

Cardiac output monitoring

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DEFINITIONS

Before describing the different types of cardiac monitoring, it is essential to understand some basic definitions:

The cardiac output is determined by, and therefore can be manipulated by, alterations to the heart rate or rhythm, the preload, the contractility and the afterload.

Cardiac output informs us of global blood flow and therefore oxygen delivery (the product of cardiac output and blood oxygen content), but does not describe delivery of oxygen to each organ, whose function must be assessed individually.

An appreciation of how information is measured and derived using a cardiac output monitor is essential in order to use the information accurately and appropriately. Thorough assessment of a patient's clinical status strongly influences interpretation of the measurements made. For example, cardiogenic shock and obstructive shock due to tamponade will both give a low cardiac output, but can be differentiated by the patient's clinical signs. There is a wide variability between practitioners in the measurement and interpretation of cardiac output data, using the various techniques that are currently available. For this reason, clear evidence that they benefit patient outcome is difficult to obtain.

Cardiac output is the volume of blood ejected from each of the ventricles of the heart per minute, and is therefore the product of stroke volume and heart rate. The unit of cardiac output is $L \cdot \text{min}^{-1}$.

Cardiac index is the cardiac output of a patient referenced to their body surface area and has units of $L \cdot \text{min}^{-1} \cdot \text{m}^{-2}$.

Stroke volume is the volume of blood ejected by each contraction of the ventricle and is determined by the preload, afterload and contractility. The stroke volume is usually 60-80ml for an average sized adult.

Preload describes the tension developed in the ventricular wall at end-diastole (i.e. at maximal filling just prior to contraction). This tension is difficult to measure and end-diastolic pressure is taken as a surrogate (or estimate) measurement. It is mainly determined by venous return and gives an indication of the filling pressure of the ventricle.

Contractility refers to the amount of work the heart can generate, at given levels of preload and afterload, and is estimated by the maximum rate at which the ventricle can generate a change of pressure over time. Inotropy is used to explain an increase in the work done by the heart that is independent of heart rate, preload and afterload.

Afterload is the tension that needs to be generated in the ventricular wall in order to eject blood into the arterial system during systole. This is largely determined by the resistance of the arterial system – the systemic vascular resistance (SVR). It is calculated by:

$$\text{SVR} = \frac{\text{Mean arterial pressure (mmHg)} - \text{Central venous pressure (mmHg)}}{\text{Cardiac output (L} \cdot \text{min}^{-1})} \times 80$$

(Recall that Ohm's Law describing electrical resistance is analogous to this: $V = IR$)

Mean arterial pressure (MAP) is the average arterial blood pressure throughout the cardiac cycle. As 2/3 of the cardiac cycle is spent in diastole, and 1/3 in systole, MAP may be calculated using the formula:

$$\text{MAP} = \text{Diastolic BP} + \frac{1}{3}(\text{Systolic BP} - \text{Diastolic BP})$$

Ejection fraction is the fraction of total blood in a ventricle that is ejected per beat. It applies to both the left and right ventricles. It gives an index of contractility. Normal value is in the region of 55-65%.

Summary

Estimation of cardiac output has an important role in patient management during anaesthesia and critical care. Cardiac output can be measured in a number of ways, from simple clinical assessment to invasive haemodynamic monitoring. Advanced monitoring techniques are often used when clinical signs are difficult to interpret. While there has been much research looking at the accuracy of these monitors there is currently very little information in the literature regarding the effectiveness of these monitors in improving clinical outcomes.

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CLINICAL INDICATORS OF CARDIAC OUTPUT

The interpretation of data from invasive haemodynamic monitoring is made in light of the clinical examination. No single clinical sign can be used to make an accurate assessment of cardiac output. Heart rate, blood pressure, pulse strength at various sites, patient colour, respiratory rate and core to peripheral temperature gradient all give an indication to a patient's haemodynamic status. Note that although blood pressure is often used as an indicator of cardiac output, it is frequently unhelpful. Blood pressure may be maintained by intense peripheral vasoconstriction in the face of a perilously low cardiac output.

