Original Research Paper

Volume-9 | Issue-9 | September - 2019 | PRINT ISSN No. 2249 - 555X | DOI : 10.36106/ijar

Anaesthesiology

REVIEW OF CARDIAC OUTPUT MONITORING

Col Vikas Srivastava Senior Adviser (Anaesthesiology & Critical Care), Department Of Anaesthesiology & Critical Care, Army Hospital (R&R), New Delhi - 110010

ABSTRACT Cardiac output monitoring is the mother of all haemodynamic monitoring and the quest for search of an ideal method of CO monitoring is continuing ever since the idea was mooted. Reviews of CO monitoring are many focusing on various aspects. This review is focusing on basics of CO monitoring i.e., technology, advantages, disadvantages and present applications.

HISTORY: It was Adolf Fick (1829-1901) who first suggested an idea that later came to be known as Fick Principle and was made possible after Dexter et al published their work in 1950[1] . Cardiac output monitoring was started in 1960s and 1970s after catheterization of the heart with a Swan-Ganz (SG) catheter[2] and even today it is considered to be 'Gold standard'. There have been modifications in SG catheter but the basic principle remained the same. But there were many complications of this method: biggest being that it was an invasive method and requires cardiac catheterization.

In the quest to decrease complications, minimally invasive methods were invented by few biomedical enterprises. These methods required an arterial catheter to be placed either in radial or femoral artery and pulse contour or pulse power analysis is done with proprietary software which translates all this data into Cardiac Output (CO). Another method in minimally invasive technique utilized Esophageal Doppler to be placed next to the Aorta to measure the cardiac output. Further, few non invasive techniques also have been in vogue for the past few years.

KEYWORDS :

INTRODUCTION

Haemodynamic monitoring is the single most important agenda for any patient admitted to ICU. The patients who are haemodynamically unstable for any reason require CO monitoring which gives better understanding to the physician regarding the physiology of the patient. In these patients a goal directed therapy is almost always instituted and CO monitor becomes the focal point of the patient assessment. This underlines the fact that any amount of meticulous patient examination cannot reasonably predict changes in CO. In this age of technologically driven ICU, a rough estimate of CO by surrogate measures do not suffice and accurate measurement has become the need of the hour. There are various technologies and maze or monitors available and the clinician is ever confused. The various principles of measuring CO include Fick's principle, thermodilution, Doppler, Pulse wave analysis or Pulse Contour Analysis and bioimpedance. This article is presented with a view of clearing all the haze involved with CO Monitoring with explanation of all relevant technologies, their advantages and disadvantages and possible applications. There is nothing called as an ideal CO monitor as the Pulmonary Artery Catheter (PAC) which is the gold standard is a majorly invasive device with numerous complications including life threatening ones and is regularly used during cardiac surgery settings.

The Cardiac Output Monitors are broadly divided into three categories, Invasive, Semi-invasive and Non-invasive. All the methods of monitoring will be discussed under four sub-heading - technology, advantages, disadvantages and current application.

INVASIVE CARDIAC OUTPUT MONITORING

There are two methods of CO monitoring by a PAC - the Fick method and the Thermodilution method.

1. FICK METHOD: TECHNOLOGY. This method was described by Adolf Fick which is based on a simple concept that the total uptake or release of a substance from an organ is determined by the difference of the concentration of the substance in blood before and after it has passed through the organ. Here the organ is taken as a whole body and the difference is taken before and after blood has been oxygenated by the lungs. Therefore CO is calculated by using the equation

$$CO = \frac{V_{o2}}{CaO_2 - CvO_2}$$

VO2 is the oxygen consumption in the lungs, CaO2 is arterial and CvO2 is mixed venous concentration of blood. CvO2 can only be determined by a PAC from lumen in the Pulmonary artery.

Advantages: This is considered the most accurate method for patients with low cardiac output[4].

Disadvantages: Uniform oxygenation of blood is required throughout passage of blood through the lungs. This method is not accurate in haemodynamically unstable patient with invasive ventilation and high FiO2. Present Applications: It is not a bedside monitoring anymore.

2. THERMO DILUTION.

Technology: This requires a PAC insertion along with a thermistor tip. It measures CO by Stewart Hamilton Equation but instead of a dye, it uses heat as indicator. Cold injectate is administered through the port in RA (Right Atrium) and the thermistor senses the decrease in temperature which is inversely proportional to the dilution[5]. The modified PAC is connected to a monitor which does all the calculations and display the CO.

