(*Acta Anaesth. Belg., 2021, 72, 63-71*)

Intraoperative management and hemodynamic monitoring for major abdominal surgery : a narrative review

A. Russo, B. Romanò

Abstract : *Background :* Several trials suggest that postoperative outcomes may be improved by the use of hemodynamic monitoring, but a survey by the American Society of Anesthesiologists (ASA) and the European Society of Anaesthesiology (ESA) showed that cardiac output is monitored by only 34% of ASA and ESA respondents and central venous pressure is monitored by 73% of ASA respondents and 84% of ESA respondents. Moreover, 86.5% of ASA respondents and 98.1% of ESA respondents believe that their current hemodynamic management could be improved (1). The interaction of general anesthesia and surgical stress is the main problem and the leading cause for postoperative morbidity and mortality. The choice of a suitable hemodynamic monitoring system for patients at high anesthesiological risk is of crucial importance to reduce the incidence of major postoperative complications. The aim of the present review is to summarize the benefits of a defined path beginning before surgery, and discuss the available evidence supporting the efficacy and safety of an individualized hemodynamic approach for major abdominal surgery.

Objective : To evaluate the clinical effectiveness of a perioperative hemodynamic therapy algorithm in high risk patients

Keywords : Hemodynamic monitoring system ; major abdominal surgery ; stroke volume variation ; pulse pressure variation ; cardiac output ; arterial elastance ; gap $C0_2$ and SvO_2

Introduction

Over the years surgical procedures have become increasingly complex and lengthy. Therefore, when elderly patients are scheduled for these operations, the rate of postoperative complications and death may greatly increase. So, an important first step is the recognition and stratification of the patient-related risk. In this regard, Bland RD et al. were among the first researchers who adopted the combination of hemodynamic and oxygen transport parameters as targets during surgery. They found a correlation between these parameters and outcome (2). As a matter of fact, the identification and treatment of additional correctable problems (i.e. anemia and electrolyte disturbances) is fundamental for a successful anesthesia. The choice of the type of monitoring system necessary for a patient is guided primarily by the patient-related risk (i.e comorbidities) as well as the complexity of the proposed surgical procedure. Nowadays, a standard monitoring during surgery for low-risk patients is based on the recording of non-invasive blood pressure, heart rate by electrocardiographic tracing, peripheral oxygen saturation, depth of anesthesia (DOA) monitoring and capnometry. However, when patient- and surgery-related risks increase, an adequate and more accurate hemodynamic monitoring system should be taken into account. Moreover, the prediction or a prompt intervention to counter perioperative hemodynamic instability episodes, by achieving predefined goals, could help anesthesiologists improve postoperative outcomes.

A. Russo, B. Romanò

Department of Anesthesiology and Intensive Care Medicine, Catholic University of the Sacred Heart, Fondazione Policlinico Universitario A. Gemelli, IRCCS, Roma, Italy.

Corresponding author : Bruno Romano', M.D.

Department of Anesthesiology and Intensive Care Medicine, Catholic University of the Sacred Heart, Fondazione Policlinico Universitario A. Gemelli, IRCCS, Largo Agostino Gemelli, 8, 00168 Roma, Italy. Phone : 0039 3474534567. Email : bruno.romano@policlinicogemelli.it

Funding Sources: None
Conflict of Interest: none
Role of Sponsor: NA
Prior Presentation: There is no prior presentation of this work.
Acknowledgements: None

> KEY STEPS – STAR method
>
> • Stratification: use of preoperative score to recognize high-risk surgical patients and estimate the postoperative rate of adverse events
> • Targets and Tools: implementation of adequate hemodynamic monitoring system based on a tailored goal-oriented protocol
> • Action: use of drugs and/or fluids to treat episodes of hemodynamic instability
> • Results: evaluation whether hemodynamic and metabolic endpoints have been achieved

Stratification of patients

Preoperative evaluation is a crucial step in the assessment of patients at high risk of cardiac adverse events, which account for about 80% of overall deaths (3, 4). An accurate cardiac risk prediction can help physicians in the decision making process. Furthermore, tailored intraoperative management and identification of patients requiring a more in-depth intraoperative monitoring are often useful. Tarhan et al. were the first to show that postponing surgery in those patients with recent myocardial infarction could reduce the rate of postoperative myocardial ischemia from 37% to about 5% (5). Therefore, identifying these subsets of patients who need more accurate treatments and intraoperative management can potentially improve outcomes (6, 7). In this regard, various preoperative scores are available to anesthesiologists for surgical risk stratification; the most commonly used are the American Society of Anesthesiologists' Physical Status (ASA-PS) classification, and the Revised Cardiac Risk Index (RCRI). ASA-PS has been shown to have an independent association with postoperative morbidity and mortality (8, 9), although it is limited to lower rather than higher mortality settings (10). In addition, the class assignment is independent of the surgical procedure and is based on the patient's overall health status.

