Hemodynamic Monitoring

Amjad Bani Hani

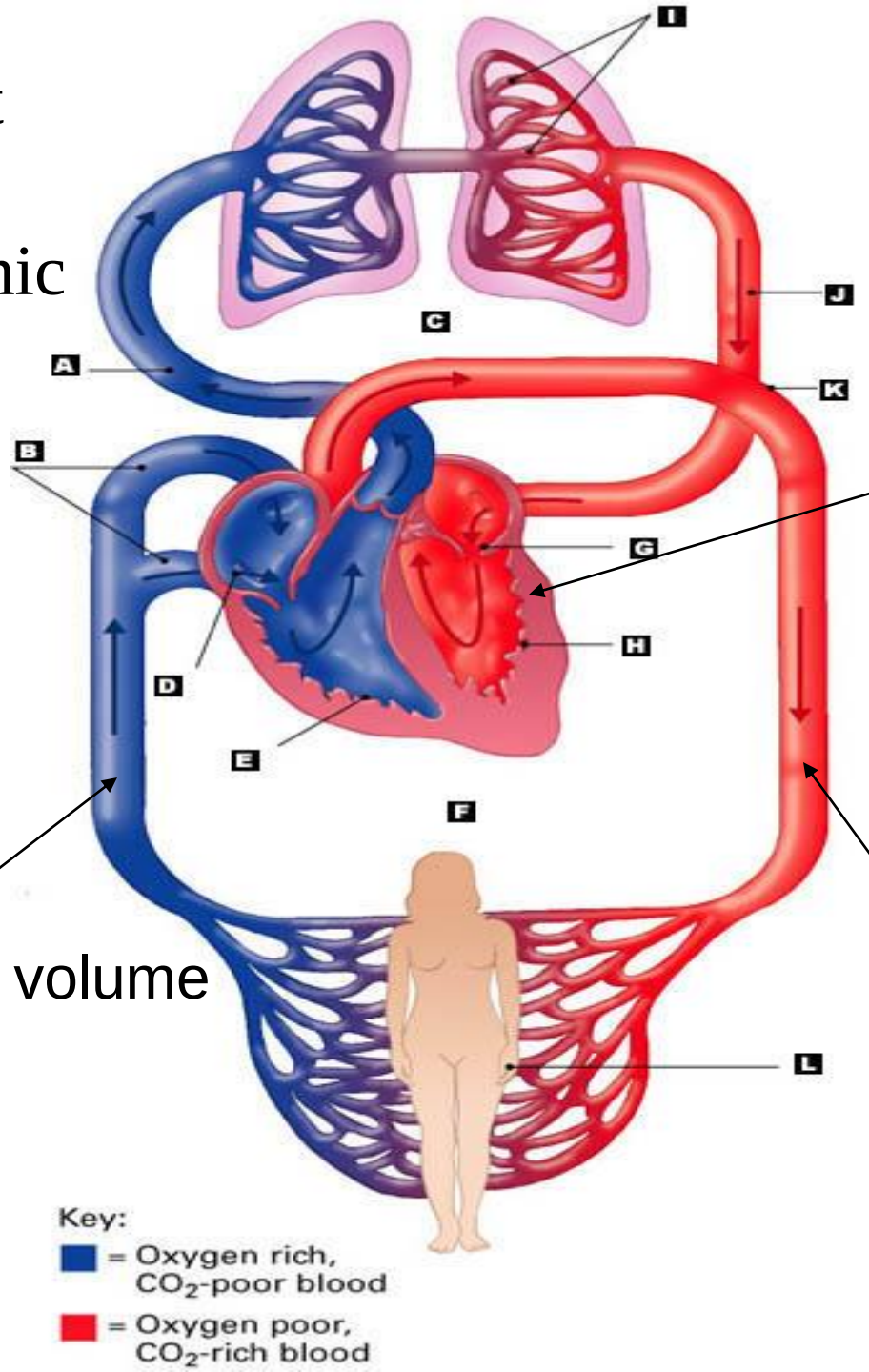
- Hemodynamic monitoring plays a fundamental part in the initial assessment and the subsequent guidance of the treatment of critically ill patients suspected of or suffering from circulatory shock

- About one-third of patients in the ICU eventually experience circulatory shock, and patients with circulatory shock have increased risks of multiorgan failure, long-term morbidity, and mortality

Introductions

- Hemodynamics is concerned with the forces generated by the heart and the resulting motion of blood through the cardiovascular system
- Hemodynamic monitoring is the intermittent or continuous observation of physiological parameters pertaining to the circulatory system with a view to early detection of need for therapeutic interventions

4 factors that affecting the haemodynamic conditions



Myocardial contraction and heart rate

Vasoactivity

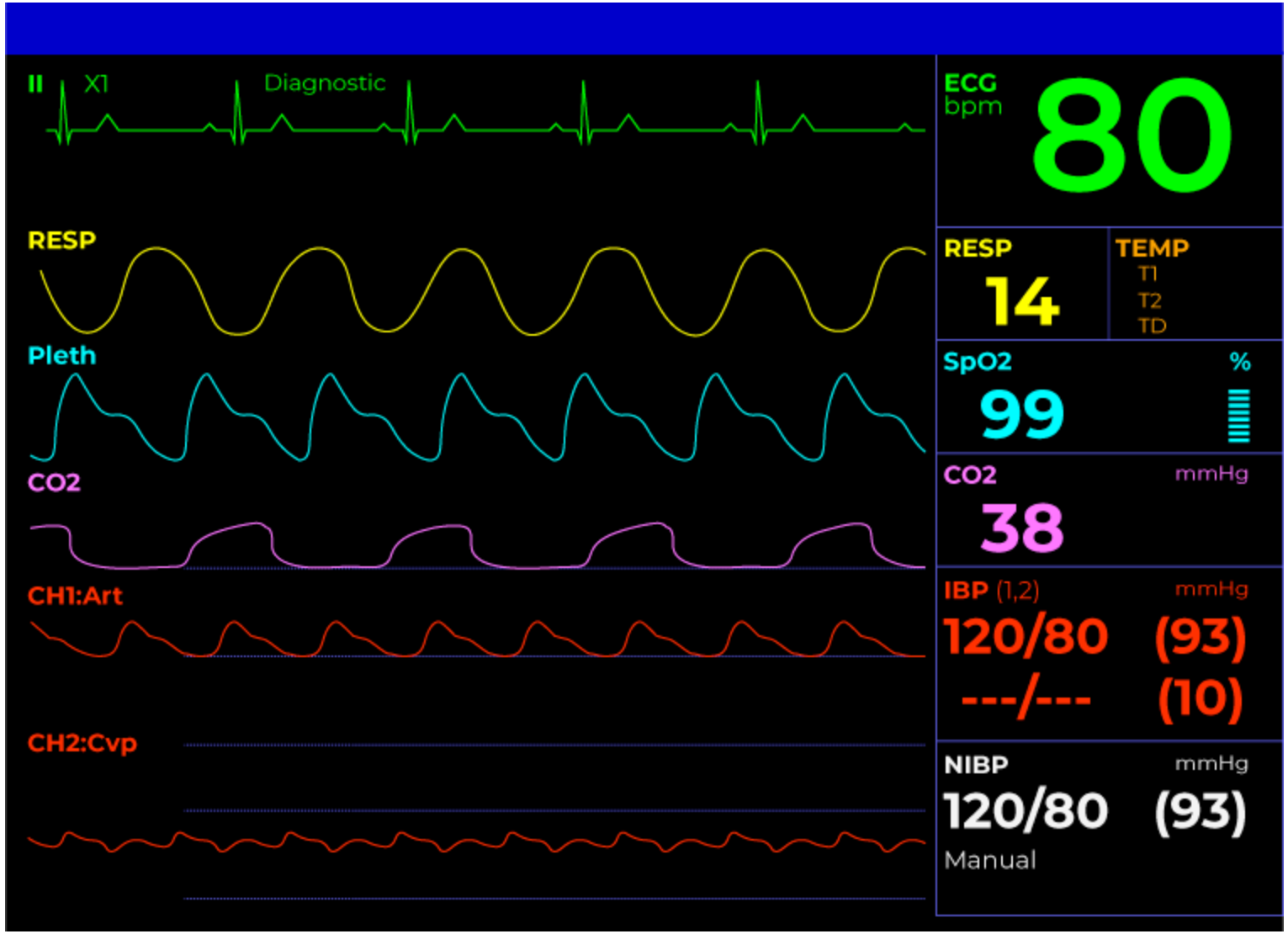
Intravascular volume

Clinical examination

- Clinical examination of the cardiovascular system can be used to assess perfusion or to estimate cardiac output (CO), and its daily application in critically ill patients makes it the first step of hemodynamic monitoring in suspected circulatory shock

- History
- Physical Examination

1. **Temperature**
2. **Pulse**
3. **Blood pressure**
4. **Respiratory rate**
5. **Pain**
6. **Oxygen saturation (SpO2)**
7. **Level of consciousness**
8. **Urine output**
9. **ECG**
10. **Lactate**

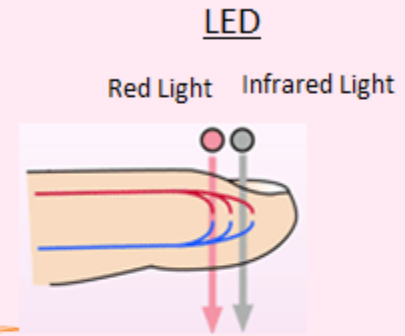

II
X1
Diagnostic
RESP
Pleth
CO2
CH1:Art
CH2:Cvp
ECG
bpm
80
RESP
14
TEMP
T1
T2
TD
SpO2
%
99
CO2
mmHg
38
IBP (1,2)
mmHg
120/80
(93)
---/---
(10)
NIBP
mmHg
120/80
(93)
Manual

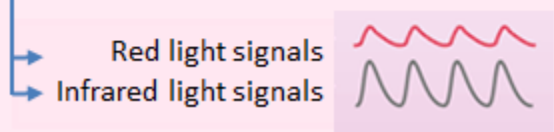
- HR 60-100
- Sinus Rhythm
- Ischemic changes
- Heart Block
- Arrhythmia
- Electrolyte imbalance

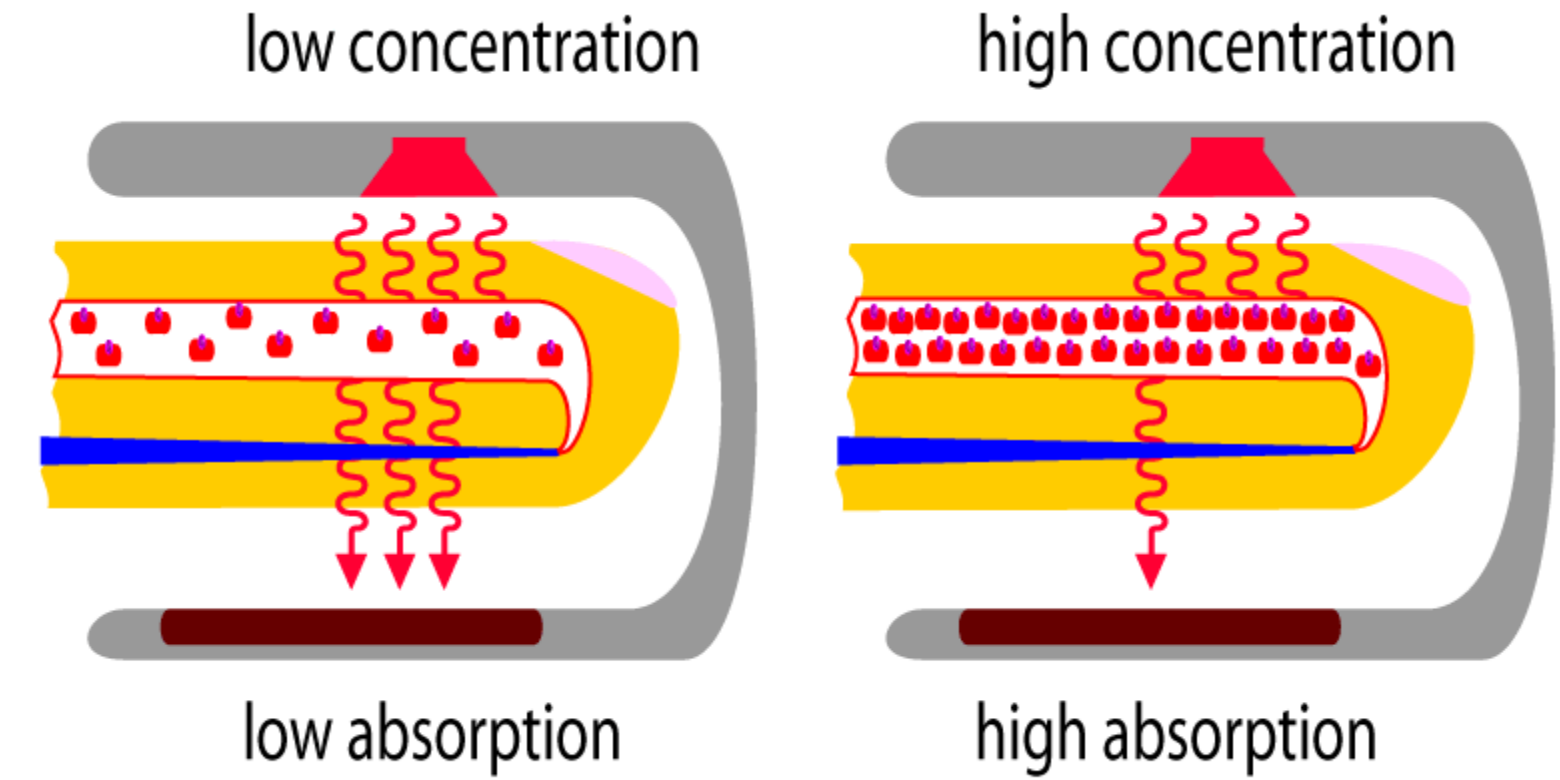
Probe emits two LED wavelength, red light emitting diode and infrared light, to measuring site

