Performing perioperative optimization of the high-risk surgical patient

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Perioperative risk of death after general surgery is quoted as overall less than 1%. However, each individual's risk varies widely according to many identified factors with some having a significantly increased risk of a worse outcome. The observation that manipulating and targeting certain physiological parameters in selected patients can influence this risk has been reported in numerous studies. Yet it is still not widely practised to assist the process, despite the availability of various invasive and non-invasive monitors. This may be in part because of a lack of experience with the practicalities of perioperative optimization, and lack of knowledge in applying currently available tools. This article aims to try and address this deficit and increase awareness of how and when to utilize monitoring equipment to achieve optimal results for the patients we treat.

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Perioperative risk of death after general surgery is quoted at less than 1%, however patients presenting for surgery are not a homogenous group and for certain individuals the risk is much higher, sometimes as high as 33%.¹ Although the risk of death directly attributable to anaesthesia has fallen appreciably over the years, the number of perioperative deaths remains static.² The reasons patients may not survive or suffer from postoperative complications are numerous such as the nature of the surgery itself, infection, thromboembolic disease, respiratory failure and cardiac compromise. Clinical acumen and observation allows us to predict some patients who may be more susceptible than others, from which comes the concept of the high-risk surgical patient. However, this leads on to the question of why some patients develop complications and others do not despite being seemingly equal in other respects. In trying to find the answer to this question the concept of adequate oxygen delivery was brought to the fore and investigated by many groups.^{1 3–7}

The normal physiological response to the increased metabolic demand of surgery is to increase cardiac output (CO) resulting in increased oxygen delivery. Shoemaker and colleagues⁸ showed that this was not always the case, and those that could not increase oxygen delivery adequately during the peri- and postoperative course developed an oxygen debt;⁹ the magnitude and length of which was associated with an increased incidence of complications. Of those that survived, the median values of the measured physiological parameters were a cardiac index (CI) of

>4.5 litre min⁻¹ m⁻², an oxygen delivery (DO₂I) of more than 600 ml min⁻¹ m⁻², and an oxygen consumption $(VO_2 I)$ of more than 170 ml min⁻¹ m⁻². Shoemaker and colleagues¹ went on to show that by using a technique involving i.v. fluids, inotropes, pulmonary artery catheter (PAC) monitoring and therapy directed to achieve these values, mortality in those who could not originally meet these values alone was reduced from 33 to 4%. Since then a number of other investigators have reproduced these results in varying patient groups to varying degrees.^{3–7} Each pointing to the fact that sub-optimal values lead to tissue hypoxia attributable to uneven microcirculatory blood flow resulting from uneven vasoconstriction in different vascular beds. Mythen and Webb¹⁰ showed that 60% of patients undergoing major surgery had gut hypoperfusion. They postulated that the result was a triggering of the systemic inflammatory response leading to organ failure, increased morbidity and death.

Identifying the patient who will benefit

A number of scoring systems have been developed over the years that aim to quantify the risk of perioperative mortality. Goldman and colleagues¹⁷ cardiac risk index gives a weighted score for various factors that confer a high risk of mortality in patients with cardiac disease. The presence of cardiac ischaemia, pump failure, or both being the most predictive of complications and death. The ASA score is widely accepted as part of preoperative
 Table 1 Shoemaker and colleagues¹ criteria for identifying patients at high risk of perioperative complications

Current or previous severe, cardio-respiratory illness (myocardial infarction stroke, heart failure, chronic obstructive pulmonary disease (COPD), severe asthma) Acute abdominal catastrophe with haemodynamic instability (pancreatitis, perforated bowel with peritoneal soiling, severe gastrointestinal bleeding) Acute renal failure (acute onset renal dysfunction with urea >18 mmol or creatinine >265 μ mol litre⁻¹)

Severe multiple trauma (more than three major organs involved or more than two systems or surgical opening of more than two body cavities)

Evidence of limited physiological reserve in one or more vital organs in elderly patients more than 70 yr