The RCRI is widely used to predict major adverse cardiovascular events (MACE) in the context of non-cardiac surgery (11), however, it has a limited predictive performance in the vascular surgical population. High-risk surgery, ischemic heart disease, congestive heart failure, cerebrovascular disease, preoperative treatment with insulin and preoperative serum creatinine above 2 mg/dl are the six independent predictors included in this score. In patients with elevated risk (RCRI ≥1, age ≥65, or age 45-64 with significant cardiovascular disease), the score helps direct further preoperative risk stratification (e.g. with serum NT-proBNP or BNP) and determine appropriate cardiac monitoring post-op (EKG, troponins). The Physiological and Operative Severity Score for the enUmeration of Mortality and morbidity (POSSUM) assesses morbidity and mortality for general surgery and can be used for both emergency and elective surgery. The physiological score should be calculated at the time of surgery, not at the time of admission. The POSSUM score Is a "widely validated" measure (12, 13) but includes a number of risk factors collected at discharge (e.g., operative blood loss and the presence of malignancy) that precludes its preoperative use. Traditionally, the risk associated with different types of surgery has been determined by observing the rate of outcome events after each type of surgery. However, this approach does not determine how much of the event rate is due to the surgery itself, and how much is due to the medical comorbidities of the patients undergoing the surgery.

ACS-NSQIP is a free online calculator, used for a postoperative risk assessment, which also includes patient-centered outcome variables such as readmission rate and non-home discharge (14). According to the recent American College of Cardiology and American Heart Association guidelines, this score provides a good estimate of surgery-specific risk of MACE or death (15). Two limits have emerged for ACS-NSQIP: a lack of an external validation by multicenter studies outside the United States and the requirement of internet connectivity. Once the high-risk patient is identified, a Goal-Directed Fluid Therapy (GDFT) should be strongly recommended, because it is likely to have the greatest benefit in terms or morbidity and mortality if implemented early (16). While this targeted approach seems to be safer than liberal fluid administration, its superiority over a restrictive regimen aiming at zero-balance is still subject to debate. In a matched-controlled study, a guided hemodynamic protocol has proven to be favorable for a subgroup of patients with low surgical risk but a consistent tumor load undergoing very extensive surgery (17). High-risk cases are likely to benefit from advanced monitoring. The cut off between those patients at high or low risk frequently depends on the cost and complexity of providing treatment to correct the risk, rather than on the risk itself.

Probably it depends on the following parameters: duration of surgery, blood loss, open vs laparoscopy and patient morbidities.

Risk is a composite of patient features (age, comorbidities) and type of surgery, qnd while scores can help to assess risk, good scores are rare. Hence, matching the ASA grade of the patient and

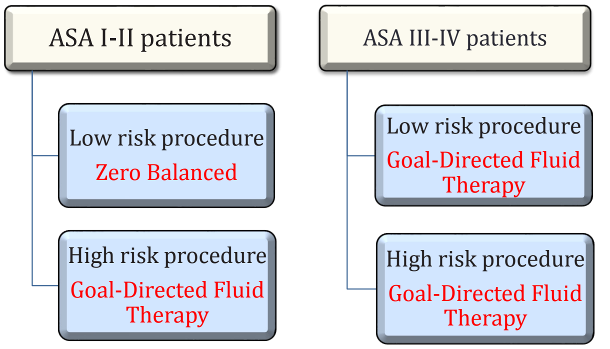

Figure 1. — Matching the monitor needs for the surgery-related risk. For major procedures and for high-risk patients a hemodynamic tailored protocol based on dynamic indices and or Cardiac Output monitoring is recommended.

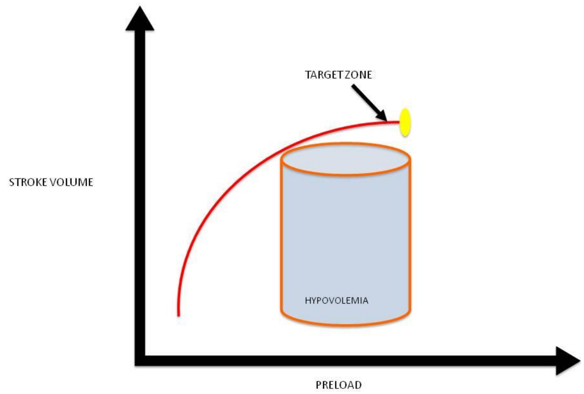

Figure 2. — Frank-Starling Curve and the hemodynamic optimization target.

the surgical risk can help anesthesiologists in the planning of the right approach (Figure 1). Then, a hemodynamic monitoring system should be chosen as well as the flow- and pressure-related target.