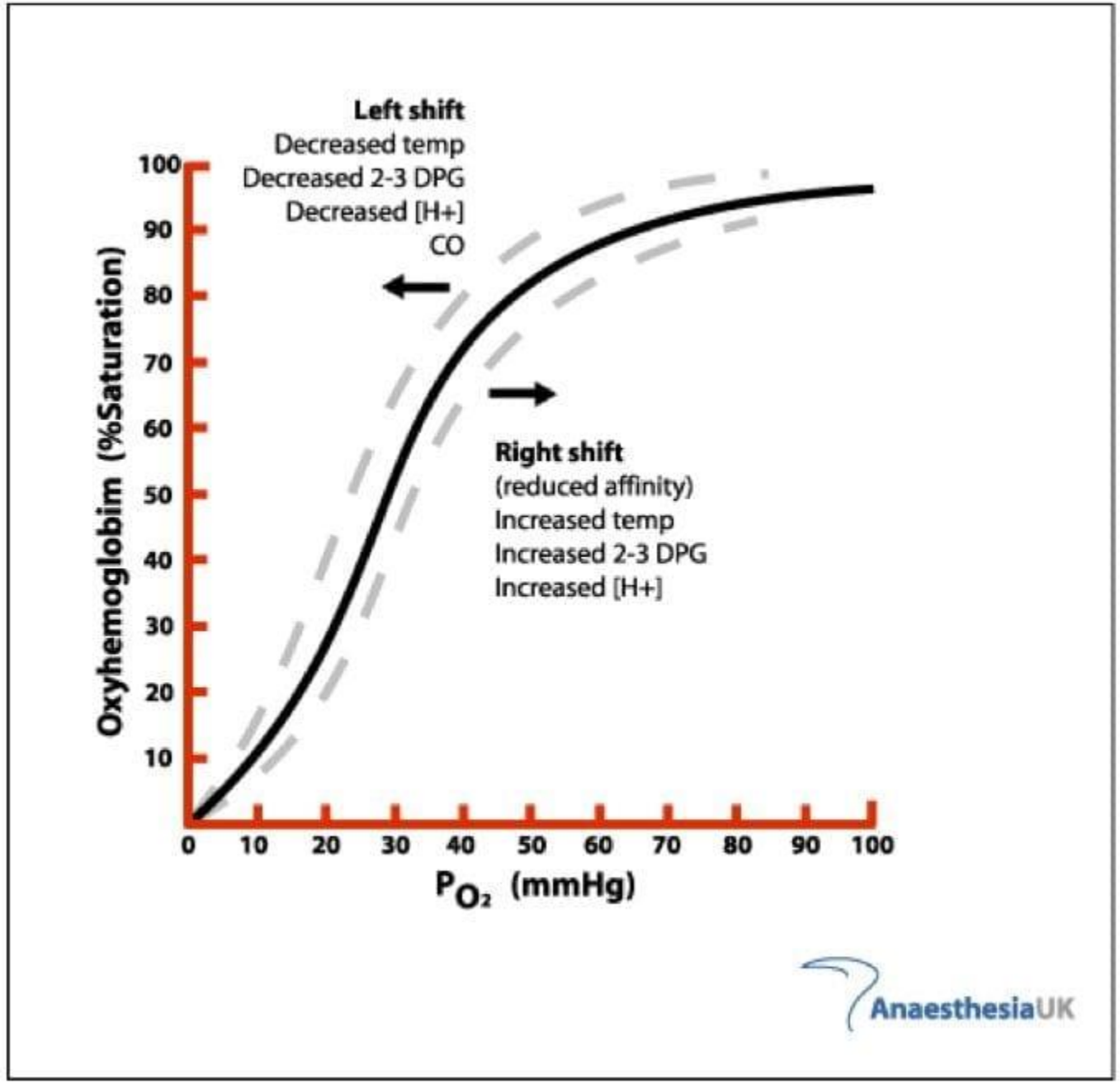
Photo detector will detect light signal of two wavelengths and pulse wave which penetrated the measurement site

SpO2 is calculated from the absorbency of the signal and pulse waves by hemoglobin






low concentration
high concentration
low absorption
high absorption
how equipment works .com


Left shift
Decreased temp
Decreased 2-3 DPG
Decreased [H+]
CO
Right shift
(reduced affinity)
Increased temp
Increased 2-3 DPG
Increased [H+]
Oxyhemoglobim (%Saturation)
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
P_{O_2} (mmHg)
AnaesthesiaUK


Romsons
CE
ml
UROMETER

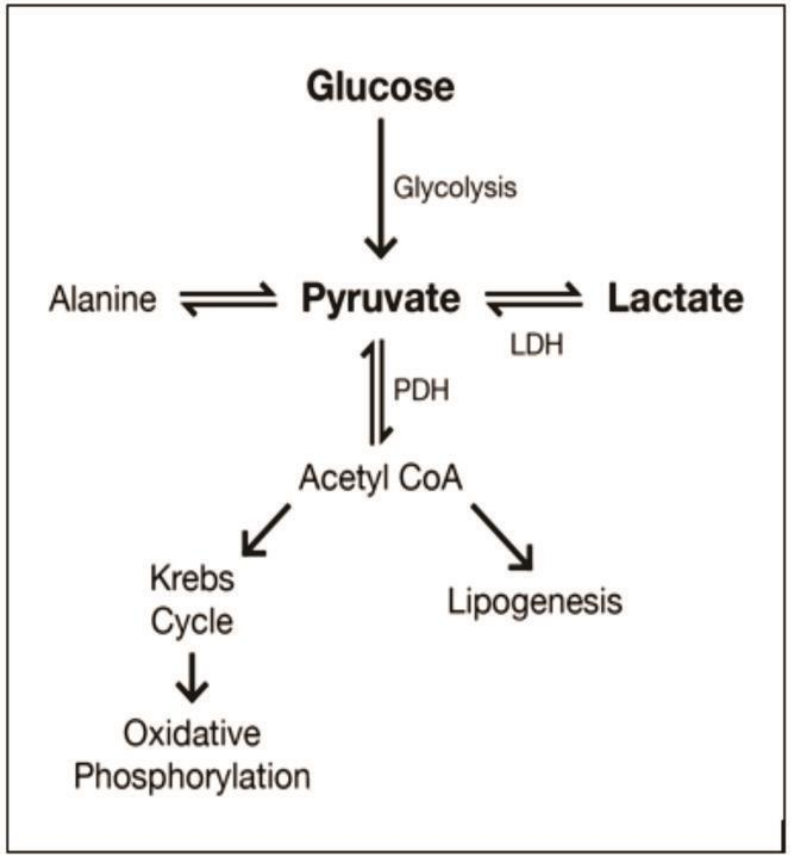


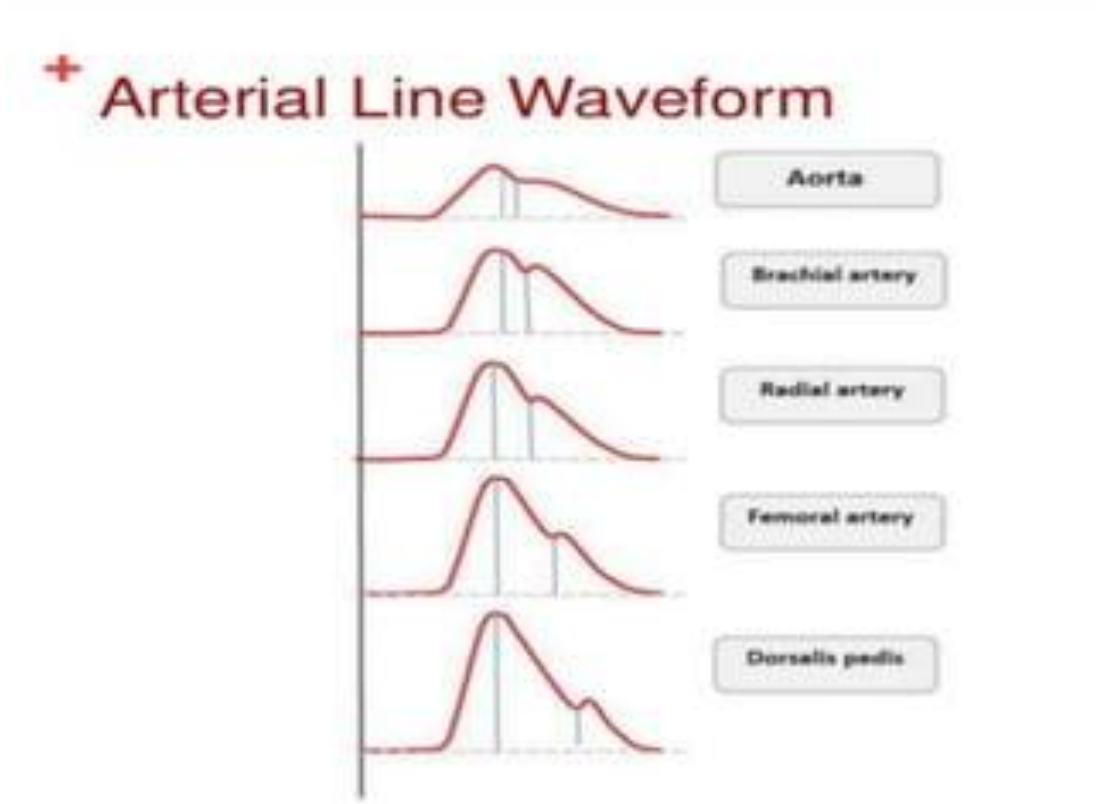
Figure 1: Pathway of pyruvate and lactate metabolism

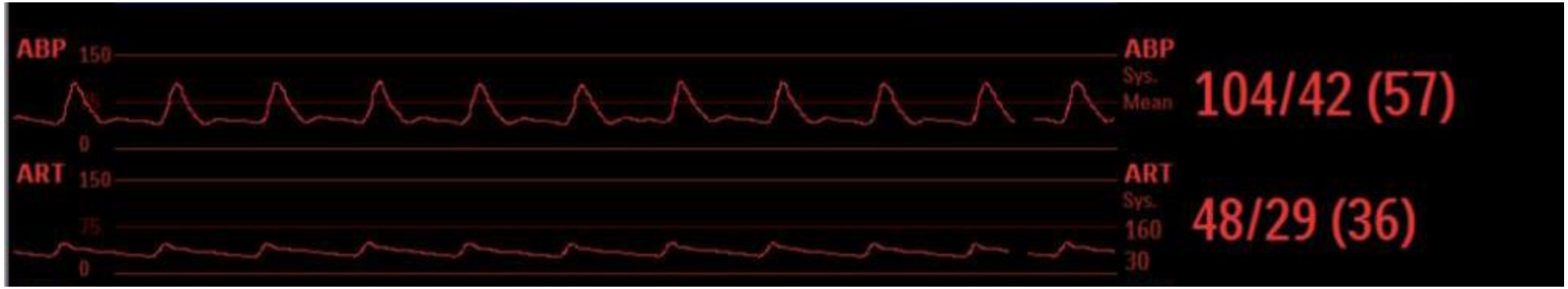
Table 2 : Diagnoses to Consider in Septic Patients with Elevated Lactate

Causes of Elevated Lactate	Consider
Hypovolaemic shock	Ensure volume resuscitation prior to or along with commencement of vasopressors
Cardiogenic shock	Consider cardiac dysfunction as a co-morbid cause of hyperlactataemia
Drugs	Consider metformin, NRTIs, linezolid
Toxins	Consider the lactate gap (ethylene glycol poisoning), cyanide poisoning, paracetamol overdose
Adrenaline / salbutamol use	Interferes with interpretation of lactate levels as markers of resuscitation
Co-existent hepatic dysfunction	Routinely measure liver function and measures of synthetic function.
Seizures	Consider as a differential diagnosis in patients with reduced conscious state
Thiamine deficiency	Consider thiamine replacement in all septic patients

Old equipments

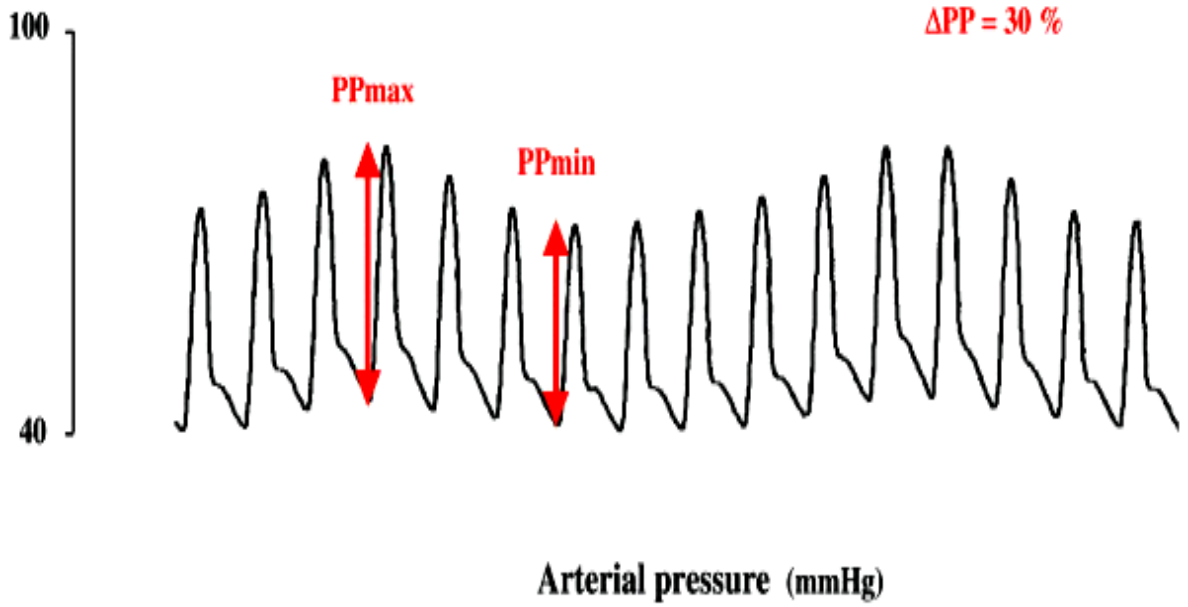
- Systolic
- Diastolic
- Pulse Pressure





Old equipments

- Arterial line
  - Real time SBP, DBP, MAP
  - Pulse pressure variation (ΔPP)



