Haemodynamic monitoring – a critical appraisal

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Beware of false knowledge; it is more dangerous than ignorance.

George Bernard Shaw

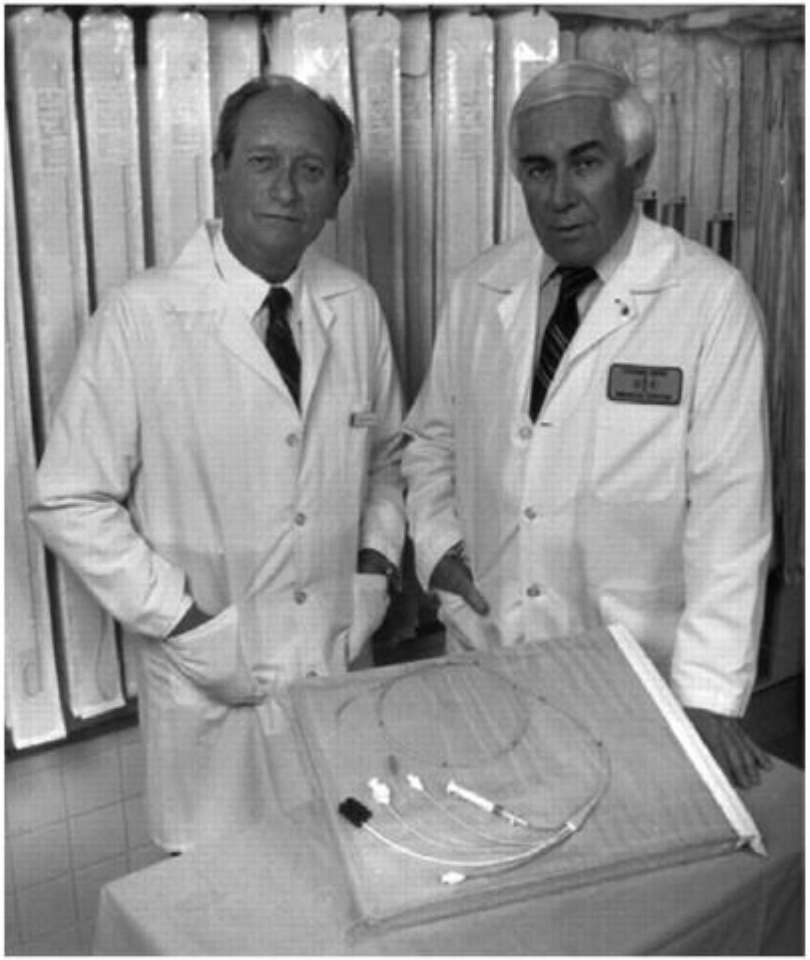
- No conflicts of interest to declare.
- No shares or financial or pecuniary interest in any cardiac output technology or device

- **Learning objectives:**
- To understand the different options for monitoring cardiac output during anaesthesia and surgery.
- To understand the advantages and disadvantages of different technologies.
- To critically appraise the evidence for different technologies.

PA catheter

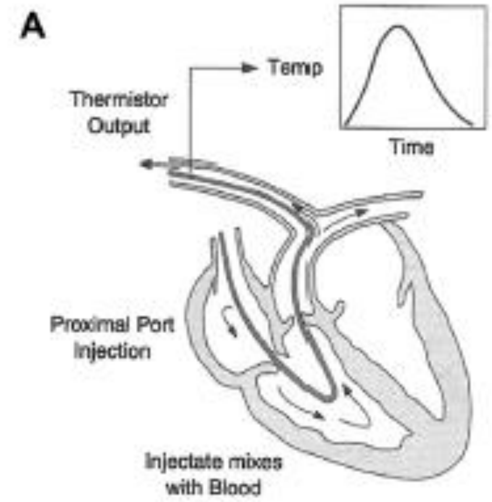
- Gold standard?
- Complications
- Effect on outcomes
- Specific uses

Catheterization of the Heart in Man with Use of a Flow-Directed Balloon-Tipped Catheter
H. J. C. Swan, William Ganz, James Forrester, Harold Marcus, George Diamond and David Chonette.
NEJM 1970; 283:447-451



