Anaesthetists' knowledge of pulse contour cardiac output monitoring in a department of anaesthesiology

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg in partial fulfilment of the requirements for the degree of Master of Medicine in the branch of Anaesthesiology.

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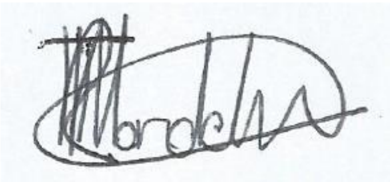
Declaration

I, Takudzwa Richard Mandebvu declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Medicine in the branch of Anaesthesiology at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



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Abstract

Background

An acceptable understanding of cardiac output measuring devices is essential for anaesthetists in order to appreciate their limitations and to safely apply their use during patient care. The aim of this study was to describe the knowledge of PiCCO among anaesthetists' working in the Department of Anaesthesiology at the University of the Witwatersrand.

Methods

A cross-sectional, contextual research design was employed in this study using a self-administered questionnaire. The study population consisted of all anaesthetists working in the department. Convenience sampling was used, and completion of the questionnaire implied consent. Adequate knowledge was determined as ≥62% using the Angoff method.

Results

The mean (SD) score obtained was 44.5% (17.6%), with seniors obtaining a significantly higher score than juniors (51.2% vs 39.1, p =0.0001). Of the 21 (14.0%) anaesthetists who had adequate knowledge, more seniors achieved an adequate score than juniors (76.2% vs 23.8%, p=0.0022). Sixteen registrars had adequate knowledge of which 12 (75%) had completed a cardiac rotation and 4 (25%) had not, with those having completed a cardiac rotation significantly achieving an adequate score than those that had not (p=0.0005). All anaesthetists with adequate knowledge had ICU exposure (p=0.0355). Anaesthetists scored the lowest in the performing of the transpulmonary thermodilution section with a mean (SD) score of 41.6% (21.9%).

Conclusion

Knowledge of the PICCO cardiac output monitoring technique was inadequate in a sample of anaesthetists in an academic anaesthesiology department. Seniority,

experience in cardiac anaesthesia or ICU are factors improving knowledge adequacy.

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Abbreviations

ARDS	Acute respiratory distress syndrome
CI	Cardiac index
COPD	Chronic obstructive pulmonary disease
CVP	Central venous pressure
EVLWI	Extravascular lung water index
GEDVI	Global end-diastolic volume index
ICU	Intensive care unit
PiCCO	Pulse contour cardiac output
PPV	Pulse pressure variation
PVPI	Pulmonary vascular permeability index
SVR	Systemic vascular resistance
SVV	Stroke volume variation
TPTD	Transpulmonary thermodilution

Statement

The Research Report consists of a literature review, draft article, study proposal and appendices. The study proposal is included for background reference and is not for examination.

The formatting of this Research Report complies with the University of the Witwatersrand's Style Guide for Theses, Dissertations and Research Reports. The formatting of the draft article may differ from the author guidelines of the Southern African Journal of Critical Care, the journal to which it is intended to be submitted, in order to comply with the University's style guide.

Section 1: Review of the literature

1.1 Introduction

“Haemodynamic optimization in critically ill patients is a complex task. Organ perfusion is not only determined by perfusion pressure but also by cardiac output. This necessitates accurate quantifications of cardiac output or at least precise detection of the change in the cardiac output peri-operatively as well as in the Intensive Care Unit.” (1)

Advanced haemodynamic monitoring can be defined as the monitoring of variables of circulatory function, which are not usually measured by basic operating theatre monitoring equipment. Examples of variables provided by advanced monitoring include cardiac output, systemic vascular resistance, pulmonary capillary wedge pressure, global end-diastolic volume and extravascular lung water (2).

One of the key roles of anaesthetists is interpreting and acting on the information provided by advanced haemodynamic monitoring. It is assumed that by early detection of pathophysiological haemodynamic derangements and subsequent early action, adverse patient outcomes could be avoided and overall outcome improved.