- ΔPP (%) = 100 × (PPmax - PPmin)/([PPmax + PPmin]/2)
- >= 13% (in septic pts,) discriminate between fluid responder and non respondaer (sensitivity 94%, specificity 96%)

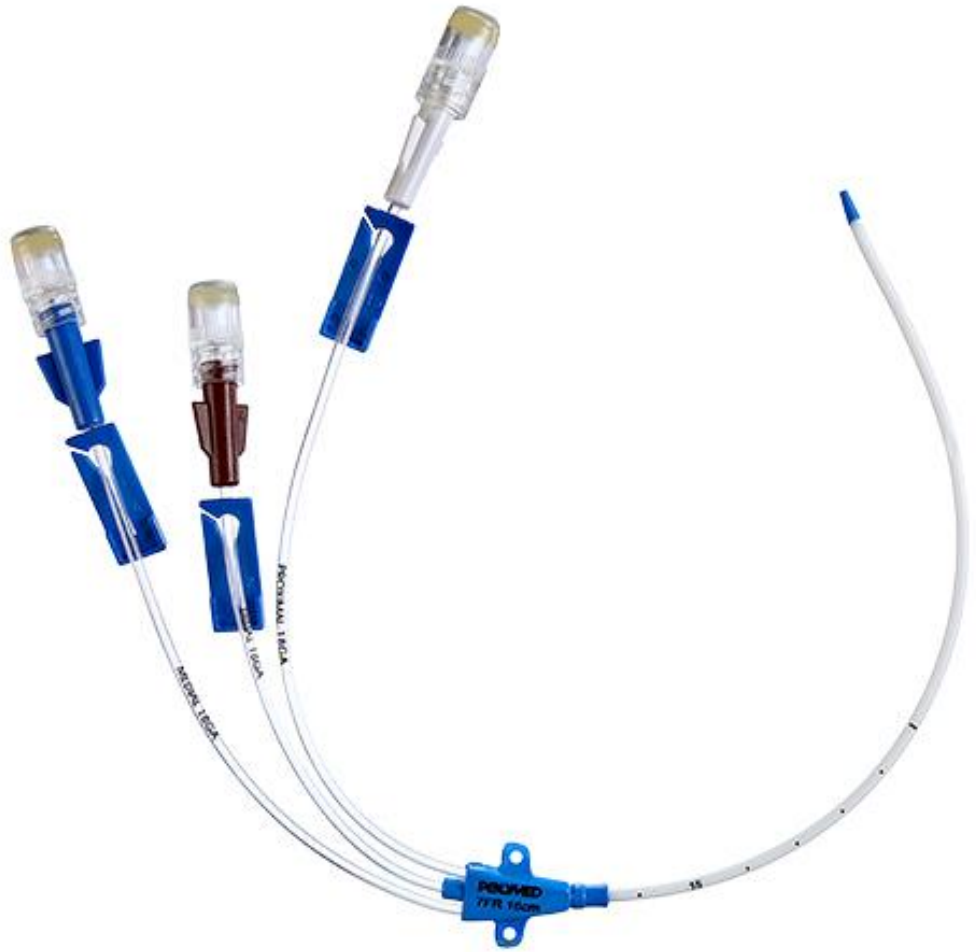
Am J Respir Crit Care Med 2000, **162:**134-138

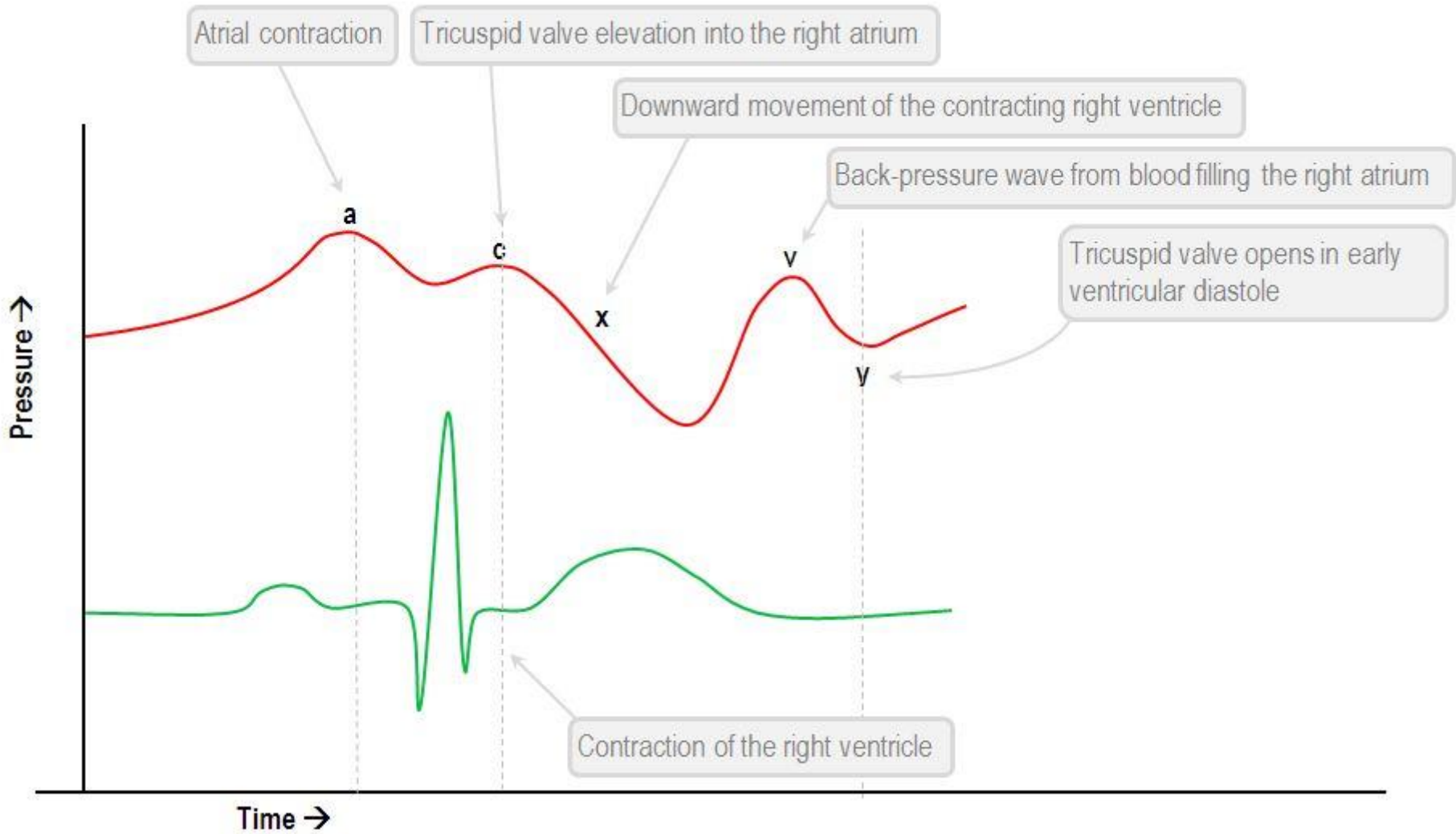
Arterial line

- Advantages
  - Easy setup
  - Real time BP monitoring
  - Beat to beat waveform display
  - Allow regular sampling of blood for lab tests
- Disadvantages
  - Invasive
  - Risk of haematoma, distal ischemia, pseudoaneurysm formation and infection

Old equipments

- Central venous catheter
  - Measurement of CVP, medications infusion, SvO2



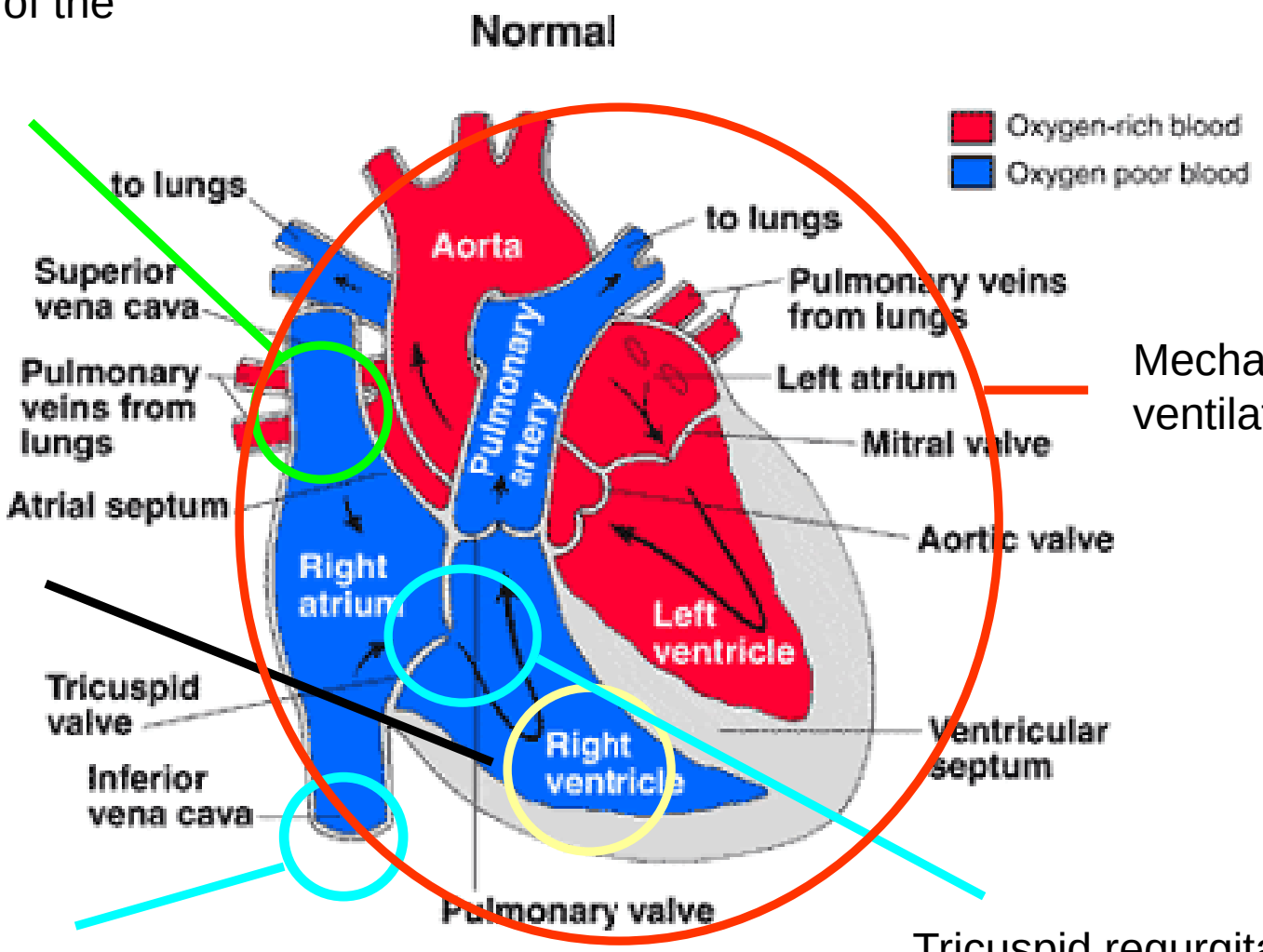

Atrial contraction
Tricuspid valve elevation into the right atrium
Downward movement of the contracting right ventricle
Back-pressure wave from blood filling the right atrium
Tricuspid valve opens in early ventricular diastole
Contraction of the right ventricle
a
c
x
v
y
Pressure →
Time →

Central venous catheter

- Advantages
  - Easy setup
  - Good for medications infusion
- Disadvantages
  - Cannot reflect actual RAP in most situations
  - Multiple complications
    - Infections, thrombosis, complications on insertion, vascular erosion and electrical shock

