International Journal of Surgery 8 (2010) 90–99

Contents lists available at ScienceDirect

International Journal of Surgery

journal homepage: www.theijs.com

Review

# Latest developments in peri-operative monitoring of the high-risk major surgery patient

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ARTICLE INFO

*Article history:*
Received 31 August 2009
Received in revised form
18 October 2009
Accepted 8 December 2009
Available online 14 January 2010

*Keywords:*
Peri-operative monitoring
Optimisation
Cardiac output
Stroke volume
Depth of anaesthesia
Cerebral oxygenation

ABSTRACT

Peri-operative monitoring technology has made great strides in the last 20 years with the introduction of minimally invasive devices to measure *inter alia* stroke volume, cardiac output, depth of anaesthesia and cerebral and tissue oxygen monitoring. Despite these technological advances, peri-operative management of the high risk major surgery patient has remained virtually unchanged. The vast majority of patients undergo a pre-operative assessment which is neither designed to quantify functional capacity nor predict outcome. Anaesthetists then usually monitor these patients using the same technology (e.g. pulse oximetry (SpO2), invasive systemic BP and CVP, end tidal carbon dioxide (etCO2) and anaesthetic agent monitoring) that was available in the early 1980s. Conventional intra-operative management can result in occult low levels of blood flow and oxygen delivery that lead to complications that only occur days or weeks following surgery and give false re-assurance to the anaesthetist that he or she is doing a "good job". Post-operative management then often takes place in an environment with reduced levels of both monitoring equipment and staff expertise. It is perhaps not surprising that outcome still remains poor in high-risk patients.[1]

In this review, we will briefly describe the role of peri-operative optimization, some of the available monitors and indicate how their combined use might be beneficial in managing the high-risk surgical patient. We believe that although there is now evidence to suggest that the use of *individual* new monitors (such as assessment of fluid status, depth of anaesthesia, tissue oxygenation and blood flow) can influence outcome, it will only be their *combination* that will radically improve the peri-operative management and outcome of high-risk surgical patients. It is a matter of some urgency that large scale, prospective and collaborative studies be designed, funded and executed to prove or disprove this hypothesis.



## 1. Definition

Advanced monitoring in the context of this review means a combined process of identification and management of the high risk surgical patient *throughout* the peri-operative period using a set of parameters, protocols and user interfaces that facilitate assessment and optimization of anaesthesia, fluids and drugs on the major determinants of adequacy of oxygen delivery (DO2), oxygen utilization, stroke volume (SV) and cardiac output (CO) including preload, after load, heart rate and contractility as well as tissue oxygenation.

## 2. Pre-operative

Much work and energy have been expanded on optimizing the high-risk surgical patient pre-operatively to usually very good effect.[2] However it is now generally recognized that it is not cost effective to admit *all* patients pre-operatively to a high dependency environment, especially if this high quality of care is not then scrupulously maintained in the intra-operative and post-operative period.[3]

Cardiopulmonary exercise testing (CPET) is increasingly being used in the pre-operative period to either exclude patients from major surgery if their anaerobic threshold and maximum oxygen delivery does not exceed pre-defined (and arbitrary) parameters or to distinguish patients who may need high dependency post-operative management from those that will not.[4–7] However, despite the enthusiasm in some quarters, there is surprisingly little data to support this form of triage in the form of randomized, controlled trials, although a recent systematic review identified benefit in some patients, e.g. those undergoing open aortic aneurysm repair.[8] The pitfalls and limitations have been the subject of a recent editorial.[9]

Indeed, there is little evidence to support the contention that major surgery is necessarily associated with or requires an increase in oxygen delivery and consumption in the post-operative period.

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1743-9191/$ – see front matter 
doi:10.1016/j.ijsu.2009.12.004

Such evidence is only available from randomized controlled trials in which oxygen delivery and cardiac output were not optimized *intra-operatively*.[10–13] Thus, the increase in oxygen delivery and consumption seen *post-operatively* may simply reflect the accumulation of an *intra-operative* oxygen debt and may not occur if DO2 is optimized intra-operatively. In the vast majority of trials of intra-operative optimization of fluid input (see later), measurement of stroke volume and cardiac output have only been initiated *following* induction of anaesthesia and thus the pre-operative CO is not known. In our experience of over 200 cases of intra-operative CO monitoring initiated *prior* to induction, there have been relatively few cases where CO has increased substantially above pre-operative levels during the procedure (suggesting increased oxygen demand) despite optimization of depth of anaesthesia and protocol driven fluid management.