Targets and Tools

Impairment of tissue perfusion and cellular oxygen debt are probably the leading cause of perioperative complications and poor outcomes (18, 19). The peripheral arterial oxygen saturation (SpO_2), blood pressure (both invasive and non) and heart rate are simple and essential diagnostic tools, but unsuitable for the discrimination a stable versus unstable patient. Indeed, these basic hemodynamic parameters still may be in a normal range in a pre-shock status, because of the compensatory reflex mechanisms that preserve blood flow and organ perfusion. An unanswered question in hemodynamic support is what the optimal level of tissue perfusion may be. To prevent tissue hypoperfusion, target-oriented protocols have proven to improve outcomes (20). More than 20 years ago, Shoemaker WC observed that in 708 high-risk surgical patients the survivors had greater postoperative increase in Cardiac Index (CI), Delivery of Oxygen (DO_2), Oxygen Consumption (VO_2) and other flow-related variables than the nonsurvivors (21). Later, a large number of studies have been conducted to clarify the real need of measuring oxygen transport parameters.

Considering the formula $DO_2 = 10 \times CO \times CaO_2$, the *cardiac output* and the *Oxygen Content* (CaO_2, the arterial quantity of O_2) represent the physiological pillars of hemodynamics.

Cardiac Output (CO)

Cardiac performance is the ability of the heart to pump blood into arteries and is expressed as cardiac output per unit time or as stroke volume per heartbeat. Heart rate as well as preload and afterload can modulate its value. Indeed, CO is equal to the product of Stroke Volume (SV) and Heart Rate (HR) as follows : $CO = SV \times HR$. Hence, CO can be normalized through a proper fluid management aiming at SV optimization. This concept of preload dependence/independence is described by the Frank-Starling curve (Figure 2).

In the past, cardiac output was measured by pulmonary artery catheter (PAC) because of the absence of non-invasive technologies (22). PAC is used to obtain haemodynamic parameters which, together with clinical observations, indicate how efficiently the heart is functioning. Right pulmonary systolic and diastolic pressures (PAP), Pulmonary Artery Wedge Pressure (PAWP), Cardiac Index (CI), Systemic and Pulmonary Vascular Resistance (SVR & PVR), core body temperature, and mixed venous oxygen saturation can all be assessed. Because of its invasiveness, however, limited applications still remain to particular settings such as shock states, multiorgan failure, cardiac surgery, liver transplantation and ICU patients. Nowadays, the technique of arterial waveform analysis has largely replaced the use of the PAC, as it is a minimally invasive tool providing continuous detailed hemodynamic data in real time.

Several authors have investigated the association between the CO-target fluid therapy by the use of esophageal doppler (TED) and post-operative endpoints in order to optimize fluid administration (23, 24). They demonstrated the superiority of a CO-oriented fluid therapy compared to the conventional parameters such as arterial blood pressure, central venous pressure, heart rate and urine output. TED has proven to be in agreement, but not interchangeable, with the gold standard PAC for pulmonary catheter-CO measurement, with a low mean bias (25).Transesophageal Doppler (TED) and transesophageal echocardiography (TEE) can provide immediate point-of-care evaluation of sudden hemodynamic fluctuations during surgery. Echocardiography is useful for monitoring purposes, including probe placement, real-time 2-dimensional image acquisition and interpretation for continuous asessment of (dynamically changing) cardiac pump function and may also provide real-time assessment of therapeutic measures.

TEE is used mostly in the perioperative time of cardiac surgery, when the patient's condition requires repetitive evaluation of cardiac function in order to guide ongoing management or to guide surgical interventions (e.g., myocardial re-vascularization, valvular competence and repair of congenital hearts defects) and to guide therapy and/or fluid administration. Intraoperative TEE monitoring is typically indicated in patients with histories of congestive heart failure, severe ischemic heart disease, aortic aneurysm, major trauma and burns, among other conditions.

Fluid responsiveness and Dynamic indices

Hypovolemia as well as overhydration are associated with poor outcomes and morbidity rate; a U-shaped curve describes this relationship (26). The debate is still open: Is a fluid challenge always the answer?

Basically, euvolemia is a state of fluid volume that allows adequate filling of the heart chambers and vascular bed to produce a cardiac output to meet oxygen demands of the cells. Fluid responsiveness is the ability of the heart to respond to alterations in filling 1volume by modifying stroke volume. But when patients are at the flat portion of the Frank-Starling curve, a fluid challenge is not required, and only hemodynamic monitoring identifies the position of such patients on the curve. Static and dynamic variables can be used to assess fluid responsiveness (Table 1) ; among these, numerous reports documented the superiority of dynamic indices in discriminating responders from non-responders.

Traditionally fluid responsiveness is defined as an increase in cardiac output of at least 10 to 15% after a fluid bolus.

In mechanically ventilated patients, according to the Frank-Starling mechanism, cyclic changes of blood flow through the vena cava, pulmonary artery and aorta produce variations in SV and arterial pulse pressure (PP). These dynamic changes due to the heart-lung interaction become the basis of the so-called dynamic variables (Stroke Volume Variation, SVV and Pulse Pressure Variation, PPV) that can predict fluid responsiveness more accurately than traditional static parameters (i.e. Central Venous Pressure, CVP). When volume optimization is achieved by using these dynamic indices, hemo-dynamic stability, as well as the reduction of postoperative complications, are obtained (27). Interestingly, a recent metanalysis found that the combination of multiple goals was associated with a significant improvement in postoperative clinical outcomes (28). Despite the growing number of clinical studies demonstrating the efficacy of GDT, a recent survey showed that a minority of anesthesiologists use a target fluid therapy in high-risk surgical patients (29).