Advantages: This is considered as 'Gold Standard' for CO monitoring owing to accuracy of reading and wide applications

Disadvantages: Insertion of PAC catheter has potentially life threatening complications. A few of them related to insertion procedure related are inadvertent arterial puncture, pneumothorax and haemothorax: SG catheter insertion can lead to life threatening arrythmias and bundle branch blocks: related to maintainance of PAC are rupture of Pulmonary artery, pulmonary infarction, air embolism, venous thrombosis, pulmonary embolism, cardiac tamponade from perforation of superior venacava, right atrial, or right ventricle, infection and mechanical problems like catheter coiling or knotting, catheter tip migration, balloon rupture[6].

Current Application: Thermodilution technique is extensively used in cardiac surgical and cardiology settings. However there has been a moratorium on its use in Critical Care setting since past decade[6,7] due to various studies indicating harm in these subset of patients.

3. CONTINUOUS CARDIAC OUTPUT (CCO).

Technology: This is a modification of PAC which has an embedded copper heater element designed to remain in the RA. It intermittently heats the blood, the signal of which is captured by the thermistor at the tip of PAC, a monitor does all the calculations and displays CCO. Mixed venous oximetry can be added to display oxygen delivery as well as utilization[8].

Advantages: CO is calculated over a period of past 3-5 min. A lot of parameters for right ventricular functions like RVEDV (Rt ventricle end diastolic volume), RVESV (Rt ventricle end systolic volume) and derived RVEF (Rt ventricle ejection fraction) can be monitored.

Disadvantages: The same disadvantages as mentioned in thermodilution method applies.

Current Applications: Used in cardiac surgical settings and in selected cardiology patients.

MINIMALLY INVASIVE CARDIAC OUTPUT MONITORING

Minimally invasive systems were developed to reduce the adverse outcomes of Invasive devices. However all of these methods universally employ an arterial cannula from which CO is determined using various methods and algorithms. It is pertinent to mention here that accuracy of all these monitors are dependent upon 'crispness' of the arterial trace and is affected by aortic regurgitation, intra-aortic balloon pump, dampned arterial line, postaortic surgery, arrythmias and intra/extracardiac shunts[9]. Few of them which are common are described here

1. LiDCO. It works on the principle of Lithium indicator dilution combined with pulse contour analysis. Pulse power analysis is based on the principle that the CO and SV changes causes variation of the pulse pressure which can be measured from arterial pressure trace and is dependent upon compliance of the vascular system, wave reflection, aortic systolic outflow and damping of the transducer[9,10].

Technology. It employs an arterial line and a venous line (central or peripheral). A bolus of lithium chloride is injected into the venous line and the concentration is plotted by measurement from disposable sensor in the arterial line[11]. LiDCO monitors are manufactured by LiDCO limited USA and consists of LiDCO rapid, LiDCO Unity, LiDCO Plus etc which differ from each other with respect to parameters monitored.

Advantages. Ease of use due to user friendly interface makes it good modality of CO measurement and correlates will with PAC[12].

Disadvantages. This modality is expensive as the transducer used is disposable. It also require calibration every 8 hours during stable periods and frequently during haemodynamic instability. It cannot be used in patients on lithium therapy and with quaternary ammonium neuro-muscular blockers.

Current applications. This is used for fluid resuscitation in sepsis and intra-operative monitoring in high-risk surgery like liver transplantation[12].

2. Pulse Contour Analysis.

Technology.

This works on the principle that area under the systolic part of the arterial pressure waveform is proportional to the SV[13]. The parameters considered are aortic impedance, compliance and peripheral vascular resistance in the Windkessel model. In this model, the area is measured from start to end of systole divided by aortic impedance that measures SV. SVV (Stroke Volume Variation) and PPV (Pulse Pressure Variation) can also be derived from the monitor.The system consists of an arterial line connected to the monitor and a slave CVP line.

Advantages. It is a simple and

3.PiCCO system Technology: it is the combination of both pulse contour analysis and transpulmonary thermodilution method to measure cardiac output.It requires both cemtral venous access and the arterial line placemnt.Indicator solution is injected through the central venous catheter and change in blood temperature is measured by the thermistor tip placed in the artery.

