In the Intensive Care setting, the measurement of cardiac output (CO) is a vital component necessary for the understanding of cardiovascular dysfunction. Until recently, however, it had only been possible to measure the patient’s CO invasively using a pulmonary artery catheter (PAC). Lately, several new and less invasive technologies have become available. This article focuses on the use of one such minimally invasive technology, namely arterial pressure waveform analysis, that has a great potential in the assessment of a patient’s CO in the intensive care setting.

Cecconi, M., Fawcett, J. and A. Rhodes

Introduction

Haemodynamic monitoring is a vital tool in the treatment of the critically ill. It provides a comprehensive overview of the circulatory status of the patient and allows early detection of cardiovascular dysfunction. Until recently, the most common way to obtain CO information was through the use of a pulmonary artery catheter (PAC). In recent years, however, there has been concern regarding both the safety and efficacy of this monitoring modality.1

As a direct result, several innovative, minimally invasive technologies have been introduced for the monitoring of a patient’s CO, including the use of the arterial pressure waveform. This type of haemodynamic monitoring not only allows physicians to adopt their treatment almost immediately upon a patient’s changing health status, but can be described as being virtually non-invasive since most critically ill patients already have an arterial access site. Currently, there are a number of companies that market devices that use the arterial pressure waveform to measure stroke volume or CO.

Correcting the waveform for a patient’s arterial vascular compliance presented a problem that until recently prevented the accurate conversion from arterial pressure to a volume (stroke volume). The vascular compliance represents the relationship between pressure and volume, and unfortunately this relationship is both non-linear and difficult to predict for any given patient at any given time. Lately, however, some industrial companies have made enough technological progress to solve the underlying problem and to allow engineers to design monitoring systems that are sophisticated enough to warrant being made available on a large scale.

Pioneering technologies

The two technologies that have been around longest both utilise an initial calibration process that compensates for the differences in arterial compliance. One of the first two technologies to become commercially available was developed by Pulsion. This system measured the systolic area of the arterial waveform and corrected for non-linear compliance by assessing the morphology of the arterial contour and calibrating with a transpulmonary thermodilution technique.2

A second technology, pioneered by LiDCO, measured the power of the arterial waveform. In order to correct for the specific compliance of a patient, calibration was performed with a lithium dilution curve.3 Both of these systems use a calibration technique that is intrinsically accurate. However, both systems require a complementary manual input that carries with it an inevitable potential for error during episodes of acute haemodynamic instability. For the calibration to be both valid and effective, it must be performed with the utmost attention to detail. If errors do occur, the result is that instead of the calibration being helpful it could complicate things and in time even lead to clinicians questioning the value of the data obtained. To avoid this potential for human error, a number of new CO monitoring methods have been developed over the last few years. They have the value of providing an adequate degree of accuracy without requiring specific calibration to correct for the differences in arterial compliance.

Newer CO monitoring algorithms

PRAM model

The Pressure Recording Analytical Method (PRAM) is based on the physics of perturbations.4 The monitor based on this algorithm performs beat-to-beat analysis of the entire arterial pressure waveform, using an acquisition signal of 1000 Hz. The points in the wave that are most critical to compute are the initial point of the pulse wave (diastolic pressure) and the point of closure of the aortic valve. The PRAM algorithm then analyses other points of ‘perturbation’ and calculates the impedance of the system. The stroke volume (SV) is then calculated from the area under the curve in the interval between the diastolic part of the curve and the dicrotic notch, considering the correction of the impedance derived from the ‘perturbation analysis’ of the curve. No calibration is thus required to correct for compliance.

APCO model

The Arterial Pressure Cardiac Output (APCO) algorithm was developed by Edwards Lifesciences.5 It is a method that relates blood flow to arterial pressure using a haemodynamic model. This uses basic cardiovascular haemodynamic concepts according to which the arterial circulation, acting as an elastic storage system, transforms the discontinuous flow due to the pumping of the heart into a steady flow in the peripheral organs. The model assesses the standard deviation of the mean arterial pressure and corrects this for age, gender and weight of the patient as well as by a shape analysis of the actual waveform. This enables real-time tracking of SV without the need for calibration. This algorithm is currently commercially available in the form of the FloTrac sensor and the complementary Vigileo monitor.

Results of two research studies designed to validate the monitor have been published in the scientific literature. The first study was performed by Gerard Manecke, M.D., Professor and Interim Chair, Department of Anaesthesiology, University of California, San Diego (USA) and presented at the Society of Critical Care Medicine meeting in 2005.6 This study validated the APCO algorithm against the continuous cardiac output (CCO) from a pulmonary artery catheter thermodilution technique (Edwards Lifesciences). In 11 cardiothoracic patients undergoing cardiac surgery, CO ranged between 3 and 8 l/min and the mean value of 6 l/min. Accuracy in terms of the bias was −0.4 l/min with a precision of ±1.6 l/min. This study suggests that the accuracy of the monitor is approaching that of the more traditional pulmonary artery catheter, but with the advantages of being both minimally invasive. William McGee, M.D., director of ICU Quality Assurance at Baystate Medical Centre in Springfield, MA, USA followed this up with a multi-centre study assessing the Vigileo monitor against both intermittent (ICO) and continuous (CCO) cardiac outputs from a pulmonary artery catheter.7 This study involved 36 patients from three centres in Europe and the USA. The subject cohort presented a wider range of medical conditions and included both patients during the peri-operative phase as well as critically ill subjects. A wide range of ages (24 to 84 years, mean 68), heights (148 to 185 cm, mean 170) and weights (41 to 151 kg, mean 62) were represented. The range of COs seen in this study was wide, from 2.2 l/min to 11.4 l/min. The accuracy of the APCO monitor when compared to ICO was good (0.2 l/min) with a precision of ±2.6 l/min. It is interesting to note how similar the data are in comparison to those seen when comparing ICO to TCO (bias 0.8 l/min and precision of ±2.3 l/min). This study confirmed the findings from the previous paper by Manecke in a broader group of patients and again suggested that the monitor utilising the APCO algorithm has an accuracy level approaching that of the pulmonary artery catheter as used in these studies, and in continuous CO monitoring, although with a slightly greater degree of variability. Data were also analysed to assess whether the accuracy was maintained when the values changed in an individual patient. Ninety-eight percent of all data points remained within ±2.4 l/min, the way with a clinically acceptable degree of accuracy. This suggests that the monitor may have a slight inherent (but not clinically significant) bias against standard techniques and that it seems to track SV well when a patient’s condition changes.

Conclusions

Before throwing out old technologies in order to embrace the new, we should insist that the new technique has an accuracy at the very least...
approaching that of the older technology or offer other advantages to the user. Results of the two studies briefly described above suggest that the monitoring system using the APCO algorithm has an accuracy level similar to that obtained by the continuous pulmonary artery catheter, which for a long time has been perceived as the gold standard tool for measuring CO. In addition to the accuracy, it is a minimal-invasive device that provides near-real time data without the need for calibration.

References

Dr A. Rhodes
Department of Intensive Care, St. George’s Hospital, London SW17 0QT, UK
Tel. +44-20-8725 0884 Fax +44-20-8725 0879 arhodes@sgul.ac.uk