Shock (MAP <60 mm Hg, urine output <0.5 ml kg⁻¹ h⁻¹)

Acute respiratory failure (Pa_{0_2} <8 kPa, Fl_{0_2} >0.4, shunt fraction >30%, mechanical ventilation required for >48 h)

Septic shock

>These are not equally weighted and subsequent work by Hayes and colleagues³² and Gattinoni and colleagues³³ showed GDT in critically ill patients with established multi-organ failure was of no benefit and even harmful

assessment. It is simple to use and although it suffers from the potential pitfall of user interpretation, it consistently identifies high-risk patients associated with higher scores. Other groups have tried to be more specific in identifying high-risk patients. Mangano and colleagues¹⁸ showed postoperative cardiac ischaemia triples the complication rate. The American College of Cardiology continue to produce updated guidelines on preoperative investigations and management of patients with cardiac disease.¹⁹ Older and colleagues²⁰ have produced studies showing preoperative cardiopulmonary exercise testing as an extremely good predictor of mortality particularly in the elderly, those with a low anaerobic threshold having a significantly higher mortality than those with a higher threshold (18% vs 0.8%). POSSUM scoring and APACHE II are not widely used in the preoperative assessment partly because of their cumbersome nature but are used frequently in statistical analysis and audit. Shoemaker and colleagues suggested a set of physiological conditions that would deem a patient to be high risk (Table 1) and a number of trials have broadly based patient selection on this.

However other factors have to be considered (Table 2). The type of surgery can influence morbidity and mortality. The mortality in major vascular surgery can reach 15% in elective patients. Colorectal surgery has a mortality of around 8% and a complication rate of up to 22%. Furthermore these figures are significantly worse in the emergency scenario.

Although patients presenting for surgery invariably have some form of scoring system applied, in the context of periopreative optimization it is more appropriate to consider physiological variables in identifying the group that will most benefit, as this is the basis upon which the majority of studies have been conducted. In the study by Pearse and colleagues,⁶ integration of the Shoemakers criteria and the identified surgical risk factors (i.e. Tables 1 and 2) formed the inclusion criteria for application of the postoperative optimization protocol. These criteria are shown in **Table 2** Surgical considerations for identifying the high-risk patient. ^aStudies by Mangano and colleagues³⁴ and Polderman and colleagues³⁵ amongst others have identified a group of patients who may do better from perioperative β blockade, the primary risk being from cardiac ischaemia

Colorectal, vascular,^a intra-abdominal surgery Trauma surgery involving more than two body cavities or intraperitoneal soiling with bowel contents Prolonged surgery (>1¹/₂ h) Emergency surgery

Table 3 Optimization inclusion criteria integrating Tables 1 and 2

Known history of severe cardiac or respiratory illness for example COPD, myocardial infarction, heart failure Extensive surgery for carcinoma involving bowel anastamosis for example oesophagectomy Acute massive blood loss (>2.5 litres) Aged more than 70 with limited physiological reserve in one or more vital organ Septicaemia (positive blood cultures or septic focus) Respiratory failure ($Pa_{o_2} < 8$ kPa on $Fl_{o_2}>0.4$) Acute abdominal catastrophe (e.g. pancreatitis, perforated viscous, gastrointestinal bleeding) Acute renal failure (urea> 20 mmol litre⁻¹; creatinine >260 µmol litre⁻¹) Late stage vascular disease

>Protocol should be applied even if urine output, Scv_{O_2} , blood pressure, lactate and base excess are normal

Table 3 and provide a practical approach to patient selection for whom optimization would be of benefit.

Physiological principles of optimization

Goal-directed therapy works on the principle of identifying physiological parameters that are associated with an improved outcome and manipulating a patient's physiology to achieve these targets. Some of these targets have already been mentioned: a CI of >4.5 litre min⁻¹ m⁻², a tissue DO₂I of more than 600 ml min⁻¹ m⁻², and a tissue VO₂ I of more than 170 ml min⁻¹ m⁻².

