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Review Article

A Narrative Review of Cardiac Output Measurement in Cardiac Surgery

Alireza Jahangirifard[1], Seyed Bashir Mirtajani[2], Ali Jabbari[3], Leila Saliminejad[2], Mohammad Ghaheri[4], Zargham Hossein Ahmadi[2]*

[1]Chronic Respiratory Diseases Research Center (CRDRC), National Research Institute of Tuberculosis and Lung Diseases (NRITLD), Shahid Beheshti University of Medical Sciences., Tehran, Iran.

[2]Lung Transplant Research Center, National Research Institute of Tuberculosis and Lung Diseases (NRITLD), Shahid Beheshti University of Medical Sciences, Tehran, Iran.

[3]Department of Anesthesiology and Critical Care Medicine, Golestan University of Medical Sciences, Gorgan, Iran.

[4]Student Research Committee, Alborz University of Medical Sciences, Karaj, Iran.

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ABSTRACT

Continuous monitoring of the cardiovascular system and control of the changes affecting it is a constant challenge for the surgical team. The need to control the condition of the heart and better understand its condition is raised in the topic of advanced hemodynamic monitoring, which is a set of different techniques for real-time monitoring of the cardiovascular condition and its influencing factors. Cardiac output, as the most important indicator of cardiac function, is an integral part of cardiac monitoring systems. The measurement of this index has witnessed extensive changes in the past few years, which clearly shows its importance. Cardiac surgery is one of the most serious cases that requires accurate assessment of cardiac output and advanced hemodynamic monitoring. Therefore, the present study examines the types of cardiac output in cardiac surgery.

Introduction

Hemodynamic monitoring is a careful monitoring of the cases and details of the patient's hemodynamic constituents (for correct and timely intervention) [1]. The correct replacement of fluids, the use of inotropic and vasoactive drugs, is the basis of many surgical procedures, including cardiac surgery. The algorithm used for treatment in this section is based on the measurement and recording of hemodynamic data. In fact, hemodynamic monitoring can be an active review of the patient's cardiovascular status using vital sensors that will reveal the biological conditions of each individual [2]. Hemodynamic monitoring in this type of surgery is often presented at two (basic and advanced) levels. Classical and basic assays, including pulse oximetry, invasive blood pressure measurements, capnography, central venous pressure measurement, central measurement of temperature, urine measurement and analysis of arterial blood gases. Often, they are considered as a tool for measuring initial conditions; however, with some problems and limitations, the use of these conventional methods is not credible [3]. In this context, the discussion of the use of new and more precise tools and techniques (in the form of advanced hemodynamic monitoring) is proposed. These techniques, using a physiological stressor, access the physiological reserves of the individual being examined. The main component of this monitoring is the presence of cardiac output, as it is an indicator of cardiac function and is the basis for calculating other

The authors declare no conflicts of interest.
*Corresponding author.
E-mail address: dr.zarghamahmadi2020@gmail.com

hemodynamic components, such as systemic and pulmonary vascular resistance [4]. The use of advanced techniques in hemodynamic monitoring enables the physician to answer the following questions correctly [5]:

What are the conditions for the cardiovascular function of the patient?

Is the condition of the patient's intravascular fluid acceptable and the patient benefits from the administration of fluids?

What is the supply and demand of oxygen in the patient's body?

Is there a good relationship between heart function and lung function? What are the conditions of lung vessels and fluid levels in pulmonary tissues?

Advanced Hemodynamic Monitoring in Heart Surgery

The main objective in proper control of patients' medical conditions during cardiac surgery and during critical is to maintain an appropriate balance between the supply and demand of oxygen at the tissue level [6].

An overview of the calculation method for these factors, which is presented below [4], shows that we will not be able to achieve this solely with the use of basic monitoring information.

Oxygen Delivery (DaO2) = CaO2 x CO x 10

Arterial Oxygen Content (CaO2) = (1.34 x Hgb x SaO2) + (0.003 x PaO2)

Cardiac Output (CO) = SV x HR

With all of these, new and advanced monitoring is needed in order to achieve hemodynamic details of the patients and to improve the quality of service through timely and correct intervention. Advanced monitoring systems are used in heart surgery in two major parts, controlling and evaluating cardiac outflow and fluid volume management. The present study is based on the review of techniques used in advanced hemodynamic monitoring for controlling cardiac output.

