

CUFF VS. CATHETER: UNDERSTANDING THE DIFFERENCES IN BLOOD PRESSURE MEASUREMENTS

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Topics:

- **Origin of blood pressure**
- **Effects of measurement location**
- **Indirect measures of blood pressure**
 - **Auscultatory**
 - **Oscillometric**
- **Direct measures of blood pressure**
 - **Effects of tubing, stopcocks, air bubbles**
- **Why the differences**

Blood pressure measurement

“The measurement of blood pressure is the clinical procedure of greatest importance that is performed in the sloppiest manner.”

Kaplan N. M. Amer J Hypertension 1998: 11: 134-6

Hypertension Research (2023) 46:1961–1969
<https://doi.org/10.1038/s41440-023-01311-0>

ARTICLE

Accuracy of cuff blood pressure and systolic blood pressure amplification

Korotkoff sound versus oscillometric cuff sphygmomanometers: comparison between auscultatory and DynaPulse blood pressure measurements

Blood pressure measurement: an evaluation of direct and indirect methods

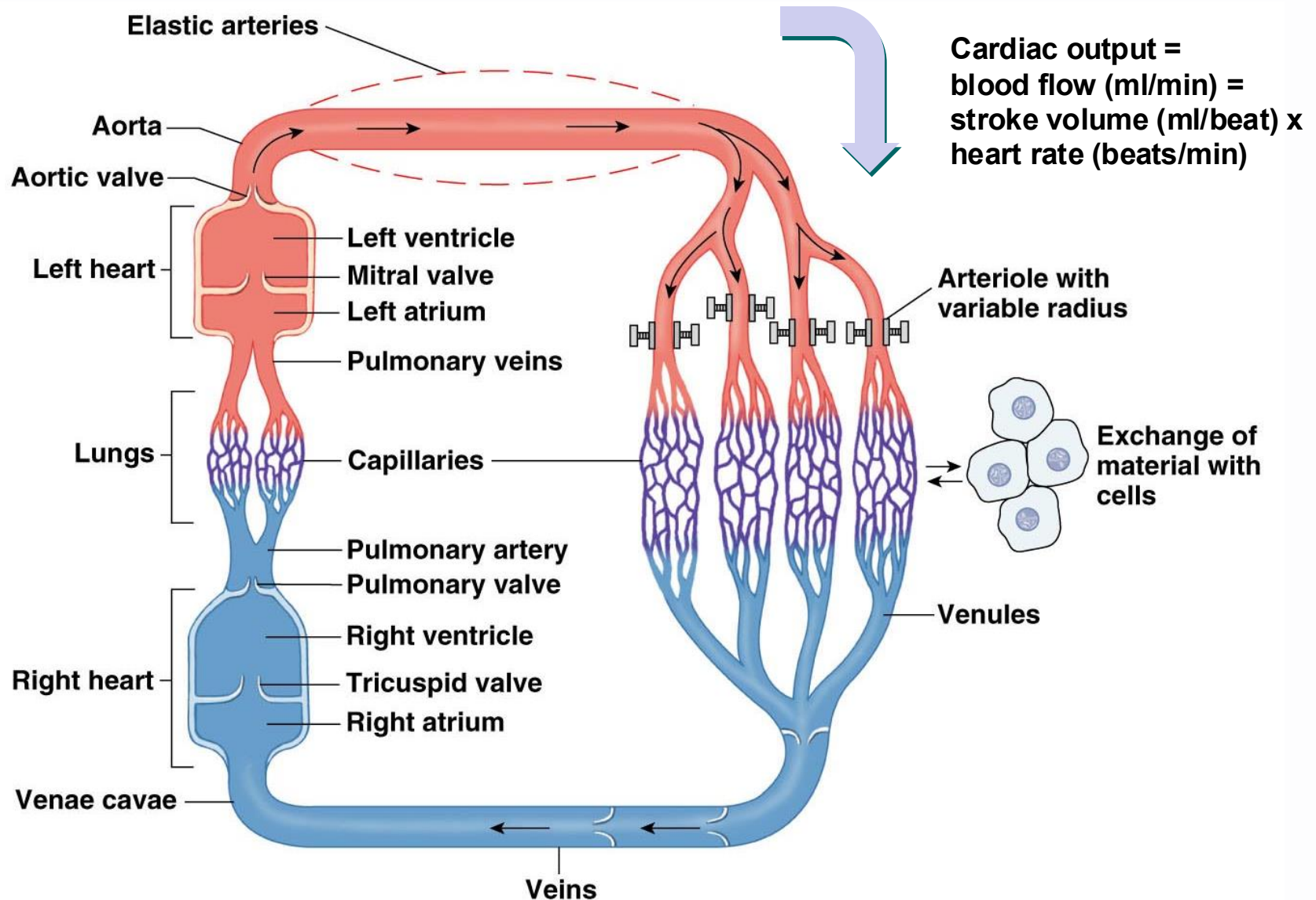
“The bias between invasive and noninvasive ABP measures can be relevant and misleading in the therapeutic management.”

E. Franchi, et al., Critical Care 2012: 16: P212

ACCURACY OF FOUR INDIRECT METHODS OF BLOOD PRESSURE MEASUREMENT, WITH HEMODYNAMIC CORRELATIONS

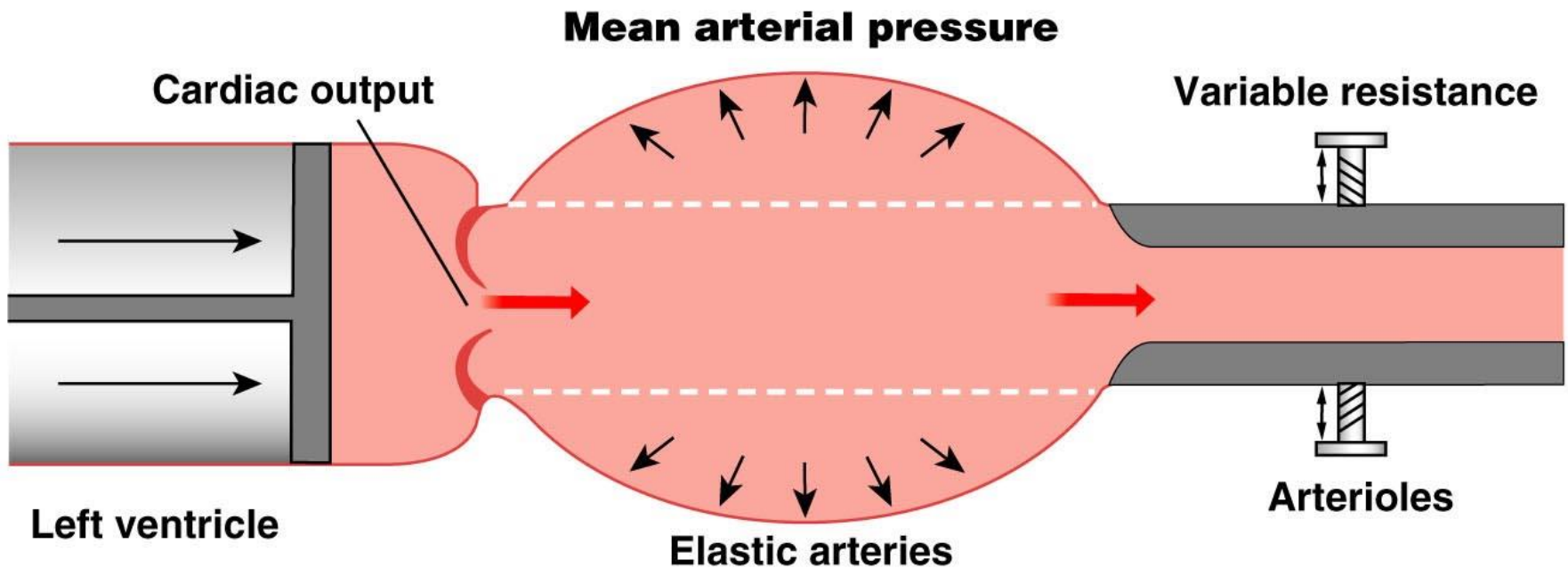
*Glenn P. Gravlee, MD,
and Joni K. Brockschmidt, MS*

Model of the cardiovascular system and the origin of arterial blood pressure



Blood Pressure

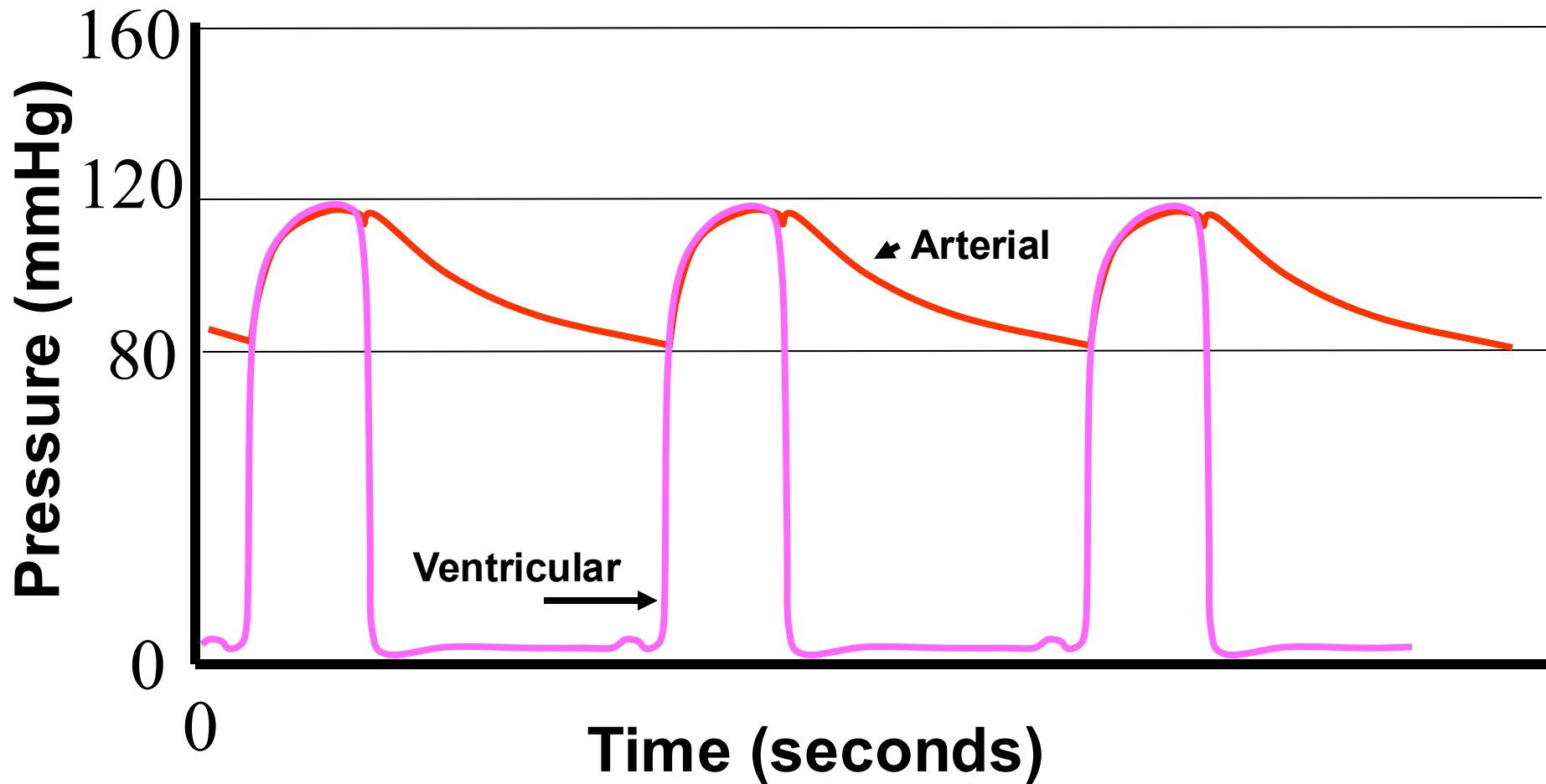
Mean arterial pressure is a function of cardiac output and resistance in the arterioles



Mean arterial pressure \propto cardiac output \times resistance

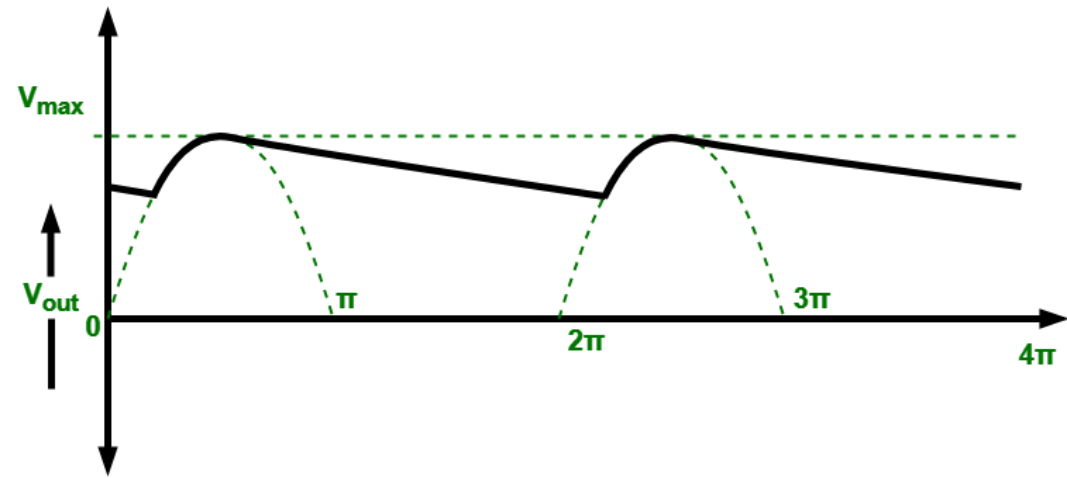
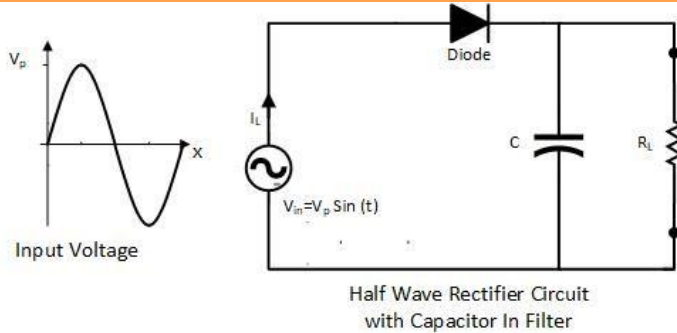
This is analogous to Ohm's Law: $V = I \times R$

Arterial and left ventricular blood pressure

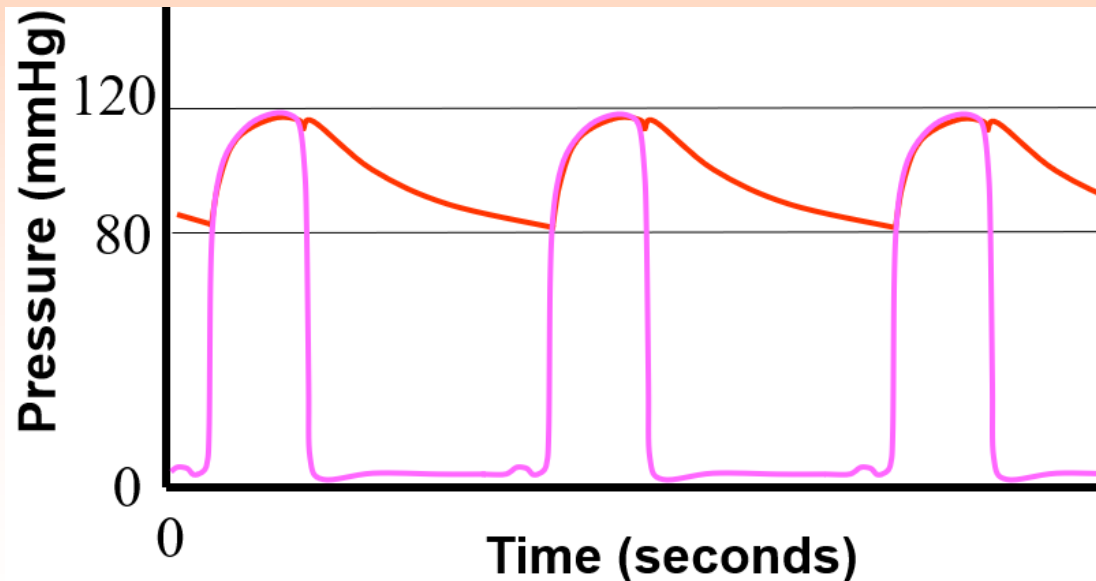


Right ventricular waveforms are similar in shape, just having lower pressures.

