NEET SS ANAESTHESIA CRITICAL CARE

CONTENT

HEMODYNAMIC MONITORING-PART 1

Introduction 00:00:16

- Body here Cardiovascular organ dysfunction : 2nd most common organ dysfunction.
- Continuously observing changes in physiologic variables :
  1. To monitor organ function.
  2. For prompt therapeutic interventions.
  3. To evaluate response to therapeutic interventions.
- monitoring per se not improve patient outcomes.
- Timely applied right interventions can do.

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.

→

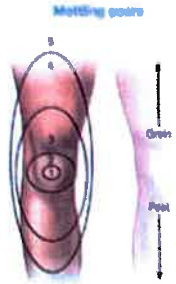
- Tachypnoea, tachycardia.
- Confusion.
- Altered skin perfusion.
- Oliguria.

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.

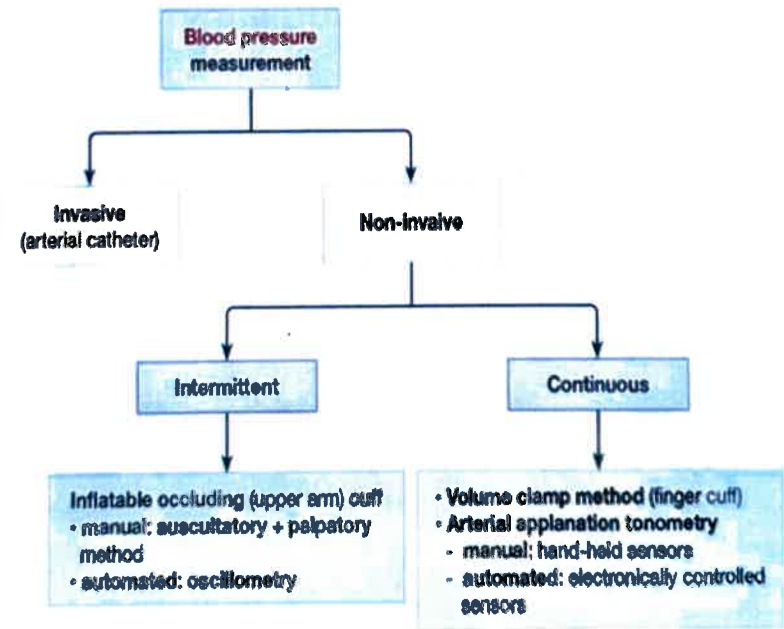
- Score 3 : mild mottling area that does not extend beyond the mid-thigh.
- Score 4 : Severe mottling area, not going beyond the groin fold.
- Score 5 : Extremely severe mottling area, extending beyond groin fold.



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

Manual intermittent	Automated intermittent
• Described by KOROTKOW 1905. • Sphygmomanometer, cuff, and stethoscope. • 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 inflates 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).

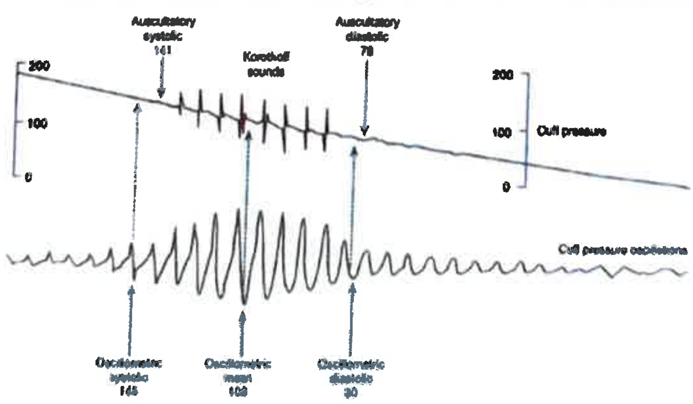
Cuff Size :

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

BP Cuff size

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)

Comparison of blood pressure measurements via Korotkoff sounds and oscillometry :



CNAP : Continuous noninvasive arterial pressure

Volume clamp method (finger cuff):

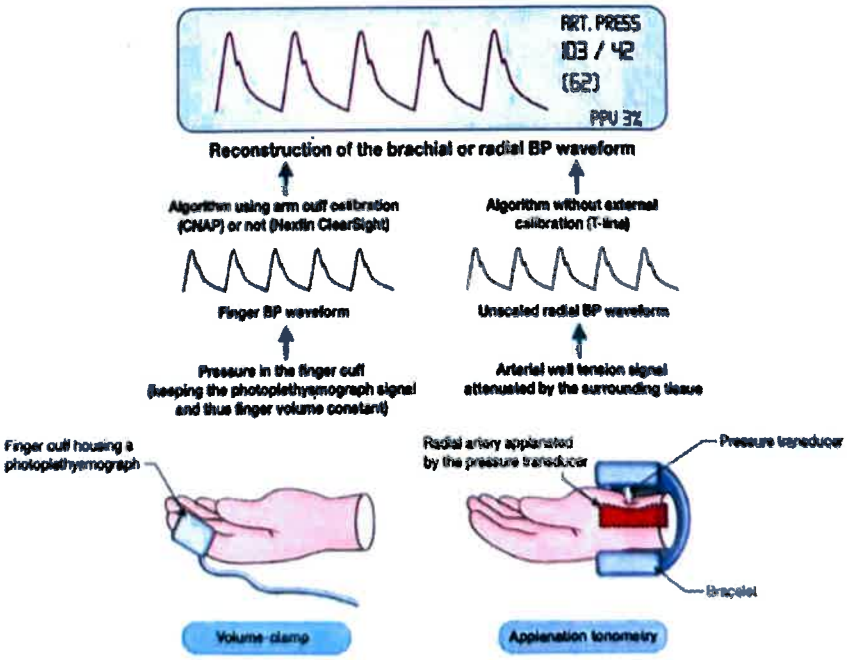
- Inflatable finger cuff with infrared plethysmography & monitor.
- Adjusts its pressure multiple times per second to finger artery constant.
- Produce a brachial arterial waveform.

B

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).

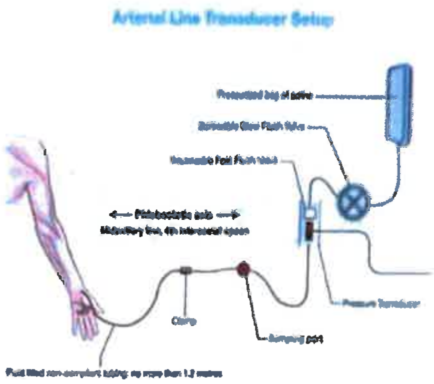
Oscillometric, volume-clamp, and applanation tonometry technol arterial BP



Invasive blood pressure:

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

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



Invasive blood pressure : Indications.

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

Relative contraindications : 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 (e.g. 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%).

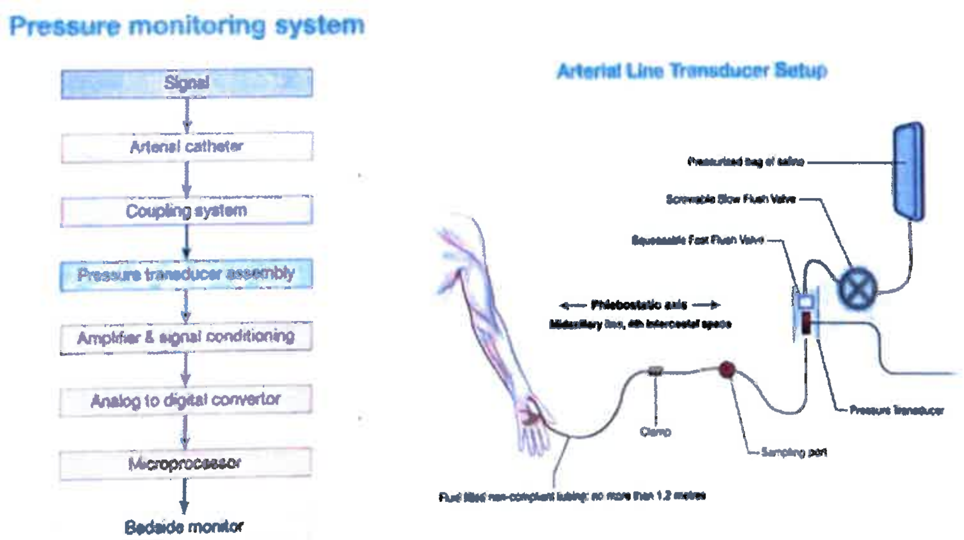
Common sites :

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 :



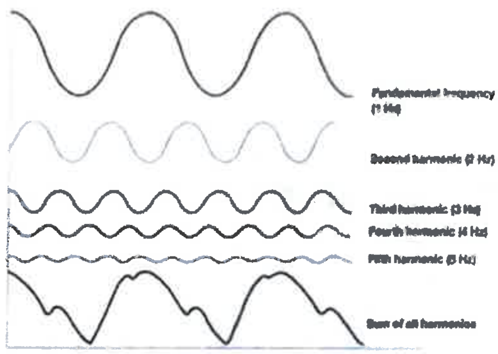
Zeroing & Levelling :

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

Fourier analysis of a complex waveform

00:20:27

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



Natural frequency :

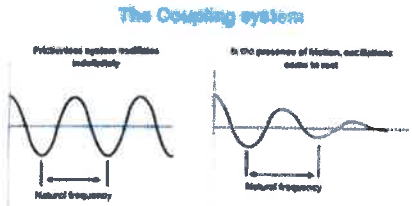
- Frequency at which a system oscillates.

