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# MINIMALLY INVASIVE AND NON-INVASIVE METHODS OF HEMODYNAMIC MONITORING

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**Abstract: Objective**: Evaluate recent scientific evidence on minimally invasive and non-invasive hemodynamic monitoring methods, highlighting their effectiveness, precision and clinical applicability. **Methodology**: The searches were carried out by searching the PubMed Central (PMC) database. The search terms were used in combination with the Boolean term "AND" through the following search strategy: ((hemodynamic monitoring) AND ((noninvasive) OR (noninvasive) OR (minimally invasive)). A total of 23 were selected articles to compose the present study, based on the PVO strategy (Population, Variables and Outcome). **Discussion**: Various minimally invasive and non-invasive hemodynamic monitoring techniques are discussed. Among them, Bioimpedance and Thoracic Bioreactance evaluate changes in thoracic blood volume. Photoplethysmography and Volume Clamp are optical methods for monitoring blood pressure. The ClearSight System provides continuous measurements of blood pressure and cardiac output, while ultrasound-based methods such as POCUS provide real-time data on several hemodynamic variables. Techniques such as PiCCO and PhysioFlow®Q-LinkTM use mathematical models and bioimpedance to assess cardiac output and cardiac function. Furthermore, electrocardiographic monitoring combined with infrared spectroscopy and assessment of capillary refill time provide additional insights into circulatory efficiency. These technologies represent significant advances, providing accurate monitoring with less risk to patients. **Final considerations**: It is noteworthy that non-invasive or minimally invasive hemodynamic monitoring treatments influence the prognosis of patients as they are a less aggressive approach, although further studies and technical developments are still needed to adequately replace traditional

methods.

**Keywords**: Non-invasive hemodynamic monitoring; minimally invasive hemodynamic monitoring; Hemodynamic monitoring.

## INTRODUCTION

The practice of monitoring patients in intensive care units is a fundamental pillar for the effective and safe management of individuals with critical conditions. This monitoring encompasses the continuous or consecutive assessment of physiological functions and vital signs, being essential for the early detection of changes that may precede potentially fatal scenarios (KHANNA A. K. et. al., 2019). The primary focus of monitoring lies in the analysis of blood pressure and cardiac function, crucial indicators of cardiovascular integrity (POUR-GHAZ I. et. al., 2019). Hemodynamic monitoring, whether through invasive or non-invasive methods, is essential in the management of critically ill patients, providing valuable insights that guide therapeutic approaches (PINSKY M. R. et al., 2022).

Currently, technology has allowed the advancement of non-invasive methods that facilitate the obtaining of electrocardiographic (ECG) tracings, measurement of oxygen saturation, blood pressure and monitoring of patients' physical activity in various clinical environments, expanding the monitoring spectrum beyond borders hospital (FARAGLI A. et. al., 2021). Despite the convenience of non-invasive methods, critical situations often demand the precision and reliability provided by invasive methods, such as arterial cannulation, essential in scenarios of severe hypotension, severe trauma or multiple comorbidities (POUR-GHAZ I. et. al., 2019).

The relevance of hemodynamic monitoring goes beyond mere clinical observation, playing a crucial role in improving prognoses by allowing a less aggressive and more individualized therapeutic approach, in addition to providing early detection of signs of clinical deterioration (PINSKY M. R. et al., 2022; KHANNA A. K. et. al., 2019). Based on this, this review aimed to evaluate and synthesize recent scientific evidence on minimally invasive and non-invasive methods of hemodynamic monitoring, focusing on their effectiveness, precision and clinical applicability, thus providing an in-depth understanding that can contribute to medical practice in management. of patients in critical environments.

## METHODOLOGY

This is a narrative bibliographic review developed according to the criteria of the PVO strategy, an acronym that represents: population or research problem, variables and outcome. Used to prepare the research through its guiding question: "How effective, accurate and clinically applicable are minimally invasive and non-invasive methods of hemodynamic monitoring in patients who require such monitoring?". In this sense, according to the parameters mentioned above, the population or problem of this research refers to patients who require hemodynamic monitoring, the variable would be the use of Minimally Invasive and Non-Invasive methods with the objective or outcome of evaluating their effectiveness. and accuracy and its applicability in different clinical scenarios.

