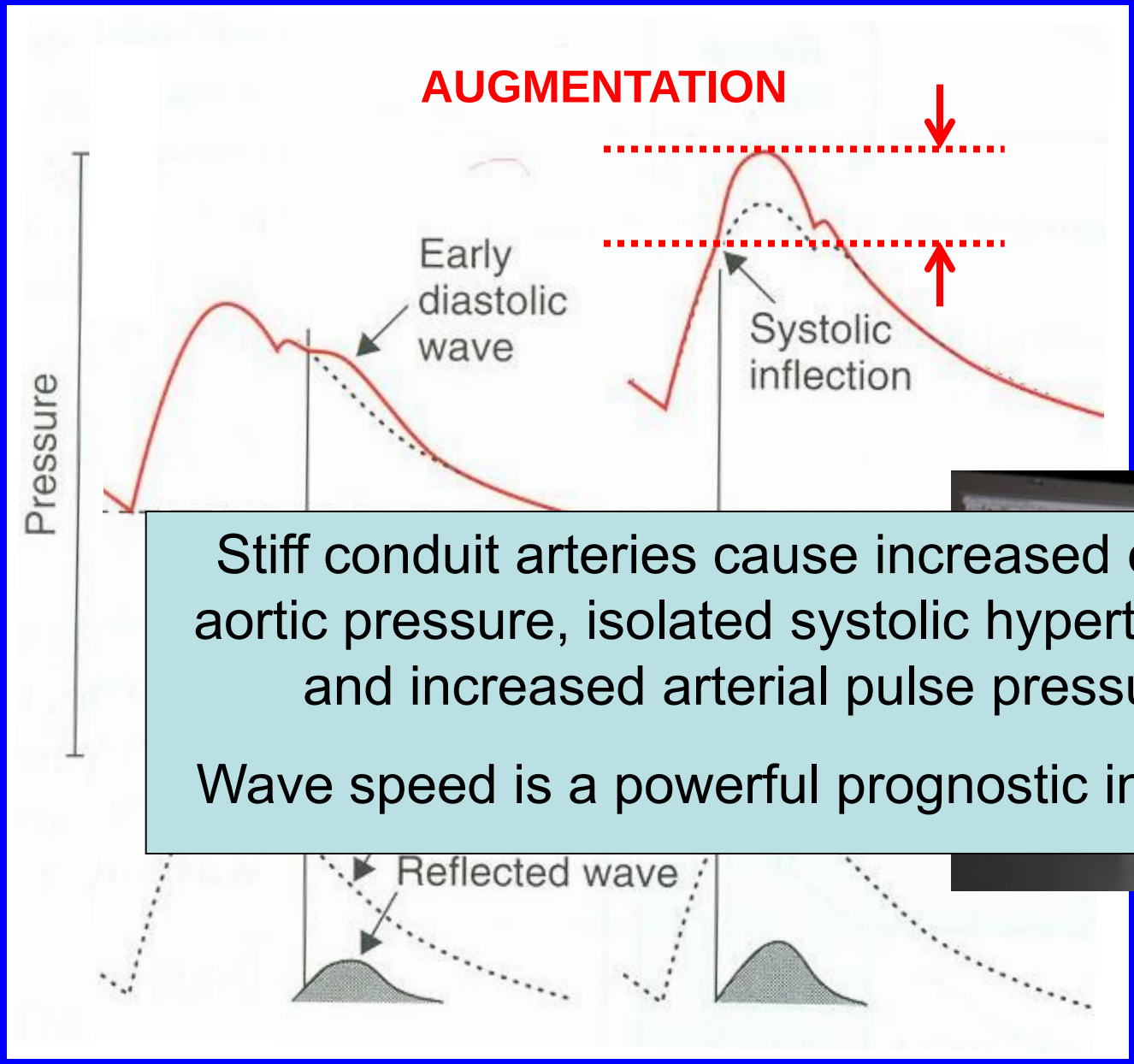
Ventricular–arterial coupling

- Increased loading triggers LV hypertrophy
- Ventricular response is asymmetrical
- Central arterial pressure
- Conduit arterial stiffness
- Ventricular and vascular elastance
- Arterial waves and energy

Central arterial pressure changes with age

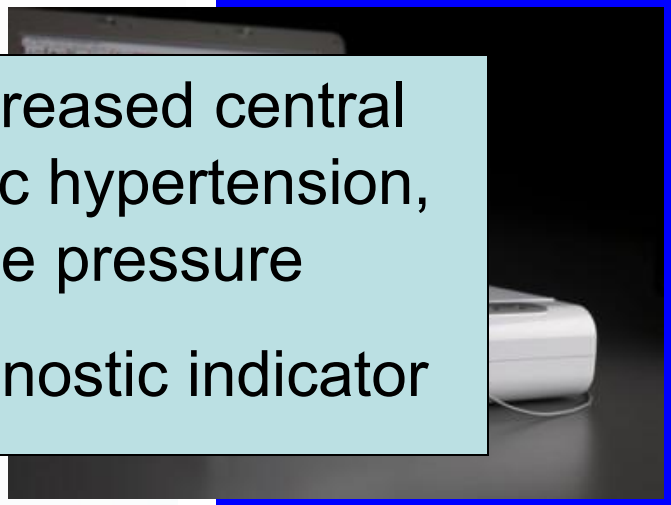


McDonald's Blood Flow in Arteries



Stiff conduit arteries cause increased central aortic pressure, isolated systolic hypertension, and increased arterial pulse pressure

Wave speed is a powerful prognostic indicator



Applanation tonometry

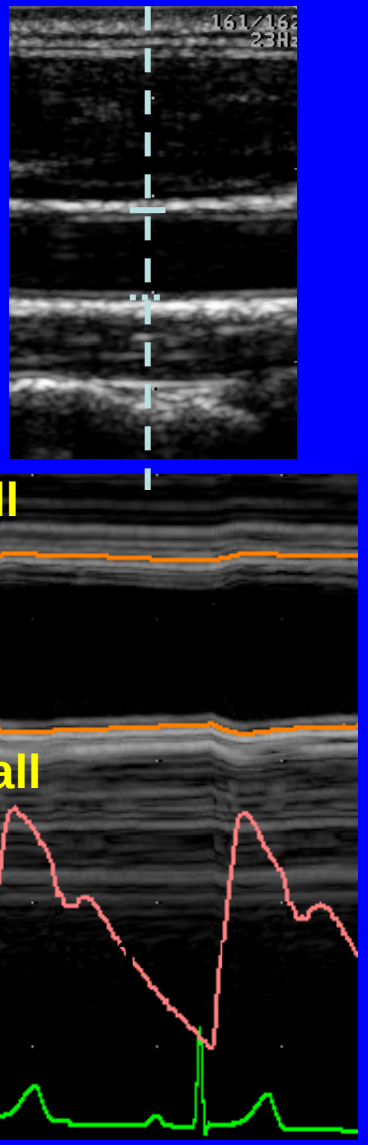
Imaging arterial stiffness

- **BETA INDEX**
  - Pressure-independent Young's modulus of stiffness
  - Adjusted for BP
  - No units

$$\beta = \frac{\log_n (Ps / Pd)}{(Ds - Dd / Dd)}$$

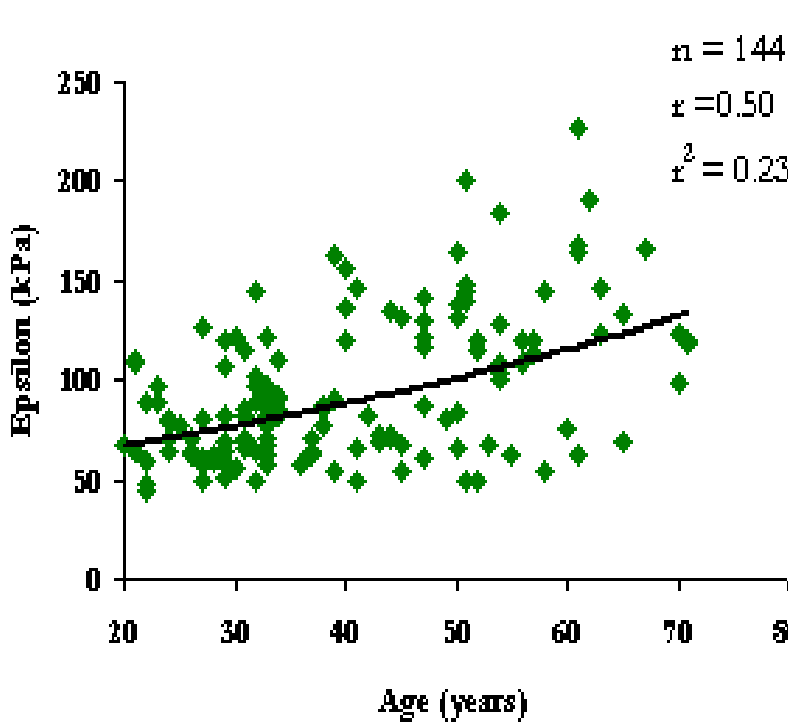
- **EPSILON**
  - Pressure-strain elastic modulus
  - Measured in kPa

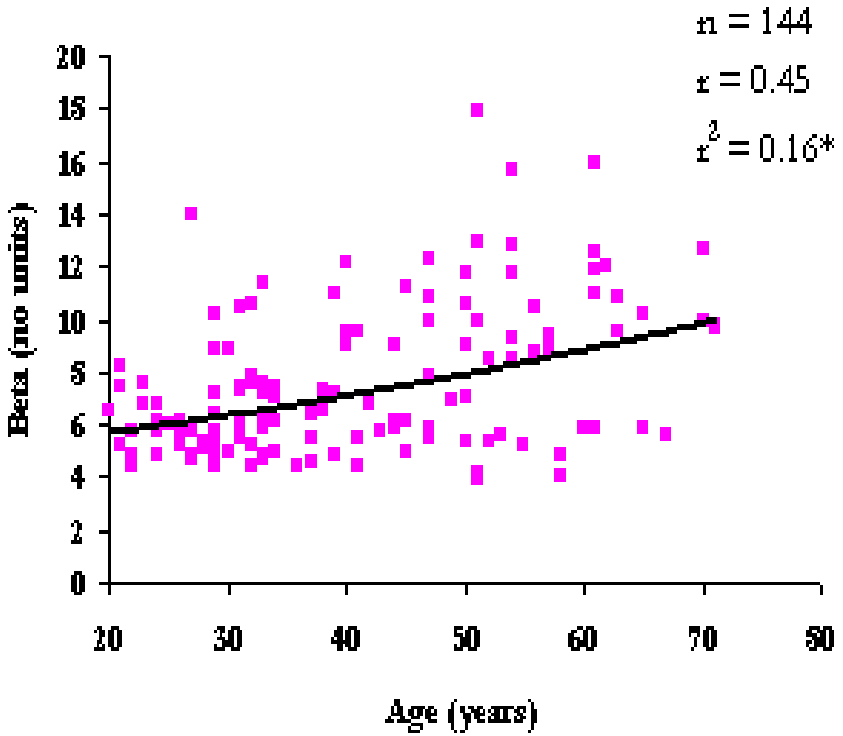
$$Ep = \frac{(Ps - Pd)\, Dd}{(Ds - Dd)}$$



