Critical Care Medicine

Volume - 1

MARROW
Super Speciality

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• 2025 ACC/AHA CPR

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HEMODYNAMIC MONITORING

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Cardiovascular organ dysfunction : 2nd most common organ dysfunction.
Continuously observing changes in physiologic variables :

- To monitor organ function.
- For prompt therapeutic interventions.
- To evaluate response to therapeutic interventions.

monitoring per se does not improve patient outcomes.
Timely applied right interventions can cause imrpovement in outcomes.

Assessing global and regional perfusion

00:01:19

Initial steps :

1. Clinical assessment.
2. Basic monitoring and assessment of global perfusion.
3. Preload monitoring and fluid responsiveness.

Advanced monitoring measures :

1. Cardiac output monitoring.
2. Assessment of cardiac contractility.
3. Assessment of tissue perfusion.

Step 1 : Clinical assessment.

- Thirst.
- Cold extremities.
- Poor peripheral pulses.
- Impaired capillary refill.

→

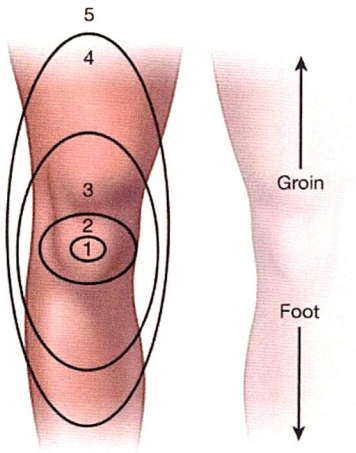
- Tachypnoea, tachycardia.
- Confusion.
- Altered skin perfusion.
- Oliguria.

Skin mottling :
Important predictor of adverse outcome.

- Score 0 : No mottling.
- Score 1 : Small area of mottling, localised to centre of knee.
- Score 2 : Modest mottling area that does not extend beyond superior border of kneecap.
- Score 3 : Mild mottling area that does not extend beyond the mid-thigh.
- Score 4 : Severe mottling area, not going beyond the groin fold.
- Score 5 : Extremely severe mottling area, extending beyond groin fold.

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Mottling score



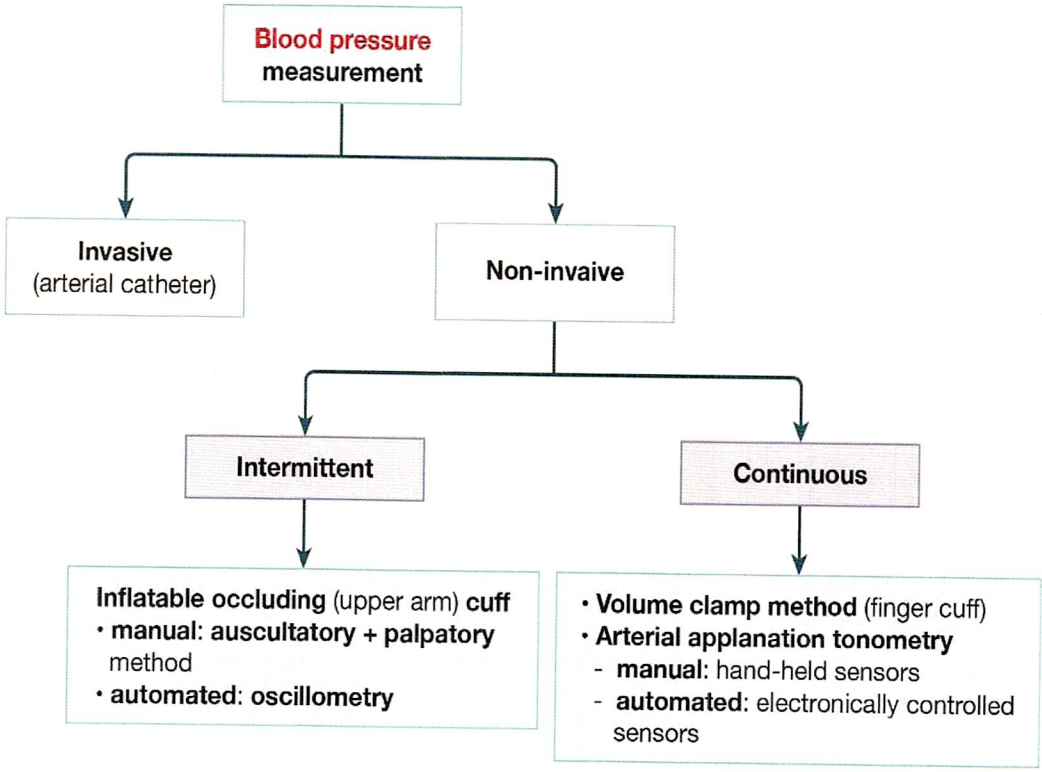
GRADE 2 MOTTLING



Step 2 : Basic monitoring and assessment of global perfusion :

- 12 lead ECG.
- Blood pressure : Non invasive and invasive.
- Pulse oximetry (SpO_2).
- Lactate levels.
- Biochemical variables.