The searches were carried out by searching the PubMed Central (PMC) database. The search terms were used in combination with the Boolean term "AND" through the following search strategy: ((hemodynamic monitoring) AND ((non invasive) OR (noninvasive) OR (minimally invasive)) . From this search, 637 articles were found, subsequently submitted to the selection criteria. The inclusion criteria were: articles in English and Spanish published between 2014 and 2021 and which addressed the themes proposed for this research, review-type studies, meta-analysis, observational studies and trials clinical studies, made available in full. The exclusion criteria were: duplicate articles, made available in summary form, which did not directly address the proposal studied and which did not meet the other inclusion criteria. A total of 23 articles were selected to compose the present study.

## DISCUSSION

When caring for trauma patients, it is imperative to carry out a thorough assessment of the hemodynamic status in order to rule out any possible occurrence of hemorrhage. During the initial phase of this assessment, measuring blood pressure and heart rate is a common approach to estimating potential blood loss. However, it is important to highlight that these parameters may vary due to factors such as pain, hypothermia, administration of analgesics or relaxants, as well as other elements related to the patient's condition (Kuster et al., 2015).

According to Juri T. et al. (2018), managing hemodynamic status through continuous and non-invasive monitoring of blood pressure can promote the maintenance of hemodynamic stability during an anesthetic procedure. The precision of this monitoring has been demonstrated to be clinically reliable, resulting in hemodynamic stability during surgery and a reduction in the occurrence of episodes of hypotension and hypertension during anesthesia.

In the case of patients undergoing moderate-risk abdominal surgeries, there does not appear to be any significant benefit when opting for an individualized approach using the Goal Directed Fluid Therapy (GDFT) technique with a closed-loop system, without basal infusion of crystalloids, compared to an established protocol to maintain cardiac index (CI) or systolic volume change (SVV) within predefined targets (Joosten et al., 2019).

Minimally invasive hemodynamic monitoring encompasses a set of techniques and devices that enable the assessment of a patient's cardiovascular functions in a less invasive way when compared to traditional methods, which often involve invasive surgical procedures. This approach is especially useful in clinical situations in which it is necessary to continuously monitor blood pressure, cardiac output, and other hemodynamic parameters to assess the patient's status. Additionally, this technique minimizes the risks associated with invasive monitoring, such as infections and complications related to catheter insertion. Minimally invasive monitoring is crucial for the clinical monitoring of patients in various clinical situations, such as surgical procedures, intensive care, recovery rooms and emergency units. It is important to highlight that this technique offers many advantages in terms of patient safety and comfort, however, it is imperative that healthcare professionals choose the correct method based on the patient's clinical needs and the therapeutic specifications of each technique (QUILIS A. et al., 2015).

However, before incorporating the practice of continuous and non-invasive automated monitoring, several issues and obstacles need to be addressed and resolved. These challenges encompass the validation of monitoring systems with regard to their measurement performance, the reduction of artifacts and incorrect alarms, the integration and analysis of large volumes of data, covering multiple health indicators, and technical issues related to systems connectivity. (KHANNA A. K. et. al., 2019). Effective treatment of critically ill patients is dependent on a rigorous assessment of hemodynamic status. Adequate hemodynamic monitoring can determine the type of shock, assist the doctor in choosing the best management and evaluate the patient's response to the selected treatment (ZHU G. et al., 2020).

Monitoring cardiac output (CO) is essential for critically ill patients and has evolved over the years. Former intermittent monitoring has given way to those that provide data continuously, and the medical community's attention has shifted from invasive devices to minimally or non-invasive ones (ZHU G. et al., 2020).

Thermodilution using a pulmonary artery catheter is considered the gold standard for measuring cardiac output. However, due to its invasive nature, this approach cannot be readily applied in the initial phase of emergency situations. Furthermore, this technique has notable limitations, including the fact that insertion of catheters into the pulmonary artery is a time-consuming procedure, susceptible to complications, requires extensive training, and can be challenging in severely injured patients. Furthermore, it demands a sterile intensive care environment and, sometimes, the suspension of other interventions that may be more urgent (KUSTER M. et al., 2015).