  Maximum diameter
  minimum length
  Low Compliance

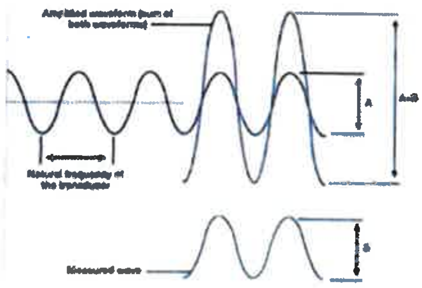
$$\text{Natural frequency } f_n = \frac{1}{2\pi}\sqrt{\frac{\pi D^2}{4\rho L}\cdot\frac{\Delta P}{\Delta V}}$$

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.



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



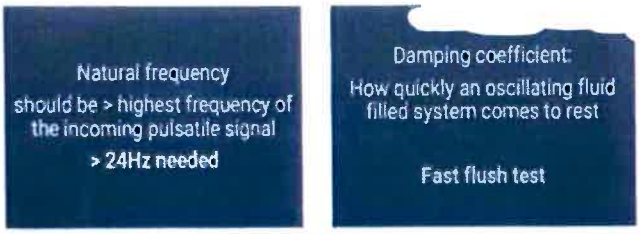
- If natural frequency of pressure transducer matches with each peak of arterial pressure wave :
  - Increase amplitude of the measured values.
- Transducer system must have a natural frequency well above the 8th harmonic frequency of a rapid pulse :

Damping :

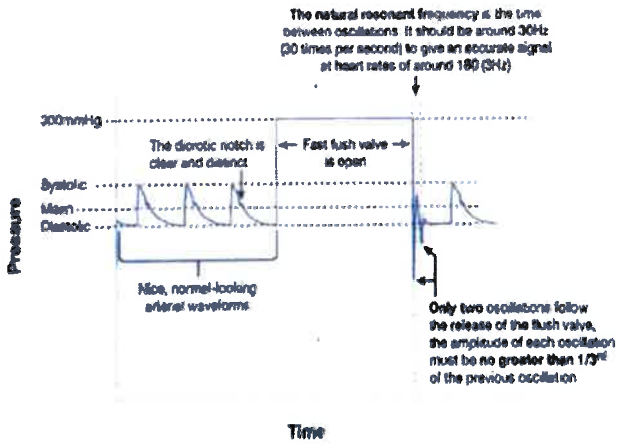
- Absorption of energy (amplitude) of oscillations :
  - Decreases amplitude of waves.
  - Reduces natural frequency of a system.
- Transducer system must be adequately damped :
  - Amplitude should not change due to resonance.
- Diameter of the tubing has the greatest effect on damping.
- Damping increases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

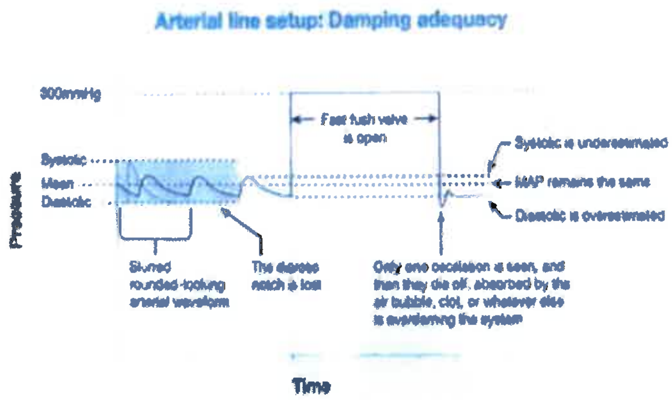
Dynamic response :

- Ability of the system to accurately reproduce hemodynamic waveform.

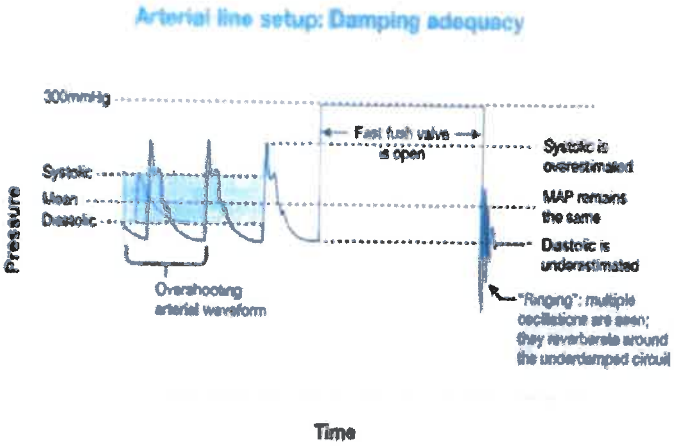


Arterial line setup : Damping adequacy



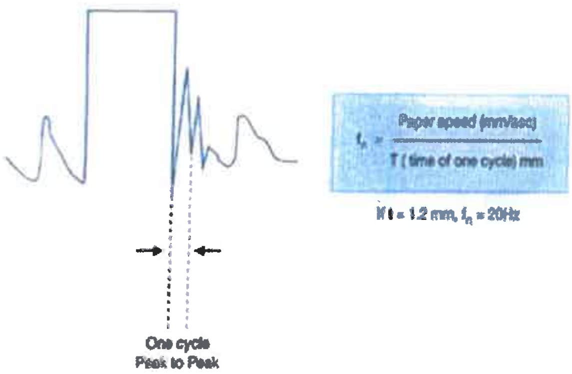


Clots, kinks, air bubbles, low compliant tubings, loose connection

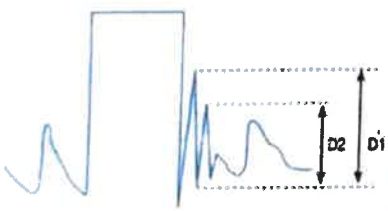


Long tubing, hyperdynamic circulation, tachycardia, hypertension, atherosclerosis

Determining fn :

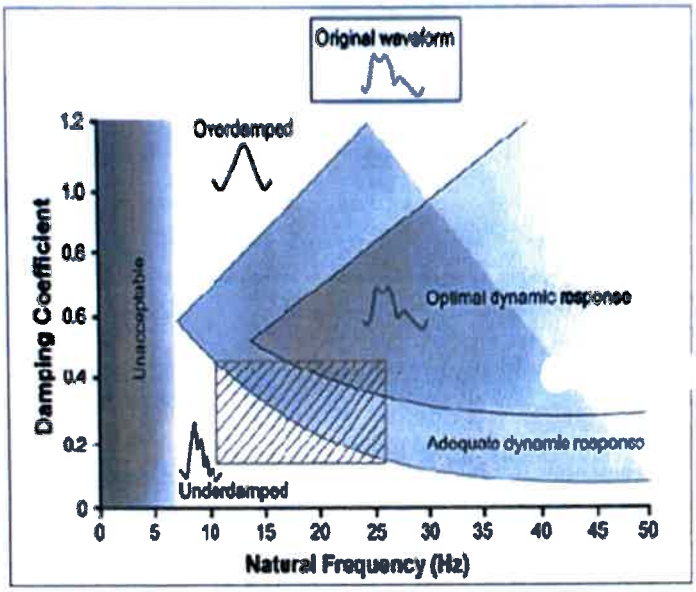


Amplitude Ratio :



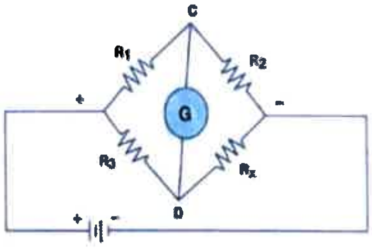
Amp Ratio (D2/D1)	Damping coefficient
0.9	0.034
0.8	0.071
0.7	0.113
0.6	0.160
0.5	0.215
0.4	0.280
0.3	0.358
0.2	0.456
0.1	0.591
0.05	0.690

Arterial line setup : dynamic response

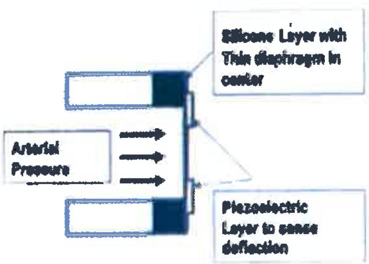


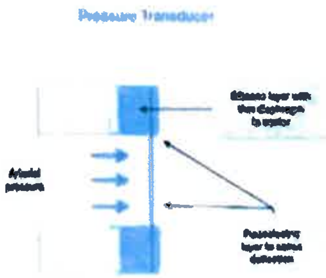
Pressure transducer :

- 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.