Monnet and Teboul (3) point out that the objective measure of cardiac output given by monitoring ensures that results remain objective and reproducible. This improves subjective clinical assessment paving the way for improved clinical decisions. A caveat mentioned by the authors highlights the importance of the contextual interpretation of the absolute cardiac output. The authors caution that cardiac output values should be interpreted in the context of the patient’s state of oxygen demand. A “high” cardiac output may be inadequate in a state of high oxygen demand, while a “low” cardiac output may be sufficient in a state of low oxygen demand (3).

The use of cardiac output monitoring has evolved over the past few decades, with the emergence of newer devices and potentially safer non-invasive devices (3-6). The choice of the appropriate method of cardiac output monitoring for a particular patient is challenging with the arsenal of different devices available (4). The invasiveness of the device (3, 4, 7), measurement performance (3, 4), ability to provide continuous cardiac output readings (4, 7, 8), need for calibration(4, 7, 8), provision of additional hemodynamic variables (4) and the clinicians' experience and expertise (4, 7, 8) all need to be considered when making the choice of cardiac output monitoring method. As with any data provided by monitoring technology, measured parameters are of little benefit unless prompting appropriate clinical action, again contextual to the unique clinical scenario at the time (3).

There are numerous advanced haemodynamic monitors available, and these monitors utilise different techniques. For effective monitoring choosing an appropriate parameter to monitor, knowing the limitations of the technology and reacting appropriately with a suitable treatment strategy is of utmost importance.

1.2 Haemodynamic monitors

The primary aim of anaesthesia is the maintenance of cell and organ homeostasis, therefore ensuring appropriate delivery of nutrients and oxygen is paramount (9). Cardiac output and vascular tone are pivotal factors in the maintenance of organ perfusion, therefore of oxygen delivery. Studies have shown that the identification and surveillance of variables that contribute to oxygen delivery, when tailored to an appropriate intervention in response to these variables, result in improved patient outcomes (10-14).

Determinants of oxygen delivery are haemoglobin concentration, haemoglobin oxygen concentration and cardiac output as expressed by the equation:

$$\mathrm{DO_2} = \mathrm{CaO_2} \times \mathrm{CO}$$

where DO_2 is oxygen delivery,
CaO_2 is arterial oxygen content and
CO is cardiac output.

As is evident in the formula, delivery of oxygen is dependent on the cardiac output; thus, safe and accurate knowledge of cardiac output measurement and associated corrective therapies is necessary for anaesthetists (3-5, 15, 16).

In 2019, Porhomayon et al (17) surveyed the utilisation of cardiac output monitoring devices among anaesthesiology programs in the United States of America. Ninety-seven of the 133 anaesthesiologists used cardiac output monitoring for the management of fluid optimisation and vasopressor support. The majority, 84, felt that cardiac output monitoring was clinically beneficial in terms of monitoring response to treatment (17).

1.3 Haemodynamic monitors

1.3.1 The ideal monitor

From the literature, it is evident that the search for the ideal cardiac output monitor is continuing. De Waal et al (18) outlined the properties of an ideal cardiac output monitor:

- appropriate for conscious, anaesthetised, sedated, intubated or non-intubated patients
- appropriate for adult or paediatric patients
- accurate and reproducible results
- provide continuous real-time data
- allow response to interventions to be tracked and targeted
- reliable under different physiological conditions
- require minimal specialised training
- easy to use
- assess preload or predict volume responsiveness
- assess contractility
- safe (18)

Although there is no “ideal” monitor available, an understanding of the development of cardiac output monitoring and the physical principles underlying the most widely used monitors is essential.

1.3.2 Contemporary cardiac output monitoring

In 1628 William Harvey was the first to correctly describe the circulation of blood (19). Theories and speculation regarding circulatory dynamics were replaced with facts based on accurate observation and experiment, thus prompting exponential developments in cardiac physiology and pathology (19-21).