## BIOIMPEDANCE AND THORACIC BIOREACTANCE

Cardiac output is also an important clinical parameter in hemodynamic monitoring, with methods such as bioimpedance and reactance being notable. This method evaluates changes in the amount of blood in the chest, mainly in the arteries, through electrical impedance between a pair of electrodes placed on the chest wall or tracheal tube. Variations in impedance or reactance during the cardiac cycle are indicative of stroke volume and are calculated based on the patient's physical characteristics stored in the device's internal database (YAMADA T. et al., 2018). To perform hemodynamic monitoring without the need for invasive procedures, the most widely used technique is thoracic electrical bioimpedance. In this method, eleven electrodes are positioned at pre-determined points on the surface of the skin: three of them perform functions similar to electrocardiogram leads, while the other eight are arranged in pairs to cover the upper and lower regions of the chest. Each pair includes an injection electrode (which emits an alternating current of 100 kHz and 4 mA through the chest) and a detection electrode (which measures voltage variations that occur during the cardiac cycle). Each contraction of the heart ejects stroke volume into the aorta, resulting in a decrease in electrical resistance across the thorax, since electrical signals preferentially follow the course of the aorta, rather than passing through the air-filled pulmonary alveoli. Consequently, a pulsatile electrical impedance curve is captured by the sensing electrodes. This device has the ability to calculate stroke volume, which is then multiplied by heart rate to determine cardiac output (KUSTER M. et al., 2015).

According to Kuster M. et al. (2015), the bioreactance method is a modification of the thoracic electrical bioimpedance technology that is based on the analysis of the relative phase changes of an oscillating current that occurs when this current crosses the thoracic cavity. The non-invasive cardiac output monitor (NICOM) is a monitoring technology based on biological response in which the bioreactance method is used (ZHU G. et al., 2020). NICOM correlates with thermodilution and continuous cardiac output with pulse index (PiCCO), and may become a substitute for traditional invasive hemodynamic monitoring techniques (ZHU G. et al., 2020).

In terms of volume response prediction, the variation in the stroke volume index (ΔSVI) provided by NICOM can be successfully used during surgeries in which the patient is in the prone position (ZHU G. et al., 2020) . When compared to some better-known methods, NICOM can be interchangeable without any harm from a therapeutic point of view, such as ultrasound and PiCCO (ZHU G. et al., 2020). In the passive leg elevation (PPE) test, the use of NICOM can predict, to a certain extent, the volume responsiveness of patients with non-cardiogenic circulatory shock (ZHU G. et al., 2020). The reliability of its use in testing patients with lung injury or pleural effusion needs to be further studied (ZHU G. et al., 2020).

However, for patients in cardiogenic shock, NICOM is not indicated. This is due to the fact that the technique considers the alternating current that passes through the thoracic cavity, and cardiogenic shock is often accompanied by pulmonary edema, making the technology less sensitive. Patients with severe pulmonary arterial hypertension (>60 mmHg), severe aortic or tricuspid valve insufficiency may have an excessively high estimate of cardiac output when NICOM is used, making its use inappropriate in patients with congenital heart disease with complex intracardiac shunts (ZHU G. et al., 2020).

It is important to highlight that measuring cardiac output non-invasively has significant limitations. Movement artifacts, inadequate positioning of electrodes, agitation, tremors, anxiety, hyperventilation and restlessness can interfere with measurements. However, it is important to note that all of these conditions can also compromise the accuracy of measurements obtained through pulmonary artery thermodilution and most other hemodynamic monitoring techniques (KUSTER M. et al., 2015).

There are specific benefits associated with non-invasive hemodynamic monitoring devices. Among them, the continuous and real-time presentation of measurements stands out, allowing the immediate identification of signs of circulatory deterioration and contributing to clinical decisions. Another relevant aspect emphasized is the ability to apply these devices early in the emergency room. Furthermore, these devices are highly portable and convenient, which allows them to be used at the patient's bedside. They are easy to handle, providing quick use. Finally, the learning curve is relatively short, making them viable and accessible. Studies suggest that the use of non-invasive hemodynamic monitoring may be associated with shorter hospital stays in surviving patients with complex injuries (KUSTER M. et al., 2015).