The VO_2I , although observed cannot be practically altered and as such does not form part of the goals of therapy.

The values are simply derived from well-known physiological equations:

When CO=heart rate (HR)×stroke volume (SV)

nd
$$CI = \frac{CO}{Body \text{ surface area}}$$
 and

a

 $DO_2I=CI\times oxygen$ content of arterial blood (C_aO_2)

with C_aO₂=1.34×haemoglobin (Hb)

$$\times \frac{\text{arterial saturation } (Sa_{O_2})}{100}$$
then DO₂I=CI×1.34×HB× $\frac{Sa_{O_2}}{100}$

It can be seen that there are four variables that can be manipulated to obtain optimal oxygen delivery: HR, SV, Hb, oxygen saturation; using inotropes, fluid and blood transfusion and oxygen.

However there are other parameters which give evidence of flow or, more appropriately, low flow states. Mixed and central venous saturations (Sv_{02}, Scv_{02}) and lactate can give valuable information regarding global oxygen delivery and consumption.^{21 22} This has become particularly topical of late since the publication of data²³ regarding resuscitation in sepsis; which suggested targeted therapy against central venous pressure (CVP), Scv₀₂ and lactate. Optimization trials have also explored this approach with success. Polonen and colleagues¹⁴ used Sv_{0_2} and lactate to direct fluid and inotrope therapy in patients immediately post cardiopulmonary bypass. In so doing, they reduced the length of hospital stay (6 days vs 7 days) and morbidity (1.1% vs 6.1%). Recently, Pearse and coworkers²⁴ have shown low Scv_{02} (<64.4%) in the postoperative period to be an independent risk factor for increased complications, suggesting Scv_o, may have prognostic significance post surgery. This then adds another variable that can be monitored and targeted.

How to perform optimization

Despite a weight of evidence in its favour, perioperative optimization is not widely practised, partly because of lack of intensive care facilities and partly because of apprehension in using PACs.^{11–13} With the advent and validation of non-invasive CO (NICO) monitors the necessity for a PAC is no longer a requirement to undertake this goaldirected therapy. There is an array of non-invasive monitors available, some, such as the oesophageal Doppler monitor (ODM), the LiDCO and PiCCO are more established, or more readily available than others (e.g. NICO monitor, Bioelectrical impedance cardiography and cardiac ultrasonography methods). Additionally, it is becoming increasingly clear that goal-directed therapy instituted in the intraoperative or immediate postoperative phase may also improve outcome^{6 14–16 25}

Cardiovascular monitors that may be used for goal-directed therapy

Although CO monitoring can be achieved by numerous means, only the more common techniques are described here.

Pulmonary artery catheter

Perioperative optimization is a process that may commence before, during or after operation. The original studies began in the preoperative period and invariably used PAC monitoring essentially because this was the only flow monitor that was available. The PAC has been used for many years and is well known to many intensivists although recently Table 4 Perioptimization using PAC. Adapted from Grounds³⁶ and reproduced with permission from Cambridge University Press

Assess patients before operation: perform cardiovascular measurements to assess cardiac performance. Perform CO and oxygen delivery measurements If CI >4.5 litre min $^{-1}$ m $^{-2}$ and oxygen delivery >600 ml min $^{-1}$ m $^{-2}$, then no further goal-directed therapy will be indicated. Patient can proceed to operation with normal anaesthesia and resuscitation therapy

If CI <4.5 litre min⁻¹ m⁻² and/or oxygen delivery <600 ml min⁻¹ m⁻², then further goal-directed therapy is indicated before surgery. [If this cannot be performed or has not been performed before surgery, then a number of studies have shown that similar results can be obtained if this goal-directed therapy is applied immediately on arrival in the ICU at the end of surgery (see later). If goal-directed therapy is delayed or not achieved within 1 h after surgery then technique will confer no benefit to the patient's outcome]

If oxygen delivery <600 ml min⁻¹ m⁻² increase i.v. fluid therapy using flow directed monitoring equipment to improve intravascular filling to pulmonary artery occlusion pressure of 12-16 mm Hg

