Haemodynamic Monitoring During Anaesthesia

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Growing complexity of surgical and anaesthetic procedures requires a careful evaluation of the pre-operative patient status and an accurate intra-operative haemodynamic monitoring, considering the progressive increase of fragile and elderly population undergoing surgical procedures.

There are no doubts that intraoperative monitoring of heart rate, body temperature, pulse oximetry, end-tidal CO_2, depth of sedation (complicated to assess objectively through reliable tools), depth of neuromuscular blockade, systemic invasive and non-invasive blood pressure have led to increased safety in the operating room. However, anaesthesiologist's interpretation of these parameters is of great importance.

Modern monitoring system allows clinicians/anaesthesiologists to achieve therapeutic goals, minimizing complications and improving patient outcomes.

Haemodynamic monitoring is not only an alert system avoiding misunderstanding errors (passive monitoring), but also a decision-making instrument for haemodynamic disarrangement evaluation (targeted or active monitoring) which allows prompt action.

Haemodynamic monitoring is necessary for the global patient status assessment, both in the operating room and in intensive care unit.

Monitoring devices are employed in an increasingly invasive and complex steps based on clinical examination and on the patient's response to treatment. Obviously every device could lead to some adverse events (infection, bleeding, etc.).

Appropriate and early application of diagnostic information from haemodynamic monitoring has been shown to reduce mortality and to improve outcome. Data obtained by patient's monitoring are used to manage a clinical plan, according to specific algorithm like the Goal Directed Therapy strategy.

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At the bedside, in the operating room and in intensive care unit, a rapid and easy way to assess fluid responsiveness is to give fluid, called a "fluid challenge". More recently, less invasive monitoring improved the assessment of fluid responsiveness (e.g. pulse pressure variation, PPV, systolic pressure variation, SPV, stroke volume variation SVV) rather than a more invasive pulmonary artery catheter monitoring.

Monitoring system devices are getting more and more innovative, with the use of new technologies and advanced assessment devices which can lead to a better comprehension of physiological evaluation in critically ill patients.

Haemodynamic monitoring is the cornerstone of the perioperative patient status evaluation. In an unconscious patient it could offer information regarding cardiac output, fluid challenge status, organ and tissue perfusion, with indirect information about depth of sedation and pain control (hyperdynamic status).

Actually, a new challenge for the anaesthesiologist is to select the appropriate monitoring system for that specific patient in that specific setting.

There are no monitoring systems which can provide a complete evaluation of the patient haemodynamic status, at the same time. On the other hand, it does not seem adequate using several monitoring systems simultaneously.

In this chapter we will focus on different types of haemodynamic monitoring systems in the operating room setting, evaluating different diagnostic information derived from every single system and providing tools to choose the most adequate one for a specific clinical situation.

6.1 Introduction

The SIAARTI Study Group for the security in anaesthesia has developed the document called "Standards for monitoring during Anaesthesia" (ed. 2012; a next publication actually in review) dealing with the haemodynamic monitoring (cardiovascular function monitoring). In this document there are some generic information regarding:

6.1.1 Cardiovascular Assessment

Rationale: to assess an adequate cardiovascular function during anaesthesia.

1. ECG (electrocardiographic) and HR (heart rate). All patients should have a continuous ECG and HR monitoring during anaesthesia (loco-regional or general), with low and high values alarmed.
2. Arterial blood pressure (AP). All patients must have a non-invasive systolic and diastolic blood pressure monitoring, every 5 min interval or more frequent, according to the attending physician. The time of measurements will sign on medical record.
3. According to the clinical patient condition and the type of surgical procedure, the anaesthesiologist could increase the level of monitoring system, using invasive or non-invasive techniques, completed by echocardiography. Invasive arterial

blood pressure, central venous pressure, cardiac output or myocardial function parameters could be recorded.

Our challenge is to achieve the most adequate haemodynamic monitoring for a specific setting, optimizing the cardiovascular function and improving patient outcome.

Haemodynamic monitoring provides dynamic measures of cardiovascular system changes, in real time.

During anaesthesia, monitoring target is to guarantee an adequate tissue perfusion and oxygen delivery; predict and correct all causes of instability, avoiding irreversible organ failure and formulate the next step of therapy.

Different conditions could lead to haemodynamic instability: heart failure, fluid shift, hypovolemia and vascular tone modification.

