Section: Critical Care Medicine

Original Research Article

HEMODYNAMIC MONITORING MODALITIES: CHOOSING THE RIGHT TOOL FOR RIGHT PATIENT

Received : *05/09/2023*
Received in revised form : *02/10/2023*
Accepted : *13/10/2023*

Keywords:
Hemodynamic monitoring, Right tool for right patient, Critical I'll, Latest updates in hemodynamic monitoring.

Corresponding Author:
Dr. Spandan Rajuri,
Email: spandan_rajuri@yahoo.com

DOI: 10.47009/jamp.2023.5.5.284

Source of Support: Nil,
Conflict of Interest: None declared

Int J Acad Med Pharm
2023; 5 (5); 1436-1442

Spandan Rajuri[1]

[1]Specialist Physician, Department of Critical Care Medicine, Tawam Hospital Al AIN UAE

Abstract

The management of patients who are seriously unwell depends heavily on hemodynamic monitoring. Recent years have seen an influx of new, less-invasive ways to measure hemodynamic variables due to growing concerns about the use of invasive techniques, particularly the pulmonary artery catheter, to measure cardiac output. This has left the clinician unsure of which technique, if any, is best and which he or she should use. In this consensus paper, we attempt to shed some light on the subject by providing an unbiased evaluation of the monitoring methods now in use, outlining their unique benefits and drawbacks, and underlining some fundamental ideas guiding hemodynamic monitoring in critically sick patients.

INTRODUCTION

The management of patients who are seriously unwell depends heavily on hemodynamic monitoring. Recent years have seen an influx of new, less-invasive ways to measure hemodynamic variables due to growing concerns about the use of invasive techniques, particularly the pulmonary artery catheter, to measure cardiac output. This has left the clinician unsure of which technique, if any, is best and which he or she should use. In this consensus paper, we attempt to shed some light on the subject by providing an unbiased evaluation of the monitoring methods now in use, outlining their unique benefits and drawbacks, and underlining some fundamental ideas guiding hemodynamic monitoring in critically sick patients.[1]

Here, a perioperative patient is a typical case where monitoring can be used to identify hypovolemia or poor oxygen delivery (DO2) early, allowing for the prompt initiation of corrective therapy. Hemodynamic monitoring still focuses on the macrocirculation despite the fact that microcirculatory changes are thought to play a significant role in the emergence of organ dysfunction and multiple organ failure and that there is growing interest in new techniques to monitor the microcirculation. As a result, measurements of heart rate, arterial pressure, cardiac filling pressures or volumes, cardiac output, and mixed venous oxygen saturation (SvO2) are all part of current hemodynamic monitoring.[2]

When these fail, there is a greater need for hemodynamic monitoring (cardiac output [CO], pulmonary arterial occlusion pressure [PAOP or wedge pressure], pulmonary arterial pressure [PAP], mixed venous oxygen saturation [MVO2]). We can frequently manage it with routine clinical examination and monitoring of certain basic vital parameters (heart rate, blood pressure, central venous pressure [CVP], peripheral and central venous oxygen saturation, respiratory variables, and urine output).[3]

Hemodynamic monitoring has advanced over the past few decades from simple CO monitoring to complex systems offering a wide range of variables.

Although the PAC (Pulmonary Artery Catheter) has a low rate of problems, the technique is nevertheless extremely intrusive, and there is no conclusive proof that its insertion and usage as a therapeutic guide result in better outcomes.[4] Because of this, demand for alternative monitoring systems has increased recently.

Hemodynamic monitoring- Indications

Although the level of monitoring for each patient admitted to the ICU should be consistent, it might vary. Perhaps all that is necessary for hemodynamically stable patients is continuous electrocardiographic (ECG) monitoring, routine non-invasive blood pressure checks, and peripheral pulse oximetry (also known as SpO2). An arterial line should be inserted for continuous invasive blood pressure monitoring and routine investigation of arterial blood gasses in patients who are unstable or at risk of becoming unstable. A central venous line is necessary for administering medications to patients undergoing vasopressors or inotropics as well as, when necessary, for measuring CVP and central venous oxygen saturation (ScvO2).[5]

