

Clinical measurement of arterial stiffness: augmentation index vs. pulse wave velocity

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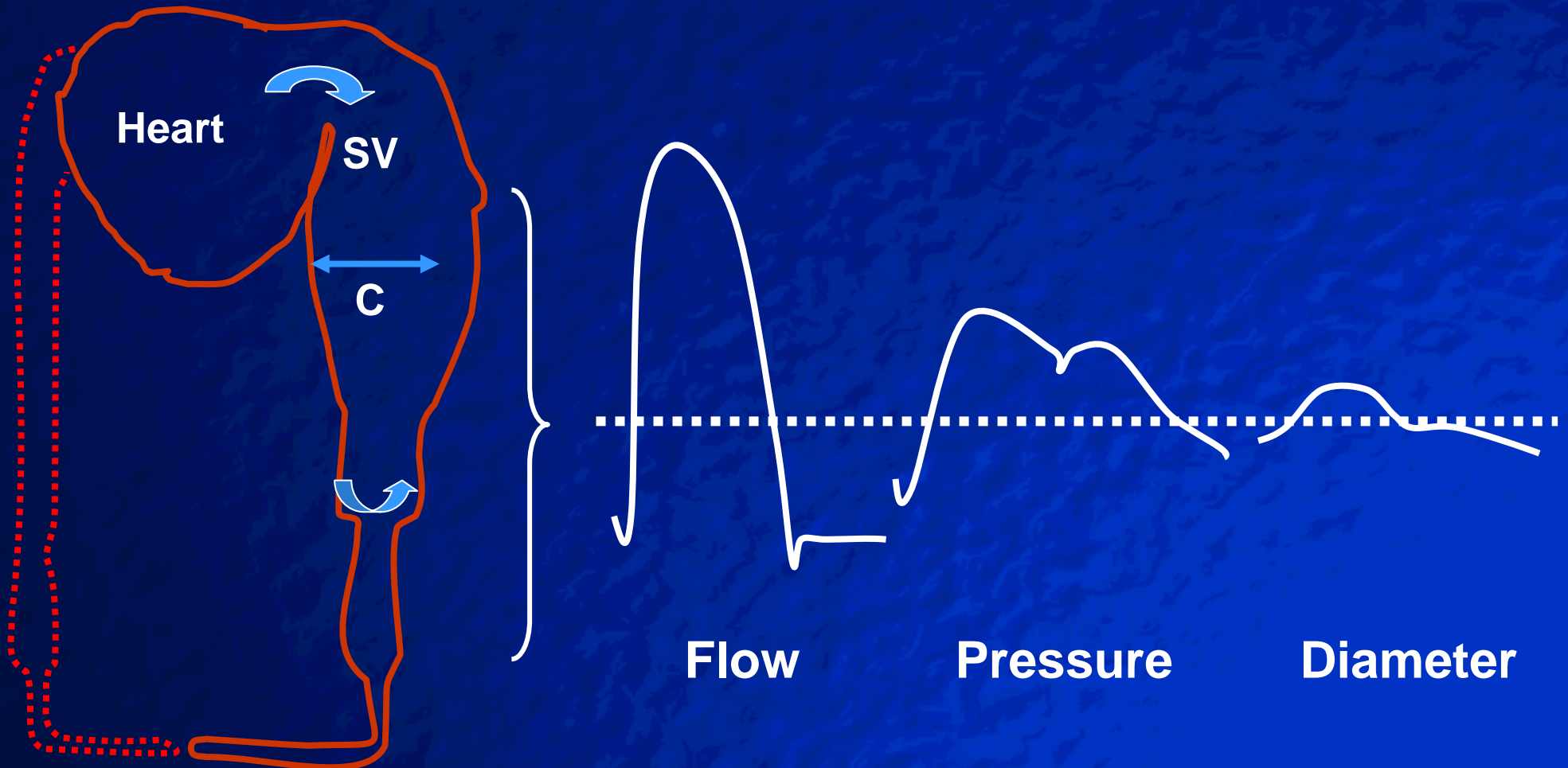
Arterial Stiffness as a Predictor of Morbidity and Mortality

- **Target Organ Damage**
 - Pressure-dependent or -independent arterial stiffness and LV hypertrophy.
 - Increased stiffness of central arteries
 - independently associated with kidney damage in patients with mild-to-moderate renal insufficiency.
- **Cardiovascular Morbidity and Mortality**

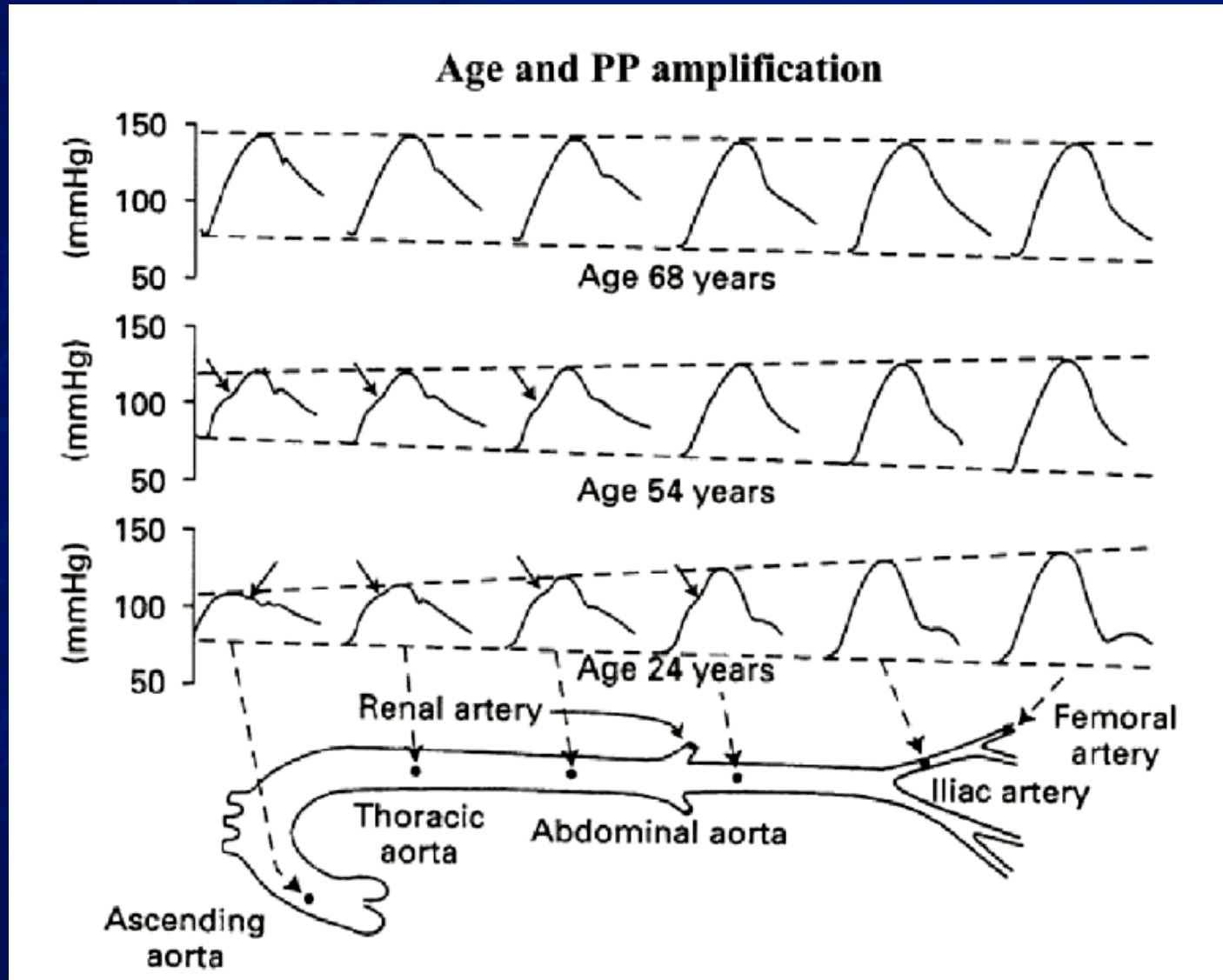
Relationship Between Markers for Arterial Stiffness and Other Risk Factors for CVD

- Hypertension
- Obesity
- Metabolic syndrome
- Diabetes
- Hypercholesterolemia
- C-reactive protein

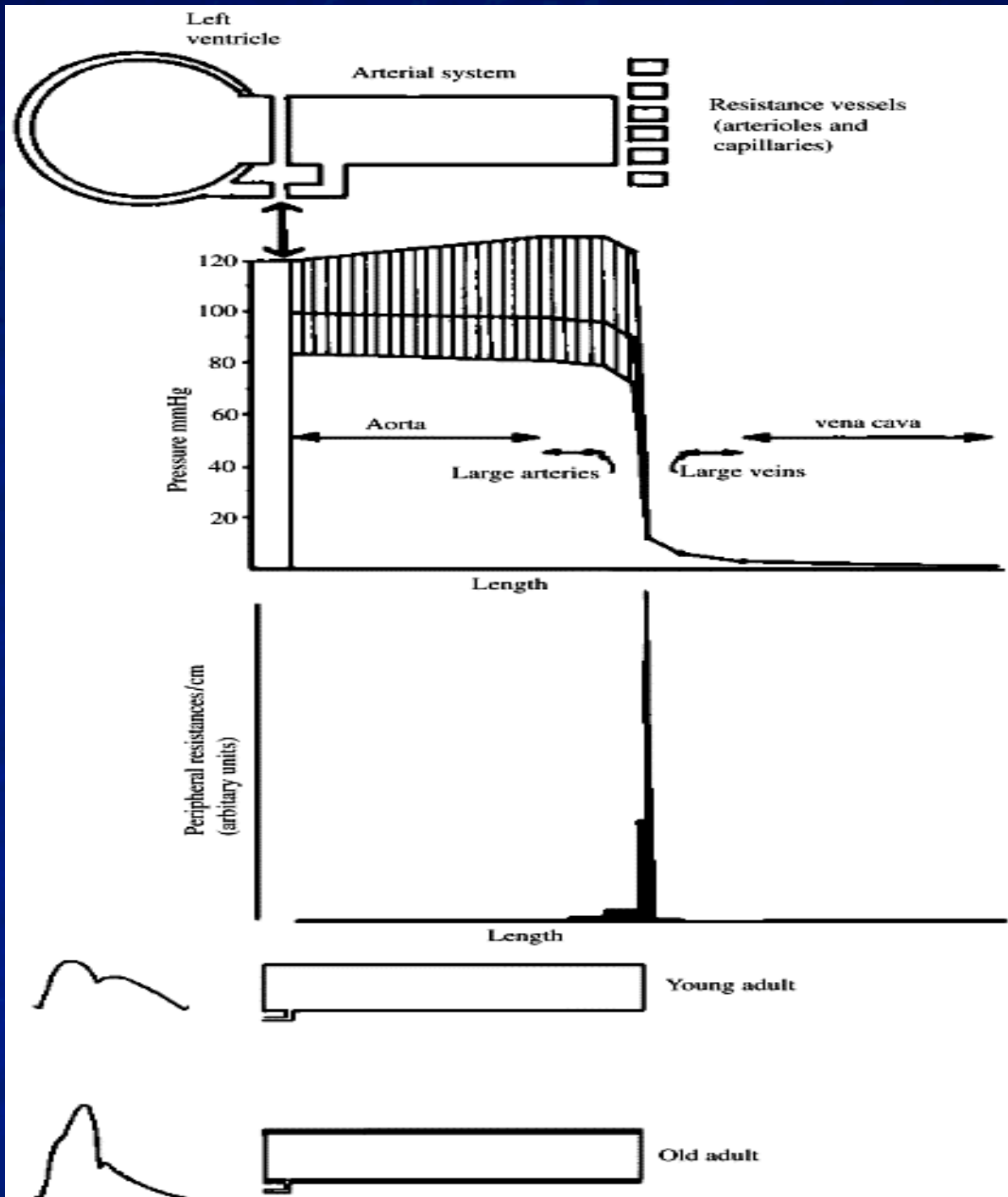
Fluctuations in amplitude of flow, pressure, and diameter in a large artery



Propagation of the PP wave from central to peripheral arteries in patients 24, 54, and 68 years of age.



A Model of the Systematic Circulation.