In simple terms, we use dynamic measures to determine if the cardiac output (CO) is adequate or not and if it will increase with specific treatments (fluid administration, vasoactive or inotropic drugs use). Timely an adequate therapeutic strategy is started, the monitoring tool can assess the answer to therapy.

A combination of clinical examination, prior assessment of therapeutic strategy and the treatment response is often called "dynamic or functional monitoring" [1].

Haemodynamic basic measures and CO monitoring can provide information regarding the depth of anaesthesia and the pain control adequacy (ex: sudden increase in blood pressure and heart rate). Perioperative dynamic monitoring (GDT) involves the optimization of tissue oxygen delivery and allows to decrease the incidence of complications, in-hospital length of stay and mortality [2–4].

Despite improvements in technologies, at the moment there is not a haemodynamic monitoring device which can quantify/measure the whole haemodynamic patient assessment.

Many different tools are available. Every system has its own features and also limitations.

Devices which measure systemic blood pressure, heart rate and cardiac output can be extremely basic and non-invasive, but less accurate for some critical setting (ex: poor peripheral perfusion and vasoconstriction).

Minimal invasive (arterial catheter) and more invasive (central venous line and pulmonary artery catheter) devices directly allow measuring cardiac output. They can require time for positioning and lead to some complications.

Between these two categories of devices there are some monitoring systems which indirectly measure the CO and the fluid responsiveness. They can be used in less critical patients providing cardiac output monitoring, during anaesthesia.

6.1.2 Non-Invasive Arterial Blood Pressure and Heart Rate Measurement

Measuring arterial blood pressure (AP) is a cornerstone of haemodynamic assessment.

Blood pressure may be measured non-invasively with a cuff placed around a limb and attached to a sphygmomanometer or an oscillometric device. The oscillometric

device measures systolic and diastolic pressure and the mean arterial blood pressure (MAP) through an algorithm. These devices correlate with the old mercury column system. Oscillometric techniques are less accurate in patients with arrhythmia or if the limb cuff is not well positioned; too small or too tight cuff can overestimate pressure values, on the other hand too wide and too big cuff can underestimate it [5].

Despite being easy to perform, the arterial pressure and the heart rate measures are very difficult to examine. Even if a very low value of blood pressure is often matched with a tachycardia, a normal blood pressure value is not always a haemodynamic stability index [6].

Hypotension can be due to an autonomic nervous system inability to balance the decreased cardiac output and the anomalous oxygen delivery.

The degree of the hypotension value can be different according to patient age, depth of anaesthesia, anaesthetic drug effect on haemodynamic status, pain control, and patient comorbidities. Under general condition, if CO decreases, baroreceptor activity tries to increase the sympathetic tone, leading to an increase in heart rate and vascular tone to restore the mean arterial pressure. So patient could have a sudden haemodynamic instability with a low CO, before hypotension appears [7].

Arterial blood pressure alone is a late marker of haemodynamic instability; if we consider simultaneously the heart rate, we can have information of the haemodynamic status.

During low blood flow or fluid loss, HR and non-invasive AP can detect haemodynamic changes.

Recent clinical trials evaluated the accuracy of less invasive devices which can continuously monitor the non-invasive blood pressure [8] and the cardiac output measured by arterial waveform or plethysmography analysis, in the operating room during anaesthesia [9].

Clinical trials suggest that non-invasive devices with more complex algorithm have a better performance and can be used in selected cases [10].

The gold standard for the arterial blood pressure monitoring is the invasive measure, especially in patients with haemodynamic derangement, needing controlled hypotension or increased organ perfusion or multiple arterial blood gas analysis [11].

Radial artery is the most used for cannulation, because it is rapid to detect and it has lower complications. You need a 20 G artery cannula with Seldinger technique or ultrasound-guidance or direct cannulation.

Allen test can be performed to evaluate the collateral arterial circulation, but with low sensitivity. Complication of this procedure can be: thrombosis, arterial spasm, distal embolism, infection, blood loss, and accidental drug injection.

The arterial blood pressure measurement is done by a non-squeezable closed circuit with a pressure transducer which transforms mechanical pulse in electrical one, visible on monitor screen. The zero of the system is done with the transducer at atmosphere pressure, positioned at the right atrium level or at the Willis circle (surgical procedure in sitting position) [12].

6.1.3 Intravascular Catheter

Central venous catheter and especially the pulmonary artery catheter (PAC) are the most invasive system of monitoring. They provide characteristic haemodynamic information as no other system can do. PAC is inserted through a central venous access (generally right internal jugular or left subclavian vein) and air inflation into the cuff on the tip of the catheter let it sail through the right heart till the pulmonary artery.