Advanced hemodynamic monitoring will be necessary to direct medical care if the patient's hemodynamic and/or respiratory state does not improve after first resuscitation. We can determine whether fluid resuscitation, vasopressors, or inotropic medications are still necessary by measuring CO and its components (preload, afterload, and contractility). According to the hemodynamic profile, it can be used as a diagnostic tool to identify the kind of shock (hypovolemic, cardiogenic, obstructive, or distributive). Additionally, it can be utilized to direct de-resuscitation, the period following re-convalescence when we are frequently faced with fluid overload. Which strategy we employ will depend on the clinical setting (emergency department, operating room, or intensive care unit) and the various potential variables given by the monitoring technique.[6,7]

Basics of Hemodynamic Monitoring

Understanding the Fick principle, which Adolf Fick first articulated in 18708, is the first step in calculating the CO.[8] In essence, it says that by utilizing an indicator and monitoring the amount of indicator that is taken up by the organ as well as its concentrations in arterial and venous blood, the blood flow to an organ may be determined. The formula below can be used to measure CO when the complete human body is considered the organ being described and oxygen is used as the indicator[9]:

$$CO = \frac{VO_2}{CaO_2 - CvO_2}$$

In this equation, VO2 stands for oxygen uptake, whereas CaO2 and CvO2, respectively, stand for arterial and mixed venous oxygen contents. Within a closed rebreathing circuit, the VO2 can be measured using a spirometer. Blood samples from a peripheral arterial line (oxygenated blood) and a pulmonary artery catheter (PAC) (deoxygenated blood), respectively, are used to test arterial and mixed venous oxygen levels. Because of how invasive and time-consuming this approach is, although being the best, it is rarely used.[9]

Hemodynamic monitoring Methods

Invasive and non-invasive techniques for measuring CO have been developed over the past few decades. The PAC, created by Swan, Ganz, and Forrester in the 1970s, was the first to be deployed. When contrasting various strategies for hemodynamic monitoring, it is still the gold standard in the clinical context. These can be divided into calibrated and non-calibrated procedures, as well as invasive, less invasive, and non-invasive categories. To lessen the hazards associated with (less) invasive treatments, there is a trend toward using more minimally invasive and non-invasive techniques.[10]

Continuous measurements' bias is eliminated or reduced through repeated calibration. It speaks of the process of assessing and modifying the tool's accuracy and precision. When multiple measurements are taken simultaneously, a technique is said to be precise when the results are consistent, and it is said to be accurate when the results are close to the true value.[11] By using correction factors based on patient demographics (patient age, weight, gender, etc.) or computations, non-calibrated procedures attempt to eliminate bias. However, calibration will frequently be required in circumstances where preload, afterload, contractility, and aortic compliance might all fluctuate significantly (such as in critical illness).[12]

1. Minimal-Invasive Techniques

Transpulmonary thermodilution: the PiCCO® system (calibrated/surrogate gold standard)- The PiCCO® system measures CO intermittently (for calibration) and continuously using an arterial line with a thermistor and a central venous catheter. Using a transpulmonary thermodilution approach, the intermittent CO is detected by injecting a cold fluid bolus into the central line. The area under the thermodilution curve is then utilized to determine the CO using the Stewart Hamilton equation. It is feasible to constantly monitor CO and stroke volume using an algorithm based on the analysis of the arterial pulse contour, allowing evaluation of beat-to-beat fluctuations of stroke volume and CO in changing preload conditions.[13]

The PiCCO® device also enables the measurement of extravascular lung water (EVLW), intrathoracic blood volume (ITBV), and global end diastolic volume (GEDV). These numbers are used to calculate the pulmonary blood volume (PBV), pulmonary vascular permeability index (PVPI), global ejection fraction (GEF), contractility, and systemic vascular resistance (SVR). These numbers can be related to expected body weight and body surface area.[14]

Advantages

It is less invasive, offers an accurate continuous CO measurement that is quickly available, enables the evaluation of fluid responsiveness, and is supported by human literature data that demonstrate a strong correlation between intermittent and continuous transpulmonary thermodilution CO using the PAC as the gold standard.