Advantages : It is realtively minimally invasive. Along with cardiac output measurement , It also helps in measuring intrathoracic blood volume and global end diastolic volume which is a measure of cardiac preload. It also helps in quantifying pulmonary edema by measuring extravascular lung water volume.It also measures SVV/PVV.(14)

Disadvantages : Manual calibration is required every 8hrly and hourly, if hemodynamic instability is there(15). Its accuracy is affected by vascular compliance, aortic impedence, peripheral arterial resistance, clots or air bubbles inmeasuring lines.Other factors affecting its accuracy includes vascular regurgitation, aortic aneurysm, arrhythmias and rapid temperature changes.(16)

4.FloTrac system Technology:

Its working is based on the principle of linear relationship between the pulse pressure and stroke volume.Stroke volume is estimated as

$$SV = SDAP \times \mu$$

SDAP = Standard deviation of data points that reflects pulse pressure.

μ = Conversion factor depends on arterial compliance, mean arterial pressure, waveform characteristics.

Advantages: It is minimally invasive; just an arterial line. It is simple and easy to use, operator independent. And moreover, it doesn't require external calibration.

Disadavntages: The readings are affected by IABP,in morbid obese patients or patients having clinically significant arrhythmias.

5.Pressure recording analytic method (PRAM) Technology: It uses the arterial wave form morphology to determine cardiac output. It analyses the cardiac cycle and area under pressure wave is measured which is divided into systolic and diastolic phase.(17)

Adavntages: it is simple. minimally invasive and no external calibration is required. Internal calibration is done automatically.
Disadvantages : Not proven accuracy till date.

6. Esophageal Doppler Technology: It measures the flow in the descending aorta considering it as a cylinder. The flow can be measured by

$$FLOW = CSA \times Velocity$$

The blood flow velocity is measured by ultrasound processor using Doppler equation :

$$V = fd \times c/2 \times f0 \times \cos\theta$$

V = velocity of blood, fd = Doppler shift in frequency, c = speed of ultrasound in tissue (1540 m s21), f0 = initial ultrasound frequency, and θ = the angle of ultra- sound beam in relation to the blood flow

Velocity-time curve is plotted and area under this curve gives the Velocity-Time integral (VTI) which is used as stroke distance. Hence, stroke volume is calculated as

$$SV = CSA \times VTI$$

Thus, Cardiac output(CO) = SV × HR (18)

Disadvantages : Total flow is not measured, its only 70% of it i.e flowing in descending aorta; hence a correction factor is required. The calculations can vary in cases such as aortic aneurysm, coarctation, IABP or cross clamp .Hemodynamic changes can vary the CSA giving the false readings. Positioning of the probe should be within 20° of the axial flow.

7.TEE Technology:

NON INVASIVE METHODS

1.Partial gas re-breathing Technology: It uses indirect Fick's principle to calculate cardiac output. In intubated patients and in steady state, the amount of CO_2 entering lungs is proportional to CO. During re-breathing the amount entering the ungs doesn't change much but the amount expirated decreases and hence the endtidal CO_2 increases which is proportional to CO. CO is calculated as follows:

$$CO = VCO_2/CvCO_2 - CaCO_2$$

VCO_2 is CO_2 consumption, $CaCO_2$ and $CvCO_2$ is arterial and venous CO_2 content

Disadvantages: It requires tracheal intubation. It is not much of a use in chest trauma. intrapulmonary shunt, increased CO states and decrease minute ventilation. Studies have shown underestimation of CO in pre operative states and overestimation in post operative periods(19).

2.Thoracic bioimpedence Technology: It is based on the principle of measuring the electrical resistance, which depends on the fluid in the thoracic cavity, to a high frequency and low amplitude current. Two electrodes are placed in the either side of the neck and four electrodes are placed in the thorax; and resistance to the current is measured from outermost to innermost electrodes. Any variation in CO will be reflected by a change in the thoracic bioimpedence as it will alter the aortic blood flow. SV is calculated(18) as :

$$SV = VEPT \times VET \times EPCI$$

VEPT = volume of electrically participating tissue
VET = ventricular ejection time taken from the R-R interval
EPCI = ejection phase contractility index which is indirectly proportional to TEB.

Disadvantages: It is not useful in patients undergoing surgery because of the electrocautery use. Patient's movements, arrhythmias , improper placement of the electrodes can alter its readings. Efficacy has not much been proved in critically ill patients.