Maintain haemoglobin concentration 8-10 g dl⁻¹ by transfusion if necessary Maintain blood oxygen saturation 95% or greater by use of supplementary oxygen therapy where appropriate

If despite these measures oxygen delivery is still $<600 \text{ ml min}^{-1} \text{ m}^{-2}$, consider

the use of inotrope or inodilator therapy; for example dopexamine Start dopexamine at 0.25 μ g kg⁻¹ min⁻¹ and increase every 15 min by a further $0.25 \ \mu g \ kg^{-1} \ min^{-1}$ until either a target oxygen delivery is achieved or there is an increase in HR of 20% over the patient's resting rate. (If the patient is very tachycardic before starting this goal-directed therapy then it is important to recognize this and not to attempt to increase CO at the expense of baseline then the infusion rate of the inotrope should be reduced to the previous dose where the heart rate had not achieved this 20% increase and held at that rate)

Maintain intravascular filling pressures (pulmonary artery occlusion pressure (PAOP) 12-16 mm Hg), haemoglobin concentration (8-10 g dl⁻¹) and arterial oxygen saturation (>95%) at the figures given above during this period of vasoactive therapy

Maintain this goal-directed therapy in the immediate postoperative period Maintain therapy until base deficit and blood lactate returns to normal Aim: mixed venous oxygen saturation is above 70%

it has fallen out of favour to some degree.^{11–13} As it is so well established, the basic working principles will not be discussed here, however of the numerous parameters available the most commonly used are CVP, CO, CI, Sv_{O2} and DO₂. Although there is considerable controversy regarding the use of the PAC,^{11 12} it is still considered to be the gold standard in CO monitoring and the favoured approach in some circumstances. A technique for goal-directed therapy using the PAC is shown in Table 4. The basic principles of optimization are summarized in this protocol but it is not a prerequisite to use the PAC to implement this type of protocol as most other cardiovascular measurement devices can be adapted for this type of goal-directed therapy.

Oesophageal Doppler monitor

The Cardio Q[™] oesophageal Doppler monitor (Deltex Medical, Chichester, UK) uses the principles of ultrasound to measure blood flow velocity in the descending thoracic aorta. The area of the resultant velocity time wave form produced, with the application of a calibration factor according to the patient's age, height and weight produces an estimate of SV and CO. The corrected systolic flow time (FT_c) is a useful index of preload with a normal range of 330-360 ms (Fig. 1). The ODM provides a wealth of information regarding the haemodynamic state of a patient from



Fig 1 Characteristic oesophageal Doppler waveform trace in a hypovolaemic patient (A): note the narrow base indicating a short FT_c . (B) Same patient after fluid loading.

both waveform analysis and numerical data. For the purposes of optimization using the ODM, the parameters most useful are SV, FT_c and CO. In the first instance volume loading can be achieved with respect to SV and FT_c. Sinclair and colleagues¹⁶ adopted a protocol that was easy to follow and demonstrated a shorter hospital stay with intraoperative goal-directed fluids alone in elderly patients presenting for hip surgery. For patients with a FT_c less than 350 ms, suggesting hypovolaemia, the protocol consisted of a fluid challenge (3 ml kg⁻¹) over 5–10 min.

There were three possible outcomes:

- (i) SV same or increased, $FT_c < 350$ ms—repeat fluid challenge;
- (ii) SV increases by >10%, FT_c >350 ms—repeat fluid challenge till no increase in SV; and
- (iii) $FT_c > 400 \text{ ms}$ —no further fluid till FT_c or SV decreased by 10%.

Wakeling and colleagues²⁵ have more recently reported a similar intraoperative study in patients having major bowel surgery using the ODM and fluid therapy guided by SV response to colloid challenge. This again showed a decreased hospital stay and reduction in morbidity (59.3% vs 37.5%). Median DO₂I was greater in the study group as opposed to the control, being 535 vs 445 ml min⁻¹ m⁻² at the end of the operation. Although the study terminated here, it would be an ideal starting point for postoperative goal-directed therapy whereby a DO₂I of 600 ml min⁻¹ m⁻² could be targeted with the addition of an inotrope. This is becoming more plausible with the availability of softer ODM probes which are better tolerated nasally in the awake patient²⁶ although use of the traditional ODM nasally in awake patients has also been described.