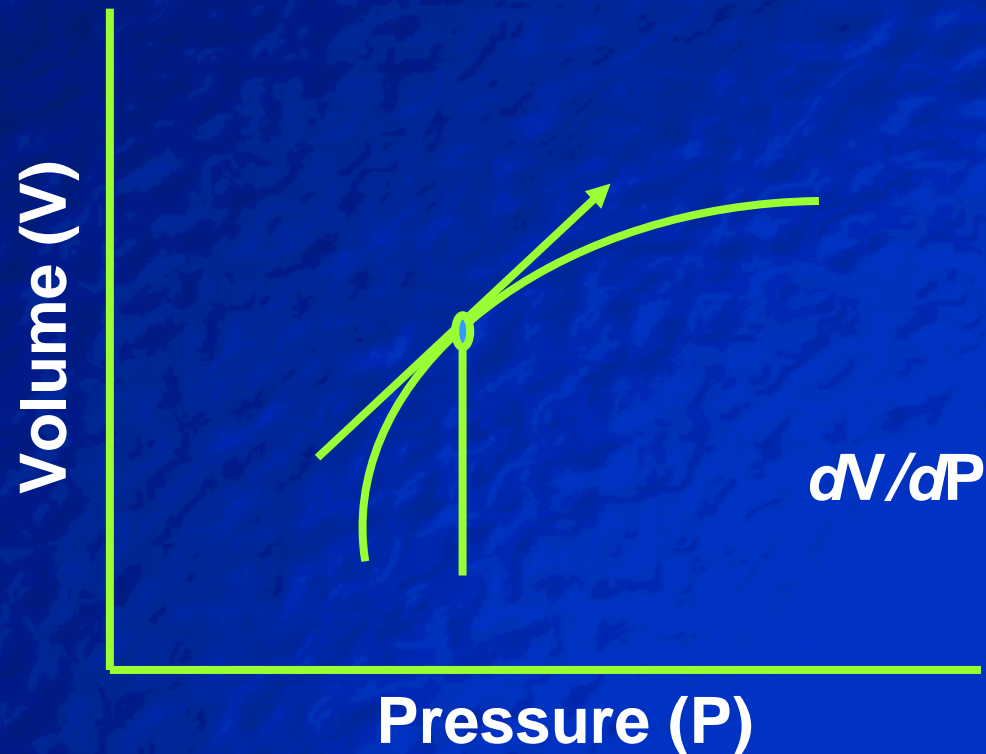
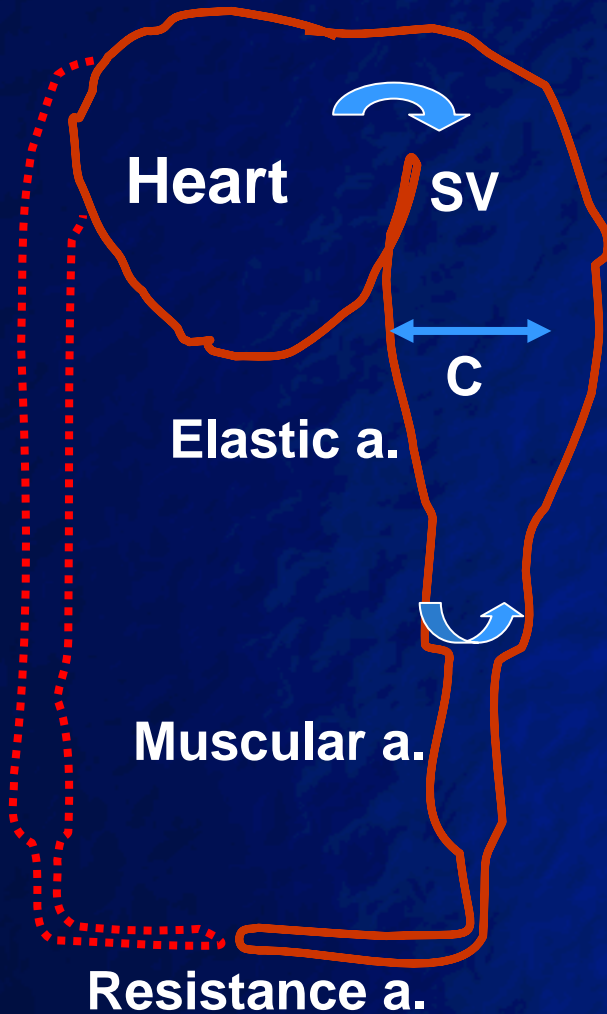


Terminology

Parameter	Definition	Formula
Distensibility	The relative change in vessel diameter (or area) for a given change in pressure	$\Delta D/(\Delta P \times D)$, $\Delta A/(\Delta P \times A)$
Compliance	The absolute change in vessel diameter (or area) for a given change in pressure	$\Delta D/\Delta P$, $\Delta A/\Delta P$
Elastic modulus	The pressure change required for (theoretical) 100% stretch from resting diameter (inverse of distensibility)	$(\Delta P \times D)/\Delta D$
Pulse wave velocity	The speed with which the pulse wave travels along a length of artery	Distance/ Δt
Stiffness index (β)	The ratio of the natural logarithm of SBP/DBP to the relative change in diameter	$\ln(P_s/P_d)$ / $[(D_s - D_d)/D_d]$
Augmentation index	Size of increase or decrease in the pulse height as a result of the reflected wave, or Size of reflected peak ($P2/P1$)	$(P2 - P1)/(P_s - P_d)$, $(P2/P1)$

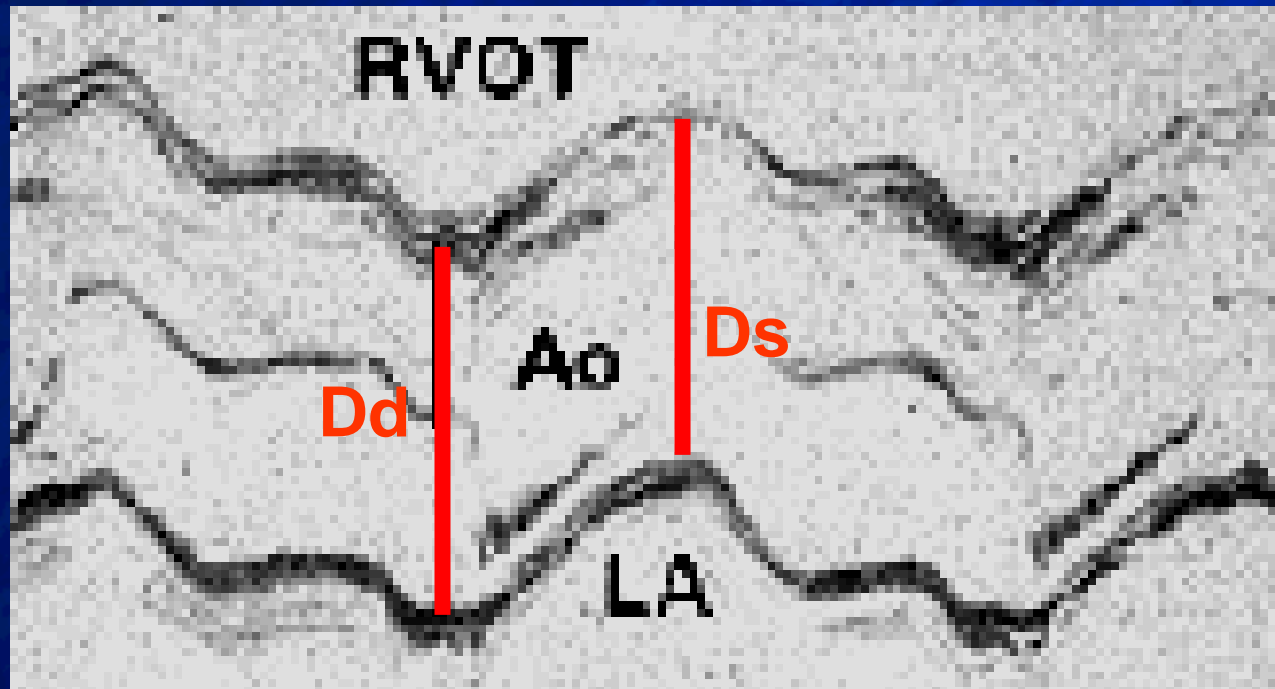
I. Compliance

Def: The absolute change in vessel diameter (or area) for a given change in pressure. $\Delta D/\Delta P$ or $\Delta A/\Delta P$



I-2. Local Arterial (Aortic) Stiffness

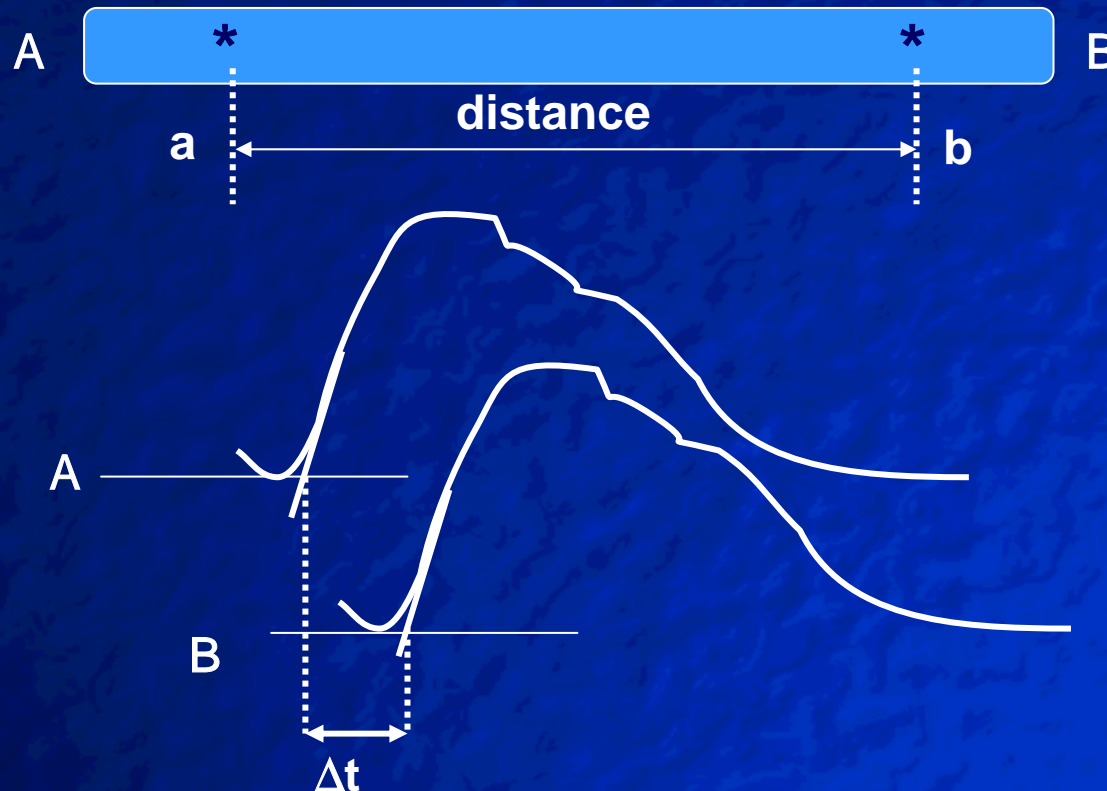
: β Stiffness index
= $\text{Ln} (\text{SBP}/\text{DBP}) / (\text{D}_{\text{sys}} - \text{D}_{\text{dia}}) / \text{D}_{\text{dia}}$