According to Kuster M. et al. (2015), it has been suggested that agreement ranges of around +/- 30% must be considered acceptable when evaluating cardiac output monitoring devices, as pulmonary artery thermodilution, in itself, presents a measurement error. intrinsic value ranging from 10% to 20%. Therefore, the non-invasive cardiac output monitor proves to be an effective tool for non-invasive hemodynamic monitoring of critically ill patients (ZHU G. et al., 2020). However, despite being a non-invasive method and with no associated complications reported, it may be inaccurate in patients with chronic lung, heart or valvular diseases, as measurements may be affected (YAMADA T. et al., 2018).

## PHOTOPLETHYSMOGRAPHY

According to Hill B. L. et al. (2021), in two-thirds of intensive care unit patients and 90% of surgical patients, blood pressure (BP) is monitored non-invasively and intermittently, using a blood pressure cuff. Given the association between brief episodes of hypotension and increased morbidity and mortality, in the remaining patients at high risk, blood pressure is assessed continuously and invasively, with data obtained from recorded curves. However, invasive monitoring can lead to complications such as infections, hemorrhages and thrombosis, highlighting the need for continuous and non-invasive BP monitoring.

Currently, the reference for monitoring BP is the use of an invasive catheter, which consists of a small instrument inserted into an artery, allowing uninterrupted monitoring of blood pressure. However, this technique is highly intrusive and is associated with significant complications, such as hemorrhages, hematomas, formation of pseudoaneurysms, infections, nerve damage and distal limb ischemia, and is therefore exclusively applied to patients at a very high level of risk (HILL B. L. et al., 2021).

Devices that allow continuous and non-invasive monitoring of blood pressure are susceptible to interference resulting from the patient's movement, are expensive and exert constant pressure on the finger, which can interfere with blood flow. Furthermore, the accuracy of the device may degrade in patients with severe vasoconstriction, peripheral vascular disease or finger deformities resulting from arthritis (HILL B. L. et al., 2021).

Photoplethysmography uses an optical sensor to measure blood volume variations in peripheral arteries; these variations are then used to estimate systolic and diastolic BP measurements, obtaining the continuous waveform. Although other computational methods have been developed to predict blood pressure measurements using R-R variability, these only predict systolic/diastolic blood pressure measurements and not the actual continuous waveform. The arterial pressure waveform configuration can be used to calculate highly relevant cardiac parameters, such as stroke volume (SV), cardiac output (CO), vascular resistance and variations in pulse pressure, factors that cannot be be deduced from heart rate variability measurements alone (HILL B. L. et al., 2021).

## VOLUME CLAMP

Blood pressure assessment is generally performed using a sphygmomanometer, which is a device that measures blood pressure indirectly by inflating a cuff around the patient's arm and listening to Korotkoff sounds using a stethoscope (QUILIS A. et al., 2015). However, the "volume clamp" tool may refer to a newer, more advanced method of measuring blood pressure. The "volume clamp" technique is a non-invasive method that involves using advanced electronic devices, such as optical or impulse-based sensors, to monitor changes in blood volume in a part of the body, such as the finger or earlobe. This technique is based on the idea that blood volume varies with heartbeat, and these variations are used to determine blood pressure (YAMADA T. et al., 2018).

The main steps involved in monitoring blood pressure with the "volume clamp" tool include: a sensor is placed on the end of the patient's finger or ear, where changes in blood volume can be accurately detected, recording variations in volume blood flow that occurs with each heartbeat. This is done using technologies such as photoplethysmography, which measure changes in light absorption by blood cells. Based on information about changes in blood volume, an algorithm is used to calculate the patient's blood pressure, including systolic pressure and diastolic pressure. The biggest advantage of the "volume clamp" technique is that it offers continuous, real-time blood pressure measurement, which can be useful in situations where continuous monitoring is necessary. Additionally, it may be less uncomfortable for the patient compared to traditional blood pressure measurement with an inflatable cuff. However, it is important to note that this method can be sensitive to factors such as patient movement and sensor position, which can affect the accuracy of measurements. Therefore, healthcare professionals must be trained in the appropriate use of this technology (YAMADA T. et al., 2018).