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





Arterial pulse waveform : Components

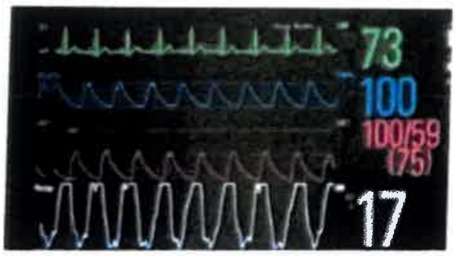
- Systolic phase : Rapid increase in pressure to a peak.
  - Begins with opening of aortic valve.
  - Corresponds to LV ejection.

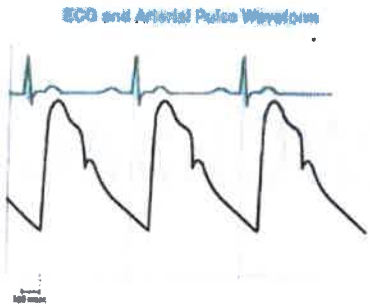
- Dicrotic notch :
  - Closure of aortic valve.

- Diastolic phase :
- Run-off of blood into peripheral circulation.

Arterial pulse waveform : Analysis

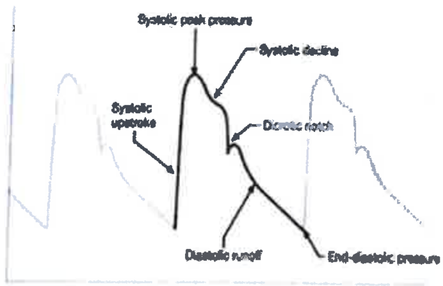
- On ECG, R wave signals beginning of systole.
- Systolic upstroke does not occur immediately following systole.
- There is 160-180 millisecond delay.





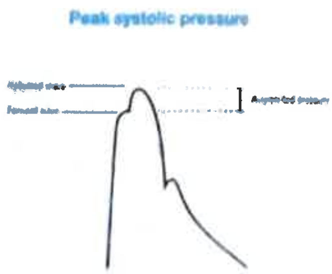
Systolic upstroke :

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



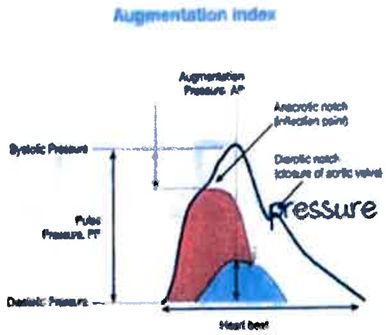
Peak systolic pressure :

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



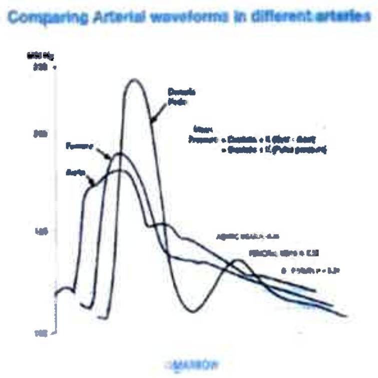
Augmentation index :

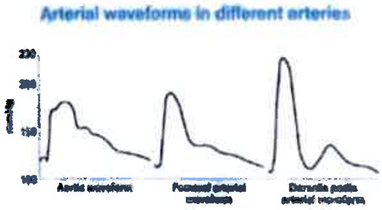
- Wave reflected from periphery to central aorta augments aortic pressure.
- It is a measure of systemic arterial stiffness.
- Calculated as ratio of augmentation to pulse pressure.



Distal systolic pulse amplification :

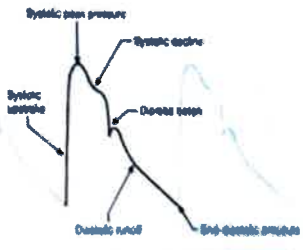
- Demonstrates change in systolic pressure on moving further from aortic root.
- Due to action of reflected waves on systolic pressure.
- Accumulating more of reflected pressure waves on top of systolic peak.





Systolic decline :

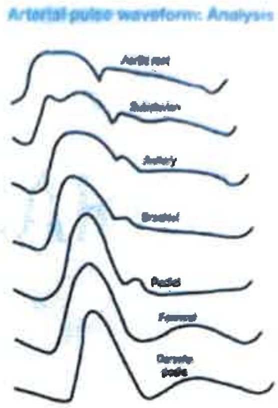
- Rapid decline in pressure as ventricular contraction ceases.
- Efflux of blood from central arterial compartment is faster than influx of blood from left ventricle.
- more rapid: Left ventricular outflow tract obstruction.



Arterial pulse waveform : Analysis

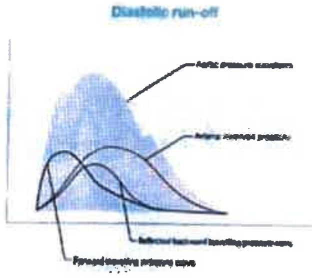
Dicrotic notch

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



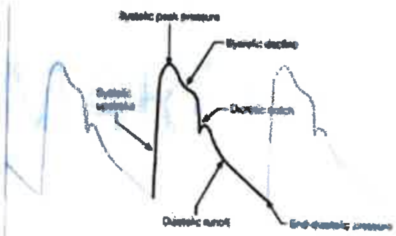
Diastolic run-off :

- 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.

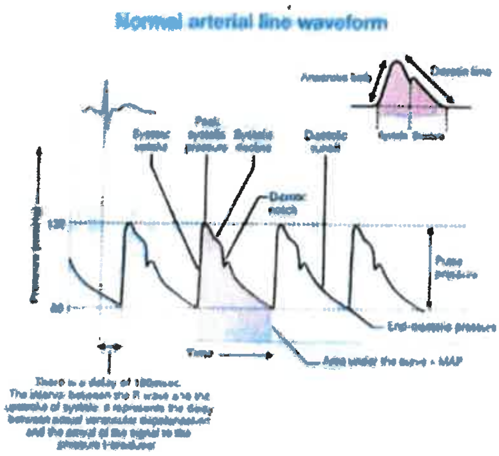


End diastolic pressure :

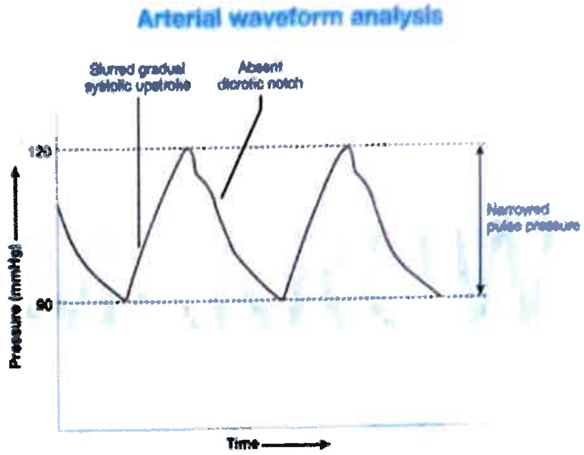
- Pressure exerted by vascular tree back upon aortic valve.
- Non-compliant vessels will raise it.
- Vasoplegic patient : Low diastolic pressure.



Normal arterial line waveform :

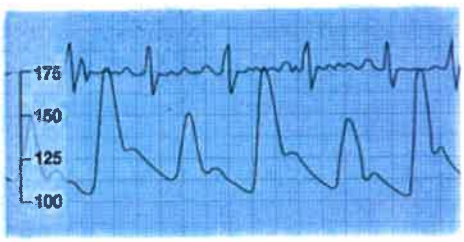


Arterial waveform analysis : Cardiac dysfunction



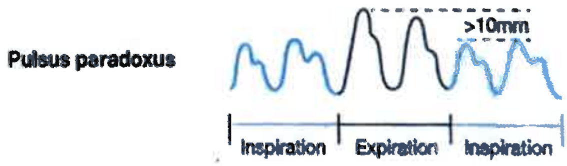
Pulsus alternans :

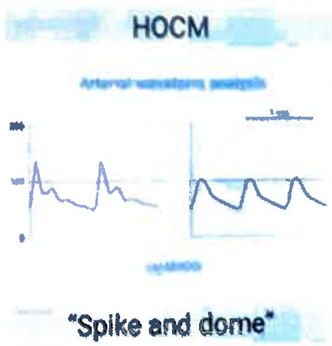
Alteration of beats with higher & lower pulse pressures indicative of severe left ventricular dysfunction.



Pulsus paradoxus :

Exaggerated inspiratory fall in systolic blood pressure >10 mm Hg.