Pooled observations in 144 subjects – Age

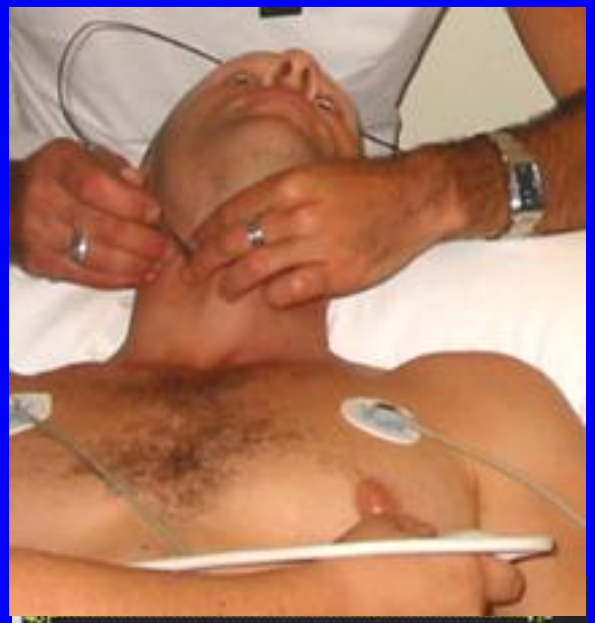
Conduit arterial stiffness

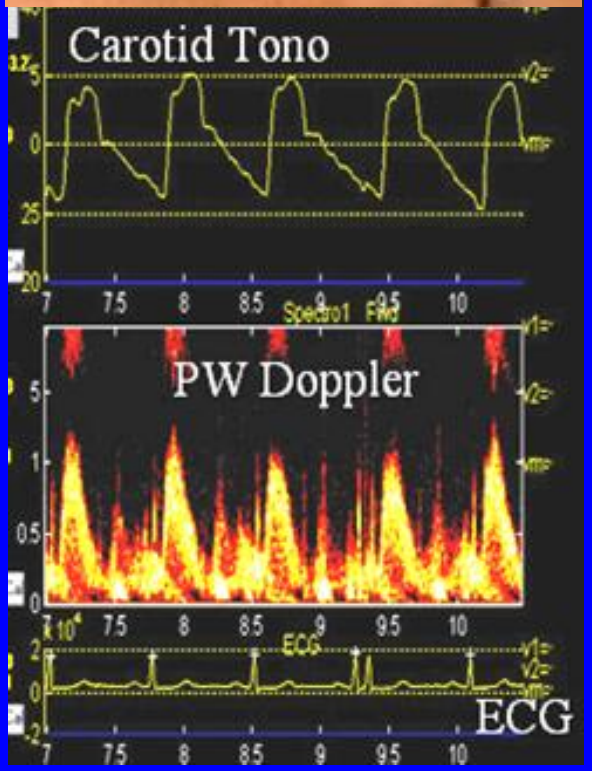


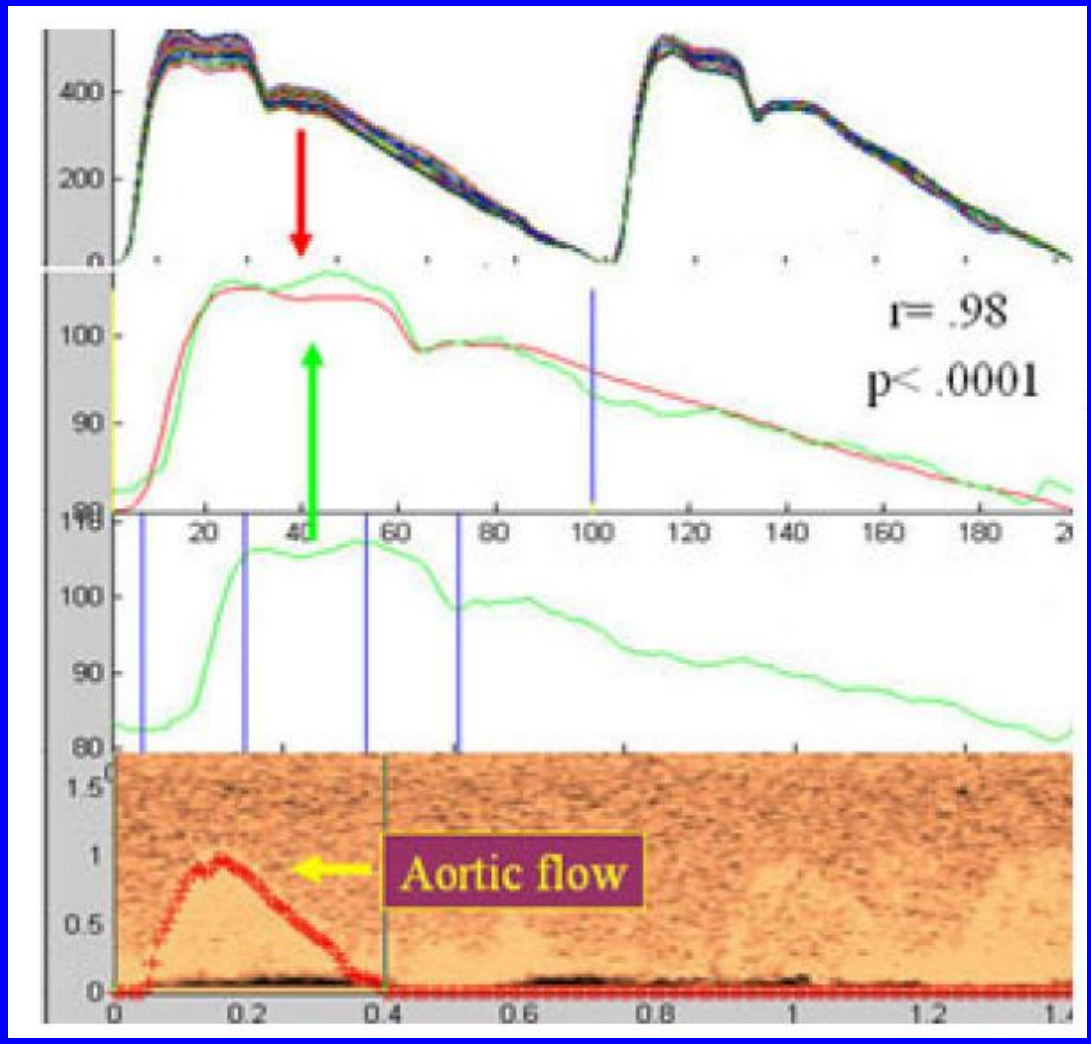


J Swampillai

Central pressure waveforms can be derived from tissue Doppler

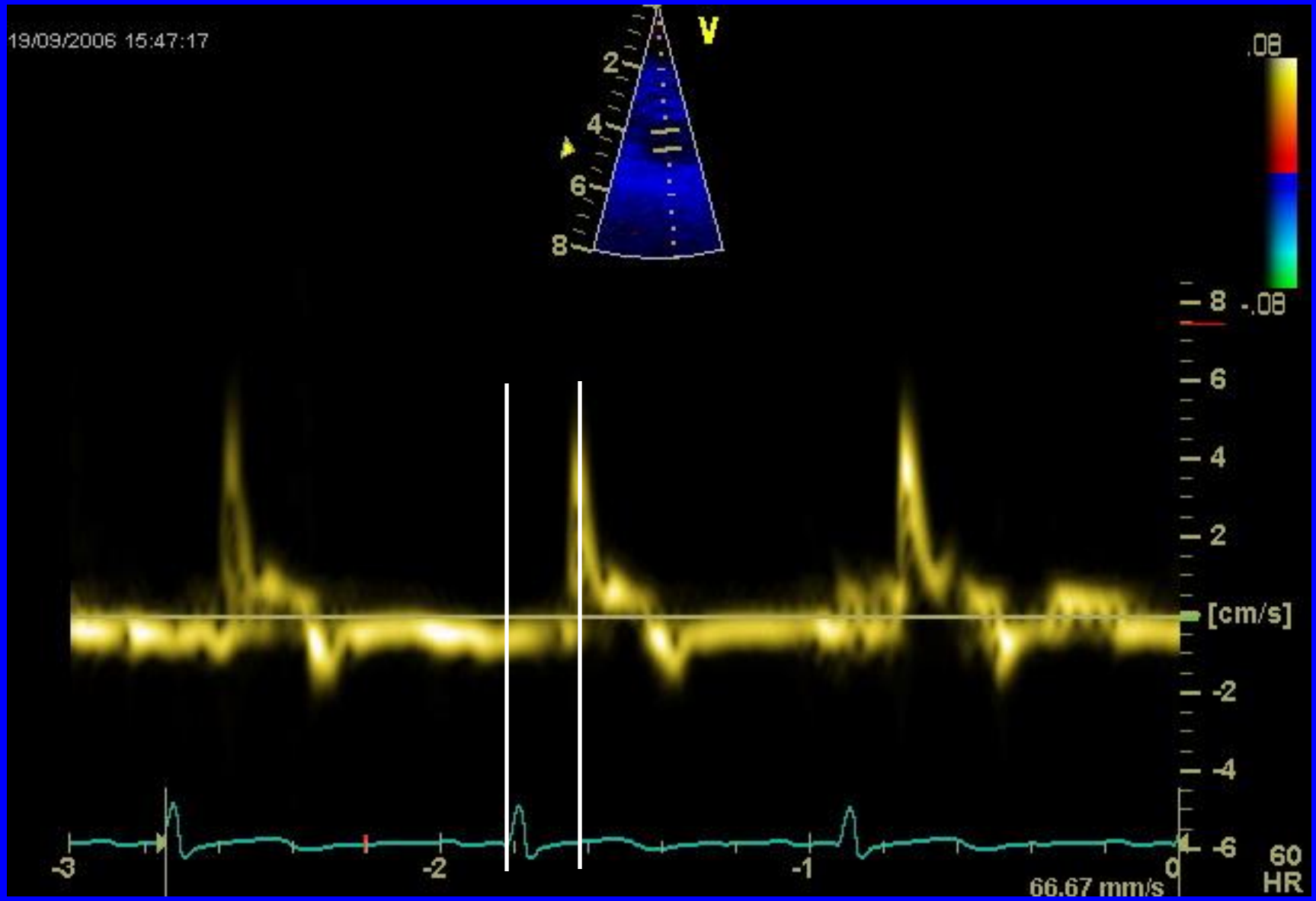






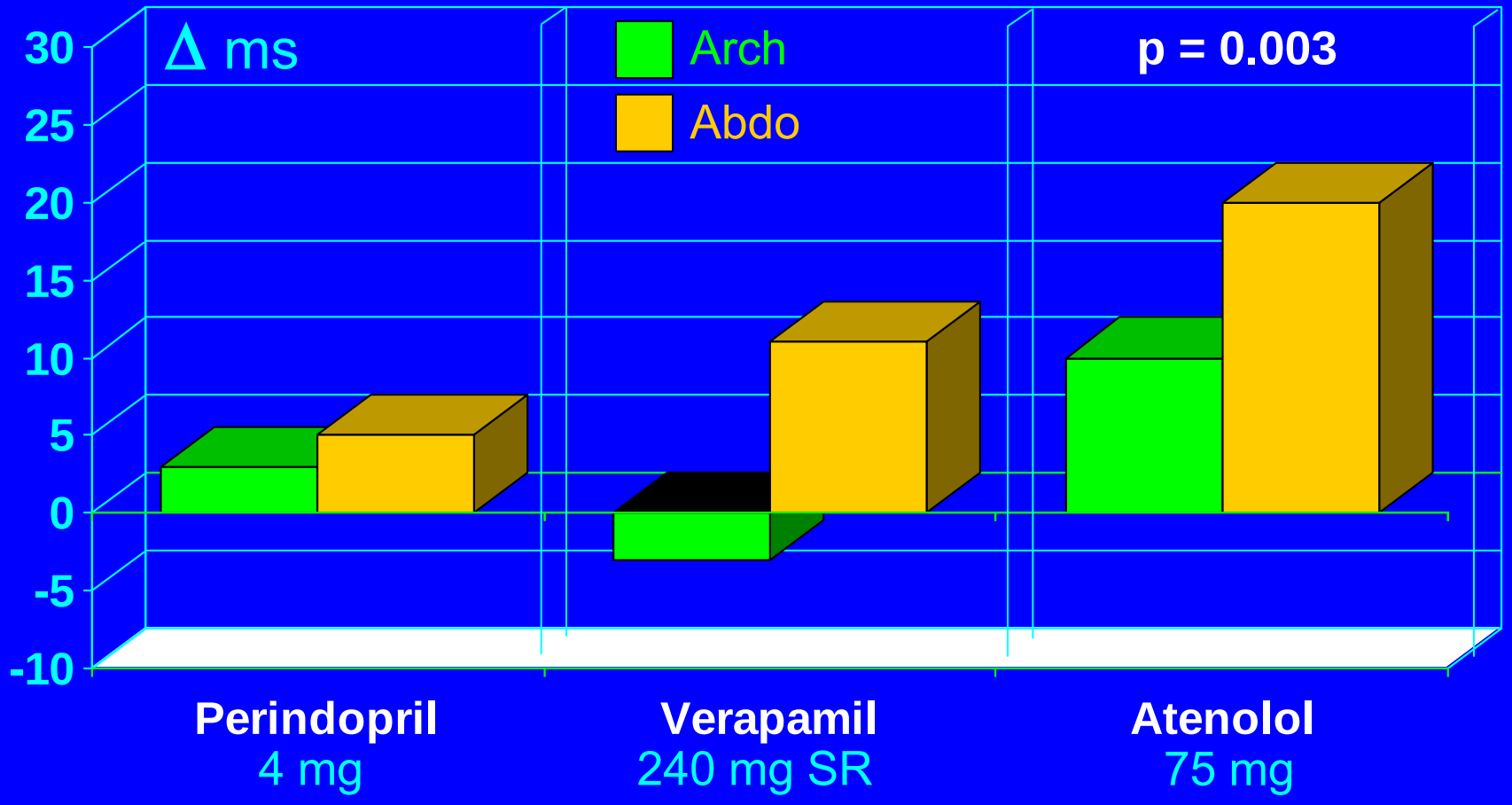
Haluska B et al, Cardiovasc Ultrasound 2007;5:6