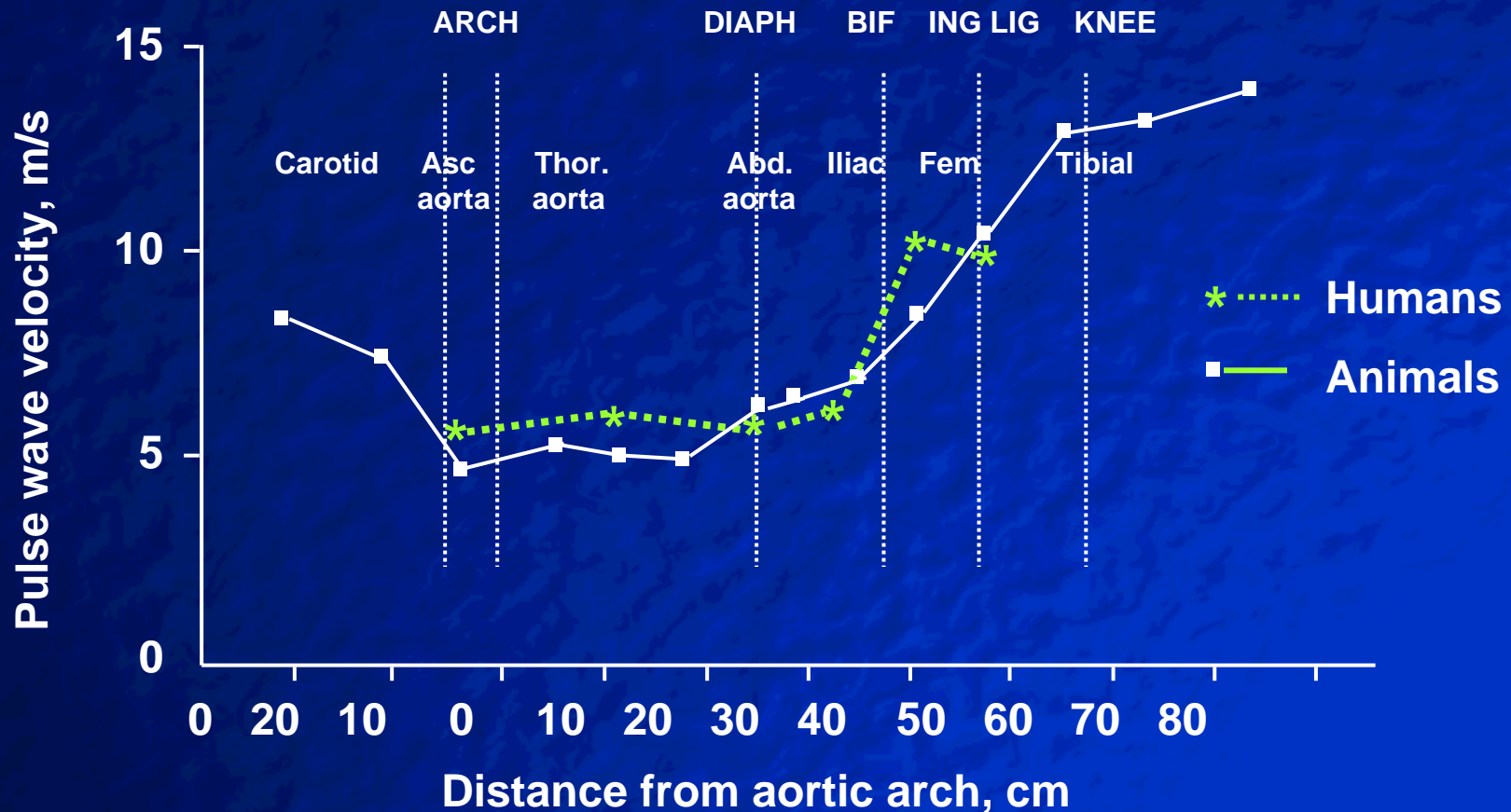
II. Pulse wave velocity

The speed with which the pulse wave travels along a length of artery

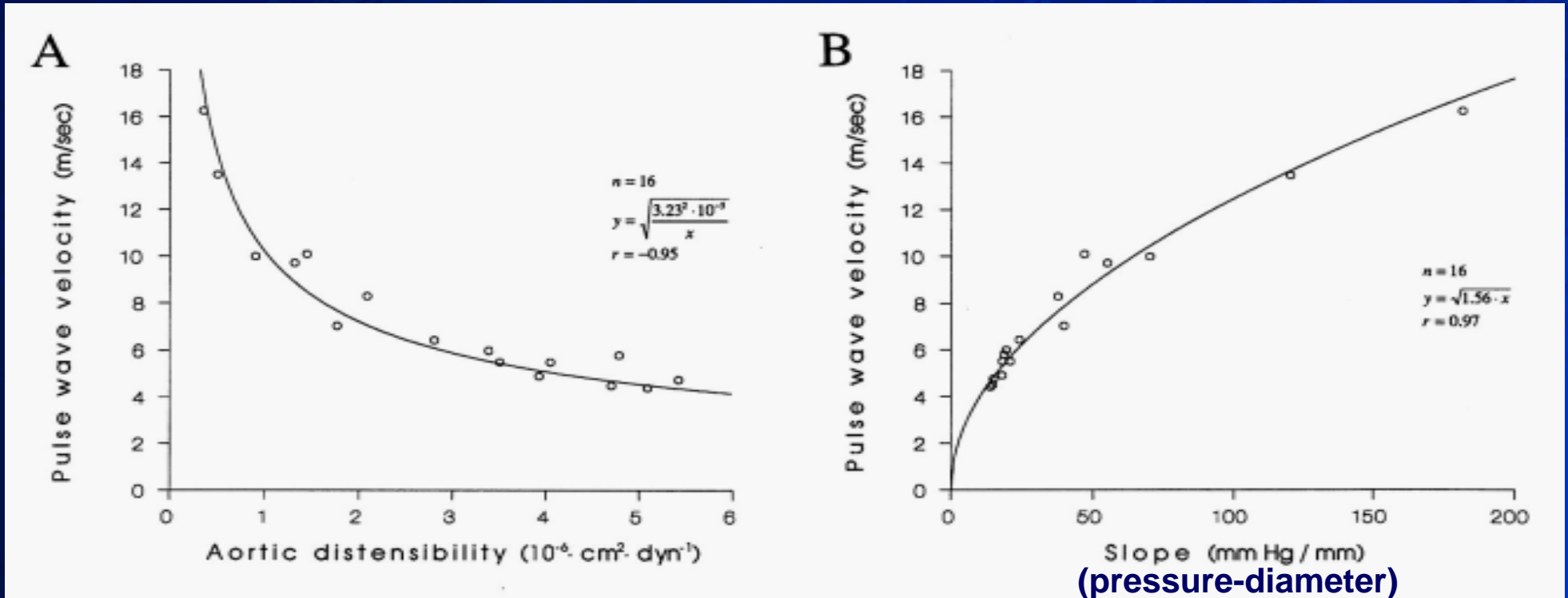
(Distance/ Δt)



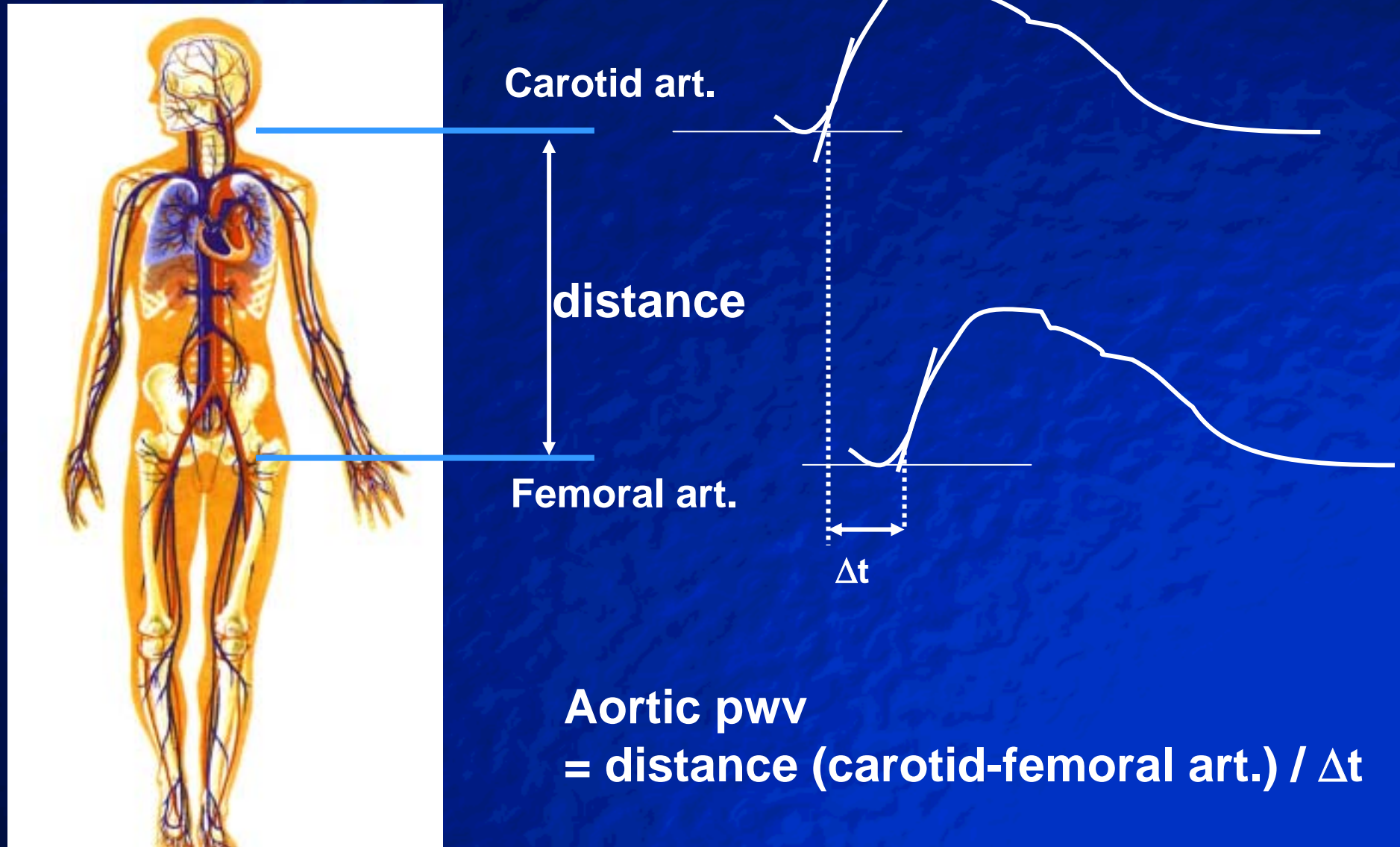
Pulse Wave Velocity in Different Arteries



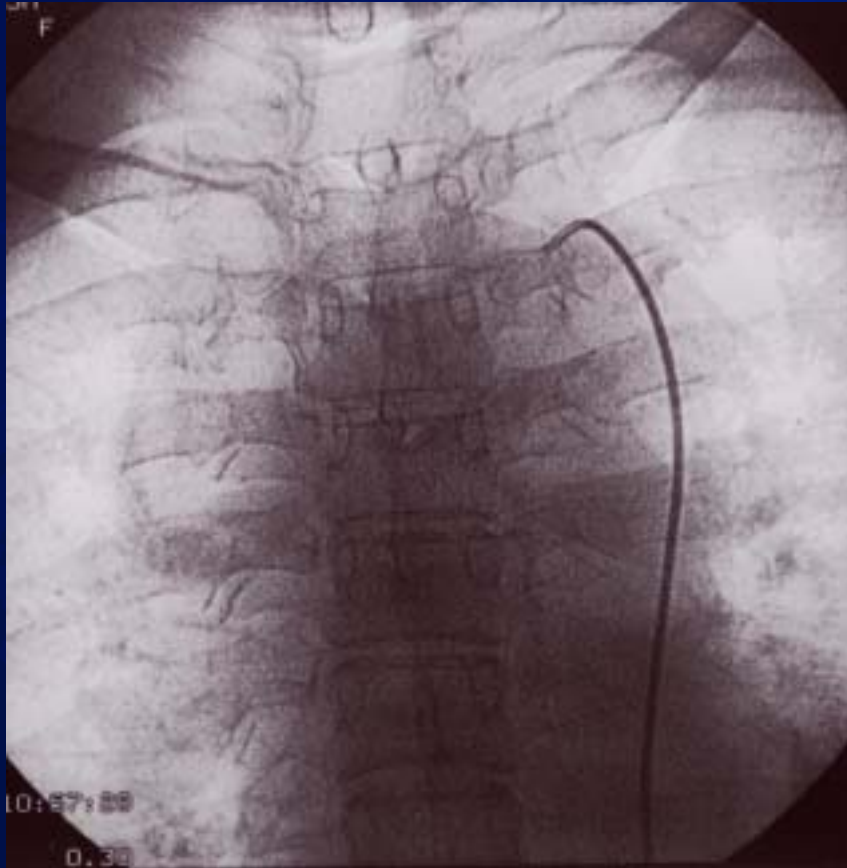
Relation of measured pulse wave velocity and aortic distensibility



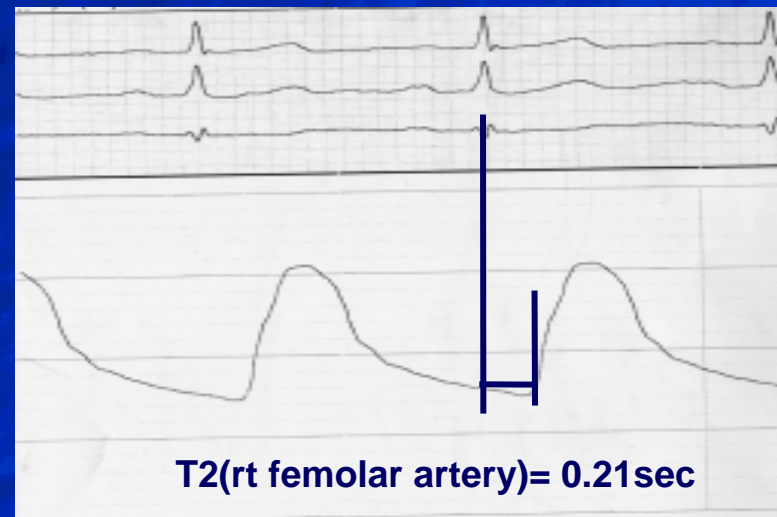
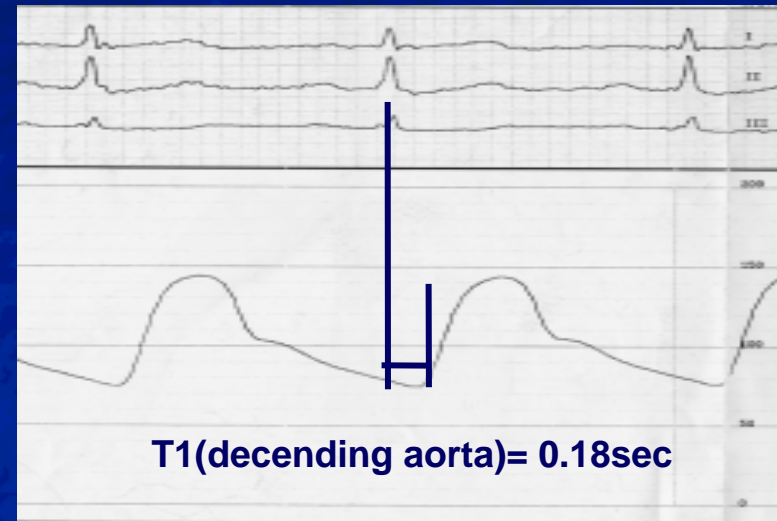
Noninvasive measurement of pulse wave velocity by Echocardiogram



