Southern African Journal of Anaesthesia and Analgesia. 2022;28(4):62-67
https://doi.org/10.36303/SAJAA.2022.28.4.2614

South Afr J Anaesth Analg
ISSN 2220-1181 85EISSN 2220-1173

REVIEW

Haemodynamic monitoring in patients undergoing high-risk surgery: a survey of current practice among anaesthesiologists at the University of the Witwatersrand

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Background: Haemodynamic monitoring and optimisation in high-risk surgery patients improve postoperative outcomes. High income countries have reviewed their haemodynamic monitoring and management practices. There is, however, a paucity of literature in low and middle income countries in this regard. The aim of this study was to describe the current haemodynamic monitoring practice in high-risk surgery patients among anaesthesiologists at the University of the Witwatersrand.

Methods: A survey was conducted among anaesthesiologists at the University of the Witwatersrand using a convenience sampling method by means of an adapted questionnaire from previous research done on this topic.

Results: A total of 64 out of 76 questionnaires were analysed, attaining a response rate of 84%. Ninety-seven percent (97%) of the respondents either provided or directly supervised anaesthesia for high-risk surgery patients. Ninety-seven percent (97%) of them frequently monitored invasive arterial blood pressure (IABP), 68.8% monitored stroke volume variation (SVV) and 53% monitored cardiac output (CO). The most frequently optimised parameter was IABP (68.8%); while CO was optimised by only 39.1% of the respondents. The Vigileo™ monitor was the most frequently used CO device (84.4%). The main reason for not monitoring CO was the use of dynamic parameters of fluid responsiveness as a surrogate for CO (57.8%). Seventy-five percent (75%) of the respondents used SVV as a diagnostic indicator for volume expansion, but the haemodynamic effects of volume expansion were frequently assessed using change in heart rate (78.1%) and blood pressure (76.6%). Most of the respondents (98.4%) believed that their haemodynamic management practice could be improved.

Conclusion: Anaesthesiologists at the University of the Witwatersrand frequently monitored and optimised IABP rather than CO in high-risk surgery patients. The respondents used dynamic parameters of fluid responsiveness as a surrogate for cardiac output monitoring and as an indicator for volume expansion. Most of the respondents believed that their current haemodynamic management practice in this setting could be improved.

Keywords: haemodynamic, monitoring, high-risk surgery patients, cardiac output, optimisation

Introduction

Patients with complex comorbidities undergoing major surgery are at high-risk of perioperative complications and mortality.[1,2] In high income countries (HICs), high-risk surgery patients account for less than 15% of inpatient procedures but these patients have a greater than 70% postoperative mortality rate.[1,2] Perioperative mortality rate is one of the indicators of strength of a country's surgical system. However, it is challenging to conduct outcomes studies measuring perioperative mortality in low and middle income countries (LMICs).[3] The African Surgical Outcomes Study by Biccard et al.[4] is one of the few studies on perioperative outcomes of patients in LMICs. In their study, out of the 1977 (18.2%) patients who developed postoperative complications, 843 (42.7%) had major surgery; and in the 239 (2.1%) mortalities that occurred, 114 (47.9%) had undergone major surgery.[4] Therefore, the need for improved perioperative monitoring for deteriorating physiological function and the availability of sufficient resources to achieve this objective, are highlighted in their study.[4]

Major surgery entails large fluid shifts and blood loss. The use of haemodynamic monitors to assess and respond to changes in fluid status that may occur in the perioperative period, is highly recommended.[5-9] Cardiac output (CO) contributes to the delivery of oxygen to tissue; and in major surgery, metabolic demands are increased.[10] Haemodynamic monitoring and optimisation in patients undergoing high-risk surgery has been shown to reduce postoperative complications and improve patient outcomes.[5-9]

There are multiple haemodynamic monitoring techniques available with varying levels of invasiveness and accuracy.[10-13] Although invasive monitoring using a pulmonary artery catheter (PAC) is considered the gold standard for monitoring CO, there are alternative, minimally invasive and non-invasive techniques available.[11-13] An understanding of the different CO monitoring methods and the underlying principles of how these work, as well as the potential errors and limitations will allow for more effective and safer use.[11-13]

Surveys among anaesthesiologists have been undertaken in HICs to describe the haemodynamic monitoring practice in high-risk surgery patients over the past ten years.[14-17] The results revealed a gap between the available evidence regarding the benefits of haemodynamic optimisation in this group of patients and the clinical practices, thus highlighting the need for education on the use of these monitors and their application.[14-17]

Owing to the wide variation in the clinical use of CO monitoring, some HICs have reviewed their haemodynamic monitoring practices and developed protocols to guide the management of high-risk surgery patients.[11-13,18] Vincent et al.[18] emphasise individualisation of treatment and describe two approaches to optimising perioperative haemodynamic management which aim to increase stroke volume and CO by increasing preload with fluid loading or increasing cardiac contractility with inotrope administration. The first approach is reactive where intervention is applied only when haemodynamic change occurs.[18] Identification of hypovolaemia with increased stroke volume variation (SVV), pulse pressure variation (PPV), systolic pressure variation (SPV) or pleth variability index (PVi), or a reduction in CO or central venous oxygenation ($ScvO_2$) is followed by a prompt fluid bolus.[18] If fluid response is inadequate, inotropic agents are then added.[18] The second option is proactive where haemodynamic strategies are employed, targeting supranormal CO or oxygen delivery values and, therefore, decreasing the risk of tissue hypoperfusion.[18]