Tissue velocity of aortic wall motion



Aortic wall motion in Marfan syndrome

Prospective, double-blind, randomised cross-over

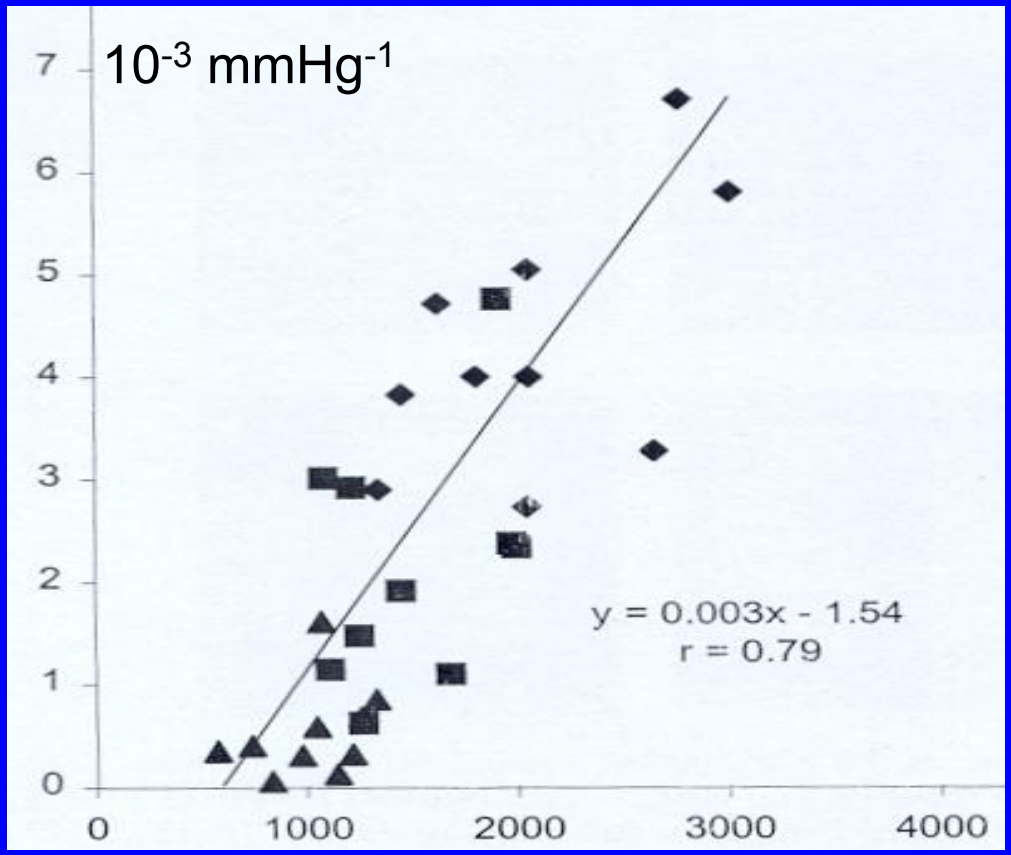


Time to peak systolic velocity
of anterior aortic wall motion

Williams A et al

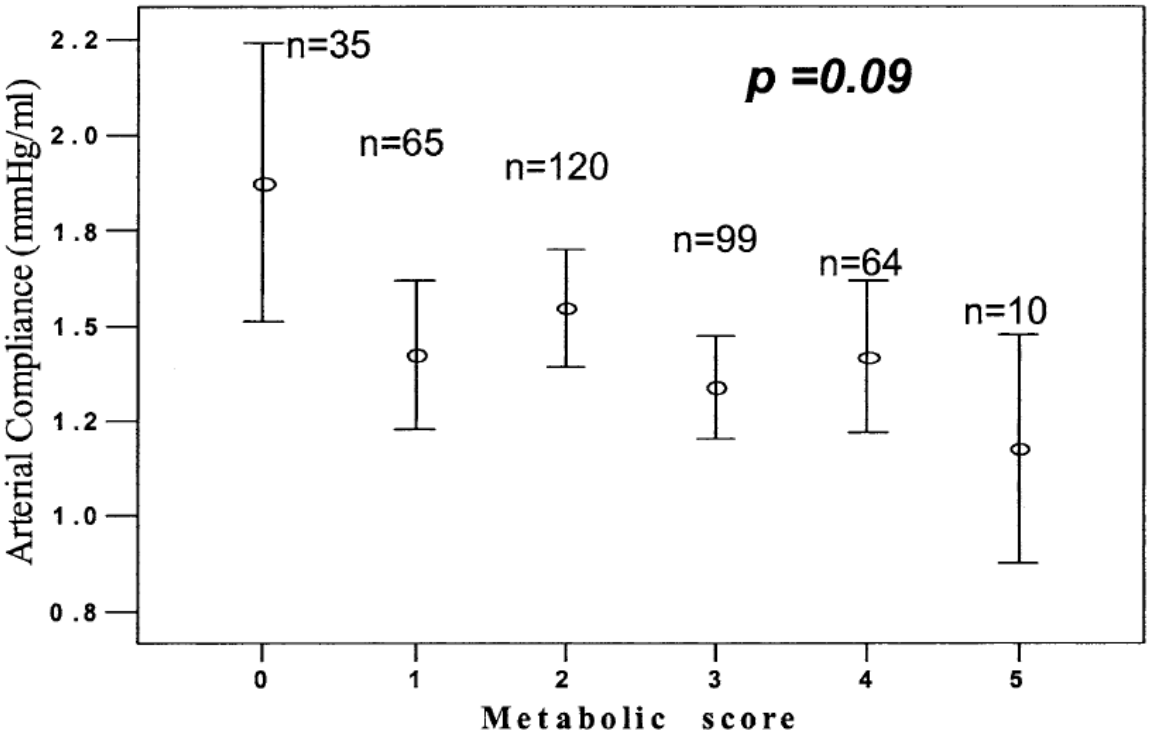
Arterial stiffness is a determinant of VO_2 max

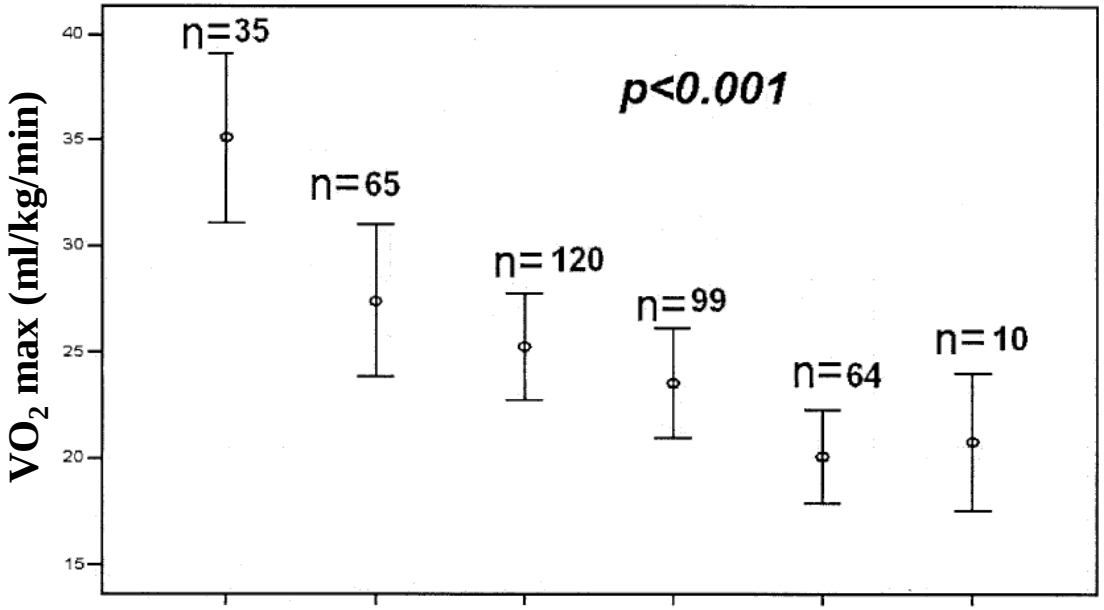
Distensibility



VO_2 max (ml/min)