Arterial waveform : Information

- From measurements :
  - Heart rate.
  - Systolic pressure.
  - Diastolic pressure.
  - mean arterial pressure.
  - Pulse pressure.
  - Changes in amplitude with respiration.

- From waveform shape :
  - Slope of anacrotic limb : Aortic valve & LVOT flow.
  - Slurred/collapsing wave : AS.
  - Rapid systolic decline : LVOTO.
  - Low dicrotic notch : Poor peripheral resistance.
  - Quality of dicrotic notch : Damping coefficient.

CENTRAL VENOUS LINE AND CVP MEASUREMENT

Need of CVP lines

00:00:33

- Physical examination of the neck veins has been a fundamental aspect of cardiovascular assessment.
- The bedside diagnosis of low, normal, or high CVP is often inaccurate, particularly in critically ill patients.
- Direct measurement of CVP is necessary in hemodynamically unstable patients & those undergoing major operations.
- SSG (2016) deemphasized the role of CVP as a marker of fluid responsiveness.

Introduction

- It is the pressure in thoracic veins near right atrium.
- major determinant of filling pressure/ Preload of RV.
- Preload = End diastolic volume.
- Assumptions :
  - Linear relationship between ventricular volume & Pressure.
  - This relationship is constant.
  - LV end diastolic pressure correlates with Atrial Pr / CVP.
- CVP measures filling pressure of the right ventricle (RV).
- CVP measures the interplay of the :
  1. Circulating blood volume.
  2. Venous tone.
  3. Right ventricular function.

Indications for central venous cannulation :

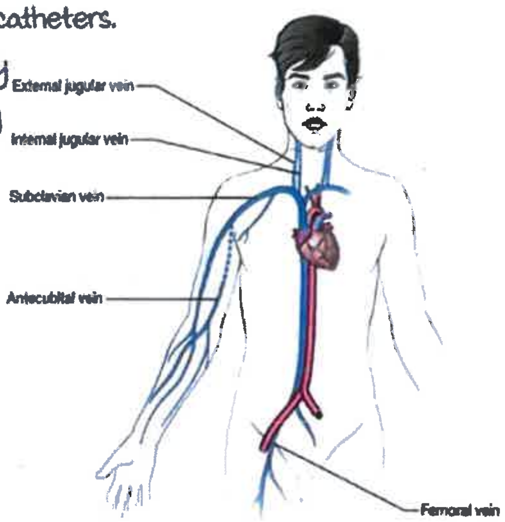
- CVP monitoring.
- Temporary HD.
- Aspiration of air emboli
- Drug administration :
  - Concentrated vasoactive drugs.
  - RPM.
  - Chemotherapy.
  - Prolonged antibiotic therapy (e.g., endocarditis).

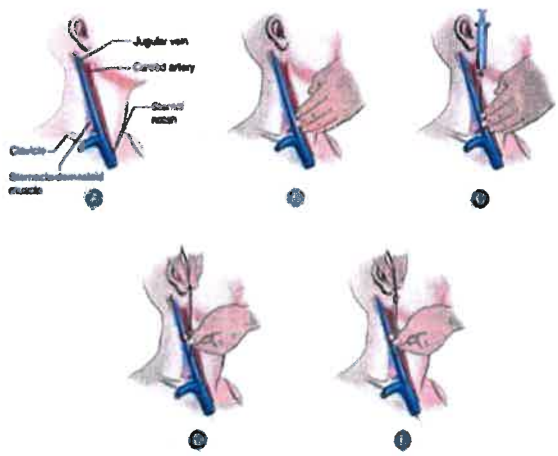
- Inadequate peripheral IV access.
- Sampling site for repeated blood testing.
- Transvenous cardiac pacing.

Choosing the catheter site, & method of central venous cannulation

00:06:45

- Seven-French, 20-cm multiport catheters.
- Length of catheter inserted vary according to puncture site, being 3 to 5 cm greater when the left IJV or EJV are chosen versus the rt IJV.
- Trauma : SV.
- Emphysema : IJV.
- Coagulopathy : IJV.





- A, Important surface landmarks are identified.
- B, The course of the ICA is palpated.
- C, The IJV is punctured at the apex of the triangle formed by 2 heads of the SCM muscle, with the needle tip directed toward the ipsilateral nipple.
- D, A guidewire is introduced through the thin walled needle into the vein.
- E, The central venous cannula is inserted over the guidewire while making sure that the proximal end of the guidewire protrudes beyond the catheter & is controlled by the operator.

Site selection for CVC :

Location selection		
Location	**Advantages**	**Disadvantages**
Internal Jugular	• Most ultrasound compatible • Straightest path into SVC	• Difficult with tracheostomy • Difficult if pacer wires or old HD catheters
Femoral Vein	• Highest success rate • Least mechanical complications	• Highest risk of DVT • Limits patient mobility • Obesity increases difficulty • No CVP monitoring • Avoid if IVC filter
Subclavian Vein	• Most comfortable for patient • Lowest risk of thrombosis • Lowest risk of infection	• Highest failure rate • Highest risk for pneumothorax • Highest risk of arterial puncture • Non-compressible bleeding • Stenosis and thrombosis of HD catheters

USG guided central venous cannulation :

- Fewer needle passes are required.
- Reduces the time required for catheterization.
- Increases overall success rates.
- Fewer complications

Short axis USG image showing Rt IJV & Common carotid artery :

Confirming catheter position :

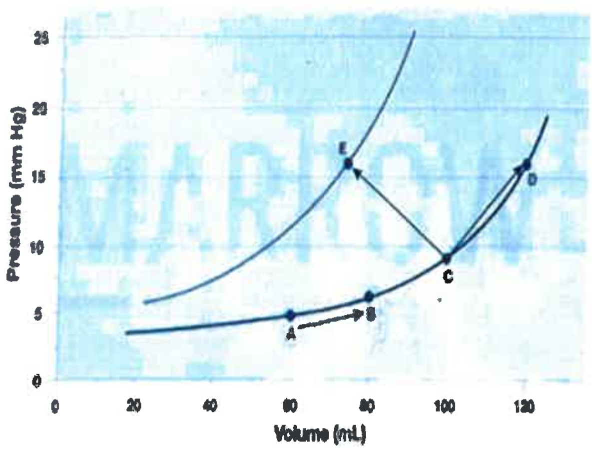
- Within the SVC, parallel to the vessel wall.
- Positioned below the inferior border of the clavicles & above the level of the 3rd rib/ T4 to interspace/azygos vein/ the tracheal carina, or the takeoff of the rt mainstem bronchus.

Complications of central lines

00:12:30

- mechanical :
  - Vascular injury :
    - Arterial.
    - Venous.
    - Haemothorax.
    - Cardiac tamponade.
- Respiratory compromise :
- Airway compression from hematoma.
- Pneumothorax.
- Arrhythmias :
- Subcutaneous/mediastinal emphysema.
- Thromboembolic :
  - Venous thrombosis.
  - Pulmonary embolism.
  - Arterial thrombosis & embolism (air, clot).
  - Catheter or guidewire embolism.
- Infectious risks (max at femoral site).

Physiologic considerations for CVP



Diastolic P-V relationships & transmural pressure :

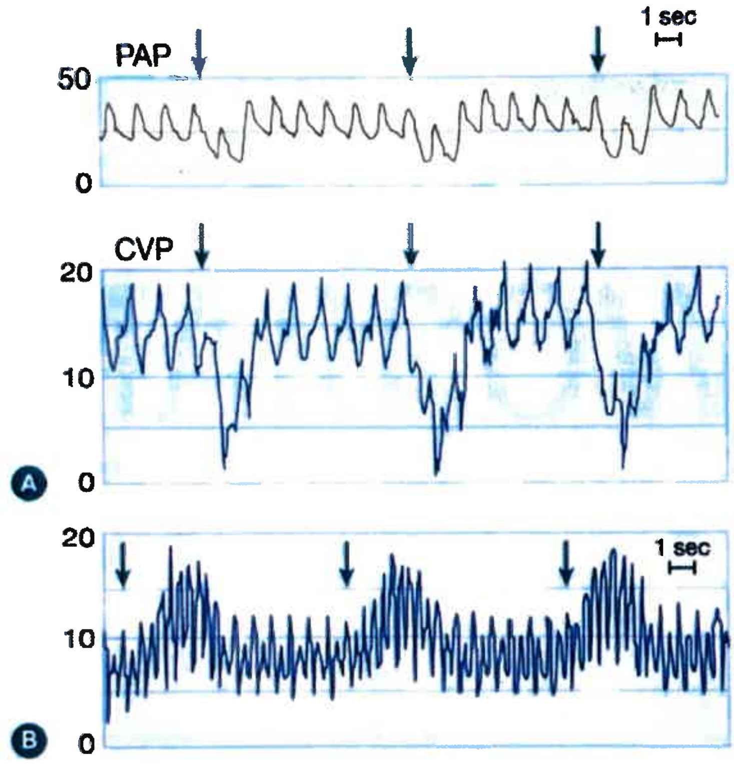
- The relationship between ventricular volume & filling pressure depends on the portion of the P-V curve over which the patient's heart is operating & the shape or slope of the curve.
- Diastolic dysfunction is present when changes in ventricular pressure are

abnormally elevated for any given change in ventricular volume.

