ICU MANAGEMENT & PRACTICE

ICU Volume 6 - Issue 1 - Spring 2006 - Product Comparison:Cardiac Output Monitors

Cardiac Output Monitoring with Intravascular Catheters

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In this paper we present the main characteristics of devices that can provide cardiac output measurement and which require the placement of an intravascular catheter.

Introduction

Haemodynamic monitoring is part of routine clinical practice in the intensive care scenario and its application is now spreading further to other critical care areas such as the emergency department. The first device able to give some estimate of the cardiac output at the bedside was the pulmonary artery catheter (PAC). It has been used now for nearly 30 years and even if the PAC is still considered the gold standard for measurement of cardiac output, several concerns have been raised regarding its invasiveness, usefulness and associated complications (Boyd et al. 1983). Indeed despite the growing evidence that monitoring cardiac output can guide fluid and drug management in the haemodynamically unstable patient, there is still a lack of evidence on which form, if any, is best for monitoring cardiac output. The use of the PAC opened the way to the use of dilutional techniques for the determination of cardiac output. In this paper we will briefly describe devices using intravascular catheters for the determination of cardiac output in the intensive care unit.

Thermal dilution was the first dilution technique used in clinical practice. Nowadays two kinds of thermal dilution are possible with PAC: intermittent thermal dilution and semi-continuous inverted thermal dilution (Boldt et al. 1994). Another device developed more recently is the PiCCOplus by Pulsion. It uses thermal dilution to measure the cardiac output and to derive volumetric indices. This is then used to calibrate a continuous measure of stroke volume (SV), taken from the arterial waveform (Goedje et al. 1999). As well as thermal dilution, dye dilution techniques have been used in clinical practice. Currently the only device available on the market that uses a dye dilution technique to measure cardiac output is LiDCO, by LiDCO, UK. These measurements can be used to calibrate an algorithm for the continuous determination of cardiac output (Jonas and Tanser 2002).

Is a dilution technique fundamental to the determination of cardiac output? Recently two new devices have been developed that analyse the arterial pressure waveform. PRAM, FIAB, Italy and Vigileo Monitor with Flotrac Sensor, Edwards Lifescience, CA, USA, can track stroke volume and cardiac output from the analysis of any arterial pressure waveform (Manecke et al. 2004; Romano and Pistolesi 2002). Nowadays some devices can give an estimate of the cardiac output without the need for calibration, for instance through thoracic bioimpedance and oesophageal doppler monitoring; neither of these two techniques require the placement of an intravascular catheter.

PAC

The PAC provides measurement of cardiac output, (through intermittent thermodilution), of pulmonary artery pressures and of pulmonary artery occlusion pressure (PAOP). It has been modified in recent years by adding a thermal coil which semi continuously produces thermal waves. This allows a semicontinuous measurement of the cardiac output. The most recent development in PAC technology is the volumetric PAC. This is equipped with a rapid response sensor and integrates the signal from the electrocardiogram. In this way it calculates the right ventricular ejection fraction and then, combining this data with the SV, calculates the right ventricular end diastolic volume (RVEDV: Cheatham and Right 2000). Intermittent measurement of cardiac output using the PAC is still considered by many to be the gold standard of clinical cardiac output measurement. Semi-continuous cardiac output has been validated against intermittent thermodilution and offers the great advantage of not requiring any operator to direct its measurement. The accurate placement of the catheter is the most important requirement for reliable measurement. Although cardiac output can now be measured by other less-invasive devices, the PAC is the only device that allows continuous measurement of pulmonary artery pressure and determination of the pulmonary artery occlusion pressure (PAOP). Many PAC's also continuously monitor the mixed venous oxygen saturation (SvO2). Despite concerns regarding the usefulness of both PAOP and RVEDV to predict preload status, there are some patient groups, for instance acute right ventricular dysfunction, where the continuous monitoring of pulmonary artery pressures remain both important and useful.

Despite much criticism of the PAC in recent years, especially regarding the lack of evidence for improved outcome in critically ill patients, there are several studies of haemodynamic optimisation using PAC to monitor cardiac function and to direct therapy which have shown some improvement in outcome (Boyd et al. 1993).