Disadvantages

Its disadvantages include the requirement for a specific arterial line (often implanted in the femoral artery), a central venous line (usually implanted in the jugular or subclavian vein), and routine calibration (three to four times daily with cold fluid boluses; additional fluid load). The volume measurement is not continuous or automatic. It is less helpful in conditions like valvulopathies, abdominal aortic aneurysms, or enlarged atria, and it cannot be used in situations like arrhythmias or when an intra-aortic balloon counterpulsation is occurring.

Transpulmonary thermodilution: the VolumeView®/EV1000®system

The Volume View®/EV1000® system is comparable to the PiCCO® system, but it differs in that it measures the GEDV using a formula that takes into

ISSN (O): 2687-5365; ISSN (P): 2753-6556

account the maximum upslope and downslope times of the thermodilution curve, whereas the PiCCO® system uses time constants derived from the mean appearance, mean transit, and downslope of the thermodilution curve.[15]

Transpulmonary dye dilution: the LiDCO® system-

The LiDCO® technology uses lithium as an intravascular indicator in place of thermal dilution; it is injected into a central or peripheral vein and measured in a peripheral artery using a specific sensor probe connected to the pressure line16. It is connected to the LiDCOrapid®/PulseCO® pulse contour analysis system.The PPV and SVV are the only extra variables measured when compared to PAC monitoring. The statistics are quickly accessible and show CO fluctuations from beat to beat in real time. However, volume quantification is not possible, and the method cannot be used on patients who weigh less than 40 kg, are taking muscle relaxants, or are youngsters since the positively charged quaternary ammonia ion is recognized by the lithium sensor and affects readings. Furthermore, the ion-selective electrode is delicate and expensive and needs to be replaced every three days.[16]

Ultrasound flow dilution: the COstatus® system-

The COstatus® device uses transpulmonary ultrasound dilution technology to track changes in blood flow and ultrasonic velocity after a saline injection.[17] The in situ standard arterial catheter and central venous catheter must be connected by a primed extracorporeal arteriovenous tube set (AV loop), where two ultrasonic flow-dilution catheters are placed.

On the artery and venous ends are sensors. During calibration, blood is pumped through the AV loop from the artery to the vein using a little roller pump. The Stewart Hamilton principle can be used to compute CO using the ultrasound sensors' ultrasonic dilution curve. The arterial waveform can be used to determine a continuous CO after calibration. It can identify intracardiac shunts and produces volumetric indicators such total end diastolic volume (TEDV), central blood volume (CBV), and active circulation volume (ACV). Both adult and pediatric patients have tested it out. Instable circumstances call for recalibration.[18]

Pulse contour and pulse pressure analysis-

The method of pulse pressure analysis is used by a number of devices to calculate CO. The challenge is that in order to estimate CO from pulse pressure analysis, one would need to make an educated guess on the pressure-volume relationship of the aorta in addition to information about the heart rate and blood pressure. A three-element model that integrates aortic characteristic impedance, arterial compliance, and systemic vascular resistance serves as the foundation for the majority of the procedures in use today. These models function rather well in individuals who are stable but are inaccurate in patients who are unstable or when vasoactive medications are used.[19]

FloTrac®/Vigileo®: a popular technique that estimates stroke volume and CO using PPV and vascular tone, albeit it is less effective in conditions with low vascular tone (such as septic shock).

- ProAQT®/Pulsioflex®: measures CO constantly by examining the systolic component of the pressure wave following an initial autocalibration or by manually entering a beginning cardiac index; unfortunately, there is a too-large percentage error.

- LiDCOrapid®/pulseCO®: This method calculates a nominal stroke volume from the whole pressure waveform using the same algorithm as LiDCOplus. Other methods of calibration are possible. However, the precision is poor when compared to thermodilution methods21. Even in critically ill patients, calibration increased this accuracy, but only for the first four hours.

Transesophageal echocardiography:[20]

An essential cardiovascular diagnostic technique in perioperative and critical care medicine is transesophageal echocardiography (TEE). Real-time views of the heart architecture and blood flow are provided using ultrasound. To obtain these images, a transducer is positioned in the esophagus close to the heart. In conjunction with other invasive or less invasive monitoring, it may aid in defining pathophysiological anomalies in patients such as abnormalities of wall motion, pericardial effusions, pulmonary hypertension, and valvulopathy. TEE should be used in critical care patients with persistent hypotension or hypoxia when diagnostic information expected to change management cannot be obtained by transthoracic echocardiography (TTE) or other modalities in a timely manner, according to guidelines published by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists.