Hundley, JACC 2001; 38: 796





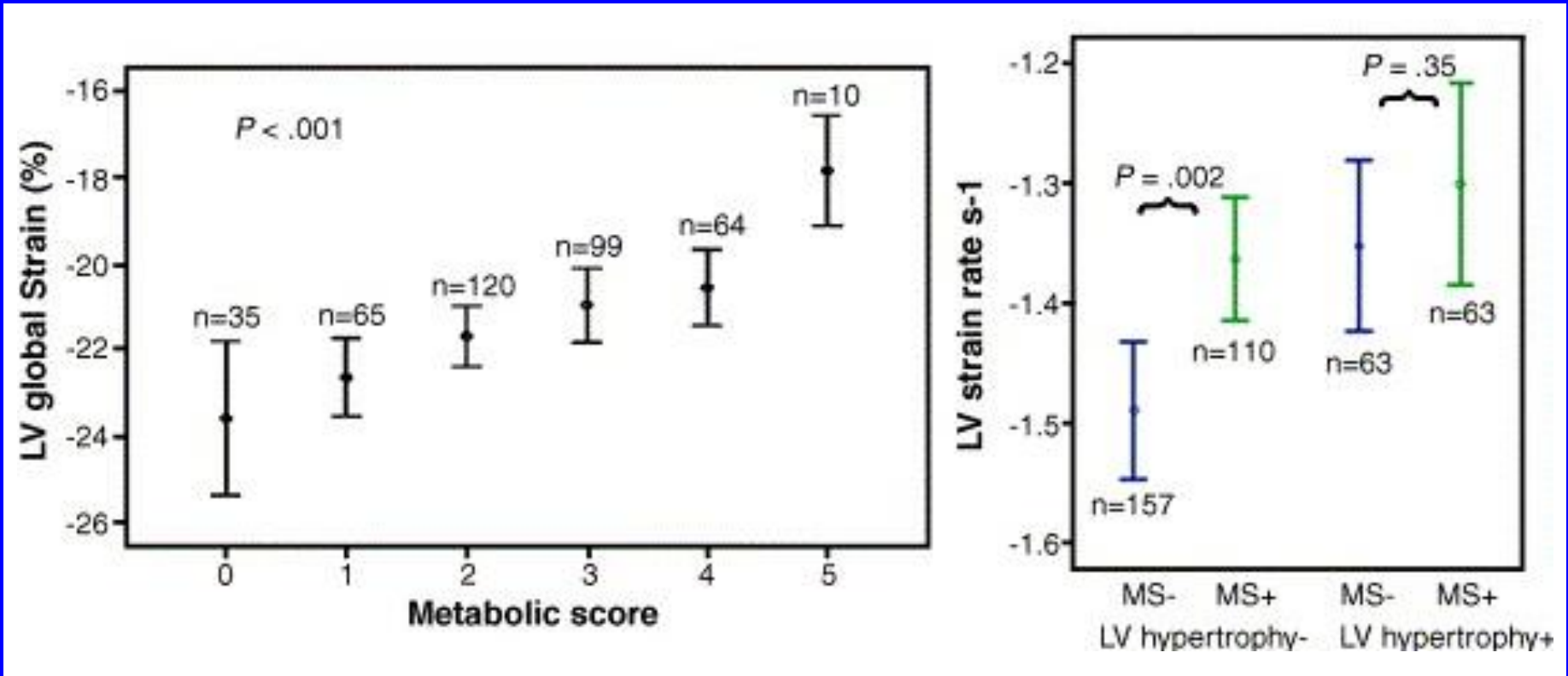
Arterial compliance & peak exercise capacity are related

& both decline with risk factors & severity of the metabolic syndrome

Wong C et al, AJC 2005;96:1686

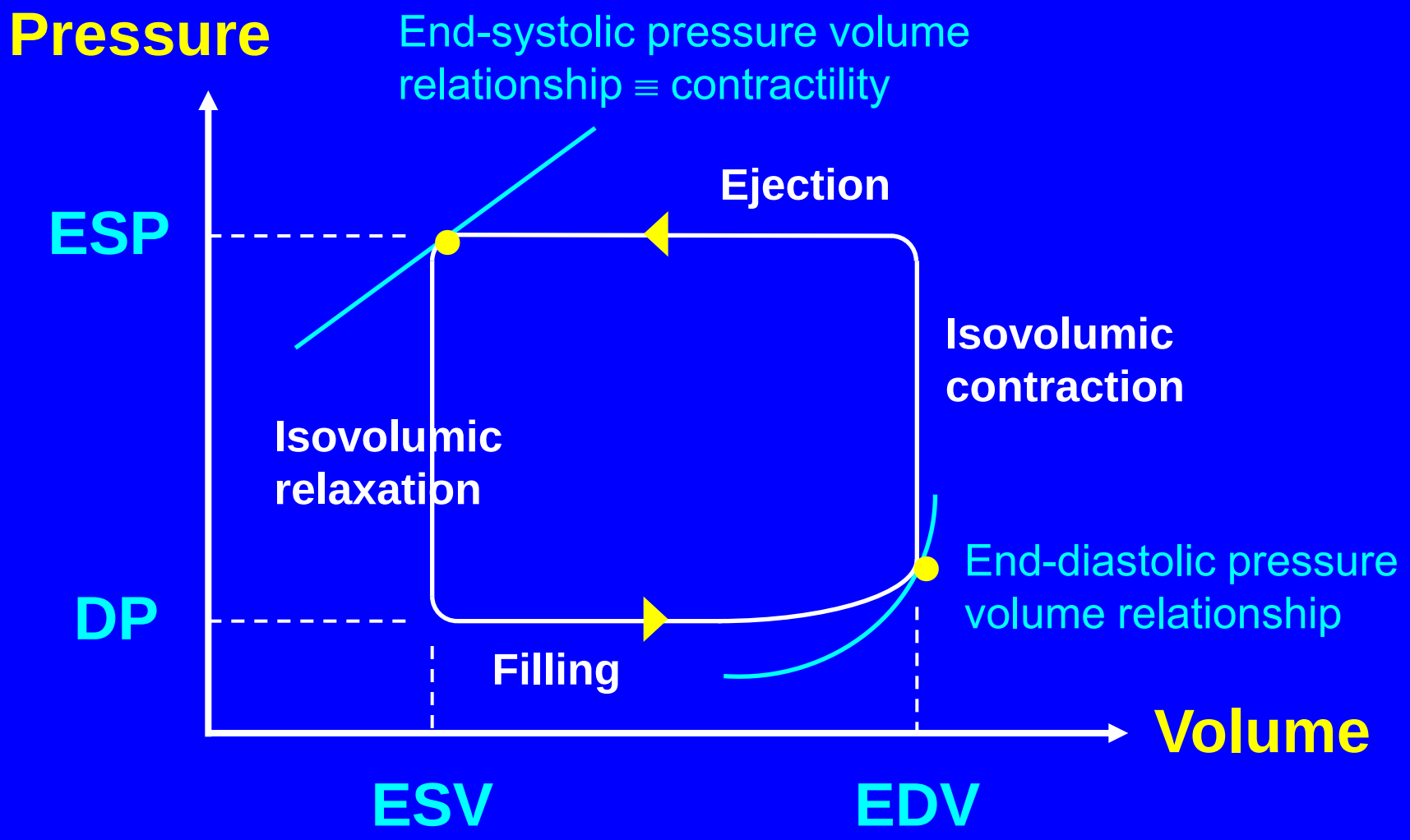
Myocardial dysfunction in metabolic syndrome correlates with number of diagnostic features

393 subjects with negative stress echocardiography

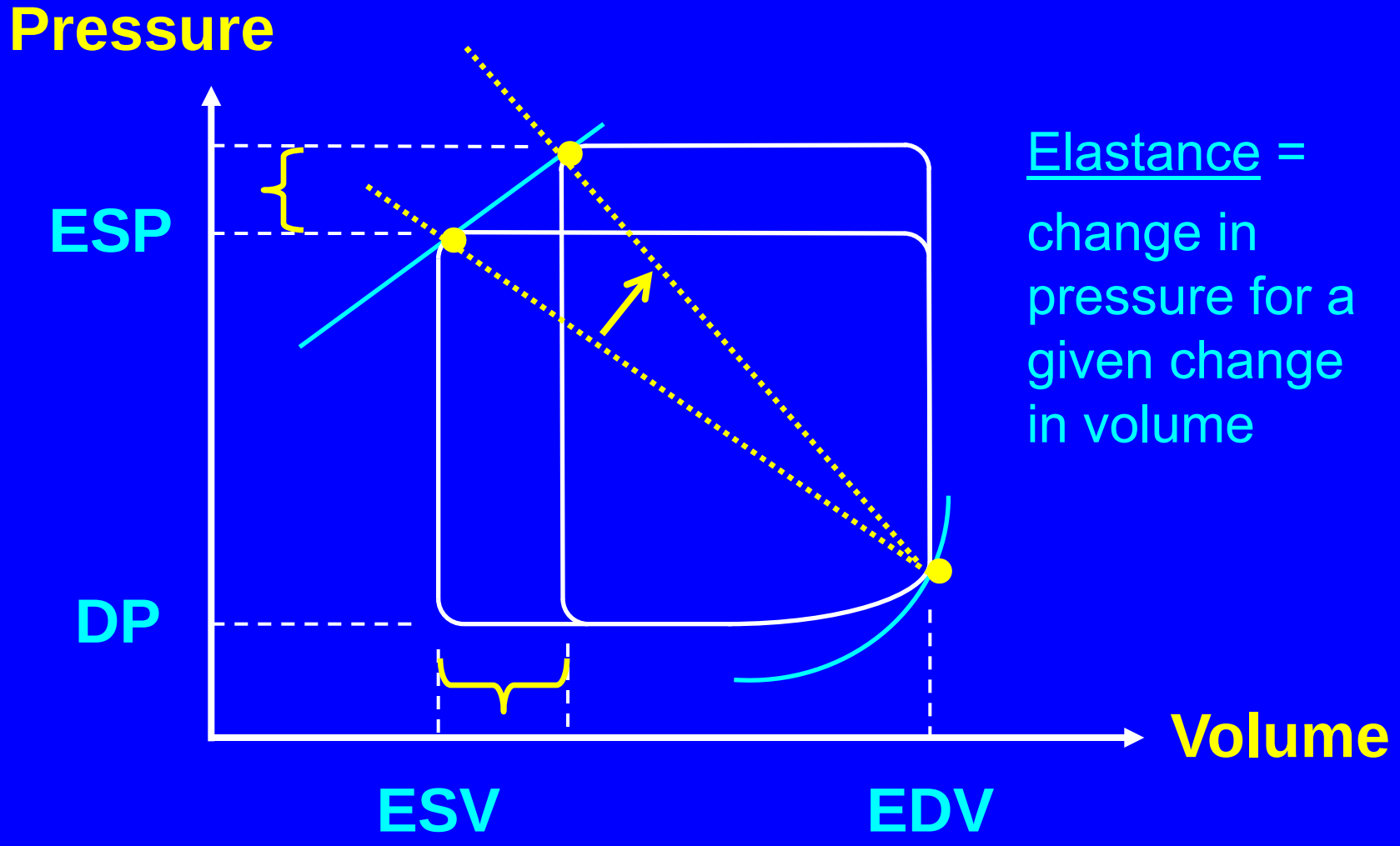


Wong C et al, Am J Cardiol 2005; 96: 1686-91

Left ventricular pressure-volume loop



The traditional concept of ventricular-arterial coupling



Elastance = change in pressure for a given change in volume

Elastance

Change in pressure for a unit change in volume (mmHg/ml)

- Arterial elastance

  E_A = ESP / SV (SV stroke volume)

  Higher elastance = greater sensitivity to volume change, more variable pressure

- Ventricular elastance

  E_{LV} = ESP / ESV (ESV LV end-systolic volume)

