haemodynamic monitoring

complications of PAC

Complications of catheter insertion
- Dysrhythmias
- Knotting/kinking
- Valve damage
- Perforation of pulmonary artery
- Right bundle branch block
- Complete heart block

Complications post insertion
- Thrombosis
- PA rupture (0.2%)
- Sepsis
- Endocarditis
- Pulmonary infarction
- Dysrhythmias (37%)
- Air embolus (due to repeated attempts to fill ruptured balloon)

Risk factors for major morbidity (in particular PA rupture)
- Pulmonary hypertension
- Anticoagulation
- *In situ* duration >3 days

complications of CVP monitoring

Early
- Pneumothorax / haemothorax / chylothorax / hydrothorax
- Arterial puncture
- Injury to subclavian artery, aorta or pulmonary artery
- Dysrhythmias, right bundle branch block
- Nerve injury (e.g. phrenic, recurrent laryngeal, Horner's syndrome)
- Air embolism
- Tracheal injury

Late
- Catheter-related sepsis
- Disconnection (bleeding or air embolism)
- Superior vena caval erosion (hydrothrax, cardiac tamponade)
- Arteriovenous fistula
- Thrombosis (superior vena cava, subclavian vein)

comparisons

Monitoring device	Preload	Contractility	Afterload
Clinical	Skin turgor Urine output JVP Response of blood pressure, skin perfusion and urine output to fluid challenge	Urine output JVP Skin perfusion Ability to respond to a fluid challenge	Skin perfusion Core-peripheral temperature gradient
Direct intra-arterial pressure	Response to fluid challenge. Systolic pressure variation and Δdown component.	Pre-ejection period (with Q wave from ECG)	
Central venous line	CVP + response to fluid challenge		
PA catheter	PAoP, RAP	LVSWI, RVSWI	SVRI, PVRI
Volumetric PA catheter (additional information)	RVEDVI	RVEF	
Transpulmonary thermodilution	Intrathoracic blood volume. Global end-diastolic volume		
Pulse contour continuous cardiac output	Stroke volume variation		
Echocardiography	Ventricular end-diastolic areas	Ejection fraction. Regional wall motion abnormalities.	
Oesophageal Doppler	Flow time (left ventricular ejection time)	Peak flow-velocity	Peak flow-velocity. Flow time

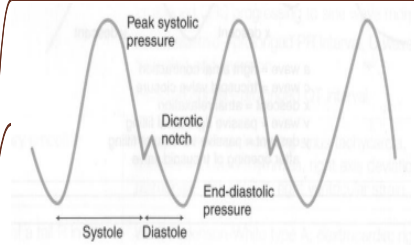
PAoP, pulmonary artery occlusion pressure; RAP, right atrial pressure; LVSWI, left ventricular stroke work index; RVSWI, right ventricular stroke work index; SVRI, systemic vascular resistance index; PVRI, pulmonary vascular resistance index.

Method	Invasion/risk	Ventricular preload assessed	Complexity	Measurement error
Indicator dilution				
Thermodilution (using PA catheter)	+++	From 'wedge' pressure	++	+
Fick	+++	No	+++	+
Indocyanine green	+++	No	++	+
Lithium	++	Yes	+	+
Respired gas				
Modified Fick	+	No	++	++
Inert gas rebreathing	+	Yes	+++	++
Doppler (transoesophageal)	+	Yes	++	++
Echocardiography	0	Yes	++	+++
Impedance cardiography	0	No	++	++
Pulse contour analysis	+	Yes (ITBV)	+	++
Clinical assessment	0	Yes	+	++

arterial blood pressure

general:
- systemic pulse wave moves out from the aortic valve at 6-10m/s
- during its passage into the peripheral vasculature there is a progressive increase in systolic and reduction in diastolic pressures, as standing and reflected waves become incorporated into the waveform
- MAP is arguably the most relevant index to monitor for three reasons:
1. MAP is least dependent on measurement site or technique
2. MAP is least altered by measurement dampening
3. MAP determines tissue blood flow via autoregulation (apart from the left ventricle which autoregulates from diastolic pressure)

problems with NIBP measurement:
1. oscillometry overestimates low pressures and underestimates high pressures (although for the normotensive range 95% CIs are +/-15mmHg
2. dysrhythmias increase likelihood of error
3. narrow cuffs overestimate while wide cuffs understimate blood pressure
4. repeated cuff insufflations can cause skin ulceration, oedema and bruising (more so when the conscious state is impaired)
5. ulnar nerve injury is possible with low cuff placement



arterial waveform analysis

Characteristic	Significance
Pulsus paradoxus (>10 mmHg reduction in systolic pressure during inspiration in the spontaneously breathing patient and expiration in the positively pressure-ventilated patient)	Reduced left ventricular preload, pericardial tamponade, severe bronchospasm
Pulsus alternans (alternating beats of higher systolic pressure)	Pericardial effusion or severe left ventricular failure
Pulse deficit (every QRS complex is not accompanied by a transmitted beat)	Atrial fibrillation, ectopic atrial or ventricular beats
Slow upstroke	Severe aortic stenosis or reduced myocardial contractility
Wide pulse pressure	Aortic regurgitation
Narrow pulse pressure	Elevated systemic vascular resistance
Location of dicrotic notch (should be at least a third of the height of the systolic peak)	Low dicrotic notch suggests low systemic vascular resistance

system requirements

general:
- phlebostatic axis is represents the zero point and is located at the 4th ICS in the midaxillary line
- ideally the natural resonant frequency of the system should exceed 30Hz for heart rates up to 180bpm and 20Hz for heart rates up to 120bpm

dampening and frequency measurement:
- Make a paper record of transducer output
- Snap the valve of the continuous flush system. This produces a square wave on the output trace.
- Repeat the process at least twice.
- Resonant frequency is the distance between successive peaks divided by the paper speed in millimetres per second.
- Damping is satisfactory if each snap test has two to three oscillation waves, with each wave one third or less the size of the preceding wave.

complications of invasive arterial pressure monitoring

- Haematoma (including retroperitoneal bleeding from femoral lines)
- Distal ischaemia (risk factors include shock, sepsis, embolus of air or clot, hyperlipoproteinaemia, vasculitis, female sex, prothrombotic states, accidental intra-arterial injection of drugs)
- Infection
- Retrograde embolisation (e.g. cerebral embolus from retrograde flow of air or clot during flush – radial, brachial or axillary lines)
- Pseudoaneurysm
- Arteriovenous fistula
- Compartment syndrome
- Damage to neighbouring structures, e.g. median nerve, bowel (femoral approach)
- Exsanguination from accidental disconnection