Pasipoularides (22) noted that in 1661 the enigma of the cyclic interconversion of the venous and arterial circulating blood was explicated. The visualisation of capillaries under the microscope by Malpighi illustrated the link between the minute final terminations and initial branches of the arterial and venous systems. This being the missing link in Harvey's conception that the output of the heart determines life and organ function. Since it was recognised that the function of the heart and the subsequent output of blood determines life and organ function, the challenge was to find a simple and safe means to monitor and determine these factors. A number of methodologies and technologies have been developed over the past 150 years (22).

Traditional clinical indicators of cardiac output include monitoring urine output, skin temperature and capillary refill time, but all of these are characterised as insensitive and are considered late signs (1, 23). Lactate, an indicator of hypoxic metabolism and low perfusion state, is a non-continuous parameter and can be influenced by lactate-buffered solutions. Mixed venous oxygen saturation, an indicator of tissue oxygenation, reflects the oxygen supply and demand balance of the entire body and normal values cannot exclude hypoxia (1, 23, 24).

Cardiac output monitoring aims to discriminate the aetiology of cardiovascular dysfunction. The different constituents of haemodynamics, contractility, preload and afterload, are considered separately without disregarding the fact that they are part of a more extensive integrated system (23).

Saugel and Vincent (4) reviewed different methods available for the assessment of cardiac output, tailoring them to specific indications in intensive care and perioperative medicine. The authors classified methods for the assessment of cardiac output into the following categories:

- "invasive
    - thermodilution
    - pulse dye densitometry
    - lithium dilution

- minimally invasive
    - arterial waveform analysis
    - oesophageal Doppler
- non-invasive
    - pulse wave analysis
    - transthoracic impedance and bioreactance analysis
    - transthoracic Doppler
    - partial CO_2 rebreathing" (4).

Kobe et al (1) are of the opinion that it is useful to discuss contemporary monitoring techniques by the underlying technology. The authors classified the major principles and techniques of cardiac output measurement into:

- "the Fick principle
- indicator dilution techniques that include
    - thermodilution
    - pulse dye densitometry
    - lithium dilution technique
- arterial waveform analysis technique" (1).

These principles and techniques will be briefly discussed.

The Fick principle

In 1870, Adolf Fick first described a way of measuring cardiac output in humans, which would later be known as the Fick principle (1, 25, 26). Fick postulated that the total uptake or release of oxygen by the lungs is the product of blood flow through the lungs and the arteriovenous oxygen content difference. From this hypothesis, cardiac output could be calculated by dividing the oxygen consumption by the difference between the arterial and mixed venous oxygen content. Despite this technique being very accurate, it is not practical for bedside use and cannot be routinely applied in clinical practice (1, 4).

The equation for the Fick principle is:

$$\mathrm{CO} = \frac{\mathrm{VO_2}}{(\mathrm{CaCO_2} - \mathrm{CvO_2})\ \times 100}$$

where CO is cardiac output,

VO_2 is the oxygen consumption,

CaO_2 and CvO_2 refer to the arterial and mixed venous oxygen content, respectively (1).

The non-invasive cardiac output (NICO) system utilises a modification of the Fick principle, using carbon dioxide to obtain cardiac output measurements in intubated, sedated and mechanically ventilated patients. The monitor consists of a proprietary disposable rebreathing loop that is attached to the ventilator circuit, a mainstream infrared carbon dioxide sensor, a disposable airflow sensor and a pulse oximeter (1, 6, 23, 25). Carbon dioxide production is calculated as a product of carbon dioxide concentration and airflow during a breathing cycle. Arterial carbon dioxide content is derived from the end-tidal carbon dioxide with adjustments for the slope of the carbon dioxide dissociation curve and the degree of dead space ventilation (1, 25).

The attached rebreathing loop generates a partial rebreathing state every three minutes that results in increased end-tidal carbon dioxide and reduced carbon dioxide elimination. The difference between normal and rebreathing ratios is used to calculate cardiac output with an assumption that cardiac output does not change significantly between normal and rebreathing states (1, 4). There are several limitations to the use of this device due to various requirements such as intubation, mechanical ventilation with fixed ventilator settings and minimum gas exchange abnormalities (1, 27).

