haemodynamic monitoring [created by Paul Young 16/10/07]

Model Flow

General:
- Model Flow estimates beat-to-beat SV and CO by an arterial line or a non-invasive finger pressure using a non-linear three-component model of arterial impedance.

Measured values:
- model flow stroke volume and cardiac output

Derived values:
- absolute values of SV and CO can be obtained in a clinical setting by calibrating against a monitor that provides an absolute value for stroke volume.

Additional Considerations:
- MF is easy to install and requires minimal technical skills.
- The cuff used to measure finger pressure is unreliable under circumstances in which the patient develops peripheral vasoconstriction

Evidence:
- Changes in SV measured with MF have been validated against other modalities but have not been validated in studies of outcome

central venous oxygen sats

General:
- measured from superior vena cava via a central line
- ScvO2 is <SvO2 because it contains predominantly SVC blood which is lower than IVC blood

Evidence:
- The use of Scvo2 rather than Svo2 is argued by studies showing consistently higher values of Scvo2 than Svo2 of approximately 5%, but with parallel changes in response to a volume load
- Svo2 value of more than 70% forms part of the strategy of'early goal-directed therapy' in sepsis which has been shown to improve outcome

other data generated from monitoring device:
(i) CVP

situations where ScvO2 > SvO2
(i) anaesthesia - because of increase in CBF and depression of metabolism
(ii) patients with head injury where cerebral metabolism is depressed
(iii) shock - because of diversion of blood from splanchnic circulation, there is increased oxygen extraction & therefore IVC saturation decreases

Mixed venous oxygen sats

General:
- measured from a pulmonary artery catheter
- more invasive than ScvO2
- SvO2 is > ScvO2 as it contains blood from both SVC and IVC

Direct measurements:
- SvO2 (a value of 0.5 corresponds to the theoretical critical PvO2 of 26mmHg below which tissue dysoxia is highly likely; values exceeding 0.8 are highly suggestive of high flow states such as sepsis, hyperthyroidism and severe liver disease)

Derived measurements:
- mixed venous oxygen content can be used to determine Qs/Qt (venous admixture), VQI (simplified venous admixture) & VO2I (oxygen consumption index) [the latter of these is CI x (CaO2-CvO2)x10]

Evidence:
- Gattinoni RCT showed no benefit from SvO2 monitoring

Other data generated from monitoring devices:
- see PAC

near-infrared spectroscopy

- Near-infrared spectroscopy (NIRS) facilitates the estimation of oxygenation within tissue. By the use of an optode placed on the skin, near-infrared light is sent through the tissue and the reflected light is used to estimate oxygenation.

gastric tonometry

General
- The gastric tonometer is used for the evaluation of perfusion to the splanchnic bed. Reduced perfusion and resulting ischaemia are registered by changes in the pH of the gastric mucosa using a probe. A decreased pH of the gastric mucosa is associated with a poorer outcome
- during splanchnic hypoperfusioni, intramuscosal PCO2 increases and intramuscosal pH is reduced.

Evidence:
(i) low intramuscosal pH (pHi) has been linked with bleeding from stress ulcers, weaning failure, post-traumatic ARDS trauma, morbidity after liver transplant, major complications after cardiac surgery, MODS & death
(ii) there is no convincing evidence that titrating therapy to pHi or CO2 gap improves outcome

Additional considerations:
(i) there is uncertainty about the true dysoxic threshold (current recommendations are to maintain the CO2 gap <25mmHg)
(ii) regional PCO2 is insensitive to tissue dysoxia if blood flow is preserved

echocardiography

General:
- echocardiography visualizes the real-time anatomy and physiology of the heart

Evidence:
- Fluid therapy guided by echocardiography has not been evaluated in an outcome study

Additional considerations:
- requires expert personnel and training

pros & cons of continuous intraarterial PaO2 monitoring

Advantages	Disadvantages
Eliminates pre-analytic errors of intermittent blood gas analysis.	The 'wall' effect – a sudden decrease in measured PaO_2 due to contact with the arterial wall, with averaging of arterial and wall oxygen tensions. The problem is reduced in larger arteries such as the femoral artery.
More sensitive than pulse oximetry to changes in arterial oxygenation when PaO_2 >70 mmHg (the flat part of the HbO_2 dissociation curve).	The 'flush' effect. Unless the sensor is inserted a sufficient distance beyond the cannula tip, measured PaO_2 can be altered by contamination with the continuous flush solution
Free from the sources of error of pulse oximetry (see Table 11.3).	Damping of the arterial wave form.
Near real time PaO_2 allows prompt tracking of responses to changed ventilator settings.	Large footprint of the free-standing monitor
Reduced exposure of personnel to potentially infected blood.	
Reduced blood loss for diagnostic purposes.	