3.Thoracic bioreactance Technology: It is based on variation in capacitance and induction when current is made to flow from one electrode to the other. The variation gives the change in the intrathoracic volume.

Advantages: External interferences or arrhythmias do not vary the results. It can be used with electrocautery during surgery.

Disadvantages:
Clinical applications: It is simple and easy to use in intubated patients, in emergencies and operating theatres.

4.ECOM Technology: It is based on the principle of bioimpedence and calculates CO using impedence plethysmography. Two electrodes are used;one placed at the shaft of the ET, from where the current is passed and the second electrode is placed at the cuff of the ET, which detects change in the impedence due to aortic blood flow. This gives the SV, based on algorithm and hence the CO.

Disadvantages: It is costly. It doesn't measures the coronary blood flow. Electrocautery alters the measurement, so cannot be used during surgery.

5.Ultrasonic cardiac output monitors Technology: It uses the Doppler principle to measure the flow through aorta or transpulmonary flow.(20)

Advantages: It is simple, portable, easy to carry device and do not require expertise to interpret.

Disadvantages: Proper placement of the probe is mandatory to get the correct reading.

Clinical applications: It can be used easily in emergency room, theatres, ICU or general wards.

6.Photoelectric plethysmography Technology: It is based on Penaz principle. Also known as volume clamp method. It uses photoelectric plethysmography to analyse pulse pressure. Modelflow method is used to calculate CO.

Disadvantages: It is not useful in patients of cardiogenic or hypovolemic shock as there will be low cardiac output and high systemic vascular resistance, hence the readings will be unreliable(21-26). The values will be distorted in patients having finger site oedema.

7.Radial artery applanation tonometry Technology: A non invasive method which uses an autocalibrating algorithm for continuous recording of the arterial pressure waveform obtained by a sensor placed over the radial artery.

CONCLUSION

The desirable characteristics for haemodynamic monitoring techniques are accuracy, reproducibility, fast response, operator independency, continuous and ease of use with no increased mortality and morbidity. None of the technique combines all the criteria. Most of the techniques are still relatively invasive, requiring either sedation and mechanical ventilation or arterial and central venous access. The pulse contour and pulse power methods require frequent calibration. Fick/CO2 method does not provide an instantaneous measure of CO, but rather a mean value every 3 min. Recent technological advances have allowed the development of completely non-invasive CO monitoring using impedance cardiography. This technique is ideal for continuous online and intermittent CO monitoring. However, large amount of thoracic fluid may interfere with the impedance signal making the haemodynamic data less reliable. No single method stands out or renders the others obsolete. By making CO easily measurable, these techniques should all contribute to improvement in haemodynamic management.