Blood pressure monitoring :



NIBP : Intermittent.

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Manual intermittent	Automated intermittent
• Described by Korotkow in 1905. • Sphygmomanometer, cuff, and stethoscope needed. • Auscultating sounds generated by turbulent arterial blood flow beyond cuff. • Systolic : First Korotkoff sound. • Diastolic : Before disappearance.	• Based on oscillometry. • Cuff is coupled to an oscillometer. • The cuff inflated above systolic pressure → Then gradually deflates. • MAP : pressure at peak amplitude of arterial pulsations. • SBP & DBP : Derived from proprietary formulas (Rate of change of pressure pulsations).

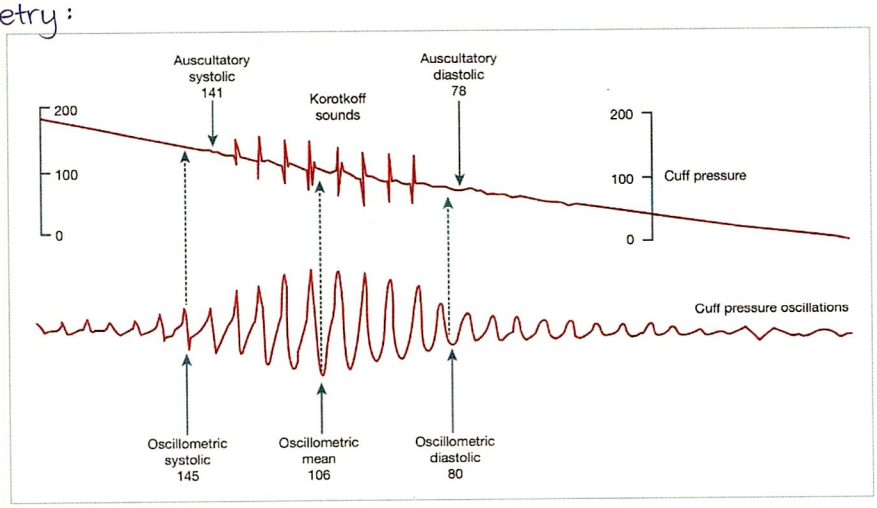
Cuff Size :

- Bladder length : 80% of arm circumference.
- Bladder width : 40% of arm circumference.
- Midline of cuff bladder should be positioned over the arterial pulsation.

Patient	Recommended cuff size
Adults (by arm circumference)	
22 to 26 cm	12 x 22 cm (small adult)
27 to 34 cm	16 x 30 cm (adult)
35 to 44 cm	16 x 36 cm (large adult)
45 to 52 cm	16 x 42 cm (adult thigh)

BP cuff size

Comparison of blood pressure measurements via Korotkoff sounds and oscillometry :



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Non invasive :

CNAP : Continuous noninvasive arterial pressure.

Volume clamp method (finger cuff) :

- Inflatable finger cuff with infrared
- plethysmography & monitor.
- Adjusts its pressure multiple times per second to keep volume in finger artery constant.
- Produce a brachial arterial waveform.



T- line system :

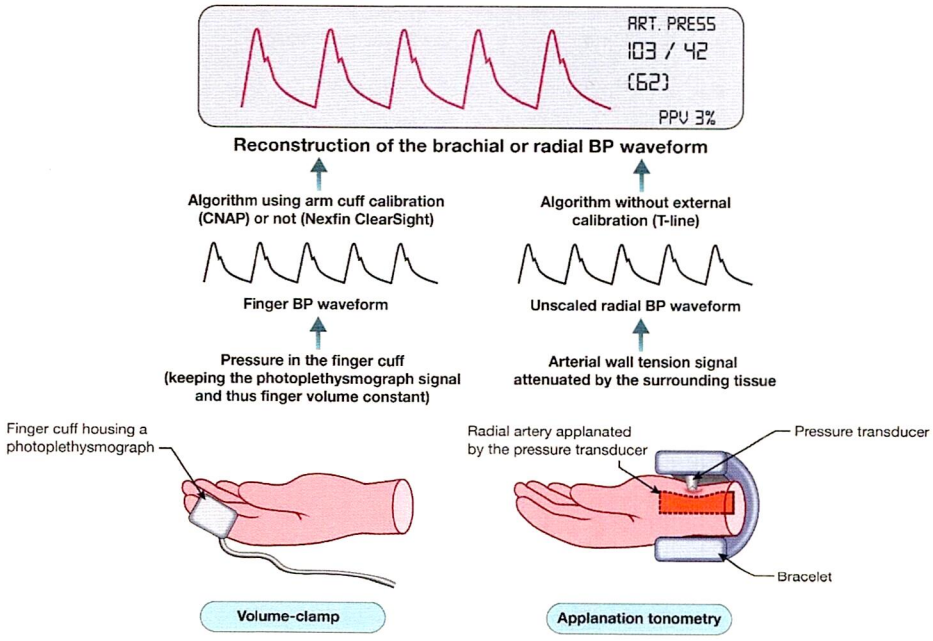
Based on applanation tonometry.