William Ganz and H.J.C. Swan

PA catheter

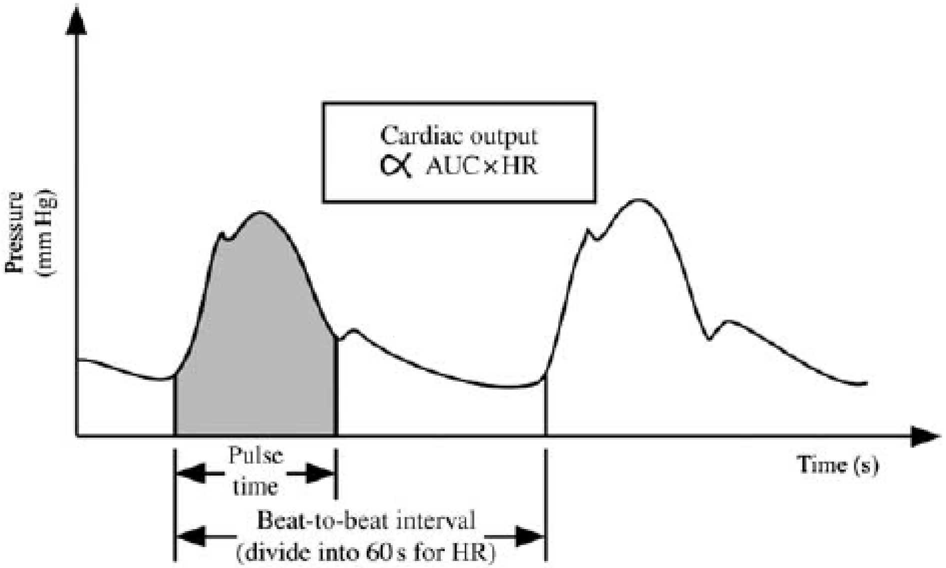


- Diagnostic and haemodynamic monitoring tool
- Not itself a therapeutic intervention
- Cochrane review of 5686 patients in 13 trials
- Pooled RR for mortality in ICU 1.02 (95%CI 0.96 to 1.09) and for high-risk surgery patients RR 0.98 (95% CI 0.74 to 1.29).
- Newer, less-invasive haemodynamic monitoring tools need to be validated against PAC prior to clinical use in critically ill patients

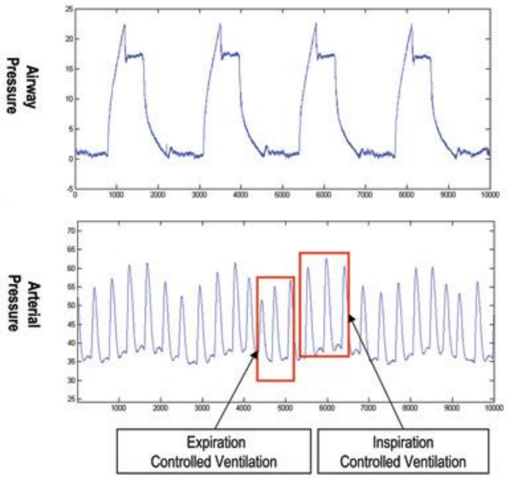
Rajaram SS et al. Pulmonary artery catheters for adult patients in intensive care. Cochrane Database Syst Rev 2013;2:CD003408.

Pulse contour analysis

- Contour of arterial pressure waveform related to stroke volume and SVR
- Algorithm used to determine CO