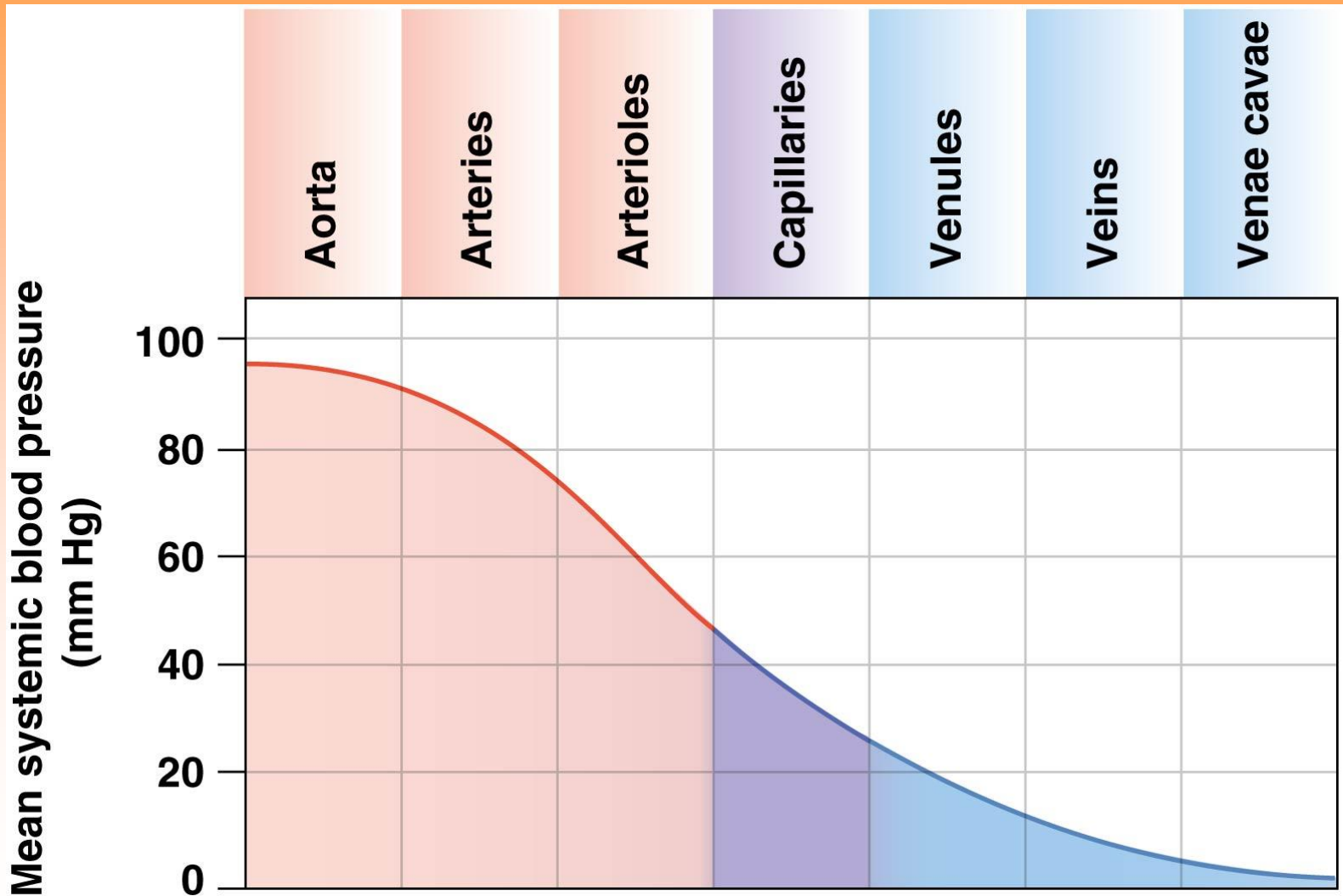
Aortic compliance



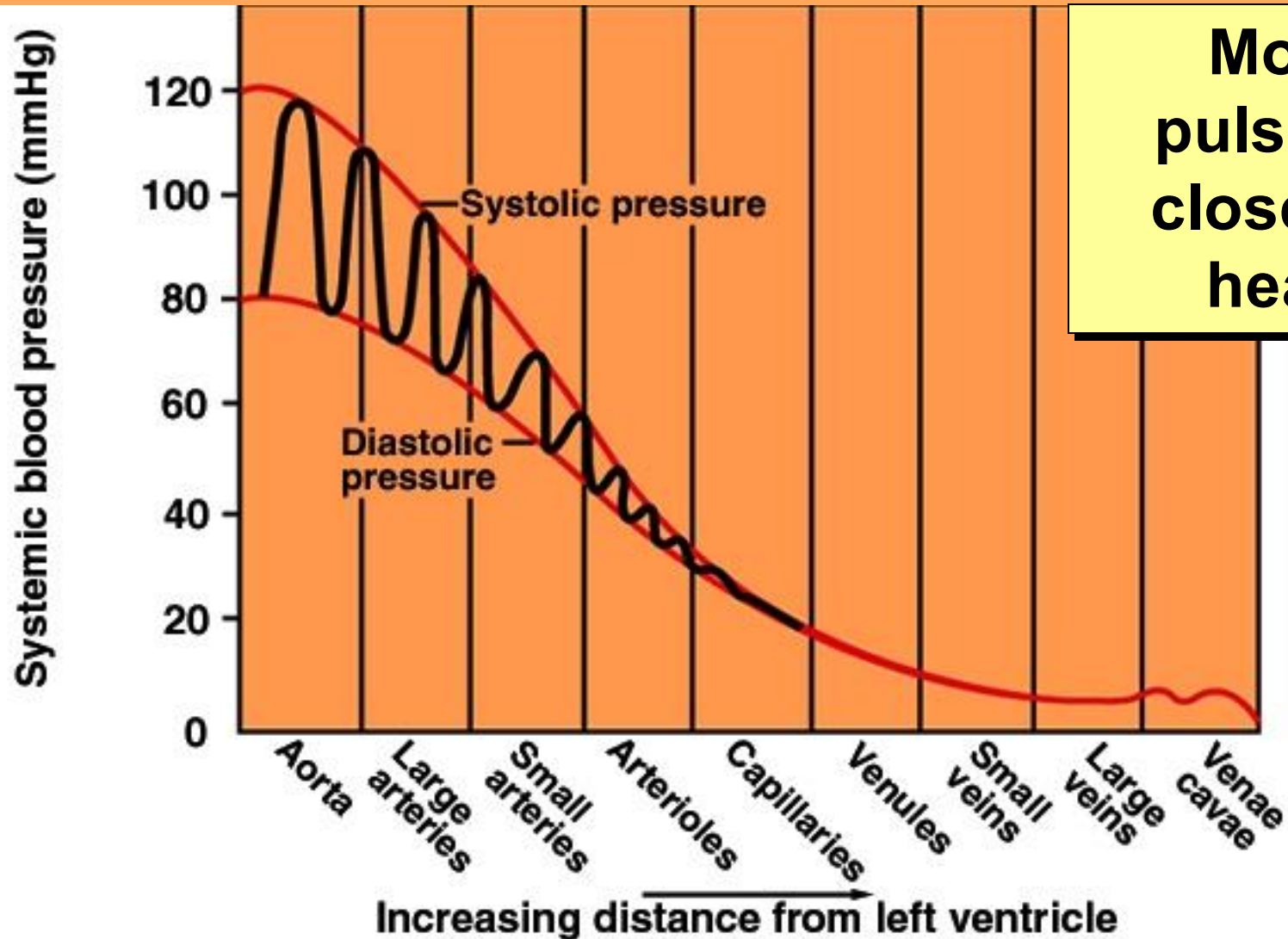
Is analogous to the filter capacitor in a power supply. The elastic nature of the aorta behaves like a hydraulic capacitor, 'filtering' the pulsatile ventricular pressure.



Blood Flows Down a Pressure Gradient

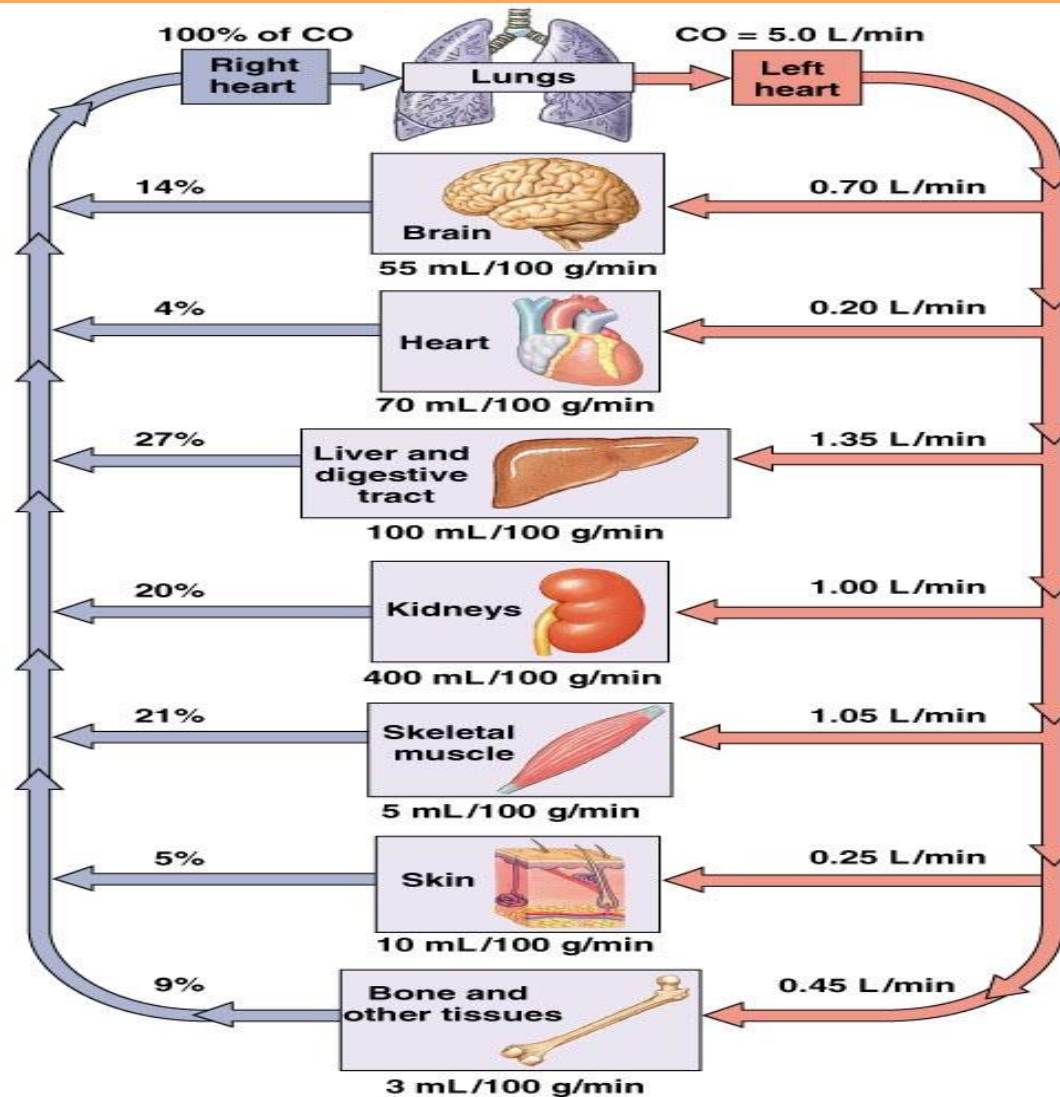


Blood Pressure Changes With Distance

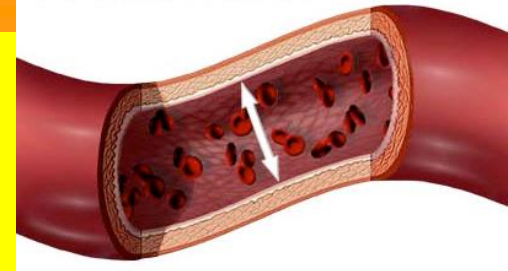


More
pulsatile
closer to
heart

Distribution of blood flow throughout the body – produced by blood pressure



Blood pressure:

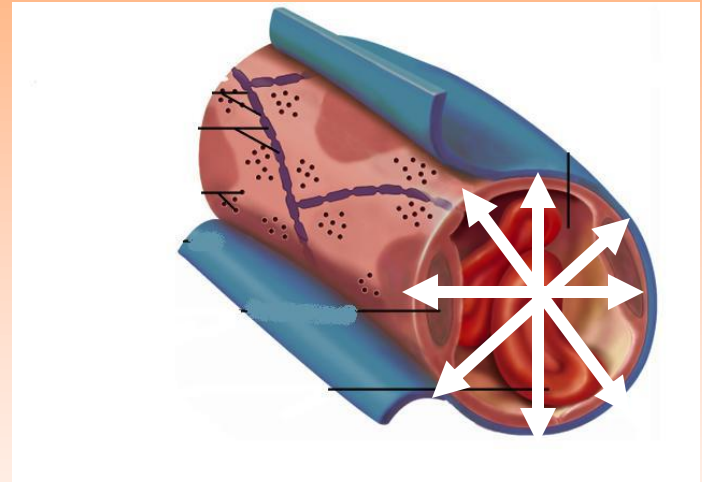


- The pressure that blood exerts across the blood vessel wall

Pressure, P, is defined as force, F, per unit area, A:

$$\mathbf{P = F / A}$$

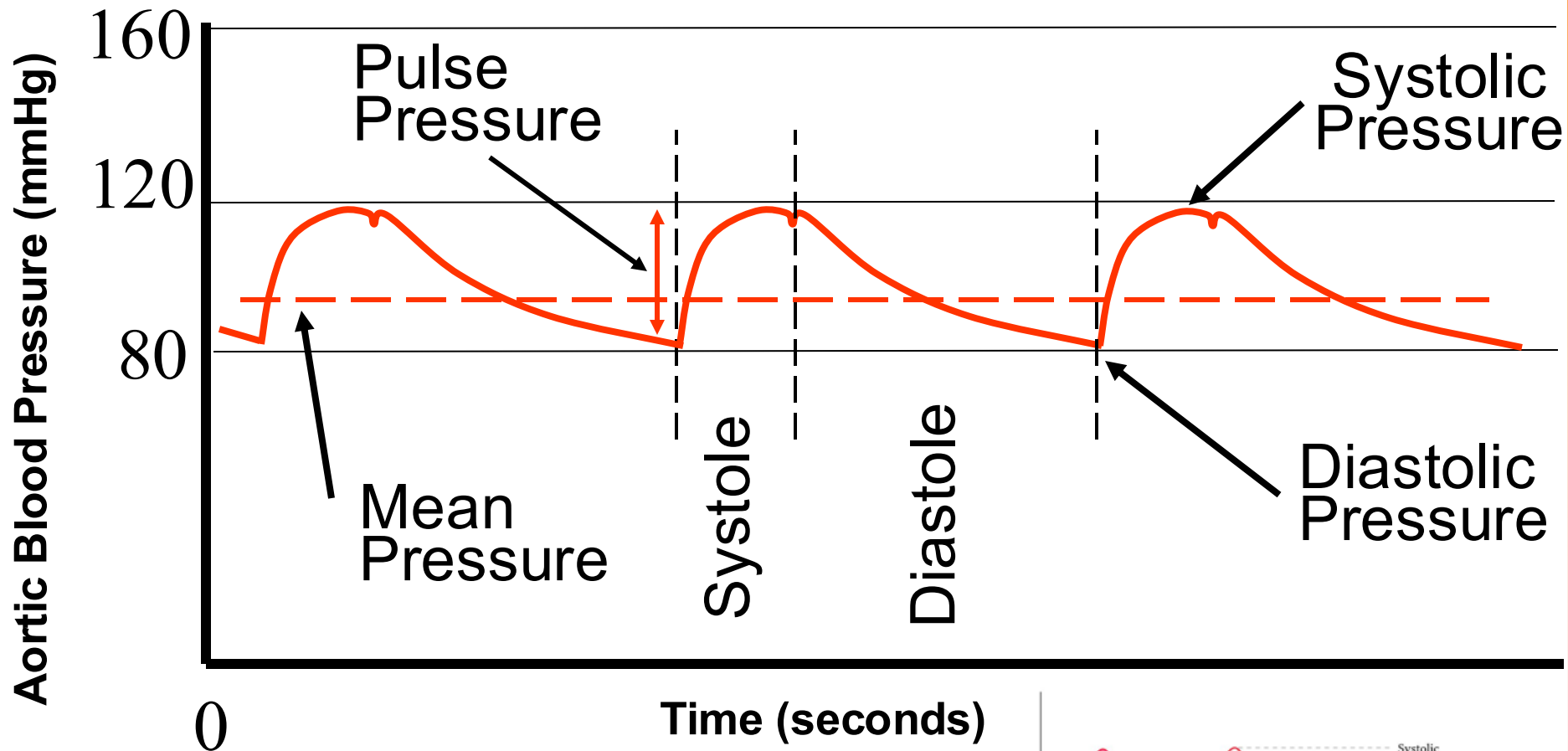
Pressure can also be stated in terms of the force exerted by a column of fluid.