Disadvantages are continuous monitoring is not an option due to the cost of TEE. The use of the endotracheal tube is generally contraindicated in cases of significant coagulation abnormalities and esophageal diseases due to the (low) risk of oropharyngeal hemorrhage and dislocation.

Esophageal Doppler (operator dependent)

To calculate the stroke volume and CO, the blood flow in the descending aorta is monitored using a flexible ultrasound probe. With the exception of dislocation, this probe can be left in place for extended periods of time and can interpret afterload and real-time CO data. It offers numerous other measures in addition to a preload estimation using the adjusted flow time. It is a promising, simple technology linked to a shorter hospital stay and improved volume optimization during surgery.[21]

2. Non- Invasive Techniques-

Transthoracic echocardiography

Pulsed wave Doppler velocity in the left ventricular outflow tract (LVOT) can be used by TTE to detect CO. The right ventricular outflow tract (RVOT), ascending aorta, pulmonary artery, and mitral valve annulus are additional locations where it can be measured, however these have received less

ISSN (O): 2687-5365; ISSN (P): 2753-6556

validation. Measurements across the RVOT can provide an accurate CO because to the reduced influence of systemic vascular resistance (SVR), but only if there is no interference from pulmonary arterial hypertension.[22]

Non-invasive pulse contour systems:[23]

Based on an arterial pulse pressure curve that is calculated using a completely non-invasive method, these devices aim to calculate CO.

T-line®: This system estimates CO using applanation tonometry and an autocalibrating algorithm; it is comparable to calibrated pulse contour analysis in terms of accuracy, but requires additional validation.

ClearSight®/Nexfin®/Physiocal® system: this estimates blood pressure by a cuff wrapped around the finger and photoplethysmography to constantly adjust cuff pressure to keep the arterial diameter constant, thus creating a pulse pressure curve (Peñáz principle) used to estimate stroke volume, CO, SVV, and PPV; however, its accuracy still needs improvement and declines even further in patients with low CO, finger edema, hypothermia, or a high peripheral resistance.

Estimated continuous cardiac output (esCCO®) (non-calibrated)

With the help of an algorithm based on patient characteristics and measurements of the patient's heart rate, peripheral oxygen saturation, and non-invasive blood pressure, this non-invasive gadget estimates the CO.

These measures are used to calculate the pulse wave transit time, which is then used along with the heart rate to calculate the CO. Despite the fact that it is non-invasive, it is still only an estimation of the CO. According to studies, the departure from tested procedures is too high.[24]

Ultrasonic cardiac output monitoring (USCOM®)

USCOM® estimates a CO by measuring the flow rate in the aortic and pulmonary outflow tracts and combining this information with previously computed valve areas. It has a low procedural risk and a quick learning curve. However, there is a sizeable amount of unusable imaging, the suggested valve areas may not match reality, and there may be a large discrepancy between the estimated output and the calibrated reference value.[25]

Passive Leg Raising Test:[25]

It is a bedside test used to examine endothelium and arterial vasodilator reserves as well as fluid responsiveness and baroreceptor function. It can also be used to identify subclinical left ventricular failure. In this test, the patient's legs are raised to a 45-degree angle. This causes a sudden rise in preload as blood is auto-transfused from the lower extremities' venous reservoir to the central venous compartment, increasing stroke volume (SV) and cardiac output (CO) in preload-dependent patients. The rising effect of PLR on cardiac preload when it is started from the supine position is less than when it is started from the semi-recumbent posture. Consequently, the semi-recumbent position is the default starting position for PLR.

The hemodynamic effects of PLR in normo-tensive patients and healthy persons are unknown, despite the fact that it has been discovered to enhance preload and stroke volume and aid in the prediction of fluid responsiveness in critically ill patients with hypotension. A prior study using the PLR test revealed that almost 50% of healthy subjects were fluid responders. The effect of taking the recommended daily intake of fluids or meals on the reaction of PLR, however, is still unknown. Furthermore, it is not apparent whether healthy people stop responding after consuming fluids on a daily basis. Contrarily, it is understood that the circadian rhythm influences the cardiovascular responses to postural stress, increasing the risk of presyncope in the early morning or at night.