Complications are due to attempt of venous punctures and the passage in the right heart sections. The correct positioning in a pulmonary arterial branch is confirmed by the waveform on the monitor (pulmonary capillary Wedge Pressure Waveform—Pcwp).

Although not perfect, the pulmonary artery catheter has long been considered the optimal form of haemodynamic monitoring. Recent clinical trials have not confirmed the clinical effectiveness of its use [13, 14].

However in these trials no clinical target was selected and data have been often misunderstood. It is important to emphasize that the PAC insertion did not affect patient mortality [15] and it is the unique system that can continuously monitor the cardiac output, the mixed venous oxygen saturation (SvO_2), the intra-thoracic vascular pressure and the oxygen delivery (DO_2).

Shoemaker proposed a pre-operative optimization of haemodynamic values to improve post-operative outcomes, based on DO_2 600 mL/min/m^2, haemoglobin 11 g/dL, Pcwp 12 mmHg and targeted inotropic drugs to maximize the oxygen delivery [16–19].

However elevation of DO_2 values to improve haemodynamic status is not always resolving strategy and it can also be harmful [20–22].

Assessing a peri-operative optimization, PAC has to answer the question: could cardiac output provide an adequate oxygen delivery to satisfy metabolic tissue demand? If DO_2 is inadequate, tissue oxygen extraction is increased, with a consequent SvO_2 reduction (<70%). In this setting, low SvO_2 and high intra-thoracic vascular resistances, the cardiac output detects the instability status, leading to a specific therapy. A high CO value with low MAP can show a distributive shock status. On the other hand, a low cardiac output shows: hypovolemic shock (low right atrial pressure CVP and low Pcwp), cardiogenic shock (high CVP and high Pcwp), obstructive shock (CVP > Pcwp and high main pulmonary artery pressure MPAP).

In the presence of haemodynamic instability, the key point is to determine if the cardiac output will increase with fluid administration (preload dependent patient).

The assessment of preload and fluid responsiveness is crucial also in cardiogenic shock [23].

Static pressure (CVP and Pcwp) traditionally have been used to guide fluid management, but they are a poor predictors of fluid responsiveness: low value shows a “poor fluid filling” and high value an “adequate fluid filling”.

Since they were rigorously designed, pulmonary artery occlusion pressure and central venous pressure fail to predict ventricular filling volume or fluid responsiveness, with a 50% reliability [24, 25].

The authors suggest that intra-operative or intensive care unit monitoring, with a single measurements of CVP, is not predictive of the patient's volemic status and it should not be used [26].

Even if the pulmonary artery catheter can predict the relationship between cardiac output and metabolic demand, it cannot predict the fluid challenge response.

Dynamic measures such as Stroke Volume Variation (SVV) are more accurate than static measurements for assessing fluid responsiveness in mechanically ventilated patients, during anaesthesia.

Stroke volume is the difference between the maximum and the minimum stroke volume over the main stroke volume measured at the same time, over consecutive mechanical breath. During positive pressure inspiration, the increased intra-thoracic pressure is associated with decreased venous return to the right ventricle (RV) and consequent RV cardiac output reduction (RV is preload-dependent). After 2–3 beat time, left ventricle (LV) stroke volume decreases due to reduced RV filling. These changes in LV stroke volume are most marked when a patient is hypovolemic. Given that the pulse pressure variation (PPV) varies beat-to-beat according to the SVV, PVV measure reflects the stroke volume variation [27–29].

Stroke volume variation and pulse pressure variation are specific and sensitive predictor of fluid responsiveness.

An SVV>15% in patients during mechanically ventilation with tidal volume >8 mL/kg or >10% with tidal volume 6 mL/kg predicts a fluid responsiveness [30–32].

Pulmonary artery catheter cannot quantify the SVV, and in the operating room, clinicians can use two alternative devices to get these information: pulse contour analysis (arterial waveform analysis) and oesophageal-Doppler.

6.1.3.1 Pulse Contour Analysis

Pulse contour analysis requires positioning an arterial line/catheter, generally in the radial or femoral artery. There are five devices providing continuous CO measurement using the arterial pressure waveform. Three of these systems require calibration with the thermodilution method. These monitoring tools assume that the pulse pressure is linked to the stroke volume. However this relationship is not easy and the amplitude of the differential pressure, in a specific stroke volume, depends on the aortic compliance (which has not a linear trend).