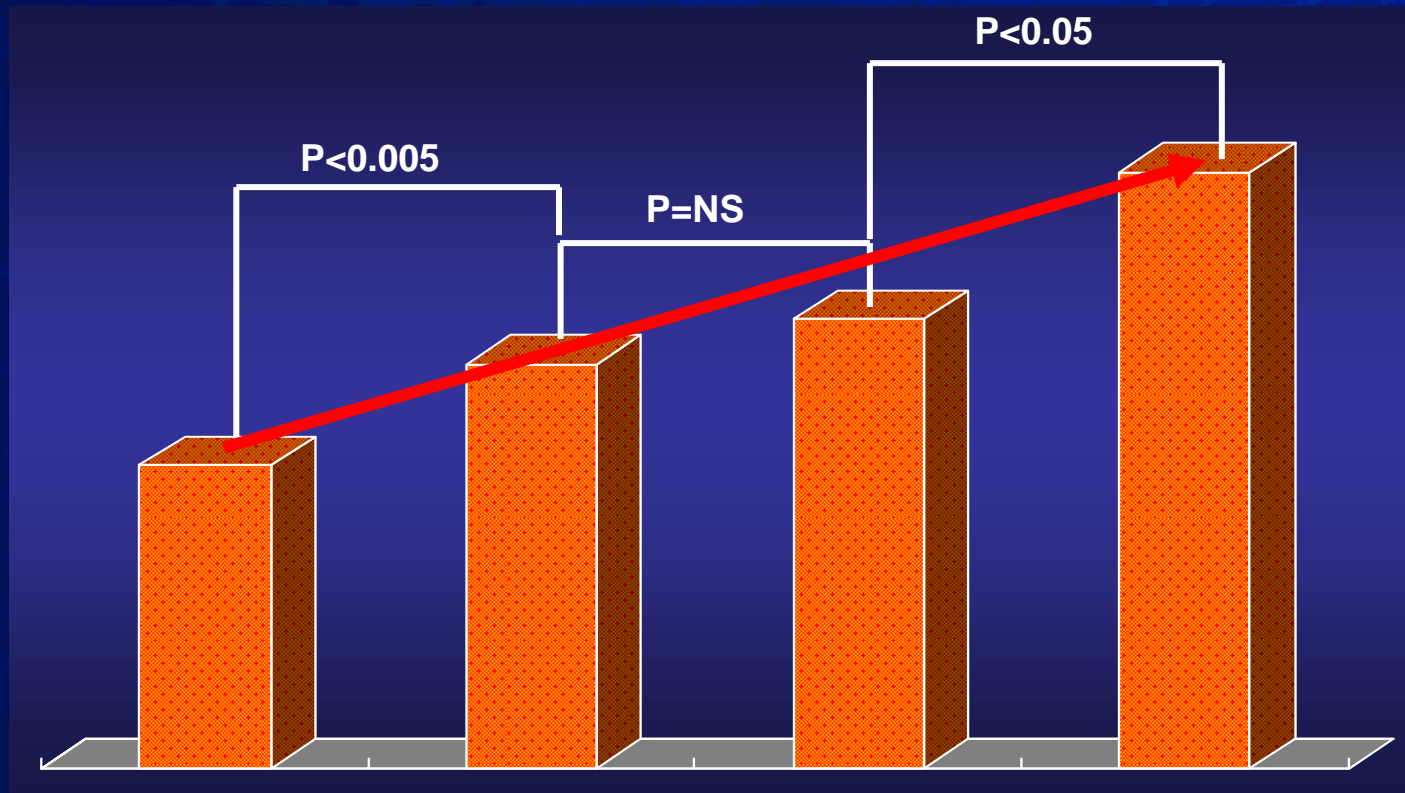
High aortic pulse wave velocity is a powerful predictor of coronary artery stenosis and calcification in suspected coronary artery disease patients



Catheter location ; descending aorta just distal to left subclavian artery



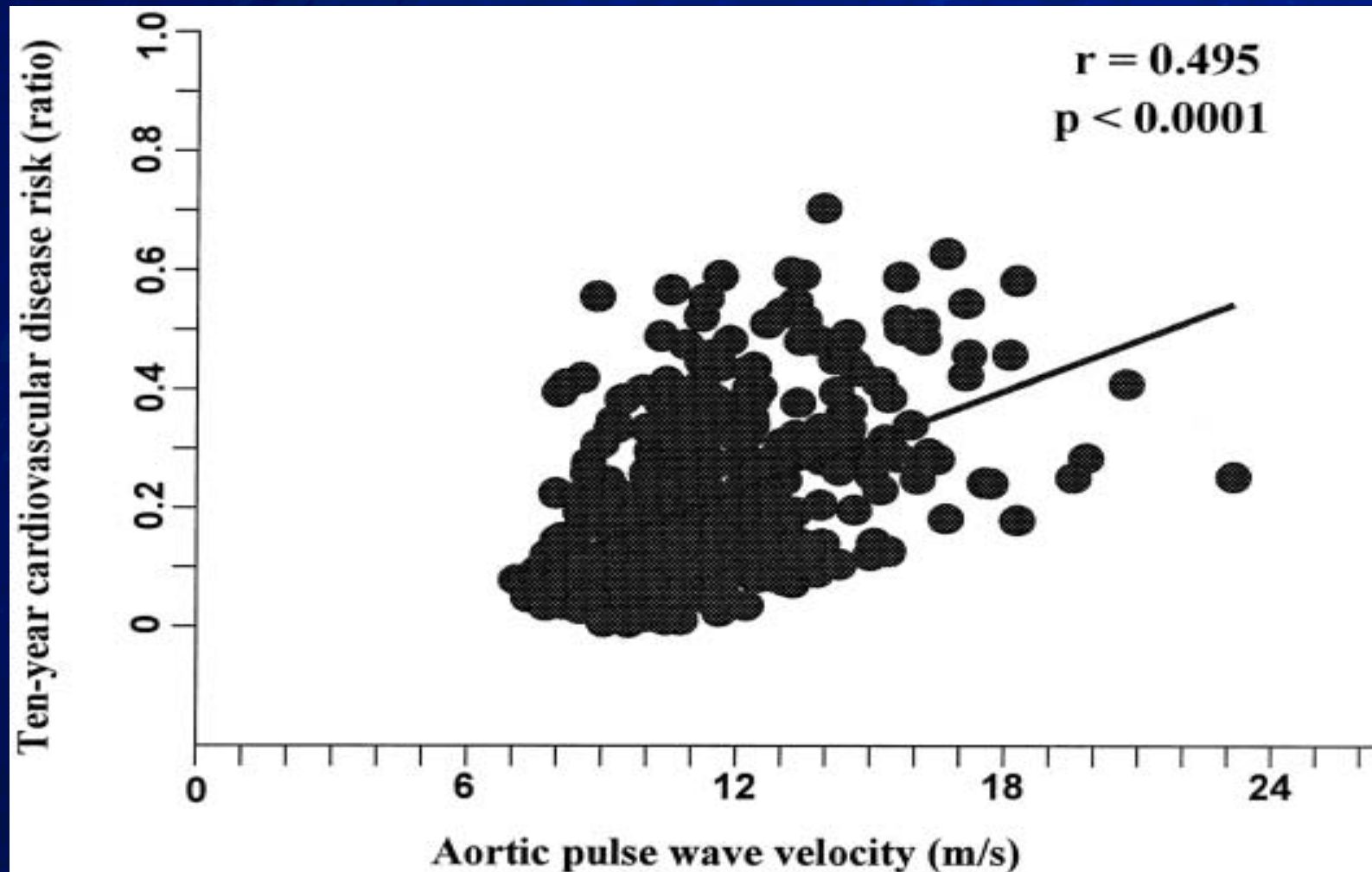
Log PWV adjusted by age, SBP, DBP according to the number of coronary artery stenosis



Stenosis	0	1	2	3 vessel
Log PWV	2.24+/-0.03	2.42+/-0.04	2.50+/-0.07	2.76+/-0.11
PWV	9.82+/- 0.43	12.56+/-0.62	12.89+/-0.98	17.22+/-1.57

Park CG et al.
2002 ISH
Prague, Czech

Relation between 10-year CVD risk and aortic pulse wave velocity



Relative risk for cardiovascular (CV) mortality according to pulse wave velocity (PWV) and other risk factors

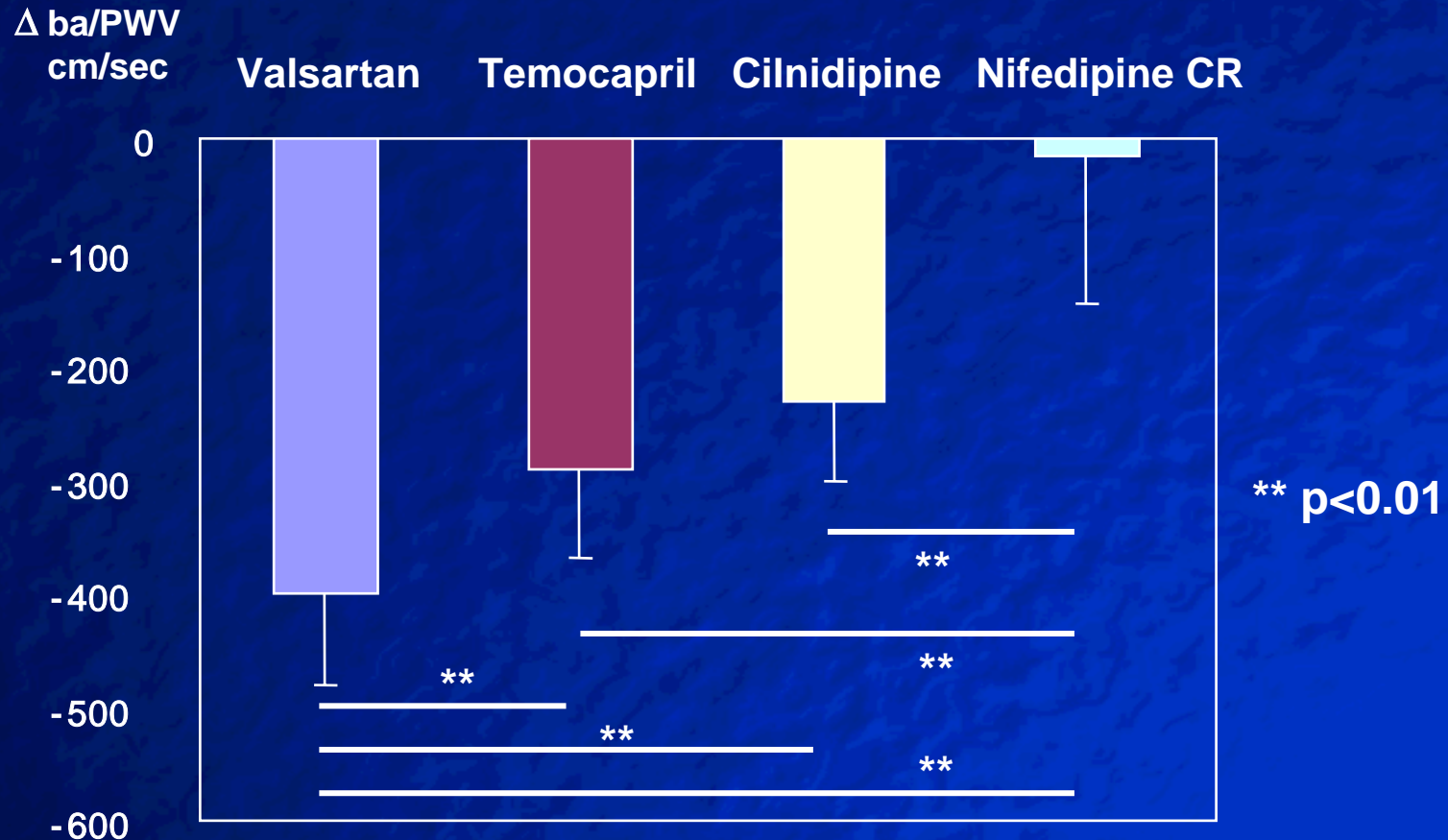
Parameter	OR	P
PWV (5 m/sec)	2.35	<.0001
Previous CVD (yes/no)	14.81	<.0001
Age (10 y)	2.32	<.0001
PP (10 mm Hg)	1.53	<.0001
SBP (10 mm Hg)	1.26	<.001
Diabetes (yes/no)	4.23	<.001

Relative risk (RR) for CHD and CV events according to PWV, Framingham risk score, and CV risk factors