The most appropriate haemodynamic monitoring device must be selected for the individual patient in this setting to help guide therapy.[11-13,18] Echocardiography, minimally and non-invasive pressure waveform analysis devices can be used to continuously monitor CO, blood pressure (BP), SVV or PPV in non-hepatic and non-cardiac high-risk surgery patients.[11-13,18] Appropriate interpretation of the measurements given by the various tools and parameters, and knowledge of their advantages and limitations can help improve perioperative haemodynamic management in these patients.[11-13,18] There is a paucity of literature on LMICs in this regard.[19,20] We, therefore, conducted a survey to describe the current haemodynamic monitoring practice in high-risk surgery patients among specialist anaesthesiologists at the University of the Witwatersrand.

Methods

Approval to conduct this study was obtained from the University of the Witwatersrand Human Research Ethics Committee (M191160) and other relevant authorities. This was a cross-sectional, contextual, descriptive and qualitative study using an anonymous self-administered questionnaire.

The study population consisted of all specialist anaesthesiologists working in the Department of Anaesthesiology at the University of the Witwatersrand. The sample size was determined in consultation with a biostatistician using the Raosoft® sample size calculator (Raosoft Inc., Seattle, USA; available from: http://www.raosoft.com/samplesize.html). There are 74 specialist anaesthesiologists in the department. Therefore, the minimum sample size for the survey was 63, to detect a margin of error of 5% with 95% confidence and attaining a response distribution of 50%.

The questionnaire that was developed by Cannesson et al.[14] was adapted and used in subsequent studies on the same topic.[15,17,19,20] Permission was granted to adapt and use the same questionnaire in this study. The questionnaire consisted of five questions related to the anaesthetic expertise/experience of the respondents and 21 questions on haemodynamic management practice in high-risk surgery patients.

The definition of high-risk surgery patients, as defined by Cannesson et al.,[14] was used in this study. These patients are aged 18 years or older presenting for major surgery expected to last more than 1.5 hours and having at least two of the following criteria:

1. Cardiac or respiratory illness resulting in functional limitation
2. Extensive surgery planned for carcinoma involving the bowel anastomosis
3. Predictable acute massive blood loss (> 2.5 litres)
4. Aged over 70 years with functional limitation of one or more organ systems
5. Septicaemia (positive blood cultures or septic focus)
6. Respiratory failure (PaO_2 < 60 mmHg (8 kPa) on FiO_2 > 0.4, that is, PaO_2:FiO_2 ratio < 150 mmHg (20 kPa) or ventilation > 48 hours)
7. Acute abdominal catastrophe (for example, pancreatitis, perforated viscus or gastro-intestinal bleed)
8. Acute renal failure (urea > 20 mmol/l, creatinine > 260 μmol/l)
9. Surgery for abdominal aortic aneurysm
10. Disseminated malignancy

A convenience sampling method was used. The questionnaires were numbered in order to calculate a response rate. The questionnaires were distributed at non-consecutive departmental academic meetings. One author (DL) was present during the completion of the questionnaires to assist with queries and to prevent data contamination. Anonymity was maintained as no personal information was requested on the questionnaire. The return of completed questionnaires implied consent.

Data were captured onto spreadsheets using Microsoft Excel® 2019. Blank questionnaires were excluded from the study while non-responses to specific questions were included in the results analysis. Data were analysed according to the number of responses obtained to each given question. Descriptive statistics were reported using frequencies and percentages. Difference in practice between anaesthesiologists based on years of experience was given descriptively.

Results

Anaesthetic expertise/experience of the respondents

A total of 76 questionnaires were handed out to specialist anaesthesiologists and 64 were completed, attaining a response rate of 84%. The results of the survey showed that 96.8% of the respondents either provide or directly supervise anaesthesia for high-risk surgery patients. More than half of the respondents

(54.7%) regard themselves as general anaesthesiologists and had less than five years' experience practising as a consultant (51.6%). Only 14% of the respondents have fellowship training. The most common fellowship completed was in critical care (4.7%), but only 3% of the respondents manage patients in the intensive care unit (ICU). The anaesthetic expertise/experience of the respondents is shown in Table I.

