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Methods of Cardiac Output Monitoring

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ABSTRACT

Cardiac output is the primary compensatory mechanism that responds to an oxygenation challenge. The determination of blood flow, i.e. cardiac output, is an integral part of hemodynamic monitoring. This is a review on methods of cardiac output monitoring. Minimally invasive cardiac output monitors have varying degrees of 'invasiveness' with some being totally non-invasive and others only marginally less invasive than a pulmonary artery catheter (PAC). All minimally invasive cardiac output monitors have their own sources of potential error. Users of cardiac output monitors should be aware of their potential sources of error and clinical limitations. There are many methods of monitoring the hemodynamic status of patients, both invasive and non-invasive, the most popular of which is thermodilution. The invasive methods are the Thermodilution and Fick method, whereas the non-invasive methods are transoesophageal echocardiography, oeshophaegeal Doppler, pulse contour, lithium dilution, and partial CO2 rebreathing and thoracic electrical bioimpedance. All the methods have their advantages and disadvantages, but thermodilution is the golden standard for critical patients, although it does many risks. But, the thermodilution technique remains the most common approach in use today.

Keywords: cardiac output, fick method, Doppler monitor, bio-impendance, critically ill patients

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INTRODUCTION

Cardiac output monitoring is an important tool in high risk critically ill surgical patients in whom large fluid shifts are expected along with hemodynamic instability and bleeding [1]. It is an important component of goal directed therapy (GDT), i.e., when a monitor is used in conjunction with administration of fluids and vasopressors to achieve set therapeutic endpoints thereby improving patient care and outcome. Cardiac output cannot be measured reliably by routine assessment and clinical examination. There are various methods of cardiac output monitoring based on Ficks principle, thermodilution, Doppler, pulse contour analysis and bioimpedance. Advances in the computer software and hardware have led to development of newer methods of cardiac output monitoring with minimal or no vascular access (Figure 1).

Factors Affecting Cardiac Output:

Methods of cardiac output monitoring are broadly classified as follows:

Invasive-

- Intermittent bolus pulmonary artery thermodilution
- Continuous pulmonary artery thermodilution

Minimally Invasive-

- Lithium dilution cardiac output (LiDCO).

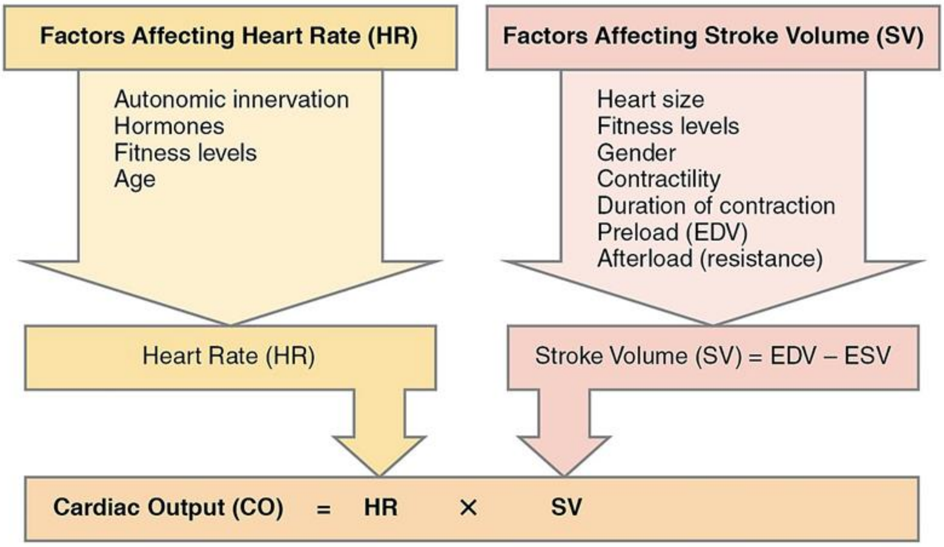

Fig. 1. *Methods of cardiac output monitoring.*

- Pulse contour analysis cardiac output (PiCCO and FloTrac),
- Esophageal Doppler (ED),
- Transesophgeal echocardiography (TEE)

Non-invasive-

- Partial gas rebreathing,
- Thoracic bioimpedance and bioreactance
- Endotracheal cardiac output monitor (ECOM),
- Doppler method
- Photoelectric plethysmography.