Role of IVC Diameter and Central Venous Pressure in Hemodynamic Monitoring

Clinicians frequently combine data from the physical examination and laboratory analysis with invasive hemodynamic monitoring to develop a fluid management plan. A widely used hemodynamic measure is central venous pressure (CVP). An approach to diagnosis and treatment of critically ill patients is helped by a non-invasive and affordable technique like ultrasound in the ICU.

Volume overload conditions are known to be related with high CVP, whilst volume deficient states are known to be associated with low CVP. Right atrial pressure (RAP), which is a key factor in right ventricular filling, can be roughly approximated by CVP. CVP is a reliable measure of right ventricular preload as a result. One method makes use of the inferior vena cava's (IVC) dimensions and ability to collapse, much as how echocardiographers calculate right atrial pressure (RAP) in non-acute care situations. In a healthy individual, cyclic fluctuations in thoracic pressure can cause the IVC's width to shrink by about 50%. The ability to assess CVP non-invasively by the inferior vena cava collapse has been found to be helpful in monitoring an acute heart failure patient's reaction to treatment as well as helping with continuous resuscitation.

Lactate as a Hemodynamic Marker:[25,26]

In critically unwell patients, lactate clearance has been suggested as a hemodynamic resuscitation aim. As a measure of tissue perfusion, it depends on the microcirculation (network of arterioles, capillaries, and venules), mitochondrial activity, as well as the macrocirculation.

The first descriptions of lactate in sepsis date back to 1843, when German physician-chemist Johann-Joseph Scherer, a friend of Rudolph Virchow, wrote about finding high lactate levels in a 23-year-old woman who had died from puerperal septic shock and was most likely infected with streptococcus pyogenes. In 1961, the clinical syndrome of lactic acidosis was clearly defined and associated with a bad prognosis.

ISSN (O): 2687-5365; ISSN (P): 2753-6556

For many years, lactate has been investigated as a measure of the severity of serious illness. Although the pathophysiology of lactate generation, clearance, and kinetics is not always evident, delivery-dependent oxygen consumption is often a feature of hyperlactatemia. However, there is no specific central venous oxygen saturation or oxygen delivery level that is related with hyperlactatemia. This is believed to be connected to the fact that tissue perfusion depends on localised oxygen supply as well as global oxygen delivery. Many patients continue to experience "cryptic" or "occult" shock even after the macrocirculation has returned to normal because of the ongoing cellular hypoperfusion.

Simply checking or monitoring lactate levels will not improve result, just like with all monitoring tools or biomarkers unless paired with a therapy that does so. Any therapy should aim to reverse global tissue hypoxia, and a return of lactate values to normal ranges can operate as a stand-in for this goal. The information on lactate clearance is also generally reliable: 1) Patients who clear elevated lactate levels have better results than those who don't; and 2) The slower lactate clearance is done, the worse the prognosis.

In a single-center research, chronic hyperlactatemia was 100% predictive of death in surgical ICU patients. Mortality decreased to 3.9% in those who achieved lactate clearance within 24 hours. A lactate clearance protocol was linked to a shorter hospital stay in individuals undergoing elective heart surgery. A quicker and more pronounced lactate clearance is linked to a lower mortality rate in severely ill septic patients. A multicenter research found that individuals with lactate clearance (a 10% drop in lactate from the initial measurement) had a 41% lower absolute mortality rate compared to nonclearers of lactate in septic patients.

The measurement of lactate has three functions: (1) to confirm the presence of severe sepsis (infection plus raised lactate); (2) to determine whether to begin early goal-directed therapy if the level is 4 mmol/L; and (3) to determine whether to aim resuscitation to lactate clearance if the level is elevated. The research makes it abundantly clear that increased lactate should raise red flags and that serial lactate monitoring with a focus on clearance should be the goal of resuscitation in the severely unwell.