- we should not equate cardiac filling pressures with filling volumes when patients are functioning over wide ranges of their diastolic P-V curve or under conditions in which diastolic stiffness is abnormal or changing rapidly.

Respiratory influences on the measurement of CVP :

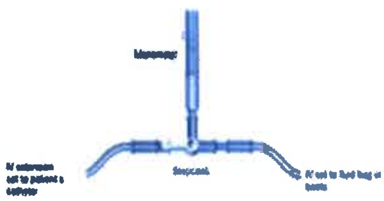
- CVP should be recorded at end-expiration.



A. During spontaneous ventilation, the onset of inspiration causes a decrease in intrathoracic pressure, which is transmitted to both the CVP & PAP waveforms.

B. During PPV, the onset of inspiration causes an increase in intrathoracic pressure.

Pressure monitoring :



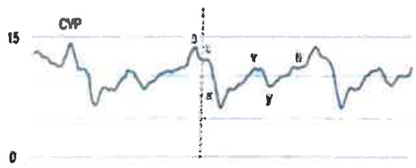
- Fluid filled transducer system.
- Fluid filled manometer.
    - Level stopcock at right Atrium.
- Used to measure cardiac filling pressures.
- CVP reflects the driving force for filling the rt atrium & ventricle

- CVP monitoring is used for assessment of blood volume & right heart function.
- Normal CVP in an awake, spontaneously breathing patient ranges between 1 to 7 mm Hg.
- CVP as the downstream pressure for organ perfusion.

CVP waveform components

00:21:50

Waveform Component	Phase of Cardiac Cycle	Mechanical Event
a wave	End diastole	Atrial contraction
c wave	Early systole	Isovolumic ventricular contraction, tricuspid motion toward the rt atrium
v wave	Late systole	Systolic filling of the atrium
h wave	Mid to late diastole	Diastolic plateau
x descent	Mid systole	Atrial relaxation, descent of the base, systolic collapse
y descent	Early diastole	Early ventricular filling, diastolic collapse



Waves	Rt Atrial Pressure	Lt Atrial Pressure
a wave	6 (2-7)	10 (4-16)
v wave	5 (2-7)	12 (6-21)
Mean	3 (1-5)	8 (2-12)

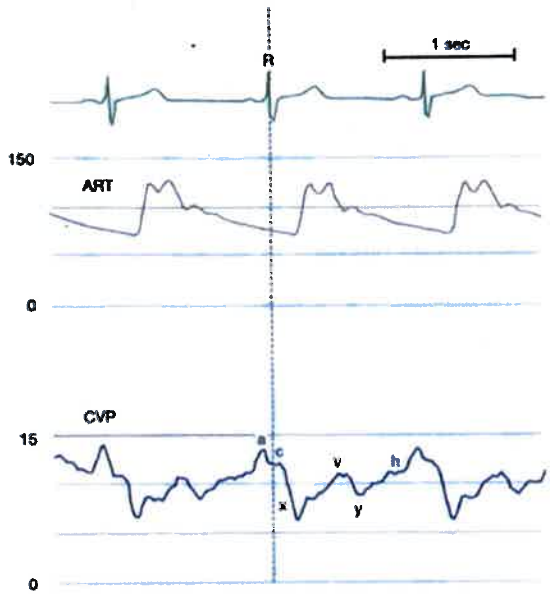
Waves	Rt Ventricle Pressure	Lt Ventricle Pressure	Pulmonary Artery Pressure	Central Aortic Pressure
Peak Systolic	25 (15-30)	130 (90-140)	25 (15-30)	130 (90-140)
End Diastolic	6 (1-7)	8 (5-12)	9 (4-12)	70 (60-90)
Mean			15 (9-19)	90 (70-105)

Normal Cardiovascular Pressures(mm Hg)

CVP waveform can be considered to have :

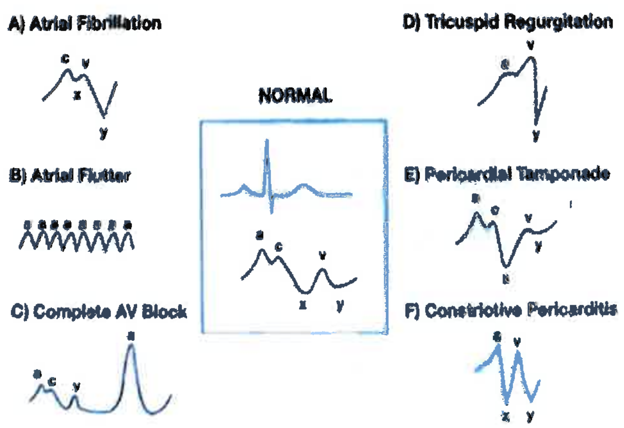
- 3 Systolic components (c wave, x descent, v wave) &
- 2 Diastolic components (y descent, a wave).
- ECG R wave mark end-diastole & the onset of systole.

CVP Waveform Components



- A short ECG PR interval causes fusion of the a & c waves.
- Tachycardia decreases the length of diastole & the duration of the y descent, which causes the v & a waves to merge.
- Bradycardia causes each wave to become more distinct, with separate x & x` descents visible & a more prominent h wave.

Abnormal CVP waveform :



Condition	Characteristics
Atrial Fibrillation	Loss of a wave
	Prominent c wave
AV Dissociation	Cannon a wave
Tricuspid Regurgitation	Tall systolic c-v wave
	Loss of x descent
Tricuspid Stenosis	Tall a wave
	Attenuation of y descent
Rt Ventricular Ischemia	Tall a & v waves
	Steep x & y descents
	M or W configuration
Pericardial Constriction	Tall a & v waves
	Steep x & y descents
	M or W configuration
Cardiac Tamponade	Dominant x descent
	Attenuated y descent
Respiratory variation during spontaneous or PPV	Measure pressures at end-expiration

CARDIAC OUTPUT MONITORING

Need for COP monitoring

00:00:31

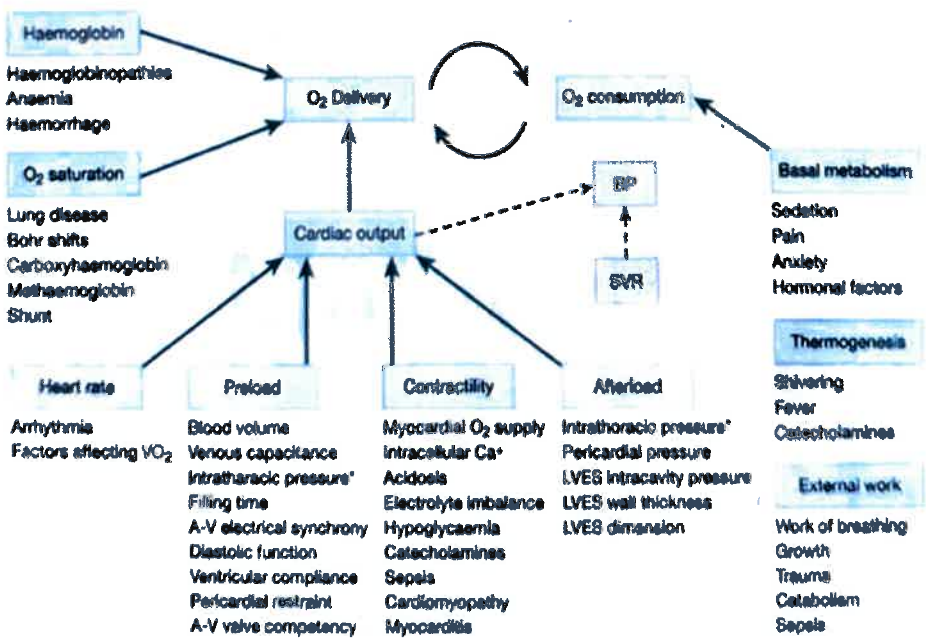
- Traditional parameters of hemodynamic stability (heart rate and blood pressure) are poor predictors of the degree of cardiac dysfunction or organ failure.
- Physicians are poor predictors of hemodynamics in critically ill patients.
- As much as 18% of "hemodynamically stable" sepsis patients (blood pressure > 90 mmHg, lactate < 4 mmol/L) can progress to severe sepsis and septic shock within 72 hours.

Glickman et al, Academic Emergency medicine, 2010

Cardiac output :

- Total blood flow generated by the heart in one minute.
- COP = SV X HR.
- Guides fluid responsiveness and need for vasopressor therapy.
- Provides an indirect indication of systemic oxygen delivery and global tissue perfusion.

