Cardiac output monitoring

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There is a reduction in post-operative complications, use of central venous catheters and in-hospital stay compared with conventional clinical assessment with or without invasive cardiovascular monitoring.

The CardioQ-ODM should be considered for use in patients undergoing major or high-risk surgery or other surgical patients in whom a clinician would consider using invasive cardiovascular monitoring.

Innovation, Health and Wealth. DOH, 2011

Intraoperative fluid management is one of the high impact innovations in the NHS

Cardiac output monitoring for certain operations is a CQUIN pre-qualifier from April 2013

Financial incentive to implement cardiac output monitoring in patients undergoing major surgery


Benefits to patients

- Low risk of cardiac complications
- Minimally or non-invasive monitoring
- Reduced risk of catheter (CVP, arterial, PAC) related infection
- Reduced length of hospital stay, patients are ‘fit for discharge’ sooner
- Fewer post-operative complications
- Reducing emergency admissions into intensive care after surgery
- Earlier detection of complications in surgery
- Reduced rate of re-admission and re-operation

A Systematic Review and Meta-Analysis on the Use of Preemptive Hemodynamic Intervention to Improve Postoperative Outcomes in Moderate and High-Risk Surgical Patients

Mark A. Hamilton, MAFC, MRCR, Mauroz Cassen, MD, and Andrew Rhodes, MD, MRCR, MRCR

- In total, the 29 trials involved 4805 patients with an overall mortality of 7.6%.
- The use of preemptive hemodynamic intervention significantly reduced mortality (pooled odds ratio of 0.48 [0.33–0.78]).
- and surgical complications (odds ratio 0.43 [0.34–0.53]).
Essential topics

- Fick’s principle
- Swan-Ganz catheter pressure wave forms
- Doppler
- Stewart-Hamilton and indicator dilution techniques
- Arterial wave form analysis
- Sources of error and limitations
- Parameters: CO, CI, SV, SI, DO2, SvO2, PCWP, SVV, PPV, FTc, SD

Tissue oxygenation

- Oxygen content
- Cardiac output
- Blood pressure
- Venous return
- Intravascular volume
- Pump function / valves
- Heart rate / rhythm
- Vasomotor tone and regional distribution
- Vasomotor tone (vascular resistance)

O2

- Near-infrared spectroscopy
- Lactate
- Mixed-venous SO2
- Systemic oxygen delivery

Systemic Oxygen Delivery = Cardiac Output x Arterial Oxygen Content
Cardiac Output = Stroke Volume x Heart Rate
Why do we need cardiac output monitoring?

- Traditional parameters can be misleading
- There is no good correlation between traditional parameters and fluid responsiveness
- Decisions based on traditional parameter can be wrong and harmful
- CO monitoring provides better end-points to guide haemodynamic interventions like intravenous fluid resuscitation, inotropes, vasopressors, vasodilators.
- CO monitoring helps to avoid complications and poor outcomes due to low cardiac output, low tissue perfusion or fluid overload.

Cardiac output monitoring

- Pulmonary artery catheter (Fick principle)
- Transoesophageal or suprasternal aortic Doppler
- Arterial wave form analysis
- Indicator dilution techniques (incl. thermodilution)
- Combined techniques
- Echocardiography (LVOT Doppler)
- Impedance cardiography, electrical velocimetry, bioreactance
- Gas rebreathing
- Electromagnetic flow meter

Fick’s equation

\[ \dot{V}_O_2 = \dot{Q} \cdot C_A - \dot{Q} \cdot C_V \]
\[ \dot{V}_O_2 = \dot{Q} (C_A - C_V) \]

250ml/min = 5L/min (200ml/L – 150ml/L)

Fick method

Limitations

- Accurate measurement of O₂ uptake required
- Only valid in steady state
- Invasive, requires pulmonary artery catheter
Pulmonary artery catheter

- Uses piezo-electric crystals to emit and receive ultrasound waves
- Detects flow in descending aorta

Transoesophageal Doppler

- Detects flow in descending aorta
- Uses nomogram (age, height, weight) derived from Swan-Ganz measurements to convert trace into stroke volume
Transoesophageal Doppler

Measured parameters
- **Stroke Distance (SD)**: Distance a column of blood will travel down the aorta with each LV contraction. Area under the velocity-time waveform. Used to calculate stroke volume.
- **Mean Acceleration (MA)**: Average acceleration of blood from start of systole to detected peak velocity (cm/sec²). Corresponds to contractility.
- **Flow Time corrected (FTc)**: Systolic flow time (ms) standardized to heart rate of 60 bpm (one cardiac cycle per second). Inversely correlated to systemic vascular resistance. Reference range 330 – 360ms