Lithium dilution CO (LiDCOplus)

The LiDCO plus system (LiDCO Ltd, Cambridge, UK) is a NICO monitor that uses bolus indicator dilution to measure CO. A small amount of lithium is injected i.v. either peripherally or centrally and with the use of a lithium sensor attached to a standard arterial line, a concentration time curve is produced from which CO can be calculated. This in conjunction with pulse contour analysis software enables continuous data on SV, SV variation (SVV), pulse pressure variability and CO to be recorded by arterial pressure waveform analysis (Fig. 2). Excessive undulation of the arterial pressure associated with ventilation has long since been recognized as a sign of possible hypovolaemia. The ability of SV variation, via pulse contour analysis, to reliably predict and assess the response to fluid challenge was demonstrated in a study of postoperative cardiac patients.²⁷ The SVV correlated well with pulse pressure variation and increases in SV in response to volume loading as predicted by the SVV. Just as FT_c in the oesophogeal Doppler, the SVV serves as a useful facet to guide volume therapy. In addition the LiDCO plus system offers a continuous calculated DO₂I which particularly lends itself to goal-directed therapy making it more dynamic with real time changes immediately appreciable in response to intervention. Pearse and collegues⁶ used the LiDCO plus system in their trial of postoperative optimization in high-risk general surgical patients following on from the studies of Polonen and colleagues¹⁴ and McKendry and colleagues,¹⁵ both of which involved postoperative optimization in cardiac patients. The approach in the protocol group rested on concerted efforts to achieve a DO₂I of 600 ml min⁻¹ m⁻² within the first hour of reaching the intensive care unit through targeted volume therapy according to SV responsiveness. If the patient did not reach target DO₂I with fluids alone dopexamine was



Fig 2 Undulating arterial waveform. Pulse contour analysis quantifies each arterial wave as a representation of SV. The difference between the maximum (A) and minimum (B) SV expressed as percentage of the mean SV gives the SVV.

commenced up to a maximum of 1 μ g kg⁻¹ min⁻¹. The whole optimization protocol was maintained for 8 h and then discontinued regardless of whether target DO₂I had been attained. There was a reduction in complication rate (68% vs 44%), and duration of hospital stay (mean 17.5 vs 29.5 days). The subsequent protocol based on this study is shown in Figure 3. The LiDCO plus system is contraindicated in the first trimester of pregnancy and cannot be used in patients taking lithium therapy. Although far from difficult the calibration process is more involved and may be awkward in the theatre environment, and is arguably more suited to the postoperative period.

Pulse contour CO (PiCCO)

PiCCO (PULSION Medical Systems, Munich, Germany) system also uses pulse contour waveform analysis but in conjunction with a thermodilution technique. The system requires a large artery thermodilution catheter, usually femoral, brachial or axillary and a central venous catheter (CVC) attached to an injectate temperature sensor. CO is measured by applying a modified Stewart-Hamilton calculation to the temperature time curve produced by injecting saline through the CVC. This is then used to calibrate arterial pulse contour analysis to provide a measure of beat-to-beat SV from which continuous CO is computed. The pulse contour analysis also provides SVV as with the LiDCO; however, three other unique volumetric parameters can also be obtained by analysis of the thermodilution curve-global end diastolic volume (GEDV), intrathoracic blood volume (ITBV) and extravascular lung water (EVLW). GEDV and ITBV have both been shown to be sensitive measures of cardiac preload²⁸ and may be used as part of a protocol to optimize volume loading in a perioperative setting along with SVV and SV.