REFERENCES

1. Dexter L. Cardiac catheterization in the diagnosis of congenital heart disease. Bull N Y Acad Med 1950; 26: 93-102 [PMID:15409417]
2. Swan HJ, Ganz W, Forrester J, Marcus H, Diamond G, Chonette D. Catheterization of the heart in man with use of a flow-directed balloon-tipped catheter. N Engl J Med 1970; 283: 447-451 [PMID: 5434111]
3. Berton C, Cholley B (2002). Equipment review: New techniques for cardiac output measurement – oesophageal Doppler, Fick principle using carbon dioxide, and pulse contour analysis. Critical Care 2002, 6:216–221
4. Ultman JS, Bursztein S. Analysis of error in the determination of respiratory gas exchange at varying FiO2. J Appl Physiol 1981;50:210-6.
5. Prabhu M (2007). Cardiac output measurement. Anaesthesia and Intensive Care Medicine, 8:63–67
6. Connors JAF, Speroff T, Dawson NV et al (1996). The effectiveness of right heart catheterization in the initial care of critically ill patients. SUPPORT Investigators. JAMA, 276:889–897
7. Sadham JD, Hull RD, Brandt RF et al (2003). A randomized, controlled trial of the use of pulmonary artery catheters in high-risk surgical patients. New England Journal of Medicine, 348:5–14
8. Mathews L, Singh RK. Swan Ganz catheter in haemodynamic monitoring. J Anaesth Clin Pharmacol 2006;22:335-45.
9. Mehta Y, Arora D. Newer methods of cardiac output monitoring. World J Cardiol 2014; 6(9): 1022-1029
10. Linton RA, Band DM, Haire KM. A new method of measuring cardiac output in man using lithium dilution. Br J Anaesth 1993; 71: 262-266 [PMID: 8123404]
11. Garcia-Rodriguez C, Pittman J, Cassell CH, Sum-Ping J, El-Moalem H, Young C, Mark JB. Lithium dilution cardiac output measurement: a clinical assessment of central venous and peripheral venous indicator injection. Crit Care Med 2002; 30: 2199-2204 [PMID: 12394944]
12. Costa MG, Della Rocca G, Chiarandini P, Mattelig S, Pompei L, Barriga MS, Reynolds T, Cecconi M, Pietropaoli P. Continuous and intermittent cardiac output measurement in hyperdynamic conditions: pulmonary artery catheter vs. lithium dilution technique. Intensive Care Med 2008; 34: 257-263 [PMID: 17922106]
13. Hofer CK, Cecconi M, Marx G, della Rocca G. Minimally invasive haemodynamic monitoring. Eur J Anaesthesiol 2009; 26: 996-1002 [PMID: 19916204]
14. Marik PE, Cavallazzi R, Vasu T, Hirani A. Dynamic changes in arterial waveform derived variables and fluid responsive- ness in mechanically ventilated patients: a systematic review of the literature. Crit Care Med 2009; 37: 2642-2647 [PMID: 19602972 DOI: 10.1097/CCM.0b013e3181a590da]
15. Oren-Grinberg A. The PiCCO Monitor. Int Anesthesiol Clin 2010; 48: 57-85 [PMID: 20065727 DOI: 10.1097/AIA.0b013e31 81c3dc11]
16. PULSION Medical Inc. Training documents-advanced he- modynamic monitoring. 2009. Available from: URL: http: //www.pulsion.com/international-english/academy/peri- operative-haemodynamic-management
17. Giomarelli P, Biagioli B, Scolletta S. Cardiac output moni- toring by pressure recording analytical method in cardiac surgery. Eur J Cardiothorac Surg 2004; 26: 515-520 [PMID: 15302045]
18. Funk DJ, Moretti EW, Gan TJ. Minimally invasive cardiac output monitoring in the perioperative setting. Anesth Analg 2009; 108: 887-897 [PMID: 19224798 DOI: 10.1213/ane.0b013e31818ffd99]
19. Gueret G, Kiss G, Rossignol B, Bezon E, Wargnier JP, Mios- sec A, Corre O, Arvieux CC. Cardiac output measurements in off-pump coronary surgery: comparison between NICO and the Swan-Ganz catheter. Eur J Anaesthesiol 2006; 23: 848-854 [PMID: 16953944]
20. Meyer S, Todd D, Wright I, Gortner L, Reynolds G. Review article: Non-invasive assessment of cardiac output with portable continuous-wave Doppler ultrasound. Emerg Med Australas 2008; 20: 201-208 [PMID: 18400002 DOI: 10.1111/ j.1742-6723.2008.01078.x]
21. FischerMO,AvramR,CarjaliuI,etal.Non-invasivecontinuousarter- ial pressure and cardiac index monitoring with Nexfin after cardiac surgery. Br J Anaesth 2012; 109: 514 – 21
22. FischerMO,CoucoravasJ,TruongJ,etal.Assessmentofchangesin cardiac index and fluid responsiveness: a comparison of Nexfin and transpulmonary thermodilution. Acta Anaesthesiol Scand 2013; 57: 704–12
23. HofhuizenC,LansdorpB,vanderHoevenJG,SchefferGJ,LemsonJ. Validation of noninvasive pulse contour cardiac output using finger arterial pressure in cardiac surgery patients requiring fluid therapy. J Crit Care 2014; 29: 161–5
24. Bubenek-Turconi SI, Craciun M, Miclea I, Perel A. Noninvasive continuous cardiac output by the Nexfin before and after preload- modifying maneuvers: a comparison with intermittent thermodilution cardiac output. Anesth Analg 2013; 117: 366 – 72
25. Monnet X, Picard F, Lidzborski E, et al. The estimation of cardiac output by the Nexfin device is of poor reliability for tracking the effects of a fluid challenge. Crit Care 2012; 16: R212
26. Ameloot K, Van De Vijver K, Broch O, et al. Nexfin noninvasive con- tinuous hemodynamic monitoring: validation against continuous pulse contour and intermittent transpulmonary thermodilution derived cardiac output in critically ill patients. Scientific World J 2013; 2013: 519080