Indicator dilution techniques

All techniques in the category of indicator dilution techniques rely on an understanding of the Stewart-Hamilton equation, as illustrated in Figure 1.

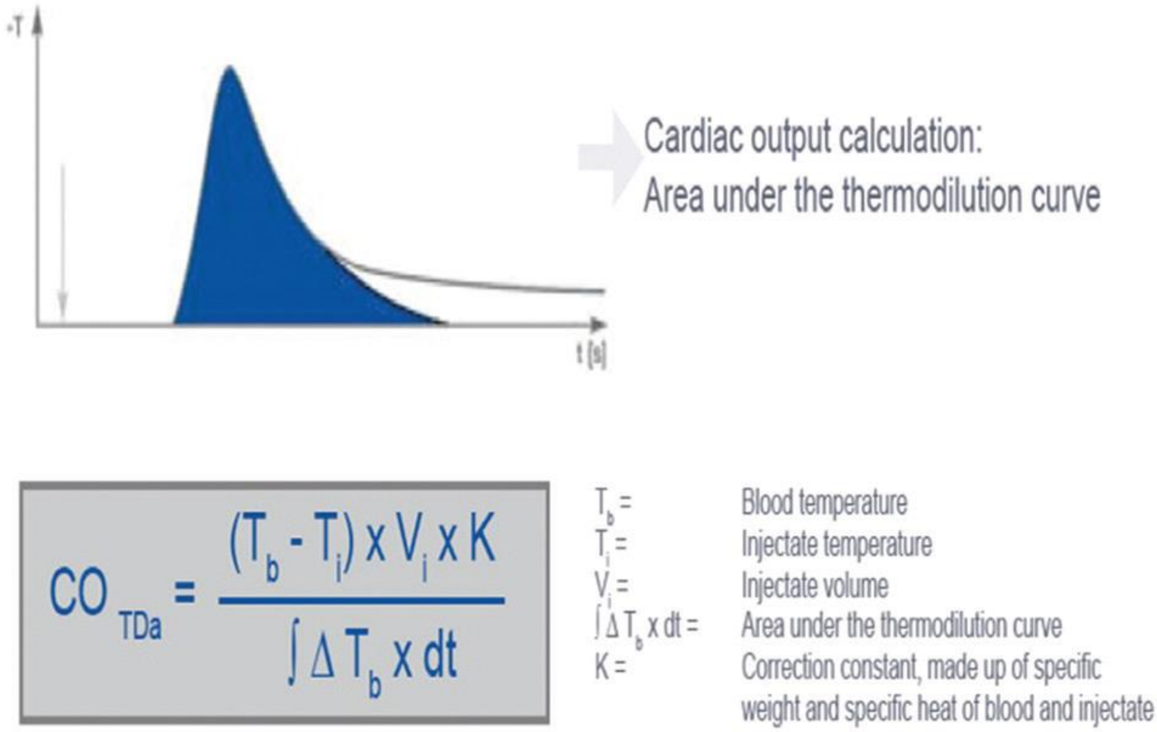

Figure 1:Calculation of cardiac output by measuring the area under the thermodilution curve using the Stewart Hamilton equation (1)

Kobe et al (1) state that a known temperature of cold saline or a known concentration of dye or lithium is instilled into the venous circulation, and analysis of the blood sample taken from either the right ventricular outflow tract or an arterial source, such as a radial arterial catheter. The change in temperature, dye or lithium concentration is proportional to the cardiac output. This relationship is quantified using the Stewart Hamilton equation, and a cardiac output number can be generated (1).