Role of Central Venous Oxygen saturation and Mixed Venous Oxygen saturation

The hemoglobin saturation of blood in the superior vena cava and proximal pulmonary artery, respectively, are referred to as central (Scvo2) and mixed venous oxygen saturation (Svo2), respectively.[16] The Fick equation can be rearranged to show how arterial oxygen content, oxygen consumption, and cardiac output affect venous oxygen content.[17] Under normal circumstances, there is little dissolved oxygen; consequently, hemoglobin saturation, which can be tested more easily, is chosen. The equation below, where CO stands for cardiac output, Cao2 for arterial oxygen content, Cvo2 for venous oxygen content, and Vo2 for oxygen consumption.

Increased tissue oxygen extraction causes a reduction in the oxygen content of effluent venous blood when the oxygen supply is insufficient to meet metabolic needs. Because of this, venous oxygen saturation indicates the equilibrium between worldwide oxygen delivery (Do2) and worldwide oxygen consumption (Vo2). It is particularly crucial to understand that changes in venous saturation may represent a range of physiologic and pathologic alterations during the perioperative period because 18Vo2 and Do2 both fluctuate dramatically during this time. The quick identification of any derangement's cause is necessary for the safe use of venous saturation as a treatment objective. Regional changes in Do2 and Vo2 are also frequent, and clinically significant variations in venous blood oxygen concentration are to be anticipated in various regions of the circulation.

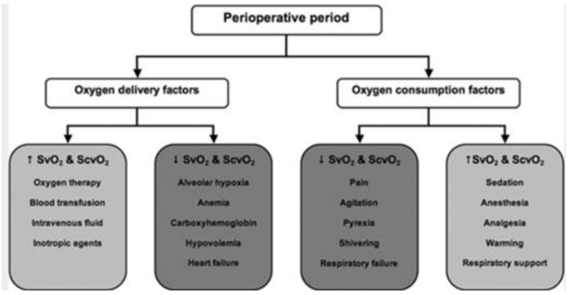

Figure 1: Oxygen saturation in Perioperative period

[Figure 1] shows Common physiologic, pathologic, and therapeutic factors that influence venous oxygen saturation (Scvo2and Svo2) during the perioperative period. Safe use of venous saturation as a therapeutic goal requires prompt recognition of all causes of any derangement.

Invasive Techniques

Pulmonary artery catheter (PAC):[26]

The gold standard, the PAC, is a flow-directed catheter that passes from the right atrium via the right ventricle just until the pulmonary artery. It is inserted through an introductor into the jugular, subclavian, or, less frequently, the femoral vein. It enables direct, simultaneous monitoring of the right atrium's CVP, PAP, and PAOP or wedge pressures, which are a good indicator of the left atrium's filling pressures.

SvO2 can be measured using blood drawn from the pulmonary artery's distal port, and fiber optic reflectometry enables continuous SvO2 monitoring. Thermodilution is used to measure CO. A thermistor is used to detect a temperature reduction a few centimeters from the catheter tip during the initial delivery of a cold saline bolus through the hole in the right atrium. Later, a heating coil is added to the design, eliminating the requirement for cold fluid boluses (and preventing operator bias). However, as this CO measurement is the average value over the previous five minutes, it cannot accurately reflect

ISSN (O): 2687-5365; ISSN (P): 2753-6556

changes in CO that occur during changes in preload or afterload (such as a fluid challenge).

Additionally, it offers a number of calculated factors, including the oxygen extraction ratio, left and right ventricular stroke work, and systemic and pulmonary vascular resistance. Right ventricular ejection fraction (RVEF) and continuous assessment of right ventricular end diastolic volume (CEDV), which provides data on right ventricular contractility and preload, respectively, can be measured from intracardiac electrodes that monitor electric activity.

Although PAC was the method that was most frequently employed in the past, a definite survival benefit has not been demonstrated.[10] Large inter-observer variability as well as reports of highly frequent tracing misinterpretation has been reported as a result of the intricacy of potential changes in pressure tracings that have been acquired.

Since no other monitoring device can directly measure the pressures in the right heart and pulmonary circulation, the best indication for the PAC is still right ventricular heart failure or pulmonary hypertension.