History

With the advent of science and the combination of medical and engineering techniques, we are seeing tremendous changes in all areas of medicine. Anesthesiology and the use of modern techniques (in order to increase the confidence and ease in the process of performing clinical services during surgery) were also no exception. 25 years after the first implementation of the modern anesthetic process in 1846 [7], Adolf Fick (1870) described the first method for estimating the rate of cardiac output, which until now has remained as the reference measure for this criterion [8]. Fick stated that all of the oxygen injected by the lung was transmitted to the blood and thus considered the cardiac output as a relation between intake of oxygen (VO2) and the difference between arterial-venous oxygen (AVDO2).

The cardiac output measurement was performed in 1966 using electrical impedance (H4); however, 1970 was a turning point for measuring cardiac output. In this year, Swan and his colleagues introduced a new technique and tool called Pulmonary artery catheter (PAC) to accurately measure cardiac output [9]. This technical approach was soon proposed as a reference method for measuring cardiac output [10]. The importance of knowing the extent of cardiac output in various surgeries, especially cardiac surgeries, has led many to research in this regard. People such as Swan, Jurin, Okamoto, Hughes, Thomas, Mark, and many [11-20] during the 1965-2000 period have increasingly sought to measure cardiac output rates, and there after a large volume of studies on this issue is recorded.

The development of surgical techniques and moving towards Non-invasive methods or with minimal-invasive has led to the emergence of new techniques for measuring the amount of cardiac output.

Method of research implementation

The present study, entitled " Cardiac output measurement methods in heart surgery", is presented. A study of 153 articles and books has been used, among which 67 articles and books have been used in writing this article. All articles and books used in this study have been extracted from valid databases (PubMed, Scopus, Springer, ScienceDirect, etc.) for a period of 48 years (1970-2018), and have been writing in 7 months.

Methods for measuring cardiac output

Cardiac output is the main index for describing cardiac function and it is important to determine the possibility of adequate blood supply to the tissues [21]. In order to better control hemodynamic and to achieve optimal conditions at the tissue level, it is necessary to know the patient's cardiac output. Measurement of cardiac output in patients is done in a variety of ways. However, all methods for measuring this cardiac index are categorized into three groups (invasive, minimal-invasive and non-invasive).

Invasive procedures:

CO measurement by pulmonary artery catheter using Bolus injection technique:

Pulmonary artery catheter (PAC) was initially considered as a tool for measuring flow and pressure. However, over time, this method has been used to measure cardiac output and central filling pressure, and since 1970 it has been proposed as a golden standard for measuring cardiac output [22-23]. However, the incidence of these side effects is small [24]. In this catheter, the thermistor is located at a distance of 4 cm from the tip. When measuring cardiac output, 10 cc cc (10 ° C or room temperature) is injected through the catheter into the right atrium. With the passage of this liquid from the thermistor, a slight decrease in blood temperature occurs, then the thermodilution curve will be plotted by connecting the catheter to a computer. In this way, cardiac output is calculated by determining the flow-pressure curve by means of BMI, central body temperature, systolic and diastolic pressures, CVP and PAP. There are various technical errors such as loss of injectate, temperature variations, thermistor defect, clot formation at the catheter tip, deviation and catheter obstruction, or injection within 4 seconds that causing an error in the process of using PAC. The information obtained through this method will not be accurate in situations such as shunting, severe regurgitation of tricospide, significant arrhythmias, abnormal respiratory pattern, and low cardiac output. Due to these errors and possible adverse effects, the development of less invasive methods for monitoring CO has been proposed [25-26].

Measurement of Continuous CO by pulmonary catheter

Continuous CO (CCO, Edwards Lifesciences, Irvine, California, United States) is a modified PAC known as Swan Ganz. It has copper filaments and is located in the right atrium and 25 to 14 cm from the catheter tip and is able to heat the blood alternately. Therefore, in this method, the need for the injection of bolus fluid is eliminated. The blood temperature is received by receptors at the catheter's head and the mean CO value over time is displayed on the monitor in accordance with the mechanism mentioned in the bolus measurement method. The main advantages of the CCO in contrast to the usual PAC is preventing repeated injections and and thus reduces the risk of infection and operator mistakes [27]. Additionally, continuous monitoring of Stroke volume (SV) and systemic vascular resistance (SVR) and Mixed venous saturation is also done with this catheter. The accuracy of cardiac output measurement in a continuous method compared with intermittent thermodilution is comparable in patients with off-pump coronary artery bypass surgery (OPCAB) [28]. A review of the history of the use of PAC has shown that some researchers have called for the PAC to be stopped [29]. The PAC-MAN study did not show any harm or benefit in using PAC [30]. The use of it in patients with OPCAB also showed no difference in mortality and outcome [31]. Nevertheless, PAC is still a "golden standard" for monitoring CO and is used in complex cardiac surgery, low cardiac output, high pulmonary hypertension, and differentiation between left ventricular or right ventricular dysfunction. However, due to the inherent risk of use, attempts to reach a minimally invasive alternate or non-invasive performance for monitoring cardiac output with all the features of an ideal monitor continue.