  Net arterial load exerted on the ventricle

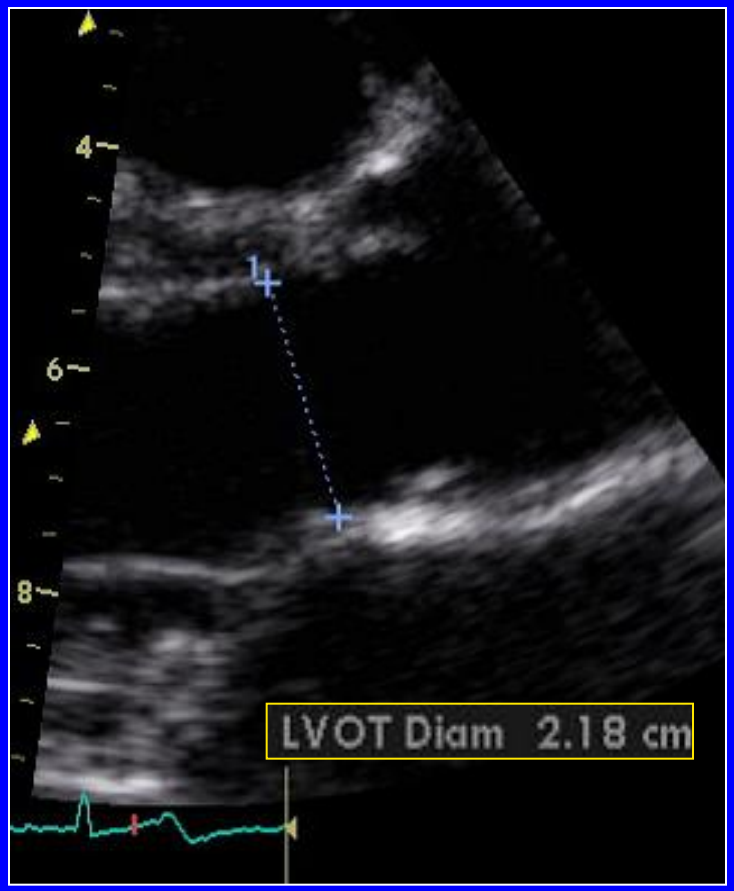
Coupling ratio

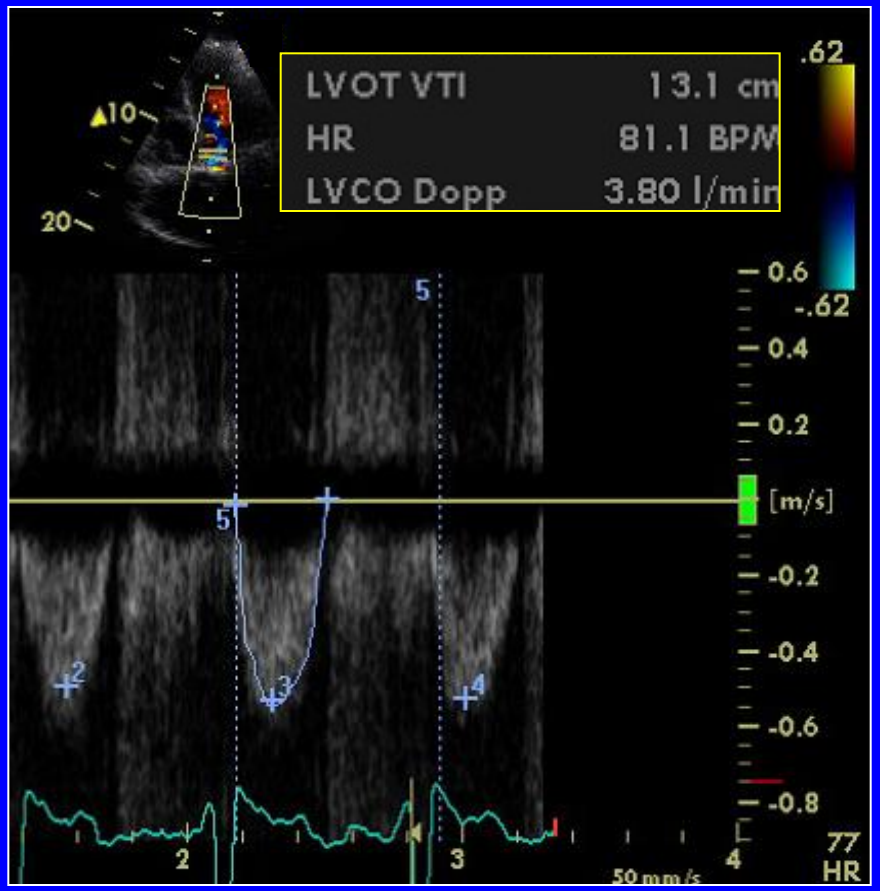
$VAC = E_A / E_{LV}$ with volumes indexed for body surface area

- Greatest efficiency when elastances are matched
- Optimal transfer of blood from LV to aorta
- BP, LV pressure, and CO are maintained in a physiological range
- Normal ratio ~ 1.0 ± 0.36 (VAC = (1/EF) – 1)
- Normal E_A 2.2 ± 0.8 mmHg/ml
- Normal E_{LV} 2.3 ± 1.0 mmHg/ml