Pulse contour analysis

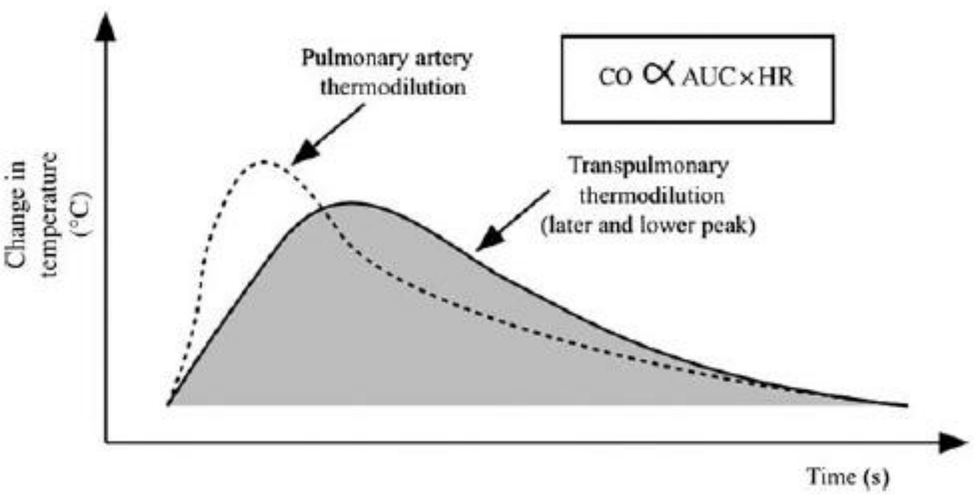


- **Stoke volume variation (SVV)**
- Difference between maximum and minimum stroke volumes over the respiratory cycle
- May be caused by changes in preload with alterations in intra-thoracic pressure.
- SVV can be used as an indicator of fluid responsiveness.
- Patients with an SVV of <10% are unlikely to be fluid responsive,
- SVV > 15% may benefit from fluid resuscitation.

Funk DJ, et al. Minimally invasive cardiac output. A & A 2009; 108: 887–97

PiCCO

- PiCCO (Pulsion Medical Systems, Munich, Germany)
- Uses a thermistor-tipped arterial line in a proximal artery
- Algorithm is used to determine CO by integrating AUC arterial pressure vs time trace.
- Central venous catheter is used to calibrate the system using a transpulmonary thermodilution technique.



PiCCO

- Probably best validated pulse contour system vs PA catheter.

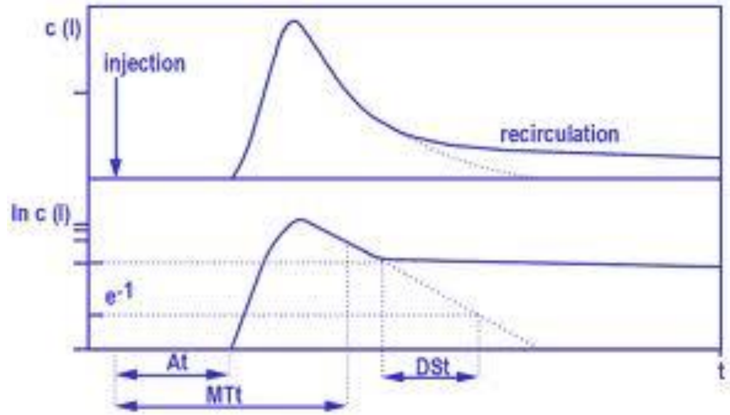
- Strong correlation at wide variety of CO and SVR even when significant variations in haemodynamics and vascular tone are present

Goedje O, et al. Continuous cardiac output by femoral arterial thermodilution calibrated pulse contour analysis: comparison with pulmonary arterial thermodilution. Crit Care Med 1999; 27: 2407–12.

- Not accurate using a peripheral arterial catheter (e.g. radial)

Orme RM, Pigott DW, Mihm FG. Measurement of cardiac output by transpulmonary arterial thermodilution using a long radial artery catheter. A comparison with intermittent pulmonary artery thermodilution. Anaesthesia 2004; 59: 590-4.

PiCCO



- Transpulmonary thermodilution is used to calibrate the PiCCO monitor.
- Uses the same principles of thermodilution as PACs.
- Cold injectate is introduced into the SVC via central line.
- An arterial line with a thermistor is placed in a major artery (femoral, axillary, or brachial) and the change in temperature of the blood is measured after the injectate has traversed the right heart, pulmonary circulation, and left heart.

- The change in temperature over time curve begins later and has a lower peak compared with the curve from a PAC.

- A number of potential sources of error have been identified.
- Thermodilution measured via a PAC measures the right heart cardiac output, whereas transpulmonary thermodilution measures the left heart.

- Indicator recirculation occurs when an increased amount of the cold injectate leaves the blood and enters the tissues, for example pulmonary oedema, and later re-enters the blood – may cause an abnormal prolongation of thermodilution curve and lead to underestimation of cardiac output.

