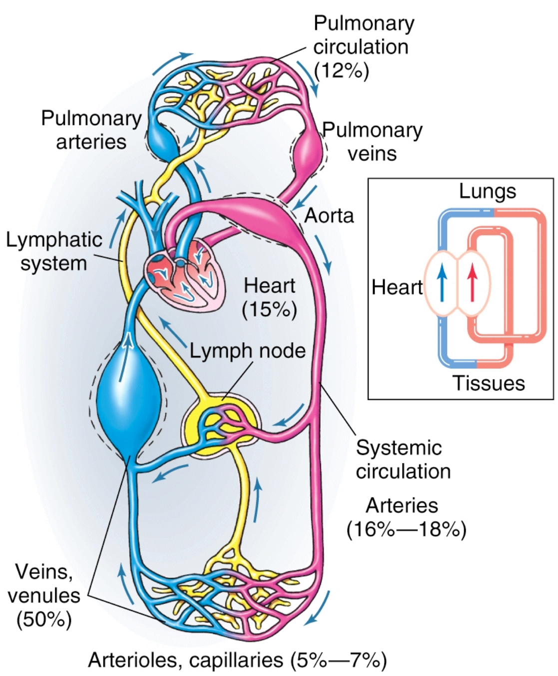
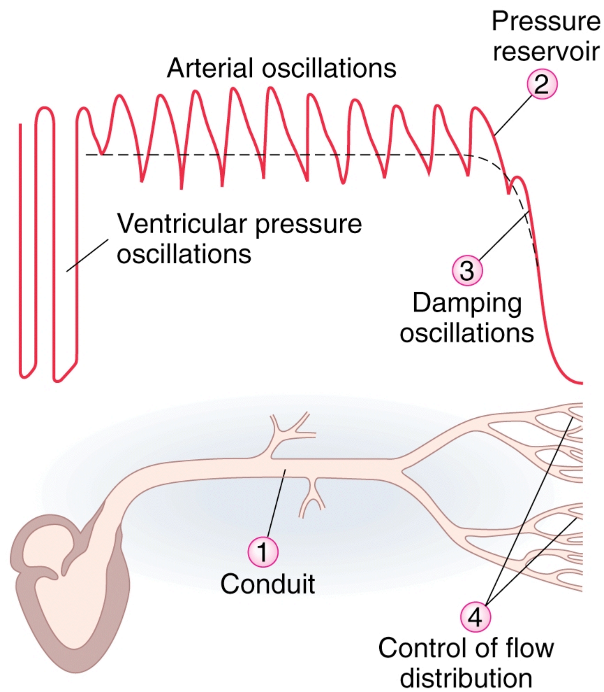
Arterial System
Lecture Block 10