Table I: Anaesthetic expertise/experience of the respondents

Respondents	*n* (%)
Provide or directly supervise anaesthesia for high-risk surgery	
More than 10 times a month	28 (43.8)
6–10 times a month	20 (31.3)
1–5 times a month	14 (21.9)
Rarely or never	2 (3.1)
Frequent surgical lists (mark all that apply)	
General anaesthesiologist	35 (54.7)
Abdominal surgery including hepatobiliary	32 (50.0)
Paediatric surgery	29 (45.3)
Neurosurgery	24 (37.5)
Vascular surgery	18 (28.1)
Thoracic surgery	17 (26.6)
Cardiac surgery	10 (15.6)
Intensive care unit	2 (3.1)
No response	1 (1.6)
Experience as a consultant in anaesthesiology	
Less than 5 years	33 (51.6)
Between 5 and 10 years	13 (20.3)
More than 10 years	13 (20.3)
No response	5 (7.8)
Fellowship training	
No	46 (71.9)
Yes	9 (14.0)
Not applicable	7 (10.9)
No response	2 (3.1)
Fellowship qualification	
Critical care	3 (4.7)
Research	2 (3.1)
Other	2 (3.1)
Paediatrics	1 (1.6)
Cardiac	1 (1.6)

Haemodynamic monitoring practices in high-risk surgery patients

The methods for routine haemodynamic monitoring and the differences in practice based on years' experience are shown in Table II. More than one option could be chosen. Invasive arterial blood pressure (IABP) and non-invasive blood pressure (NIBP) were the most routinely monitored parameters (96.9% and 70.3%, respectively). Sixty-four percent (64%) of the respondents routinely monitored SVV. Most of the respondents with 5–10 years' experience used a variety of haemodynamic monitoring techniques, including the use of dynamic parameters of fluid responsiveness, CO, transoesophageal echocardiography (TOE) and mixed venous oxygen saturation (SvO_2). This was the only group that reported usage of extravascular lung water and global end diastolic volume. Central venous pressure (CVP) was frequently monitored among respondents with > 10 years' experience (61.5%).

Optimisation of haemodynamic parameters

The respondents were asked how frequently they optimised IABP, CVP, CO, SvO_2, $ScvO_2$ and dynamic parameters of fluid responsiveness (Figure 1). The most frequently optimised parameter was IABP (68.8%); while almost 30% of the respondents frequently optimised dynamic parameters of fluid responsiveness, CO was only optimised by 39% of the respondents. CVP, SvO_2 and $ScvO_2$ were the least frequently optimised parameters.

The respondents reported performing haemodynamic optimisation is of the most value during surgery (92.2%), before

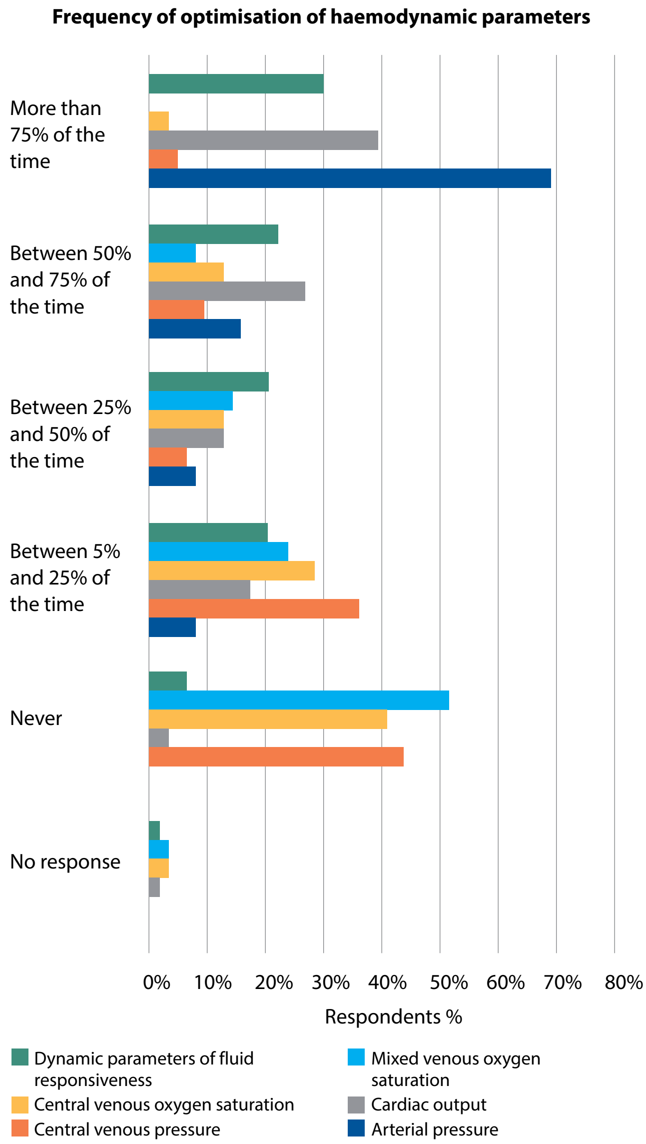

Figure 1: Frequency of optimisation of haemodynamic parameters

Table II: Routine haemodynamic monitoring used for the management of high-risk surgery patients