Indeed, if CO and DO2 are optimized intra-operatively, the requirement to markedly increase CO and DO2 in the post-operative period (on which pretext the value of CPET testing as a predictor of outcome depends) may only occur in patients who are either genetically predisposed to have a marked inflammatory response to surgery or in those who suffer a post-operative complications and become septic.[14]

## 3. Intra-operative period

### 3.1. Fluid management optimization

Intra-operative fluid management regimens have been the subject of a number of recent excellent editorials and reviews which have cast increasing doubt on the conventional intra-operative regimens used in intensive care and during major surgery.[15–18] In most cases, fluids are still administered during intra-abdominal surgery according to pre-determined "high volume" fluid regimens (such as 5–15 ml $kg^{-1}$ per hour of Hartmann's/Lactated Ringer's solution) based on the presumed "third space" fluid deficit that is "obligatory" during major intra-abdominal surgery.[19] There has thus been a presumption for nearly 50 years that patients become relatively hypovolaemic during surgery unless these so called "third space" losses are assiduously replaced. Indeed, in a recent pilot study for a major trial of fluid optimization in patients undergoing colorectal surgery using oesophageal Doppler monitoring (ODM, Deltex Cardio Q (DCQ), Deltex Medical, Chichester, UK), the intervention group was scheduled to receive, *as a matter of course*, 1 L of Hartmann's solution per hour, i.e. approximately 15 ml $kg^{-1}$ $h^{-1}$.[20]

However, recent trials have cast doubt on these "high volume" fluid regimens, even suggesting that fluid *restriction* may be beneficial,[21,22] especially in thoracic and hepatic surgery. In our experience, the additional amount (i.e. excluding blood loss, urine output and insensible loss) of crystalloid necessary to maintain predefined cardiovascular parameters using the ODM, i.e. the average "third space" requirement, was only 3.5 ml per kg per hour with a range of 0–15.[23] It is now increasingly recognized that the amount of fluid administered should be *individualized* to the patient's needs and not pre-determined by some liberal or restrictive regimen.[24]

#### 3.1.1. How to determine intra-operative fluid requirements

Unfortunately, conventional intra-operative monitoring may not predict accurately fluid requirements.[25] Since MAP is dependent on both cardiac output (CO) and systemic vascular resistance (SVR) it is not a good indicator of blood flow and thus oxygen delivery. Optimization of CVP has less predictive value in comparison to other measures of fluid responsiveness such as those provided by the ODM[25–27] and may be associated with more complications.[28] Despite this, some studies have still used CVP measurements to optimize fluid input in a control group of patients, sometimes with values as high as 12–15 mm Hg and consider this to be "conventional practice".[27] On the other hand, recent randomized trials and meta-analyses have confirmed that intra-operative fluid optimization using the ODM improves outcome.[26,27,29–31] Interestingly, many of these trials result in the intervention group receiving more fluid than the control group.

The emphasis should now be on individualized therapy and predicting responders to fluid and minimising unnecessary fluid administration. As mentioned, many intra-operative regimens involve the administration of large quantities of balanced salt solutions with no improvement in oxygen delivery but with the potential for haemodilution, fluid and Na + overload.

Stroke volume variation (SVV) and pulse pressure variation (PPV) have generally been shown to be much better predictors of fluid responders than CVP or PCWP.[32–40] However, SVV (or PPV) assessment can only be utilized in mechanically ventilated patients with adequate tidal volumes.[38] In addition the patient must be in sinus rhythm. In a fluid depleted patient the effect of an increase in intrathoracic pressure will cause a greater variation in SV (high SVV) due to the greater effect on venous return. However as fluid boluses are administered and the patient becomes fluid repleted, the SVV falls and by the time it is around 5–10% the patient is considered to be fluid optimized. Further fluid administration at this stage is less likely to produce an increase in SV. Thus, maintaining SVV at the 5–10% levels ensures optimization of stroke volume whilst at the same time reducing the risk of fluid overload and haemodilution. The use of the LiDCO*rapid* (LiDCO Ltd., Cambridge, UK) in this context will be discussed later.

Other monitors which also derive SV and SVV from analysis of the arterial waveform (versus the Doppler) are also useful in this context, including the PiCCO (Pulsion, Munich, Germany) and Flotrac (Edwards Lifesciences, USA). The PiCCO is less useful in anaesthesia versus the ICU as it conventionally relies on a femoral arterial line. Earlier versions of the Flotrac software produced a percentage error (in comparison to thermodilution) of greater than the usually accepted limit of 30%.[41] The software is now in its third generation (v1.10) and even now problems may still be experienced in certain groups of patients, for example in cirrhosis and where there are rapid changes in haemodynamics. Indeed, a recent trial where the Flotrac (v.1.07) was compared with the ODM showed no correlation of SVV, as measure by the Flotrac versus increase in SV indicated by the ODM in abdominal surgery.[42] The reader is referred to an excellent recent review where all these points are considered in more detail.[43]

#### 3.1.2. How should this affect practice

As a result of these trials, the recently published *British Guidelines on Intravenous Fluid Therapy for Adult Surgical Patients* now recommends flow versus pressure monitoring to assess fluid requirements intra-operatively.[44] It is interesting to note that the Association of Anaesthetists of Great Britain and Ireland (AAGBI) and the Royal College of Anaesthetists (RCA) were invited to participate in drawing up these guidelines but declined. Indeed the recent AAGBI publication of recommended standards of monitoring during anaesthesia and recovery seems oblivious to most of the recent publications on this subject.[45]

### 3.2. Depth of anaesthesia monitoring

#### 3.2.1. Should it be used?

Although the jury is still out on whether brain function monitoring should be routinely used during anaesthesia,[45,46] many of the peri and post-operative complications associated with the anaesthetic process today can be reduced by aiming for an optimal