In 1929 Forssmann clandestinely catheterised his own heart assisted by a nurse who had previously volunteered for the procedure. He then walked to the X-ray room located in the basement of the hospital to visualise it under fluoroscopy, whereupon he advanced it until he visualised the tip in the right ventricle (21, 28). Inspired by this procedure, further experiments conducted by Cournard and Richards in 1941 resulted in the measurements of the right atrial, right ventricle and subsequently pulmonary artery pressures (29). In earlier work by Cournard, he obtained mixed venous blood from the heart in order to calculate total pulmonary blood flow using Fick's principle (1, 13, 25).

The ability to directly measure right heart and pulmonary pressures revolutionised interventional cardiology. Forssmann, Cournand and Richards received the Nobel Prize for Medicine and Physiology in 1956 for their work (28, 29).

Thermodilution

Different catheters were developed over the next 14 years, but none could be used at the bedside without fluoroscopy until Swan and Ganz introduced the balloon flotation flow-directed catheter in 1970, which is illustrated in Figure 2 (21, 30). This then allowed its clinical application in the management of unstable and critically ill patients (30).

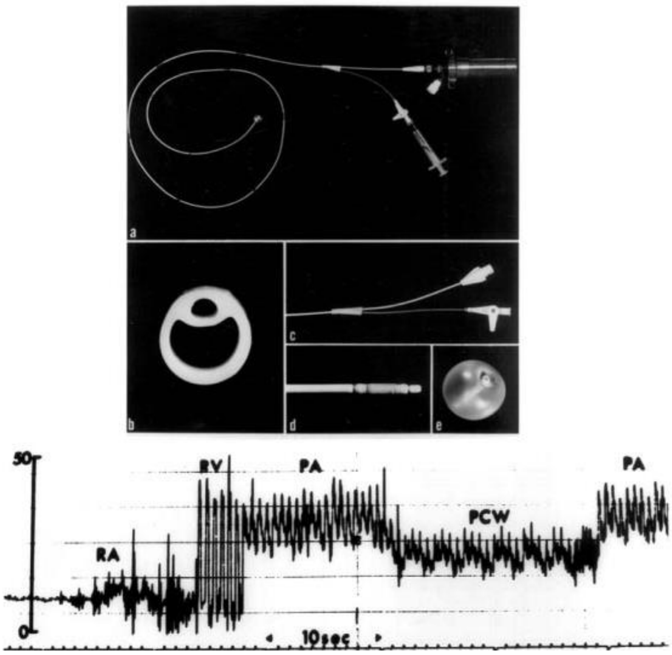

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Figure 2:The double lumen balloon flotation catheter and its placement at the bedside without fluoroscopy and by monitoring intracardiac pressures (30)

RA indicates right atrium; RV, right ventricle; PCW, pulmonary capillary wedge; and PA, pulmonary artery

The thermodilution technique is the basis on which the pulmonary artery catheter functions. A predetermined amount of cold saline is injected into the proximal port of a pulmonary artery catheter, and thermal variations of the blood are measured. Using the Stewart-Hamilton equation (31), cardiac output is derived from the thermodilution curve generated. Its use has resulted in improved knowledge of cardiovascular physiology and pathophysiology, specifically in anaesthesia and critical care (1, 26, 32).

Studies have shown that the pulmonary artery catheter does not improve outcome and may cause harm with adverse effects such as valvular damage, arrhythmias and sepsis described. This has discouraged its widespread use, and less invasive alternatives have thus emerged (7, 31, 33-36). Despite these issues, the pulmonary artery catheter is still regarded as the closest to a gold standard cardiac output monitoring device available (31).

There are many common sources of error using the thermodilution technique, including the temperature and the volume of the injectate, timing during respiration, rate of injection, presence of shunts and cardiac valvular abnormalities (1, 37). Significant mortality and morbidity have been attributed to the invasiveness of pulmonary artery catheters as well as from the misinterpretation of the data obtained from its use (36, 38).