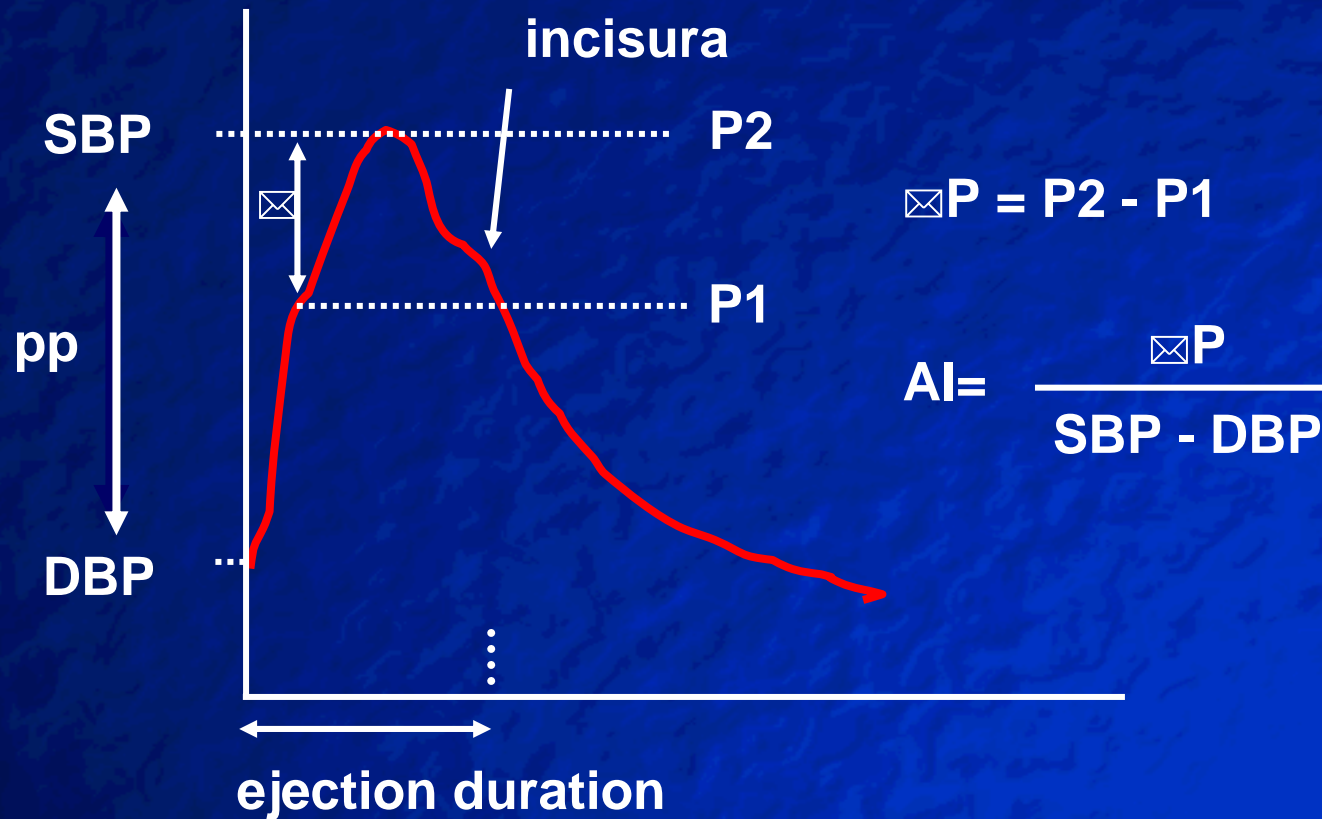
Parameter	RR	P
<u>CHD events</u>		
PWV (3.5 m/s)	1.42	<.01
FRS (4 points)	1.51	<.01
Age (10 y)	1.42	<.01
Hypercholesterolemia (yes/no)	2.49	<.01
Sex (M/F)	2.32	<.02
<u>All CV events</u>		
PWV (3.5 m/sec)	1.41	<.001
FRS (4 points)	1.57	<.0001
Age (10 y)	1.47	<.0001
SBP (10 mm Hg)	1.12	.015
PP (10 mm Hg)	1.16	.019
Hypercholesterolemia (yes/no)	1.73	.017
Diabetes (yes/no)	2.16	<.01
Gender (male/female)	1.64	.036

CVD cardiovascular disease; FRS Framingham risk score; PP pulse pressure; SBP systolic blood pressure.

Changes in the brachial-ankle pulse wave velocity between baseline and 3 months after drugs in elderly hypertensive patients



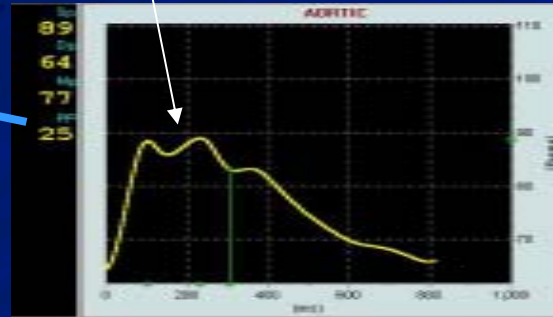
III. Augmentation pressure and augmentation index



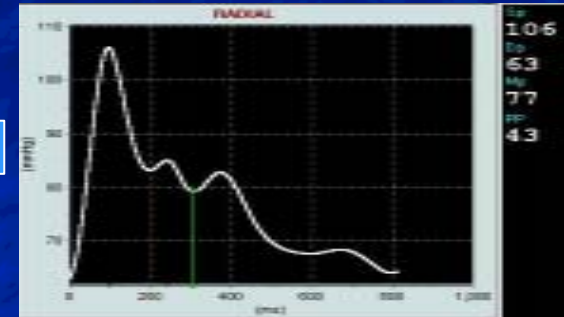
Systemic Arterial stiffness

; Augmentation index (AIx) by Sphygmocor

Augmentation index Pressure transfer function
(Degree of amplification)



Aorta

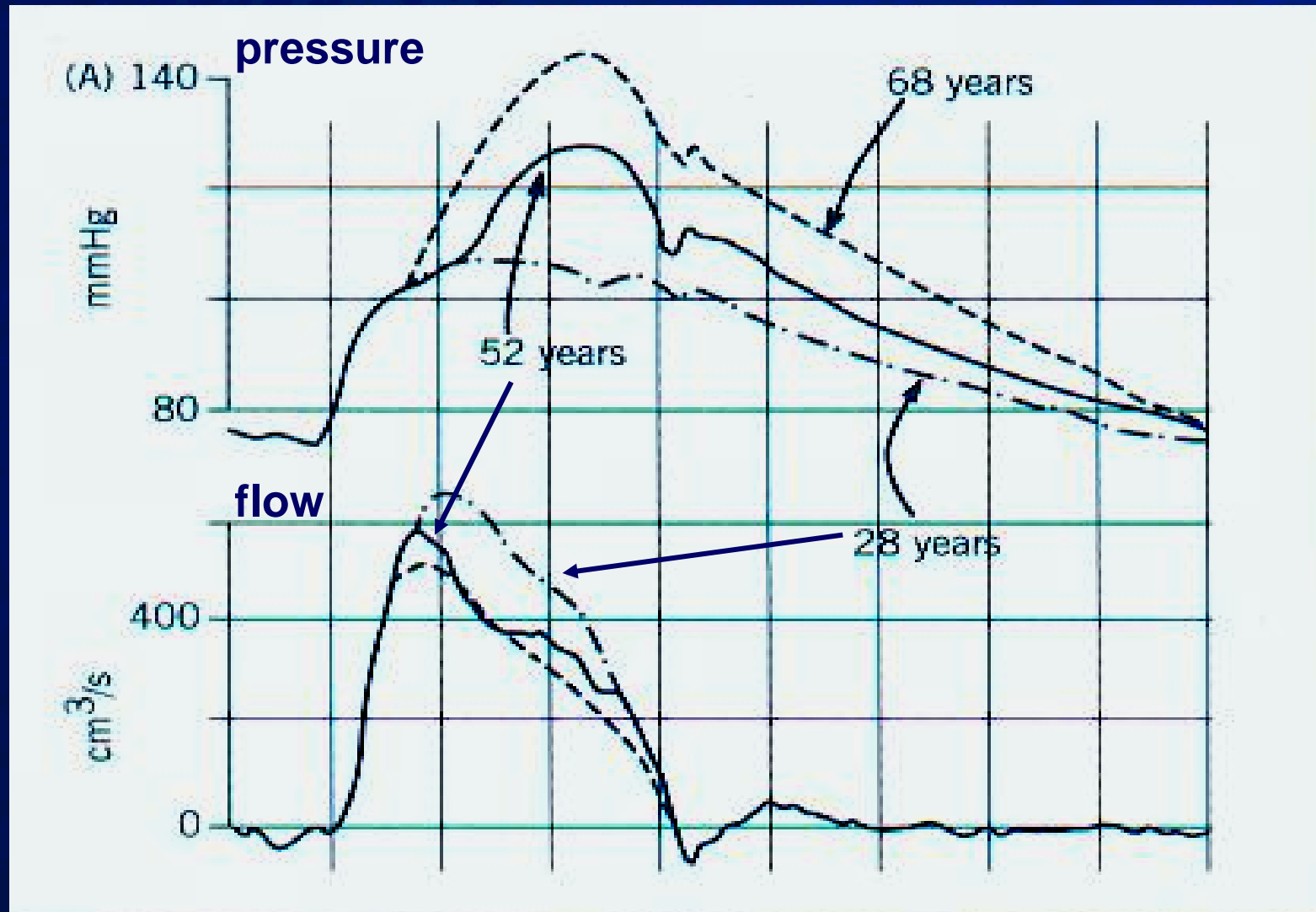


Radial artery



Radial pulse
applanation tonometry

Typical pressure and flow waves in normotensive subjects: Effect of aging

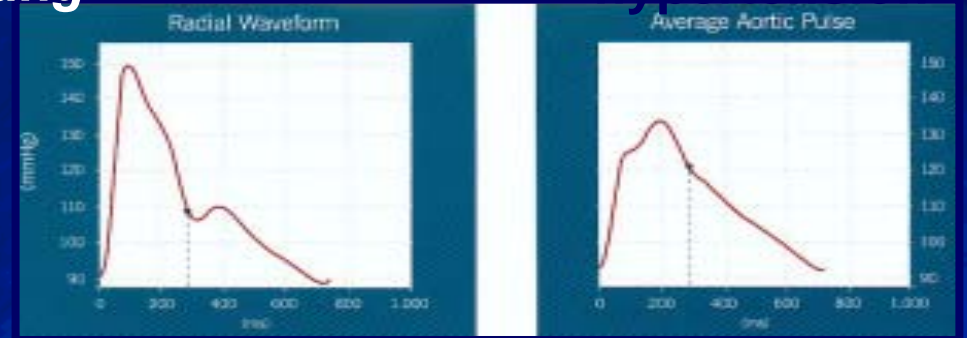
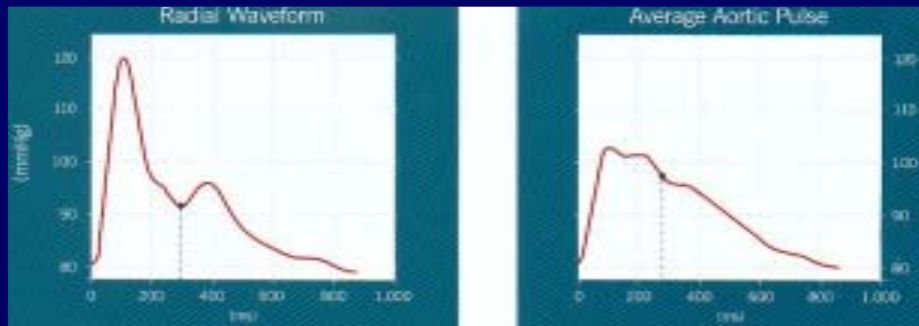


Pulse wave in normotensive and hypertensive subjects

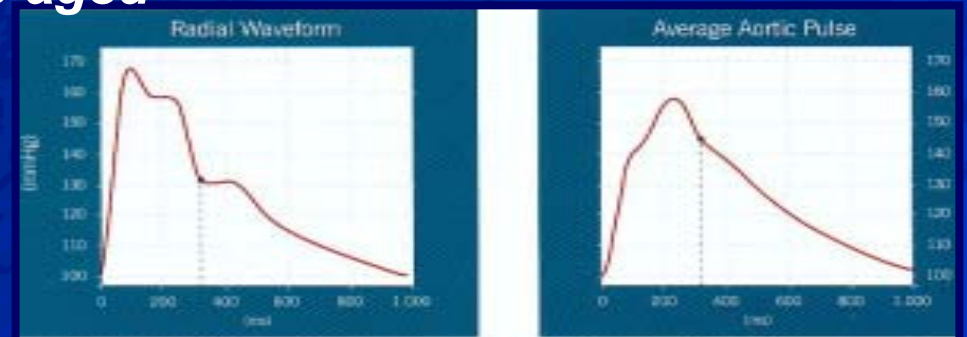
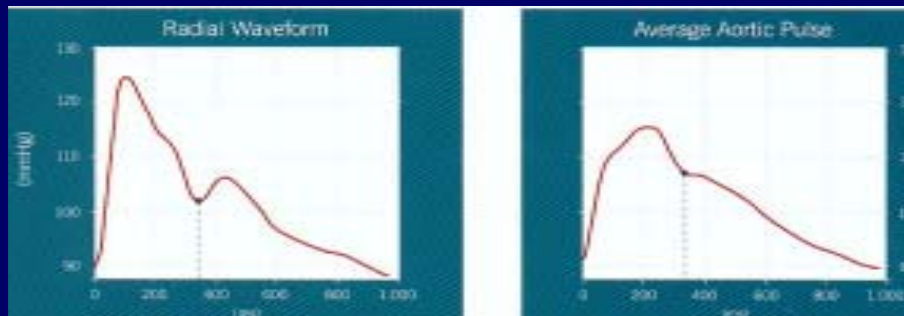
normotension