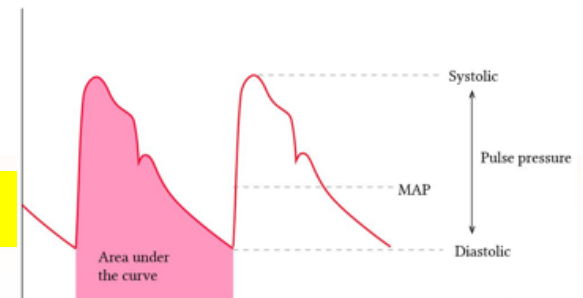
Example:

$$100 \text{ mmHg} = 53.53 \text{ in H}_2\text{O} = 1.93 \text{ psi} = 13.33 \text{ kPa}$$

The Arterial Pressure Wave

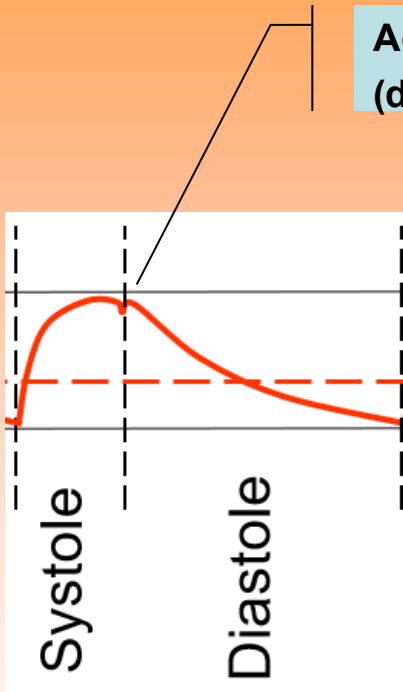


$MAP \approx \text{Diastolic Pressure} + \frac{1}{3}(\text{Pulse Pressure})$



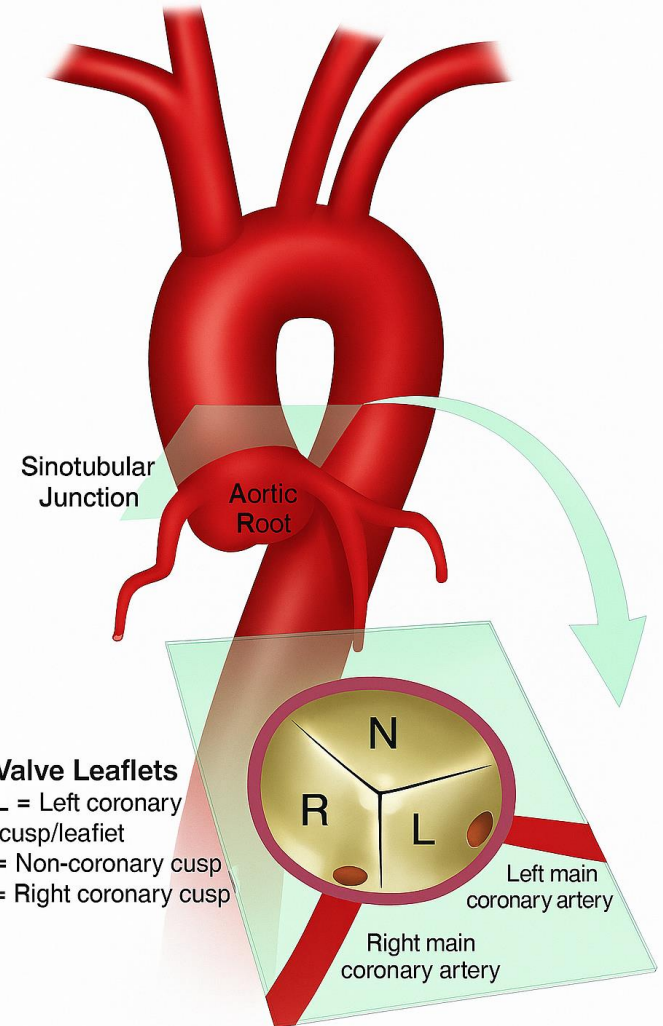
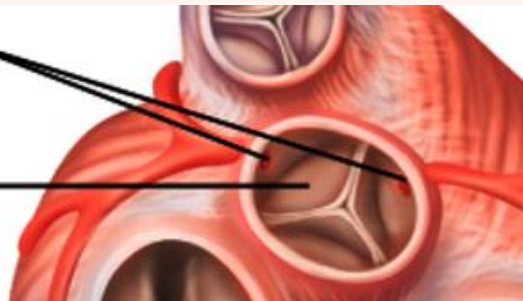
Coronary artery perfusion occurs during diastole

Aortic valve closes here (dicrotic notch)

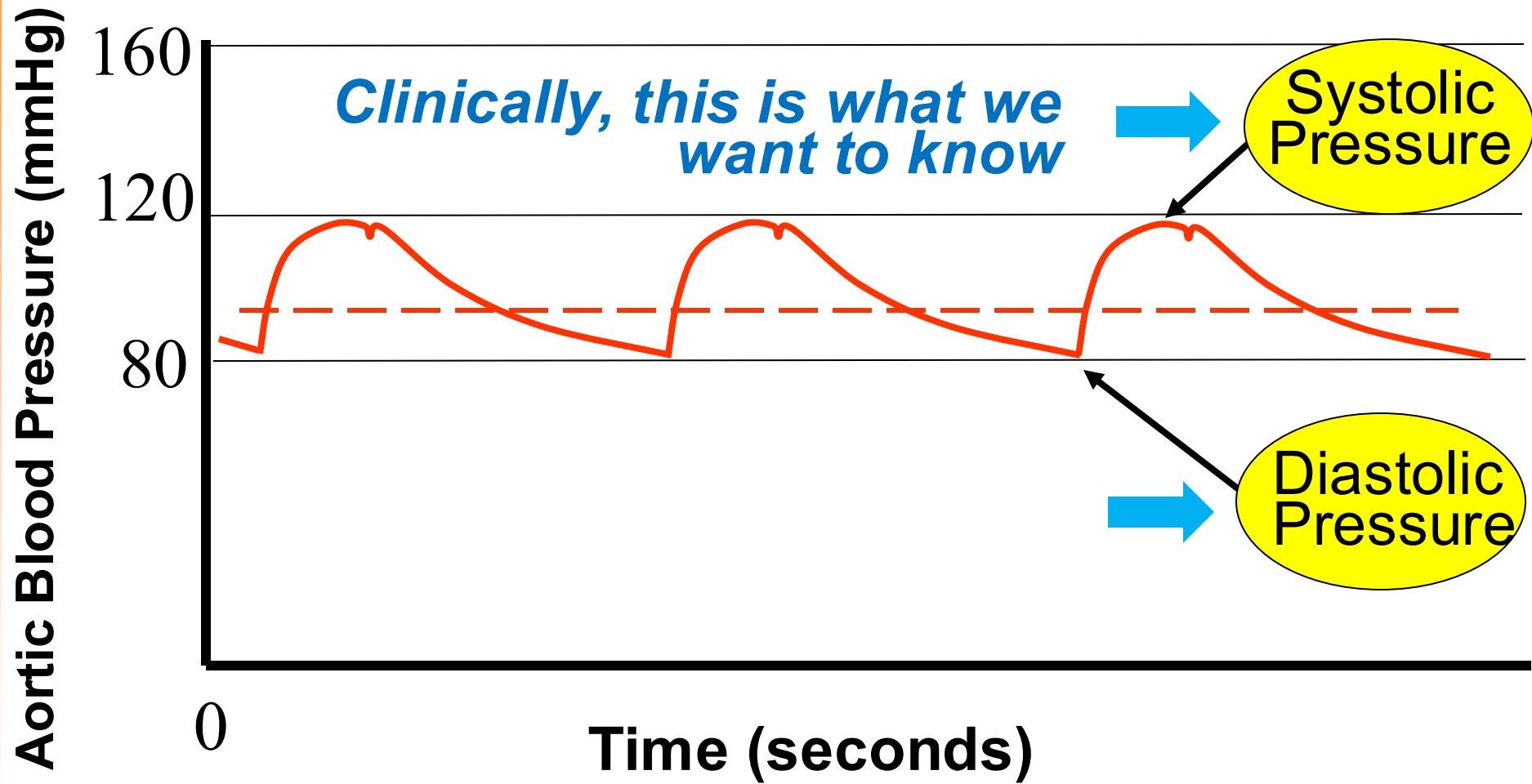


Openings to coronary arteries

Aortic semilunar valve



The Arterial Pressure Wave



What Blood Pressure Tells Us . . .

Systolic Pressure:

- Peak arterial pressure during ventricular systole (heart contraction)
- Reflects cardiac output (flow), arterial stiffness, and force of blood ejection
- Elevated values are a strong predictor of stroke, myocardial infarction, and heart failure
- Is more sensitive to aortic stiffness

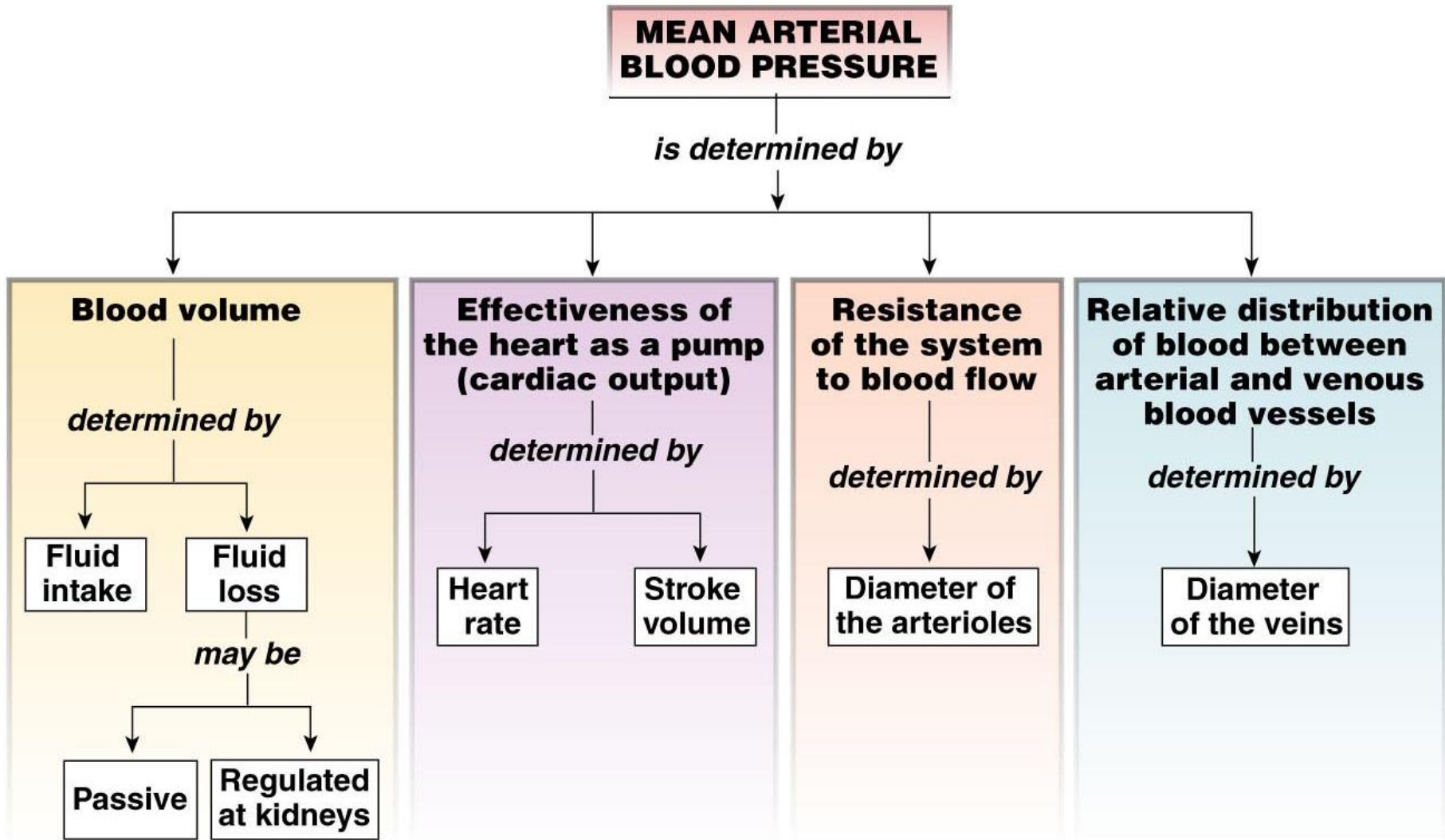
Diastolic Pressure:

- Lowest arterial pressure during ventricular diastole (heart relaxation)
- Reflects peripheral arterial resistance and is critical for coronary perfusion

Mean Arterial Pressure:

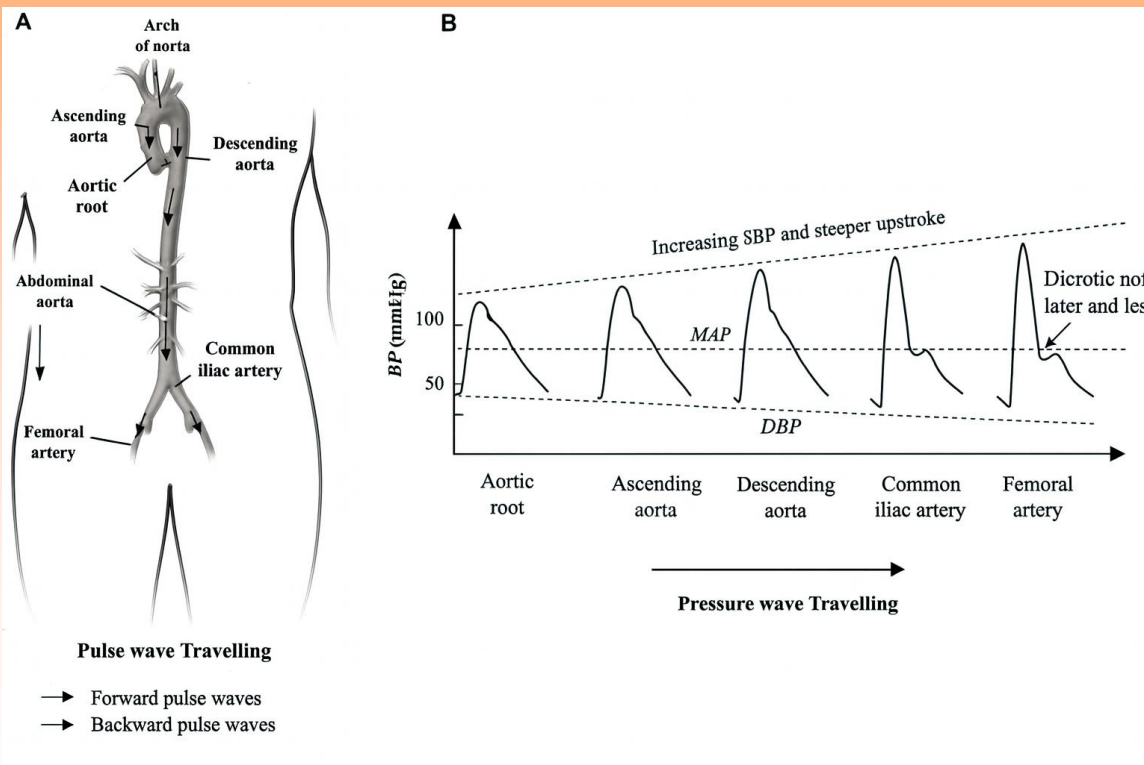
- Average pressure over one cardiac cycle
- Represents driving pressure for systemic organ perfusion
- Target parameter for management of shock, vasoactive drug titration
- Less beat-to-beat variation than systolic and diastolic pressures

Factors that Influence Mean Arterial Pressure



Pulse wave amplification . . .

is the phenomenon in which the arterial pulse pressure increases as the pressure wave travels from the central (aortic) arteries to the peripheral arteries, even though the mean arterial pressure remains nearly constant.