Minimally invasive procedures

Pulse contour analysis

This method is based on proportionality between the regions under the systolic arterial pressure wave with the SV. In this method, the measured area after the diastole up to the end of the ventricular discharge stage is divided into an aortic impedance and thus measures SV [32]. This method measures volumetric stroke (SVV) or pulse pressure changes (PVV), which are useful for predicting response to fluid administration. SVV is the difference between the maximum and minimum SV during the mechanical respiratory period and is caused by changes in the preload that results from changes in chest pressure. In addition to arterial waveforms, arterial compartmentalization, SVR values, and demographic characteristics of the patient are also required for calibration [33]. The Cantor pulse method is evaluated qualitatively in terms of the accuracy of its measurement, in comparison with other cardiac output measurement methods used in cardiac surgery and the results showed a good correlation among this method in comparison with other methods and the standard method [32].

The Cantor pulse method can be calibrated or non-calibrated:

Calibrate type:

The procedure requires central venous (internal femoral or jugular) and arterial (femoral / radial). Cold saline is injected through the central vein cannula and blood temperature changes are detected through a thermistor located at the tip of the arterial catheter. Thus, in order to determine the hemodynamic variables, the Cantor pulse method is combined with transpulmonary thermodilution. This procedure requires manual calibration every 8 hours (and hourly during hemodynamic instability) [34]. Additionally, the transpulmonary thermodilution curve can be used to measure intra-thoracic blood volume (ITBV), global end-diastolic volume (GEDV) and Extravascular lung water (EVLW). GEDV and ITBV are a benchmark for measuring cardiac preload and EVLW can measure lung edema. This method also measures the SVV / PVV that indicates the response to the liquid [35]. The accuracy of this method may be affected by vascular compulsions, aortic impedance and peripheral arterial resistance. In addition, the presence of airbubbles, clots, inadequate indicator fluid, valvular regurgitation, aortic aneurysm, significant arrhythmia, the presence of IABP, the weight of <40 kg, and rapid change in temperature may also affect its accuracy [36]. Devices currently working are based on the above method, including the PiCCO System (PULSION Medical System, Munich, Germany) and the EV1000 / Volume View system (VolumeView ™ / EV1000 ™ ‹Edwards Lifesciences ‹Irvine ‹CA, USA). Various studies have shown that a good correlation between cardiac output measured by this method and PAC during cardiac surgeries and cortical patients (other than OFF-PUMP surgery) [37-38], and these two methods were comparable in terms of cardiac outcomes [39].

calibrated type:

The non-calibrated method only uses the patient's arterial curve in the same manner as described at the beginning of this section and includes the following:

FloTrac system:

FloTrac (Edwards LifeSciences.Irvine, USA) is a minimally invasive pulse contour system because it only needs an arterial line (femoral or radial). This system does not require any external calibration and its use is convenient for the operator [40]. This machine calculates CO and SVV using the patient's artery waveform and its biometric characteristics (age, height, and gender) [41]. The third generation of this device is made with Dynamo technology, which has an automatic tuning for change in vascular tone [36]. The measurement-accuracy of this device is variable in patients with arrhythmia, people with IABP, or cases with high tonicity in the arteries and obesity [42]. Various studies have confirmed the good association between FloTrac and PAC, and have acknowledged that FloTrac is suitable for CO measurement [42]. However, some recent research has shown that this method does not work in measuring cardiac output, especially in patients with the low cardiac output [34].

Pulse power analysis:

In this method, the change in mean blood pressure is directly related to the SV, thus the whole arterial waveform will be analyzing (not just its systolic region). Various factors affect its accuracy, such as arterial compilation, arterial waveform, and wave reflection, transducer decamping and systolic output of the aorta [43].

System LiDCO, a minimally invasive device that requires an intravenous line (central or peripheral) and the arterial catheter. A bolus lithium chloride is injected into the intravenous line and the arterial concentration is measured by a lithium sensitive sensor. CO is calculated using a combination of pulse contour analysis, based on the dose of lithium and the area under the concentration-time curve, and the SV (SVV) variation is also measured [40]. This procedure requires calibration every 8 hours (and if there are major changes in hemodynamics). The use of this method is prohibited in patients undergoing lithium therapy, and since the remaining Quaternary ammonium disturb the function of the electrode, the calibration also affects by the neuromuscular blockers [44]. its accuracy is affected by aortic insufficiency, intra-aortic balloon pump (IABP), Damped arterial curve, severe vazvkanstrykshn, post-aortic surgery, arrhythmias and internal or external cardiac shunting [44]. LiDCO rapid also uses pulse power only, does not require lithium injection, and therefore it is able to measure the amount of cardiac output continuously without the need for calibration [43-44]. This method has the same efficacy and limitations of the above methods (except for lithium susceptibility and the effect of vasodilators) and its use in cardiac surgery has a good correlation with PAC and also has been associated with a reduction in complications [45]. In this system, the use of a calibrated method is preferable to analyzing arterial curves in cardiac surgeries and is recommended [46].