Factors affecting oxygen delivery and consumption



Cardiac output monitoring devices :

Method	Monitoring System
Pulmonary thermodilution	Pulmonary artery catheter (PAC)
Transpulmonary thermodilution dilution	PiCCO VolumeView
Transpulmonary indicator dilution	LiDCO
Arterial pressure waveform-derived	PiCCO LiDCO Flotrac/Vigileo Volume clamp method (Finapres, Nexfin)
Oesophageal Doppler	CardioQ
Echocardiography (TTE and TOE)	
Applied Fick (Partial CO2 rebreathing)	NICO
Bioimpedance	Lifegard TEBCO HOTMAN BioZ
Bioreactance	NICOM

Methods of measuring cardiac output

00:00:21

1. Invasive- Pulmonary Artery Thermodilution :
   - Continuous.
   - Intermittent.
2. minimally Invasive :
   - Flotrac.
   - Lithium Dilution Cardiac Output monitoring (LiDCO).
   - Pulse Index Cardiac Output monitoring (PiCCO).
   - NICO System.
   - Transesophageal Echocardiography (TEE).
   - Esophageal Doppler (ED).
   - Endotracheal Cardiac Output monitor (ECOM).
3. Non invasive :
   - Echocardiography.
   - Thoracic Bioreactance.
   - Thoracic Bioimpedance.

Invasive- Pulmonary Artery Thermodilution :

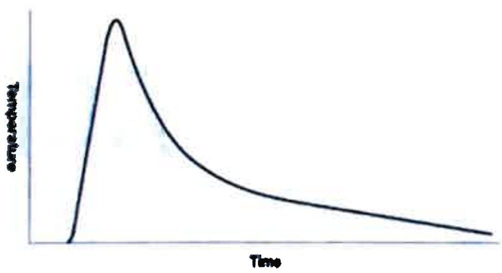
- Thermodilution is a modification of the indicator dilution technique.
- Injectate of known volume and temperature is used to obtain the thermodilution curve.
- CO is calculated from the area under the curve using the modified Stewart-Hamilton equation.

Modified Stewart-Hamilton equation

$$\dot{Q} = \frac{n}{\int c\,dt} = \frac{k(T_{core} - T_{injectate})\,V_{injectate}}{\int -\Delta T\,dt}$$

- Saline injected through the proximal port of pulmonary artery catheter.
- Thermistor at the distal end of catheter measures the change in blood temperature over time.
- Area under the curve is inversely proportional to the rate of blood flow past the pulmonary artery.

Thermodilution curve for pulmonary artery catheter



Sources of Error with PAC based measurements :

Technical errors :

- Loss of indicator before, during, or after injection.
- Variability of temperature and volume of injectate.
- Thermistor malfunction.
- Clot over the catheter tip or contact with a vessel.
- Wedged catheter.
- Coiling of the catheter.

Physiological & pathological states :

- Cardiac and respiratory oscillations.
- Rewarming in the initial minutes after cardiac bypass.

- Simultaneous rapid intravenous infusions.
- Intracardiac shunts.
- Pulmonary and tricuspid valve insufficiencies.

Continuous Thermodilution Cardiac output :

- 10 cm thermal filament located 15-25 cm from the catheter tip in the right ventricular portion of the catheter.
- It generates low-energy heat pulses transmitted to surrounding blood.
- Thermistor at the distal end of catheter measures the change in blood temperature over time.
- Updated every 30 to 60 sec & represents the average value for the cardiac output measured over the previous 3- 6 min.

Thermodilution → Advantages :

- Gold standard.
- Widely used.
- Low Cardiac Output correlated with mortality in multiple studies.
- Readily available in ICU.

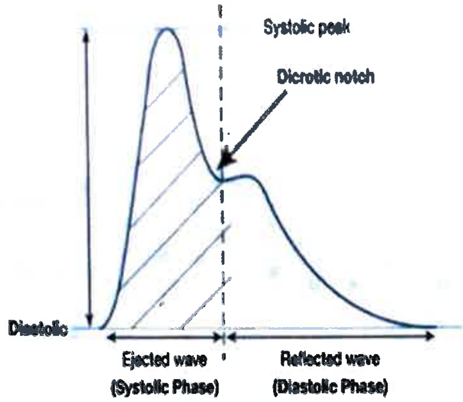
Thermodilution → Disadvantages :

- Invasive with Potential Infectious/mechanical Complications.
- Readings may Vary with Skill of Reader.
- Dynamic Variation Between measurements.
- No Definitive Evidence that Use Improves Outcomes.

Minimally invasive methods 00:14:22

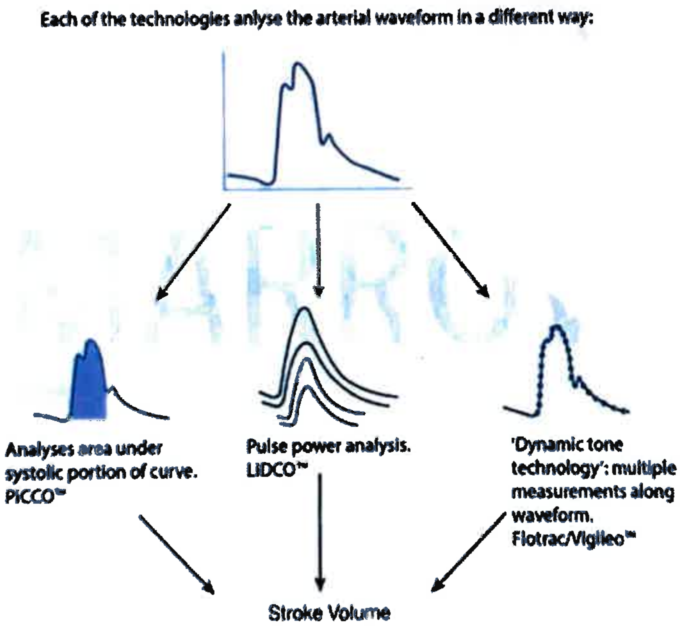
Pulse contour analysis :

- Principle :
  - Stroke volume can be continuously estimated by analyzing the arterial pressure waveform obtained from an arterial line.
  - CO is calculated from the area under the curve of the systolic portion of the arterial pressure waveform divided by the aortic impedance multiplied by the heart rate.



PiCCO system: Stroke volume is the area under systolic portion of arterial pulse waveform (shaded).
Stroke volume is calculated = (area under systolic phase (shaded) ÷ aortic complicance) x shape of pressure curve.

Arterial waveform analysis :