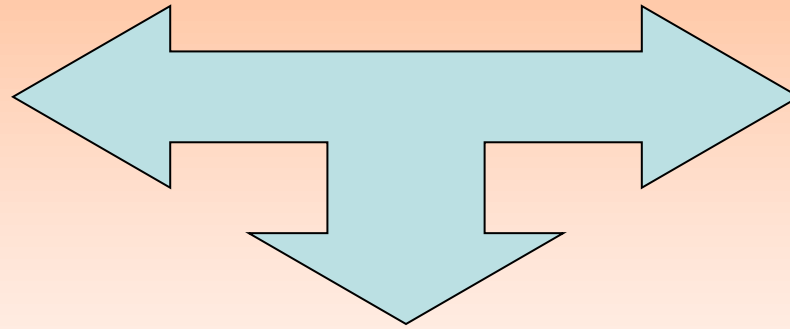


- Non-invasive (cuff) measurements may overestimate central aortic pressure
- Oscillometric systolic measurements in young individuals may be artificially elevated
- Mean arterial pressure not significantly affected.

It is also loosely analogous to the formation of standing waves in electrical transmission lines.

***Indirect* Methods of Blood Pressure Measurement**

Oscillometric

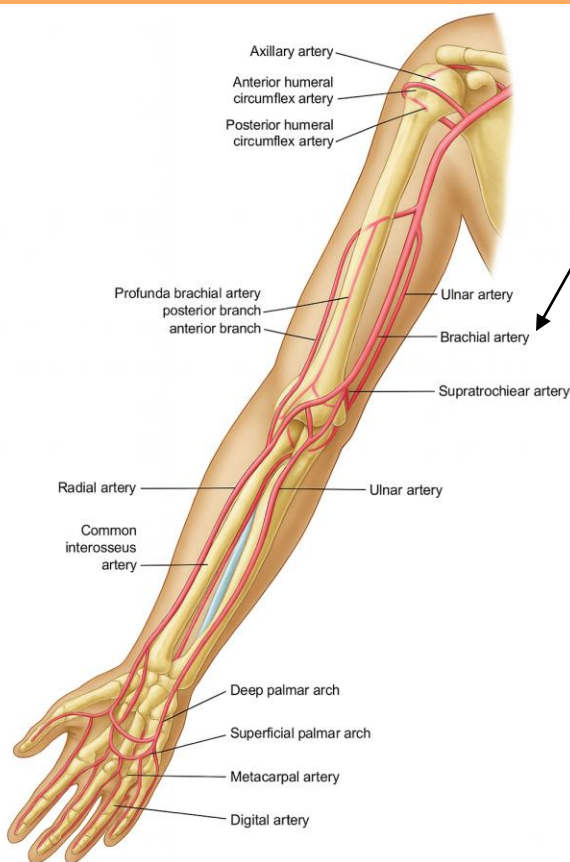


Auscultatory



Sphygmomanometry

Indirect measurement = non-invasive measurement

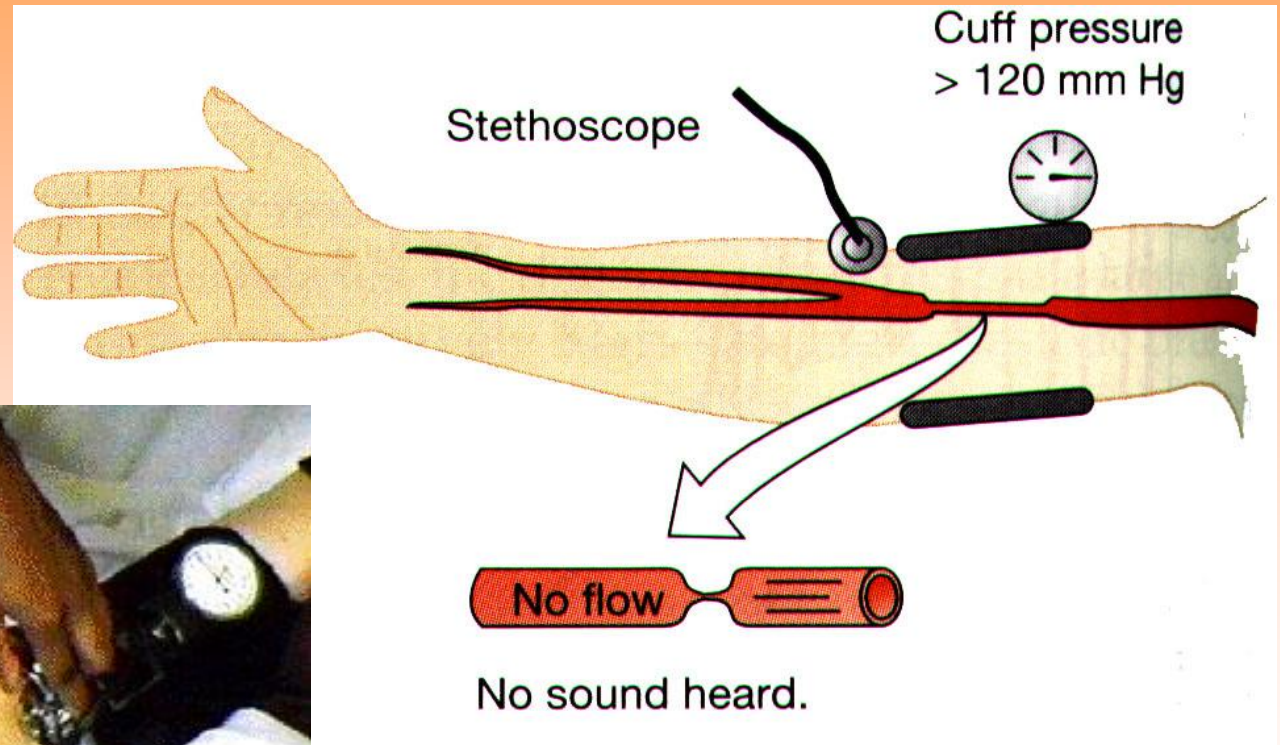


- **Brachial artery is the most common measurement site**
 - Close to heart
 - Convenient measurement
- **Other sites are e.g.:**
 - forearm / radial artery
 - wrist (tends to give much higher SP)

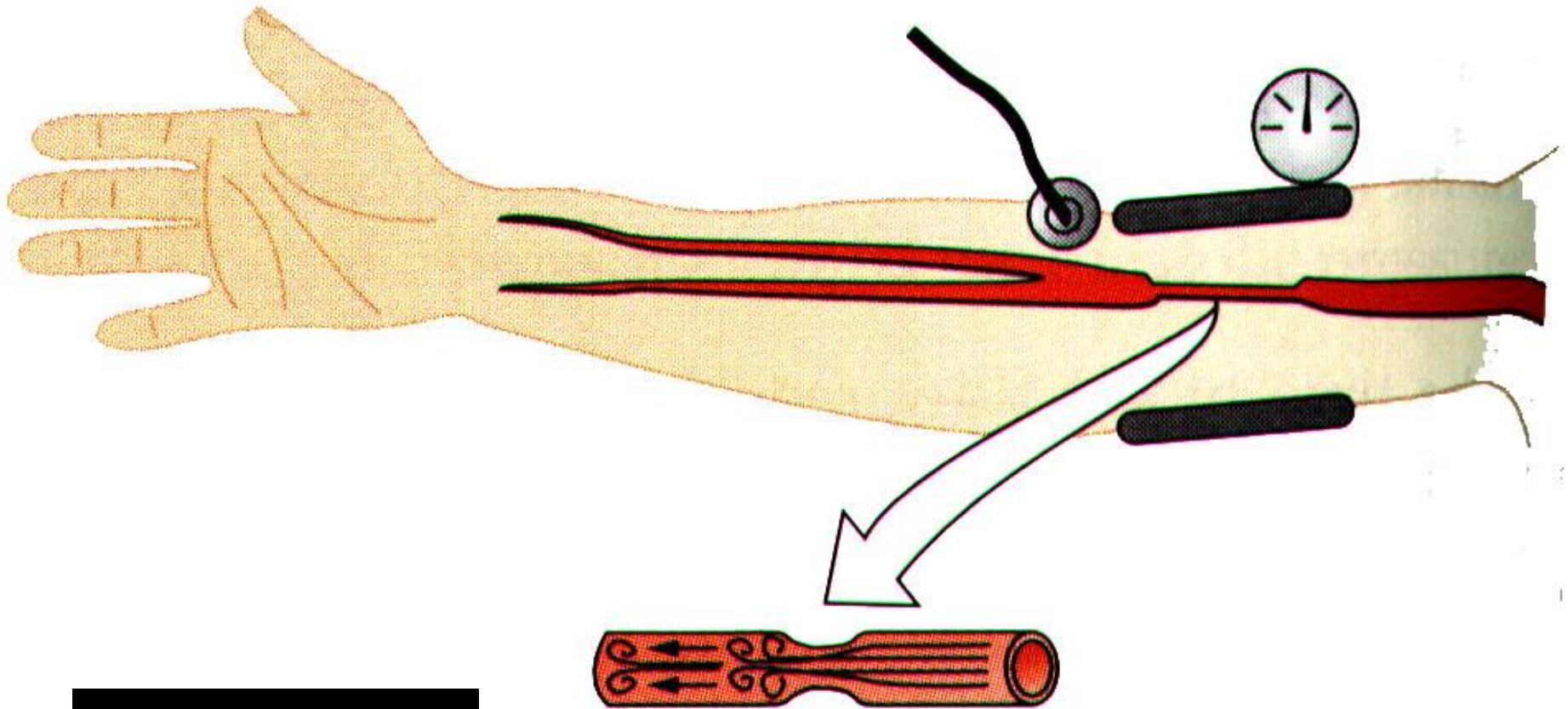
The most common indirect methods are *auscultation* and *oscillometry*

Principles of Sphygmomanometry

1. Cuff inflated until brachial artery compressed and blood flow stopped



2. Cuff pressure is slowly released

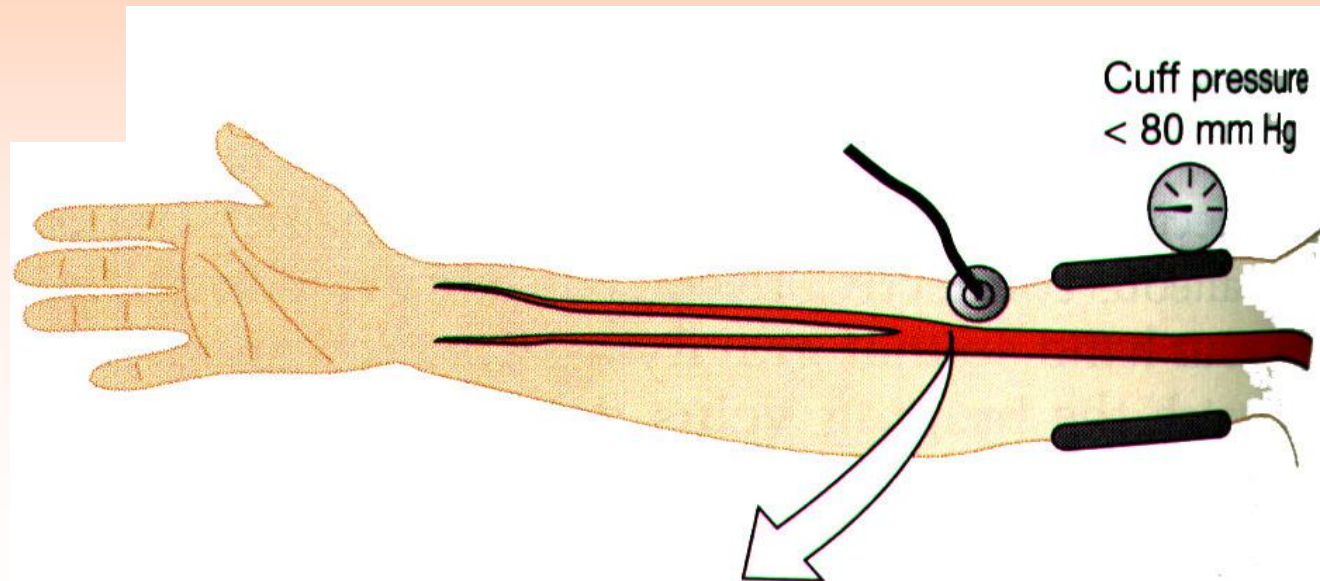


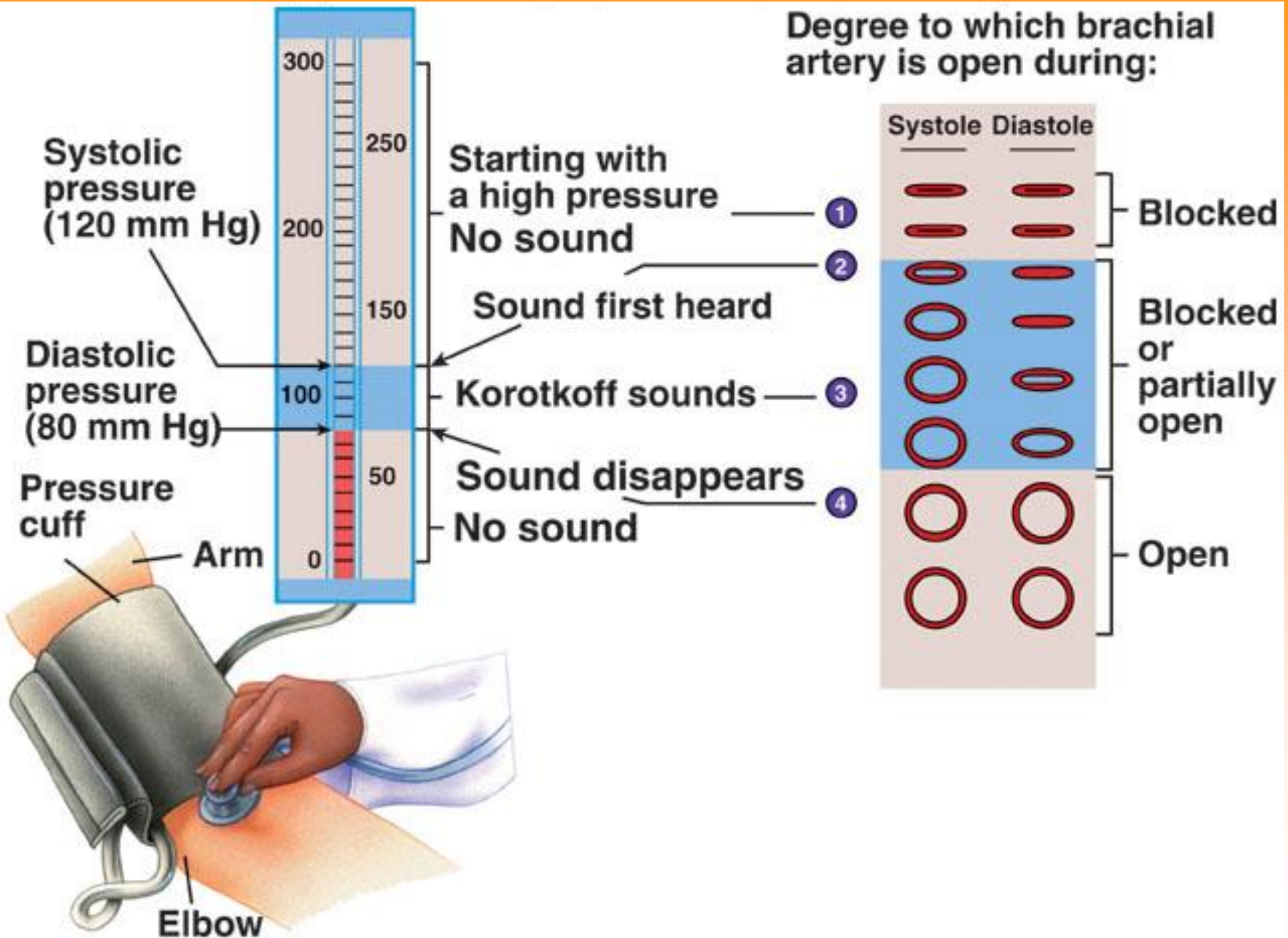
turbulent flow

Flow through a partially constricted artery creates turbulence, which creates *vibrations* that are heard as Korotkoff sounds.