After years of study, available data seem sufficient to characterize the relationship between the pressure and the aortic compliance, but only recent technologies have allowed the construction of functional devices that use complex algorithms to analyze the pulse pressure waveform which correlates to the stroke volume. Such algorithms are needed to explain the influence of the reflected waves from the periphery, the magnitude of which is influenced by the systemic vascular resistance [33].

Different monitoring tools, with different algorithms and with or without an initial calibration, use this technology for the measurement of CO, the SVV and PPV.

6.1.4 Calibrated Systems

The more experienced calibrated device uses the transpulmonary thermodilution. A bolus of 20 mL cold saline (<8 °C) is injected into the right atrium via a venous central line and the thermal profile is registered in a central artery (femoral). This calibration method does not recommend the use of the radial artery, so the catheter must be placed in the femoral, axillary or brachial artery.

This system provides the measurement of the CO, the global end-diastolic volume (GEVD), dynamic indices (PPV and SVV). Although some studies have shown that GEDV can be superior to other pressure static measurements in predicting response to preload [34, 35] other studies have however shown a lower correlation.

However, the effectiveness of SVV and PVV in the intraoperative fluid-management has been confirmed [36]. To ensure the accuracy of the continuous measurement of CO, it is important to calibrate the system every 8 hours or if changes in clinical status occur.

An alternative method to measure the cardiac output is using the lithium dilution to calibrate this device. Unlike the transpulmonary thermodilution techniques, the dilution with lithium does not require a central line. Strictly speaking, this method uses the analysis of the pulse oscillatory power to provide continuous cardiac output data.

The analysis of the pressure waves power converts the arterial wave form into a "volume-time wave" using an autocorrelation to determine the stroke volume [37]. The analysis of the pulse power is less influenced by the reflected waves and by the variations in the transducer set-up because it is less dependent on the pulse wave form.

The system needs a catheter in the radial artery, allowing for monitoring from more conventional arterial access site. As for transpulmonary system, you can measure the CO, the PPV and SVV and the system should/must be recalibrated after 8 h.

The last calibrated device based on the pulse contour analysis is a new hemodynamic platform that uses the transpulmonary thermodilution tool for calibration. It provides the same parameters than other devices, despite its greater precision in the measurement of some pulmonary hemodynamic parameters (extravascular lung water) [38].

6.1.5 Non-Calibrated System

Among non-calibrated systems, that achieved success for their easy use, a special mention is for the system provided by a transducer, easily and quickly connectable to any arterial line already placed, allowing the measurement of CO. It does not need calibration for calculating the CO, but it is necessary to insert patient's age, height, sex and weight into the system, to determine the cardiac output from the pulse contour analysis.

Not surprisingly, in critical situations/setting, a non-calibrated system is not so reliable [39], although the third generation software shows a marked improvement in performance [40]. The measurement of SVV and PPV does not depend on accurate

calibration, but when it is used to guide the perioperative fluid administration, non-calibrated system reduces complications in major surgery [41, 42].

The second not-calibrated device records the pressure value with analytical method. It is a technique designed for the continuous CO monitoring, derived from the blood pressure without initial calibration or central venous catheterization. Therefore, the system requires only an arterial line without a dedicated pressure transducer.

The technology of this system is based on the principle that in a vessel the volume variations mainly occur due to the radial expansion of pressure variations; so alterations of the systolic portion of the area under the pressure curve reflect the stroke volume variations [43].

This technique calculates the CO by physical parameters, such as left ventricle ejection strain, arterial impedance opposing the blood flow pulsatility, arterial compliance and peripheral vascular resistances [44]. The sampling frequency of this system is 1000 Hz, compared to other methods that sample at 100 Hz. The system captures 1000 times/s, compared to other methods that capture 100 times/s. A higher sampling frequency should allow for a greater precision of the measured data (CO, SVV, PPV and SVR).

Overall, these devices are very effective in predicting the preload responsiveness and protocols guided by SVV or PVV for the haemodynamic optimization, all lead to improvements in surgical outcome [45, 46].

However, it is important to remember that the SVV and PPV require the chest to be closed, to predict the preload responsiveness, although the one-lung ventilation in thoracic surgery does not compromise the predictive ability of these techniques [47].