## CLEARSIGHT SYSTEM

Although medical advances and improved management have led to a notable reduction in cardiovascular disease (CVD), these conditions remain one of the leading causes of preventable death globally (GROGAN T. et. al., 2023). The early stages of CVD, manifesting as vascular damage (endothelial dysfunction, stiffness of arterial walls and loss of vascular elasticity), are often overlooked during routine clinical assessment, which is primarily based on measurement of brachial (peripheral) blood pressure. and blood chemical parameters (GROGAN T. et. al., 2023).

More expensive and invasive tests, such as carotid ultrasound, echocardiogram, computed tomography of the coronary arteries and angiography, are generally not recommended for asymptomatic patients or those without a family history, resulting in a delayed diagnosis of asymptomatic atherosclerosis and disease progression (GROGAN T. et. al., 2023). However, it is crucial to implement non-invasive markers for the assessment of cardiovascular function in primary care, aiming to identify early vascular dysfunctions and atherosclerosis in subclinical stages (GROGAN T. et. al., 2023).

According to Grogan T. et. al. (2023), despite the introduction of 24-hour ambulatory blood pressure monitoring (ABPM), this approach continues to evaluate only peripheral blood pressure, disregarding central pressure measurements, which are critical indicators of arterial stiffness, pressure load (which can result in potential organ damage) and left ventricular hypertrophy (LVH). Pulse Wave Analysis (AOP) has been shown to be a more sensitive marker for evaluating cardiovascular function compared to arm blood pressure, in addition to being a superior indicator of cardiovascular mortality (GROGAN T. et. al., 2023).

Furthermore, intermittent assessment of blood pressure is still the norm during anesthetic procedures and surgeries (OWUSU-BEDIAKO K. et al., 2022). Continuous BP monitoring surpasses intermittent assessment and can improve clinical outcomes, particularly when caring for patients with severe comorbidities or in major surgical procedures where blood loss and hemodynamic instability are expected (OWUSU-BEDIAKO K. et al, 2022). To optimize early detection of hemodynamic compromise, several non-invasive BP devices have been developed that provide an uninterrupted reading of this parameter (OWUSU-BEDIAKO K. et al., 2022).

According to Flick M. et. al. (2022), the ClearSight System is an innovation in the medical field dedicated to the continuous measurement of blood pressure and cardiac output in a non-invasive manner, similar to the CNAP (Continuous Non-Invasive Blood Pressure) and the NICCI (Continuous Non-Invasive Cardiac Index) monitor.). These systems share the objective of enabling constant monitoring of blood pressure without resorting to invasive procedures, through the use of a cuff placed on the finger (GROGAN T. et. al., 2023).

In general, non-invasive aortic hemodynamic monitoring (NAH) devices initially measure peripheral blood pressure (BP) and then deflate the cuff. In a matter of seconds, the device starts the cuff inflation process again, starting with the recorded diastolic pressure and later reaching the suprasystolic pressure (SBP > 35 mmHg). The NAH records signals for approximately 8 to 10 seconds at both cuff pressure levels. All data obtained by NAH is transmitted wirelessly to a mobile device or personal computer, where it will be analyzed by the device's software (GROGAN T. et. al., 2023).

The NICCI device uses two digital cuffs, inflating them alternately to reduce the risk of possible ischemic injury resulting from uninterrupted inflation. The external pressure required to maintain blood flow in the fingers is quantified using infrared technology and subsequently converted into a continuous waveform on the display. In addition to incessant monitoring of blood pressure, the device can be programmed to measure or calculate other parameters related to hemodynamics, including heart rate, cardiac index, stroke volume index, stroke volume variation, pulse pressure variation, systemic vascular resistance and cardiac power index (GROGAN T. et. al., 2023).

According to Flick M. et. al. (2022), the absolute and predictive agreement between the variation in pulse pressure measured by the CNAP system and that measured invasively is moderate. According to Owusu-Bediako K. et al. (2022), clinically acceptable agreement is achieved by a mean difference (bias) of ±5 mm Hg and a standard deviation of 8 mmHg.