	Total respondents (*n* = 64)	< 5 years' experience (*n* = 33)	5–10 years' experience (*n* = 13)	> 10 years' experience (*n* = 13)
Monitoring technique	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
Invasive arterial blood pressure (IABP)	62 (96.9)	32 (97.0)	13 (100)	12 (92.3)
Non-invasive arterial blood pressure (NIBP)	45 (70.3)	24 (72.7)	9 (69.2)	7 (53.8)
Stroke volume variation (SVV)	41 (64.1)	23 (69.7)	11 (84.6)	4 (30.8)
Cardiac output (CO)	34 (53.1)	18 (54.5)	7 (53.8)	6 (46.2)
Central venous pressure (CVP)	28 (43.8)	15 (45.5)	3 (23.1)	8 (61.5)
Pulse pressure variation (PPV)	22 (34.4)	10 (30.3)	8 (61.5)	4 (30.8)
Transoesophageal echocardiography (TOE)	20 (31.3)	13 (39.4)	6 (46.2)	1 (7.7)
Plethysmograph waveform variation (PWV)	19 (29.7)	10 (30.3)	6 (46.2)	3 (23.1)
Central venous saturation ($ScvO_2$)	13 (20.3)	9 (27.3)	2 (15.4)	2 (15.4)
Near infrared spectroscopy (NIRS)	12 (18.8)	8 (24.2)	3 (23.1)	1 (7.7)
Systolic pressure variation (SPV)	11 (17.2)	6 (18.2)	2 (15.4)	3 (23.1)
Mixed venous saturation (SvO_2)	10 (15.6)	6 (18.2)	4 (30.8)	0
Oxygen delivery (DO_2)	8 (12.5)	7 (21.2)	1 (7.7)	0
Extravascular lung water (EVLW)	3 (4.7)	0	1 (7.7)	0
Global end diastolic volume (GEDV)	1 (1.6)	0	1 (7.7)	0
Other (Please specify)	1 (1.6) (delta CO_2)	0	1 (7.7) (delta CO_2)	0
Flow time corrected (FTc) (Oesophageal doppler)	0	0	0	0
Pulmonary capillary wedge pressure (PCWP)	0	0	0	0
Intrathoracic blood volume (ITBV)	0	0	0	0

induction of anaesthesia (79.7%), after induction of anaesthesia (76.6%) and in the postoperative period (57.8%). More than half of the respondents (56.3%) reported the period before induction of anaesthesia as the most critical time for haemodynamic optimisation (Supplementary Table I).

When asked how they measured respiratory variations in arterial pulse and/or systolic pressure in high-risk surgery patients, the majority of respondents (71.9%) reported eyeballing, which means using visual estimation on the monitor's trace, while 57.8% used dedicated software of the monitor, and 9.4% manually calculated it.

Table III: Indicators of volume expansion in high-risk surgery patients

	Total respondents (*n* = 64)	< 5 years' experience (*n* = 33)	5–10 years' experience (*n* = 13)	> 10 years' experience (*n* = 13)
Indicators of volume expansion	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
Stroke volume variation (SVV)	48 (75.0)	29 (87.9)	10 (76.9)	7 (53.8)
Pulse pressure variation (PPV), systolic pressure variation (SPV)	44 (68.8)	23 (69.7)	11 (84.6)	8 (61.5)
Blood pressure	42 (65.6)	24 (72.7)	6 (46.2)	8 (61.5)
Urine output	42 (65.6)	23 (69.7)	8 (61.5)	8 (61.5)
Cardiac output (CO)	40 (62.5)	23 (69.7)	7 (53.8)	8 (61.5)
Clinical experience	28 (43.8)	14 (42.4)	5 (38.5)	6 (46.2)
Transoesophageal echocardiography (TOE)	24 (37.5)	15 (45.5)	6 (46.2)	2 (15.4)
Central venous pressure (CVP)	19 (29.7)	7 (21.2)	3 (23.1)	7 (53.8)
Central venous saturation ($ScvO_2$)	13 (20.3)	9 (27.3)	2 (15.4)	2 (15.4)
Mixed venous saturation (SvO_2)	13 (20.3)	10 (30.3)	0 (0.0)	3 (23.1)
Plethysmography waveform variation (PWV)	11 (17.2)	5 (15.2)	5 (38.5)	1 (7.7)
Global end diastolic volume (GEDV)	6 (9.4)	5 (15.2)	1 (7.7)	0 (0.0)
Pulmonary capillary wedge pressure (PCWP)	2 (3.1)	0	0	1 (7.7)
No response	1 (1.6)	0	0	0
FTc (flow time corrected) (Oesophageal doppler)	0	0	0	0
Intrathoracic blood volume (ITBV)	0	0	0	0

Table IV: Variables used to assess the haemodynamic effects of volume expansion in high-risk surgery patients