Pressure recording analytic method:

MostCare (Vytech) – (PRAM, Padova, Italy) PRAM technology is able to analyze the whole of the cardiac cycle and determine the region under the pressure wave (P / T) [44]. P / t is divided into two diastolic and systolic phases with 2 impedances based on different characteristics. As a result, the stroke volume will be calculated by dividing the systolic level below the pressure curve on the calculated impedance of the patient. The main advantage of this method is that external calibration is not necessary and the internal calibration is done by the morphology of the arterial waveform. The precision of this method is still not well defined [36], but recently its use in pediatric cardiac surgeries has been successful and its cardiac output has been comparable with Fick's method [47].

Esophageal Doppler devices:

esophageal Doppler:

esophageal Doppler used by a flexible probe with a transducer at its tip that can be placed for a long time in the esophagus of patients. In this method, ultrasound waves are sent to the median level of the chest toward the descending aorta, and the reverse waves are recorded after absorption by the blood. The average blood flow rate in the aorta is measured based on the calculation of transient waves and blood flow measurements [48]. By entering the age, sex, height, and weight of the patient, the aortic cross-section is calculated and then the SV is obtained by multiplying this factor in the bloodstream. Eventually, by multiplying HR in SV, CO can be calculated [49]. In this method, the main limiting factor is that flow is measured in the descending chest aorta. This flow contains 70% of the total blood flow, and it is necessary to add a corrector to compensate for the aortic arch. In addition, the difference in flow measurement may be seen in aortic coarctation, aortic aneurysm, IABP, and various metabolic conditions. Its accuracy is affected by various factors such as changes in pulse pressure, vascular compilation, volume status or inotropes [50]. The precise velocity in this method can only be determined by the appropriate position of the probe, which should be about 20 degrees from the axial flow. Different studies have compared ED with PAC and have introduced it as an efficient method [51]. The use of this method has had a positive effect on various types of surgeries, and in cardiac surgery, there has been a reduction in hospitalization time and ICU, and no major complications have been observed in patients undergoing treatment [36].

Trans Esophageal Echocardiography (TEE):

TEE is currently a monitoring method widely used during the perioperative time. In order to measure the cardiac output, the CSA and the average blood flow at its surface (V) were first measured and the stroke volume (SV) was calculated by the formula: SV = V × CSA. Thus, the cardiac output is calculated by multiplying the stroke volume in the cardiac pulse. This measurement can be done at the levels of the lung artery, mitral valve, or aorta [52]. TEE is a useful tool in patients with unstable hemodynamics and in many cases, it is reliable compared to PAC. Of course, it should be noted that this technique exhibits low efficiency in hypotension [53]. Additionally, a skilled operator is required to work with this device, as well as limited access and high cost can be the main limitation for using it, while the TEE probe cannot be left for long periods of time in the patient.

non-invasive cardiac surgery:

Partial gas rebreathing:

This method is known as NICO (Nova Metrix Medical Systems, Wallingford, Conn., United States) and It uses the indirect Fick principle to calculate CO. In the stable phase, CO_2 enters the lungs through the lung arteries, which is proportional to the cardiac output and is equal to the output of the lungs (through expiration) and lung veins [36,54]. At first, the pop-up valve is closed and all carbon dioxide remains in the channel and ventilation is carried out. Partial rebreathing of the valve is performed every 3 minutes by opening the valve and the pulmonary blood flow is calculated by calculating the difference between the ratio of rebreathing and normal respiration [55]. The main limitation of this technique is the need to place the chip with ventilator constant settings. Also, the method described is not precise in patients with severe chest trauma, intraperitoneal shunt, high CO status and low ventilation [53]. Studies have shown that using this method leads to an incorrect estimate of cardiac output. Therefore, the result of calculating cardiac output before surgery is low and after surgery, it will be high [56]. In this way, its use is limited and not suitable in comparison with the PAC [56].