T- line system: Based on applanation tonometry



- Radial artery applanation :
- A pressure sensor applied over radial artery :
- Gently compresses artery : Applanates.
- The sensor is automatically moves over radial artery until optimal waveform is recorded.
- External applanation leads to reconstruction of BP waveform.
- Mean BP measured directly (optimal waveform).

Oscillometric, volume-clamp, and applanation tonometry technol arterial BP



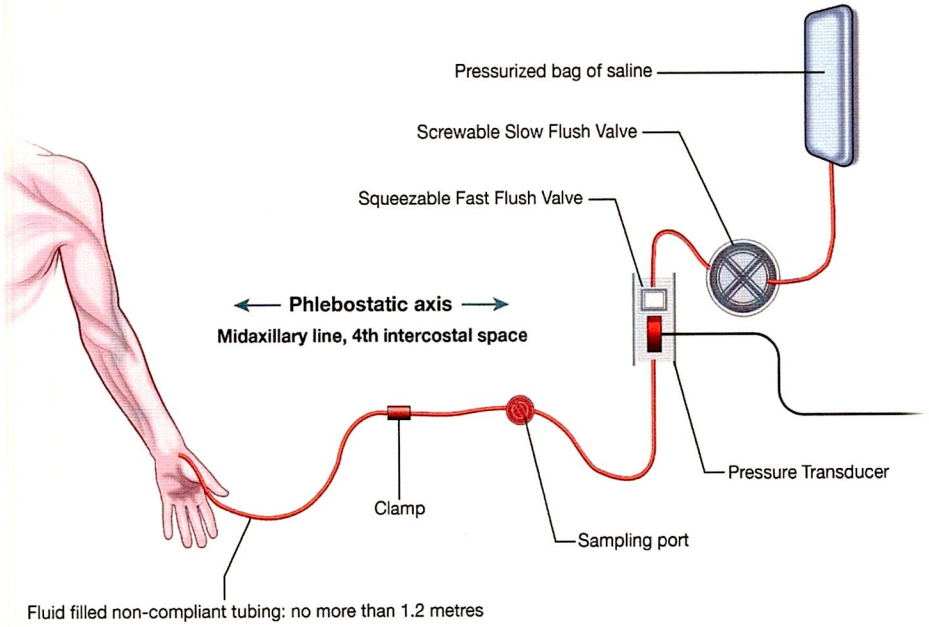
Invasive blood pressure :

- Gold standard for BP monitoring :
  - Arterial cannulation.
  - Continuous pressure transduction.
  - Waveform display.

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- Conventions :
  - Pressures expressed as mmHg.
  - Referenced to phlebostatic axis.
  - Zeroed to ambient pressure.

Arterial Line Transducer Setup



Indications :

- Unstable blood pressure/severe hypotension.
- Use of rapidly acting vasoactive drugs : Vasodilators, vasopressors, inotropes.
- Frequent sampling of arterial blood.

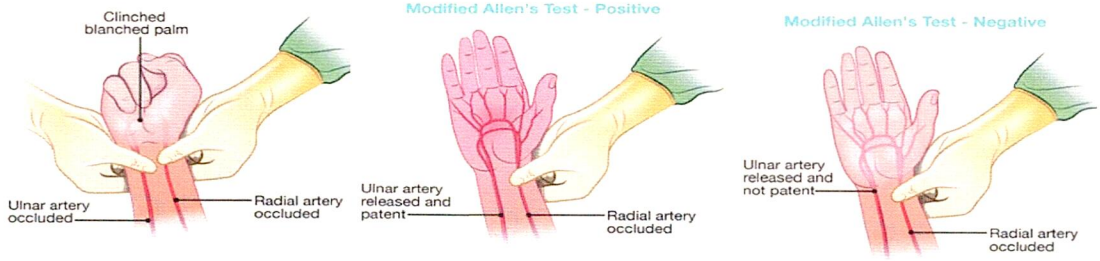
Relative contraindications for invasive arterial pressure monitoring :

- Anticipation of thrombolytic therapy.
- Severe peripheral vascular disease preventing catheter insertion.
- Vascular anomalies : AV fistula, local aneurysm, local haematoma, Raynaud's disease.
- Lack of collateral blood flow distally (Eg : Radial artery previously used for coronary artery bypass surgery).

Modified Allen test :

- Used to assess adequacy of collateral circulation.
- Reduced collateral flow when palm remains pale >6 to 10 seconds.
- Disadvantage : Sensitivity (70-80%).