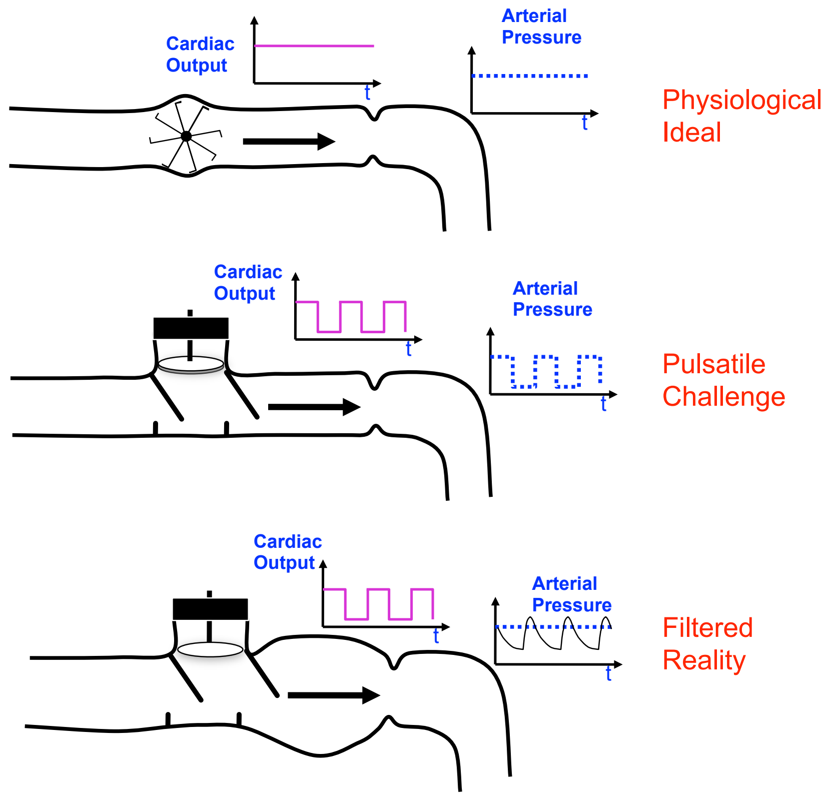
Functional Overview



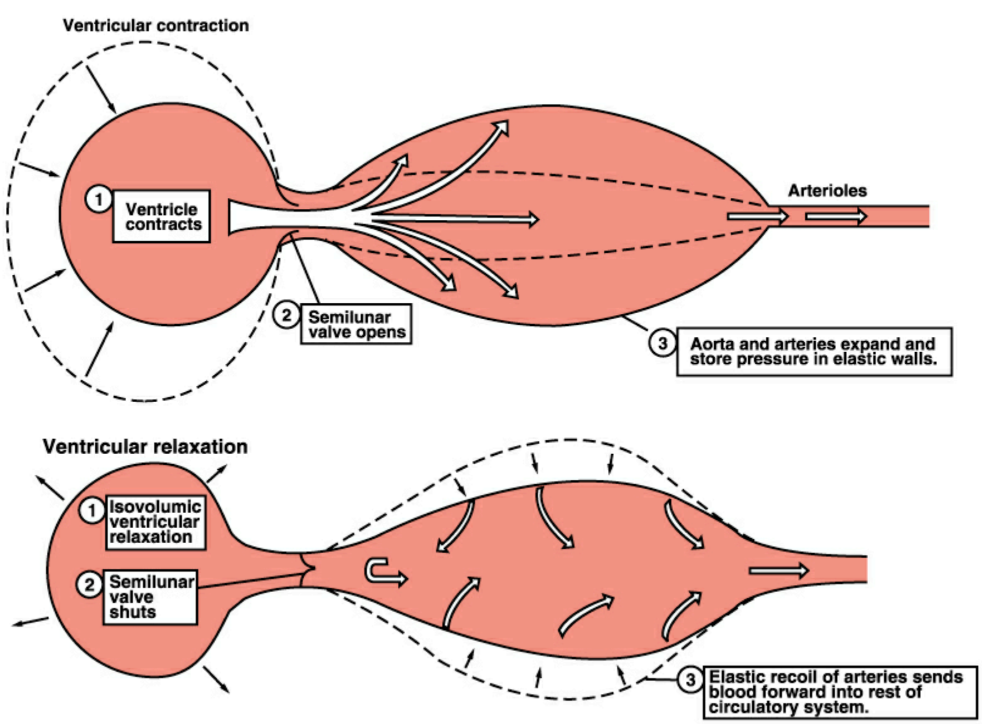


Atrial System as Hydraulic Filter

- Pulsatile --> smooth flow
- Cardiac energy conversion
- Reduces total cardiac work



Elastic Recoil in Arteries



Aortic Compliance

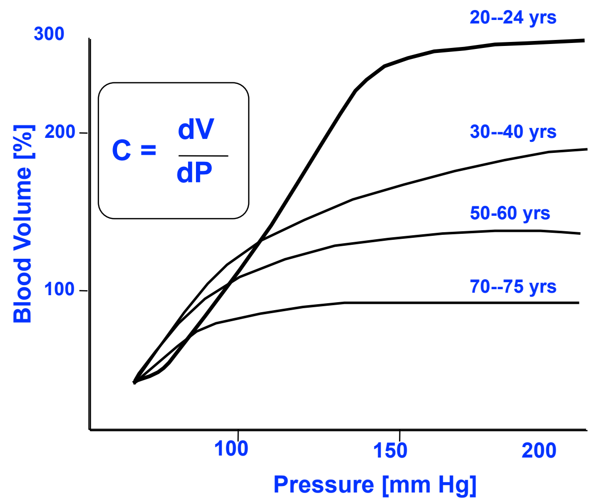
- Factors:
  - age
  - athersclerosis
- Effects
  - more pulsatile flow
  - more cardiac work
  - not hypertension