The presence of arrhythmias or atrial fibrillation is a bias in the measurement of SVV and PPV; in fact, they seem to be a result of cyclical changes in the ventricular filling, rather than a cyclical changes due to mechanical ventilation. In these situations, the dynamic indices/parameters are unable to predict the preload/fluid responsiveness. Unlike non-calibrated systems, calibrated monitoring tool provides CO measurements that correlate with PAC measures [48, 49].

6.1.6 Oesophageal Doppler

The oesophageal Doppler is an alternative technique capable of measuring the SVV and CO. The Doppler can measure the blood velocity in the descending aorta, which can be converted into a volume, if the aortic diameter is measured. Some devices use nomograms based on patient's age, height and weight, while others use 2D ultrasound to measure the aortic diameter. The small ultrasound probe is

advanced into the oesophagus of the anesthetized patient until mid-oesophageal level.

The waveform profile will indicate the correct position and orientation of the probe.

The variations of the Doppler-waveform during the ventilatory cycle can be used to determine the SVV, with the same value/meaning of that derived from the pulse contour analysis. Despite the sampling corner that may affect the measurement of CO, the Stroke Volume Variation will be able to predict the fluid response. Optimization strategies based on SVV measurements with oesophageal Doppler led to improved surgical outcomes, in a wide variety of procedures [50, 51].

6.1.7 Totally Non-Invasive Systems

A completely non-invasive system, providing a continuous cardiac output (CCO) measures, uses an inflatable cuff put on the patient's finger to measure the blood pressure and to determine the stroke volume through the systolic single-beat pulse, calculated on impedance. Some authors [52] have shown how this system provides a reliable method, when compared to invasive systems for the determination of cardiac output, absolutely to prefer in specific clinical setting (ex. Intermediate-risk pregnant).

Another non-invasive monitoring system is the plethysmographic variability index (PVI) used as a continuous measure of vascular reactivity volume, with the highest values corresponding to a greater reactivity. The examination of the plethysmographic trace, using a modified pulsossimetric probe, allows the determination of the perfusion index. The perfusion index (PI) is a numerical value determined by the strength of the detected infrared signal. The signal strength correlates with the amount of volume at the sampling site. Changes in that index may indicate regional changes of volume status.

It has been suggested as a non-invasive monitoring to evaluate the fluid responsiveness and as a measure of the volemic status, continuously sampled in the low output state, in severe peripheral vascular disease or in spontaneous ventilation. (Pleth Variability Index (PVI)% = $[(PI_{max} - PI_{min})/PI_{max}] \times 100\%$) [53, 54].

6.2 $EtCO_2$

Even often forgotten as a hemodynamic monitoring, the measurement of carbon dioxide at the end of exhalation ($EtCO_2$) represents a simple and effective haemodynamic monitoring. It is ubiquitously present as monitoring in all operating rooms. This parameter is normally used to ensure an adequate minute ventilation, but a change in the $EtCO_2$ without a corresponding change in the minute-ventilation implies a change in the pulmonary/lung hemodynamic status. An unexplained fall in $EtCO_2$ represents an increase of dead space as occurs in pulmonary embolism [55]. Therefore a reduction of $EtCO_2$, not explained by an increase in minute-ventilation should guide to a prompt assessment of the hemodynamic status.

On the contrary, an unexplained increase in $EtCO_2$ implies an increase in the transport of CO_2 to the lungs. This could occur as a result of the development of distributive shock in early sepsis.

6.2.1 Electrical Impedance Cardiography

This technology assumes that the impedance (or resistance) to a current flowing through a conductor is related to the volume of the conductor itself [56]. Impedance variations result in volume changes, therefore, applying a constant current through the thorax, we can determine the voltage variability through lower resistance way, determined by the great vessels in the thorax and to obtain information regarding the modification of their volume.

This volume variation in the thoracic aorta can be converted into stroke volume by impedance wave-form analysis, using a similar algorithm of/as the pulse contour. However, many problems have to be solved to make this technology useful in the operating room.

6.2.1.1 Bio-Reactance-Based Non-Invasive Monitoring

To overcome the limitations of a bio-impedance systems, alternative methods have been developed.

The Bio-reactance system is based on the analysis of relative phase shifts (frequency modulation) which occurs when an oscillating current goes through the thorax, by detecting the pulsatile flow, rather than the fluid volume in the chest, resulting in a better signal.

A receiving amplifier records the transthoracic voltage in response to the injected current and circuitry for determining the relative phase shift from which the stroke volume, heart rate and CO are derived. Signals are applied to and recorded from the left and the right sides of the thorax and these signals are processed separately and averaged after digital processing.