Table 1.

Variables and tests for fluid responsiveness assessement

Central Venous Pressure (CVP)
Pulmonary Artery Occlusion Pressure (PAOP)
Passive Leg Raising (PLR)
Inferior Vena Cava Diameter Variation (IVC)
Stroke Volume Variation (SVV)
Pulse Pressure Variation (PPV)
Systolic Pressure Variation (SPV)
Plethymographic Variability Index (PVI)
End-Expiratory Occlusion test (EEO)

However, some limitations exist, mainly due to heterogeneity among protocols in which different targets and interventions are described and different surgical settings as well as the small number of enrolled patients. On the other hand, it is not clear yet what the right threshold for SVV and PPV discriminating a fluid-responder from a nonfluid-responder patient is; probably a grey zone (from 10% to 15%) should be investigated. Furthermore, accuracy and validation of these variables is related to various conditions: sinus cardiac rhythm and mechanical ventilation with a tidal volume of at least 8 ml/kg. Besides, vascular tone as well as high doses of vasoactive drugs, which impact on LV filling and emptying, could alter SVV and PPV by modifying the equilibrium between stressed and unstressed volume. The unstressed volume, which does not contribute to cardiac output, just keeps the vessels at their minimally open position, while the stressed volume exerts pressure against the walls of the vessel. Norepinephrine bolus or its infusion leads to a recruitment of splanchnic blood, pushing it towards the heart, with a corresponding increase of venous return and RV output. The RV has a “permissive” function. It lowers the outflow pressure and allows veins to empty. On the other hand, the LV only can pump out what the RV gives it; increasing venous return by recruitment implies a reduction or both SVV and PPV. The passive leg raising test is another way to estimate fluid responsiveness: an increase in stroke volume provoked by an endogenous preload challenge as the patient position changes predicts a positive response to fluids.

Conversely, venodilators could cause an increase in SVV and PPV by reducing venous return and increasing redistribution of circulating blood.

During echocardiographic assessment, several indices can be used to evaluate fluid responsiveness. The size of the ventricular chambers can be used as a gauge of response to fluids. Fluid responders usually have smaller left ventricles than non-responders: response to fluids is often observed in patients with very small ventricular cavities, especially when associated with kissing papillary muscles, whereas it is unlikely in patients with dilated left or right ventricles.

Another way to assess fluid responsiveness is to evaluate central venous pressure (CVP), which can be estimated using echocardiography (30). Several indices, such as maximal IVC diameter, respiratory variations in IVC diameter, or a combination of the two, have been used to evaluate CVP. Unfortunately, as with invasive measurements of CVP, maximal or minimal IVC diameters fail to predict fluid responsiveness. Of greater interest, respiratory variations in superior vena cava diameter can predict the response to fluids with excellent specificity and sensitivity. This approach is feasible only using transesophageal echocardiography in mechanically ventilated patients (31).

Stroke volume variation and its surrogates have been shown to predict fluid responsiveness. Stroke volume can be detected and measured with a pulsed-wave Doppler reading positioned in the left ventricular outflow tract area. As left ventricular outflow tract dimensions do not change, changes in velocity-time integral (VTI) can be used to evaluate variations in stroke volume. Respiratory variations should be measured over one respiratory cycle, beginning at inspiration, and three measurements should be averaged. Respiratory variations in VTI predict fluid responsiveness in ventilated patients, at a threshold of 20% (32).

These methods, nevertheless, have several limitations. In addition to the technical limitations related to echocardiography (angle of the probe), there are also several limitations related to factors influencing stroke volume variation. The patient needs to be ventilated with a tidal volume of at least 8 ml/kg and should not have arrhythmias or increased abdominal pressure. False positives may be observed in patients with right ventricular failure, but this factor is easily detected by echocardiography. Evaluation of respiratory variations in flow is, therefore, a convenient way to predict fluid responsiveness in patients receiving mechanical ventilation provided that certain prerequisites are met.

Mean Arterial Pressure and Arterial Elastance

Mean Arterial Pressure (MAP) is one of the hemodynamic targets used to ensure an adequate perfusion pressure and organ blood flow. This variable depends on the product of cardiac output (CO) and systemic vascular resistance (SVR). In most surgical patients, several hypotensive episodes can be encountered, even shortly after anesthesia induction (33, 34). Currently, anesthesiologists treat arterial hypotension as necessary when it occurs by administration of vasoactive drugs. The right threshold value of MAP is still under debate, although most authors have chosen 60 to 65 mmHg as targets. Increasing MAP leads to higher perfusion pressure within the autoregulatory zone. In patients suffering from chronic hypertension the renal autoregulatory mechanism is altered and its lower limit is higher, therefore they may need a higher MAP resuscitation target. However, if a central venous catheter is placed, in addition to CO-derived monitoring, the decision to use vasoconstrictors could be based on vascular resistances.