PiCCOplus by Pulsion

This monitor is less invasive than PAC, requiring only a central line and a specialised arterial catheter (femoral or radial) for set-up. Like PAC it uses thermodilution as the technique for measurement of cardiac output. A bolus of cold saline is injected through the central line and transpulmonary thermodilution isregistered and computed via the specialised arterial catheter. The value of the cardiac output is then used to calibrate the algorithm of the pulse contour analysis available on PiCCOplus. In this way the monitor tracks the SV beat to beat giving a continuous estimate of cardiac output. Both transpulmonary thermodilution and continuous cardiac output monitoring have been validated in clinical practice in several situations (Della Rocca et al. 2003; Rodig et al. 1999).

In addition to the cardiac output, the PiCCOplus, through the analysis of the thermodilution curve, gives "volumetric parameters" such as global end diastolic volume (GEDV), intrathoracic blood volume (ITBV) and extravascular lung water (EVLW). These parameters have proven to be better indices of preload than PAOP and CVP. EVLW is an interesting parameter that represents the amount of water in the extravascular thoracic space. High values of EVLV correlate well with pulmonary oedema and have been associated with poor outcome in the intensive care population (Marting et al. 2005). In addition, PiCCO is able to monitor the functional haemodynamic parameters of stroke volume variation (SVV) and pulse pressure variation (PPV). These have been shown to reliably reflect fluid responsiveness in patients who are intubated and sedated (Michard et al. 2000).

LiDCO

LiDCOTMplus is a new cardiac output monitor. It measures cardiac output using transpulmonary dilution of lithium. This technique requires the injection of 0.3 mmols of lithium through a central or peripheral line and the dilution curve is detected via a sensor that can be attached to an arterial line already in-situ. Technically LiDCOTMplus requires only a peripheral line and an arterial line. Through the transpulmonary dilution of lithium the system calibrates an algorithm for continuous cardiac output monitoring derived from the arterial pressure wave analysis. Both the lithium dilution and continuous cardiac output of LIDCO have been validated in several conditions (Hamilton et al. 2002; Tsutsui et al. 2004). A recent study utilising the LiDCOTMplus to target-directed therapy versus standard management in high-risk surgical patients showed an improved outcome in the treatment group (Pearse et al. 2005). This system, like the PiCCO can also provide the functional parameters that can predict fluid responsiveness.

Vigileo Monitor and PRAM

The Vigileo system and PRAM are the most recent haemodynamic monitors that can track changes in stroke volume from the analysis of the arterial wave trace. The most interesting characteristic of these monitors is that they require no calibration and only an arterial line for their use. Flotrac is the sensor used by Vigileo to transduce the arterial line trace to the monitor. The algorithm, based on the standard deviation of arterial pressure waveforms, uses age, weight and sex of the patient and incorporates the information obtained from the analysis of the arterial trace to calculate stroke volume and cardiac output. Vigileo has been validated so far in only two studies, showing reasonable accuracy and precision in comparison with the PAC (Manecke et al. 2004; McGee et al. 2005). PRAM uses an analysis of the arterial pressure waveform which is based on the physics of perturbation. It analyses the points of "perturbance on the wave trace" and from this analysis it calculates the impedance of the system, bypassing the problem of calibration. PRAM has already been validated against the PAC in cardiac surgery patients, showing good accuracy and precision (Giomarelli et al. 2004). Whilst preliminary studies performed with these technologies appear promising, further investigations are required to establish if they can replace more invasive monitors.

Conclusions

The intensivist can now choose from several devices for monitoring cardiac output in critically ill patients. Degree of invasiveness is very different depending on which device is chosen while some monitors provide parameters that others cannot. It will be important in coming years not only to see if the new devices that are replacing the PAC prove to be as accurate, but also to determine what clinical impact treatments guided by their use can provide. We will hopefully have an answer soon. So far it is difficult to proclaim which, if any, is best.

Published on : Thu, 15 Aug 2013