FloTrac

- FloTrac/Vigileo system (Edwards Lifesciences, Irvine, CA, USA)
- Blood flow sensor is attached to a standard arterial catheter (eg radial).
- Cardiac output is calculated every 20 secs using an upgraded algorithm.
- CO = arterial pulsatility (SD) of pressure wave (over 20 s) multiplied by a constant (K) derived from the patient's specific vascular compliance
- Stroke volume is multiplied by heart rate to calculate cardiac output.
- Specific vascular compliance is updated every minute and is based on age, height, gender, and weight and waveform characteristics.
- Does not require external calibration.

FloTrac

Data regarding accuracy has been conflicting, despite software upgrades.

In patients undergoing vascular surgery, the FloTrac is not reliable compared with echocardiography.

Romagnoli S et al. JCVA 2013; 27: 1114-21.

Administration of vasoconstrictors reduces accuracy and ability to track changes in cardiac output

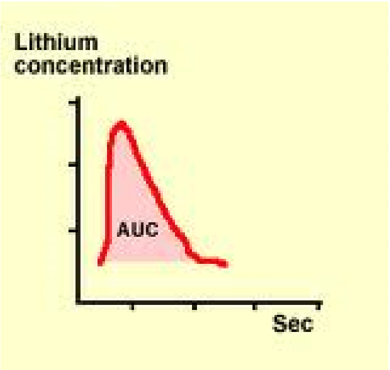
Suehiro K et al. BJA 2013; 111: 170-7.

Lacks the accuracy to reliably detect changes in cardiac output in cardiac surgery.

Desebbe O, et al. JCVA 2013; 27: 1122-7.

LiDCO

- Strictly speaking, the LiDCO monitor (LiDCO, Cambridge, UK) uses pulse power analysis rather than pulse contour analysis.
- Algorithm for CO based on the law of conservation of mass
- Assumption that net power has a linear relationship with net flow.
- A standard arterial line only is required.
- Calibrated using lithium dilution centrally or peripherally



- Correlates well with the PAC in a range of settings at a steady state.

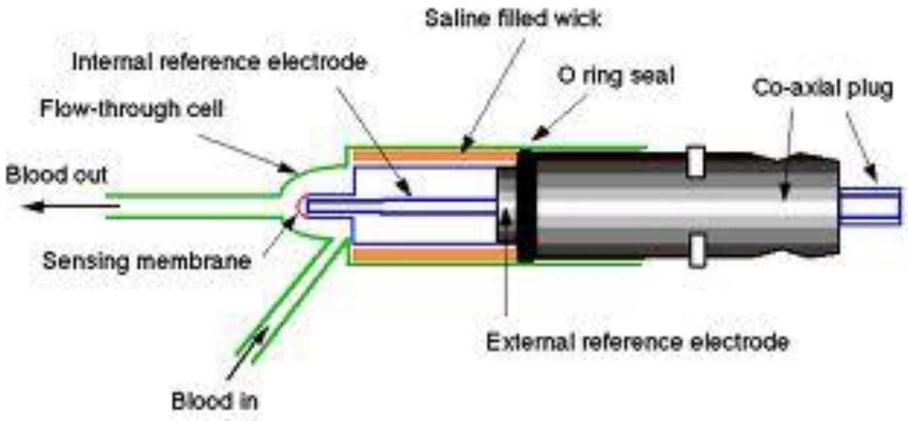
- Inaccurate after vasodilatation (induction of anaesthesia) or vasoconstriction (aortic cross clamping) – needs recalibration
  Beattie C, et al. Anaesthesia 2010; 65: 1194-9.

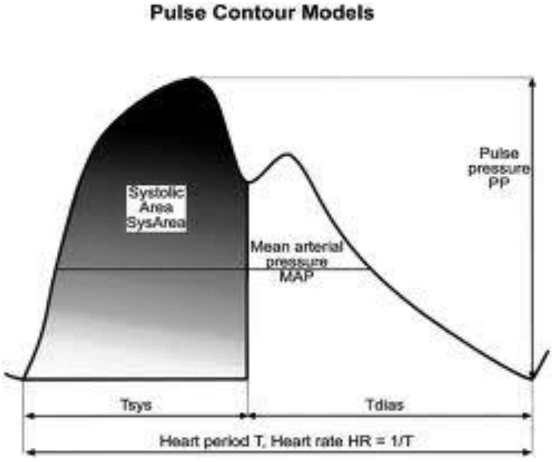
- Lithium dilution uses 0.5–2 ml (maximum cumulative dose 20 ml) boluses of lithium chloride (0.15 mmol ml/1) via a central or peripheral venous line and measured via aspiration of blood through an arterial catheter, with an attached disposable electrode selective for lithium, at a constant rate of 4 ml/min.