Laplace's Law
(thin-walled cylinder):
T = wall tension
P = pressure
r = radius

$$T = Pr$$

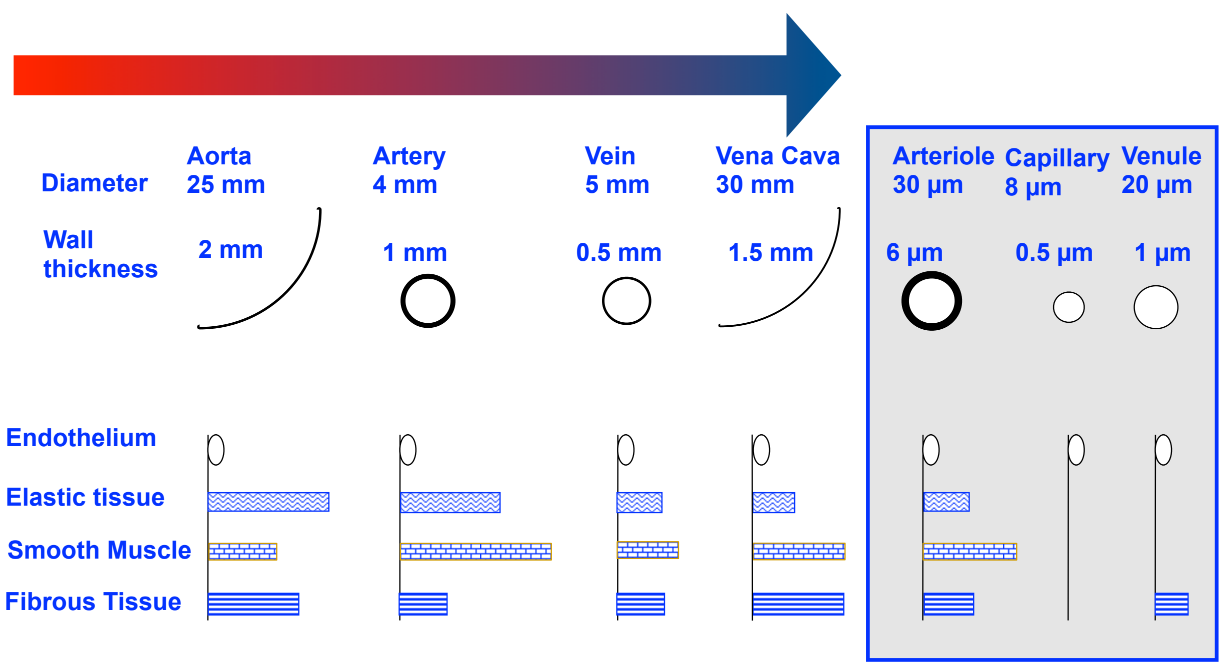
For thick wall cylinder
P = pressure
σ = wall stress
r = radius
w = wall thickness

$$\sigma = \frac{Pr}{w}$$



	Tension [dyne/cm]	Wall Stress [dyne/cm^2]
Aorta	2 x 10^5	10 x 10^5
Capillary	15-70	1.5 x 10^5