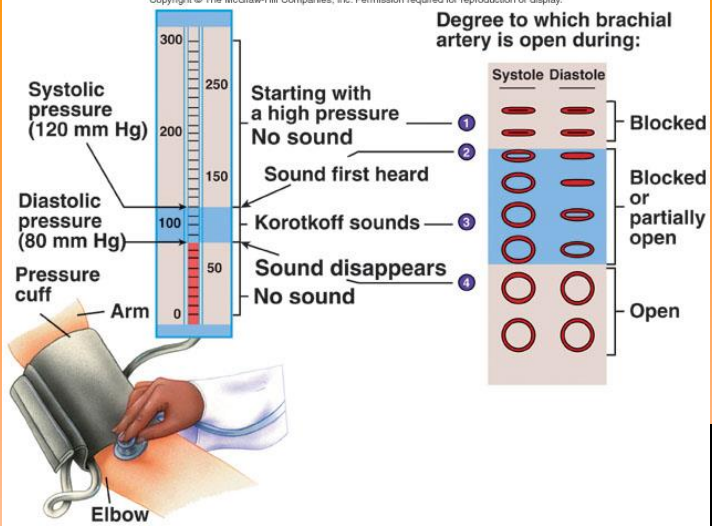
3. Pressure at which . . .

- sound (= blood flow) first heard = systolic pressure
- sound disappears = diastolic pressure

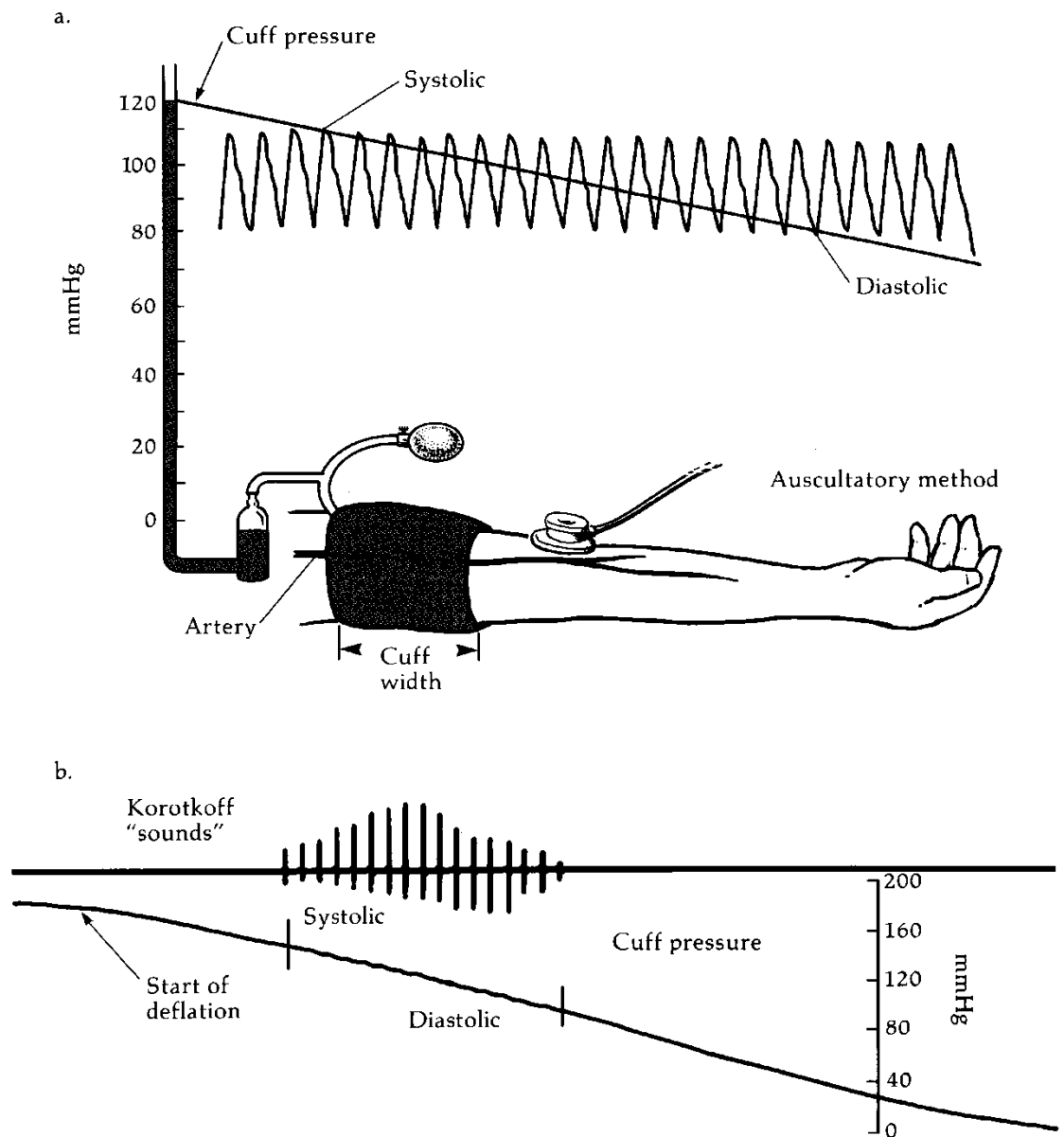




Blood Pressure Measurement



Blood pressure as obtained through auscultation is an indirect measure (or estimate) of the actual arterial pressure. And, is why it may not agree with that obtained invasively.



Sources of Error in Noninvasive BP Measurements

Equipment Factors

- Improper cuff size
- Cuff positioning
- Non-calibrated aneroid devices
- Non-validated automated devices
- Air leak in cuff or valve
- Stethoscope quality or placement

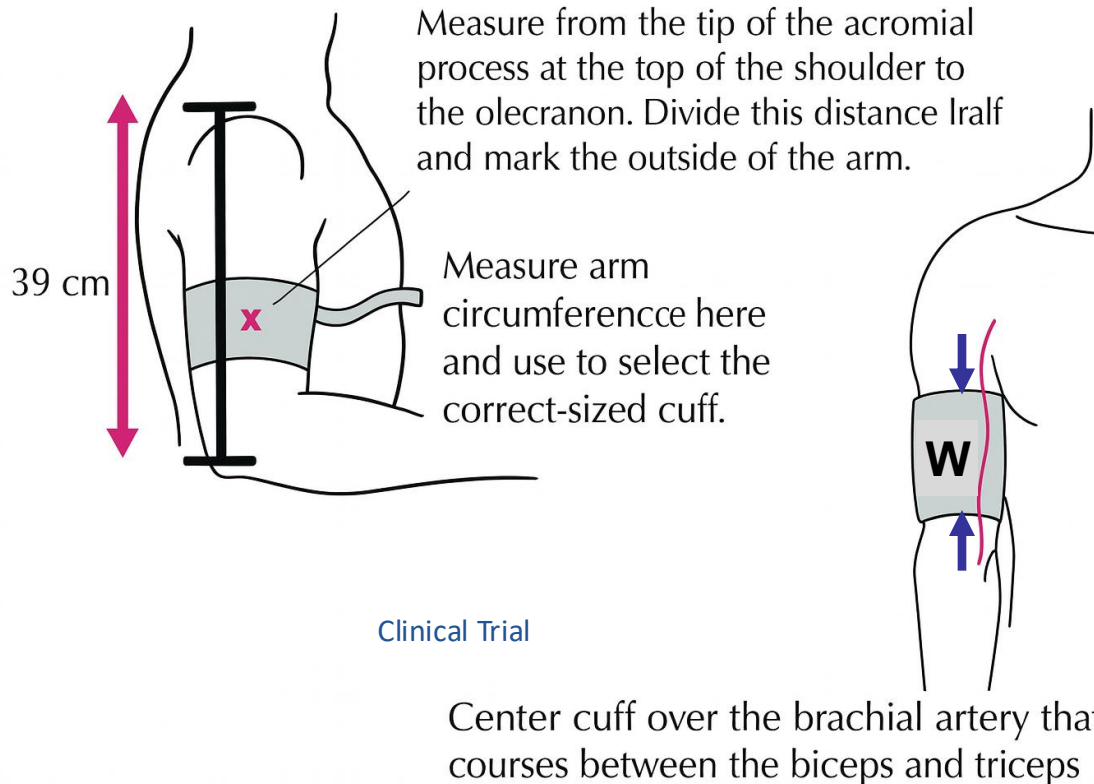
Observer Factors

- Poor measurement technique
- Deflation too fast or too slow
- Digit preference
- Expectation bias
- Background noise
- Distractions
- Hearing acuity

Patient Factors

- Conversation with observers
- No rest period before measurement
- Posture
- Arm muscle tension
- White coat effect
- Alcohol
- Caffeine
- Smoking
- Full bowel/bladder

Importance of BP cuff size . . .



- Cuffs too small artificially **increase** measured BP.
- Cuffs too large artificially **decrease** measured BP
- Optimal cuff width-to-arm circumference range from 37-50% (1), with 46% being best (2).

(1) Measurement of Blood Pressure in Humans
A Scientific Statement From the American Heart Association
Hypertension. 2019;73:e35–e66.

(2) Optimizing cuff width for noninvasive measurement of blood pressure. *Blood Pressure Monit*. 2000; June 5(3):153-8.

Auscultatory Method . . .

- **Advantages:**

- Noninvasive
- Quick, relatively easy to do
- Reasonably good correlation with direct measurement methods



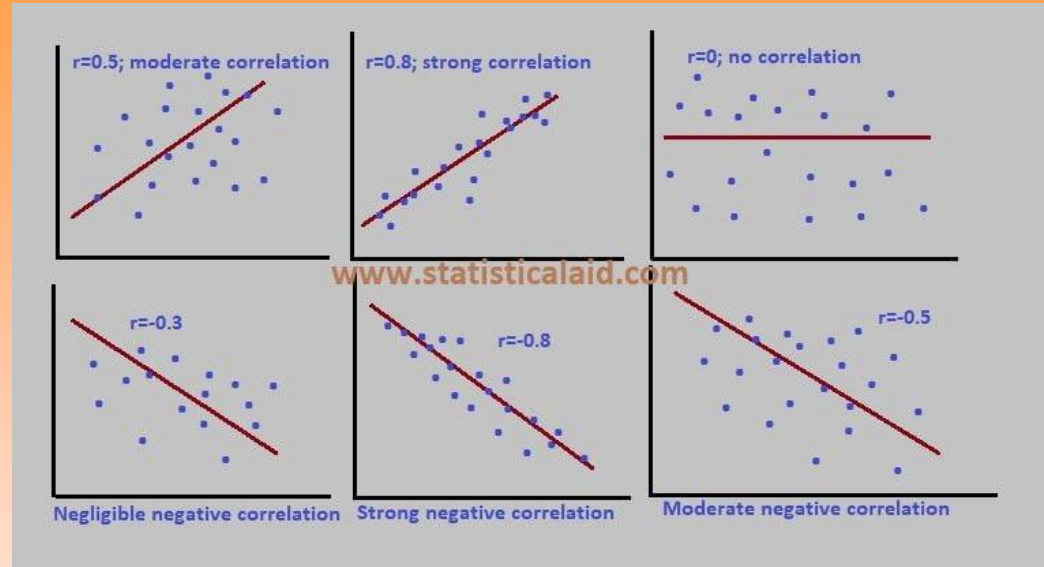
- **Disadvantages:**

- Difficult to obtain in noisy environments
- Variations between observers
- Accuracy influenced by observer hearing, technique, and cuff size
- Limited value on infants and hypotensive patients



Statistical Correlation. . .

- Measures the direction and strength of the linear relationship between two quantitative variables.
- Value of the correlation coefficient is denoted by r
- r takes on values between -1 and +1: -1 is a perfect linear relationship between the variables (with a negative slope on the line), and +1 is a perfect linear relationship with a positive slope.



$$r = \frac{N\sum xy - \sum x \sum y}{\sqrt{(N\sum x^2 - (\sum x)^2)(N\sum y^2 - (\sum y)^2)}}$$

Where,

N = Number of pairs of scores

$\sum x$ = Sum of x Scores

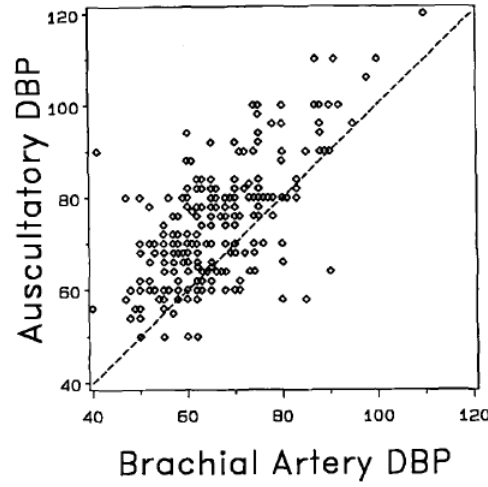
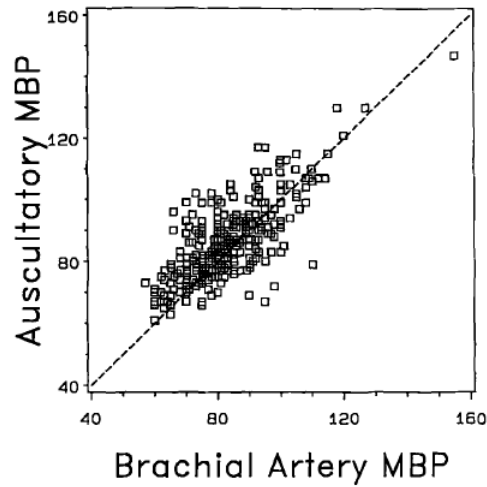
$\sum y$ = Sum of y scores

$\sum xy$ = sum of the products of paired scores

$\sum x^2$ = sum of the squared x scores

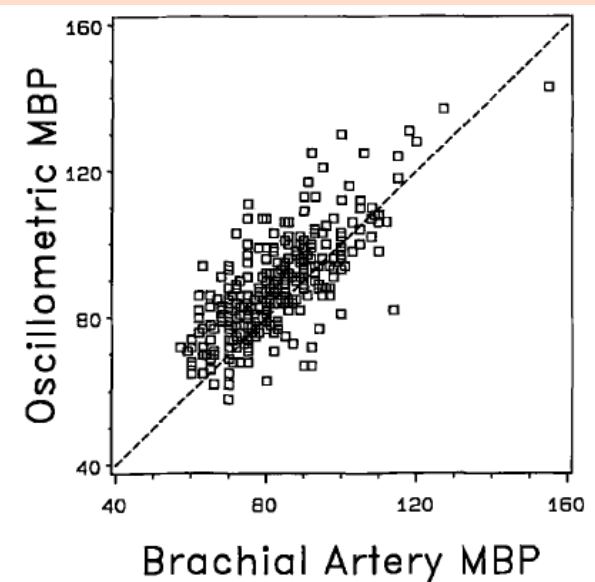
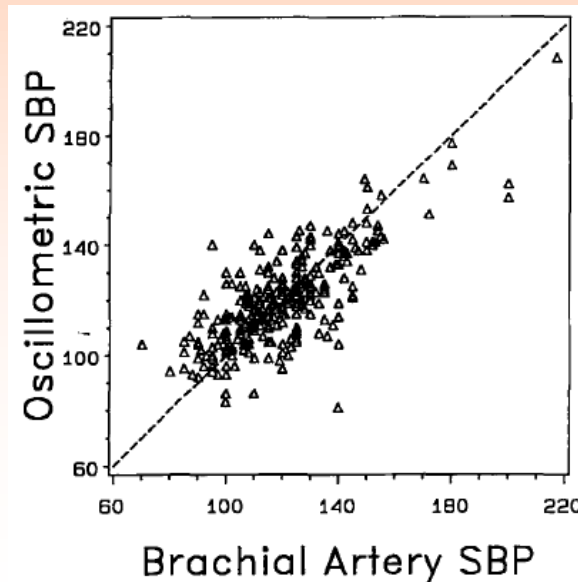
$\sum y^2$ = sum of the squared y scores

Statistical Correlation. . .