An increase in the circulating volume could also be obtained by increasing pressure through vasoactive agents (i.e. *CO = MAP – CVP /Systemic Vascular Resistance*); conversely, it is possible to increase blood pressure by fluid challenge. However, knowing that both blood pressure and flow are not constant but oscillatory, SVR does not adequately assess the arterial load. At this point, an additional physiological parameter should be mentioned: arterial elastance (Ea). Arterial elastance (Ea) is a functional measurement of the *vascular tone*. As shown in Figure 3, a patient could be classified as a probable fluid responder according to a high level of SVV, but a fluid challenge will only work if vessel compliance is low. Dynamic arterial elastance (Eadyn), defined as the *ratio between pulse pressure variations and stroke volume variations*, has been proposed to assess functional afterload. It predicts the arterial pressure response after fluid administration in hypotensive, preload-dependent patients (35).

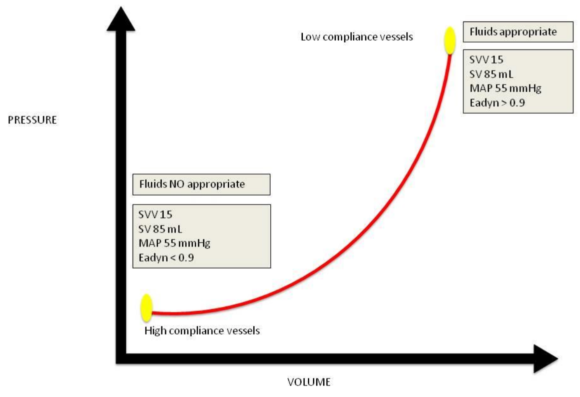

Figure 3. — Pressure-Volume curve demonstrating the possibility to correct pressure by fluids in pre-load dependent status; indeed a vasopressor drug is able to increase cardiac output based on the vasomotor tone. If vessels are in a high-compliance status, fluid challenge could be inappropriate, at the same MAP and SVV values.

Contractility

This term could describe the quality of myocardial contraction, which refers to the ability of the cardiac muscle cells to shorten and generate force independent of preload and afterload. Cardiac contractility should not be confused with cardiac performance which is dependent upon heart rate and loading conditions. Current options to assess cardiac contractility in routine clinical practice are limited because the left ventricular dP/dt_{max} requires invasive measurement of chamber pressures. Left ventricular end-systolic elastance (Ees) is the reference method for assessing LV contractility. LV ejection fraction (EFLV), estimated by echocardiography as the fractional area of contraction, is currently the most used clinical index for estimating LV systolic function. However, EFLV has known limitations as an index of cardiac inotropy, such as its elevated dependence on cardiac loading conditions. The maximum LV pressure during isovolumetric contraction (LV dP/dtmax) has been classically considered as a marker of LV inotropic state. However, as LV dP/dtmax requires direct measurement of LV pressure, other surrogates have been proposed using the arterial pressure waveform. Peripheral dP/dtmax, as measured from catheters inserted into the femoral or radial arteries have been suggested as feasible surrogates for LV dP/dtmax (36). Hence, dP/dtmax and, under euvolemic conditions, the cardiac index could be used cautiously as indices of inotropic function in the evaluation of the need to administer dobutamine (Fig. 4). This drug, due to its pharmacological properties, should be administered to treat myocardial dysfunction, as suggested by elevated cardiac filling pressures and low cardiac index, and to correct ongoing signs of tissue hypoperfusion, when proper intravascular volume has already been achieved.

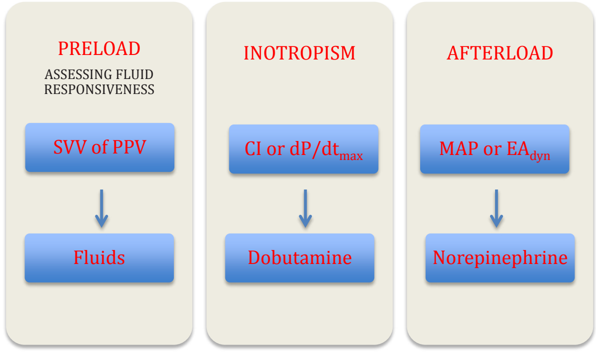

Figure 4. — Hemodynamic pillars : targets and tools.

New echocardiographic indices, such as speckle-tracking-derived LV global longitudinal strain or strain rate, have been recently introduced, although their need for sophisticated software and trained operators precludes their use in continuous hemodynamic monitoring of LV systolic function.