Limitation of CVP

Obstruction of the great veins



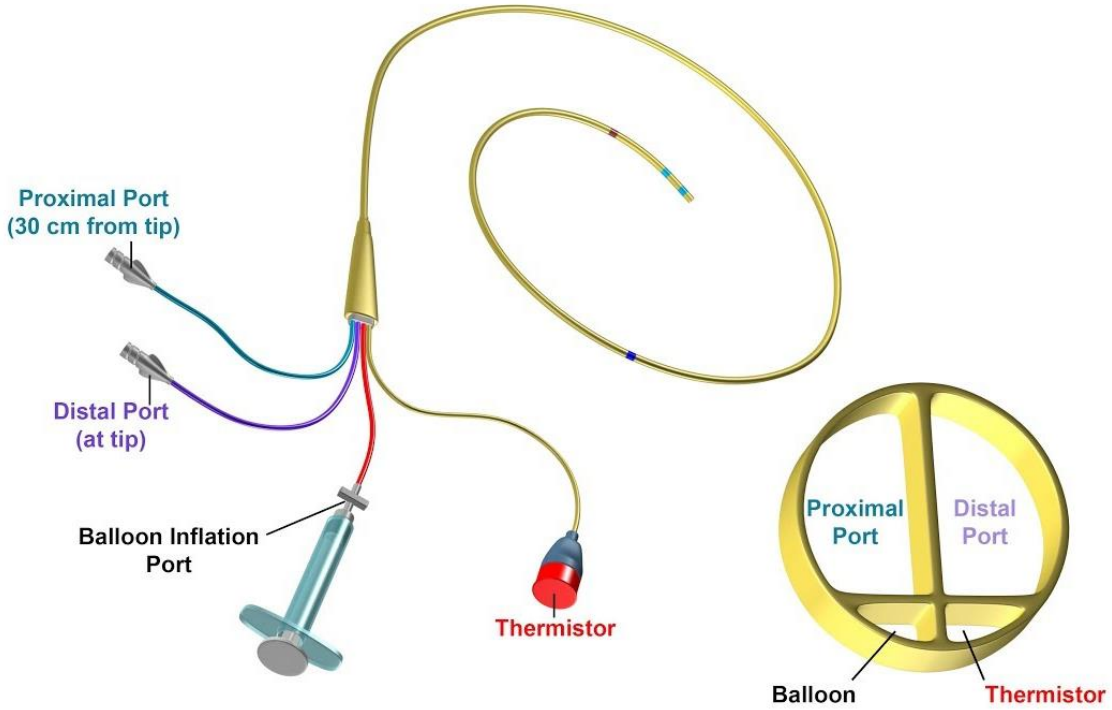
Mechanical ventilation

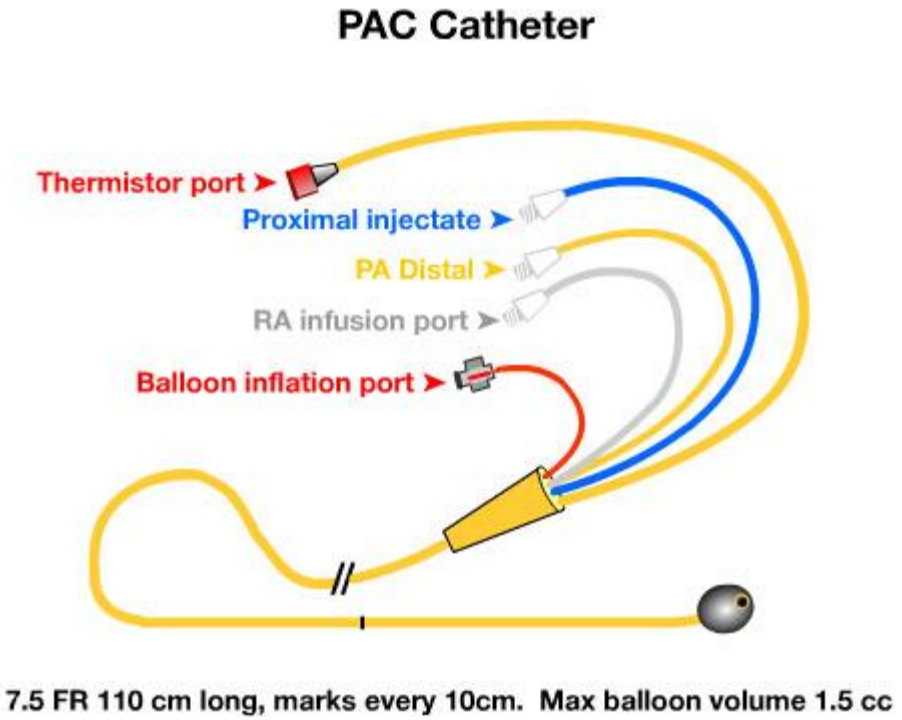
Decrease right ventricular compliance

Tricuspid regurgitation

Systemic venoconstriction

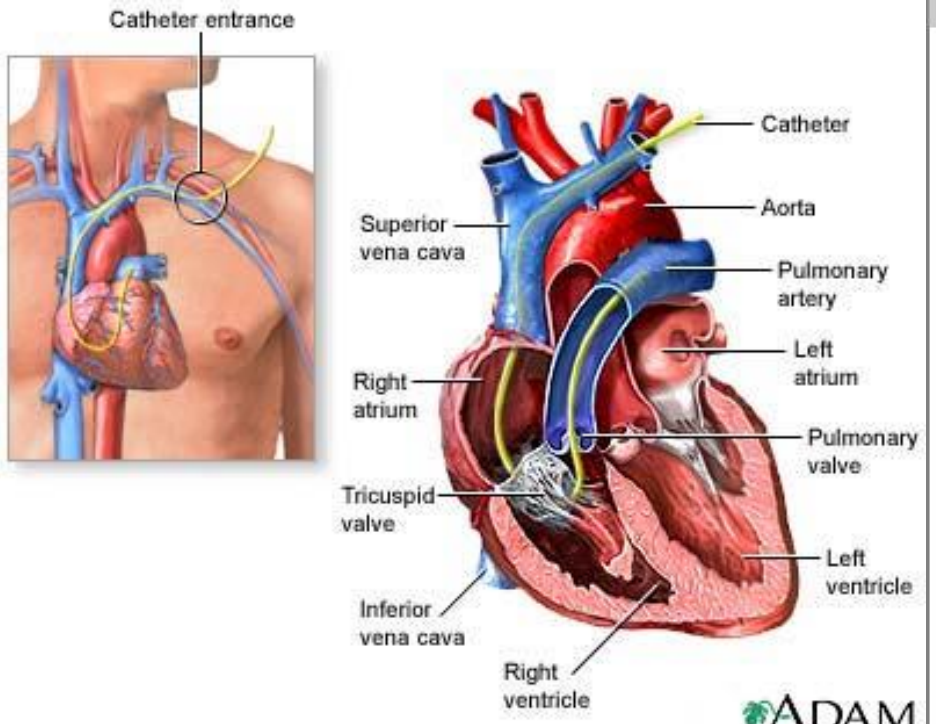
PAC

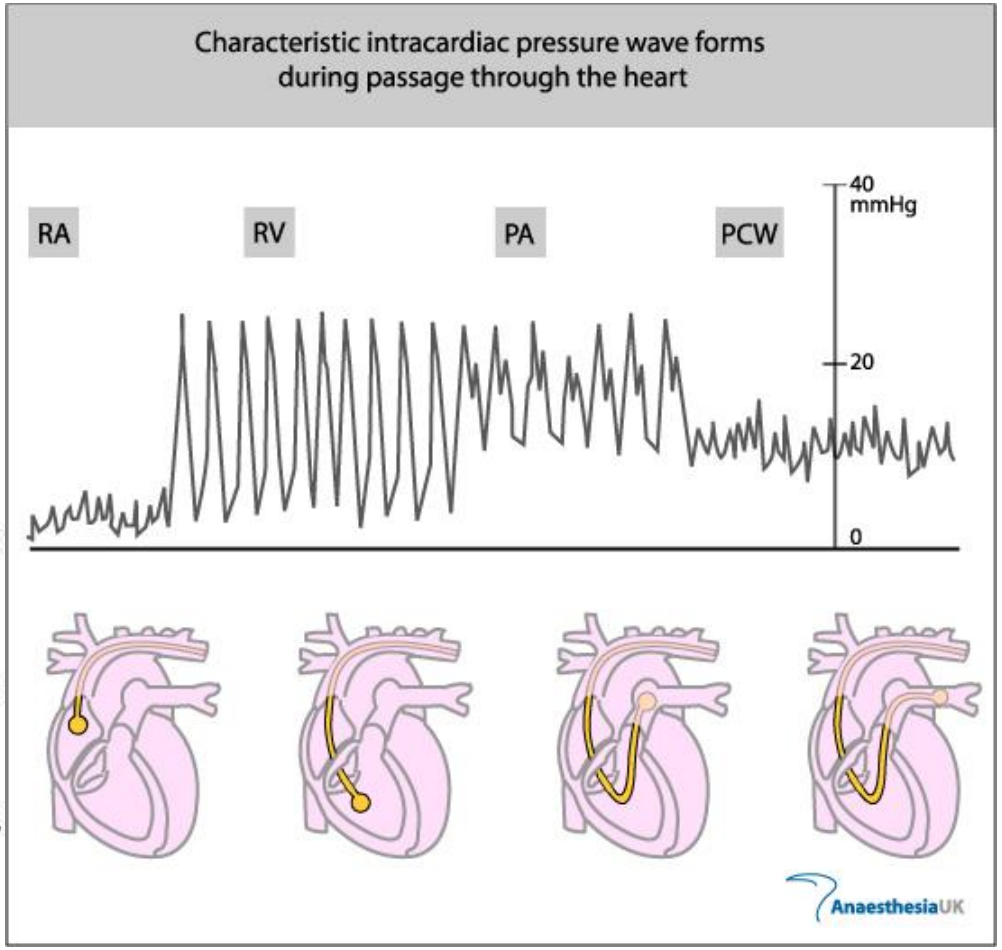

Proximal Port
(30 cm from tip)
Distal Port
(at tip)
Balloon Inflation
Port
Thermistor
Proximal
Port
Distal
Port
Balloon
Thermistor


PAC Catheter
Thermistor port
Proximal injectate
PA Distal
RA infusion port
Balloon inflation port
7.5 FR 110 cm long, marks every 10cm. Max balloon volume 1.5 cc

Old equipment

- Pulmonary arterial catheter





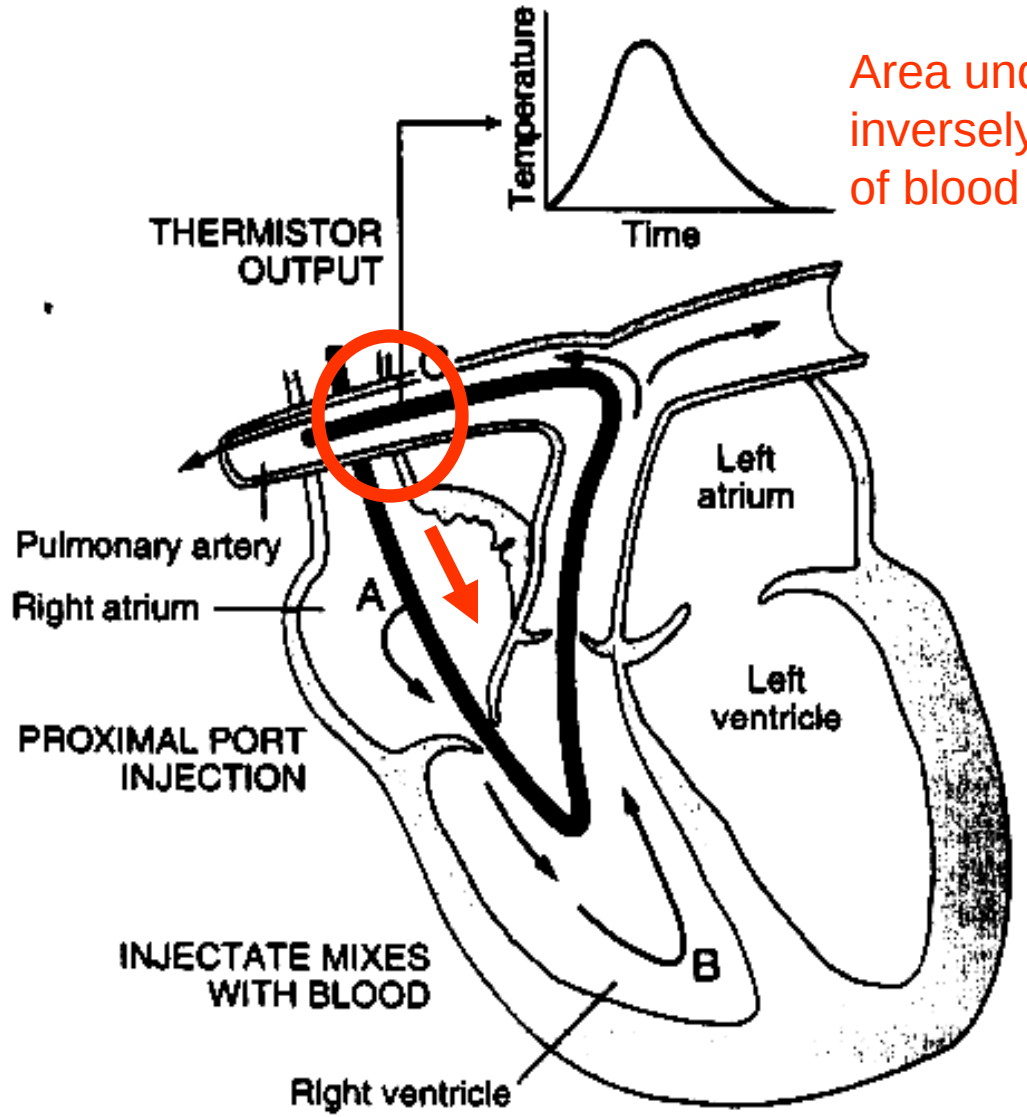
Indications for PAP monitoring

- Shock of all types
- Assessment of cardiovascular function and response to therapy
- Assessment of pulmonary status
- Assessment of fluid requirement
- Perioperative monitoring

Clinical applications of PAC

PAC can generate large numbers of haemodynamic variables

- Central venous pressure (CVP)
- Pulmonary arterial occlusion pressure (PAOP) =LAP = LVEDP
- Cardiac output / cardiac index (CO / CI) $\Rightarrow$ By thermodilution
- Stroke volume (SV)
- R ventricle ejection fraction/ end diatolic volume (RVEF / RVEDV)
- Systemic vascular resistance index (SVRI)
- Pulmonary vascular resistance index (PVRI)
- Oxygen delivery / uptake (DO2 / VO2)



Area under curve is inversely proportion to rate of blood flow in PA (= CO)

FIGURE 10–1. Schematic illustration of the thermodilution method utilizing the pulmonary artery catheter. The cold injectate is introduced into the right atrium **(A)** and mixes completely with blood within the right ventricular chamber **(B)**; the cooled blood flows into the pulmonary arterial circulation and past the thermistor bead near the tip of the pulmonary artery catheter **(C)**. (Adapted from Marino PL: Thermodilution cardiac output. In The ICU Book. Philadelphia: Lea & Febiger, 1991, p. 124.)