Vessel Structure



Human Aortic Measurements

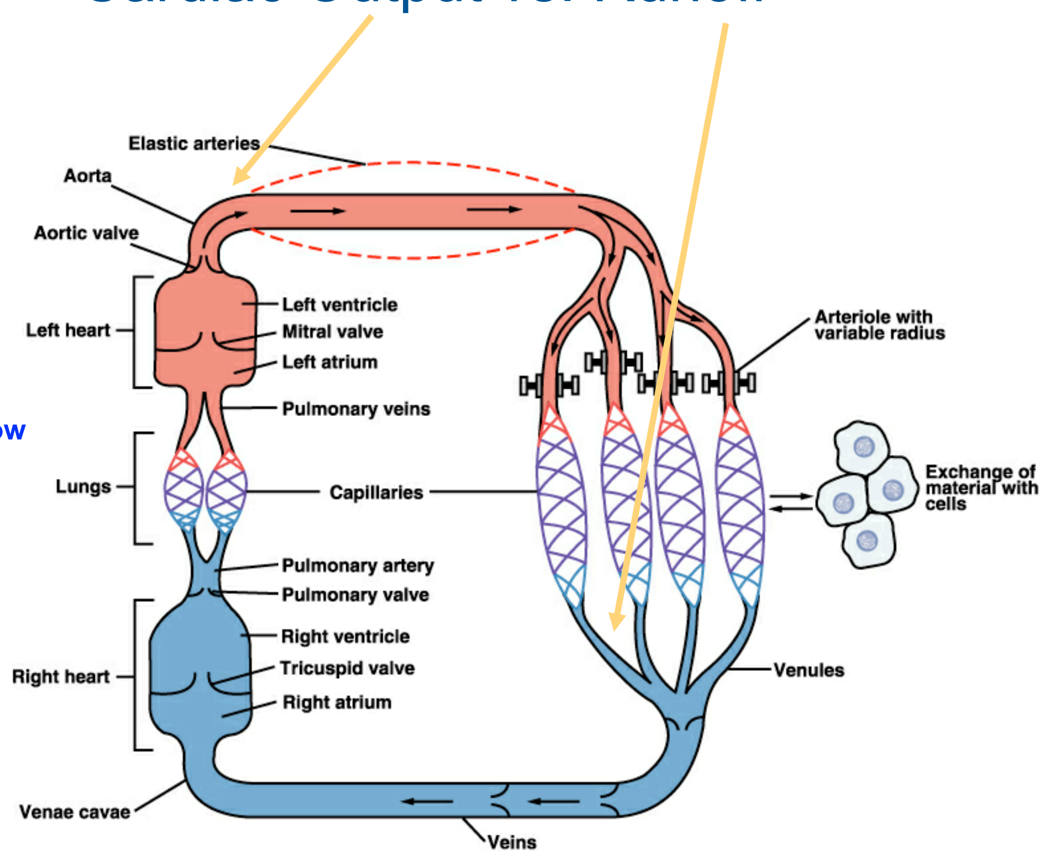
TABLE 3 Descriptive Statistics of Wall Thickness Measurements by Sex, Race, and Age

Patient Demographics	No. of Subjects	Average Wall Thickness (mm)		Maximal Wall Thickness (mm)	
		Mean (SE)	*p*	Mean (SE)	*p*
Sex			0.028		0.010
Men	98	2.32 (0.06)		3.85 (0.13)	
Women	98	2.11 (0.06)		3.31 (0.13)	
Race			0.061		0.023
Black	99	2.15 (0.05)		3.74 (0.10)	
White	97	2.27 (0.05)		3.42 (0.10)	
Age range (yr)			< 0.001		0.002
45–54	66	2.03 (0.05)		3.33 (0.12)	
55–64	52	2.18 (0.06)		3.61 (0.13)	
65–74	39	2.26 (0.07)		3.56 (0.15)	
74–84	39	2.51 (0.07)		3.98 (0.16)	

Li et al. AJR 2004;182:593–597

Cardiac Output vs. Runoff

Arterial Pressure/Flow



Basic Pressure Equations

Mean arterial pressure:

$$\bar{P}_a = \frac{\int_{t_1}^{t_2} P_a \, dt}{t_2 - t_1}$$

which we can ***approximate*** as

$$\bar{P}_a = P_d + 1/3(P_s - P_d)$$

with P_s = systolic pressure
P_d = diastolic pressure

Total peripheral resistance is

$$R_p = (\bar{P}_a - \bar{P}_{ra})/\bar{Q}_r$$

with P_a = mean arterial pressure
P_{ra} = right atrial pressure
Q_r = runoff flow into veins (=Q_h at equilibrium)