A patient's ability to compensate for a haemodynamic insult is highly variable, depending on age, premorbid status and other comorbidities. An example is the rise in the diastolic pressure in early hypovolaemic shock, associated with peripheral vasoconstriction that is usually only seen in young, fit individuals. In addition, clinical parameters such as urine output, capillary refill time and cognitive function give a guide to end organ perfusion. Change in heart rate, blood pressure and central venous pressure in response to a straight leg raise is useful to predict a patient's response to a fluid bolus.

Measurement of lactate and base deficit in arterial blood and, in particular, the trend of these variables over time gives non-specific information about a patient's organ perfusion. Lactate is produced by anaerobic metabolism, and is an indicator of tissue hypoperfusion. It is measured on most modern blood gas machines. It can be used to monitor therapy, as it will fall as oxygen delivery improves, and as liver perfusion (which enables lactate metabolism) increases.

The oxygen saturation in central venous blood ($ScvO_2$) also gives a global indication of haemodynamic status, is useful in directing fluid therapy³ and is a reliable surrogate of mixed venous oxygen saturation (see under pulmonary artery flotation catheters, below).

Learning point – blood pressure is a poor indicator of cardiac output.

OVERVIEW OF THE ROLE OF CARDIAC OUTPUT MONITORING

Mortality in sepsis increases by 15-20% for each 'organ failure' that a patient develops.¹ Organ failure results when delivery of oxygen is inadequate for the organ's requirements. Since the 1980s, research has suggested that optimisation of oxygen delivery (a product of cardiac output and blood oxygen content) in high risk surgical patients prevents organ failure and improves mortality.² This has been investigated early in critical illness, and prior to, during and after surgery.² Although no single study provides categorical evidence, the weight of evidence suggests that therapies directed at enhancement of oxygen delivery (goal-directed therapy) should be our aim. There is also increasing evidence that, while hypovolaemic septic patients need fluid to optimise their cardiovascular delivery of oxygen, excessive liberal fluid therapy may be harmful.

The major factor limiting this field of clinical practice has been development of a monitoring device that will reliably and accurately guide our use of fluid therapy - to recognise where fluid is needed and give enough, but not too much. Measurement of 'filling' is difficult. We aim to apply Starling's Law, where cardiac performance

improves with stretching of the ventricular muscle fibres, to a certain optimal point beyond which further stretching impairs performance (see Figure 1). To apply this strategy we would like to know the left ventricular end-diastolic volume (LVEDV) and monitor changes in the LVEDV as we give fluid boluses. The best surrogate estimate of LVEDV we have is to use a pulmonary artery catheter (PAC) to measure pulmonary artery occlusion ('wedge') pressure, which gives us an estimate of left atrial pressure, which is in turn an estimate of LVEDP, which is a surrogate of LVEDV (and makes assumptions about normal compliance of the left ventricle). This is not a reliable measure of filling, particularly given the effects of ventilation, applied PEEP and the anatomical location of the catheter tip in different lobar pulmonary artery branches. Thermodilution using the PAC does provide an accurate measurement of cardiac output, which can be measured continuously given the correct equipment, however use is diminishing in many parts of the world, due to concerns over safety and lack of robust evidence to support their use.

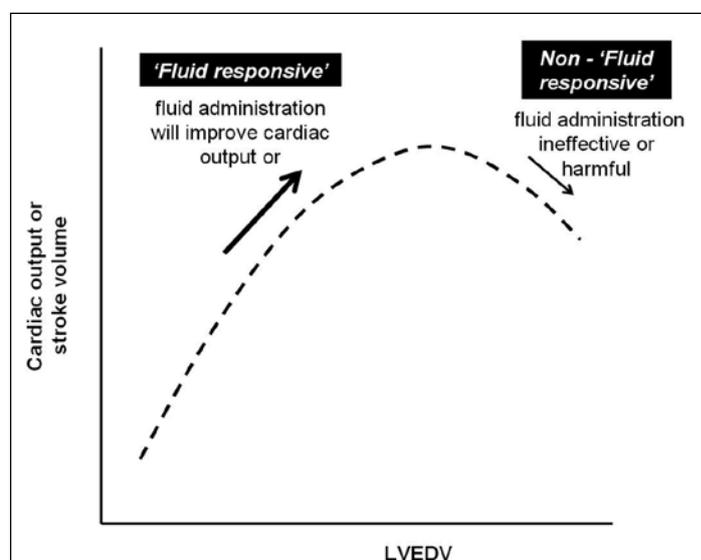


Figure 1. Simplified explanation of Starling's Law.