- Reduced accuracy in patients on long-term lithium treatment and nondepolarising neuromuscular blocking agents.

- Lithium contraindicated weight <40 kg and women in first trimester of pregnancy.

LiDCO

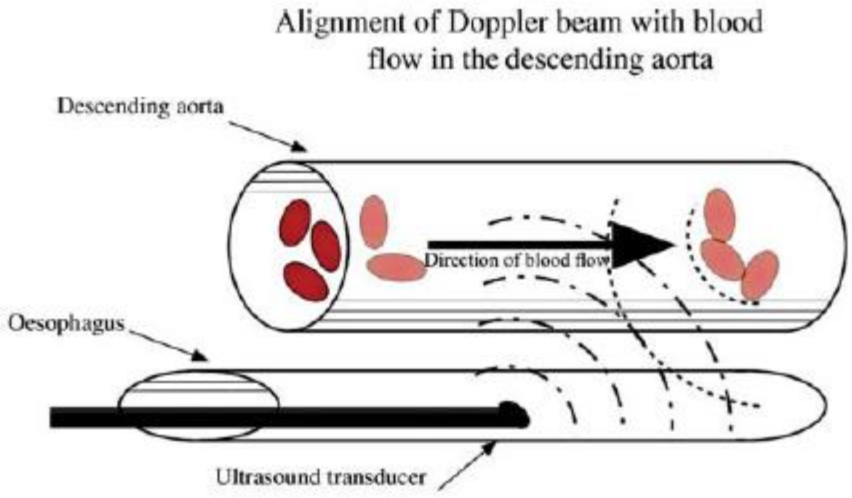




- All pulse contour analysis monitors rely on an optimal arterial signal.
- Over- or under-damped traces may lead to inaccuracies
- All are affected by arrhythmias, aortic regurgitation, and the use of an intra-aortic balloon pump and have been shown to affect accuracy.
- Changes in systemic vascular resistance may also lead to inaccuracies.
- Causes include cross-clamping of vessels, use of vasodilators or vasoconstictors, or epidural anaesthesia.

Aortic Doppler

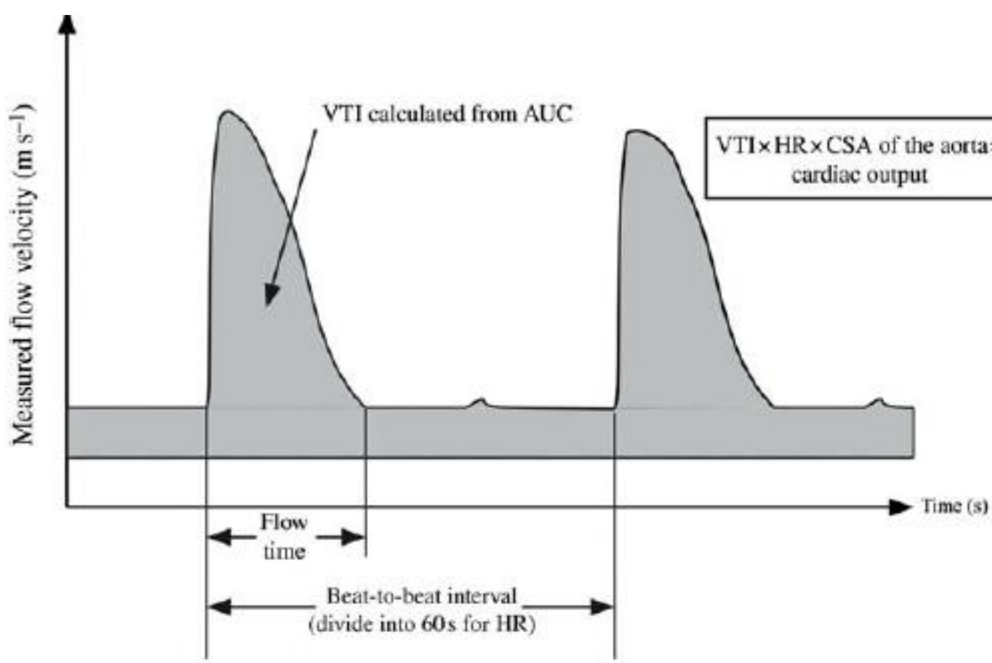
- The volume of blood passing through the aortic valve over a given cardiac cycle is the stroke volume.
- SV x HR = CO