If we assume P_{ra}=0

$$\bar{P}_a = R_p \bar{Q}_r$$

Time Course of Arterial Flow

We can estimate change in arterial volume as:

Cardiac output — Runoff flow

Arterial volume change →

$$\frac{d\bar{V}_a}{dt} = Q_h - Q_r \qquad (1)$$

Arterial compliance we define as

$$C_a = d\bar{V}_a / d\bar{P}_a \qquad (2)$$

Which we differentiate w.r.t time to get

$$\frac{d\bar{V}_a}{dt} = \bar{Q}_a = C_a \frac{d\bar{P}_a}{dt} \qquad (3)$$

Substituting (1) into (3), we get

$$Q_h - Q_r = C_a \frac{d\bar{P}_a}{dt} \qquad (4)$$

or

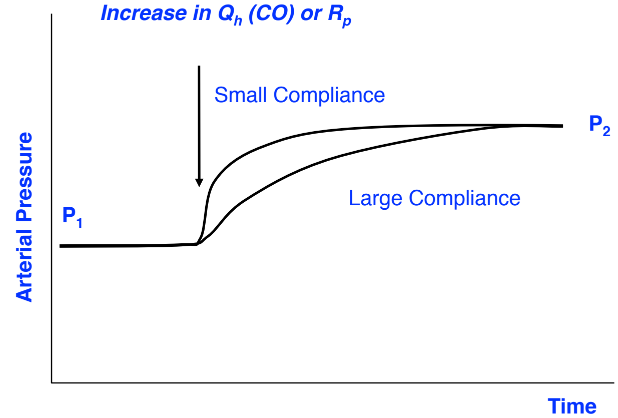
$$\frac{d\bar{P}_a}{dt} = \frac{Q_h - Q_r}{C_a} \qquad (5)$$

Arterial Pressure Response to Cardiac Output

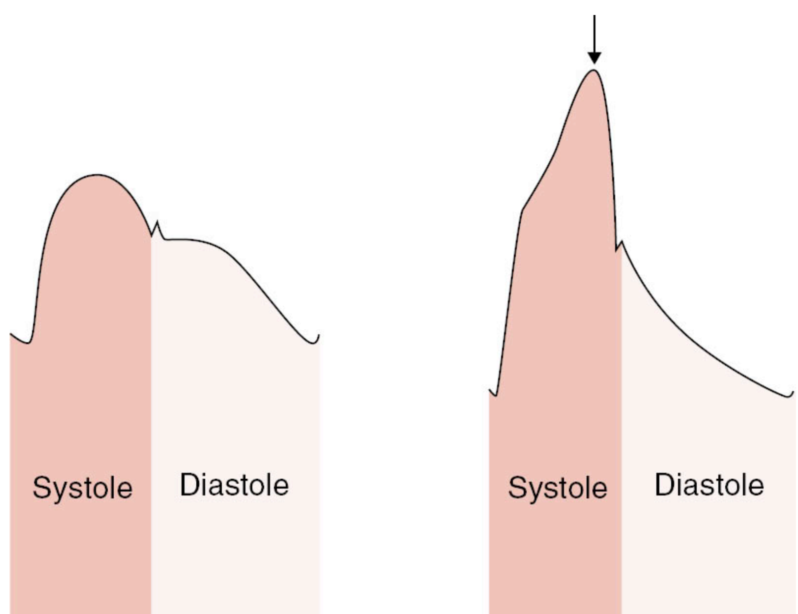
- Stable pressure determined by flow and peripheral resistance
- Increase in CO or R_p both increase pressure
- Pressure always changes to force CO to equal runoff flow
- Compliance affects rate but not final values

$$\bar{P}_a = R_p \bar{Q}_r$$

$$\frac{d\bar{P}_a}{dt} = \frac{Q_h - Q_r}{C_a}$$

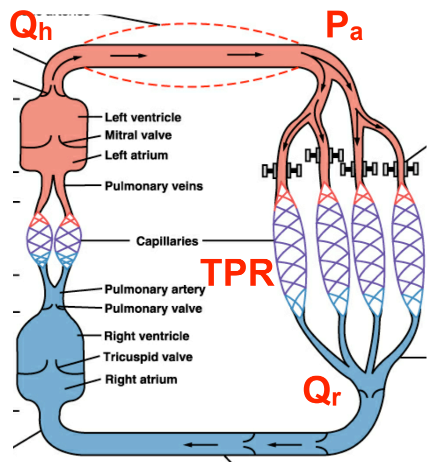


Pressure and Age (Compliance)