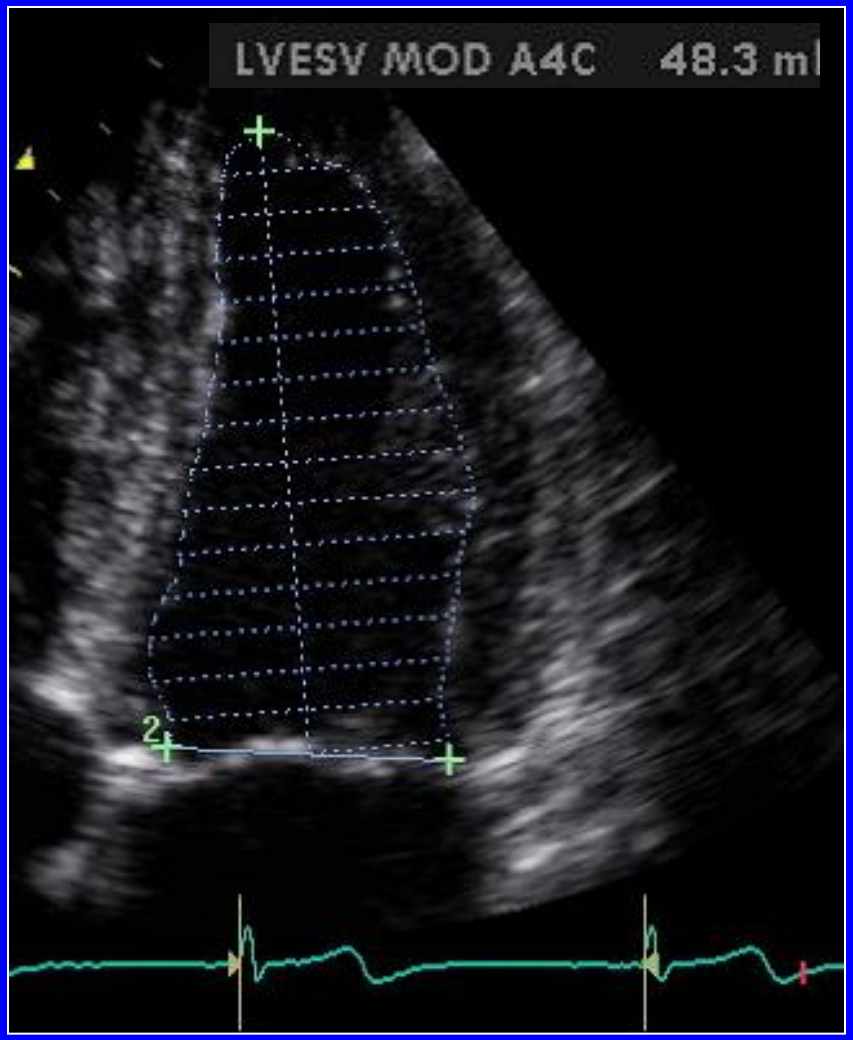
Chantler, 2008

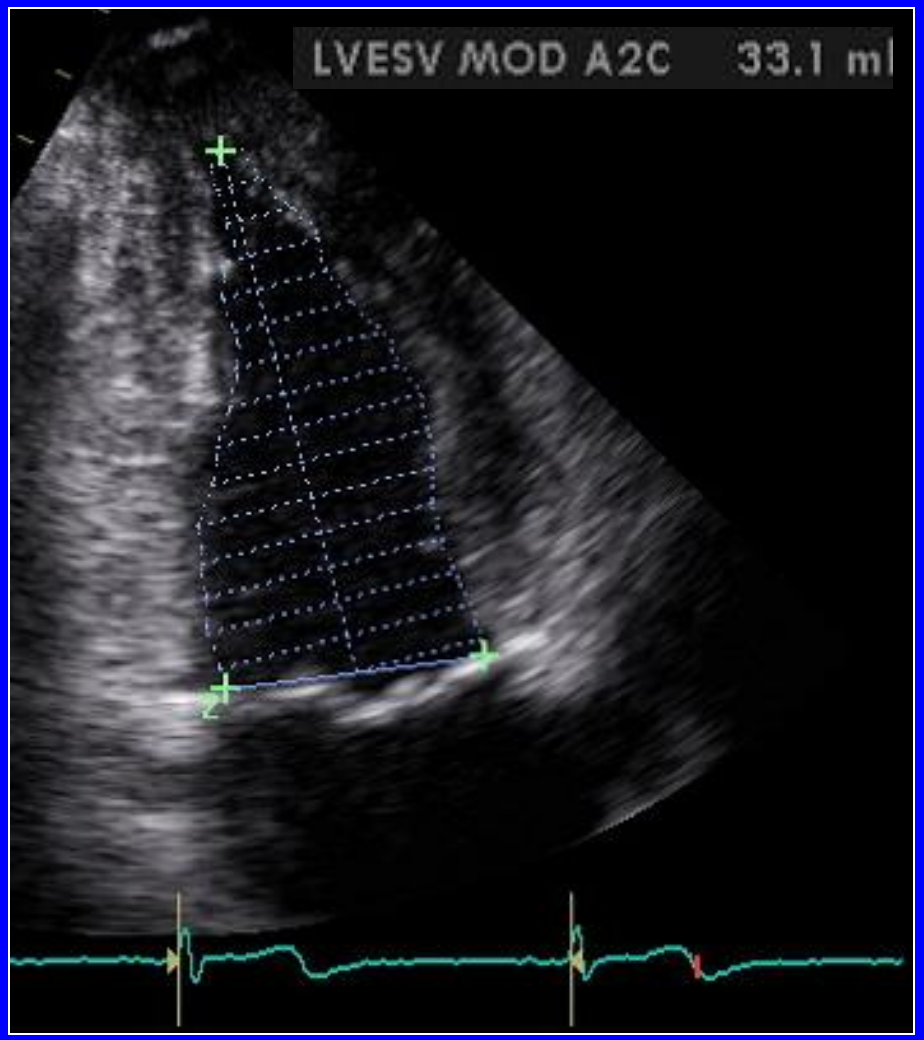
M aged 30, triathlete





SV = 49ml





EF Biplane	65.3 %
LVEDV MOD BP	117.3 ml
LVESV MOD BP	40.7 ml

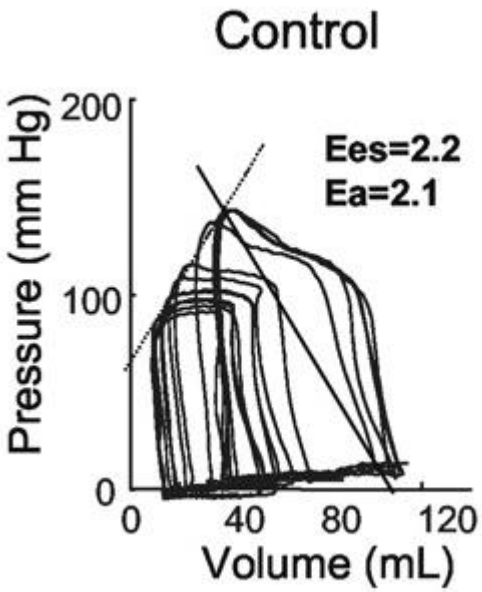
VAC = ESV / SV

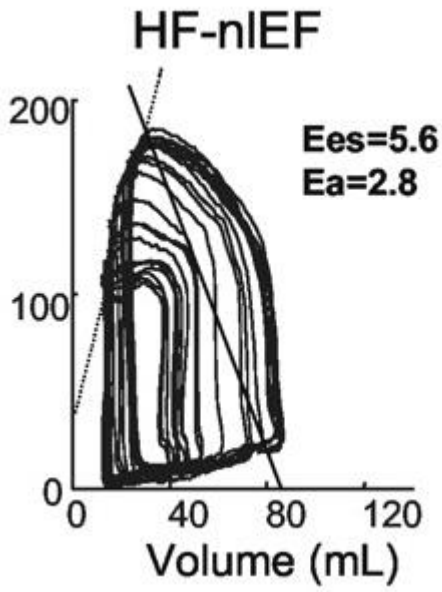
= 41/49 = 0.84

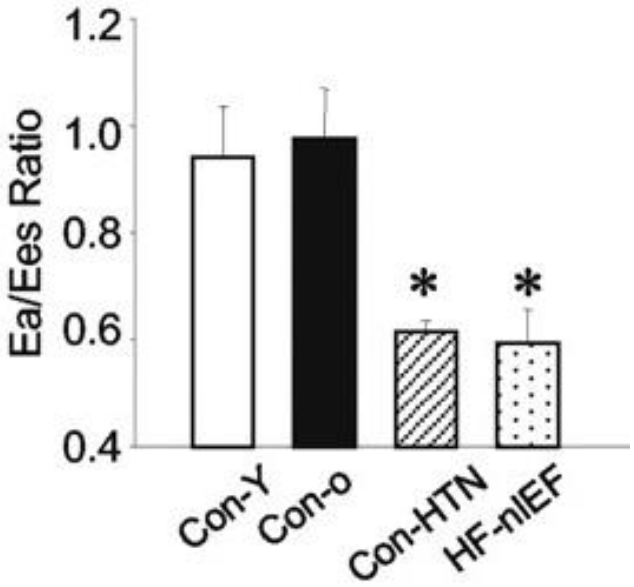
Combined Ventricular Systolic and Arterial Stiffening in Patients With Heart Failure and Preserved Ejection Fraction

Implications for Systolic and Diastolic Reserve Limitations

Miho Kawaguchi, MD; Ilan Hay, MD; Barry Fetics, MSE; David A. Kass, MD

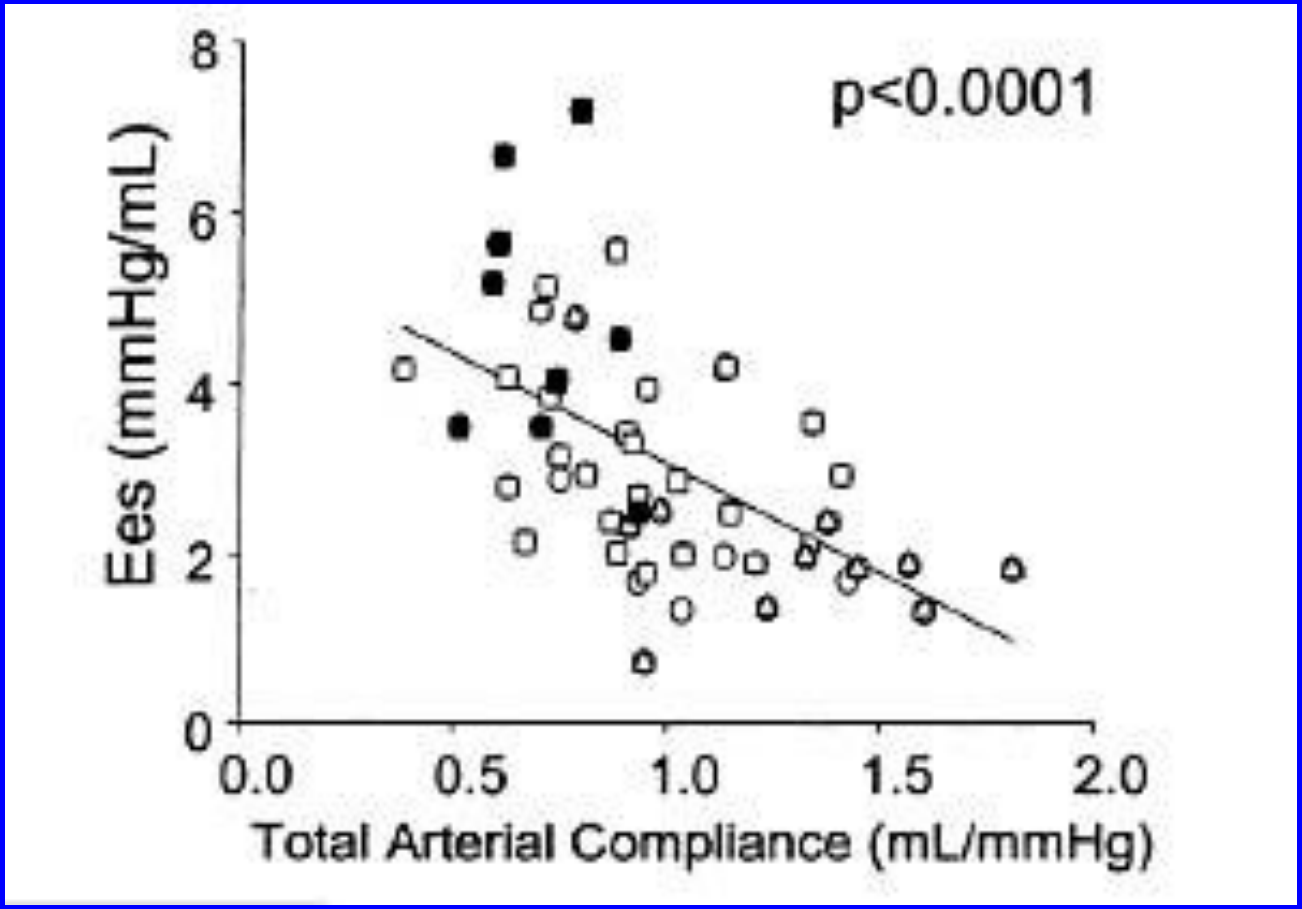






Circulation 2003; 107: 714-20

Myocardial contractility in the left ventricle is inversely related to arterial compliance



Kawaguchi M et al, Circulation 2003; 107: 714-20

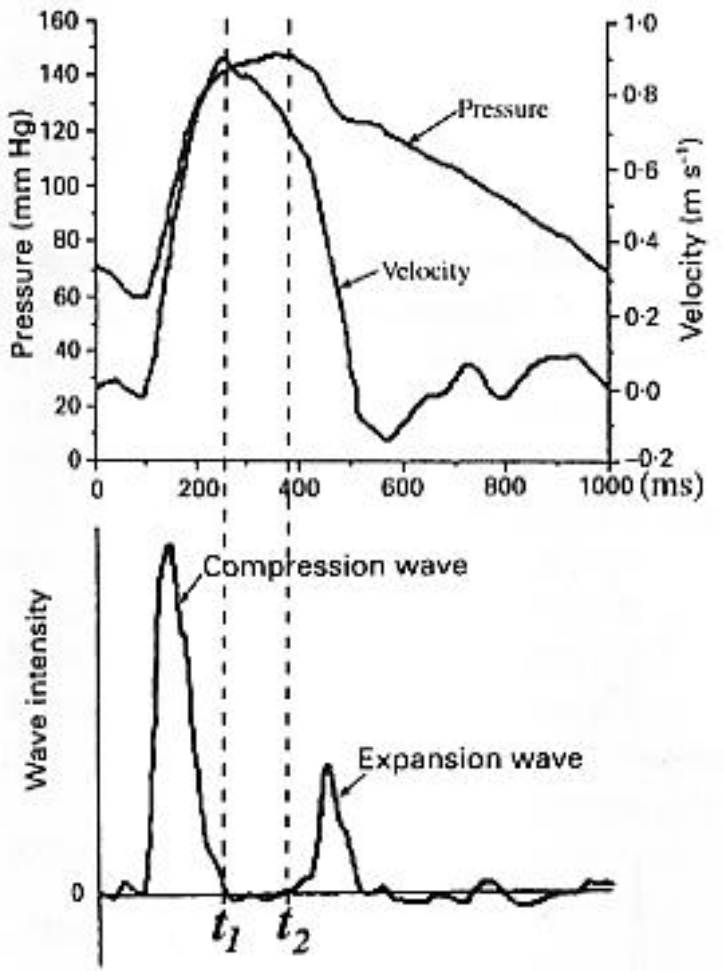
Forward and Backward Running Waves in the Arteries: Analysis Using the Method of Characteristics

K. H. Parker

C. J. H. Jones

Physiological Flow Studies Unit,
Imperial College of Science, Technology and Medicine,
London, SW7 2AZ England