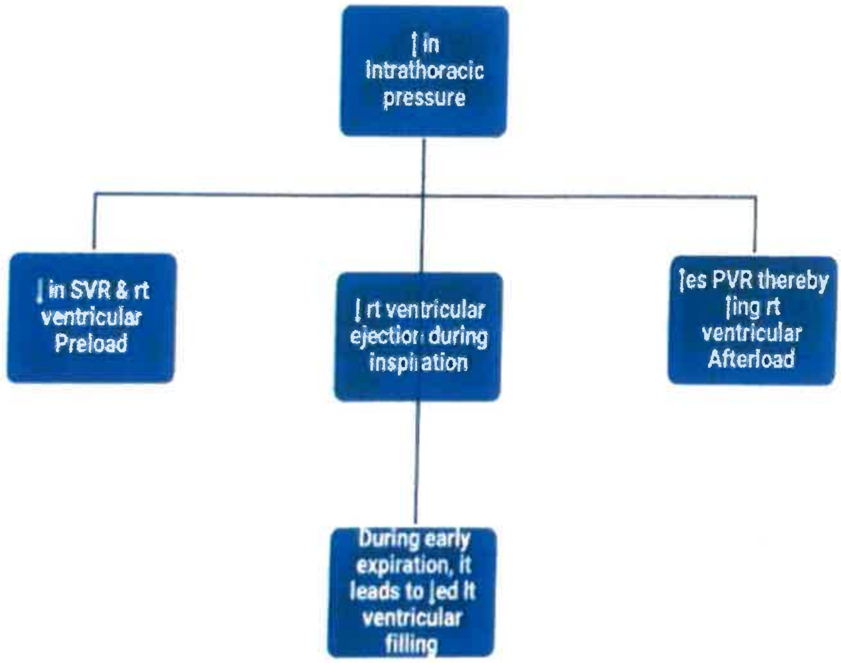


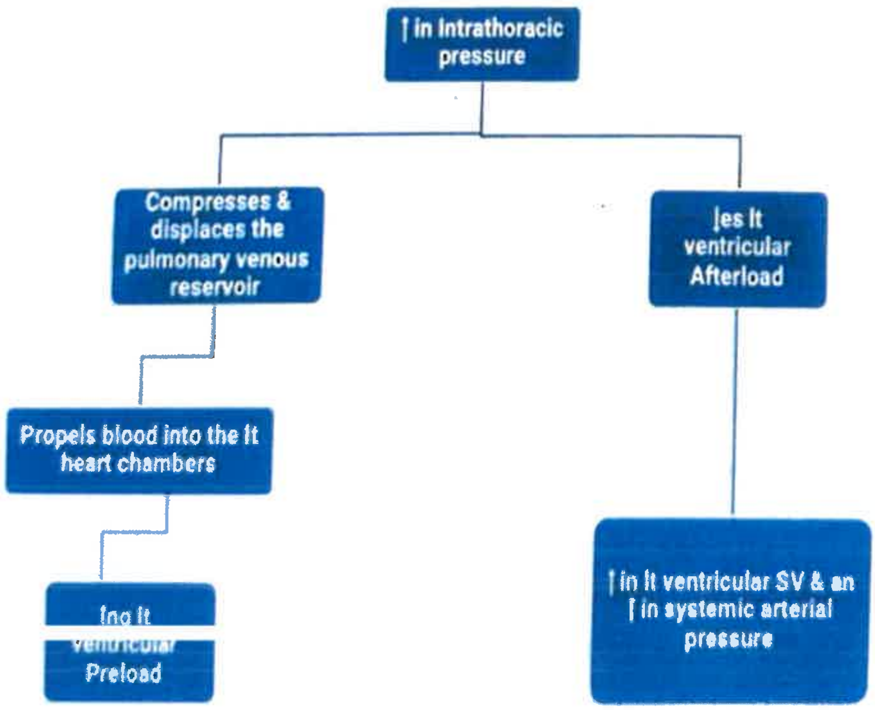
- Prerequisites :
  - Good arterial waveform signal is a must.
  - Correct identification of dicrotic notch.

- Limitations :
  - Linear relationship between Pressure & Volume.
  - Poor correlation with gold standard in low SVR.
  - Can't be used with IABP due to altered waveform.
  - Unreliable in arrythmias.

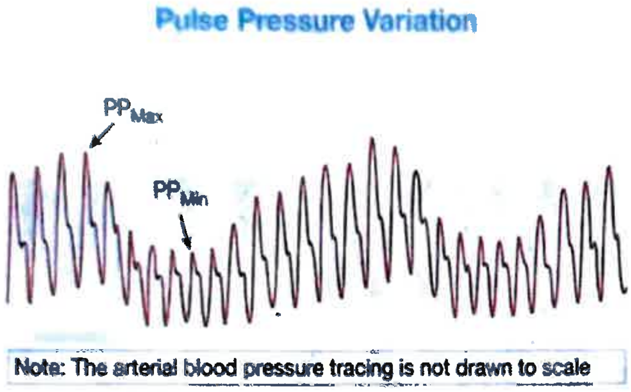
Arterial Pressure monitoring for Prediction of Volume Responsiveness :

- Variations in arterial BP observed during PPV are the most widely studied dynamic marker of volume responsiveness.
- They result from the changes in intrathoracic pressure & lung volume that occur during the respiratory cycle.





Pulse pressure variation :



$PP_{Max} = 150 - 70 = 80$

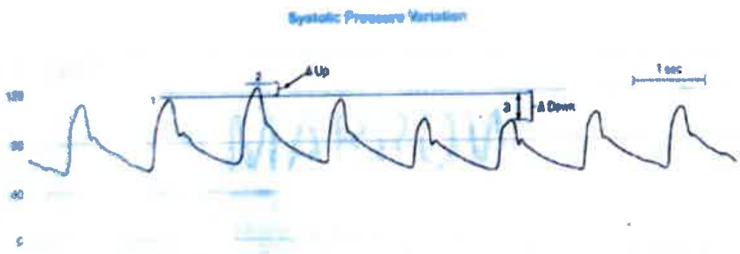
$PP_{Min} = 120 - 60 = 60$

$PPV = (PP_{Max} - PP_{Min})/([PP_{Max} + PP_{Min}]/2)$

$PPV = 80 - 60/([80 + 60]/2) = 29\%$

- Difference between the maximal (PPmax) & minimal (PPmin) pulse pressure values during oe mechanical respiratory cycle, divided by the average of these two ves.
- Normal PPV should not exceed 13%

Systolic pressure variation :



- In a mechanically ventilated patient, Normal SPV/ SVV is 7 to 10 mm Hg.
- SPV/SVV >10 indicates hypovolemia even though systolic arterial pressure & the HR are relatively normal.

Calibrated vs Non calibrated devices :

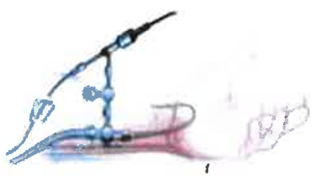
Calibrated	Non calibrated
• Device perform transpulmonary /indicatory thermodilution (TPTD). • Have calibration. • Done at specific intervals. • Better devices in sepsis, septic shock.	• Do not perform TPTD. • Analyse arterial waveform & gives reading of CO. • Reliability decreases on extreme vasoplegia.

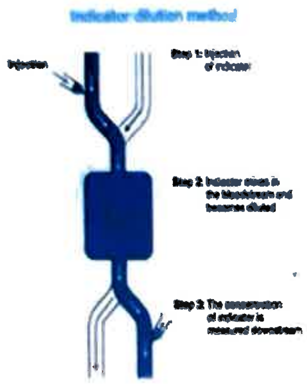
FloTrac/ Vigileo :

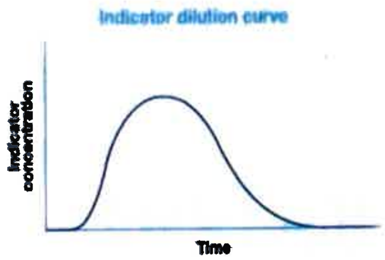
- Advantages :
  - Continuous CO measurement.
  - No calibration/ autocalibration.
  - many validation studies.
- Additional variables : SVV, SVR, CI.
- Invasiveness : Arterial line.
- Limitations :
  - Requires good fidelity of arterial waveform.
  - Not reliable in extreme vasoplegia.
  - Perform poorly with tachyarrhythmia.
  - Valvular pathology prevents accurate reading of CO.

Lithium Dilution Cardiac Output monitor(LiDCO) :

- Lithium Indicator Dilution : for calibration.
- Central/peripheral venous and arterial catheters.
- Injectate is an isotonic (150 mm) solution of lithium chloride (0.15 –0.30 mmol for an average adult).

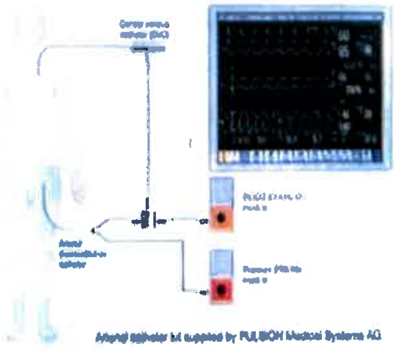




- Advantages :
  - Continuous CO measurement.
  - useful in goal directed therapy.
  - Safe, simple to use.
- Additional variables : SV, SVV, SVR.
- Invasiveness :
  - Arterial line.
  - Peripheral or central venous line.
- Limitations :
  - Requires good fidelity of arterial waveform.
  - Requires transpulmonary lithium dilution calibration.
  - Calibration affected by neuromuscular blockers.
  - Contraindicated in lithium therapy, first trimester of pregnancy.

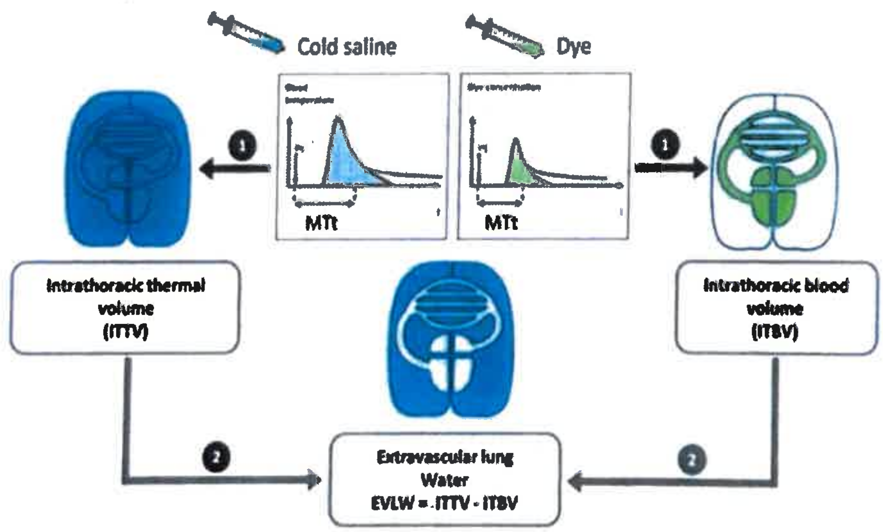
Pulse Index Cardiac Output monitor (PiCCO) :