	Total respondents (*n* = 64)	< 5 years' experience (*n* = 33)	5–10 years' experience (*n* = 13)	> 10 years' experience (*n* = 13)
Assessment of haemodynamic effects of volume expansion	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**
Decrease in heart rate	50 (78.1)	26 (78.8)	10 (76.9)	12 (92.3)
Increase in blood pressure	49 (76.6)	27 (81.8)	9 (69.2)	10 (76.9)
Decrease in blood lactates	46 (71.9)	25 (75.8)	10 (76.9)	9 (69.2)
Decrease in stroke volume variation (SVV)	46 (71.9)	27 (81.8)	11 (84.6)	7 (53.8)
Increase in cardiac output (CO)	41 (64.1)	23 (69.7)	6 (46.2)	9 (69.2)
Increase in urine output	37 (57.8)	17 (51.5)	8 (61.5)	9 (69.2)
Decrease in pulse pressure variation (PPV) or systolic pressure variation (SPV)	33 (51.6)	15 (45.5)	9 (69.2)	8 (61.5)
Decrease in plethysmography waveform variation (PWV)	13 (20.3)	7 (21.2)	2 (15.4)	4 (30.8)
Increase in mixed venous saturation (SvO_2)	11 (17.2)	7 (21.2)	2 (15.4)	1(7.7)
Increase in central venous saturation ($ScvO_2$)	9 (14.1)	6 (18.2)	1 (7.7)	2 (15.4)
No response	2 (3.1)	1 (3.0)	0 (0.0)	0 (0.0)

Assessment of volume expansion

Parameters regarded as diagnostic indicators of volume expansion by the respondents are shown in Table III. More than one option could be chosen. The most widely used indicator of volume expansion was SVV (75%). Other commonly used indicators by the respondents were PPV, SPV, BP, urine output and CO. More than half of the respondents with > 10 years' experience (53.8%) used CVP as a diagnostic tool for volume expansion while the other groups reported lower usage. Parameters used by the respondents to routinely assess the haemodynamic effects of volume expansion are shown in Table IV. More than one option could be chosen. Most of the respondents routinely used static parameters such as a decrease in heart rate (78%), an increase in BP (76.6%), a decrease in blood lactate (71.8%) and an increase in urine output (57.8%) to assess

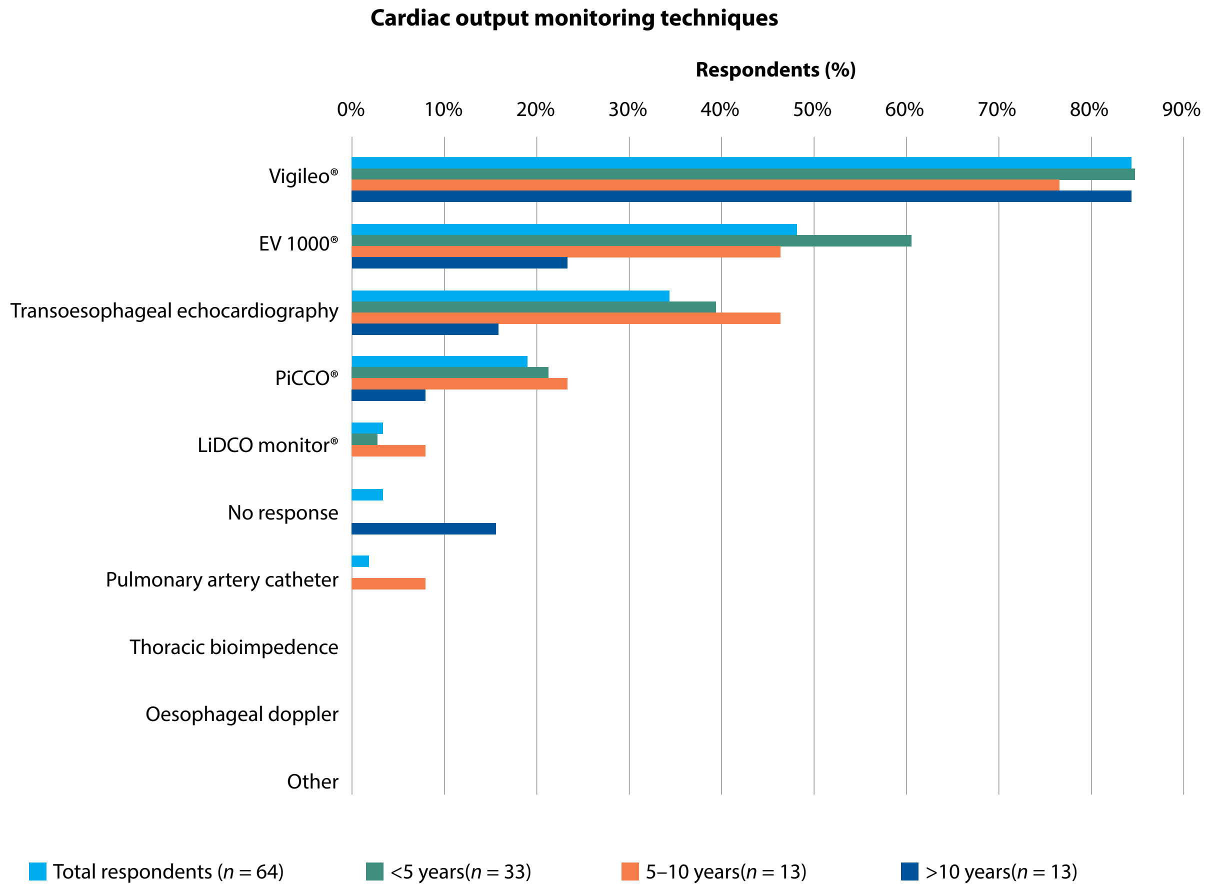

Figure 2: Cardiac output monitoring techniques used for the management of high-risk surgery patients