young

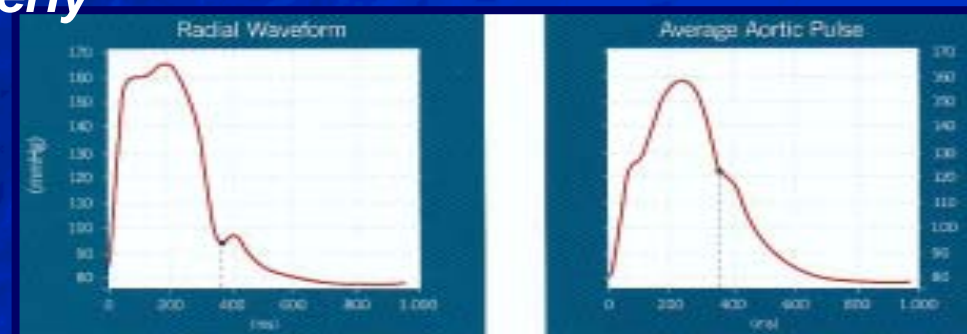
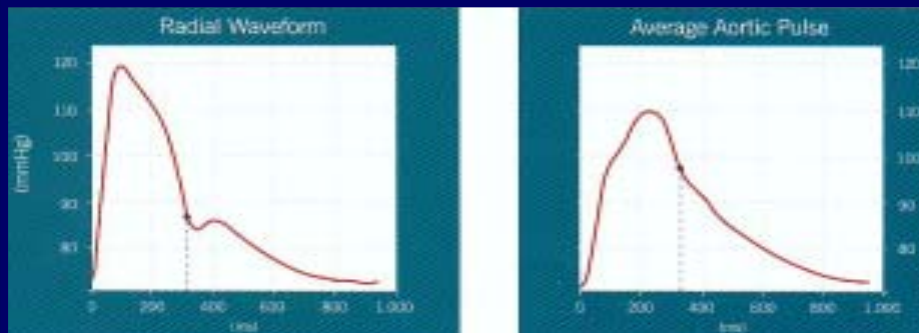
hypertension



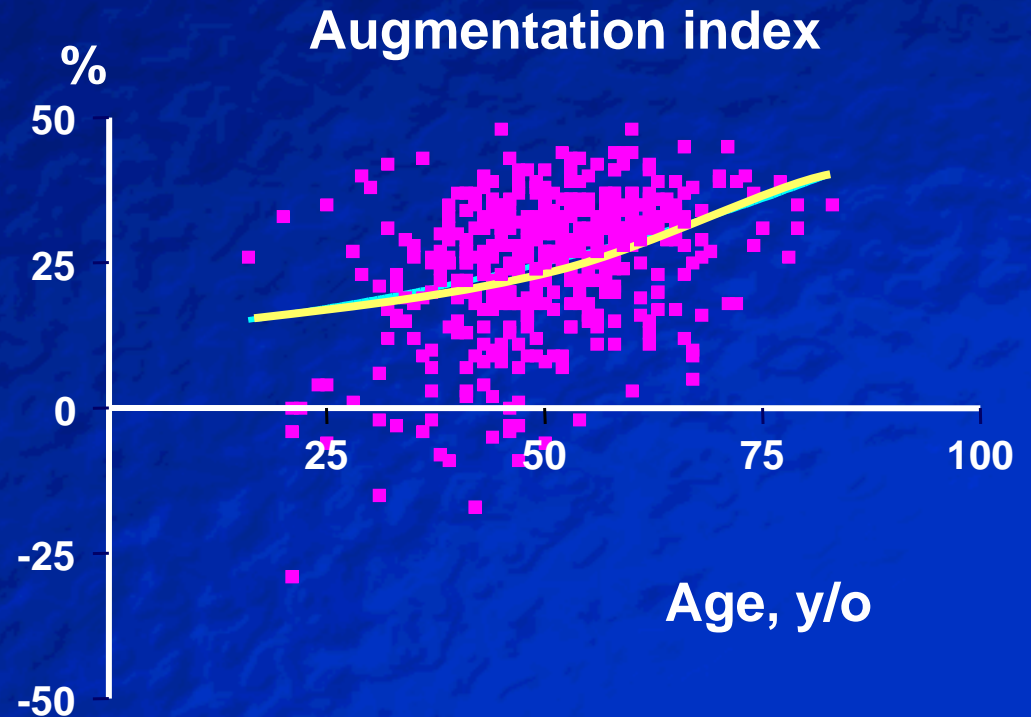
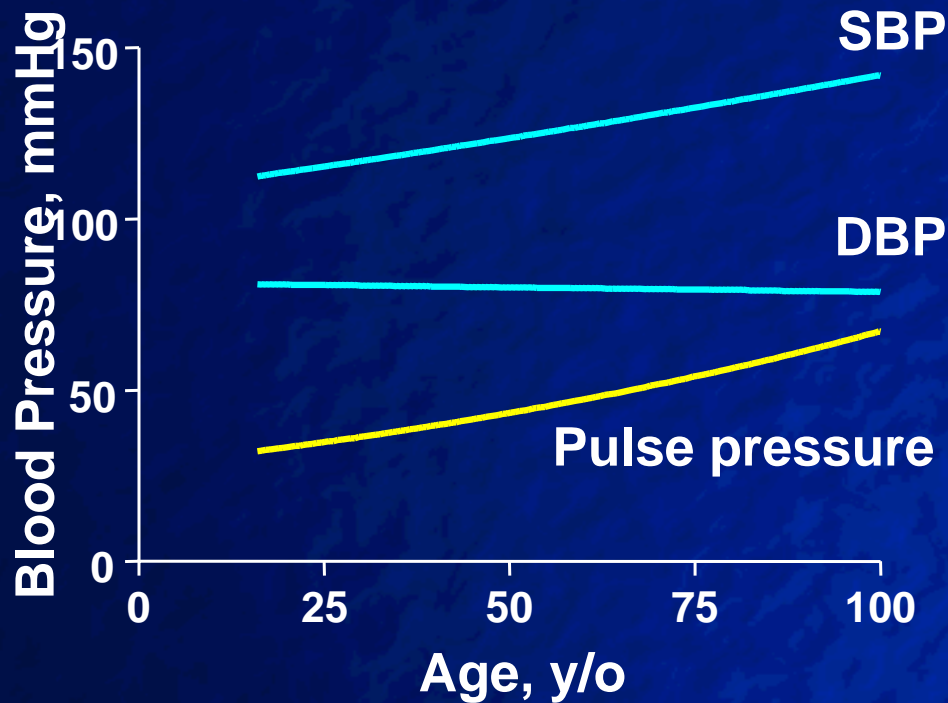
Middle-aged