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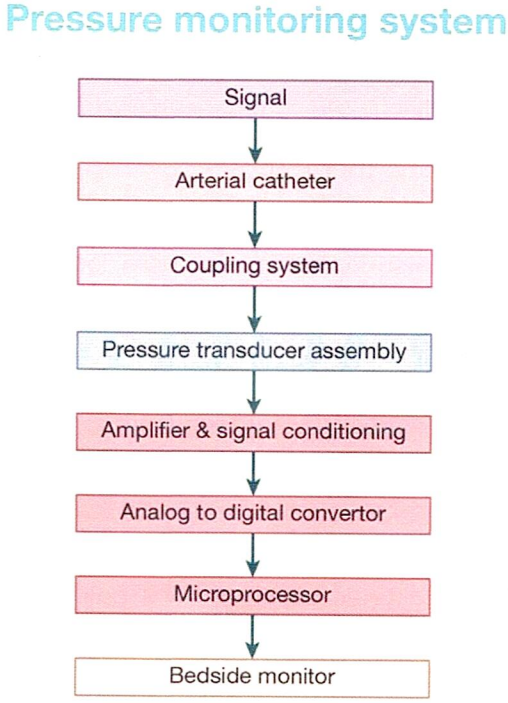
Common sites :

1. Radial.
2. Femoral.
3. Dorsalis pedis.
4. Posterior tibial.

Complications of direct arterial pressure monitoring :

- Distal ischemia, pseudoaneurysm, arteriovenous fistula.
- Hemorrhage.
- Arterial embolization.
- Infection.
- Peripheral neuropathy.
- Misinterpretation of data.
- Misuse of equipment.

Pressure monitoring system :

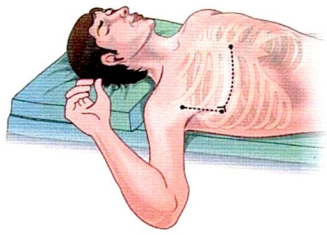


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Zeroing & levelling :

- Levelling : At level of the right atrium, we establish the 0 baseline..
- Zeroing : Opening the transducer stopcock to atmosphere.
- Stopcock at level of midaxillary line 4th ICS : Flavostatic axis.
- With the stopcock open, monitor displays 0.

Zeroing and Levelling

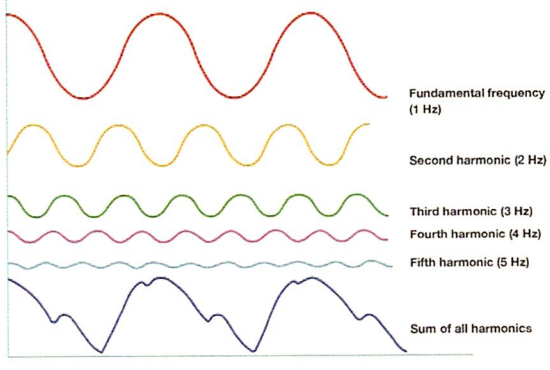


Physics of arterial waveform 00:20:27

Fourier analysis of complex waveform :

Arterial waveform is a composite of many waveforms of increasing frequencies (Harmonics).
8–10 harmonics.

Fourier analysis of a complex waveform



Natural frequency :

Frequency at which a system oscillates.

$$\text{Natural frequency } f_n = \frac{1}{2\pi}\sqrt{\frac{\pi D^2}{4\rho L}\cdot\frac{\triangle P}{\triangle V}}$$

Dependent on :

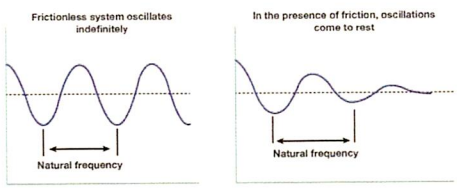
- Maximum diameter.
- Minimum length.
- Low compliance.

The coupling system :

Fluid between artery and transducer acts as simple harmonic oscillator :

- Analogous to a pendulum.
- When the pendulum is displaced, it undergoes simple harmonic motion it oscillates around the equilibrium point.

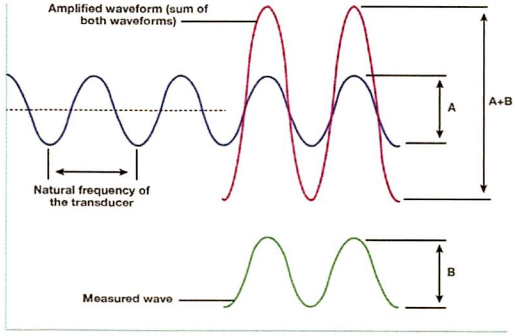
The Coupling system



----- Active space -----

- Resonance : Amplification of a signal.
  Occurs when it's frequency is close to natural frequency of a system.

The Coupling system



- If natural frequency of pressure transducer matches with each peak of arterial pressure wave → Increase amplitude of the measured values.
- Transducer system must have a natural frequency well above the 8th harmonic frequency of a rapid pulse : >24Hz (Taking HR upto 180/min).