INVASIVE METHODS

(1) Cardiac Output Measurement by Pulmonary Artery Catheter

Pulmonary artery catheter (PAC) helps to measure cardiac output and central filling pressures. It has been used as a monitoring tool in high risk surgeries and critical care units. However, its use has been associated with various complications like pneumothorax, arrhythmia, infection, pulmonary artery rupture, valve injury, knotting and thrombosis leading to embolism.

(2) Continuous Cardiac Output Measurement by PAC

Continuous cardiac output (CCO, Edwards Lifesciences, Irvine, California, United States) is a modification of PAC with copper filament in the catheter that remains in the right ventricle. There is intermittent heating of blood in the right heart by the filament and the resultant signal is captured by thermistor near the tip of the catheter. Average value of cardiac output measured over time is displayed on the monitor [2]. Main advantages of CCO over conventional PAC are avoidance of repeated boluses thus reducing the infection risk and operator errors. Moreover, continuous monitoring of stroke volume (SV), systemic vascular resistance (SVR) and mixed venous saturation can also be performed with this catheter [3].

Inspite of various arguments, PAC is still considered as the “Gold Standard” for monitoring of cardiac output. However, due to inherent risk associated with its use investigators are trying to develop a minimally or non-invasive monitor for cardiac output which has all the characteristics of an ideal monitor [4].

Minimally Invasive Methods

Pulse Power Analysis

This method is based on the principle that change of the blood pressure is directly related to the stroke volume.

LiDCO (Cambridge, United Kingdom) System

It combines pulse contour analysis with lithium indicator dilution for continuous monitoring of SV and SV variation (SVV) [5]. It is a minimally invasive technique first described in 1993and requires a venous (central or peripheral) line and an arterial catheter [6].

A bolus of lithium chloride is injected into venous line and arterial concentration is measured by withdrawing blood across disposable lithium sensitive sensor containing an ionophor selectively permeable to Li. cardiac output is calculated based on Li dose and area according to the concentration time and circulation.

It requires calibration every 8 hours and during major hemodynamic changes. It is contraindicated in patients on Li therapy and calibration is also affected by neuromuscular blockers as quaternary ammonium residue causes electrode to drift [7]. Its accuracy is affected by aortic regurgitation, intraaortic balloon pump (IABP), damped arterial line, post aortic surgery, arrhythmia and intra or extracardiac shunts.

Pulse Contour Analysis

It is based on the principle that area under the systolic part of the arterial pressure waveform is proportional to the SV [8]. In this method the area is measured post diastole to end of ejection phase divided by aortic impedance that measures SV.

a. ***PICCO system***: The PiCCO system (PULSION medical system, Munich, Germany) was the first pulse contour device introduced and was replaced with $PiCCO_2$ in 2007. It requires both central venous (femoral or internal jugular) and arterial cannulation (femoral/radial). Indicator solution injected via central venous cannula and blood temperature changes are detected by a thermistor tip catheter placed in the artery [9]. Thus, it combines pulse contour analysis with the trans-pulmonary-thermo-dilution. It requires manual calibration every eight hours and hourly during hemodynamic instability. $PiCCO_2$ is a relatively invasive method as it requires both arterial and venous cannulation. Its accuracy may be affected be vascular compliance, aortic impedance and peripheral arterial resistance [10]. Moreover, the air bubble, clots and inadequate indicator may also affect the accuracy. Valvular regurgitation, aortic aneurysm, significant arrhythmia and rapidly changing temperature may also affect its accuracy.
b. ***Flo Trac system***: Flo Trac (Edwards Life Sciences. Irvine, United States) is a pulse contour device introduced in 2005 and is a minimally invasive method as it requires only an arterial line (femoral or radial) [11]. The system does not need any external calibration, is operator independent and easy to use. It is based on the principle that there is a linear relationship between the pulse pressure and SV.
c. ***Pressure recording analytic method***: Pressure recording analytic method (PRAM)-Most Care (Vytech, Padova, Italy) measures the area under the curve of arterial waveform. Major advantage is that it does not require external calibration and internal calibration is done by morphology of the arterial waveform [12].
d. ***EV1000/volume view:*** A new calibrated pulse wave analysis method (Volume View™/EV1000™, Edwards Life sciences, Irvine, CA, United States) has been developed. It is based on pulse pressure analysis, which is calibrated by transpulmonary thermodilution.