Currently, the main focus of research and development is towards less invasive monitors with inherently lower risks of use. Broadly these are monitors that use Doppler analysis of the aortic blood velocity (viewed from the oesophagus) or monitors that analyse the shape of the arterial waveform ('pulse contour analysis').

Some of the cardiac output monitors that rely on arterial waveform analysis, use thermo- or indicator dilution to obtain an accurate estimate of cardiac output, which can then be used to calibrate continuous analysis of the waveform, transduced from a modified arterial catheter. In order to make these easier to set up and use, more recent models calibrate their pulse contour analysis using population data, based on age, weight and height. The disadvantage is that the population data is derived from healthy volunteers, and so is not validated for patients with abnormal vascular resistance, which undoubtedly has a major effect on derived indices such as stroke volume. The oesophageal Doppler also uses population data to estimate aortic diameter.

However, even if we are sceptical about the absolute numbers generated, these monitors can be reliably used to observe trends in stroke volume, and the effect of interventions such as fluid administration. The key feature is to determine whether the patient is fluid responsive; meaning

that a bolus of fluid augments their cardiovascular performance (for example their stroke volume), thereby improving oxygen delivery. Fluid responsiveness implies that we have moved the patient up the Starling curve.

A current and future area of development is the use of stroke volume variation (SVV) or pulse pressure variation (PPV) that is measured from the transduced arterial waveform. We have long observed that hypovolaemia causes an exaggerated swing in systolic pressure during the respiratory cycle; SVV and PPV quantify this swing or variation as a single number. Again, it is a change in the number, rather than the absolute value that is useful in assessing the fluid responsiveness of your patient.

From a pragmatic perspective, these monitors are most useful when observing the effect of a single intervention (such as fluid administration) in isolation - this is often difficult during the changing stimuli of surgery, or when the physiological response to sepsis is changing rapidly. Measurements are most plausible when interventions and pre- and post- stroke volume, SVV or PPV measurements are performed during a 'lull' in other stimulating activity.

DOPPLER ULTRASOUND AND ECHOCARDIOGRAPHY

Ultrasound

Ultrasound is any high-frequency sound wave. Ultrasound is used medically to create a 2 dimensional image by using a probe to transmit high-frequency sound waves (1-5MHz) into the body, and to detect the waves as they are reflected off the boundaries between tissues interfaces. By using a mathematical model involving the speed of sound and the intensity and timing of each echo's reflection, the distance from the probe to the tissue boundaries is calculated, and used to create a two- dimensional image.

Doppler ultrasound

When sound waves are reflected from a moving object, their frequency is altered. This is the Doppler effect. By using an ultrasound probe to visualise directional blood flow, the phase shift (i.e. the change in frequency before and after reflection off moving red blood cells) can be determined. This, together with the cross-sectional area of the blood vessel being observed (measured or estimated) can be used to determine flow, where:

$$\text{Flow} = \text{area} \times \text{velocity}$$

Oesophageal Doppler

Theory of technique

A Doppler probe is inserted into the distal oesophagus (Figure 2) and is directed to measure the blood flow in the descending aorta at about 35 to 40cm from the incisors. The monitor calculates cardiac output using descending aorta diameter, which is either obtained from an age-related nomogram or measured directly in newer machines. The ventricular ejection time, corrected for heart rate (the corrected flow time, FTc), gives an indication of preload and the peak flow velocity (PV) estimates the contractility of the ventricle. Newer probes incorporating M-mode Doppler measurement may improve accuracy and reliability.