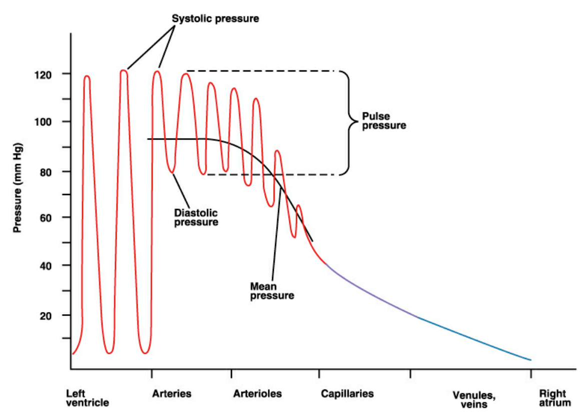
Arterial Pressure Response Mechanisms

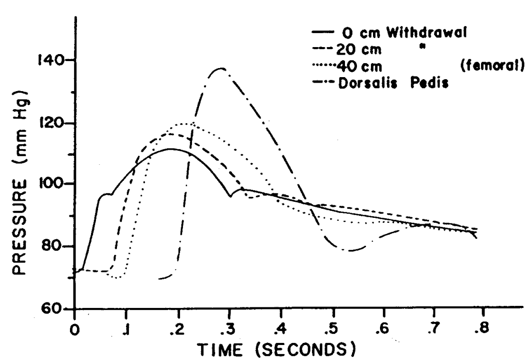
Stimulus	Transient	Steady State
↑ Heart Rate (CO) →	↑Q_h → ↑P_a → ↑Q_r →	↑ Arterial Pressure
↑ Total Periph. Resist. →	↓ Q_r → ↑P_a → ↑ Q_r →	↑ Arterial Pressure
↑ Stroke Volume +	↓ Heart Rate (@ Constant CO) →	= Arterial Pressure
↓ Compliance →	↑dP_a/dt →	= Arterial Pressure ↑ Pulse Pressure Amplitude



Peripheral Pulse Pressure

- Pressure wave velocity
  - $v_p = k/C$
  - v_p increases along the arteries and with age
- Pressure wave pulse amplitude grows with distance from heart
  - reflection/superposition
  - decrease in C
  - dispersion



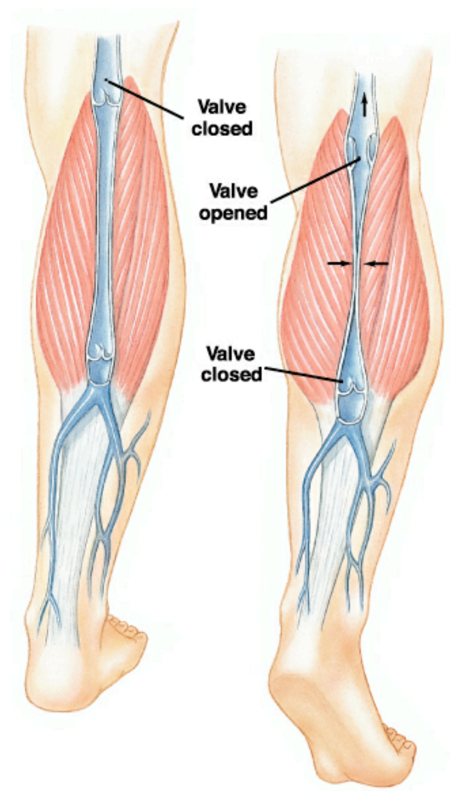


Venous System

- Venous volume
  - Large volume, low pressure system
  - Reservoir of blood (50% of total volume)
  - Blood loss covered by venous system
    - Vasoconstriction, drinking (blood doning)
- Venous flow
  - Skeletal muscle activity
  - Valves
  - Breathing
  - Paristaltic contractions in venules