Patient with hypotension

Hypovolemia
- Low CVP
- Low CI
- High SVRI

⇒ Consider fluid challenge

Cardiogenic
- High CVP
- Low CI
- High SVRI

⇒ Consider inotopic / IABP

Vasogenic
- Low CVP
- High CI
- Low SVRI

⇒ Consider vasopressor

Mixed Venous Saturation SvO_2

- Measured in pulmonary artery blood
- Marker of the balance between whole body O_2 delivery (DO_2) and O_2 consumption (VO_2)
- $VO_2 = DO_2 * (SaO_2 – SvO_2)$
- In fact, DO_2 determinate by CO, Hb and SaO_2. Therefore, SvO_2 affected by
  - CO
  - Hb
  - Arterial oxygen saturation
  - Tissue oxygen consumption

Mixed Venous Saturation SvO2

- Normal SvO2 70-75%

Decreased SvO2
- increased consumption
    - pain, hyperthermia
- decreased delivery
    - low CO
    - anemia
    - hypoxia

Increased SvO2
- Increased delivery
    - high CO
    - hyperbaric O2
- Low consumption
    - sedation
    - paralysis
    - cyanide toxicity

PAC

- Advantages
  - Provide lot of important haemodynamic parameters
  - Sampling site for SvO2
- Disadvantages
  - Costly
  - Invasive
  - Multiple complications (eg arrhythmia, catheter looping, balloon rupture, PA injury, pulmonary infarction etc)
  - **Mortality not reduced and can be even higher**

Crit Care Med 2003;31: 2734-2741

JAMA 1996;276 889-897

Advance in haemodynamic assessment

- Modification of old equipment
- Echocardiogram and esophageal doppler
- Pulse contour analysis and transpulmonary thermodilution
- Partial carbon dioxide rebreathing with application of Fick principle
- Electrical bioimpedance

Transthoracic echo

- Assessment of cardiac structure, ejection fraction and cardiac output
- Based on 2D and doppler flow technique

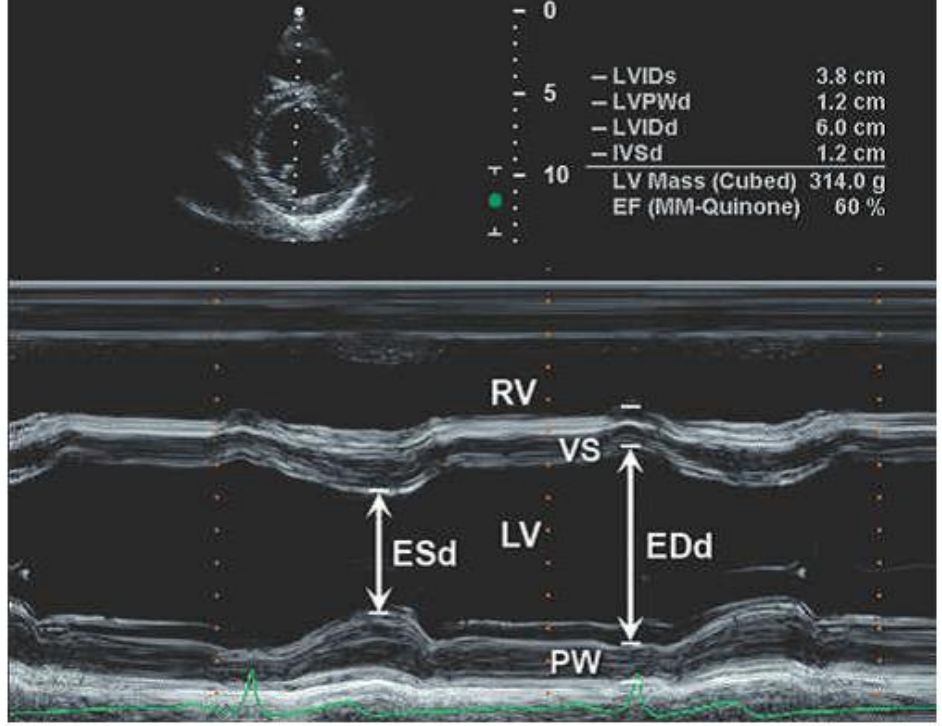


Figure 7-1 Two-dimensionalâ€"guided M-mode echocardiogram of the left ventricle (*LV*) at the papillary muscle level. The LV end-diastolic internal dimension (*EDd*) measured at the onset of QRS is 60 mm, and the LV end-systolic internal dimension (*ESd*) is 38 mm. Therefore,

$$\text{LV ejection fraction (LVEF)} = \frac{60^2 - 38^2}{60^2} \times 100$$
$$= 60\% \text{ (uncorrected)}$$

If apical contractility is normal,

$$\text{Corrected LVEF} = 60\% + [(100 - 60) \times 15\%]$$
$$= 60\% + 6\%$$
$$= 66\%$$

LV mass is also calculated from LV dimensions, posterior wall (*PW*) thickness, and ventricular septal (*VS*) thickness. *RV*, right ventricle.

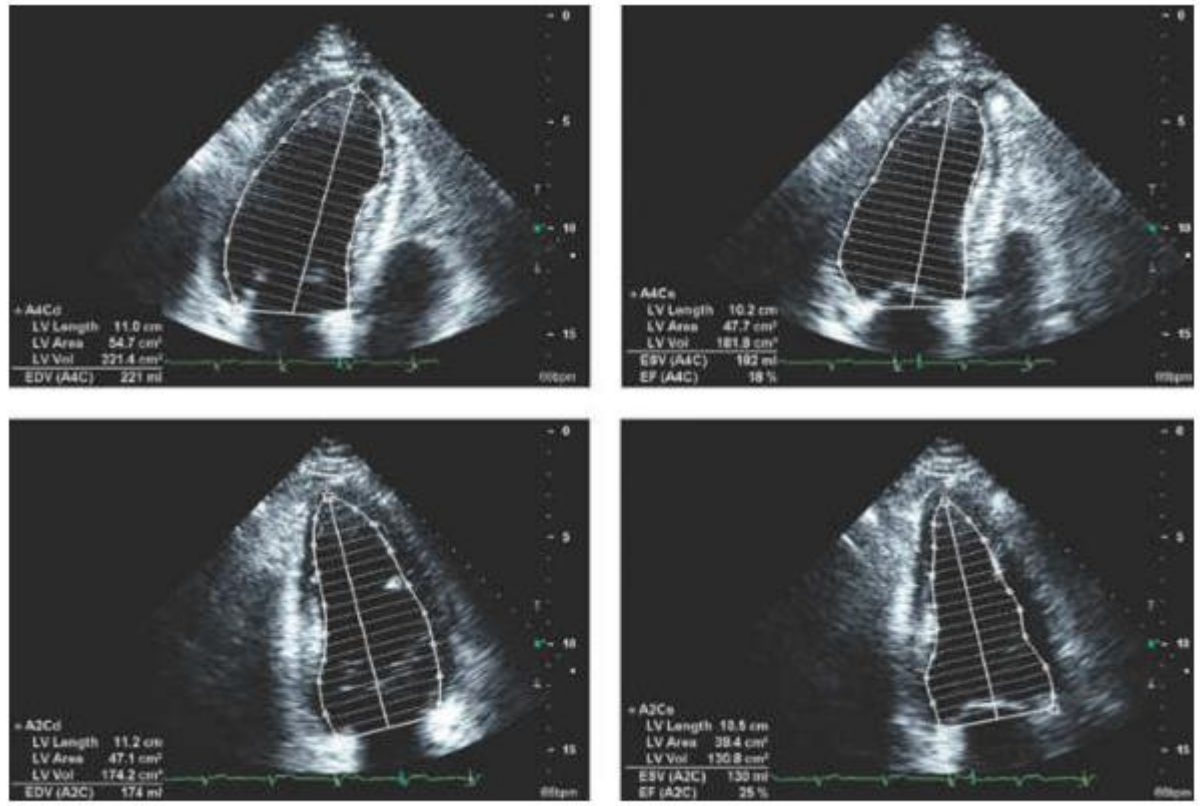


Figure 7-10 Still frames of two orthogonal views (apical four-chamber [*top*] and apical two-chamber [*bottom*] views) to calculate the left ventricular (*LV*) volume and ejection fraction using a modified Simpson method. End-diastolic (*EDV*) and end-systolic (*ESV*) frames illustrate 20 cylinders (disks) of equal height. When the endocardial border and long axis (vertical line to the short-axis lines) are identified, a fixed number of cylinders are created, and the volumes of the cylinders are summed to estimate ventricular volume (*Vol*). *EF*, ejection fraction.

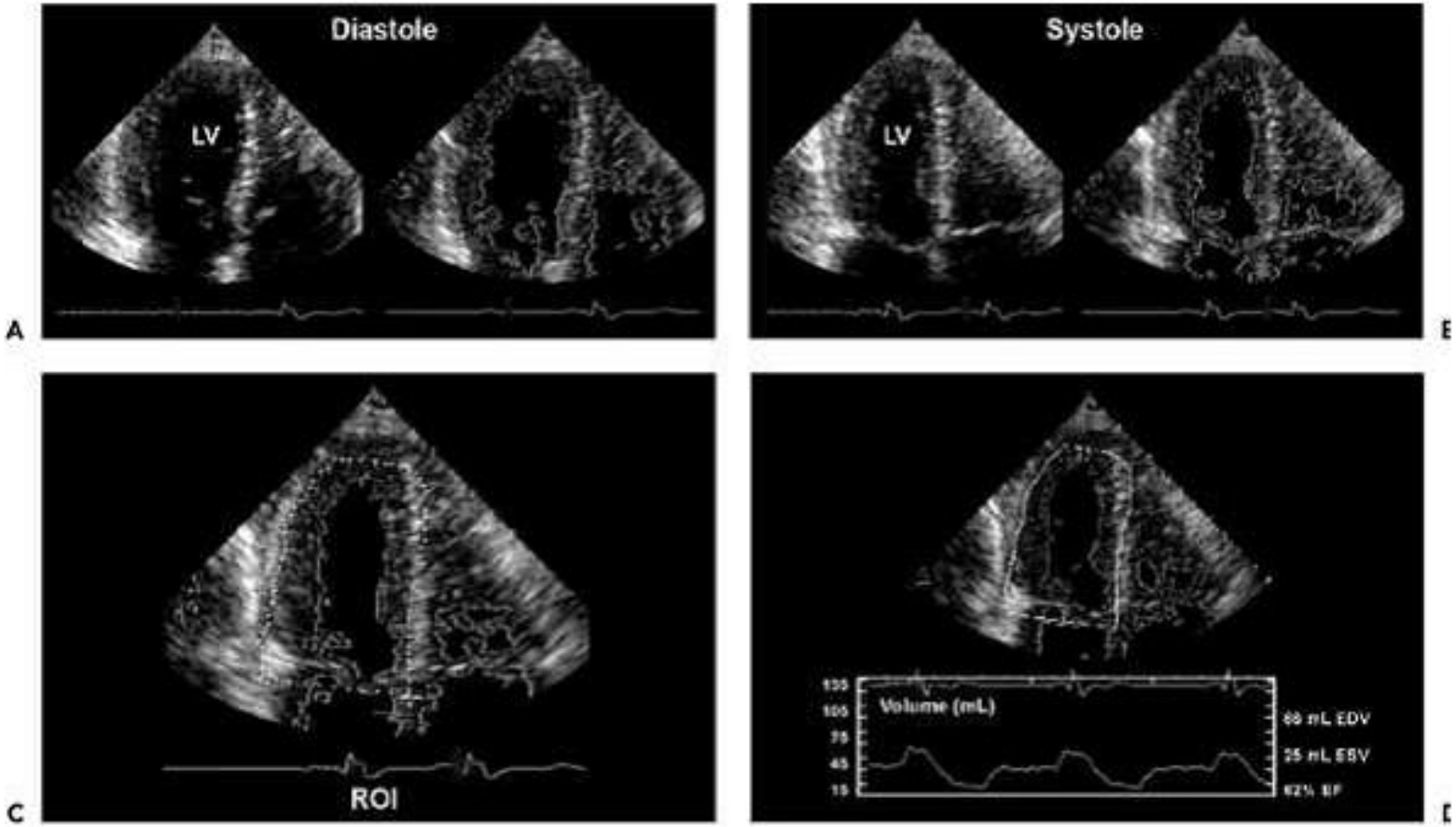
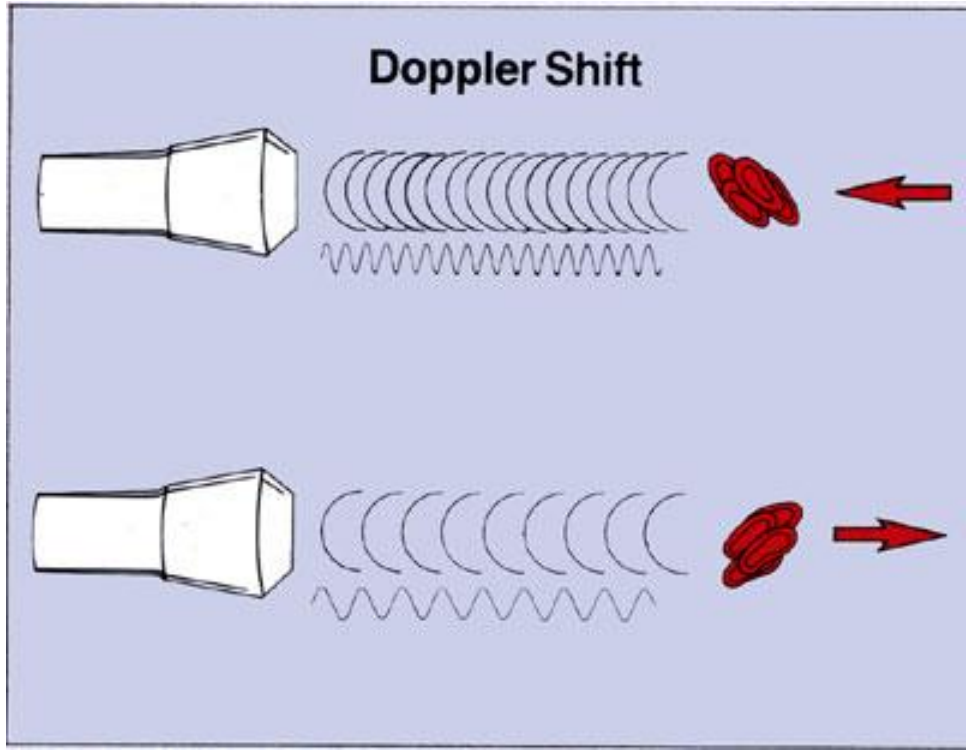


Figure 7-12 A and **B:** Ultrasound backscatter differs markedly between the myocardium and intracavitary blood pool. Therefore, the endocardial border is defined where a greater- than- preestablished threshold difference in backscatter is identified. The borders are identified and dotted. Connecting the endocardial dots creates an endocardial border in real time throughout the cardiac cycle. *LV*, left ventricle. **C:** An area of interest is identified by selecting the region. Because we are interested in the volumetric change of the LV, the LV cavity was chosen as the region of interest (*ROI*). **D:** From the real-time automatic border detection of the LV endocardium, LV volume changes are instantaneously determined to provide end-diastolic volume (*EDV*), end-systolic volume (*ESV*), and ejection fraction (*EF*).