Practical application

The technique is straight-forward, easily learned and relatively non-invasive. The disposable probes are easy to insert, however some expertise must be gained in recognition of intracardiac and pulmonary artery signals. Continuous measurement is possible, although frequent positional adjustments are needed. Some user variability is inevitable. The cardiac output data is best used as a trend to guide the effectiveness of interventions such as fluid challenges.

Wave form interpretation

A full description of the use of oesophageal Doppler is beyond the scope of this article but guidance can be obtained from the NHS Technology Adoption Centre at <http://www.ntac.nhs.uk/searchresent.aspx?search=cardioQ>

Advantages

- Minimally invasive
- Minimal interference from bone, lung and soft tissue
- Quickly inserted and analysed
- Little training required
- The system is small and relatively portable
- Paediatric probes are available.

Disadvantages

- May require sedation
- User dependent
- Interference from surgical instruments (e.g. diathermy)
- Depends on accurate probe positioning
- Probe may detect other vessels e.g. intracardiac/intrapulmonary
- Assumes a constant percentage of cardiac output (approx 70%) enters the descending aorta. May therefore be inaccurate in a hypovolaemic patient where flow may be redirected to the cerebral circulation.
- Contraindicated in the presence of oesophageal varices.

Transthoracic echocardiography

Echocardiography is cardiac ultrasound and can be used to estimate cardiac output by direct visualisation of the contracting heart in real time. Echocardiography is becoming widely accepted as one of the safest and most reliable cardiac output monitors in the critically ill.

A focused echocardiogram can be performed in a matter of minutes and assist in determining the cause of haemodynamic instability. Using transthoracic echocardiography four views are obtained (parasternal long axis, parasternal short axis, apical, and subcostal), and it is possible to make an assessment of ventricular function and size of cardiac chambers with these.

Figure 2. Image of descending aortic waveform obtained using an oesophageal Doppler probe, CardioQ® (Courtesy of Deltex Medical).