## BLOOD FLOW MEASUREMENT METHODS BY ULTRASOUND

Furthermore, another method used is radial artery applanation tonometry, which is a tool capable of continuously measuring tonometry calibrated with a conventional cuff. Although the first machine was invented in 1963, a major disadvantage of this machine was the difficulty of mounting the sensor, so that regular positioning and adjustments could not compensate for errors. However, when the sensor adjustment has become appropriate, a good blood pressure waveform is obtained and the system can produce continuous blood pressure and CO2 values through waveform analysis. Brief measurements are widely used in arterial observation studies. However, long-term measurement is not currently common and is not commercially distributed (YAMADA T. et al., 2018).

Pulse wave transit time (PWTT) is recognized as a valuable parameter in hemodynamics, correlated with stroke volume, blood pressure and vascular resistance. This technique uses a set of sensors, typically an electrocardiogram and a pulse wave detector — such as a pulse oximeter — and may include a cardiac recorder. Echocardiography can improve the accuracy of these measurements, and recent advances in temporal resolution, analysis algorithms, and processing power have improved the efficiency of cuff-free blood pressure measurements. However, the PWTT technique is still being improved, especially in cases of sudden change in vascular resistance, where its accuracy is challenged (YAMADA T. et al., 2018).

There are two methods of measuring blood flow by ultrasound: one that calculates systemic resistance from the difference between the end-diastolic volume and the end-systolic volume of the left ventricle, and another that determines systemic resistance from the cross-sectional area and of speed-integral time. Minimally invasive and non-invasive cardiac output monitors have been developed based on the latter method. Different sensors adapted to varying locations, such as the aortic valve or pulmonary artery, allow estimates of blood flow based on the patient's age and physical characteristics. However, the accuracy of this method may be limited by the skill of the user and the anatomy of the patient. The esophageal probe for measuring cardiac output has a small diameter and low heat emission, and although it rarely causes injuries, it requires adequate sedation for its manipulation (YAMADA T. et al., 2018).

Emerging methods for monitoring blood pressure and CO2 that utilize the relationship between systemic resistance and PWTT, such as the pulse transit method, are commercially available and in the testing phase. Although there is still a need for improvements in the accuracy of pulse delivery time, cardiac output can be monitored with conventional equipment such as electrocardiogram and pulse oximeter, without the need for special sensors or complex operational techniques. Commercial devices have incorporated advanced algorithms that analyze the shape of the pulse wave to calculate systemic resistance, using models such as Windkessel or wave reflex phenomenon principles (YAMADA T. et al., 2018).

Blood pressure waveforms can be obtained non-invasively, using a digital cuff, or minimally invasively, using a peripheral arterial catheter. In the equation that calculates cardiac output, a constant (κ), which reflects vascular compliance, is determined from a predefined database based on patient data. However, measurement errors can be amplified in patients with complex comorbidities. Parameters such as pulse pressure variation (PPV) and stroke volume variability (SVV) are used dynamically as indices of response to the fluid, assisting in its appropriate control. The risk of infection associated with arterial catheters is reported to be 1.3%, compared to 2.7% for central venous catheters (YAMADA T. et al., 2018).

## BEDSIDE ULTRASOUND (POINT-OF-CARE ULTRASOUND, POCUS)

Transpulmonary thermoregulation uses a special arterial catheter equipped with a thermistor at its tip to detect variations in blood temperature. During the procedure, a bolus of cold fluid is injected through a central venous catheter, with the temperature change being sensed by the thermistor. Cardiac output (CO) is then estimated based on the thermodilution curve, according to the Stewart-Hamilton equation. This intermittent measurement technique helps with continuous calibration of the pulse contour analysis, promoting a more accurate reading. Unlike the pulmonary artery catheter (PAC), this methodology can estimate the amount of extravascular lung water without resorting to double dilution of the indicator. However, certain conditions, such as pneumonectomy or cardiac shunts, can compromise measurements, and the thicker and longer nature of the catheter requires meticulous insertion to prevent damage (YAMADA T. et al., 2018).