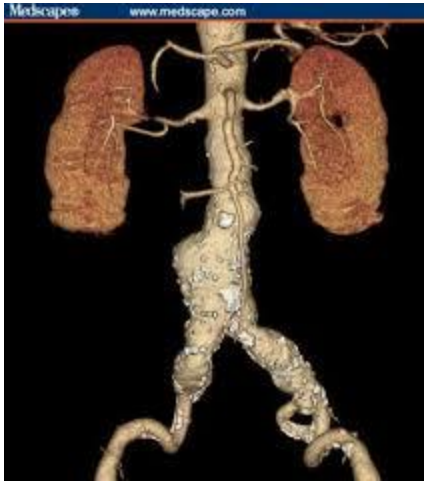


Blood flow velocity is determined from the shift in frequency of red blood cells.

Aortic Doppler

- The velocity–time integral (VTI) is calculated from the area under the velocity–time curve and used as the stroke distance
- An estimate of aortic cross-sectional area (CSA) is taken from a nomogram (height, weight, and age)
- CO = CSA x VTI x HR.
- A correction factor must be used as the measurement utilises the descending aorta, as only 70% of cardiac output passes through this vessel.





Aortic Doppler

- Estimation of cross sectional area of the aorta is an important source of error for this method of cardiac output measurement.
- The use of a nomogram may introduce measurement error, especially as CSA will change with change in vascular tone and volume status.
- The probe position is critical in reducing measurement error for both blood flow measurement and aortic cross-sectional measurement.
- Even small misalignments of the ultrasound beam with blood flow will lead to underestimation of flow.
- Any turbulent flow in the aorta will reduce measurement accuracy.

Oesophageal Doppler

- Unconscious patients only (anaesthesia or ICU)
- When optimised flow profile is obtained, meta-analysis showed low bias and acceptable limits of agreement compared with PA catheter.
- However, can be very user-dependant and values change rapidly with small movements of the probe, especially rotation.

USCOM

- Cardiac output can be measured non-invasively using supra-sternal Doppler (USCOM, Sydney, NSW, Australia).
- However, scanning can be difficult in practice in older patients.
- Chest radiographs from 60 anaesthetised patients were reviewed and scored for aortic unfolding, enlargement and calcification, and cardiac enlargement.
- Over 75% of the patients who were difficult to scan had two or more radiological features suggestive of aortic unfolding and cardiac enlargement.
- Morphological or anatomical changes associated with ageing within the upper chest play an important part in the success of using supra-sternal Doppler in older patients.

Huang et al. Anaesthesia 2013; 68: 1156-60

USCOM

- Meta-analysis of six studies
- Pooled parametric analysis consisting of 320 measurements.
- Mean weighted bias was 0.39 l.min (95% CI 0.25 to 0.53 l.min), precision 1.27 l.min and percentage error 42.7% (95% CI 38.5 - 46.9%).

Chong SW et al. Anaesthesia 2012; 67: 1266-71

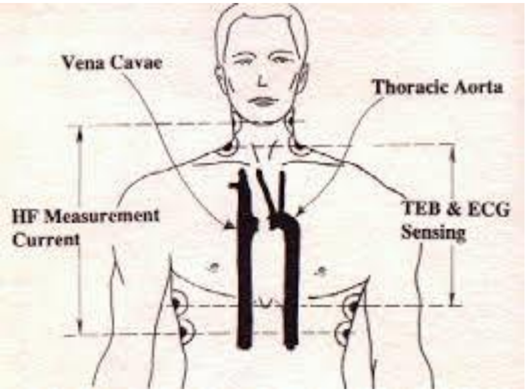
CO_2 rebreathing

- Partial gas rebreathing monitor uses the indirect Fick equation to determine cardiac output.
- A rebreathing apparatus is attached to the patient's tracheal tube and serial measurements are taken every 3 min.
- At steady state, the amount of CO2 entering the lungs via the pulmonary artery is proportional to the cardiac output and equals the amount exiting the lungs via expiration and pulmonary veins.
- During 30 s of rebreathing, the amount entering does not
- change, but the amount eliminated by expiration decreases and the expired CO2 increases in proportion to the cardiac output