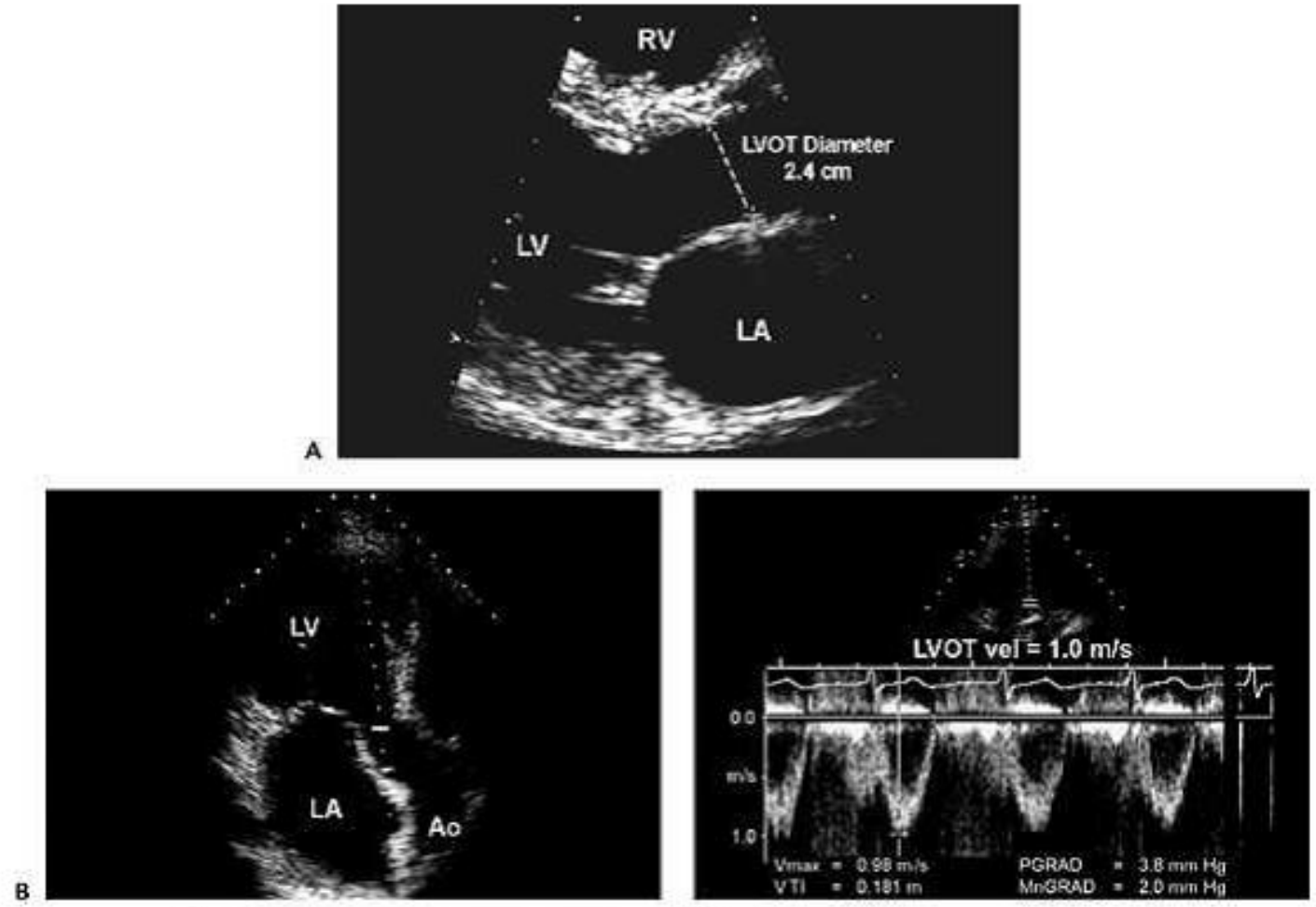
Echo doppler ultrasound

- Measure blood flow velocity in heart and great vessels
- Based on Doppler effect $\Rightarrow$ “ Sound freq. increases as a sound source moves toward the observer and decreases as the soure moves away”



For transthoracic echo

- Haemodynamic assessment for SV and CO
  - Flow rate = CSA x flow velocity
  - Because flow velocity varies during ejection, individual velocities of the doppler spectrum need to be summed
  - Sum of velocities called velocity time integral (VTI)
  - SV = CSA x VTI
  - CSA =(LVOT Diameter /2)^2 * π
  - Therefore SV = D^2 * 0.785 * VTI
  - CO = SV * HR



$$\text{LVOT area (cm}^2\text{)} = \left(\frac{D}{2}\right)^2 \times \pi$$

$$= D^2 \times 0.785$$

$$\text{SV(mL)} = \text{Area (cm}^2\text{)} \times \text{TVI}$$

$$= D^2 \times 0.785 \times \text{TVI}$$

$$= 4.5\ \text{cm}^2 \times 18\ \text{cm} = 81\ \text{mL}$$

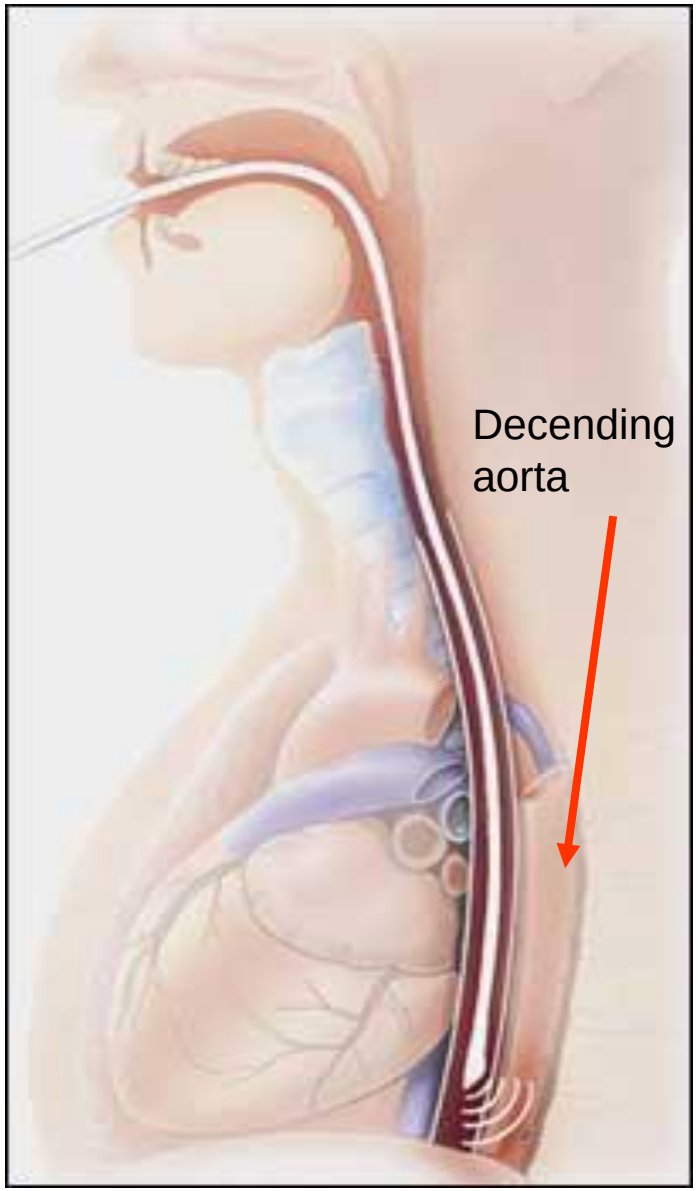
Transthoracic echo

- Advantages
  - Fast to perform
  - Non invasive
  - Can assess valvular structure and myocardial function
  - No added equipment needed
- Disadvantages
  - Difficult to get good view (esp whose on ventilator / obese)
  - Cannot provide continuous monitoring

Transesophageal echo

- CO assessment by Simpson or doppler flow technique as mentioned before
- Better view and more accurate than TTE
- Time consuming and require a high level of operator skills and knowledge

Esophageal aortic doppler US



- Doppler assessment of decending aortic flow
- CO determinate by measuring aortic blood flow and aortic CSA
- Assuming a constant partition between caudal and cephalic blood supply areas
- CSA obtain either from nomograms or by M-mode US
- Probe is smaller than that for TEE
- Correlate well with CO measured by thermodilution

Crit Care Med 1998 Dec;26(12):2066-72

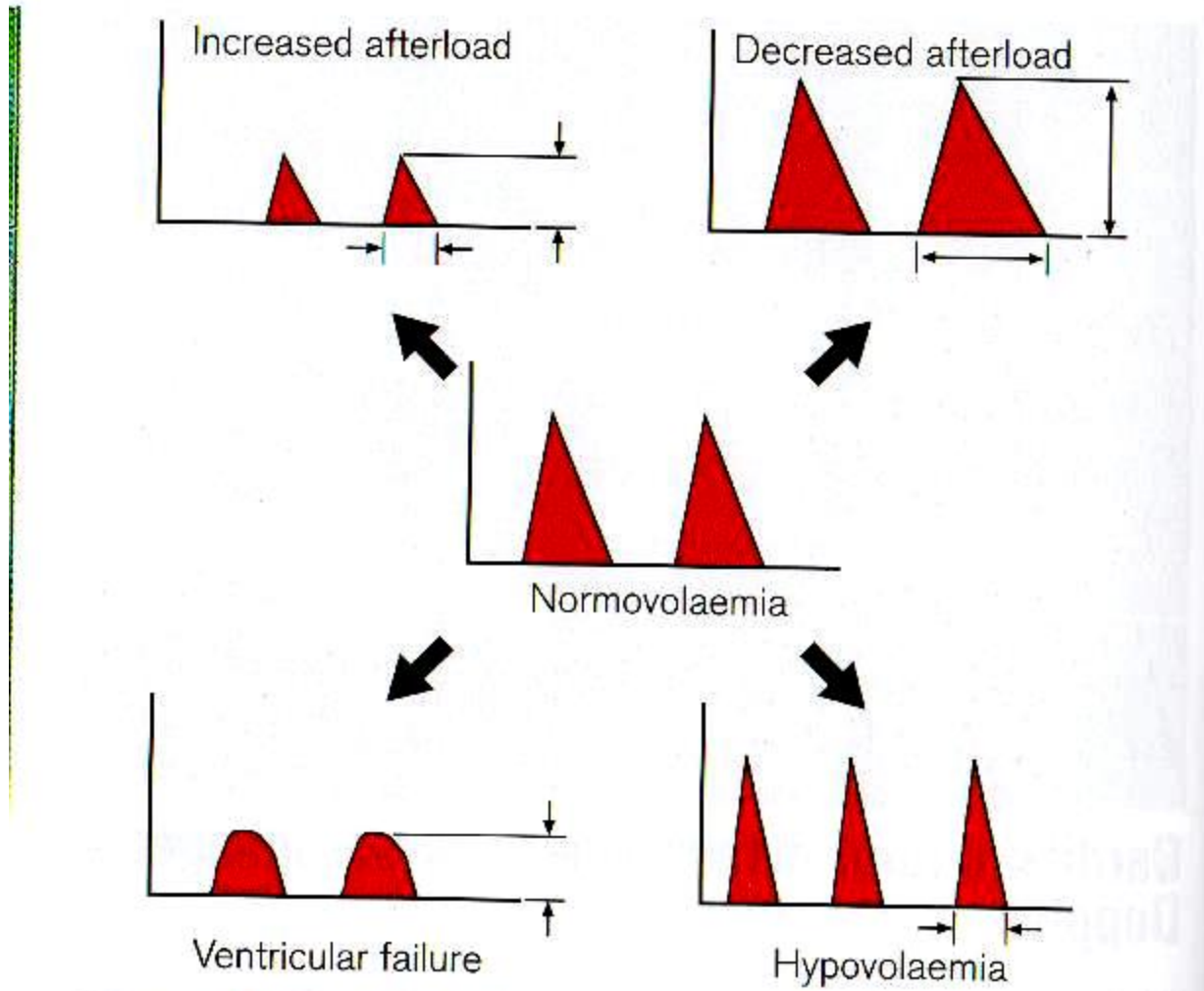


Figure 18.8 Predominant changes observed in the aortic waveform due to alterations in preload, afterload and contractility.