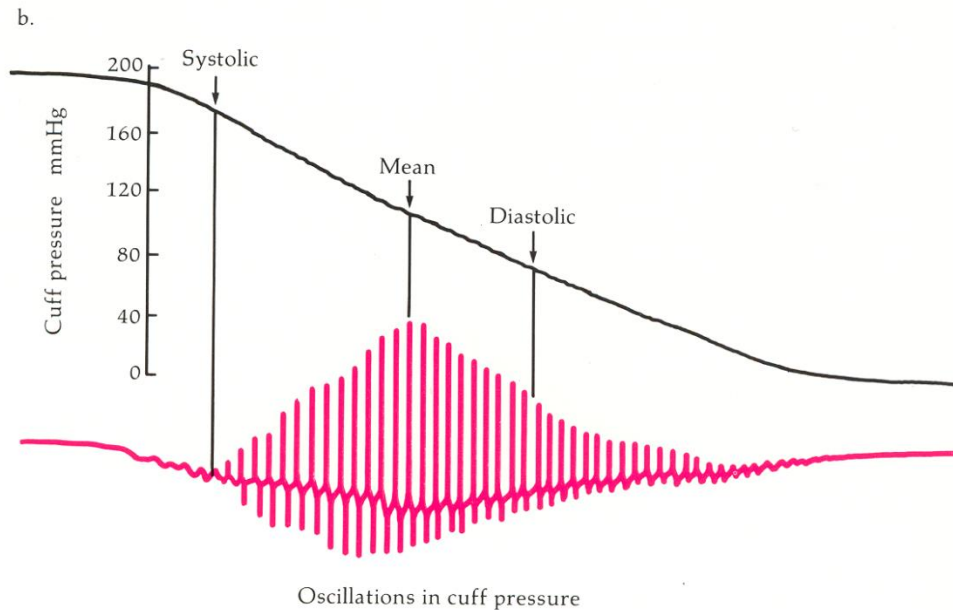
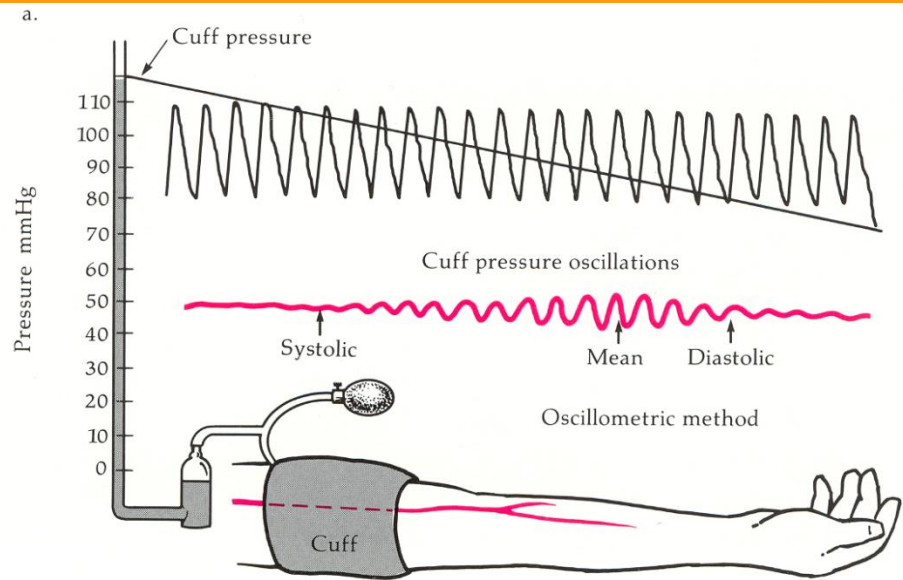


coefficients, r-values, between 0.7 – 0.8 in this study, add validity to the use of indirect methods of blood pressure measurement.

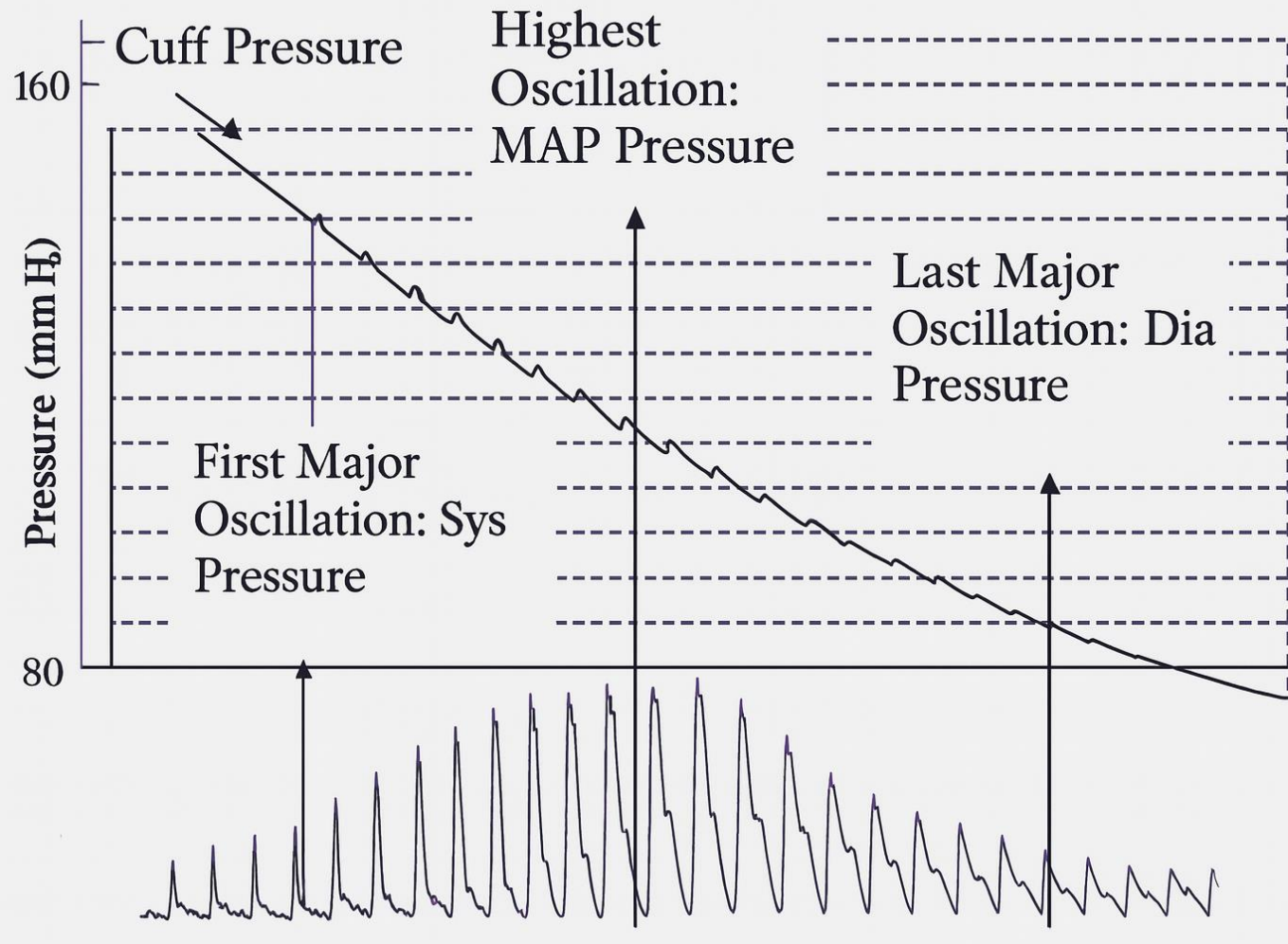
From Gravlee, G.P., et al.
“Accuracy of four indirect methods of blood pressure measurement with hemodynamic correlations”.
J. Clin. Monit, 1990; 6:284-298.



The oscillometric method of blood pressure measurement (estimation) is also an indirect measure that does not require use of a stethoscope. Systolic, diastolic, and mean pressures are derived from cuff pressure oscillations transmitted from the artery during cuff deflation.

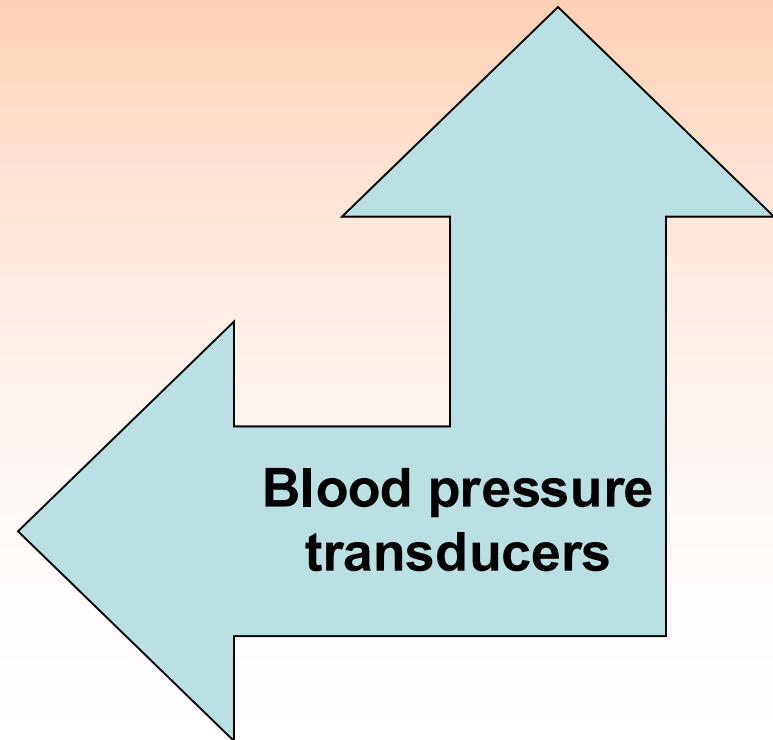
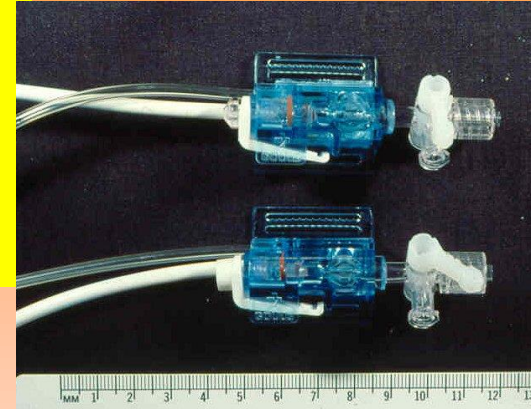


Oscillometric Method



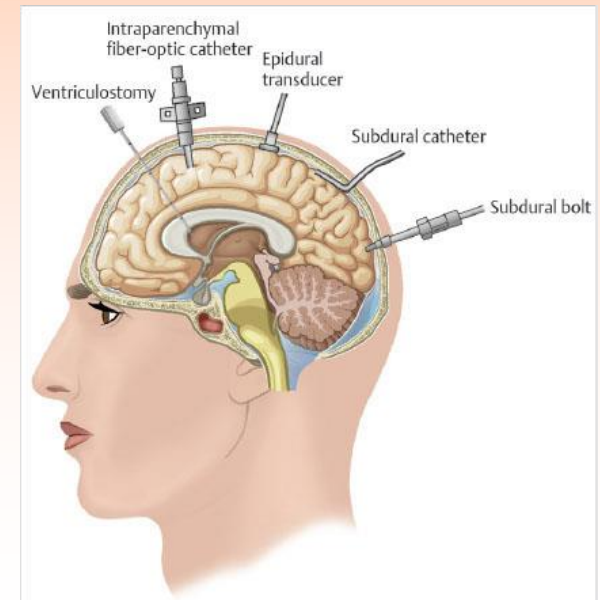
Oscillometric Method of NiBP

Direct (invasive) Methods in Blood Pressure Measurements



Common Types of Invasive, Direct Measures of Pressure Monitoring

- Arterial pressure monitoring
 - A-line
- Pulmonary artery pressure monitoring
 - PA catheter; “Swan Ganz”
- Right atrial pressure monitoring
 - RAP; CVP
- Intra-cranial pressures (ICP)

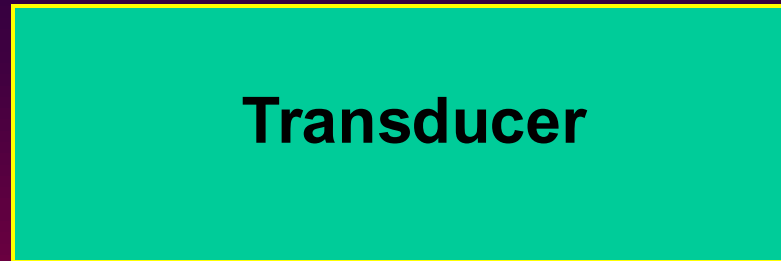
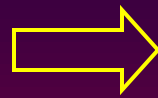


Transducers . . .

convert one form of energy into another

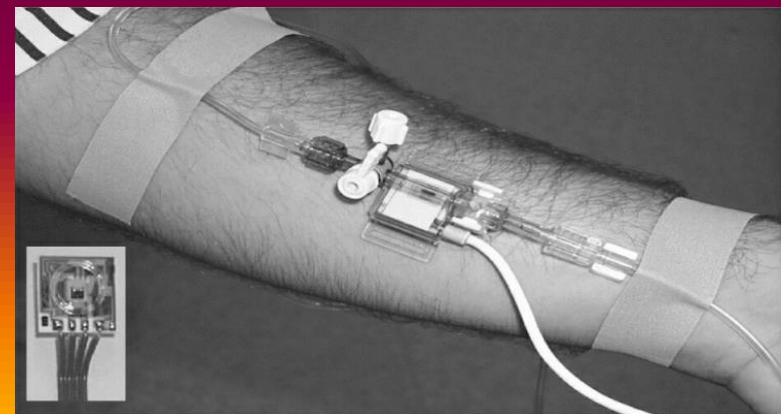
- Pressure
- Flow
- Force
- Torque
- Temperature
- Humidity
- Velocity
- Position
- Illumination
- Sound

Input

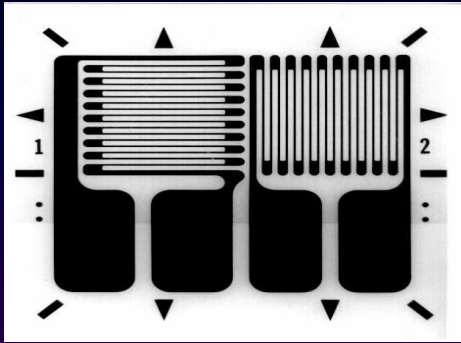


Output

(typically a voltage)

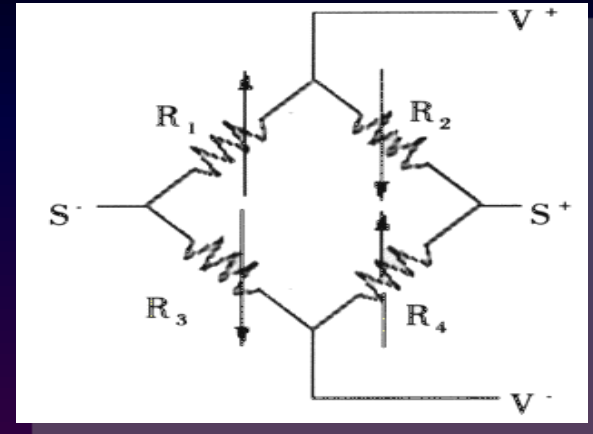


Wheatstone Bridge



strain-gauge

$$R = \frac{\rho l}{A}$$



- When a pressure (stress) is applied, the four resistances of the bridge increase or decrease in value.

- It generates an electrical output proportional to the pressure.