$C0_2$ Gap and SvO_2

Additional information could help anesthesiologists in the decision-making process during hemodynamic instability. Since the aforementioned variables, commonly used during a hemodynamic protocol, cannot be used to rule out imbalances between oxygen supply and demand, metabolic parameters should also be considered to identify and promptly treat an occult hypoperfusion. Obviously, an arterial line and central venous catheter are usually positioned to manage high-risk surgical patients; hence central venous oxygen saturation (SvO_2) and the arterial to venous carbon dioxide difference (PCO_2-GAP) could be easily calculated. Low SvO_2, as well as high PCO_2-GAP, reflect important changes in the O_2 delivery/consumption relationship, and they are closely associated with increased postoperative complications (37, 38). The SvO_2 value of 70.6% (sensitivity 72.9%, specificity 71.4%) could be used to discriminate between patients who will develop postoperative complications or not. It is still useful to measure SvO_2, because its reduction is associated with a low cardiac ouput or important pulmonary or gas-exchange problems and its optimization should lead to an increase in the DO_2 to the tissues.

Moreover, Robin and colleagues found that high-risk surgical patients with PCO_2-GAP values greater than 6 mmHg at admission in Intensive Care Unit (ICU) showed a higher rate of complications (39).

Finally, after classifying the patient as high-risk, anesthesiologists should plan an intraoperative hemodynamic optimization protocol by choosing one or more flow-related indices (preferring dynamic to static parameters) together with a metabolic parameter (SvO_2, PCO2-GAP, Lactate value). This optimization could help maintain intraoperative hemodynamic stability and better results in terms of postoperative outcomes.

Action

If the real trigger for any intervention is lasting hemodynamic instability, anesthesiologists should keep in mind the three pillars of hemodynamic system : Preload, Afterload and Contractility (Figure 4). Fluids, vasoactive drugs and inotropes, respectively, represent the basis of any treatment for each of these pillars.

Before any hemodynamic intervention, "Anesthesiologists should optimize the use of anesthetic drugs (i.e. volatile anesthetic, opioids etc.), by integrating additional information such as the "Bispectral index". An excessive depth of anesthesia could be deleterious and cause vasodilation and arterial hypotension.

If SVV or PPV have been selected as targets, a fluid challenge might be considered for values above 10-15%; but if Ea_{dyn} is not available and MAP is stably below 65 mmHg, a norepinephrine infusion is needed to recruit the unstressed volume and possibly to correct the dynamic indices (Figure 3). Afterwards, if SVV or PPV remain high, fluid administration will be the next-step intervention. Regarding the type of solution, colloids or crystalloids have been used and the superiority of one rather than another, during abdominal surgery, has never been demonstrated. Basically, all fluids should be treated as drugs by anesthesiologists and used according to patients characteristics. Most studies have focused on the effects of different types of fluids in the setting of the ICU, for critically ill patients. For this subgroup of patients with vascular bed impairment, the CHEST trial documented a greater risk of developing renal dysfunction in the colloids group (40). On the other hand, we can assume that patients that underwent elective abdominal surgery have an intact vascular endothelial bed, so that colloid administration for volume expansion during surgery should be safe (41-42). Nonetheless, the European Medicine Agency (EMA) stated that hydroxyethyl starch (HES) solutions should be used to replace plasma volume following acute blood loss, where treatment with alternative products alone is not considered sufficient. HES solutions for infusion are contraindicated in: a) patients with renal impairment, b) patients with coagulopathy, c) patients with impaired hepatic function, d) patients with sepsis or in critically ill patients, and additional studies are ongoing in patients with trauma and those undergoing elective surgery. Importantly, excessive amounts of saline solution should be avoided because of the greater risk of hyperchloremic acidosis (43). Evidence indicates that Crystalloids are associated with reduced mortality when compared with HES and gelatin (44, 45). Regarding the choice of inotropic drugs, the evidence suggests the use of dobutamine infusion to keep the Cardiac Index (CI) above 2.5 L/min/m^2. A recent review highlighted that vasoactive drugs had significant positive effects in terms of complications and hospitalization for non-cardiac surgery (46).

Results

To achieve and maintain the targeted endpoints of predefined hemodynamic and metabolic parameters is the last step of the STAR method. Using a minimally invasive monitoring system under a goal-oriented protocol with predetermined targets could produce the positive expected results (Table 2). Hourly or whenever necessary, probable fluid responsiveness should be evaluated before administering a fluid challenge and sampling blood in search of signs of tissue hypoperfusion.