Esophageal aortic doppler US

- Advantages
  - Easy placement, minimal training needed (~ 12 cases)
  - provide continuous, real-time monitoring
  - Low incidence of iatrogenic complications
  - Minimal infective risk
- Disadvantages
  - High cost
  - Poor tolerance at awake patient, so for those intubated
  - Probe displacement can occur during prolonged monitoring and patient's turning
  - High interobserver variability when measuring changes in SV in response to fluid challenges

Pulse contour analysis

- Arterial pressure waveform determinate by interaction of stroke volume and SVR

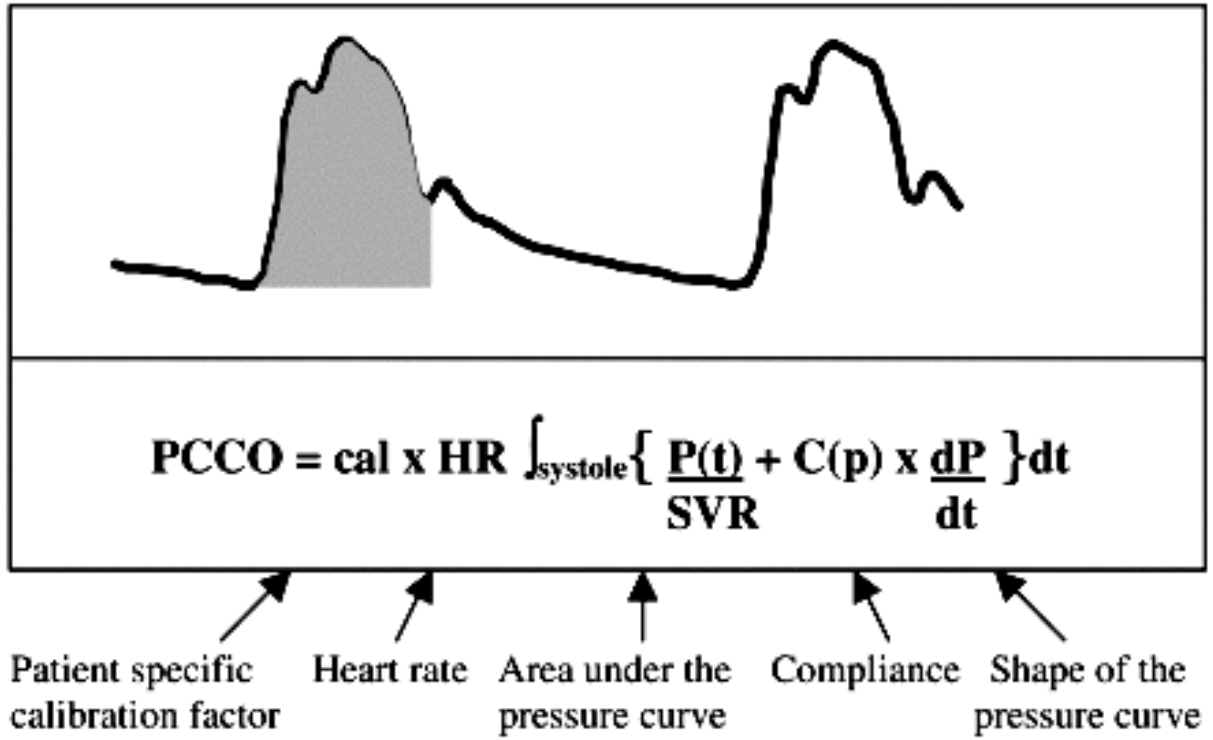


Figure 2. Calculation used by the PiCCO for measurement of continuous cardiac output.

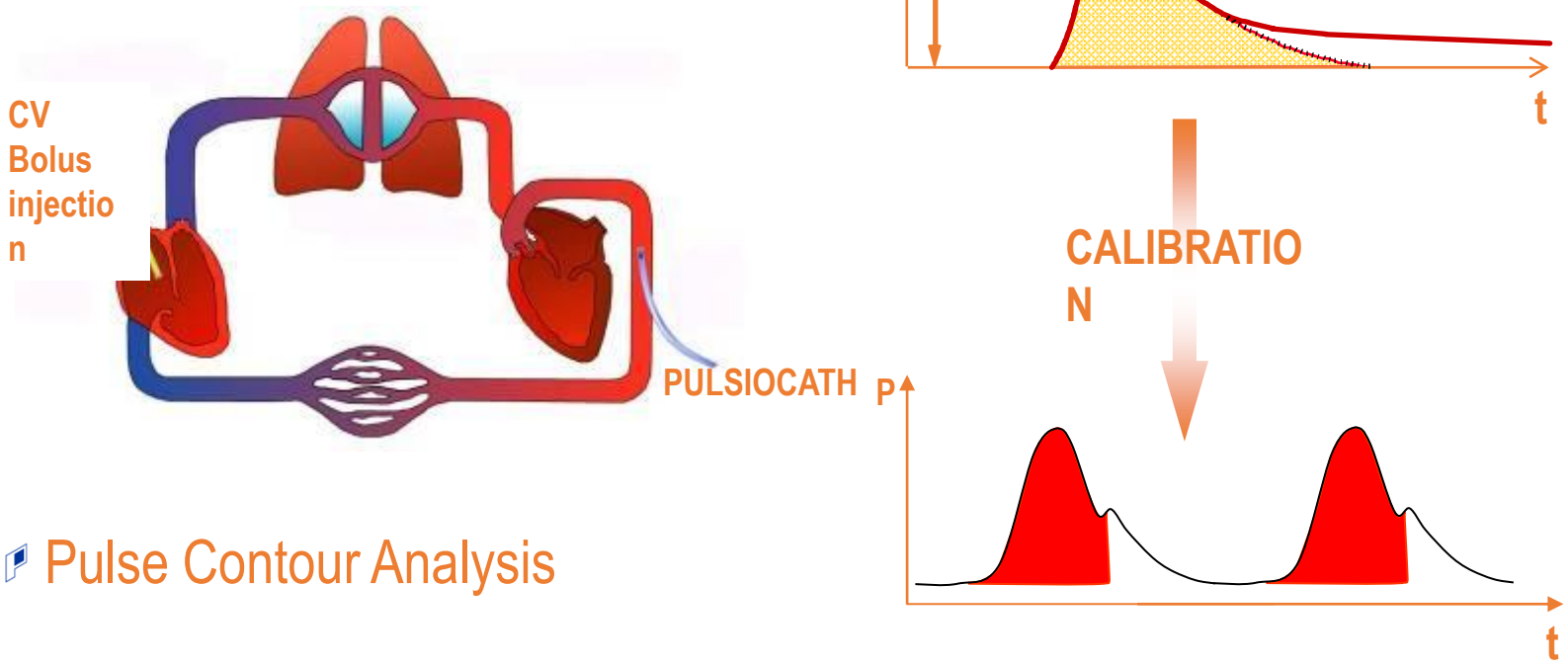
Pulse contour analysis

- Because vascular impedance varies between patients, it had to be measured using another modality to initially calibrate the PCA system
- The calibration method usually employed was arterial thermodilution or dye dilution technique
- PCA involves the use of an arterially placed catheter with a pressure transducer, which can measure pressure tracings on a beat-to-beat basis
- PiCCO and LiDCO are the two commonly used model

What is the PiCCO-Technology?

- The PiCCO-Technology is a unique combination of 2 techniques for advanced hemodynamic and volumetric management without the necessity of a right heart catheter in most patients:

- Transpulmonary Thermodilution



- Pulse Contour Analysis

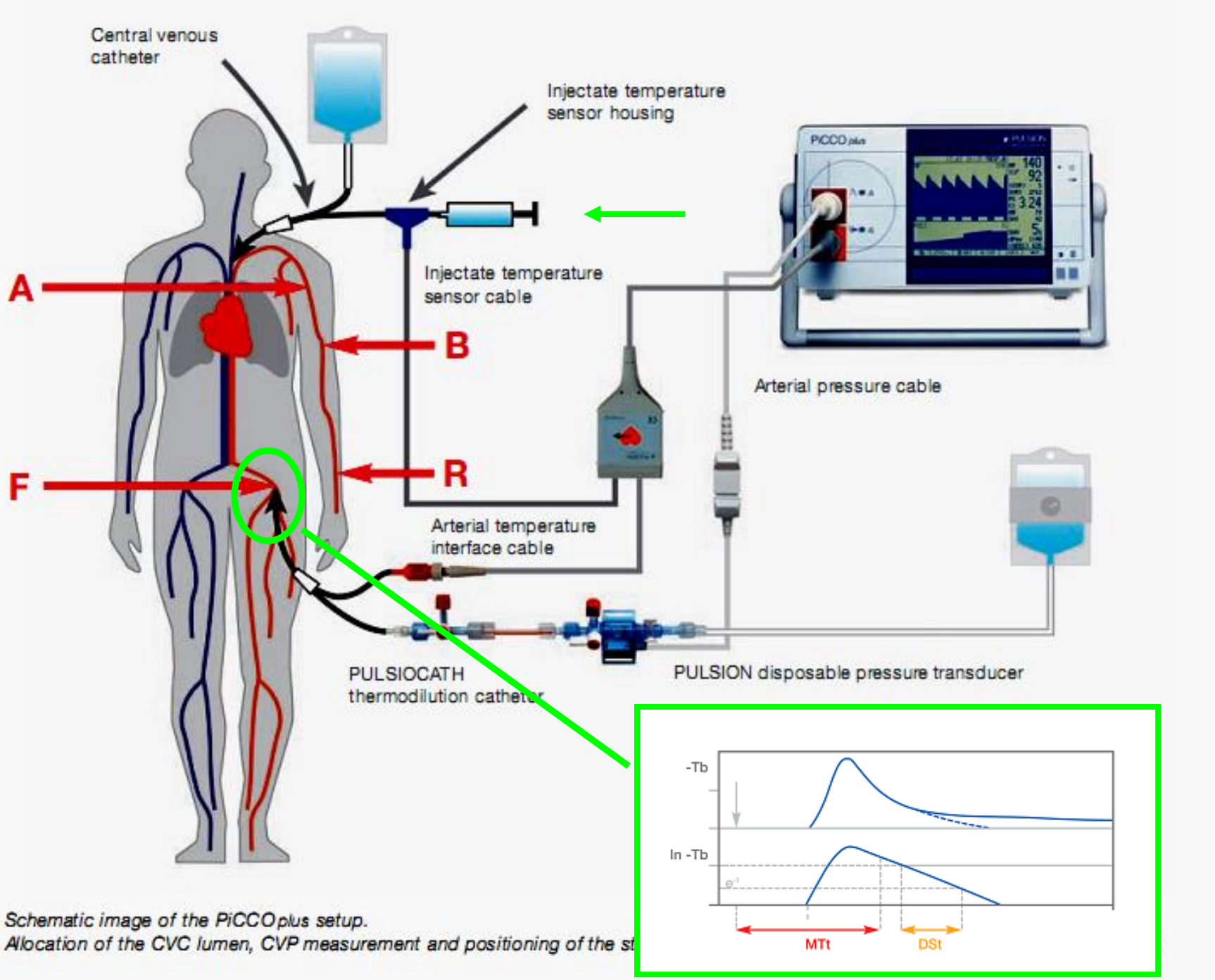
How does the PiCCO-Technology work?

- Most of hemodynamic unstable and/or severely hypoxemic patients are instrumented with:

Central venous line (e.g. for vasoactive agents administration…)

Arterial line (accurate monitoring of arterial pressure, blood samples…)

- The PiCCO-Technology uses any standard CV-line and a thermistor-tipped arterial PiCCO-catheter instead of the standard arterial line.



Schematic image of the PiCCOplus setup.
Allocation of the CVC lumen, CVP measurement and positioning of the st

Fig 1

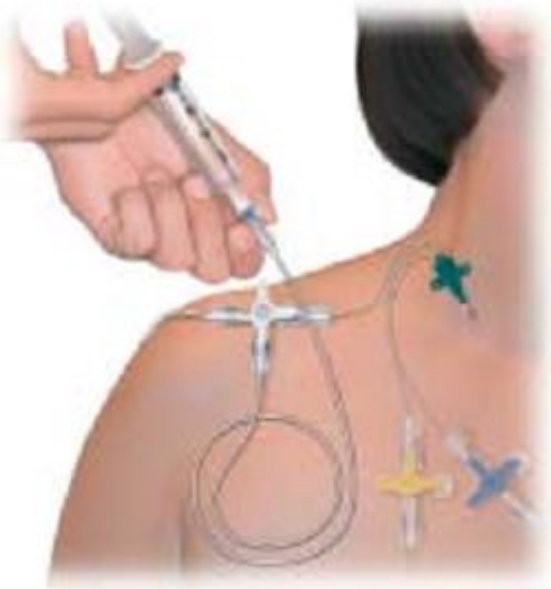


Fig 2

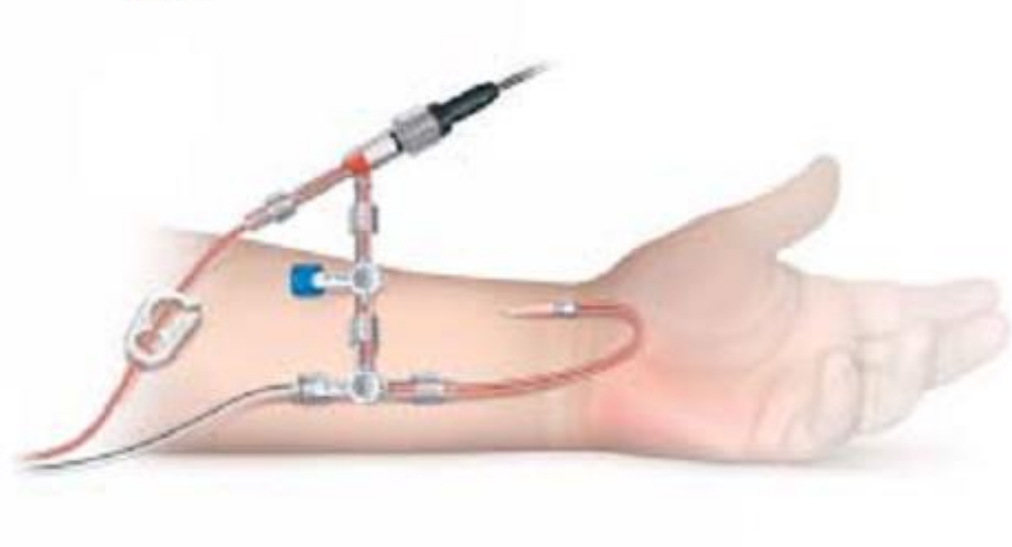
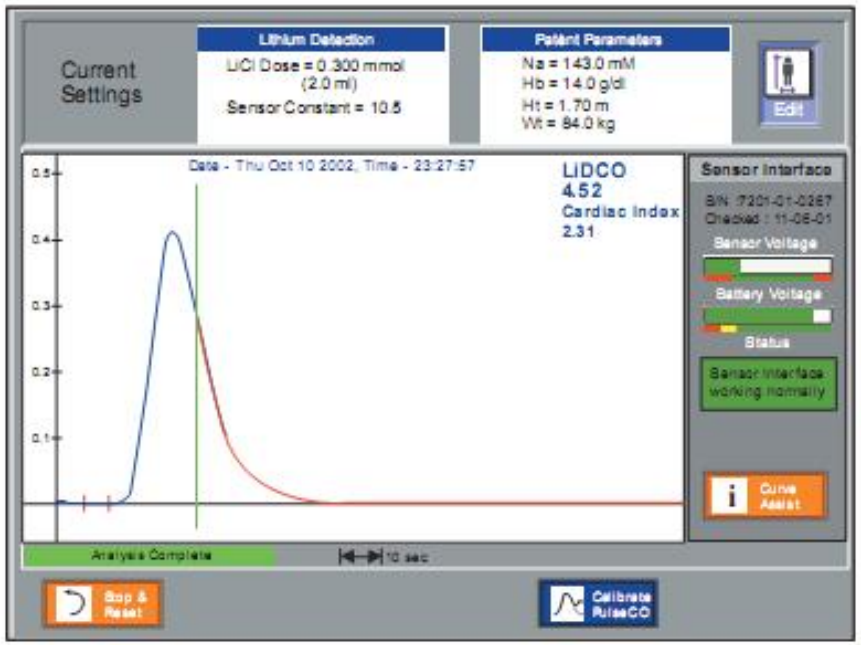