the haemodynamic effects of volume expansion. Almost a third of the respondents (31%) regarded TOE as the best predictor of an increase in CO following volume expansion rather than SVV (17.2%) or CO (12.5%). The best predictors of an increase in CO following volume expansion are shown in Supplementary Table II. The first choice of fluid therapy for volume expansion used by the respondents was crystalloids (67%), followed by starch solutions (25%) and blood derived products (7.8%).

CO monitoring

The most frequently used CO monitoring techniques are shown in Figure 2. More than one option could be chosen. Most of the respondents used the Vigileo™ monitor (84.4%) followed by the EV1000 clinical platform (48.4%) and the TOE (34.4%). Most of the respondents (70.3%) reported having CO monitoring available in their theatres. The main reasons given for not monitoring CO were the following: use of dynamic parameters of fluid responsiveness (57.8%), use of SvO_2 and $ScvO_2$ as surrogates (10.9%), available CO monitoring devices are too invasive and unreliable (7.8%), and CO does not provide clinically relevant information in high-risk surgery patients (4.7%).

Assessment of practice

Most of the respondents (81.2%) stated that the institution they worked at had no written protocols or guidelines concerning haemodynamic management in this setting, 15.6% were unsure and 3% had protocols. Almost all of the respondents (98.4%) believed that their current haemodynamic management practice could be improved. Regarding the CO and haemodynamic monitoring techniques that they currently have available at their institution, 85.6% of the respondents reported that they could be significantly improved, 12.5% did not think they could be improved, and 1.6% did not respond. The most frequently suggested ways of improving haemodynamic monitoring techniques were regular in-service training, availability of haemodynamic monitoring equipment and consumables.

Differences in practice based on frequent surgical lists performed

As sub-specialities in anaesthesia are not registered in South Africa, we sought to describe the differences in practice based on the most frequent surgical lists performed. This was not possible as the number of respondents in each group were too small for meaningful inferences. Most of the respondents chose more than one frequent surgical list and the majority considered themselves general anaesthesiologists. The responses were overlapping, and differences could not be elucidated.

Discussion

Almost all anaesthesiologists at the University of the Witwatersrand who responded to the questionnaire either provide or directly supervise anaesthesia for high-risk surgery patients. Although CO was monitored by more than half of the respondents in our study, few frequently optimised it. This finding is in line with the results of surveys conducted among anaesthesiologists in North America, Europe, China, Korea and Nigeria.[14,15,19,20] This indicates a gap between the monitoring and the actual optimisation of CO in high-risk surgery patients, despite the accumulating evidence of its benefits.[5-9] The surveys in China and Nigeria, which are LMICs, revealed lower usage of CO monitoring due to the unavailability of resources.[19,20] The respondents in our study reported having CO monitors in their setting but recommended more availability of equipment and consumables.

In our study, IABP and SVV were routinely monitored and optimised rather than CVP. In surveys conducted in other countries, anaesthesiologists routinely monitored and optimised CVP rather than SVV.[14,15,17,19]

The majority of the respondents in our study monitor CO using the Vigileo™ monitor which was a similar finding among Korean and Italian anaesthesiologists.[15,17] The Vigileo™ monitor is a minimally invasive device that uses pressure waveform analysis from an arterial catheter to derive CO and is useful for detecting short-term changes in CO during surgery as it provides continuous measurement of CO.[11] The majority of the respondents in our study and the Korean survey used SVV as a diagnostic tool for volume expansion, and this was attributed to the high usage of the Vigileo™ monitor.[15] The Vigileo™ monitor calculates SVV (which is a dynamic marker of fluid responsiveness) that can be used in the perioperative context and for goal-directed fluid therapy.[11] The derived indices estimate fluid responsiveness on the basis of cardiopulmonary interactions during positive pressure ventilation.[13] However, the Vigileo™ monitor is uncalibrated and the SVV and PPV lose their value for predicting fluid responsiveness in spontaneously breathing patients, cardiac arrhythmias, low tidal volumes and low lung compliance, which are commonly encountered perioperative situations.[11] The use of uncalibrated devices are not recommended in the setting of changes in vascular tone such as in liver transplant surgery, as the estimation of the arterial compliance and resistance is unreliable.[11]