Doppler effect

\[ f_D = \frac{2v f_0 \cos \theta}{c} \]

\[ v = \frac{c f_D}{2f_0 \cos \theta} \]
Transoesophageal Doppler

Sources of error
- Probe position
- Altered angle of insonation
- Change in vascular tone / aortic cross-sectional area
- Turbulent flow
- Diathermy artefacts (piezo-electric crystals)

Arterial wave form analysis

\[ SV = \int \frac{dP}{dt} \]

Figure 3: Stroke volume estimated from systolic portion (shaded) of arterial waveform.

Pressures

(a) hypertension
(b) control
(c) hypertension/elderly
Arterial wave form analysis

**Technical problems**
- Compliance of aorta is non-linear
- Wave reflection, proximity of sampling site, vasoconstriction
- Over- and under-damping
- Aortic outflow during systole

**Sources of error**
- Damped trace
- Arrhythmias
- Intra-aortic balloon pump
- Aortic regurgitation
- Variable aortic impedance

**Stewart-Hamilton equation**

\[
\dot{Q} = \frac{I}{\int_0^\infty C_I(t)\,dt}
\]

\[
CO = \frac{LiCl \text{ dose} \times 60}{AUC(T-PCV)}
\]
The ideal indicator

- Stable
- Non-toxic
- Easily measured
- Uniformly distributed in target compartment
- Not lost from circulation during first transit
- Rapidly dissipates to avoid recirculation

Thermodilution

\[ \dot{Q} = \frac{V_i(T_B - T_i)}{\int_0^\infty \Delta T_B(t) \, dt} \]

- \( V_i \) = injectate volume
- \( T_B \) = blood temperature
- \( T_i \) = injectate temperature
- \( K \) = comparator constant
- \( \Delta T_B(t) \) = integral of temperature change over time

PiCCO system

- Combines arterial waveform analysis and transpulmonary thermodilution
- Requires CVP line (for injectate) and special thermistor-tipped proximal arterial line to measure the temperature change over time
- Allows calculation of extravascular lung water (EVLW), global end-diastolic volume (GEDV) and intrathoracic blood volume (ITBV)

LIDCO Plus system

- Combines arterial waveform analysis and indicator dilution (Lithium)
- Uses a continuous arterial blood sample over a lithium-sensitive electrode to measure lithium plasma concentration over time
- Does not require a CVP line or a special arterial line
- Does not require proximal arterial line
- Uses pulse power analysis for arterial waveform analysis / continuous CO measurement
Lithium dilution

Sources of error
- Muscle relaxants
- Therapeutic dose lithium
- Incorrect lithium dose injected

Dilution techniques

Sources of error
- Loss of indicator (before or after injection)
- Inadequate indicator dose
- Inadequate sampling
- Haemodynamic fluctuations

Problems for all CO monitors
- Aortic cross-clamping
- Aortic stenosis/regurgitation
- Arterio-venous shunts
- Intra-aortic balloon pump
- Arrhythmias (e.g. atrial fibrillation)
Perioperative fluid management

- Hypotension
- Hypoperfusion
- Shock
- Acidosis
- Renal failure
- Surgical site infection
- Sepsis
- Multiple organ failure

- Oedema
- Respiratory failure
- Pleural effusions
- Pneumonia
- Abdominal hypertension
- Anastomotic breakdown
- Sepsis
- Multiple organ failure

How to assess preload and fluid responsiveness

**Static**
- CVP, PCWP
- Transoesophageal Doppler (FTc, SD)
- GEDV, ITBV
- Echo (end-diastolic diameter/area)

**Dynamic**
- Stroke Volume Variation
- Pulse Pressure Variation
- Pieth Variability Index (PVI)
- IVC collapsibility (ultrasound)
- Passive leg raising
- Fluid challenge
Fluid challenge
* Give 250ml of colloid over 5 minutes to all patients

SVI increases > 10%

Dopexamine
* Hb must be > 8g/L before starting Dopexamine
* Start/increase dopexamine by 0.25 μg/kg/min
* Maximum 1 μg/kg/min
* Check DO2I after 15 minutes
* Consider lower target for DO2I (e.g. 500) in patients with known cardiac disease and in vascular patients

References
- Drummond KE, Murphy E. Minimally invasive cardiac output monitors. CEACCP 2012; 12: 3-10.
- www.oliverzuzan.net