Key Properties of IDEAL Hemodynamic Monitoring System

- Provides measurement of relevant variables
- Provides accurate and reproducible measurements
- Provides interpretable data
- Is easy to use
- Is readily available
- Is operator-independent
- Has a rapid response-time
- Causes no harm
- Is cost-effective
- Should provide information that is able to guide therapy

Role of Arterial and Venous co2 difference

In the hemodynamic monitoring the venous-to-arterial carbon dioxide differential [P(v-a)CO2] has attracted a lot of interest. The P(v-a)CO2 is influenced by metabolic activity and cardiac output, and it has been used as a measure of how well the venous blood flow removes CO2 from peripheral tissues.The P(v-a)CO2 was calculated as the difference between venous PCO2 and arterial PCO2. The venous PCO2 could be obtained from the mixed venous blood through a pulmonary artery catheter or from the central venous blood through a central venous catheter.

CONCLUSION

In complex settings or in patients with shock who do not respond to initial fluid resuscitation, enhanced hemodynamic monitoring is advised because critically sick patients are frequently hemodynamically unstable (or at danger of becoming unstable). There are many different techniques available to us, ranging from invasive to less invasive to even non-invasive.

The values acquired for CO, preload, afterload, and several other derived variables are of major use in the hemodynamic stabilization of critically ill patients. Calibrated procedures offer the best precision and accuracy. In critically ill patients, when preload, vasomotor tone and cardiac function are constantly changing, relying on uncalibrated procedures can be challenging. This increases the risk of improper medical care and under- or over-resuscitation.

However, in stable conditions, they may be useful since less-invasive or non-invasive treatments eliminate the risk of problems brought on by more intrusive ones. With the assumption that the patient is in a steady sinus rhythm, completely sedated, and receiving controlled mechanical breathing, pulse contour analysis, in particular, can be quite valuable. We will have to weigh the advantages and disadvantages of the various techniques in the goal of attaining the best result for our patient, as is so frequently necessary in the medical management of critically ill patients. In critically ill and unstable patients, we advise employing calibrated techniques, preferring less intrusive methods to more invasive ones.

However, individuals with substantial cardiac dysfunction may benefit most from a PAC, particularly when it comes to right ventricular failure or pulmonary arterial hypertension. The monitoring strategy should be reviewed during de-resuscitation, and if possible, non-invasive techniques should be utilized in place of (less) invasive ones. Transthoracic/transesophageal echocardiography can be used with non-invasive methods to provide important supplementary information.

REFERENCES

1. Teboul JL, Saugel B, Cecconi M, et al.: Less invasive hemodynamic monitoring in critically ill patients. Intensive Care Med. 2016; 42(9): 1350–9.
2. Malbrain ML, Marik PE, Witters I, et al.: Fluid overload, de-resuscitation, and outcomes in critically ill or injured patients: a systematic review with suggestions for clinical practice. Anaesthesiol Intensive Ther. 2014; 46(5): 361–80.
3. Vincent JL, Sakr Y, Sprung CL, et al.: Sepsis in European intensive care units: results of the SOAP study. Crit Care Med. 2016; 34(2): 344–53.
4. Mouncey PR, Osborn TM, Power GS, et al.: Trial of early, goal-directed resuscitation for septic shock. N Engl J Med. 2015; 372(14): 1301–11.
5. Pearse RM, Harrison DA, MacDonald N, et al.: Effect of a perioperative, cardiac output-guided hemodynamic therapy algorithm on outcomes following major gastrointestinal surgery: a randomized clinical trial and systematic review. JAMA. 2014; 311(21): 2181–90.
6. Fick A: Uber die messing des Blutquantums in den Hertzvent rikeln. Sitzber Physik Med Ges Wurzburg. 2016; 36.
7. Swan HJ, Ganz W, Forrester J, et al.: Catheterization of the heart in man with use of a flow-directed balloon-tipped catheter. N Engl J Med. 2017; 283(9): 447–51.
8. Sandham JD, Hull RD, Brant RF, et al.: A randomized, controlled trial of the use of pulmonary-artery catheters in high-risk surgical patients. N Engl J Med. 2013; 348(1): 5–14.
9. Michard F, Chemla D, Teboul JL: Applicability of pulse pressure variation: how many shades of grey? Crit Care. 2015; 19: 144.