elderly

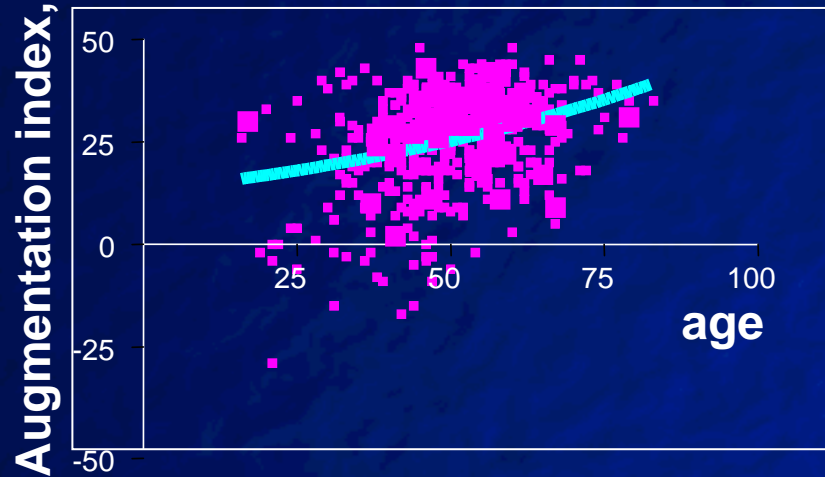


Changes of Blood Pressure and Vascular Stiffness with Aging

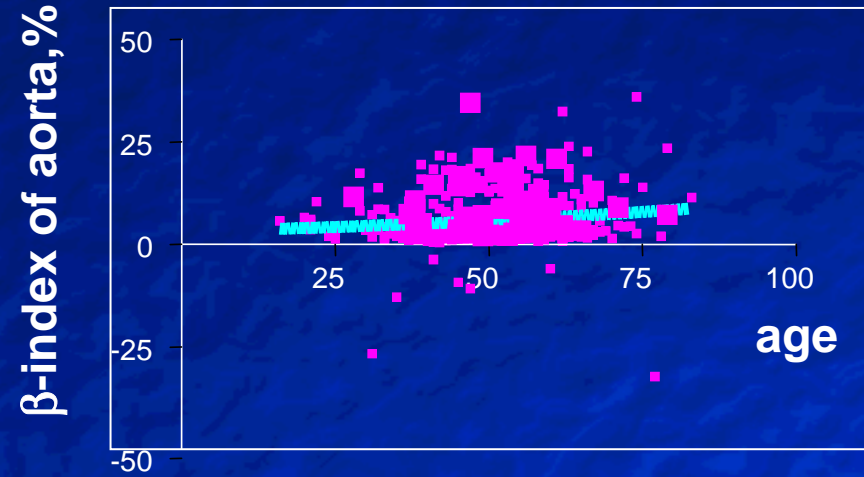


Cardiovascular Risk and Cardio-Arterial Stiffness with Aging

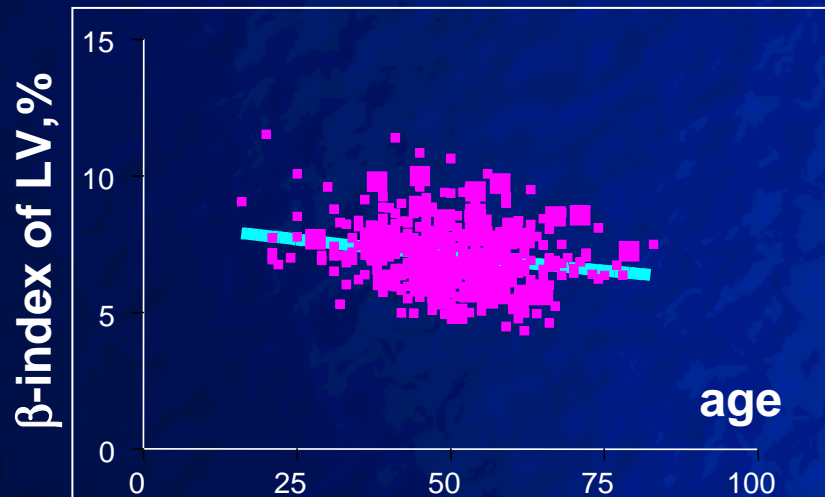
Systemic arterial stiffness



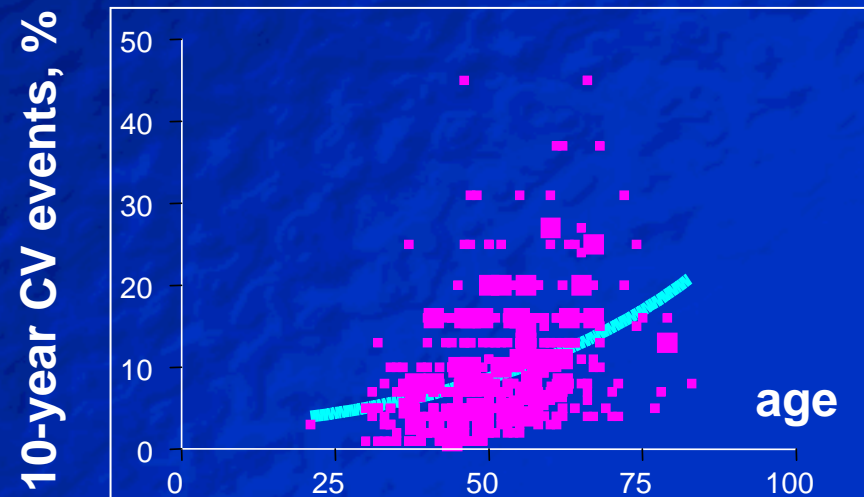
Local stiffness



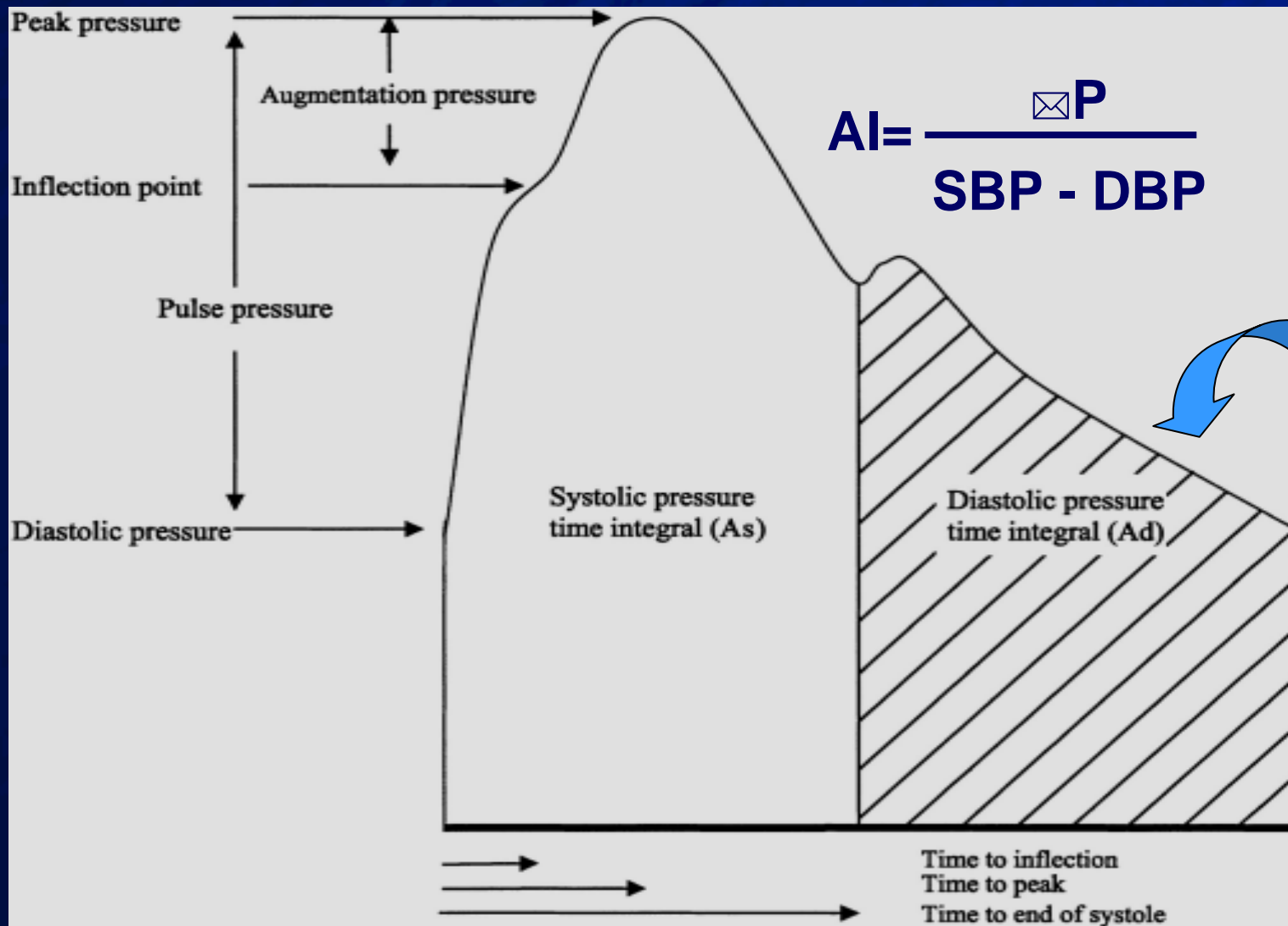
Cardiac stiffness



Cardiovascular Risk



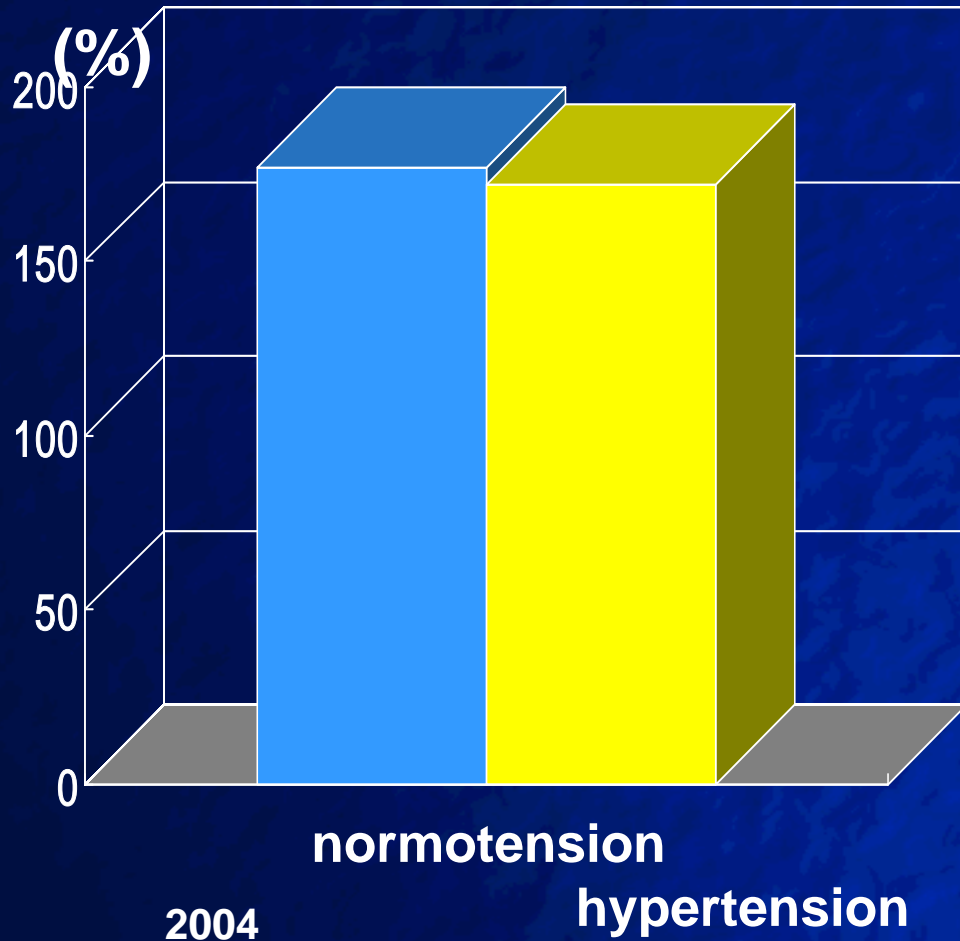
Coronary artery perfusion



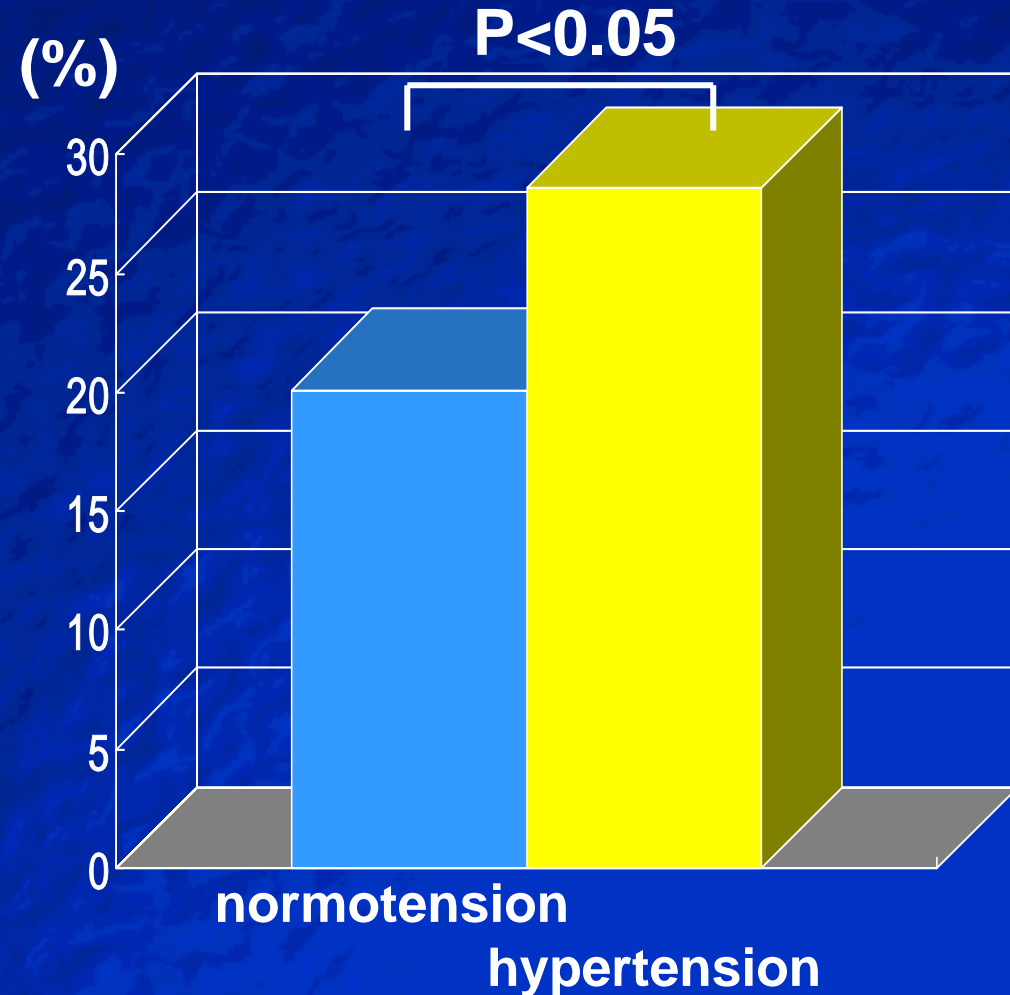
subendocardial
viability index;
(SEVR)
= A_d/A_s ratio

(n≈1,000)