The EV1000 clinical platform was the second most used CO monitoring device in our study, whereas the PiCCO monitor was commonly used in the European and Italian surveys.[14,17] The use of calibrated devices such as the EV1000 clinical platform and PiCCO monitor which are transpulmonary thermodilution based, and the LiDCOplus monitor which uses lithium dilution have been shown to be reliable in patients with marked alterations in vascular tone.[11,12] Calibrated devices are also ideal for continued use, as these monitor additional preload parameters such as extravascular lung water and global end diastolic volume.[11]

A third of the respondents in our study and in the Korean survey routinely use TOE which is a minimally invasive CO monitoring device.[15] Although the use of TOE to estimate CO has shown good correlation with the PAC, its use is limited by operator dependency and lack of continuous output of variables.[12,13] The respondents in our study rarely use the PAC which is considered gold standard for monitoring CO.[12,13] In contrast to our study, the respondents in North America, Europe, Korea and China who monitored CO used the PAC.[14,15,19] In contrast, a survey in the United Kingdom reported a higher usage of the oesophageal doppler rather than PAC for monitoring high-risk surgery patients.[16]

The current literature recommends certain monitoring devices in certain surgeries. Uncalibrated pulse wave analysis devices or oesophageal doppler is recommended in high-risk patients for non-hepatic or non-cardiac surgery, and calibrated pulse wave analysis devices or TOE are recommended for hepatic or cardiac surgery patients.[11,12] Calibrated or uncalibrated pulse wave analysis is recommended to assess fluid responsiveness and CO in patients with refractory shock.[12] Benefits from haemodynamic monitoring are not a class effect and are dependent on the quality of derived and measured variables, and interpretation thereof.[13]

The most common reason for not monitoring CO in our study was the use of dynamic parameters of fluid responsiveness as surrogates for CO. This is similar to the finding among North American, European, Korean and Chinese anaesthesiologists previously surveyed.[14,15,19] This indicates that most of the respondents are aware of the role that dynamic parameters have in fluid responsiveness, but the survey did not explore whether they are aware of the limitations associated with their use. Another reason for not monitoring CO could be cost as our study was carried out in a relatively well-resourced centre. Outside the major centres in South Africa, this could be an issue.

Dynamic parameters of fluid responsiveness were frequently used by the respondents in our study as diagnostic indicators for volume expansion, whereas anaesthesiologists surveyed in other countries widely used BP, urine output, CVP and clinical experience.[14,15,17,19,20] However, to assess the haemodynamic effects of volume expansion, the respondents in our study and other countries used static parameters such as changes in heart rate, BP and blood lactates, rather than SVV and CO.[14,15,17,20] Static parameters lack specificity and sensitivity in haemodynamic assessment of high-risk surgery patients.[18] For instance heart rate, which is the most routinely assessed parameter for the haemodynamic effects of volume expansion by the respondents, may fail to reflect the development of hypovolaemia under anaesthesia.[18] Another routinely assessed parameter by the respondents was BP which is depended on both CO and vascular tone. While BP is standard monitoring in anaesthesia practice, the use of BP to prompt volume expansion and monitor the haemodynamic effects thereof has its limitations. BP can remain within the normal range in the presence of low flow states such as hypovolaemia, as a result of increased peripheral resistance and is thus an inaccurate measure of CO.[18]

More than half of the respondents with > 10 years' experience used CVP as a diagnostic tool for volume expansion. The practice of CVP to guide therapy is without a scientific basis as it is unable to predict fluid responsiveness among a broad range of patients in various clinical settings.[21] One of our objectives was to describe the differences in haemodynamic monitoring practices based on years in anaesthesia practice. For instance, the group with more years' experience may use the PAC more frequently than the group with less years' experience in anaesthesia as it is an older monitor. Conversely, the group with less years' experience may use the newer, minimally invasive monitors more frequently due to availability and differences in training. The impact of training and familiarity with the various equipment could not be elucidated as an important factor in the more experienced respondents as the numbers in each group were too low.

An Italian survey reported high usage of SvO_2 and $ScvO_2$ as surrogates for CO monitoring among anaesthesiologists, whereas there was an overall lower usage of these reported in our study.[17] Changes in SvO_2, which are obtained from a PAC, are directly proportional to changes in CO only when the arterial oxygen saturation, oxygen consumption and haemoglobin concentration remain constant.[18] In our study, 15.6% of respondents reported use of SvO_2; however, only one respondent reported use of a PAC. $ScvO_2$ is used as a surrogate for SvO_2 when a PAC is not available, but is affected disproportionately by changes in the upper body and does not reflect the SvO_2 of the coronary sinus blood.[18] SvO_2 is also less informative during surgery as hypoxaemia is usually corrected and oxygen consumption is decreased under general anaesthesia.[18] This finding calls to question the understanding of the difference between the two variables and the limitations of their use.