Journal of Biomechanical Engineering 1990; 112: 323



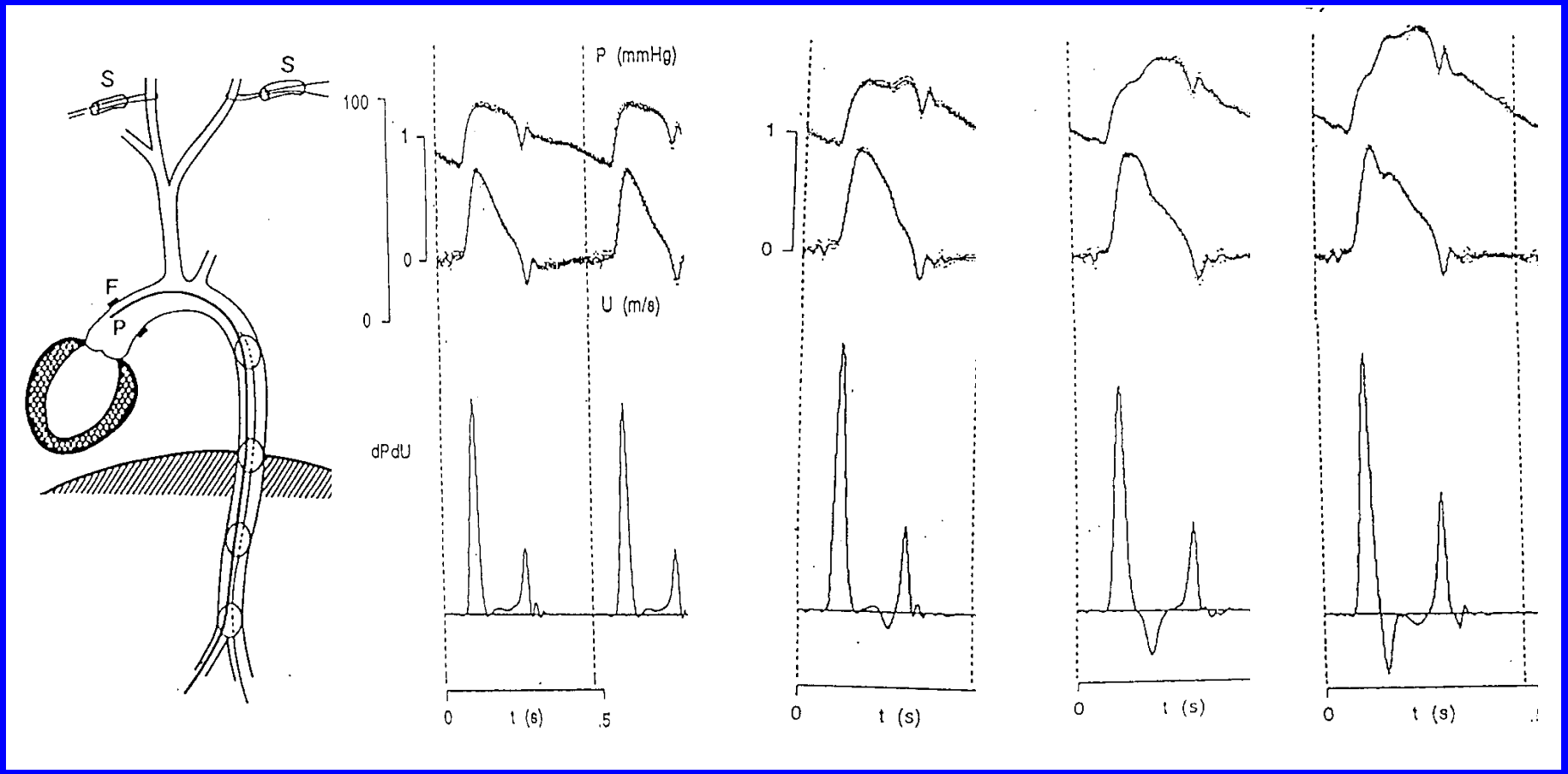
Wave intensity = dP/dt . dU/dt

There are 4 types of arterial waves

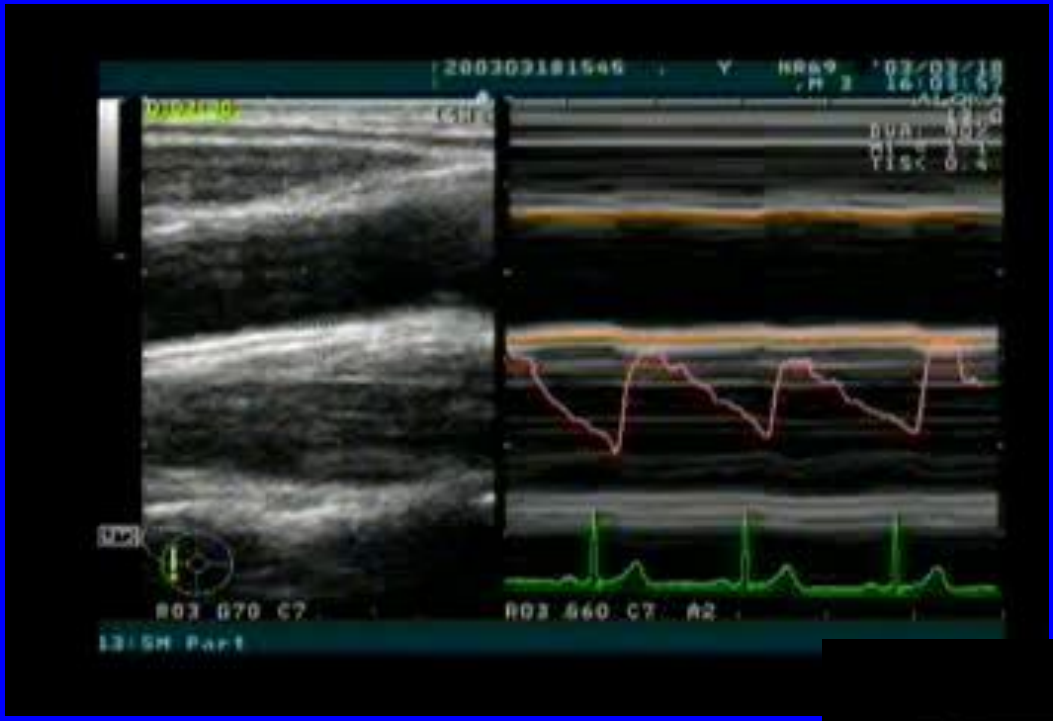
	Velocity	Pressure
Forward compression wave	↑	↑
Forward expansion wave	↓	↓
Backward compression wave	↓	↑
Backward expansion wave	↑	↓

The integral of wave intensity is energy

Wave intensity and reflection



Ramsey, Jones & Sugawara

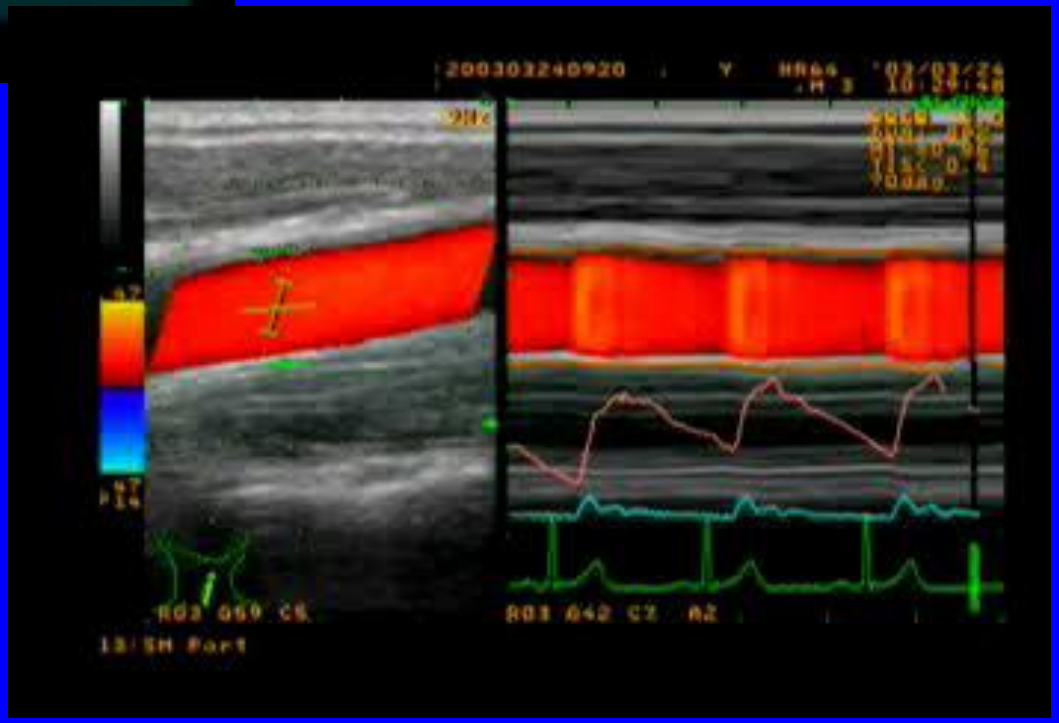


Wall tracking of common carotid artery

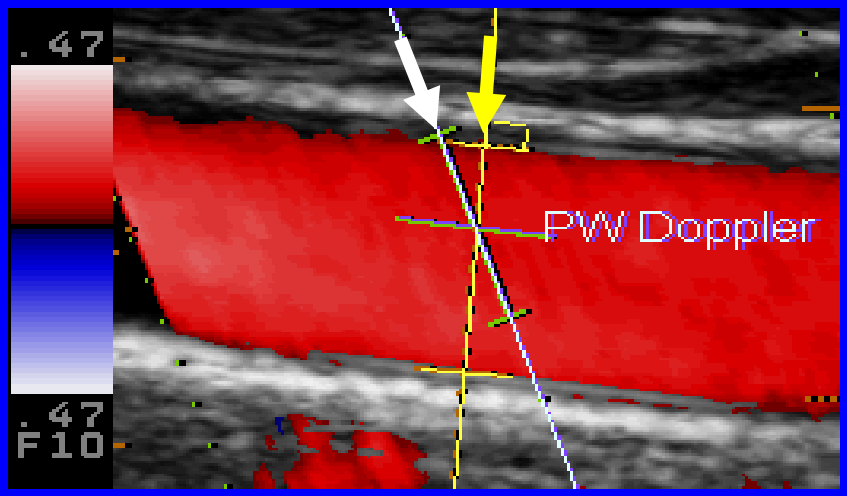
Diameter / distension waveform, calibrated as estimate of pressure

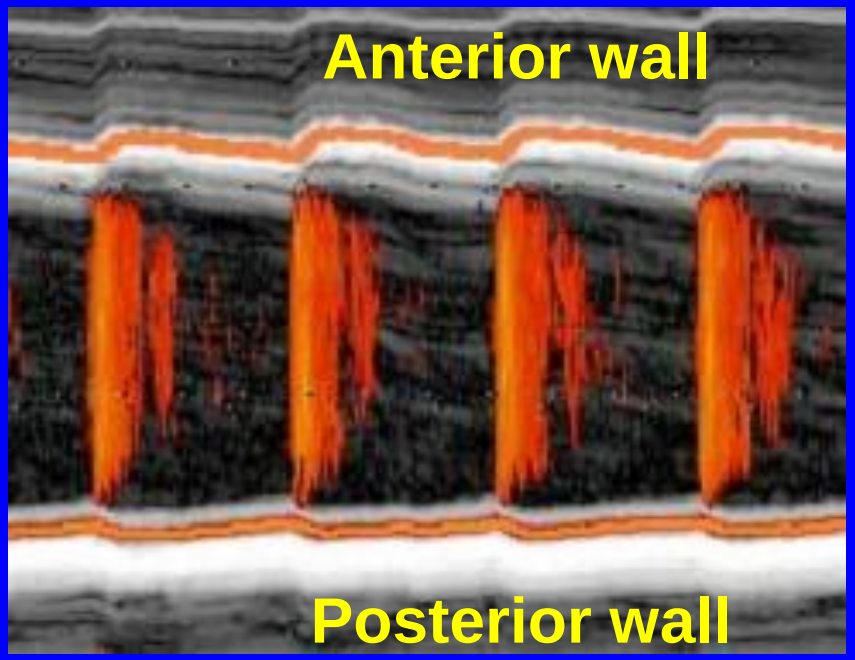
Simultaneous measurement of blood velocity at same site