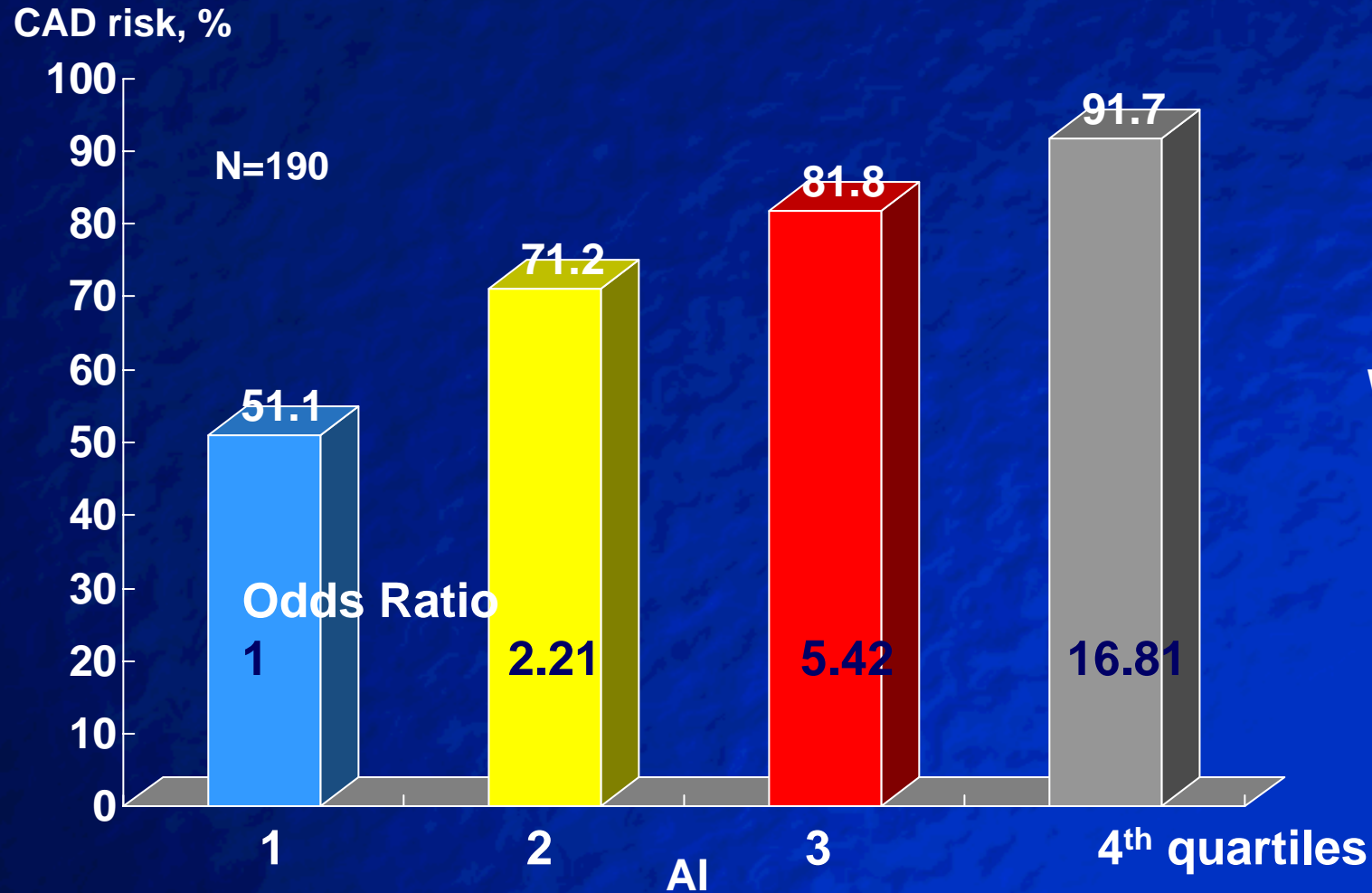
Subendocardial viability ratio



Augmentation index



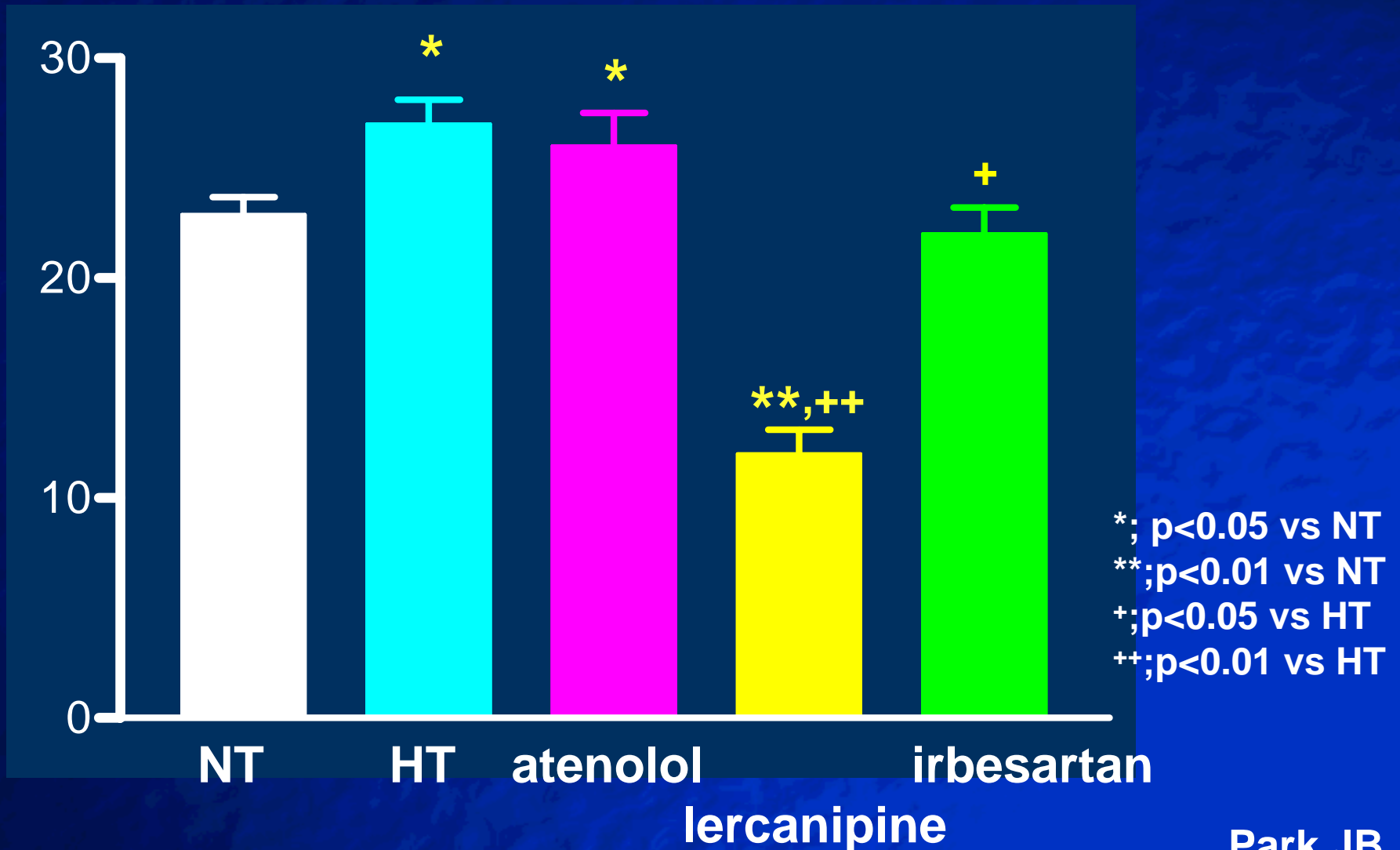
Augmentation index and presence of coronary artery disease in younger patients (<60y/o)



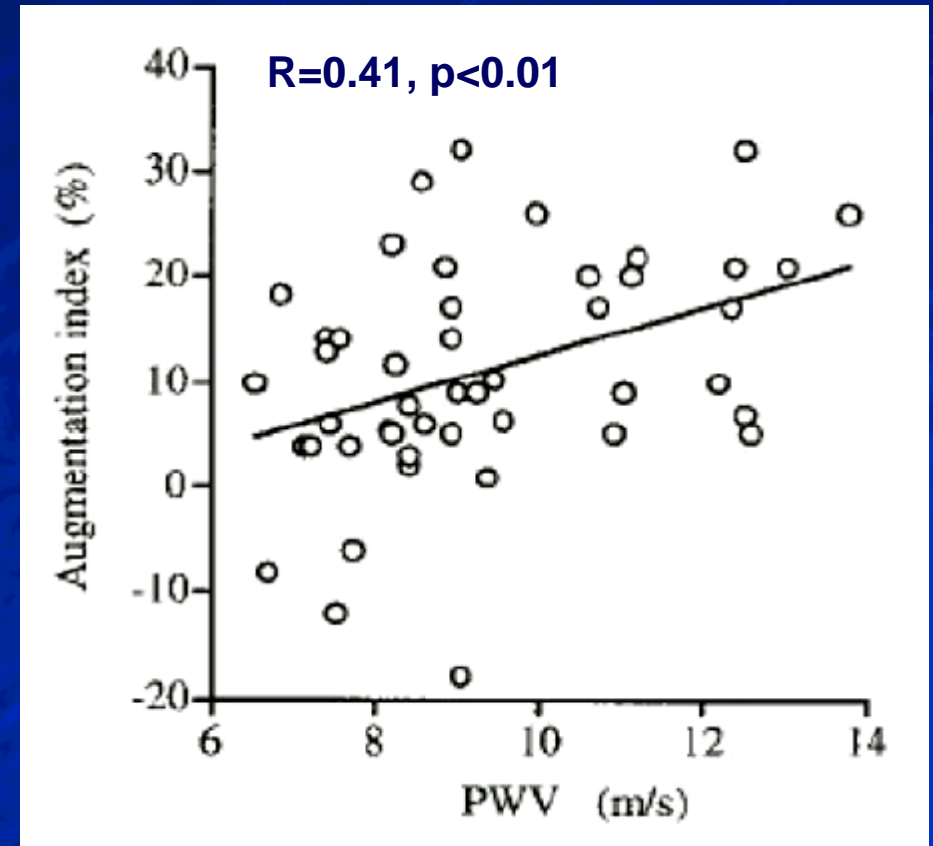
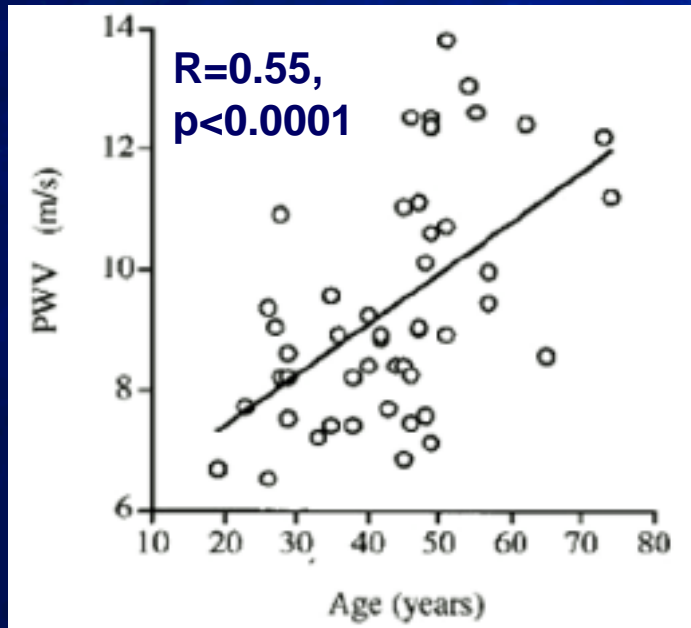
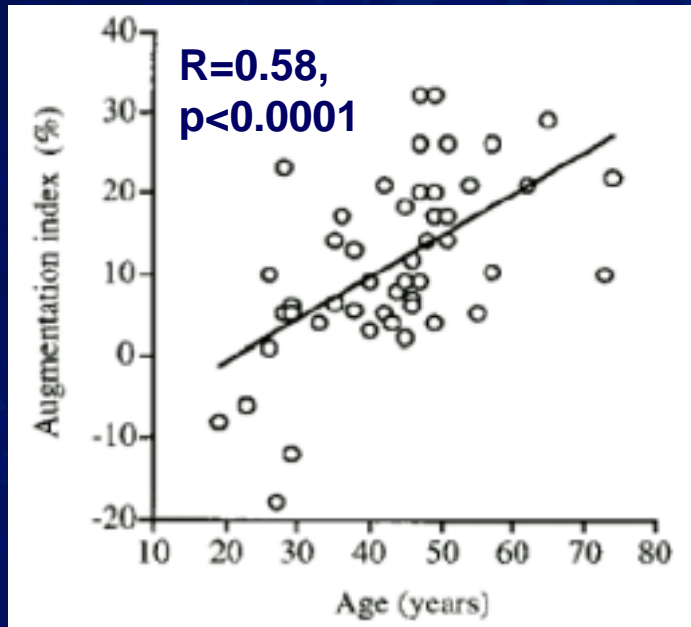
Weber et al;
Circulation
2003

Disparate effects of antihypertensive drugs on Vascular Stiffness : 6 months trial

Central augmentation index, %



Relationships between Alx, PWV, and age in 50 healthy men

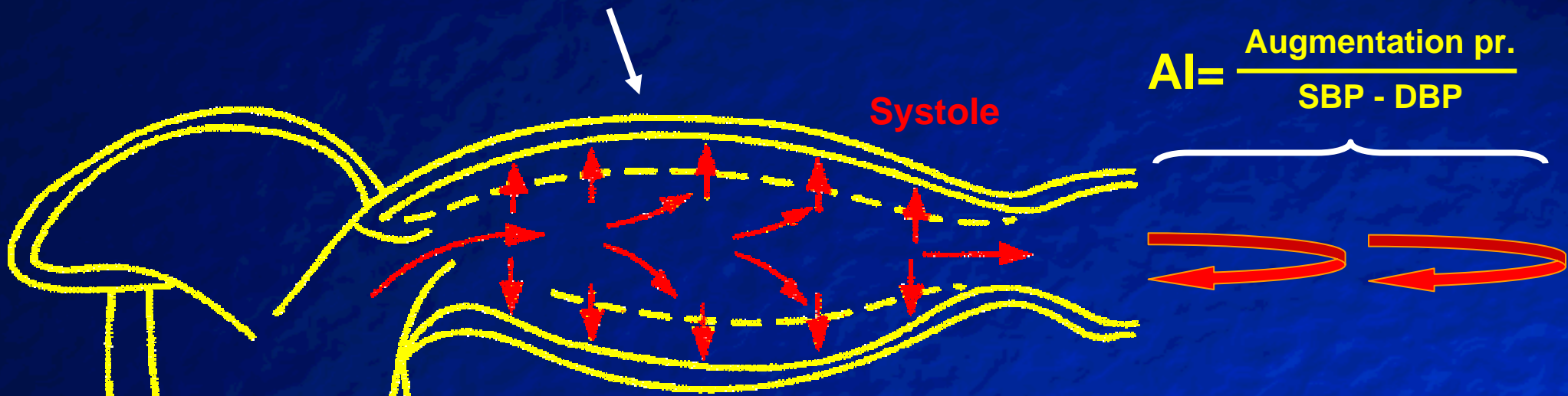


**Which one is better to estimate
vascular characteristics,**

**augmentation index
vs. pulse wave velocity ?**

Compliance, $\Delta D/\Delta P$ or $\Delta A/\Delta P$

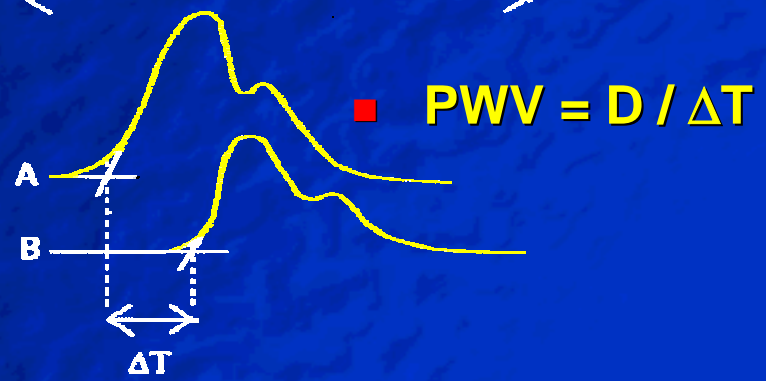
Augmentation index



vs. pulse wave velocity



L.V.



Difference of Local and Systemic Vascular Stiffness

Compliance, $\Delta D/\Delta P$ or $\Delta A/\Delta P$
; arterial stiffness at a site

Augmentation index, $\Delta\text{augmentation}/PP$
; systemic arterial stiffness

Pulse wave velocity, $PWV = D / \Delta T$
; arterial stiffness at a segment

 **Better marker of arterial stiffness?**

Conclusion

To order to estimate arterial stiffness, **systemic arterial stiffness** (eg. augmentation index), in addition to **one-site stiffness** (eg. compliance or β -index) or **one-segment stiffness** (eg. pulse wave velocity) would be the best.