The method that uses the partial CO2 ratio is based on Fick's principle, taking into account oxygen consumption and arterial and venous pressures of this gas. This technique calculates both the production of CO2 and its tension in the blood, employing a partial rebreathing circuit. This approach is not affected by vascular abnormalities or peripheral circulatory failure, focusing exclusively on gas exchange. However, severe lung pathologies can influence the accuracy of measurements, especially in cases of increased dead space/tidal volume ratio, with acute respiratory distress syndrome representing one of the main limitations of the partial CO2 rebreathing method. Additionally, variations in hemoglobin concentration may affect measurement in patients with pulmonary hypertension or increased intracranial pressure (YAMADA T. et al., 2018).

The dilution of the indicator, following the Stewart-Hamilton equation, makes it possible to measure CO using a specific dye and a corresponding detector. Detectors that do not require blood collection include arterial catheters with lithium probes and photometric sensors located at the fingertips for the detection of indocyanine green.

Furthermore, bedside ultrasound (Point-of-Care Ultrasound, POCUS) has proven to be an increasingly vital tool in hemodynamic monitoring in ICUs, including in the cardiology specialty. POCUS provides real-time data on variables such as cardiac output, peripheral vascular resistance and pulmonary function, being essential in the treatment of critically ill patients. Doppler ultrasound, in particular, makes it possible to measure blood pressure in different parts of the circulatory system and visualize the heart valves, helping to identify valve pathologies.

Finally, POCUS has application in directing invasive procedures and in the continuous assessment of cardiac function in critical situations such as sepsis, acute respiratory failure and circulatory shock. It delivers consistent information on cardiac output, contractility and intracardiac pressures, consolidating itself as a multifaceted and indispensable tool to improve the care of patients with serious cardiac conditions in ICUs. The correct interpretation of data obtained by POCUS demands in-depth clinical knowledge and solid experience to quickly identify problems and carry out informed interventions, this knowledge being crucial to raising survival standards and results in patients in intensive care (PASTORE M. C. et al., 2022).

## PICCO (PULSION MEDICAL SYSTEMS)

In critically ill patients, constant monitoring of vital signs, such as blood pressure, heart rate and peripheral oxygen saturation, is essential. Particularly in intensive care settings, additional hemodynamic variables, including cardiac output (CO) and systemic vascular resistance (SVR), are vital for assessment. Continuous hemodynamic monitoring is essential for the management of these patients, especially when using vasopressors. Although the pulmonary artery catheter (PAC) was considered the gold standard for measuring CO, due to its highly invasive nature, it is currently less commonly used. Alternatively, transpulmonary thermodilution, which employs a central venous catheter and arterial line, can be used for continuous CO monitoring. New systems also make use of minimally invasive arterial lines to provide hemodynamic data. This section discusses systems that use minimally invasive approaches to estimate CO and collect relevant hemodynamic information (POUR-GHAZ I. et. al., 2019).

One such system is PiCCO, from Pulsion Medical Systems, based in Munich, Germany, which uses the two-element Windkessel model to calculate cardiac output, stroke volume and arterial pressure wave morphology. PiCCO operates under the premise of equality between inflow and outflow, considering vascular compliance.

During systole, increased vascular pressure results in expansion and distension of the vessel, with the pressure falling and the distension being released in diastole. CO and aortic compliance are determined by transpulmonary thermodilution, while arterial pressure waveform analysis provides data on systemic pressures. Studies show that PiCCO is effective and aligns well with echocardiography in estimating CO in normothermic patients. However, its limitations include the dependence on transpulmonary thermodilution and the invasive nature of the procedure. If more distal central catheters are used, the system may fail to adequately predict cardiac function. Despite these limitations, PiCCO has proven to be very useful in the management of patients in intensive care units (ICUs), especially for early fluid resuscitation, potentially reducing mortality. Comparatively, PiCCO offers advantages in hemodynamic monitoring by combining pulse contour analysis with transpulmonary thermodilution techniques, surpassing PAC in certain aspects of the care of critically ill patients (COUTURE E. et. al., 2023); (POUR-GHAZ I. et. al., 2019).