CO_2 rebreathing

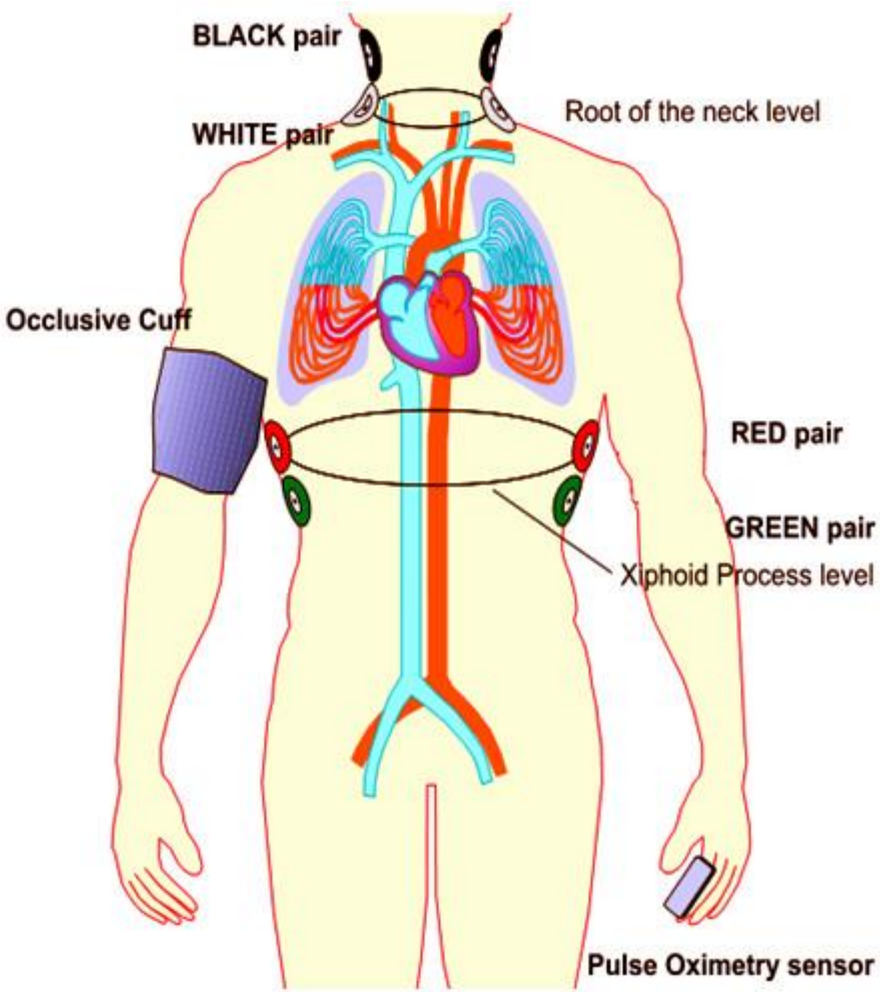
- Tracheal intubation is required.
- Inaccurate with assisted spontaneous breathing patients.
- Severe chest trauma, significant intrapulmonary shunt, low minute ventilation, and high cardiac output may all reduce accuracy

Bio-impedance



- Measures the electrical resistance of the thorax to a high frequency, very low magnitude current.
- Six electrodes are placed on the patient and the resistance to current flowing from the outermost to innermost electrodes measured.
- Bioimpedance is indirectly proportional to the content of thoracic fluid: tissue fluid volume, pulmonary and
- venous blood, and the aortic blood volume.
- Changes in cardiac output will change the amount of aortic blood and will be reflected in a change in bio-impedance.