Disposable blood pressure transducer

Components of invasive pressure monitoring

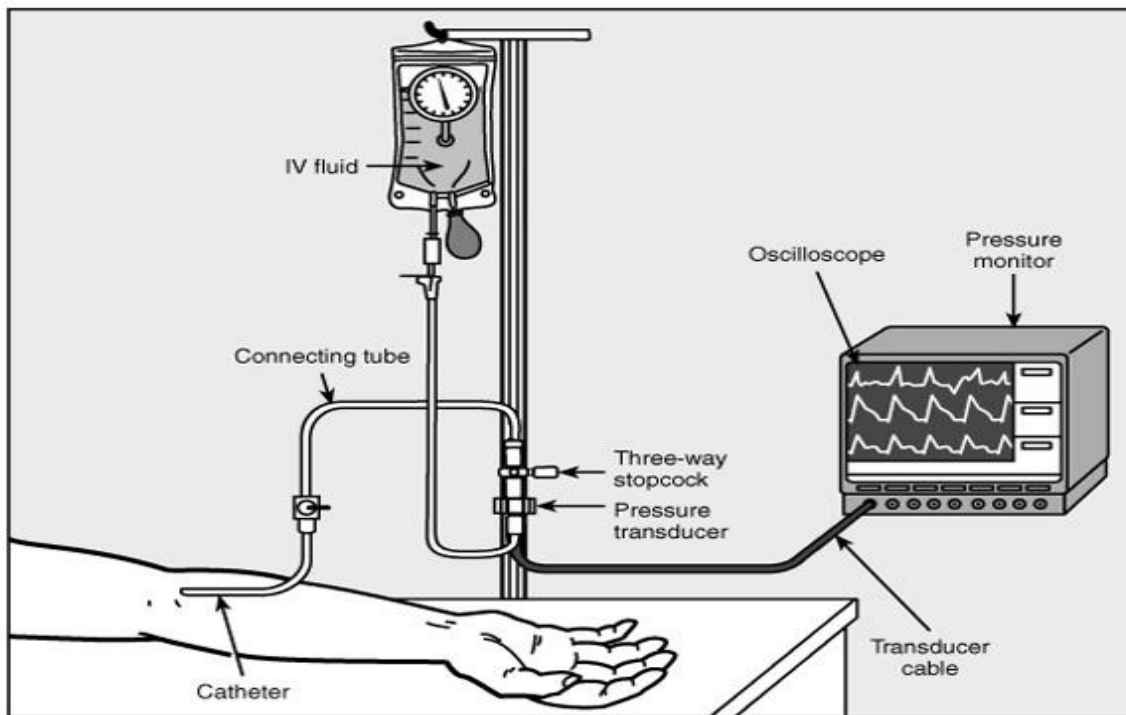
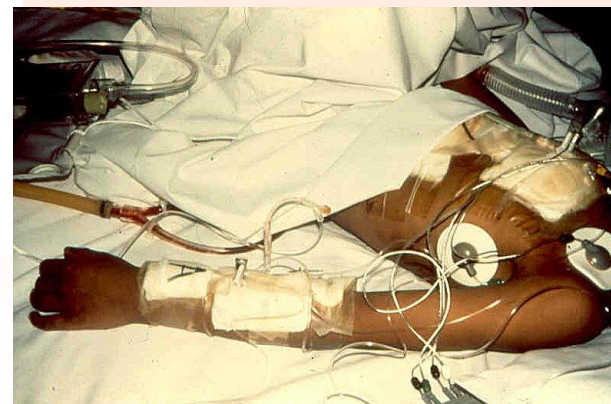
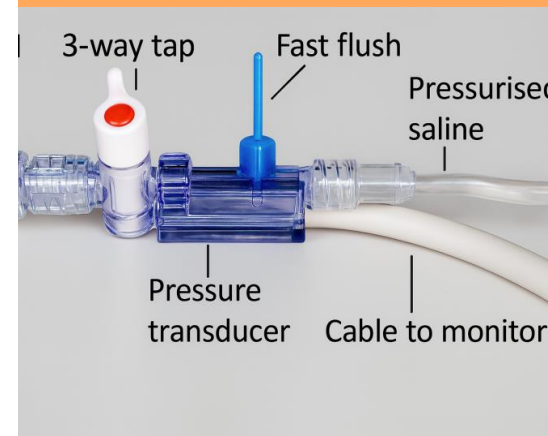


Figure 5-6 Essential components for invasive monitoring, using the brachial approach. (Parts are not drawn to scale.) (From Jackle, M., & Halligan, M. [1980]. *Cardiovascular problems: A critical care nursing focus*. Bowie, MD: Robert J. Brady.)

Copyright © 2001 by W. B. Saunders Company

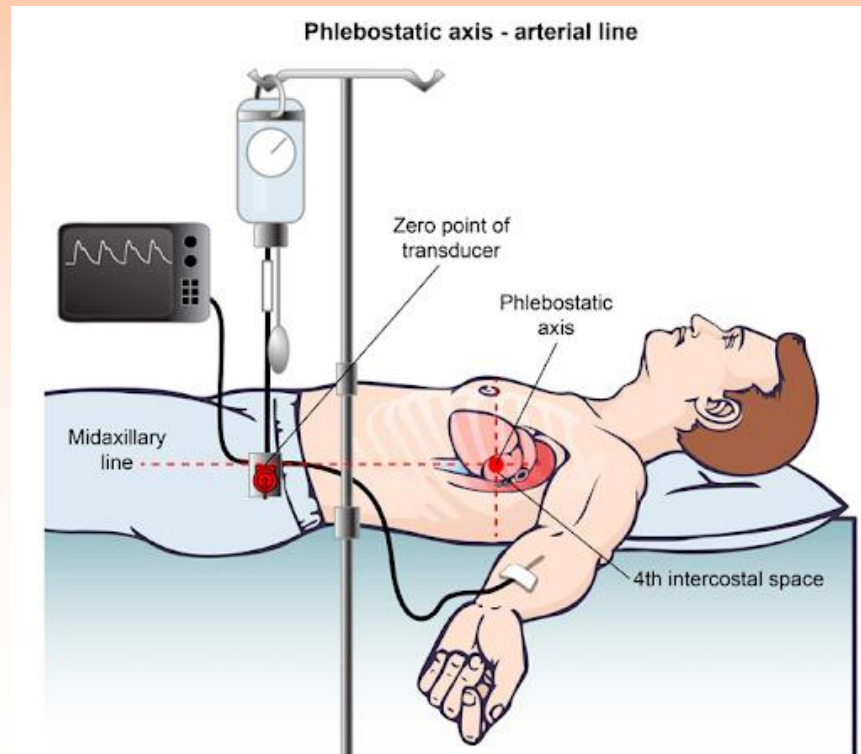
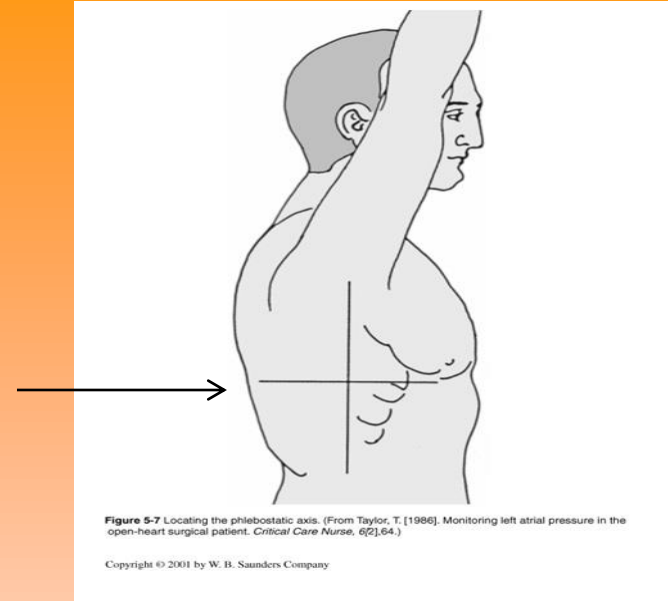


Transducer placement is important.

A physical reference point on the chest where the system should be zeroed and is used as a baseline for consistent measurements.

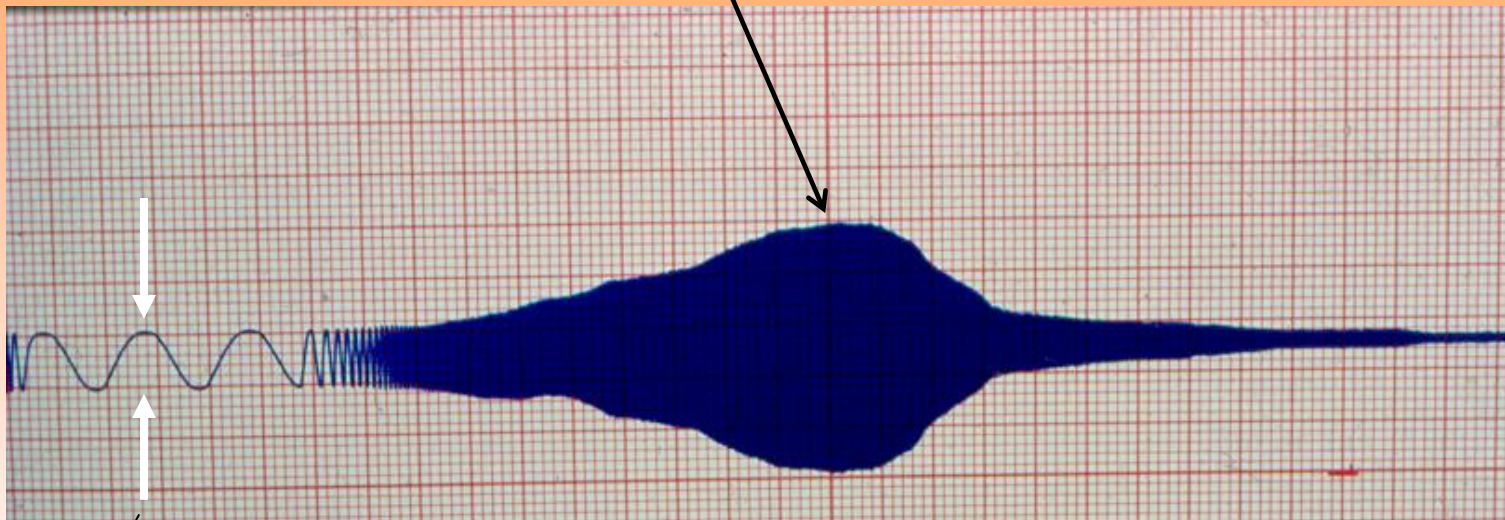
- Transducers **above** this axis artificially lower measured pressures;
- Transducers **below** this axis artificially increase measured pressures;
- Error is approximately 7 mmHg / 10 cm of elevation or depression.

The Phlebostatic Axis

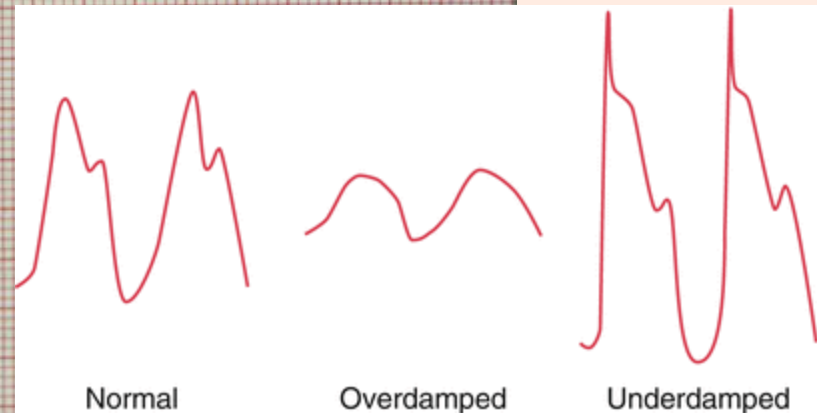


Invasive blood pressure monitoring systems have second-order characteristics

Each of which having a unique resonant frequency



Actual signal amplitude becomes artificially amplified (distorted) at resonance.

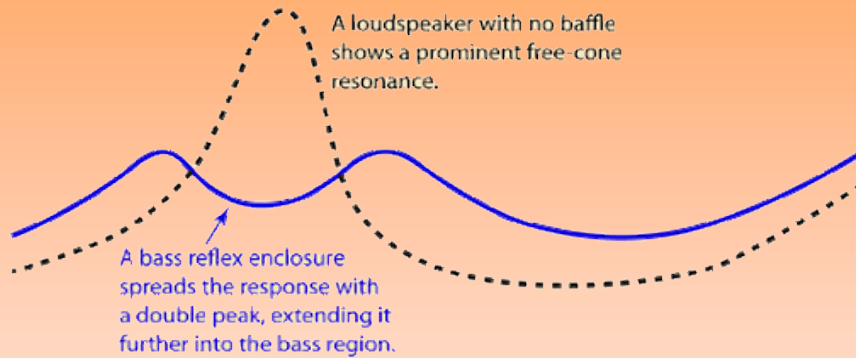


Normal

Overdamped

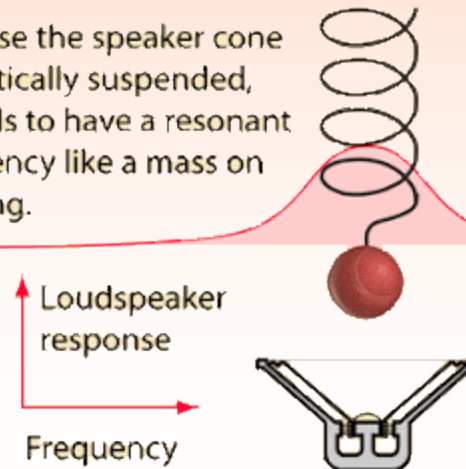
Underdamped

Loudspeaker enclosures will also distort (amplify) those frequencies near their resonant frequency



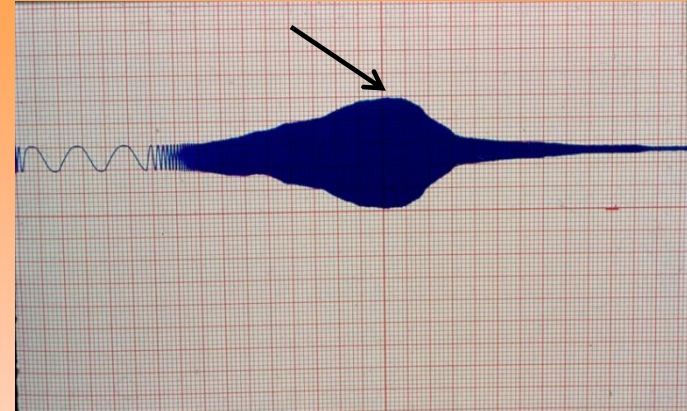
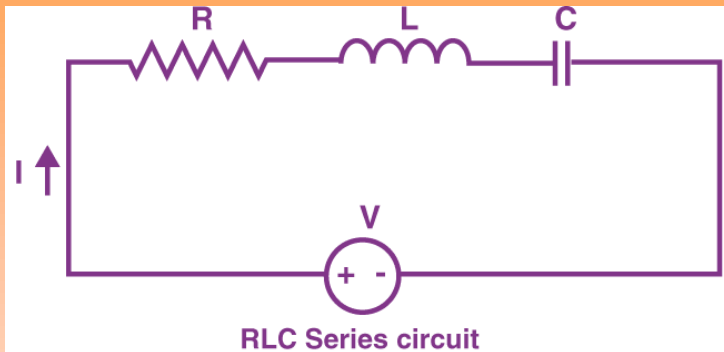
Because the speaker cone is elastically suspended, it tends to have a resonant frequency like a mass on a spring.

The tendency to respond more to a particular frequency range is often called the "free-cone resonance" of the speaker.