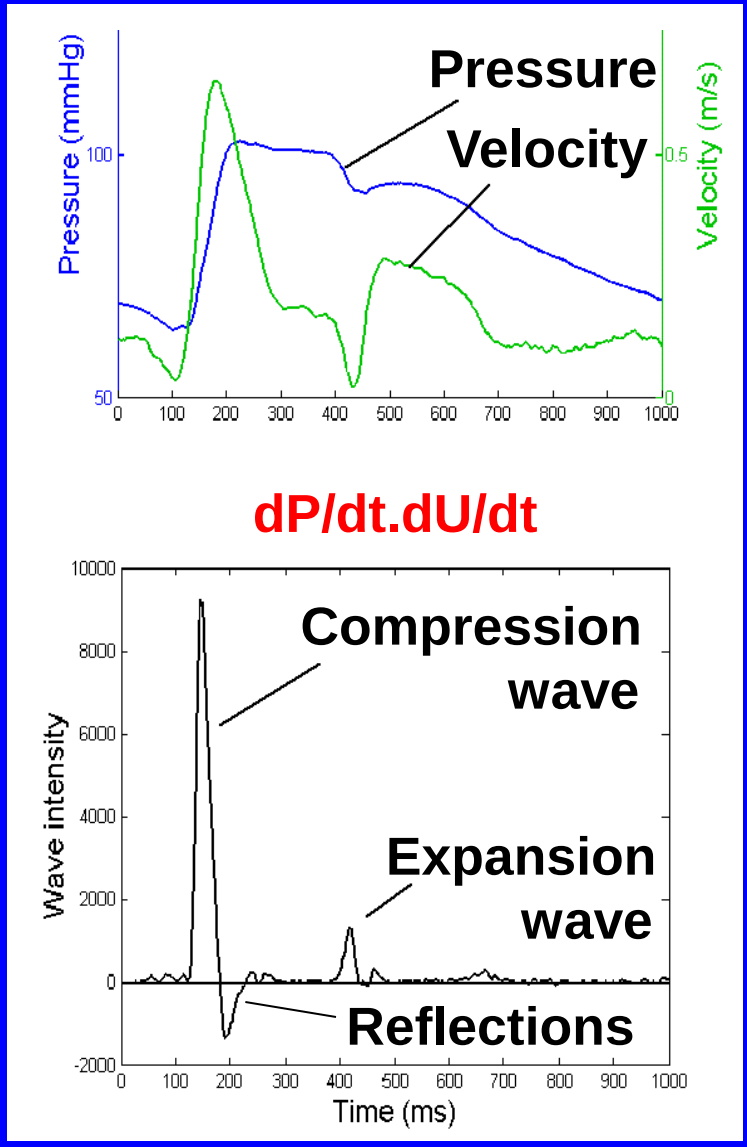
→ Non-invasive wave intensity



Aloka SSD 5500 7.5 MHz linear array transducer





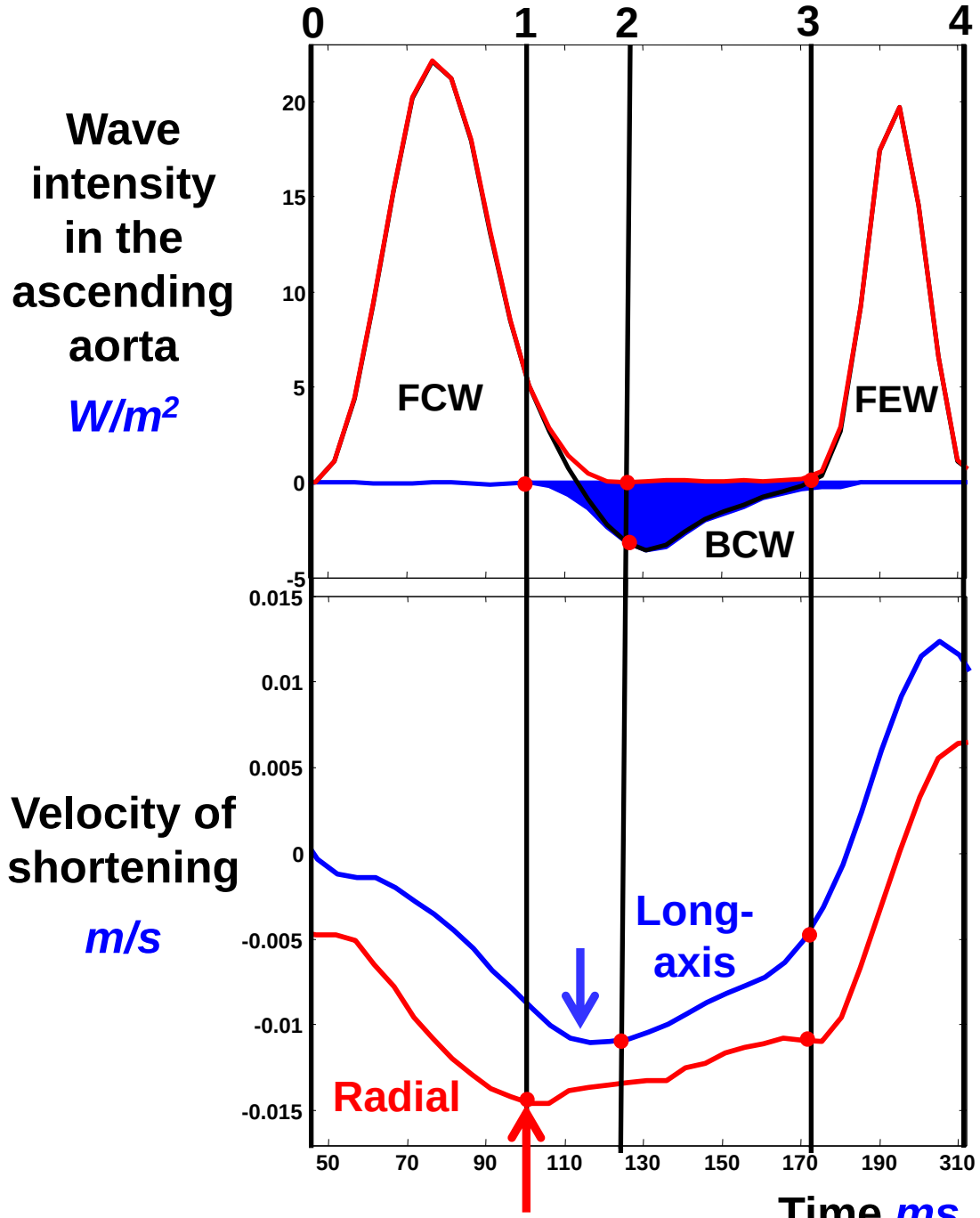


Ventricular-arterial coupling

Conduit arterial stiffness impairs *long-axis* function

	Beta index	Pressure-strain elastic modulus	Integral of mid-systolic wave reflections
Longitudinal S	-0.45**	-0.37**	-0.37**
Longitudinal E	-0.53**	-0.47**	-0.50**
Radial S	-0.07	-0.02	-0.06
Radial E	-0.28*	-0.25*	-0.13
Ejection fraction	-0.21	-0.16	-0.15
E/Ea	0.48**	0.50**	0.34**

Vinereanu D et al, Heart 2003; 89: 449

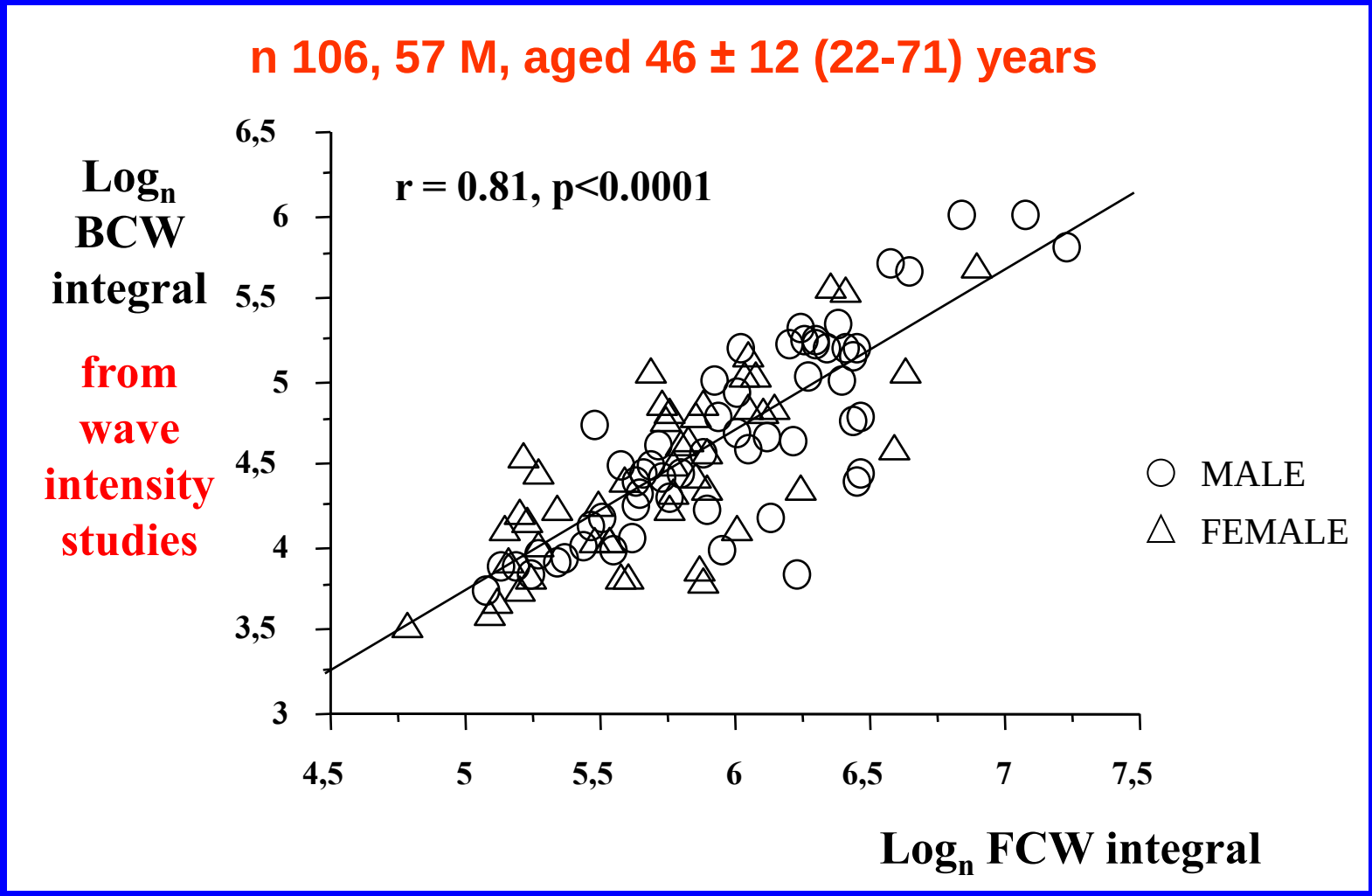


1. Peak velocity of radial shortening of the left ventricle coincides with arrival of reflected waves

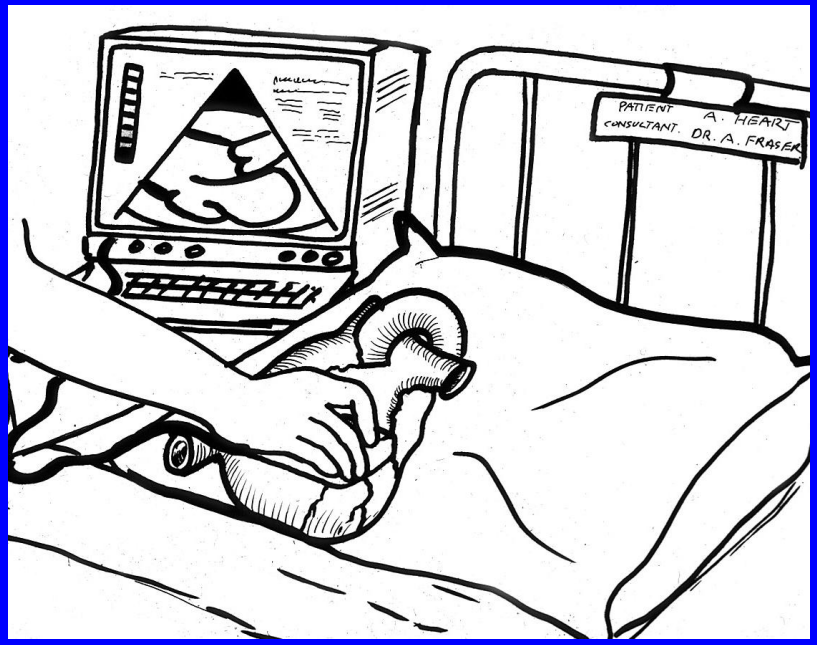
2. Generation of longitudinal shortening persists against reflections

Page C et al, Int J Cardiol 2009 e pub

The major “determinant” of reflected wave energy is left ventricular systolic function



Rakebrandt F et al, Ultrasound Med Biol 2009; 35: 266-77



The heart does not operate independently ..

.. it's part of an integrated cardiovascular symptom

Why do we have to understand V-A coupling ?

- to understand mechanisms of LV dysfunction
- because conduit arterial stiffness, central arterial pressure, and wave reflections can be important new therapeutic targets