Thoracic Electrical bio impedance:

Chest Biomorphology (TEB) is a non-invasive method for measuring CO, initially used by astronauts in the 1960s [36]. In this method, eight electrodes are placed in different regions (four on the two sides of the neck and four lowers than the chest). A high-frequency electric current and magnitude are released from the electrodes in the neck towards the electrodes under the chest. Therefore, the resistance to flow is measured according to time, from the outside electrode to its Innermost type. The biocomponent is indirectly proportional to the content of the fluid in the chest. This fluid consists of pulmonary blood, venous blood, and aortic blood volume, all of which are involved in measurements in TEB [57].

Major limitations such as electrocautery interference, inappropriate positioning of the electrode location, patient movements, obesity, pleural effusion, and arrhythmia may affect its accuracy. Also, the presence of sternum wires or arrhythmia may lead to inadequate function during the postoperative period [58]. These limitations are due to the novelty of the described methods, which resolved due to the progressive development of engineering science in the field of medicine and monitoring [57]. Generally, studies in patients undergoing cardiac surgery show a good correlation with PAC and this method can be considered as a good way to analyze the hemodynamic conditions of the patient using its Trend [59].

Thoracic Electrical bioreactance

Thoracic bioreactance (NICOM device, Cheetah medical, Portland, Oregon) is a modified TEB method is that it does not interfere with the sound and other external factors. This method involves placing two dual electrodes on both sides of the chest. One of these electrodes transmits a high-frequency sinusoidal wave (75 kHz) to the body, and another electrode is used as a voltage input. Ultimately, the final rate of cardiac output is calculated using changes in electrical current at any time [36].

Electrocautery affects the accuracy, but if the device receives 20 signals within a minute, the CO value can be accurately determined. The main advantage of this method is ease of use in intubation and arrhythmic patients, in an emergency room, ICU and surgery room. The comparison of its value with PAC shows a good correlation between the two methods with minimal difference [31] and in pediatric cardiac surgery, the results are comparable with the Fick method [60].

Endotracheal Cardiac Output Monitoring (ECOM):

ECOM (Con-Med, Irvine, Calif, United States) measures CO by using plethysmography of impedance. The electric current passes through the electrode on the body of the endotracheal tube (ETT), and change in the second impedance to the aortic flow will be received by the electrode on the cuff. SV and CO are calculated based on algorithmic bases and impedance changes. Electrocautery also affects its accuracy and coronary blood flow is calculated. The use of this technology, which has not yet been approved, is unpopular and expensive [59]. However, recent reports have shown evidence of its efficiency in cardiac surgeries, such as its application in OPCABG patients [61].

Portable doppler device

Cardiac output ultrasonic monitor (USCOM, Sydney, Australia) is a portable and non-invasive device that has a probe. This probe can be placed in two way that including suprasternal for measure the flow of aorta or on the left side of the chest to estimate the transpulmonary flow [62]. This device uses the Doppler principle as the DE and TEE methods. The main advantage of this device is its portability, which can be used in the surgery room, emergency and ICU, even in the care sector. Because this device is a non-invasive device, it can be used by trained nurses and is also considered as a tool for postoperative follow-up of patients undergoing cardiac surgery. The USCOM device was used in patients after cardiac surgery to measure CO, CI and SV and had a good relationship with PAC-measured numbers [63-64].

Photoelectric plethysmography

A completely non-invasive device for analyzing pulse pressure, which measures pulse pressure using photoelectric plasticization combined with the volume-clamp technique (flexible finger cuff). The cuff maintains a constant flow of blood in the arteries (based on the measurement of the diameter of the arteri by photo plethysmography). The pressure required for this operation is proportional to the arterial pressure curve. After analyzing these pressures, blood pressure is calculated by the algorithm of the device, and CO is the result of the information obtained from this pressure curve and analyzed by the contour pulse method [65]. This technique is used in Nexfin HD (BMEYE B.V, Amsterdam, Netherlands). So far, there have been few studies on its effectiveness, but according to recent studies, CO calculated using this method is in good agreement with PAC and is reliable in cardiotrophy surgery, even though dosages of vasoconstriction are not used [66]; However, its accuracy under the conditions of low cardiac output is debatable [67].

Conclusions

The measurement of cardiac output is an essential part in the management of hemodynamics in patients undergoing complex cardiac surgery and in patients with a critical and imbalanced hemodynamic condition because without it, measurement of other hemodynamic components, such as systemic vascular resistance and pulmonary arterial resistance, is not feasible. Today, there are various methods for measuring or calculating this index, each containing certain advantages and disadvantages. Given these conditions, having sufficient information on the mechanism of the performance of these methods, measuring the benefits, benefits, and limitations can help to make a good choice on how to apply and, as a result of better decision-making.

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