**PHYSIOFLOW®Q-LINKTM**

For patients suffering from acute myocardial infarction (AMI), hemodynamic monitoring during and after intensive treatment is crucial, particularly because techniques such as thrombolysis or primary percutaneous coronary intervention (PCI) can induce ischemic reperfusion injury (IRI). It is essential to assess cardiac function in real time during this period. (LEWICKI L. et al., 2021). In current practice, post-MI hemodynamic monitoring includes assessment of cardiac function using echocardiography (EGC), blood pressure (BP) measurement, and transthoracic echocardiography (TTE) performed at the bedside. Methods such as three-dimensional ultrasound and magnetic resonance imaging, despite their high precision in assessing myocardial function, are restricted due to their high cost and the need for specialized professionals. Treatment guidelines do not recommend the use of invasive hemodynamic monitoring measures, such as Swan-Ganz catheterization, due to their complexity and increased risk of complications. (LEWICKI L. et al., 2021).

A viable alternative is impedance cardiography (ICG), a technique that quantifies cardiac activity. PhysioFlow®Q-LinkTM, which is based on bioimpedance, is a non-invasive hemodynamic assessment system that examines the patient's cardiovascular status. (LEWICKI L. et al., 2021).

In a single-center study, PhysioFlow®Q-LinkTM was used to analyze changes in the hemodynamic profile of patients with AMI. Results were correlated with B-type natriuretic peptide (BNP) levels and TTE measurements for a comprehensive assessment of hemodynamic changes during the perioperative period. (LEWICKI L. et al., 2021). Considering that IRI is a serious clinical indicator in patients with AMI, ICG presents itself as an effective and non-invasive tool for detailed hemodynamic monitoring during ICU stay, helping to monitor the clinical evolution of patients in the perioperative period. (LEWICKI L. et al., 2021).

**ELECTROCARDIOGRAPHIC MONITORING: INFRARED SPECTROSCOPY AND CAPILLARY RECHARGE TIME**

In the context of acute coronary syndrome, electrocardiographic (ECG) monitoring is capable of detecting significant arrhythmias, which may signal worsening of myocardial ischemia or progression to fatal arrhythmias. However, for non-acute coronary syndromes, ECG monitoring is less efficient. Likewise, pulse oximetry ($SpO_2$) monitoring, although used in emergency and intraoperative transport, has not demonstrated benefits in perioperative patients. (PINSKY M. R. et al., 2022). Infrared spectroscopy, a non-invasive method used to measure tissue saturation ($StO_2$) in the forearm, has been shown to be effective in identifying occult circulatory shock when tested in response to transient vascular occlusion. (PINSKY M. R. et al., 2022).

Capillary refill time (CRT) is a free and effective assessment technique for the patient's circulatory efficiency, being more sensitive than visual observation of spots on the skin to identify chronic venous insufficiency (CVI). Additionally, CRT is useful for evaluating recovery after resuscitation from septic shock, as well as for evaluating response to fluid bolus or vasoactive medication adjustments. In early septic shock, faster CRT is associated with less need for intervention, less organ dysfunction, and lower mortality compared to the goal of lactate normalization. Hyperlactatemia, despite being associated with several conditions, may be slower to respond to treatment than CRT and therefore less useful as an immediate prognostic indicator. Furthermore, the quest to normalize lactate can lead to unnecessary fluid overload, especially when other signs of hyperperfusion are not present. (PINSKY M. R. et al., 2022).

## FINAL CONSIDERATIONS

This review addresses the growing field of minimally invasive and non-invasive methods of hemodynamic monitoring, a critical area in modern medicine. Techniques such as Bioimpedance and Thoracic Bioreactance, Photoplethysmography, Volume Clamp, ClearSight System, and Ultrasound Blood Flow Measurement Methods, including Point-of-Care Ultrasound, POCUS, represent significant advances in the hemodynamic monitoring of patients. These technologies offer efficacy and precision and are particularly valuable for patients who require continuous monitoring of hemodynamic parameters but who may be at risk from more invasive procedures. The use of these minimally invasive and non-invasive methods has been shown to positively influence patients' prognosis, providing crucial data with less exposure to risks and complications associated with invasive techniques. The accuracy and applicability of these technologies allow for safer and less disruptive hemodynamic assessment, which is especially important in critical care settings and for patients with vulnerable conditions. The need to continue research and development in these areas is highlighted to ensure that these technologies are accessible, efficient and adaptable to diverse clinical needs. As these technologies evolve, continued improvement in patient management and outcomes is expected, while simultaneously reducing the risk of complications associated with hemodynamic monitoring.

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