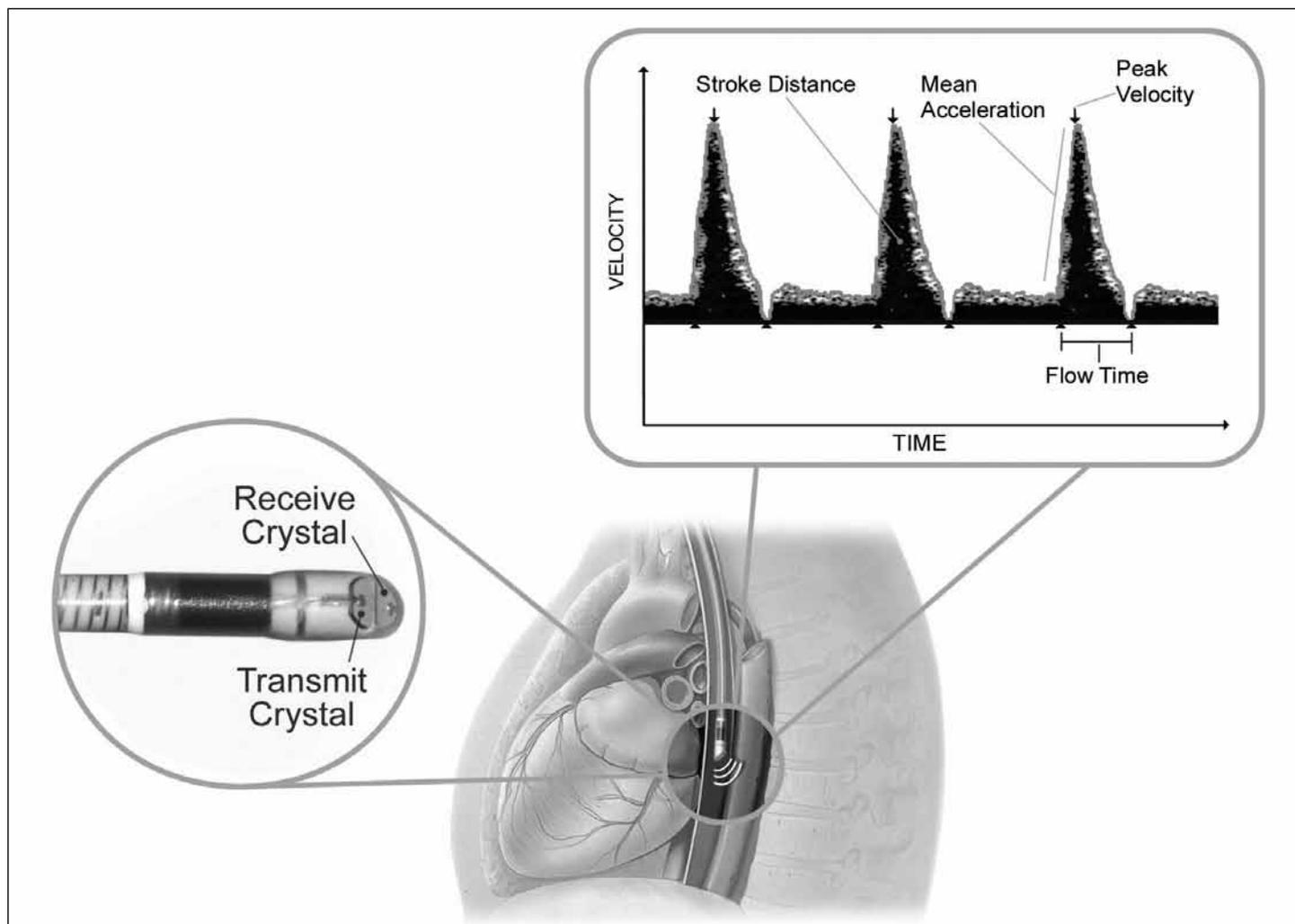


Table 1. Summary of variables obtained from oesophageal Doppler

Variable	Description	Interpretation
Height	Peak velocity	The highest detectable aortic flow – can be used as a measure of afterload, vascular resistance and contractility
Slope of upstroke	Mean acceleration	Measure of contractility
Width of base	Flow time	Left ventricular ejection time, i.e. duration of aortic blood flow. When corrected for heart rate gives an index of preload (e.g. if base is narrow suggests hypovolaemia)
Area under waveform curve	Stroke distance	Distance a column of blood travels along the aorta during each ventricular systole
Stroke distance	Stroke volume	Aortic cross-sectional area
Afterload	SVR	Shown by a reduction in waveform height and base

Transoesophageal echocardiography

Theory of technique

A specialized probe is inserted into the oesophagus, providing real-time, high resolution ultrasound images. Both qualitative and quantitative values for cardiac output are available, using a two dimensional cross-sectional area measurement, a Doppler flow measurement at that point and the heart rate.

Practical application

A multiplane transducer is inserted into the oesophagus and stomach, where various standardized views are gained.

Advantages

A large amount of haemodynamic information is available beyond just cardiac output.

Disadvantages

The probes are still expensive and the machinery is large and bulky. Various levels of examination skill are required and these take time and resources to learn. A full study can take over twenty minutes. Some form of local pharyngeal anaesthesia or sedation is required to tolerate the probe. There is a risk of trauma from the probe, although the risks are low in patients with no oesophageal disease. The probes generate a degree of heat and are therefore not suited to continuous measurement. As the technology advances and costs decrease, TOE may find more applications in theatre and the ICU.

DILUTION METHODS

These techniques require:

- a marker substance that can completely mix with blood, remain within the circulatory system, and is minimally metabolised.
- a central vein (into which the marker substance is injected) and a peripheral artery (from which the arterial content of the substance can be measured) must be cannulated.

As long as blood flow between the injection and measuring sites is constant, flow (i.e. cardiac output) can be calculated from the area under a concentration versus time graph, using a modified Stewart-Hamilton equation.

Advantages of dilution methods

- Less invasive than PAFC (see below).

Disadvantages of dilution methods

- Can only be used to calculate cardiac output in ventilated patients in sinus rhythm.
- Specific heart-lung interaction is required for the calculation of stroke volume variation (SVV) and pulse pressure variation (PPV)
- Invasive and associated morbidity / mortality.
- User dependent.
- Can underestimate cardiac output in low output states.