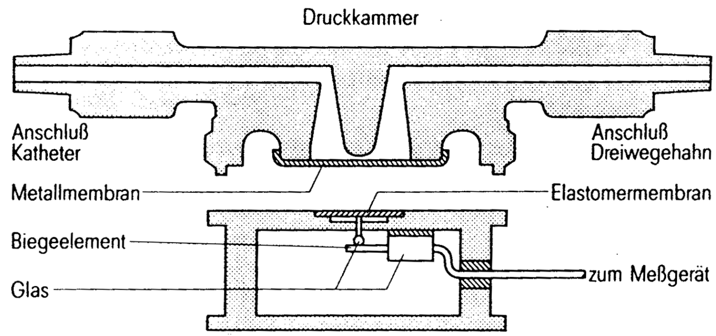
Venous Valves

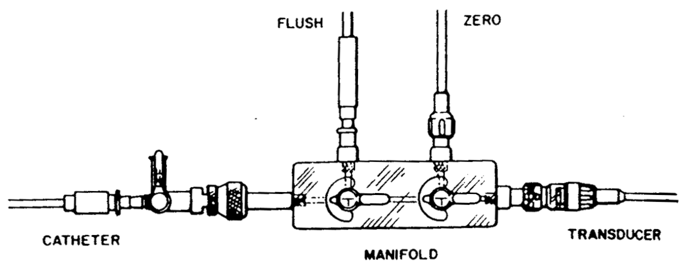
- Muscle pump
- Unidirectional flow
- Vericose veins



Measuring Blood Pressure: Catheters

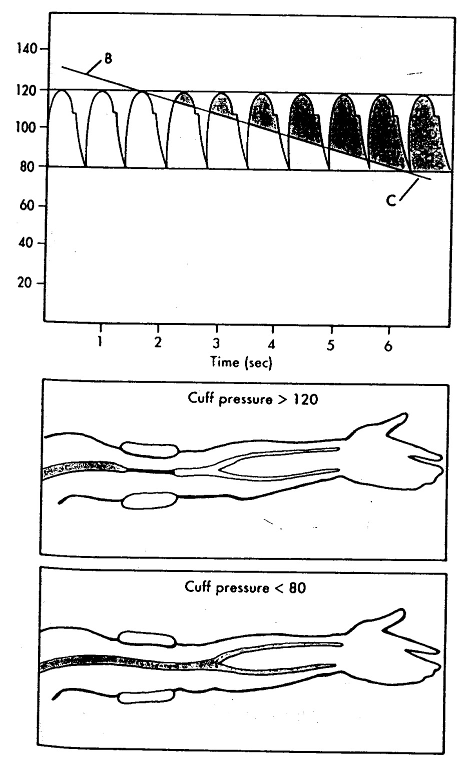
- Liquid column and external manometer
  - frequency response of transducer and fluid column
  - calibration and zeroing
  - motion artifacts
- Manometer-tipped catheters
  - higher frequency response
  - less motion artifact