Damping :

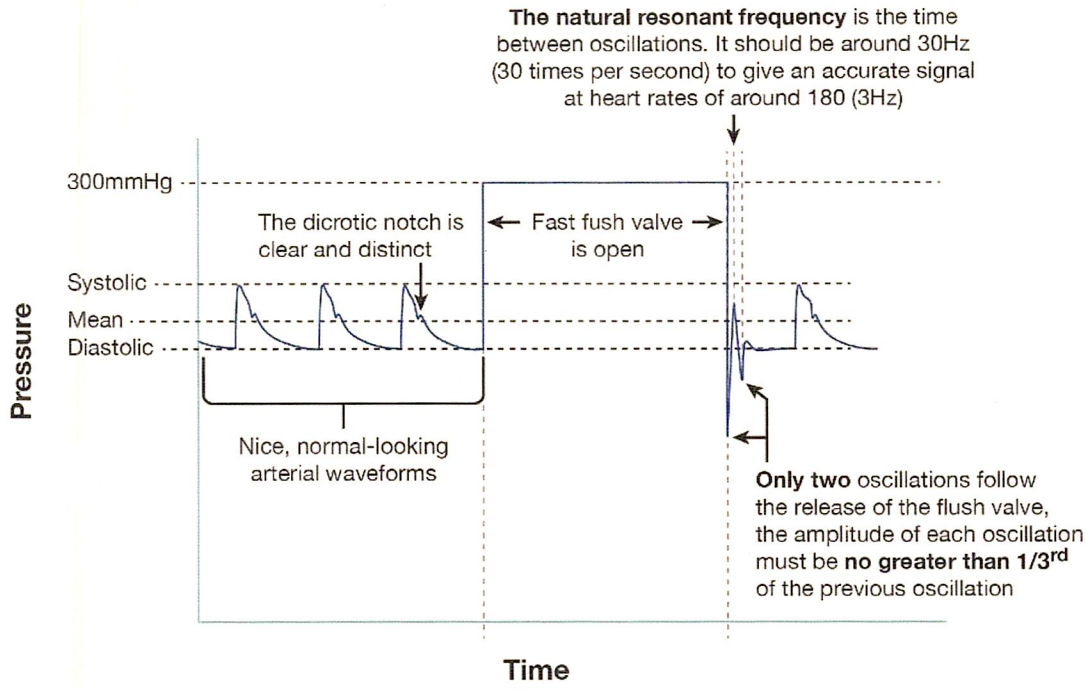
- Absorption of energy (Amplitude) of oscillations :
  - Decreases amplitude of waves.
  - Reduces natural frequency of a system.
- Adequately damped → Amplitude should not change due to resonance.
- Diameter of the tubing has the greatest effect on damping.
- Damping increases by third power of any decrease in tubing diameter.

Dynamic response :
Ability of the system to accurately reproduce hemodynamic waveform.

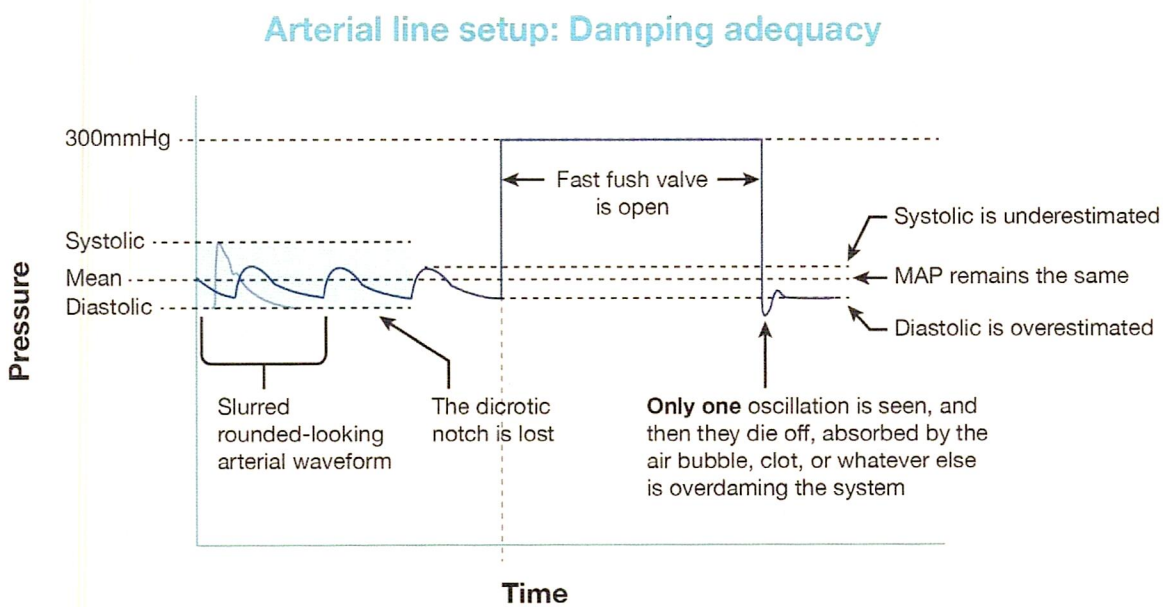
Damping coefficient :
To assess how quickly an oscilating fluid filled system comes to rest.
Test : Fast flush test.

Arterial line setup : Damping adequacy.