Analogous to a series R-L-C electrical circuit

Each of which also having a unique resonant frequency



Where:

C, capacitance => tubing compliance, air bubbles;

R, resistance => frictional losses due to saline, blood movement

L, inductance => inertance due to mass of fluid column

Where:

- $\omega_n = \sqrt{\frac{1}{LC}}$ is the natural frequency
- $\zeta = \frac{R}{2} \sqrt{\frac{C}{L}}$ is the damping ratio

This maps directly to how the physical properties of the system determine the waveform fidelity:

- Low damping ($\zeta < 0.5$) → Underdamped (ringing)
- Optimal damping ($\zeta \approx 0.64$) → Accurate reproduction
- High damping ($\zeta > 1$) → Overdamped (flattened waveform)

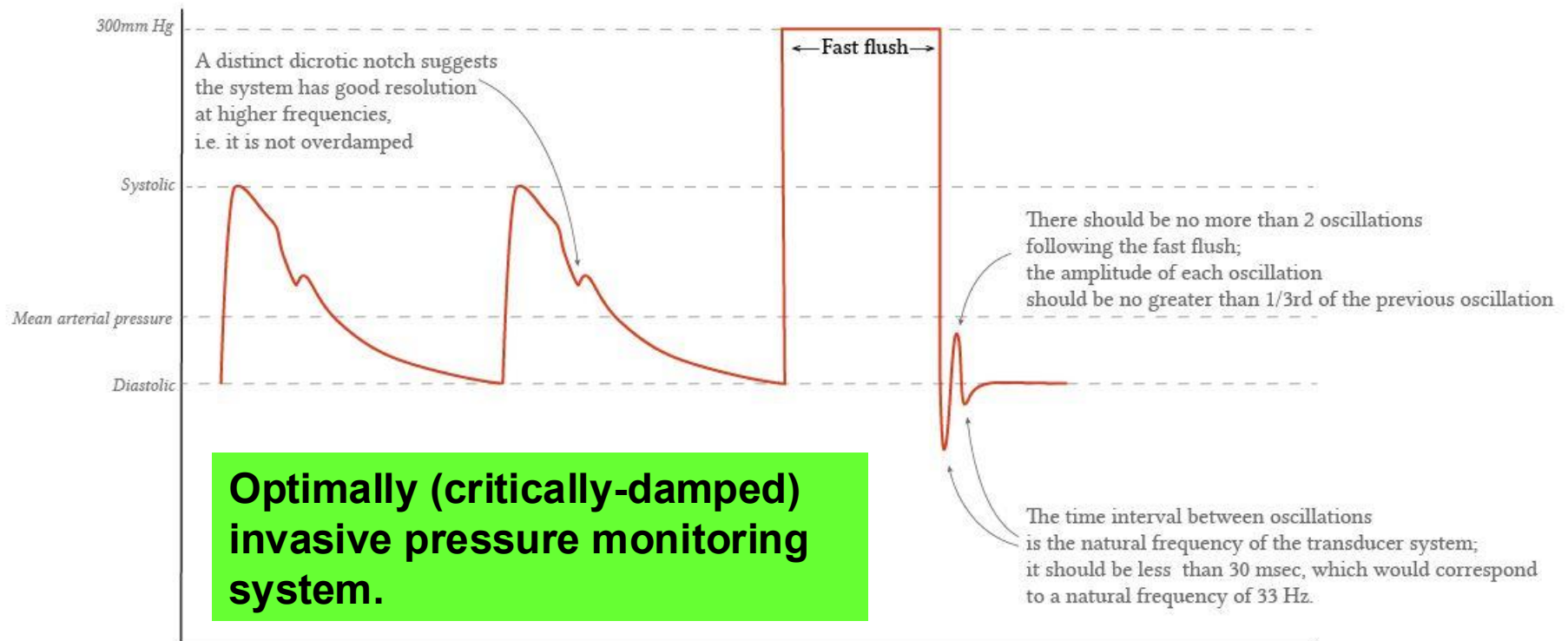
Normal Arterial Waveform



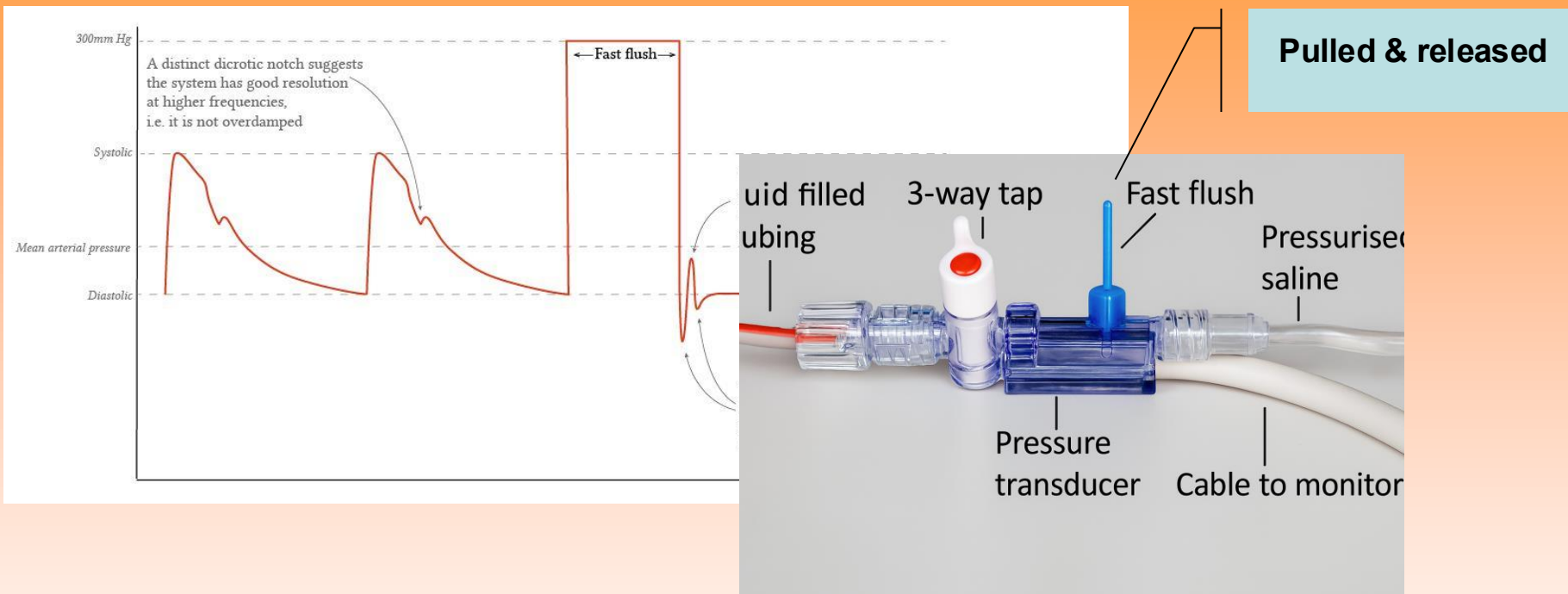
**Dicrotic notch.
Due to
closure
of aortic
valve.**

Figure 5-10 A, Normal arterial waveform depicting sharp upstroke and clear dicrotic notch. (From Jackle, M., & Halligan, M. [1980]. *Cardiovascular problems: A critical care nursing focus*. Bowie, MD: Robert J. Brady.)

Invasive blood pressure monitoring systems have second-order characteristics



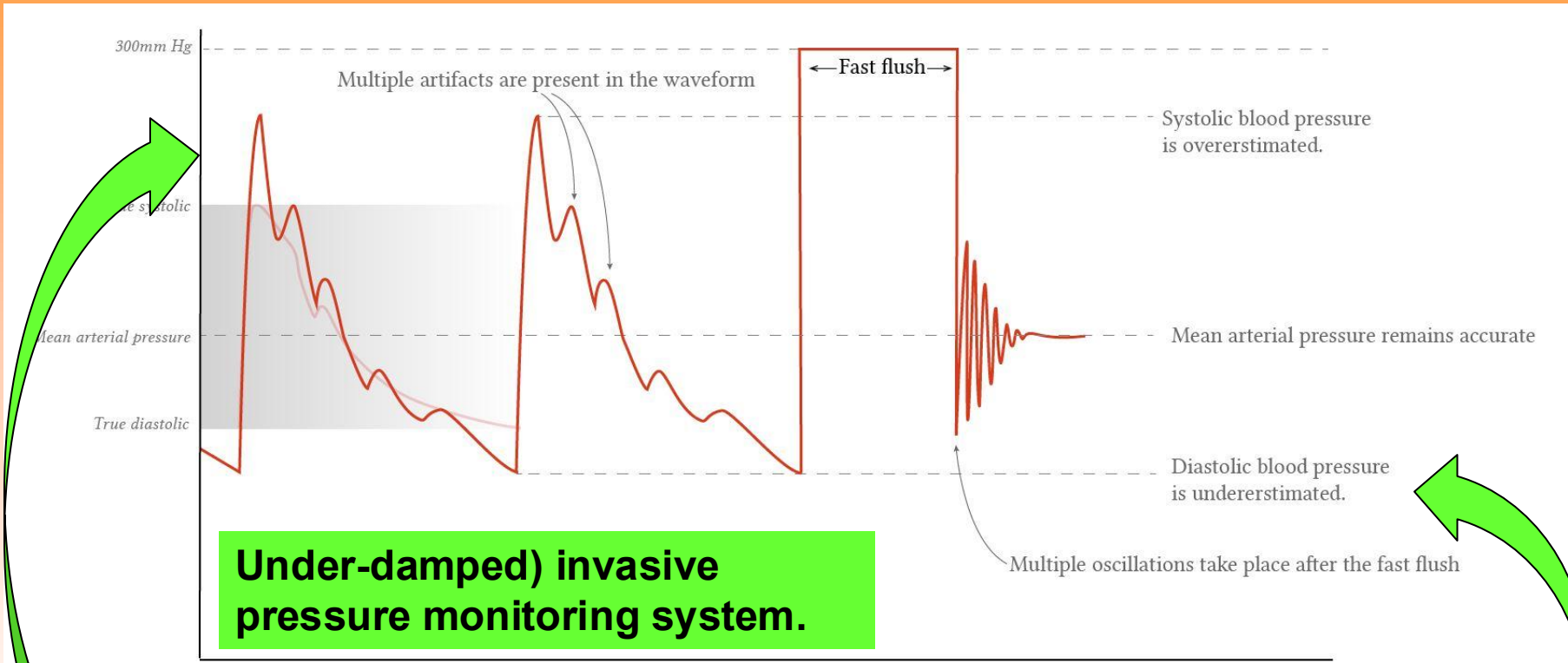
Use of transducer 'fast flush' in assessing dynamic response



NOTE:

- BMETs or CEs are **NEVER** to perform such tests!! They may, however,
 - Inspect the monitoring system,
 - Observe, interpret waveforms,
 - Recommend a flush test be performed if warranted.

Invasive blood pressure monitoring systems have second-order characteristics

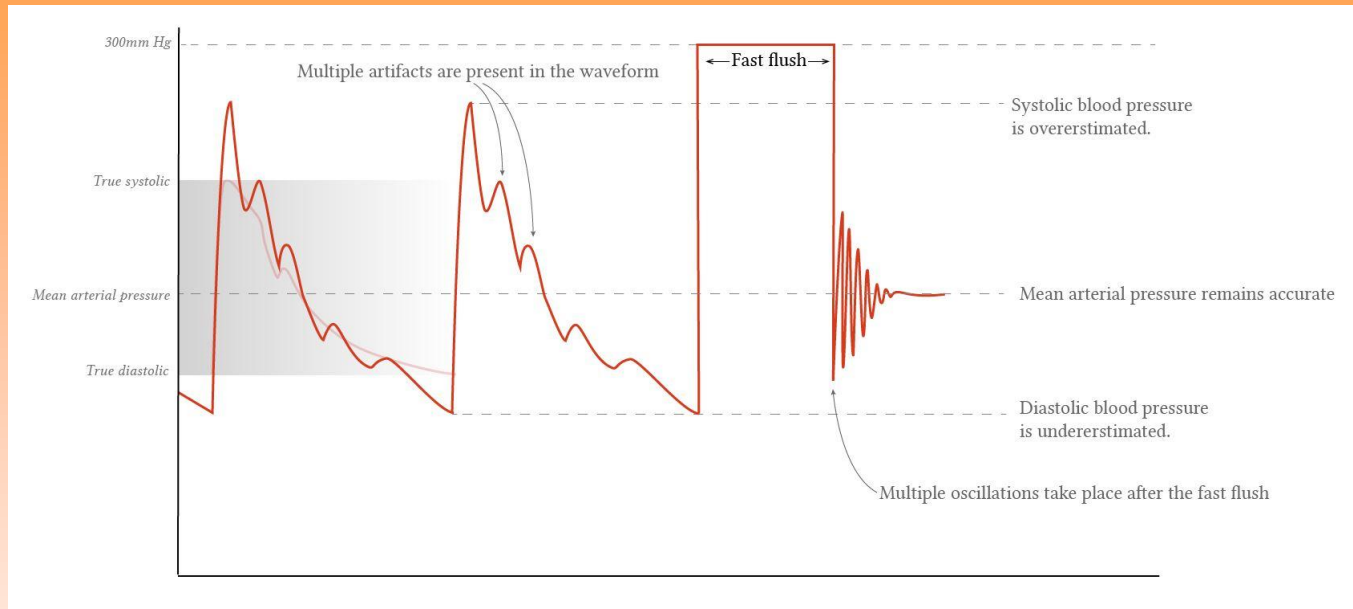


BP monitor will display **higher** than actual systolic pressures;



and display **lower** than actual diastolic pressures.

Under-damped pressure monitoring system



Clinical cues:

- Tall, narrow systolic peaks;
- Exaggerated dicrotic notch;
- Artifactual systolic hypertension with normal or low mean arterial pressure.

Causes: (ironically)

- Stiff, short, large-bore tubing;
- Air-free, rigid connections;
- Lack of compliant elements.

Over-damped Arterial Waveform



Figure 5-10 B, Damped waveform depicting slow upstroke, lower systolic M. [1980]. *Cardiovascular problems: A critical care nursing focus*. Bowie,

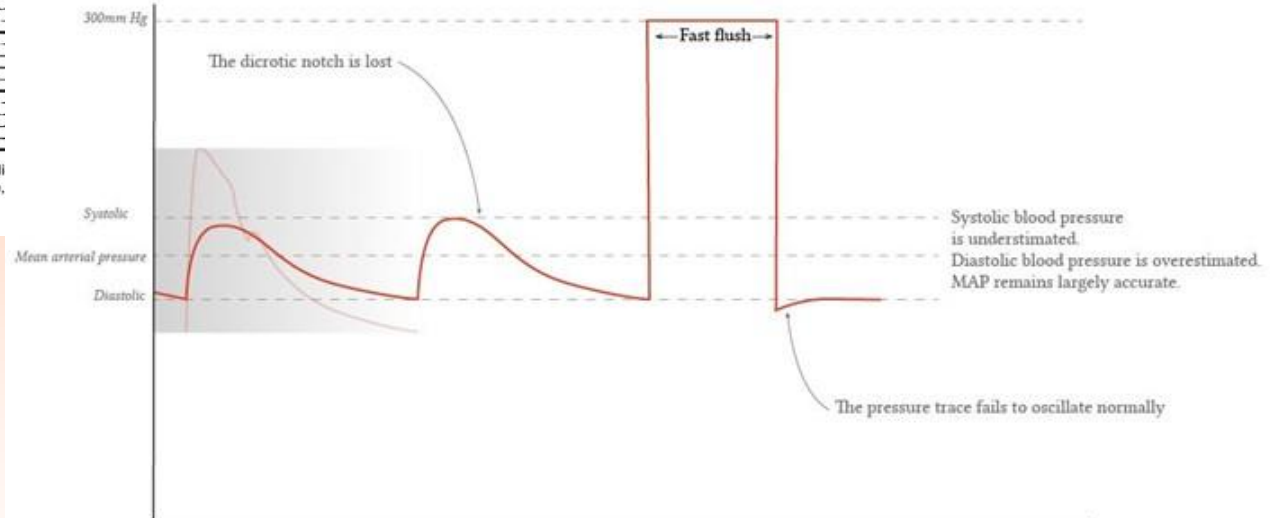
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Effects:

- Systolic pressure underestimated
- Diastolic pressure overestimated
- Mean pressure less affected

Causes:

- Air bubbles
- Compliant tubing
- Occluded, kinked catheters
- Loose connections, clots



Summary:

Cuff



vs.

Catheter



- Provides an indirect or an **estimate** of arterial blood pressure;
- Detects the beginning and ending of turbulent blood flow;
- Is sensitive to cuff size and user technique;
- Provides a reasonably good proxy (correlation) to direct, invasive measurements.

- Provides a direct measure of both systolic and diastolic arterial blood pressure;
- Allows for real-time viewing of arterial pressure waveform morphology and characteristics (e.g., dicrotic notch).
- Alarm limits can be continuously monitored.