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Cardiac Output Monitors: An Overview

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Although there is no evidence for an improved outcome of critically ill patients by measurement of cardiac output (CO) per se, this haemodynamic variable is still considered clinically important, as it is a major determinant of systemic oxygen delivery. Since the early 1970's, the pulmonary artery thermodilution technique, which enabled measurement of cardiac output at the bedside, has become the clinical reference technique par excellence. However, due to lack of benefit in outcome pulmonary artery catheterization, currently it is less frequently used in the critical care scenario. As a consequence, alternative and less invasive techniques have been developed and introduced into the clinical setting over the last years.

For instance, the transpulmonary thermodilution technique is currently increasingly applied in intensive care units and it has been shown in various studies that CO measurement works well with pulmonary artery thermodilution in numerous clinical and experimental situations. In addition, this technique enables assessment of cardiac preload by volumetric and dynamic parameters, which are superior to cardiac filling pressures in critically ill patients. It also allows assessment of lung oedema and vascular permeability that may be helpful in guiding treatment in critically ill patients. The latter has been emphasized recently, as goal-directed fluid management reduces vasopressor and catecholamine use in cardiac surgery patients.

Usage of another indicator, transpulmonary lithium dilution, has been introduced with comparable reliability for measurement of CO in critically ill patients. However, this technique does provide information on fluid responsiveness but not lung water and is less convenient, as an extracorporeal system is required for quantification of lithium, a substance whose use may be limited by the frequency of application. Nevertheless, transpulmonary thermodilution and lithium dilution techniques are clinically attractive, as they also offer continuous cardiac output monitoring from arterial pulse contour analysis that may be recalibrated at any time by the integrated reference technique.

While algorithms for continuous CO monitoring by pulse contour analysis are still modified, these systems are also increasingly reliable during various changes in treatment. Despite a long history, determination of CO by arterial pressure curve alone has received considerable attention, particularly since systems based on pressures recording analytical method (PRAM) have become commercially available. Since it is less invasive and obtainable from a single peripheral arterial line, continuous cardiac output measurement by arterial waveform analysis alone-without any internal reference is also clinically attractive. Although extremely desirable for the clinical scenario, validity of absolute CO and changes in CO with the currently available technology is an issue. These systems are still in a clinical validation process and further data are required for broad use in critically ill patients with manifold clinical conditions. In general, all systems based on arterial pressure recording have the potential to assess dynamic parameters on fluid responsiveness such as systolic pressure variation (SPV), pulse pressure variation (PPV) and stroke volume variation (SVV), which are considered to be superior to cardiac filling pressures in critically ill patients with positive pressure ventilation.

Ultrasound techniques (oesophageal Doppler) or transcutaneous Doppler for detection of aortic flow profiles are also increasingly used. These systems are minimally to non-invasive and promising in their results. However, absolute CO values obtained by these techniques may be questionable, while changes may be more correctly reflected and helpful in guiding treatment. Additionally and clinically relevant, indices of cardiac preload can also be derived by these systems. Notably, goal-directed intra-operative fluid administrations, based on algorithms using this technique have had positive effects on length of hospital stay and complications after major surgery. Independently, data on critically ill patients is still limited and further studies are required for validation of these techniques.

Finally, non-invasive techniques using airway access for CO_2 re-breathing (Fick's principle) have been suggested. However, this technique may be limited in patients with lung pathology and not be applicable in all critically ill patients. Unfortunately, assessment of cardiac preload is not possible with such systems. The CO_2 re-breathing technique cannot be regarded as validated in severely ill patients with different underlying diseases. A further completely non-invasive and safe technique, bioimpedance, which is based on the electric properties of flowing blood, has been developed for many years and has been the subject of further study more recently. So far, reported studies have had mixed results and further evaluation is required before these systems can be regarded as sufficiently accurate for use with critically ill patients.

In conclusion, a number of manifold techniques for CO measurement in critically ill patients have been developed and introduced into the clinical setting in recent years. However, some of these techniques are still in a validation process and indicator dilution techniques are currently regarded as the clinical reference.

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