Table 2.
Recommended values of haemodynamic and metabolic parameters

SVV	< 15%
CI	> 2.5 L/Min/m^2
MAP	> 65 mmHg
SvO_2	>70%
CO_2-Gap	< 6 mmHg
Lactate	< 3 mmol/L

Conclusions

When patients are scheduled for major abdominal surgical procedures, an accurate assessment consisting of preoperative comorbidities and surgical scores for emergency risk estimation and general elective surgery is critical to identify a high-risk patient. In high-risk patients, arterial cannulation and a central venous line can provide accurate hemodynamic data when paired with minimally invasive hemodynamic devices system, like the FloTrac/EV-1000 (Edwards Lifesciences, Irvine, California) system, which are suitable for high-risk patients. Pulmonary artery catheters as well as calibrated monitoring systems should be limited to critical care settings, cardiac or transplantation surgery. Knowledge of the predefined targets and the assessment of their alterations before and after any treatment strategy could help clinicians to guide their fluid therapy or vasoactive drugs usage in response to hemodynamic instability. The mechanism of the therapeutic effect of GDT remains unclear. It may be that increased global oxygen delivery results in increased tissue partial pressure of oxygen (PO2), with improved tissue healing and reduced infection rates. There is some evidence that additional intravenous fluid use improves tissue PO2 during surgery and that decreases in global oxygen delivery and regional oxygen tension are associated with poor tissue healing and infection. The use of GDT may also have financial implications. Previous studies have shown peri-operative GDT to be associated with reduction in mean duration of hospital stay. This suggests that the use of GDT might reduce the overall cost of surgical care (47, 48, 49).

References

1. Cannesson M., et al. Hemodynamic monitoring and management in patients undergoing high risk surgery: a survey among North American and European anesthesiologists. Crit Care. 2011;15(4):R197.
2. Bland RD, et al. Hemodynamic and oxygen transport patterns in surviving and nonsurviving postoperative patients. Crit Care Med. 1985 Feb;13(2):85-90.
3. Jhanji S. et al. Mortality and utilisation of critical care resources amongst high-risk surgical patients in a large NHS trust. Anaesthesia 2008;63:695-700.
4. Pearse RM. et al. Identification and characterisaton of the high-risk surgical population in th UK. Crit Care 2006;10:R81.
5. Tarhan S. et al. Myocardial infarction after general anesthesia. JAMA 1972; 220:1451.
6. Moonsinghe SR. et al. Risk stratification tools for predicting morbidity and mortality in adult patients undergoing major surgery:qualitative systematic review. Anesthesiology 2013;119:959-981.
7. Bilimoria KY. et al. Development and evaluation of the universal ACS NSQIP surgical risk calculator: a decision aid and informed consent tool for patients and surgeons. J Am Coll Surg 2103;217:833-42.e1-3.
8. Riley R. et al. Inter-rater reliability of the ASA physical status classification in a sample of anesthesia in Western Australia. Anaesth Intensive Care 2014;42:614-618.
9. Sankar A. et al. Reliability of the American Society of Anesthesiologists physical status scale in clinical practice. Br J Anesth 2014;113:424-432.
10. Koo CY. et al. A meta-analysis of the predictive accuracy of postoperative mortality using the American Society of Anesthesiologists' physiscal status classification system. World J Surg 2015;39:88-103.
11. Lee TH. et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation 1999;100:1043-1049.
12. Lam CM, et al. Validation of POSSUM scoring systems for audit of major hepatectomy. Br J Surg 2004; 91:450–4
13. Merad F, et al. Prospective evaluation of in-hospital mortality with the P-POSSUM scoring system in patients undergoing major digestive surgery. World J Surg 2012; 36:2320–7
14. Bose S. et al. American College of Surgeons National Surgical Quality Improvement Program Risk Calculators Should Be Preferred Over the Revised Cardiac Risk Index for Perioperative Risk Stratification. J Cardiothoracic Vasc Anesth 2018;32:2417-2419.
15. Fleisher LA. et al. 2014 ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines. J Am Coll Cardiol 2014;64:e77-137.
16. Cecconi M. et al. Clinical Review: Goal-directed Therapy – what is the evidence in surgical patients? The effect on different groups. Crit Care 2013; 17(2):209.
17. Russo A. et al. Goal-directed hemodynamic management in patients undergoing primary debulking gynaecological surgery: A matched-controlled precision medicine study. Gynecol Oncol 2018;151(2):299-305.
18. Gurgel ST. et al. Maintaining tissue perfusion in high-risk surgical patients: a systematic review of randomised clinical trials. Anesth Analg 2011;112:1384-91.
19. Jhanji S. et al. Microvascular flow and tissue oxygenation after major abdominal surgery: association with post-operative complications. Intensive Care Med 2009;35: 671-7.
20. Pearse R. et al. Early goal-directed therapy after major surgery reduces complications and duration of hospital stay. A randomised, controlled trial. Crit Care 2005;9:R687-93.
21. Shoemaker WC. et al. Hemodynamic and oxygen transport responses in survivors and nonsurvivors of high risk surgery. Crit Care Med 1993;21:997.
22. Sandham JD. et al. A randomised, controlled trial of the use of pulmonary artery catheters in high-risk surgical patients. N Engl J Med 2003;348:5-14.
23. Gan J. et al. Goal-directed intra-operative fluid administration reduces lenght of hospital stay after major surgery. Anesthesiology 2002;97:820-6.
24. Wakeling HG. et al. Intraoperative oesophageal Doppler guided fluid management shortens postoperative hospital stay after mahor bowel surgery. British Journal of Anesthesia 2005; 95:634-42.
25. Moller-Sorensen H. et al. Transesophageal Doppler reliably tracks changes in cardiac output in comparison with intermittent pulmonary artery thermodiluition in cardiac surgery. J Clin Monit Comput 2017;31(1):135-142.
26. Bellamy MC. et al. Wet, dry or something else? Br J Anaesth 2006;97:755-757.
27. Benes J. et al. Intraoperative fluid optimization using stroke volume variation in high risk surgical patients: results of prospective randomized study. Crit Care 2010;14(3):R118.
28. Deng WQ. et al. Is goal-directed fluid therapy based on dynamic variables alone sufficient to improve clinical outcomes among patients undergoing surgery? A meta-analysis. Crit Care 2018;22(1):298.
29. Srinivasa S. et al. Goal-directed fluid therapy – a survery of anesthesists in the UK, USA Australia and New Zeland. BMC Anesthesiol 2013,13:5.