Fig 3



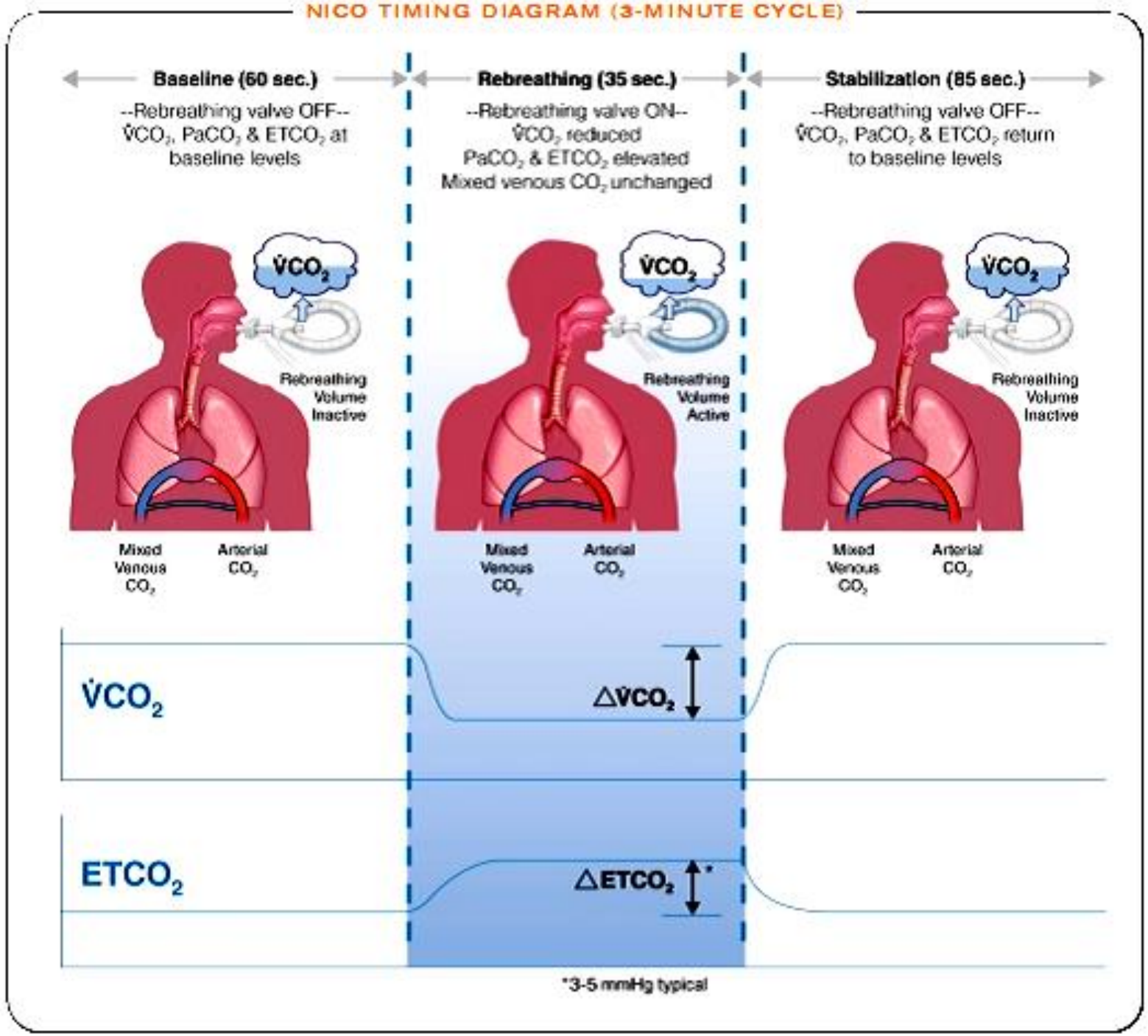
LiDCO system

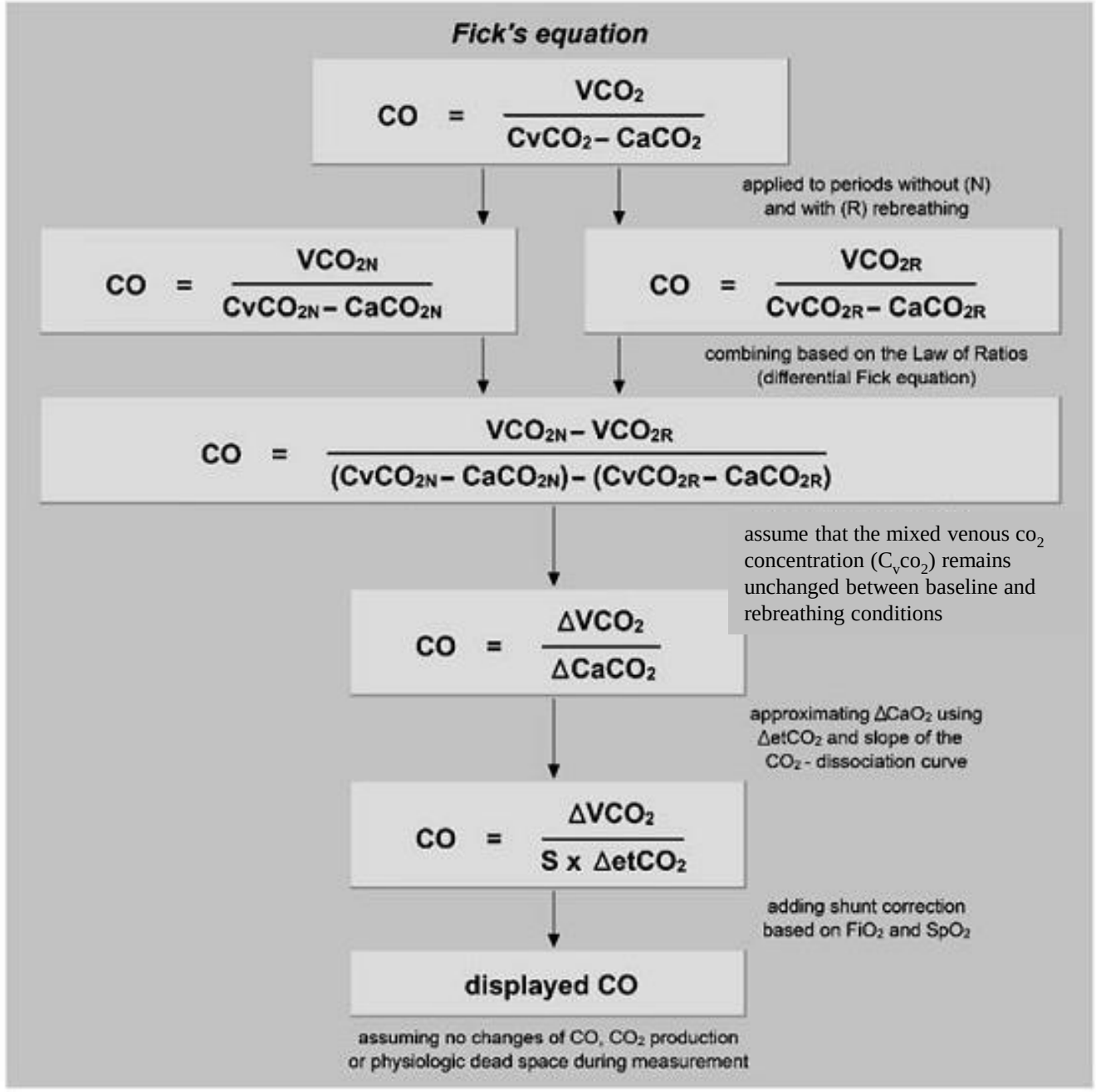
Pulse contour analysis

- Advantages
  - Almost continuous data of CO / SV / SV variation
  - Provide information of preload and EVLW
- Disadvantages
  - Minimal invasive
  - Optimal arterial pulse signal required
    - Arrhythmia
    - Damping
    - Use of IABP

Partial carbon dioxide rebreathing with application of Fick principle

- Fick principle is used for CO measurement
- $CO = VO_2 / (CaO_2 – CvO_2) = VCO_2 / (CvCO_2 – CaCO_2)$
- Based on the assumption that blood flow through the pulmonary circulation kept constant and absence of shunt
- Proportional to change of CO_2 elimination divided by change of $ETCO_2$ resulting from a brief rebreathing period
- The change was measured by NICO sensor


NICO TIMING DIAGRAM (3-MINUTE CYCLE)
Baseline (60 sec.)
--Rebreathing valve OFF--
V̇CO2, PaCO2 & ETCO2 at baseline levels
Rebreathing (35 sec.)
--Rebreathing valve ON--
V̇CO2 reduced
PaCO2 & ETCO2 elevated
Mixed venous CO2 unchanged
Stabilization (85 sec.)
--Rebreathing valve OFF--
V̇CO2, PaCO2 & ETCO2 return to baseline levels
V̇CO2
Rebreathing Volume Inactive
Rebreathing Volume Active
Rebreathing Volume Inactive
Mixed Venous CO2
Arterial CO2
V̇CO2
△V̇CO2
ETCO2
△ETCO2
*
*3-5 mmHg typical



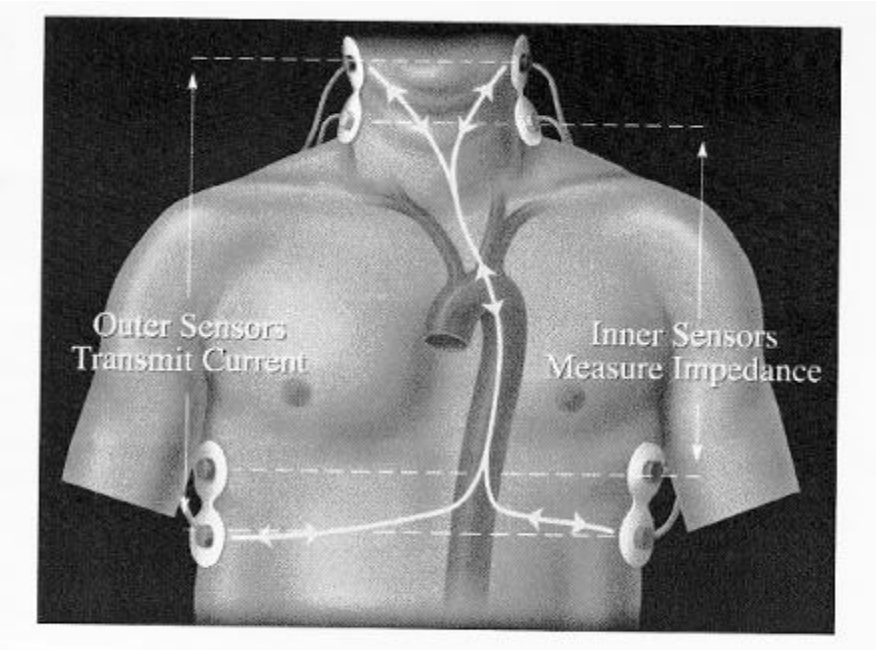
S = slope of CO2 dissociation curve

Partial carbon dioxide rebreathing with application of Fick principle

- Advantages
  - Non invasive
- Disadvantages
  - Only for those mechanically ventilated patient
  - Variation of ventilation modality and presence of significantly diseased lung affect the CO reading
  - Not continuous monitoring

Electrical bioimpedance

- Made uses of constant electrical current stimulation for identification of thoracic or body impedance variations induced by vascular blood flow



- Electrodes are placed in specific areas on the neck and thorax
- A low-grade electrical current, from 2 - 4 mA is emitted, and received by the adjacent electrodes
- Impedance to the current flow produces a waveform
- Through electronic evaluation of these waveforms, the timing of aortic opening and closing can be used to calculate the left ventricular ejection time and stroke volume

Electrical bioimpedance

- Some report same clinical accuracy as thermodilution technique

Crit Care Med 22: 1907-1912

Chest 111: 333-337

Crit Care Med 14: 933-935

- Other report poor agreement in those haemodynamically unstable and post cardiac surgery

Crit Care Med 21:1139-1142

Crit Care Med 23: 1667-1673

- Newly generation EB device using upgraded computer technology and refined algorithms to calculate CO and get better results

Curr Opin Cardio 19:229-237

Int Care Med 32:2053-2058

Electrical bioimpedance

- Advantage
  - Non invasive
- Disadvantage
  - Reliability in critically ill patients still not very clear

Classic Hemodynamic Changes Associated with Shock States								
Shock States	SVR	PVR	CI	SvO2	RAP	RVP	RAP	PAOP
Cardiogenic	↑	N	↓	↓	↑	↑	↑	↑
Distributive	↓	N	N/↑	N/↑	N/↓	N/↓	N/↓	N/↓
Hypovolemic	↑	N	↓	↓	↓	↓	↓	↓
Obstructive	N/	↑	↓	N/↑	↑	↑	↑	N/↓

Table 3: Expected changes to classic hemodynamic parameters in shock states.

In conclusion

- Haemodynamic monitoring enable early detection of change in patient’s conditions
- New techniques provide reasonably good results and less invasive
- Always correlate the readings / findings with clinical pictures in order to provide the best treatment options

Thank you for your Attention