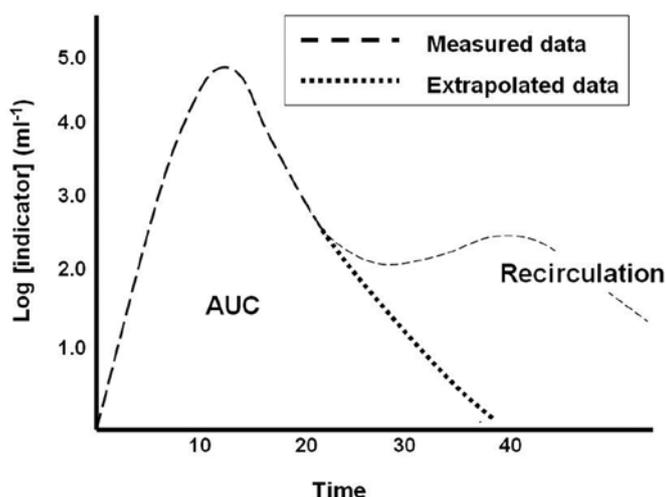


Figure 3. Concentration-time graph for determining cardiac output.

Lithium Dilution Monitoring – Lidco® and PulseCO® and Lidcoplus®

Theory of technique

This technique combines the techniques of lithium dilution (Lidco and Lidcoplus) and pulse contour analysis (PulseCO). A small dose of lithium is injected into a peripheral vein and an ion selective electrode is attached to a peripheral arterial line. The area under the curve of a plot of lithium concentration against time allows calculation of the cardiac output. This information is then used to calibrate the PulseCO which provides 'beat-to-beat' cardiac output measurement, using *pulse contour analysis* of the arterial waveform.

Practical application

The convenience of this system is that it uses catheters which are likely to be in place or are likely to be needed in a critically ill patient. The system requires some familiarity to set up, but is relatively quick. The total dose of lithium is small and is clinically insignificant. Calibration is recommended every 8 hours, or after any significant change in the patient's clinical condition.

Advantages

A figure for stroke volume variation is produced and provides an indicator of volume responsiveness to fluid therapy.

Disadvantages

The system cannot be used for patients taking lithium and those who have recently received vecuronium or atacurium. The monitor performs poorly in the presence of atrial fibrillation and other tachyarrhythmias. The system is prone to technical difficulties related to damping and resonance within the measurement system (see page 38).

Thermodilution pulse contour monitoring – PiCCOplus®

Theory of technique

This technique utilises thermodilution in combination with Pulse Contour Analysis (PulseCO) to measure cardiac output, and correlates well with the PAFC (below). 'Stroke volume variation' (the mean difference between the highest and lowest arterial pressure wave peaks over 30 seconds) gives an indication of the blood volume status of the patient.

The system is calibrated using intermittent cold transpulmonary thermodilution, where cold fluid is injected through a central venous catheter and traverses the pulmonary circulation. A curve of blood thermodilution is measured in a systemic artery and, in addition to cardiac output, other data is derived. The calculated *extra-vascular lung water* (EVLW) gives an indication of the water content of the lungs and is increased in left ventricular failure, pneumonia and sepsis. The normal range is 3-10ml.kg⁻¹ and values greater than 14ml.kg⁻¹ are associated with an increased mortality. The *intra-thoracic blood volume index* gives an indication of blood volume status (normal value 850-1000ml.m²).

PiCCOplus replaced the original PiCCO machines in 2002 and has subsequently been replaced by PiCCO₂ with improved displays, automated features and the use of room temperature injectate for calibration.

Practical application

A specialised arterial catheter, inserted into either the brachial artery or femoral artery is required, along with either a thoracic or femoral central line. Some centres use treatment algorithms based on these variables, to guide use of fluid and inotropes in an attempt to maximise intravascular filling, without increasing the EVLW and causing pulmonary oedema. The use of EVLW as an endpoint for resuscitation has not been validated.