Bio-impedance



- Affected by interference due to electrocautery (diathermy)
- Very sensitive to movement.
- Arrhythmias may lead to inaccuracy due to an irregular R–R interval.
- Bias and precision 1.0+/- 10.8 ml/m2 mean error above 30%

De Waal EE, et al. Int Care Med 2008; 34: 735-9

Nexfin – photo-electric plethysmography

- Cardiac output measured in 38 intensive care unit patients before and after a fluid challenge, using both pulse contour analysis (Nexfin®, BMEYE, Amsterdam, the Netherlands) and transthoracic echocardiography.
- The ability of the Nexfin device to detect significant changes in the velocity-time integral was evaluated.
- The pulse wave could not be detected by the Nexfin device in five patients (13%), leaving 33 patients for analysis.
- The percentage error between the Nexfin and echocardiography was 448%; lower limit of agreement -48% (95% CI -62 to -36%) and upper limit of agreement, 32% (95% CI 20-45%).
- The Nexfin device does not adequately track changes in cardiac output in critically ill patients

Taton O, et al. Anaesthesia 2013; 68: 917-23.

Meta-analysis

- Percentage error (95% limits of agreement / mean cardiac output) should be < 30%.
- At least one single independent measurement on each subject was required.
- **Pulse contour analysis:** 24 studies, precision 1.2 l/min, 41.3%
- **Oesophageal Doppler**: 2 studies, precision 1.1 l/min, 42.1%
- **Partial carbon dioxide rebreathing**: 8 studies, precision 1.12 l/min, 44.5%
- **Transthoracic bioimpedance**: 13 studies, precision 1.1 l/min, 42.9%
- None of the four methods has achieved agreement with bolus thermodilution which meets the expected 30% limits.

Peyton PJ, et al. Anesthesiology 2010; 113: 1220-35

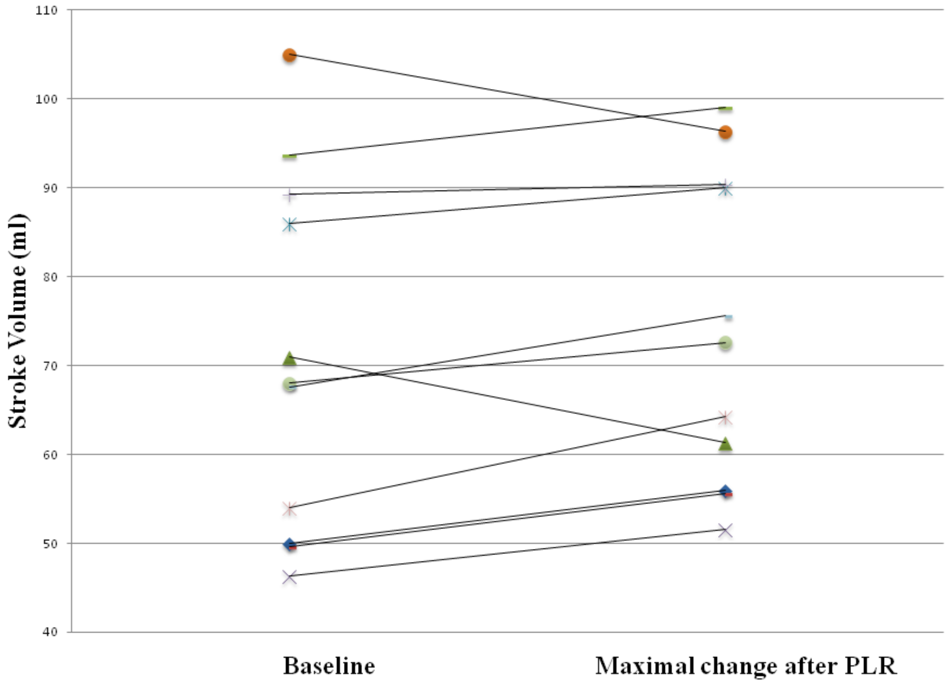
Echocardiography

- Line up Doppler beam
- Measure exact diameters/CSA
- Measure SV an calculate CO
- TTE vs TOE
- ? Gold standard
- TIMING

Echocardiography

- Stroke volume variation
- Effect of passive leg raise variable

Godfrey et al. Anaesthesia 2014 Earyl View



Summary

- All methods somewhat limited by accuracy
- Are any of them worth using?
- Absolute numbers vs trends or both inaccurate?
- Can we accept limitations because of reduced invasiveness?