Recent studies evaluated the accuracy and reliability of this system compared to PAC for CO monitoring, also in the variations over time and in CO changes induced by passive leg raising [57–59].

Recently, the system was also validated in surgery [60], but data are still not consistent to draw conclusions.

6.2.2 Ultrasound

The transthoracic echocardiography easily allows to identify a pericardial or pleural effusion, to assess volume status, to assess right and left ventricles contractility and the presence of hypokinesia caused by ischemia, to identify any valve abnormalities or obstructive heart failure which lead to hemodynamic impairment. With more experience, clinicians can make a general assessment of the ejection fraction and the volume status.

It is a perioperative diagnostic system rather that an intraoperative monitoring tool. Nevertheless, the evaluation of the inferior vena cava (ICV) has been used, even during anaesthesia, as a measure of volume status and as a predictor of preload responsiveness.

The diameter of the ICV can be easily measured; measures less than 2 cm, with a greater inspiratory collapse of 50% are related to intravascular volume depletion, while measures greater than 2 cm, with a less than 50% inspiratory collapse suggest an adequate volume or the inability of the right heart to accept further volume [61].

A transient and reversible increase in preload (passive leg raising), demonstrated by the distensibility of the ICV, can be used as a surrogate of a fluid challenge. (Distensibility Index (DI): $(ICV_{max} - ICV_{min})/ICV_{(max)} = DI\% \times 100$).

A DI> 18% identifies patients responding to fluids challenge with a sensitivity and specificity of 90% [62].

Some limitations related to the echocardiographic technique include: the inability to obtain adequate projections because of patient habitus or positioning and because of the operator skills.

Transesophageal echocardiography (TEE) is not a conventional monitoring device. It needs to be performed by an experienced sonographer and it may require a specialized cardiologist evaluation.

A standard TEE examination is based on 20 tomograms for the assessment of the global ventricular function, the volume status, the valve evaluation, the aorta vessel, the pericardium and the pleura evaluation [63].

TEE assessment is crucial for routine intraoperative monitoring in cardiac surgery and it should be also used in high-risk patient with hemodynamic instability and undiagnosed pathology. However, the use of TEE may change with the routine use of a miniaturized transesophageal probe [64] which allows left ventricular function and filling status assessment, through the trans-gastric left ventricle short axis.

6.2.2.1 Goal-Directed Therapy

The Goal-directed therapy (GDT) is a strategy of hemodynamic management. This term describes a potentially effective method to determine the optimal dose of fluid-therapy, vasopressors and inotropic drugs to use. It is based on clinical algorithms to optimize the cardiac output (CO) and the tissue oxygen delivery, avoiding tissue hypoperfusion.

This setting involves the use of more-invasive or less-invasive hemodynamic monitoring, according to the severity of patient condition and the complexity and duration of surgical procedures. The main reason to perform this approach (targeted-therapy and target-control) is that it can improve outcomes in terms of survival and quality of life, as evidenced by recent meta-analysis [4] and by studies examining long-term complications [65].

The importance of perioperative hemodynamic optimization has increased over the past decade and it has developed with the evolution of hemodynamic monitoring technologies [66], relegating the use of pulmonary artery catheter only in cardiac surgery and rarely to high-risk patients. From the over-physiological hemodynamic targets (CO and DO_2) we moved to the evaluation of the so-called functional hemodynamic monitoring parameters (SVV, PPV)[1], although recently a meta-analysis showed doubts related to the GDT with targeted-DO_2 [67].

A recent meta-analysis has enrolled adult patients undergoing non-cardiac surgery (elective or emergency surgery) managed with intra-operative Gold Directed-Therapy and with an algorithm of post-operative GDT. It showed benefits in terms of complications and mortality [68].

Conclusions

There are several devices for hemodynamic monitoring in anaesthesia.

In low risk surgery, when brief cases without blood loss are scheduled, monitoring of non-invasive blood pressure, heart rate and $EtCO_2$ will be able to provide sufficient data to diagnose an unexpected hemodynamic instability. In high-risk patients or in intermediate-risk surgery it may be sufficient the SVV monitoring to guide the hemodynamic optimization and the patient's preload management. In major and complex surgical procedures, where "mixed shock" can occur (for example in abdominal emergency surgery or in a patient with pre-existing cardiomyopathy or valve disease or pulmonary hypertension), complete and more invasive hemodynamic assessment must be performed with a calibrated device for the cardiac output measurement or a combined PAC with an SVV measuring tool.

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