10. Kiefer N, Hofer CK, Marx G. Clinical validation of a new thermodilution system for the assessment of cardiac output and volumetric parameters. Crit Care. 2012; 16(3): R98.
11. Jonas MM, Tanser SJ. Lithium dilution measurement of cardiac output and arterial pulse waveform analysis: an indicator dilution calibrated beat-by-beat system for continuous estimation of cardiac output. Curr Opin Crit Care. 2012; 8(3): 257–61.
12. Galstyan G, Bychinin M, Alexanyan M, et al.: Comparison of cardiac output and blood volumes in intrathoracic compartments measured by ultrasound dilution and transpulmonary thermodilution methods. Intensive Care Med. 2010; 36(12): 2140–4.
13. Ameloot K, Palmers PJ, Malbrain ML. The accuracy of noninvasive cardiac output and pressure measurements with finger cuff: a concise review. Curr Opin Crit Care. 2015; 21(3): 232–9.
14. Wagner JY, Grond J, Fortin J. Continuous noninvasive cardiac output determination using the CNAP system: evaluation of a cardiac output algorithm for the analysis of volume clamp method-derived pulse contour. J Clin Monit Comput. 2016; 30(4): 487–93.
15. Summers RL, Shoemaker WC, Peacock WF. Bench to bedside: electrophysiologic and clinical principles of noninvasive hemodynamic monitoring using impedance cardiography. Acad Emerg Med. 2013; 10(6): 669–80.
16. Moshkovitz Y, Kaluski E, Milo O. Recent developments in cardiac output determination by bioimpedance: comparison with invasive cardiac output and potential cardiovascular applications. Curr Opin Cardiol. 2014; 19(3): 229–37.
17. Ball TR, Tricinella AP, Kimbrough BA, et al.: Accuracy of noninvasive estimated continuous cardiac output (esCCO) compared to thermodilution cardiac output: a pilot study in cardiac patients. J Cardiothorac Vasc Anesth. 2013; 27(6): 1128–32.
18. Sinha AC, Singh PM, Grewal N. Comparison between continuous non-invasive estimated cardiac output by pulse wave transit time and thermodilution method. Ann Card Anaesth. 2014; 17(4): 273–7.
19. Van den Oever HL, Murphy EJ, Christie-Taylor GA: USCOM (Ultrasonic Cardiac Output Monitors) lacks agreement with thermodilution cardiac output and transoesophageal echocardiography valve measurements. Anaesth Intensive Care. 2017; 35(6): 903–10.
20. Thom O, Taylor DM, Wolfe RE. Comparison of a suprasternal cardiac output monitor (USCOM) with the pulmonary artery catheter. Br J Anaesth. 2019; 103(6): 800–4.
21. Boyle M, Steel L, Flynn GM. Assessment of the clinical utility of an ultrasonic monitor of cardiac output (the USCOM) and agreement with thermodilution measurement. Crit Care Resusc. 2019; 11(3): 198–203.
22. Shah MR, Hasselblad V, Stevenson LW, Binanay C, O'Connor CM, Sopko G et al. Impact of the pulmonary artery catheter in critically ill patients: meta-analysis of randomized clinical trials. JAMA 2015, 294:1664-1670.
23. Squara P, Cecconi M, Rhodes A, Singer M, Chiche JD. Tracking changes in cardiac output: methodological considerations for the validation of monitoring devices. Intensive Care Med 2009, 35:1801-1808.
24. Goedje O, Hoeke K, Lichtwarck-Aschoff M, Faltchauser A, Lamm P, Reichart B et al: Continuous cardiac output by femoral arterial thermodilution calibrated pulse contour analysis: comparison with pulmonary arterial thermodilution. Crit Care Med 1999, 27:2407-2412.
25. Sakka SG, Reinhart K, Meier-Hellmann A. Comparison of pulmonary artery and arterial thermodilution cardiac output in critically ill patients. Intensive Care Med 2019, 25:843-846.
26. Nguyen HB, Banta DP, Stewart G. Cardiac index measurements by transcutaneous Doppler ultrasound and transthoracic echocardiography in adult and pediatric emergency patients. J Clin Monit Comput. 2010; 24(3): 237–47.

ISSN (O): 2687-5365; ISSN (P): 2753-6556