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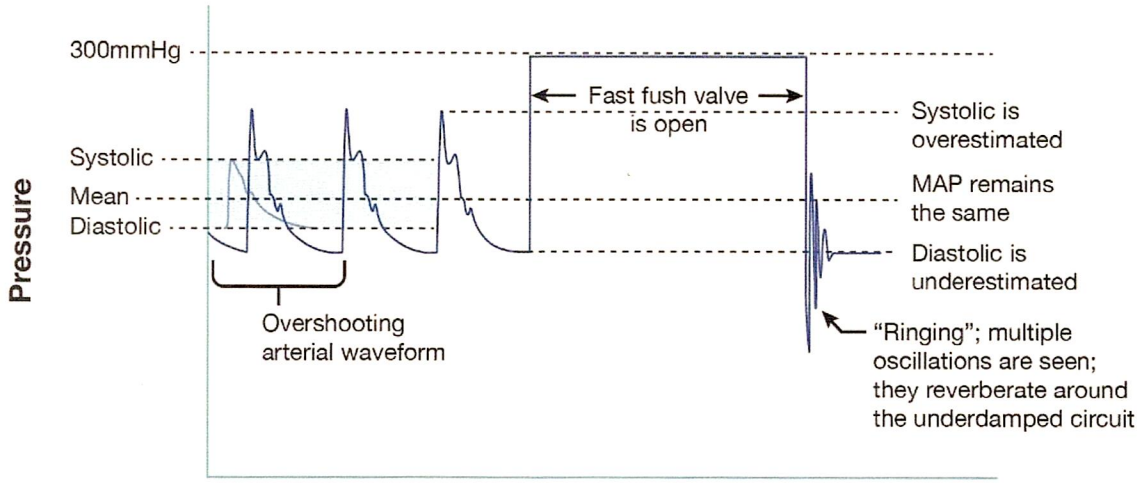
Over damped system :



Occurs in cases of : Clots, kinks, air bubbles, low compliant tubings, loose connection.

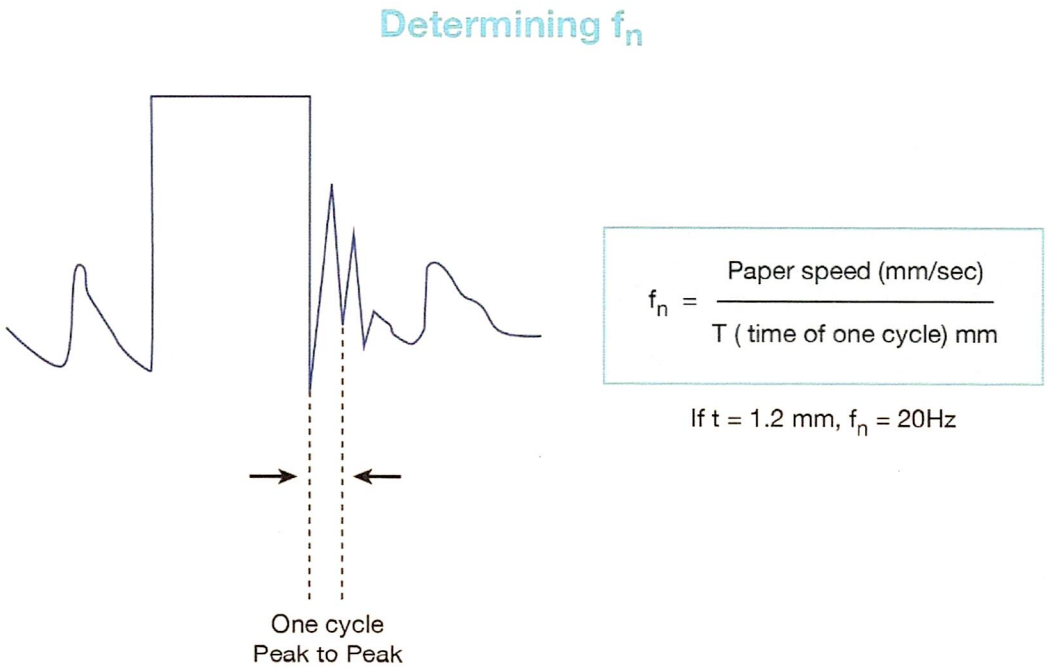
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Underdamped system :



Occurs in : Long tubing, hyperdynamic circulation, tachycardia, hypertension, atherosclerosis.