30. Prekker ME et al. Point-of-care ultrasound to estimate central venous pressure: a comparison of three techniques. Crit Care Med 2013;41:833–841
30. Maheshwari K. et al. The association of hypotension during non-cardiac surgery, before and after skin incision, with postoperative acute injury: a retrospective cohort analysis. Anaesthesia. 208;73(10):1223-1228.
31. Vieillard-Baron A et al. Superior vena caval collapsibility as a gauge of volume status in ventilated septic patients. Intensive Care Med 2004;30:1734–1739
32. Charron C et al. The influence of tidal volume on the dynamic variables of fluid responsiveness in critically ill patients. Anesth Analg 2006;102:1511–1517
33. Green RS. et al. Postintubation hypotension in general anesthesia: a retrospective analysis. J Intensive Care Med. 2016;31(10)667-675.
34. Monge Garcìa MI. et al. Dynamic arterial elastance to predict arterial pressure response to volume loading in preload-dependent patients. Crit Care 2011;15:R15.
35. Monge Garcìa MI. et al. Performance comparison of ventricular and arterial dP7dtmax for assessing left ventricular systolic function during differen experimental loading and contractile conditions. Crit Care 2018;22(1):325.
36. Collaborative Study Group on Perioperative $ScVO_2$ Monitoring. Multicentre study on peri- and postoperative central venous oxygen saturation in high-risk surgical patients. Crit Care 2006;10(6):R158.
37. Futier E. et al. Central venous O2 saturation and venous-to-arterial CO2 difference as complementary tools for goal-directed therapy during high-risk surgery. Crit Care 2010;14(5):R193.
38. Robin E. et al. Central venous-to-arterial carbon dioxide difference as a prognostic tool in high-risk surgical patients Crit Care 2015;19:227.
39. Mynurgh JA. et al. Hydroxyethyl starch or saline for fluid resuscitation in intensive care (CHEST trial). N Engl J Med 2012,367(20):1901-1911.
40. Westphal M. et al. Hydroxyethil starches: different products – different effects. Anesthesiology 2009, 111(1)187-202.
41. Endo A. et al. Intraoperative hydroxyethil starch 70/0.5 is not related to acute kidney injury in surgical patients: retrospective cohort study. Anesth Analg 2012, 115(6):1309-1314.
42. Joosten A et al. Long-term Impact of Crystalloid versus Colloid Solutions on Renal Function and Disability-free Survival after Major Abdominal Surgery Anesthesiology. 2019 Feb;130(2):227-236.
43. Handy JM. et al. Physiological effects of hyperchloraemia and acidosis. Br J Anaesth 2008, 101(2):141-150.
44. Rochwerg B. et al. Fluid resuscitation in sepsis: a systematic review and network meta-analysis. Ann Intern Med 2014;161(5):347-55.
45. Zarychanski R. et al. Association of hydroxyethyl starch administration with mortality and acute kidney injury in critically ill patients requiring volume resuscitation: a systematic review and meta-analysis. JAMA 2013;309(7):678-88.
46. Deng C. et al. Systematic review and meta-analysis of the perioperative use of vasoactive drugs on postoperaive outcomes after major abdominal surgery. Br J Anaesth 2020.
47. Guest JF et al. A cost analysis of a treatment policy of a deliberate perioperative increase in oxygen delivery in high risk surgical patients. Intensive Care Med. 1997;23:85–90.
48. Fenwick E. et al. Pre-operative optimisation employing dopexamine or adrenaline for patients undergoing major elective surgery: a cost-effectiveness analysis. Intensive Care Med. 2002;28:599–608
49. Perilli V. et al. Impact on outcome and healthcare costs from hemodynamic optimization in patients undergoing pancreatic surgery: a preliminary report. MeMeA 2018-2018 IEEE International Symposium on Medical Measurements and Applications, Proceedings.