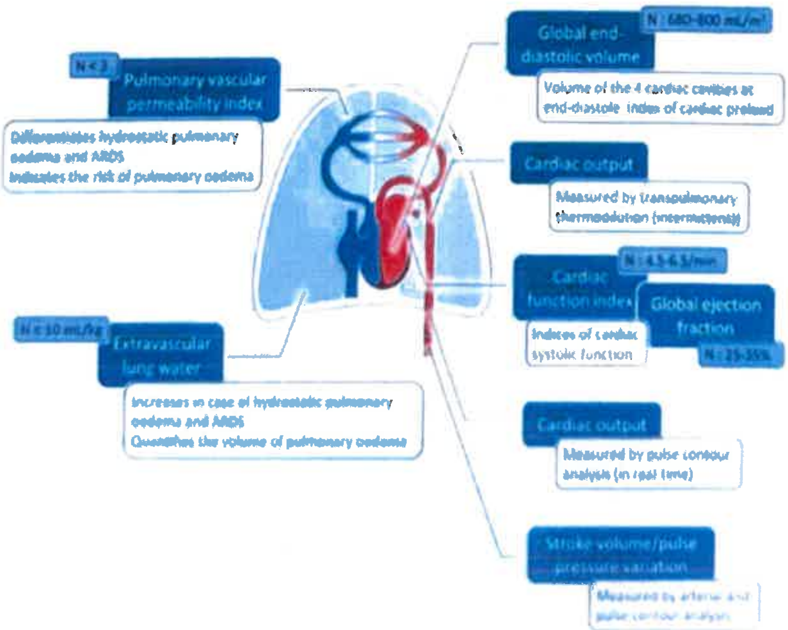
- Pulse contour analysis with intermittent thermodilution measurement.
- Enables continuous hemodynamic monitoring using :
  - Femoral or axillary artery catheter.
  - Central venous catheter.
- Adult or pediatric patients who have or may develop pulmonary edema or ARDS are likely candidates.



PiCCO measures :

1. Via Continuous pulse contour cardiac analysis :
   - Arterial blood pressure (AP).
   - Heart rate (HR).
   - Stroke volume (SV).
   - Stroke volume variation (SVV).
   - Systemic vascular resistance (SVR).
2. via intermittent transpulmonary thermodilution :
   - Transpulmonary cardiac output (C.O).
   - Intrathoracic blood volume (ITBV).
   - Extravascular lung water (EVLW).

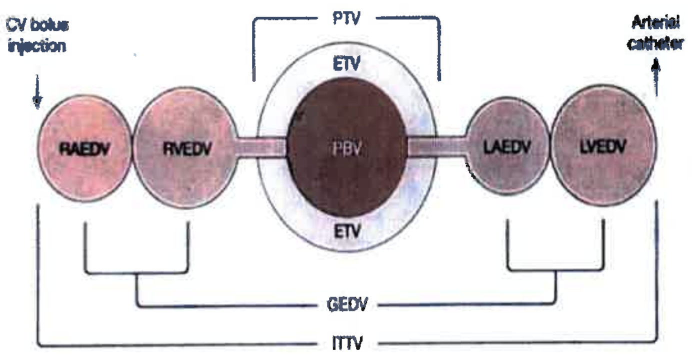




Clinical applications :

- Continually monitor cardiac output.
- Pulse contour devices also measure GEDV (global end diastolic volume) :
  - GEDV : ITTV – PTV.
  - ITTV (intrathoracic thermal vol) : CO x MTT.
  - PTV (pulmonary thermal vol) : CO x t.
- ITBV (intrathoracic blood vol) : 1.25 x GEDV.
- EVLW (extravascular lung water) : ITTV – ITBV.

Different volumes



PAC vs PiCCO

Aspect/variable	PAC	PiCCO
Cardiac output	Yes (continuous with special technology)	Yes (always continuous)
PAOP	Yes	No
Pulmonary pressures	Yes	No
RAP	Yes	Yes
RVEDV	Yes, with special technology	No
End-diastolic intrathoracic volume	No	Yes
Extravascular lung water index	No	Yes
Risk of pneumothorax	Yes	No
Risk of infection	+++	+
Risk of arterial puncture	Yes	No
Risk of pulmonary artery rupture	Yes	No
Risk of air embolus	Yes	No

PAC - Pulmonary artery catheter
PAOP - Pulmonary artery occlusion pressure
PiCCO - Pulse contour cardiac output
RAP - Right atrial pressure
RVEDV - Right ventricular end-diastolic volume

Advantages and disadvantages of different variables :

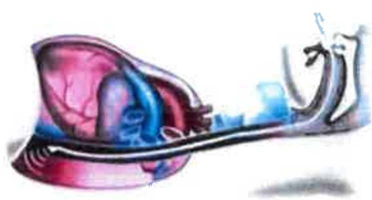
Variable	Main advantages	Main drawbacks
Cardiac output measured by TPTD	As reliable as pulmonary thermodilution	Does not provide a continuous measurement
Cardiac output measured by pulse contour analysis	Continuous measurement Precise measurement Assesses short-term and small changes	Requires regular recalibration
Global end-diastolic volume	Better reflects cardiac preload than pressure markers of preload	Does not distinguish between the right and left ventricles Less directly reflects the risk of pulmonary oedema than PAOP
Stroke volume variation	Continuous automated assessment of fluid responsiveness	Cannot be used in case of spontaneous breathing, cardiac arrhythmias and ARDS
Cardiac function index, global ejection fraction	Can be used as an alarm for decreased LV systolic function	Overestimate LV systolic function in case of right ventricular dilation Indirect markers of cardiac systolic function Do not precisely assess cardiac structure and function
Extravascular lung water	Directly estimates the volume of lung oedema	Unreliable in case of pulmonary embolism, lung resection, large pleural effusions
Pulmonary vascular permeability index	Directly estimates lung permeability Distinguishes hydrostatic from permeability pulmonary oedema	Same as for extravascular lung water

Fick's Principle :

- Carbon dioxide rebreathing technique.
- Advantages : Ease of use.
- Additional variables :
  - Shunt.
  - Ventilatory variables.
- Invasiveness :
  - Endotracheal intubation.
  - Valid only with $PaCO_2$ > 30 mmHg.
- Limitations :
  - Affected by changes in dead space or V/Q matching.

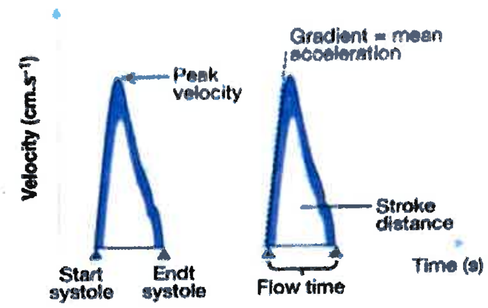
Esophageal Doppler :

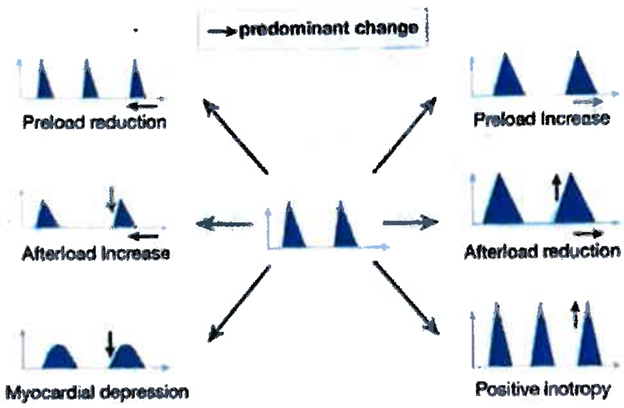
- measurement of blood flow velocity in the descending aorta at the tip of the flexible probe.
- 4 MHz continuous or 5 MHz pulsed wave.
- measures CO , SV, HR.



Interpretation of data :

- SV is measured by stroke distance x aortic root diameter.

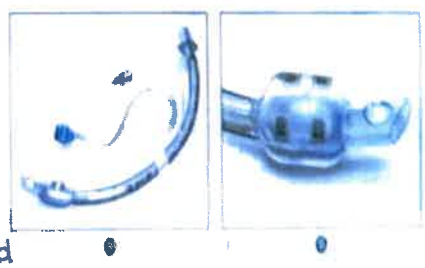




- Advantages :
  - Continuous cardiac output monitor.
  - useful in goal-directed therapy.
- Invasiveness : Esophageal probe.
- Limitations :
  - Needs intubated patient.
  - measures only descending aortic flow.
  - Assumptions about aortic size may be erroneous.
  - Operator dependant.

Endotracheal Cardiac Output monitor(ECOM) :

- measures CO using impedance plethysmography.
- The ascending aorta lies in close proximity to trachea.



- using the principle of bioimpedance, a current of 2mA and 200 KHz is delivered from electrodes attached to a standard endotracheal tube.
- Sensing electrodes on the cuff detect the change in impedance secondary to aortic blood flow.