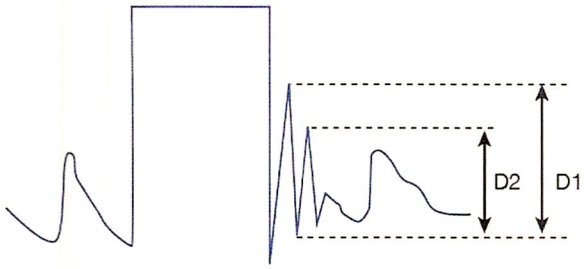
Determining frequency of a system :



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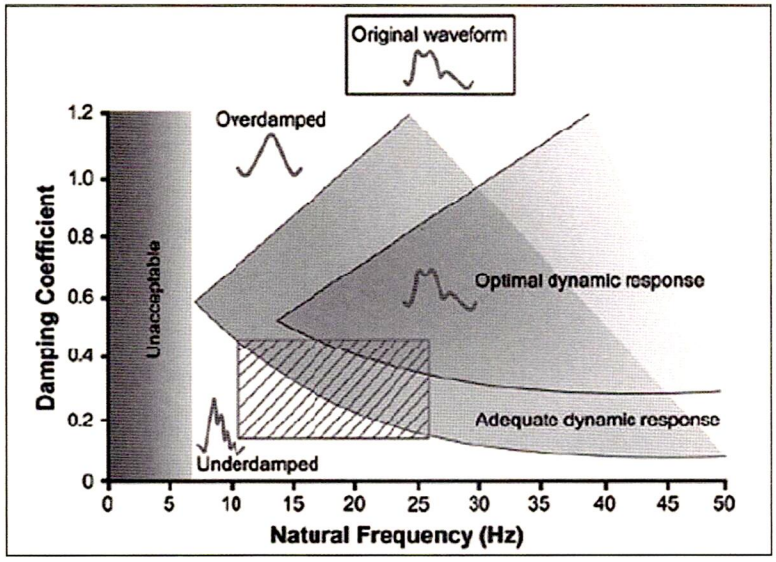
Amplitude ratio :

Height of waves generated following a fast flush test.



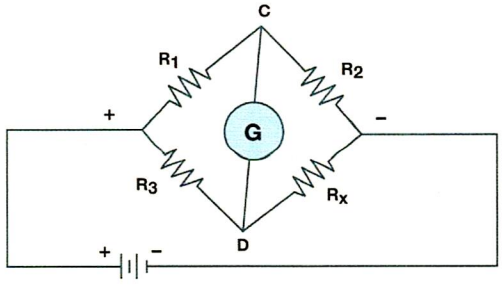
Amp Ratio (D2/D1)	Damping coefficient
0.9	0.034
0.8	0.071
0.7	0.113
0.6	0.160
0.5	0.215
0.4	0.280
0.3	0.358
0.2	0.456
0.1	0.591
0.05	0.690

Arterial line setup : Dynamic response.



Pressure transducer :

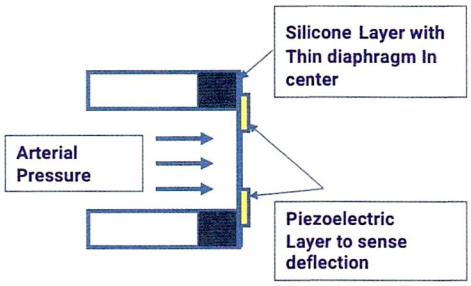
- A transducer is a device which converts energy from one form to another : Pressure into electrical energy.
- It acts on the principle of Wheatstone bridge.
- Wheatstone bridge : Electrical circuit with one unknown resistor.

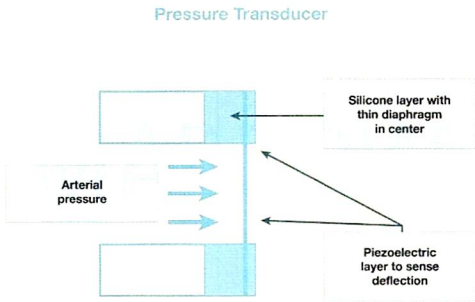


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Mechanism :

- Piezoresistive strain gauges is used to complete the circuit.
- Wheatstone bridge is used to measure the unknown resistance (Of strain gauge).
- Resistance of unknown resistor is determined by pressure.





Components of arterial pulse waveform 00:33:21

Components :

i. Systolic phase :

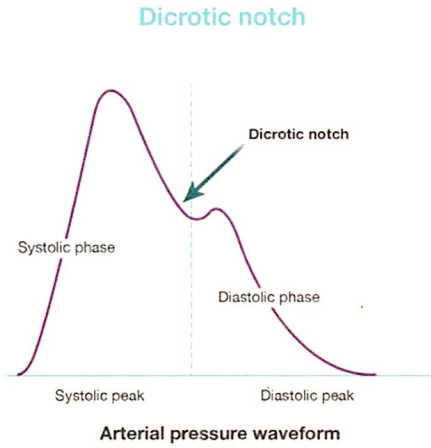
- Rapid increase in pressure to a peak.
- Begins with opening of aortic valve.
- Corresponds to LV ejection.

ii. Dicrotic notch :

Closure of aortic valve.

iii. Diastolic phase :

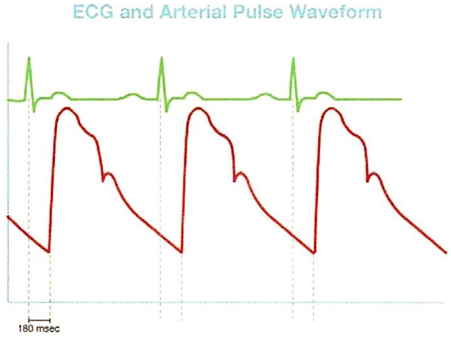
Run-off of blood into peripheral circulation.