Although most of the respondents in our survey reported that their institution had no written protocols or guidelines concerning haemodynamic management of high-risk surgery patients, none of the respondents suggested it as a way of improving their current practice in this setting. A third of respondents in the Chinese survey reported having written protocols concerning haemodynamic management of high-risk surgery patients, but still regarded their haemodynamic practice as inadequate.[19] HICs have reviewed their baseline haemodynamic management practices in high-risk surgery patients and some have developed guidelines and protocols in this setting.[12,13,18,22,23] Haemodynamic monitoring and protocolised perioperative management standardise treatment in high-risk surgery patients, and have been shown to reduce complication rates but not mortality rates.[22] Personalised perioperative management of high-risk surgery patients individualises treatment and, hence, the variability of care, and the mixture of both protocols may be more beneficial than just using one method, since management has to be individualised for patients.[23]

The majority of the respondents in our study believed that their current haemodynamic practice in high-risk surgery patients could be improved, which was a similar finding in surveys conducted in other countries.[14,15,17,20]

Haemodynamic monitoring, however, is not a panacea. Clinicians have questioned the utility of haemodynamic monitoring based on the invasiveness of the monitoring device, its complications and costs.[24,25] The advent of enhanced recovery pathways have meant that goal-directed therapy is part of routine clinical practice, regardless of the monitor chosen to fulfil this purpose and thus clinical benefits from a monitoring device alone will not be found in trials.[24] Publication bias of trials with neutral or limited positive effects from haemodynamic monitoring and protocolised care limits our knowledge of the deleterious effects such as volume overload and its consequences.[24] Despite this, the future of haemodynamic monitoring holds promise of refined goals of therapy, monitoring of vasomotor tone as a parameter for optimisation, closed loop systems technologies and monitoring of microcirculatory flow markers.[24]

Limitations

The survey was conducted among specialist anaesthesiologists at the University of the Witwatersrand and cannot be generalised to other institutions. Practice is also influenced by monitoring techniques and equipment available at each institution and may not reflect the ideal monitoring that respondents would use in a well-resourced setting.

Conclusion

Anaesthesiologists at the University of the Witwatersrand frequently monitor and optimise IABP rather than CO in patients undergoing high-risk surgery. The respondents use dynamic parameters of fluid responsiveness as a surrogate for CO monitoring and indicators for volume expansion. Most of the respondents believed that their haemodynamic management could be improved, and these findings are specific to this institution. A national online survey may show differences in trends at different institutions and may better inform practice guidelines for South Africa.

Acknowledgements

To Dr Zainub Jooma, thank you for your guidance and support throughout this research project. Thank you to Dr Palesa Motshabi for being a positive force driving research in the department. Thank you to Dr Michel Muteba and Dr Moses Kebalepile for your assistance with the statistical analysis in this research project.

Conflict of interest

The authors declare no conflict of interest. This research project was completed as partial fulfilment of a Masters in Medicine degree.

Funding source

No funding was required.

Ethical approval

Approval to conduct the study was obtained from the University of the Witwatersrand Human Research Ethics Committee (M191160).

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Supplementary tables

Supplementary Table I: The timing that the respondents think haemodynamic optimisation is of the most value

	Total respondents (*n* = 64)	**< 5 years' experience (*n* = 33)**	**5–10 years' experience (*n* = 13)**	**> 10 years' experience (*n* = 13)**
Period of optimisation	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
Before induction of anaesthesia	36 (56.3)	20 (60.6)	6 (46.2)	8 (61.5)
During surgery	19 (29.7)	9 (27.3)	5 (38.5)	2 (15.4)
After induction of anaesthesia	2 (3.1)	1 (3.0)	0	0
In the postoperative period	1 (1.6)	0	1 (7.7)	0
No response	6 (9.4)	3 (9.1)	1 (7.7)	1 (7.7)

Supplementary Table II: Best predictors of an increase in CO following volume expansion

	Total respondents (*n* = 64)	**< 5 years' experience (*n* = 33)**	**5–10 years' experience (*n* = 13)**	**> 10 years' experience (*n* = 13)**
Predictor of increase in CO	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
Transoesophageal echocardiography (TOE)	20 (31.3)	11 (33.3)	4 (30.8)	4 (30.8)
Stroke volume variation (SVV)	11 (17.2)	7 (21.2)	1 (7.7)	2 (15.4)
Cardiac output (CO)	8 (12.5)	2 (6.1)	2 (15.4)	3 (23.1)
Blood pressure	4 (6.3)	0	0	1 (7.7)
Mixed venous saturation (SvO_2)	3 (4.7)	1 (3.0)	2 (15.4)	0
Pulse Pressure Variation (PPV), Systolic Pressure Variation (SPV)	3 (4.7)	1 (3.0)	1 (7.7)	1 (7.7)
Central venous pressure (CVP)	2 (3.1)	1 (3.0)	0	0
Global end diastolic volume (GEDV)	2 (3.1)	2 (6.1)	0	0
Central venous saturation ($ScvO_2$)	2 (3.1)	2 (6.1)	0	0
Clinical experience	1 (1.6)	0	1 (7.7)	0
Pulmonary capillary wedge pressure (PCWP)	1 (1.6)	0	0	0
Plethysmography waveform variation (PWV)	0	0	0	0
No response	7 (10.9)	5 (15.2)	0	1 (7.7)