pulmonary artery catheter

Measured values:
cardiac output: 4-8L/min
cardiac index: 2.5-4L/min
CVP: 2-6mmHg
PAOP: 8-12mmHg
PAP: 25/10mmHg
SVO2: 0.65-0.70

Derived values
stroke volume: 50-100ml/beat
stroke volume index: 25-45ml/beat/m2
SVR 900-1300 dynes-sec/cm5
SVRI 1900-2400 dynes-sec/cm5
PVR 40-150 dynes-sec/cm5
PVRI 120-200 dynes-sec/cm5

Evidence
- Randomized studies have not shown a positive effect of PAC
- The timing of monitoring and intervention in the era of PAC may also explain the inconsistency of the results. In the critically ill patient with multi-organ failure, intervention is not as efficacious as in earlier stages of illness, probably because of more advanced pathophysiological processes.

Additional considerations:
- The use of PAC is also complicated by the invasiveness of the procedure and potential complications.

Oesophageal Doppler

General:
- A Doppler probe in the mid-oesophagus, is used to measure the velocity of blood in the descending aorta. This velocity can be transformed to a corresponding SV by a nomogram derived from correlation studies with PAC measurements.

Measured values:
- blood velocity

Derived values:
- OD derived stroke volume and cardiac output
- systolic flow time, which may indicate systemic vascular resistance. The normal range of the systolic flow time is 330-360 ms and, with lower values, hypovolaemia should be suspected

Evidence:
- early validation studies showed good agreement with thermodilution techniques; however, it is now known that the agreement is poor when upper / lower body blood flow distributions are altered or when estimates of aortic cross sectional area are inaccurate

Additional Considerations:
- OD does not require calibration
- relatively little training is needed to provide a reproducible result.
- The position of the probe, however, must be accurate and adjustments are required frequently. Values for SV and CO must therefore be interpreted with attention to the probe position.
- requires a sedated patient
- contraindicated in oesophageal pathology, aortic balloon counterpulsation & severe coarctation
- unreliable in children due to large fluctuations in aortic cross-sectional area during systole
- assumptions that descending aorta is 70% of cardiac output can be incorrect

PICCO

General:
- The pulse contour cardiac output method (PiCCO) is the most validated system in pulse contour analysis and correlates with PAC thermodilution measurements

Direct Measurements
- Pulse pressure

Derived Measurements
- Stroke volume
- Cardiac output

Evidence:
- comparisons with PA catether cardiac output measurement has shown good agreement

Additional Considerations:
- results in patients with arrhythmia may be unreliable because of the irregular arterial waveforms
- PiCCO is calibrated by transpulmonary thermodilution and is therefore invasive, as, in addition to a central venous catheter, it requires a femoral or axillary artery line.
- recalibration is advisable every few hours to allow for changes in SVR (esp during haemodynamic instability or infusion of vasoactive drugs)

ITBVI	Cardiac index	EVLWI	Interventions to consider
Low	Normal or high	High	Diuresis for improved pulmonary function
Low	Normal or high	Low	Volume loading for improved tissue perfusion
Low	Low	High	Cautious volume loading in conjunction with vasoactive drugs—vasoconstrictor/dilator and inotrope balance based on SVR and effect of chosen therapy
Low	Low	Low	Fluid load
High	Normal or high	High	Volume restriction and consideration of diuresis for improved pulmonary function
High	Normal or high	Low	Observation
High	Low	High	Cautious diuresis in conjunction with vasoactive drugs—vasoconstrictor/dilator and inotrope balance based on SVR and effect of chosen therapy
High	Low	Low	Vasoactive drugs—vasoconstrictor/dilator and inotrope balance based on SVR and effect of chosen therapy

Lithium Dilution Cardiac Output

General:
- LiDCO is a monitor that uses pulse power analysis.
- requires arterial and venous lines

Measured Values:

Derived Values:

Evidence:
- Measurements with LiDCO suggest a comparable accuracy to PiCCO, and reports propose comparable precision to CO determined by thermodilution.
- Reports on the clinical application of LiDCO are limited

Additional Considerations:
- It requires initial calibration, either by a small lithium bolus or a value of CO attained with another monitor.
- The amount of lithium used to calibrate the system has not been associated with any reported side-effects. However, there is interference with non-depolarizing neuromuscular blockers so that calibration with lithium must take place before or 15-30 min after their administration
- LiDCO has been reported to be contraindicated in patients weighing less than 40 kg, in the first trimester of pregnancy and in patients on lithium therapy.
- corrections for packed cell volume are necessary since lithium is only distributed in plasma
- blood is toxic after assay in the lithium sensitive electrode and must be disguarded