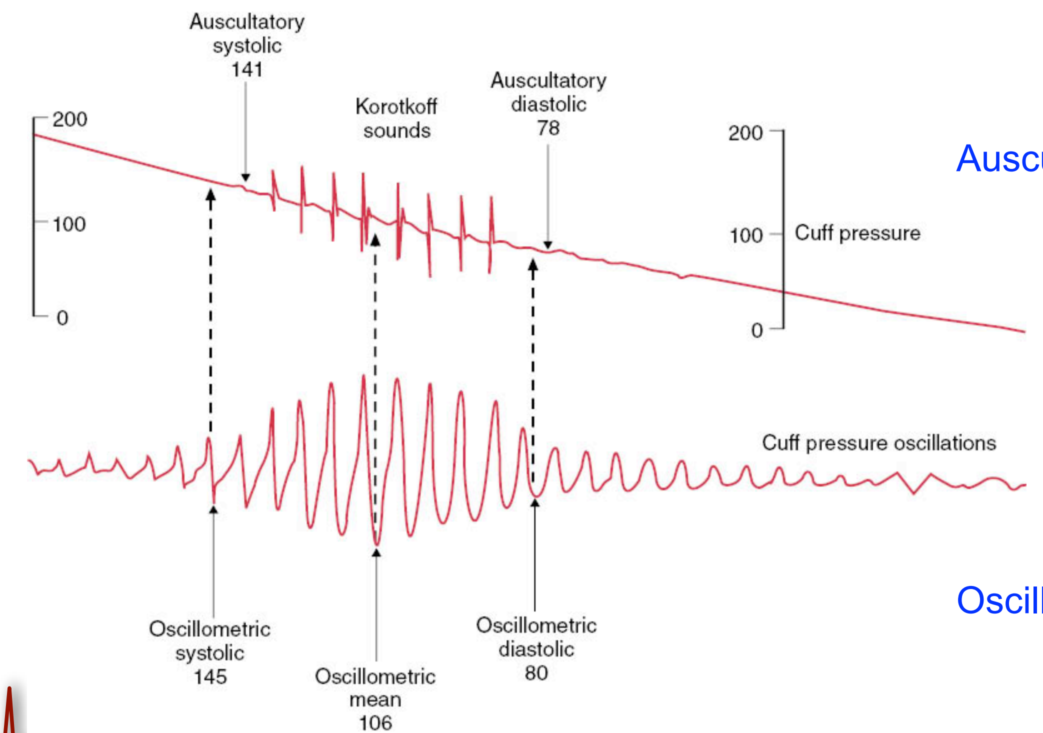


Auscultatory Blood Pressure Method

- Effect of arm position
- Alternate measurement locations (leg)
- Pressure varies during the day (lowest during sleep)
- Psychological bias in measurements (in subject and operator)



Automated Pressure Measurement



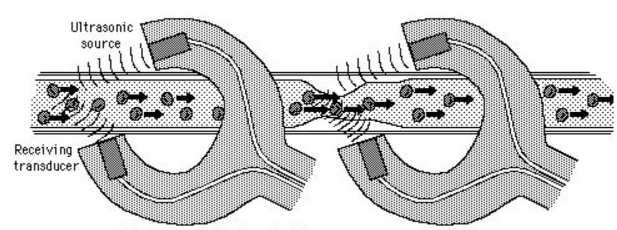
Ausculatory

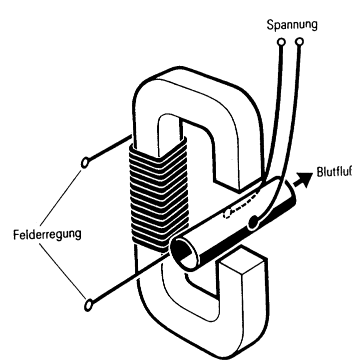
Oscillometric

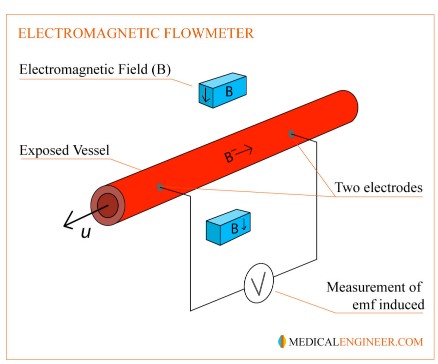
(From Geddes LA: Cardiovascular Devices and Their Applications. New York, John Wiley, 1984, Fig. 34-2. Reprinted by permission of John Wiley & Sons, Inc.)

Measuring Blood Flow

- Ultrasound flowmeter (velocity)
- Electromagnetic flowmeter (velocity)
- Thermal dilution
- Functional MRI (diffusion or oxygenation)







Measuring Blood Flow II

- Bioelectric impedance (plethysmography)
- Light (pulse oxymetry)