Esophageal Doppler

Esophageal Doppler uses a flexible probe with transducer at the tip. At the midthoracic level it measures flow as it is presumed to be parallel to the descending aorta. Doppler ultrasound is used to measure the SV.

Transesophageal Echocardiography (TEE)

TEE has now been a widely used monitor in perioperative setting. It is an important tool for the assessment of cardiac structures, filling status and cardiac contractility. Moreover, aortic pathology can also be detected by TEE.

NON-INVASIVE METHODS

Partial Gas Rebreathing

It is also known as the NICO system (Nova-metrix Medical Systems, Wallingford, Conn, United States) or partial gas re-breathing monitor and uses indirect Fick's principle to calculate cardiac output. It is used in intubated patients under mechanical ventilation. At steady state, the amount of CO_2 entering the lungs via the pulmonary artery is proportional to the cardiac output and equals the amount exiting the lungs via expiration and pulmonary veins [13].

During 30s of re-breathing, the amount entering does not change, but the amount eliminated by expiration decreases and end tidal CO_2 increases in proportion to the cardiac output. Major limitation is that tracheal intubation with fixed ventilator setting is required. It is also not very accurate in patients with severe chest trauma, significant intrapulmonary shunt, high cardiac output states and low minute ventilation.

Thoracic Bioimpedance

Thoracic bioimpedance (TEB) is a non-invasive method of cardiac output monitoring. It is based on the hypothesis by considering thorax as a cylinder perfused with fluid with specific resistivity. It measures the electrical resistance of the thorax to a high frequency, low amplitude current. Electrodes six in number are placed (two on either side of neck and four in lower thorax) on the patient and the resistance to current flowing from the outermost to innermost electrodes is measured. The bioimpedance is indirectly proportional to the content of thoracic fluid. Major limitations like interference with electrocautery, proper electrode placement, patient's movements and arrhythmia may affect its accuracy.

Thoracic Bioreactance

Thoracic bioreactance (NICOM device, Cheetah Medical, Portland, Oregon) is a modification of TEB which avoids interferences by noise and external sources. It analyses changes in the phase of electrical voltage signal to the current applied across the thorax.

Endotracheal Cardiac Output Monitoring

ECOM (Con-Med, Irvine, Calif, United States) measures cardiac output using impedance plethysmography. It is based on the principle of bioimpedance and current is passed through electrodes attached to endotracheal tube shaft and cuff. Current is passed from electrode on the shaft of endotracheal tube (ETT) and change in impedance secondary to aortic blood flow is detected by electrode on the cuff of ETT.

Portable Doppler Device

Ultrasonic cardiac output monitors (USCOM, Sydney, Australia) is a portable device which is non-invasive and uses a probe placed suprasternally to measure flow through the aorta or on the left chest to measure transpulmonary flow. It uses the Doppler principle as used with ED and TEE.

Photoelectric Plethysmography

The Nexfin HD (BMEYE B.V, Amsterdam, Netherlands) is a completely non-invasive pulse pressure analysis device that assesses pulse pressure using photoelectric plethysmography in combination with a volume-clamp technique (inflatable finger cuff).

CONCLUSION

There are various newer devices for cardiac output monitoring available in clinical practices that are validated against the gold standard method. Newer devices have the advantage of being minimally or non-invasive and portable. Hence, a few of them can be used outside the OR and ICU. The criteria for selection of newer devices should be based on the institutional protocol and clinical condition of the patients. PAC will remain a gold standard for cardiac output monitoring; however, use of newer devices based on pulse pressure analysis, pulse contour analysis and Doppler methods should be encouraged.

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