Advantages

The arterial line can be simultaneously used for blood pressure monitoring and for blood sampling. The system is relatively easy to set up and calibrate. It can also be used to estimate preload using global-end-diastolic volume and index (GEDI), intra-thoracic blood volume (ITBV) and pulmonary vascular permeability index (PVPI) which gives a ratio of EVLW to pulmonary blood volume. Note that pleural effusions do not affect measurements.

Disadvantages

The arterial catheter is relatively large gauge and expensive, although few complications have been reported. Recalibration is required every 12 hours, or following a major change in the patient's clinical condition. Variations in speed of injection and thermistor positioning may affect results. Results can be affected by arrhythmias, shunting, positive pressure ventilation and tricuspid regurgitation.

Pulse contour analysis

ProAQT (Pulsion), Vigileo (Edwards Lifesciences) and LIDCOrapid (LIDCO) are all similar, minimally invasive cardiac output monitors. They all work by pulse contour analysis using a specialised transducer on any arterial line. Parameters obtained may include: continuous cardiac output, stroke volume, stroke volume variation (SVV) and pulse pressure variation (PPV). In order to obtain SVRi (the systemic vascular resistance index), the patient needs CVP monitoring. To obtain values for PPV and SVV, the patient should be ventilated with a fixed tidal volume and so is less useful when weaning respiratory support in intensive care. dP max gives an indication of contractility.

Pulmonary artery flotation catheters (PAFC)

The use of PAFCs has been hotly debated in recent years and use in

the United Kingdom is currently low. The PAC-Man trial showed no improvement in survival for patients randomised to have a PAFC inserted, compared to those who were not.³

Theory of technique

A flexible balloon-tipped, flow-directed catheter is inserted via a wide-bore catheter sited in a central vein. The catheter is 'floated' through the right atrium and ventricle to enter the pulmonary trunk. From this position it can intermittently be 'wedged' in one of the pulmonary arteries.

The catheter allows a number of variables to be measured and others to be derived.

The measured variables are pulmonary artery pressure, pulmonary capillary wedge pressure (PCWP), cardiac output and mixed venous oxygen saturation. Traditionally, cardiac output is measured by thermodilution of 10ml iced water, injected through the proximal lumen of the catheter. Measurement of the fall in blood temperature against time from injection, as the cooled blood passes the distal end of the catheter, allows calculation of the cardiac output of the right (and therefore the left ventricle). Semi-continuous cardiac output measurements are now available which use warming coils in the right ventricular portion of the catheter. A sequence of heating and recording gives an averaged cardiac output after a short delay.

Practical application

The catheter is inserted with reference to certain waveforms seen in the right atrium, right ventricle, pulmonary outflow tract and when wedged in the pulmonary artery. Insertion may take several attempts and is more difficult in patients with a low cardiac output.

Advantages

Measurement of cardiac output is probably the most reliable of the variables measured using a PAFC and is therefore a valuable guide to interventions introduced to increase cardiac output. The numerous assumptions made in interpretation of the PCWP as a measure of preload or ventricular filling make the PCWP a less reliable measurement. Some units use the mixed venous oxygen saturation, measured using a sample taken slowly from the pulmonary artery aperture of the catheter, as a further indicator of a patient's overall tissue perfusion (see below).

Table 2. Interpretation of SvO₂ readings.

SvO ₂	Interpretation
>75%	Increased O ₂ delivery e.g. high FiO ₂ , or Decreased O ₂ utilization e.g. sepsis causing shunt
50-75%	Maybe normal or reflect compensation by increase O ₂ extraction by tissues
30-50%	O ₂ demand is greater than supply Implies tissue beyond maximal O ₂ extraction
25-30%	Severe lactic acidosis
<25%	Cellular death

Disadvantages

This invasive monitor is associated with a number of potential complications. The PAC-Man study recorded non-fatal complications in 10% of insertions. In addition to the usual complications of central venous access, PAFCs may cause arrhythmias, heart block, rupture of the right heart or pulmonary artery, thromboembolism, pulmonary infarction, valvular damage, endocarditis.³

Mixed venous oxygen saturation (SvO₂)

Mixed venous oxygen saturations can be used as a surrogate marker of the global balance between oxygen delivery and consumption. Oxygen delivery depends on cardiac output and the oxygen content of the blood. In the face of an increased demand for oxygen, there will be a greater degree of oxygen extraction. Occasionally SvO₂ may be increased in severe sepsis due to decreased extraction resulting from shunting (where blood bypasses the tissues). SvO₂ can be used as an early warning system where a sudden decrease in SvO₂ of 10-20% requires immediate assessment. SvO₂ can also be used to assess treatment.