Arterial pressure waveform

Analysis :

- On ECG, R wave signals beginning of systole.
- Systolic upstroke does not occur immediately following systole. There is 160–180 millisecond delay.

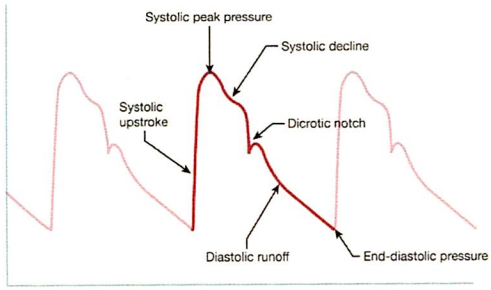


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Systolic upstroke :

- Represents ventricular ejection.
- Corresponds to peak aortic blood flow.
- Factors influencing aortic flow rates affect it :
  - Contractility.
  - Aortic valve flow.
  - Peripheral resistance.

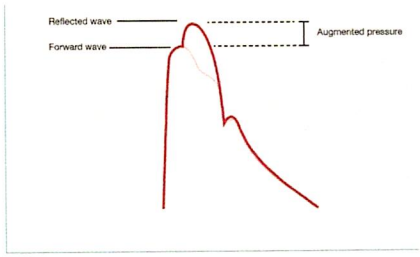
Systolic upstroke



Peak systolic pressure :

- Maximum pressure in central arteries generated during systolic ejection.
- Major contributions :
  - LV contraction.
  - Central arterial compliance.
  - Reflected pressure wave.

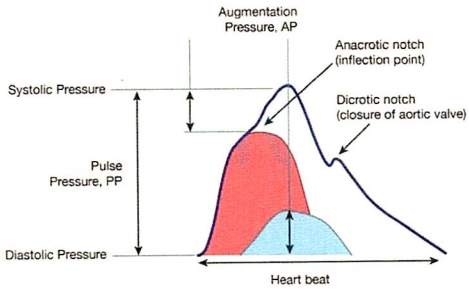
Peak systolic pressure



Augmentation index :

- Wave reflected from periphery to central aorta augments aortic pressure.
- It is a measure of systemic arterial stiffness.
- Calculated as ratio of augmentation pressure to pulse pressure.

Augmentation index

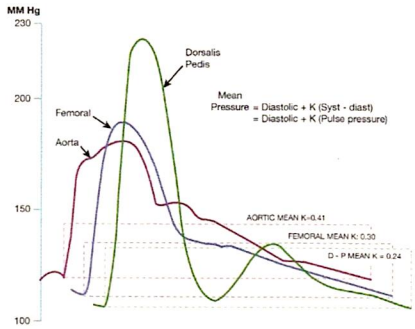


Distal systolic pulse amplification :

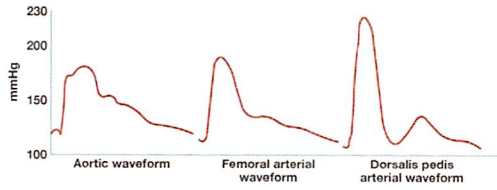
- Demonstrates change in systolic pressure on moving further from aortic root.
- Due to action of reflected waves on systolic pressure.
- Accumulating more of reflected pressure waves on top of systolic peak.

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Comparing Arterial waveforms in different arteries

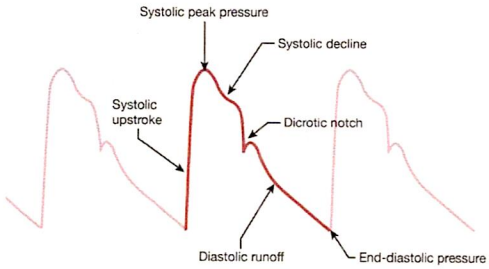


Arterial waveforms in different arteries



Systolic decline :

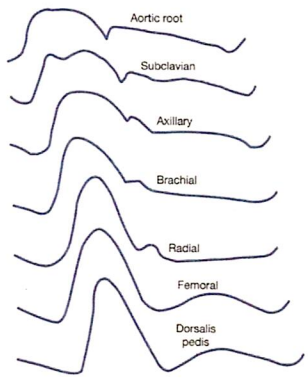
- Rapid decline in pressure as ventricular contraction ceases.
- Efflux of blood from central arterial compartment is faster than influx of blood from left ventricle.
- More rapid: Left ventricular outflow tract obstruction.



Dicrotic notch :

As aortic valve closes, there is a sudden increase in pressure.

Arterial pulse waveform: Analysis



Diastolic run-off :

- Drop in pressure after aortic valve has closed.
- No flow from the LV :
  - But pressure does not drop suddenly, decreases gradually.
  - Due to reservoir effect of aorta.
- Shape of reservoir pressure depends on characteristics of reservoir.

Diastolic run-off