Perioptimization: a practical approach

Thus far it can be seen there are a number of methods to perform perioperative optimization; however, they all have the same end point, that is achieving adequate tissue oxygen delivery and they all have the same starting point—that is fluid loading. The method by which this is maximally and efficiently achieved is not necessarily as important, as long as it is properly guided and applied in a logical manner, identifying the usefulness of establishing a protocol. The

process of optimization in the intensive care setting can be very efficiently nurse led as shown by McKendry and colleagues¹⁵ who assessed specifically nurse delivered postoperative optimization and this again highlighted the benefits of a simple protocol. The positive results of Pearse and colleagues⁶ postoperative optimization study are also likely in part to reflect a comprehensive protocol allowing nursing staff to begin optimization without delay. In the intraoperative setting it involves the anaesthetist being aware of the various techniques available for them to implement and maintain goal-directed therapy dependent on which monitoring tools are accessible within their department. The use of PACs is an ongoing unresolved debate: however, one thing is clear-the knowledge to process and use the information correctly is not held by all doctors or nurses for a number of reasons¹² and most are becoming more proficient with non-invasive techniques of flow monitoring simply through more use. The role and importance of CVC monitoring should not, however, be diminished. This is a valuable monitoring tool that has been used for many years and the concept of fluid challenging CVP measurements rather than accepting static values is firmly acknowledged. However, it is also apparent that an adequate CVP reading, normal blood pressure and good blood gases do not necessarily represent adequate CO, or identify regional tissue hypoxia and a developing oxygen debt. This is exemplified by the observation that in the studies mentioned the amount of fluid given to patients with CVC and flow monitoring was greater than those with CVC alone. The simplest extension of the CVC, especially in the intraoperative stage where flow monitoring may not be in place, is the measurement of Scv_{O_2} , this will in part give some guidance to whether fluid loading is necessary. The timing of commencement of optimization is another point of debate. Goal-directed therapy before surgery has been shown to be effective but difficult to institute because of resource constraints. As there is increasing evidence that both intra- and postoperative optimization work, it would seem these are alternative strategies where preoptimization is not possible.

Dopexamine, dobutamine and epinephrine have been used as the inotrope of choice to achieve target values if not met by fluid loading alone. Wilson and colleagues³ used both epinephrine and dopexamine and although targets were met with both, the observed decrease in morbidity and Perioperative optimization of high-risk patient



Fig 3 LiDCO optimization protocol.

hospital stay was only seen with dopexamine. There is no data to suggest dopexamine is better than dobutamine in this setting; however, the observation that gut hypoperfusion is a frequent occurrence seems to make dopexamine a more popular choice especially as it is also known to have anti-inflammatory properties. The use of an inotrope is likely to cause a tachycardia, if this increases more than 20% above baseline, the dose should be reduced to one that is better tolerated.

The concept of an oxygen debt which develops at the time of surgery was postulated by Shoemaker and colleagues.⁸ They went on to suggest that if this debt is 'paid back' within 8 h, the incidence of postoperative complications decreases, and if it is never paid then cell dysfunction and death occur.



Fig 4 Generic algorithm for perioptimization.

Certainly the limited work done up to now purely on postoptimization⁶ will concur with this and provides a time line for how long it should be continued in the postoperative period.

Figure 4 shows a generic algorithm for perioptimization. It can be applied in the majority of settings regardless of method of flow monitoring and commenced at any point in the time line. If this is to be in the postoperative period, strenuous efforts should be made to start targeted therapy within the first postoperative hour.

Conclusion

Both meta-analysis and reviews have shown that optimization is beneficial.^{29–31} The purpose of this article is not to argue the case for optimizing the high-risk surgical patient, but instead to provide a methodical approach to how it can be performed in any institution using the monitoring tools that are readily available. As new monitors become integrated into modern day medicine it is inevitable that anaesthetists and intensivists will be called upon to use them in regular practice, and it is important that they are familiar as to how they can be used correctly and to the patient's benefit. It has been said that it is the fluid and not the monitor that makes the difference—this is only partially correct as it is not only the fluid but the flow that is important, and also that one knows the flow will be sufficient.

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