Central venous oxygen saturation (ScvO₂)

Measurement of ScvO₂ requires a central venous catheter rather than a pulmonary artery catheter. ScvO₂ can be used as a surrogate marker of the regional balance between oxygen delivery and consumption in the head, neck and upper body. The value is usually 2-7% less than SvO₂ – partly due to mixing with returning venous blood. Under non-shock conditions, ScvO₂ correlates well with SvO₂. In shock states the

difference from SvO₂ increases – and can be up to 7% higher than SvO₂. ScvO₂ trends with SvO₂ in a parallel manner but should be used in combination with other markers of perfusion.

CeVox (PULSION) is a system which monitors continuous SvO₂ and can calculate oxygen delivery, consumption and oxygen extraction. It uses a fiberoptic probe that can be inserted through any central line.

Thoracic bioimpedance

Theory of technique

The technique depends on the change in bioimpedance of the thoracic cavity during systole. Impedance is a measure of the opposition to alternating current. Baseline impedance reflects total thoracic fluid volume. Cardiac output is estimated by measuring changes in electrical resistance through the thorax, since blood volume within the aorta changes during systole and diastole. Magnitude and rate of change reflects LV contractility.

Practical application

A series of ECG type electrodes are placed on the thorax and neck. A small, non-painful current is passed and measurements made.

Advantages

Derived stroke volume is calculated and cardiac output computed. Thoracic fluid content is also measured. This is the least invasive method of cardiac monitoring and was initially conceived for space flight monitoring.

Table 3. Comparison of different cardiac output monitors.

Method	Technique	Invasiveness	Cannulae	Continuous	Limitations
PAFC	Thermodilution	High	PA catheter	Yes	Shunts, arrhythmias. Requires regular injection speed and thermistor positioning
LiDCO	Lithium-dilution + pulse contour analysis (PCA)	Moderate	Any venous + arterial	Yes	Shunts, arrhythmias, haemodynamic instability, cannot be used if on lithium therapy or if pregnant, lithium can accumulate. PCA requires good quality waveform
PiCCO	Thermodilution + pulse contour analysis (PCA)	Moderate	Central venous + arterial	Yes	Shunts, arrhythmias, haemodynamic instability. PCA requires good quality waveform.
ProAQT Vigileo LiDCOrapid	Pulse contour analysis	Low	Arterial line	Yes	Waveform dependant, useful for trend only.
TOE	Doppler / two-dimensional imaging	Moderate	None	No	User dependent, needs sedation
TOD	Doppler	Low	None	Yes	User dependent, needs sedation, may pick up interference from other vessels
NICO	Partial CO ₂ rebreathing Fick principle	Nil (although requires intubation)	None	Yes	Needs intubation, poor accuracy in lung disease
Thoracic Bioimpedance	Measurement of change of impedance	Nil	None	Yes	Inaccurate in the critically ill in general

Disadvantages

It is not useful with significant aortic regurgitation and open chest procedures. The correlation with PAFC in critically ill patients is inconsistent.

Bioreactance

The NICOM (non-invasive cardiac output monitor) measures the 'phase shift' of pulses of alternating current, passed through the body using three electrodes. Early studies show promising correlation with passive leg raise, as an indicator of fluid responsiveness.⁴

SUMMARY

At present no perfect system exists, but each of the monitors above, can aid the clinician when uncertain about the patient's condition. The information gained must be understood in the context of how

it was gathered and interpreted alongside clinical evaluation of the patient. Only then can it be safely used to guide subsequent therapeutic strategies.

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