Pulse dye densitometry

Pulse dye densitometry estimates the arterial concentration of indocyanine green after intravenous bolus injection. A fingertip sensor is used to detect the dye concentration non-invasively after passage through the pulmonary circulation. The relative ratio of the dye concentration is used to calculate cardiac output (1, 21). Baulig et al (39) concluded that pulse dye densitometry using indocyanine green is inaccurate due to a high incidence of low pulse dye densitometry signal amplitudes in their study of 28 patients in 2005.

Hori et al (40) in 2008 advocated the advantageous use of non-invasive, simple and real-time measurement of cardiac output with pulse dye densitometry in a study of 28 liver transplant recipients. The evidence concerning pulse dye densitometry remains conflicted mainly due to the limited literature regarding its use (1, 39, 40).

Lithium dilution technique

The lithium dilution technique uses a bolus of lithium chloride, which is injected through a venous catheter, upon which the concentration of lithium is measured by a sensor attached to an indwelling arterial catheter. The resulting lithium concentration versus time curve is used to calculate plasma flow and, therefore, cardiac output using the Stewart-Hamilton equation (1). The measured cardiac output is then used as to provide continuous cardiac output monitoring using pulse contour analysis. Pulse contour analysis is described in more detail in the following section.

In the review by Reuter et al (41), the authors noted limitations of the lithium dilution technique in the presence of non-depolarising neuromuscular blocking agents, especially atracurium and rocuronium. The cross-reaction of these muscle relaxants with the lithium sensor at high peak doses leads to an overestimation of cardiac output.

Arterial waveform analysis

In 1899, Otto Frank conceived that blood flow changes could be measured using the blood pressure waveform. Working on this premise, Erlanger and Hooker, in 1904, described the principle of pulse pressure analysis in the estimation of stroke volume using aortic-arterial pulse pressure. Multiple methods have since been described using these same principles that are collectively referred to as pulse contour analysis methods (1).

The pulse intermittent and continuous cardiac output (PiCCO) monitor provides cardiac output measurements by use of a central venous catheter and arterial line with a thermistor. Using a transpulmonary thermodilution technique where a cold fluid is injected through the central line, the intermittent cardiac output is measured. Applying the Stewart Hamilton equation, the area under the thermodilution curve is then used to calculate the cardiac output. An algorithm based on the analysis of the arterial pulse contour is used to continuously monitor cardiac output and stroke volume, allowing assessment of cardiac output in changing preload conditions and beat to beat variations of stroke volume (26). In the absence of cardiac arrhythmias, stroke volume variation and pulse pressure variation have been proposed as variables to guide fluid loading in critical care settings (42, 43).

Additional measurements of global end-diastolic volume, intrathoracic blood volume and extravascular lung water can be obtained by the PiCCO. From these values, systemic vascular resistance, contractility, global ejection fraction, pulmonary vascular permeability index and pulmonary blood volume can be derived, which can be indexed to body surface area and predicted body weight. The PiCCO has a number of advantages over the pulmonary artery catheter including, the provision of continuous cardiac output monitoring rapidly available measurements allowing the assessment of fluid responsiveness. It is less invasive and is supported by data in humans that show a good correlation between intermittent and continuous transpulmonary thermodilution cardiac output with the pulmonary artery catheter as the gold standard (26).

The need for a specialised arterial line typically placed in the femoral artery, a central venous line ideally placed in the jugular or subclavian vein and regular calibration, with a cold fluid bolus three to four times a day are deterrents to the use of the PiCCO (26, 44). The PiCCO obtained variables of pulse pressure variation and stroke volume variation are in the absence of cardiac arrhythmias and in sedated patients receiving controlled mechanical ventilation. This then precludes the use of PiCCO in clinical conditions with low heart rate or respiratory rate ratio, irregular heartbeats, intra-aortic balloon counterpulsation, increased abdominal pressure, spontaneous breathing, open thorax and mechanical ventilation with low tidal volume (45)

The pulse pressure analysis model to calculate the stroke volume using the arterial waveform is shown in Figure 3 and the derivation of cardiac output from the pulse pressure analysis of the arterial waveform is shown in Figure 4.

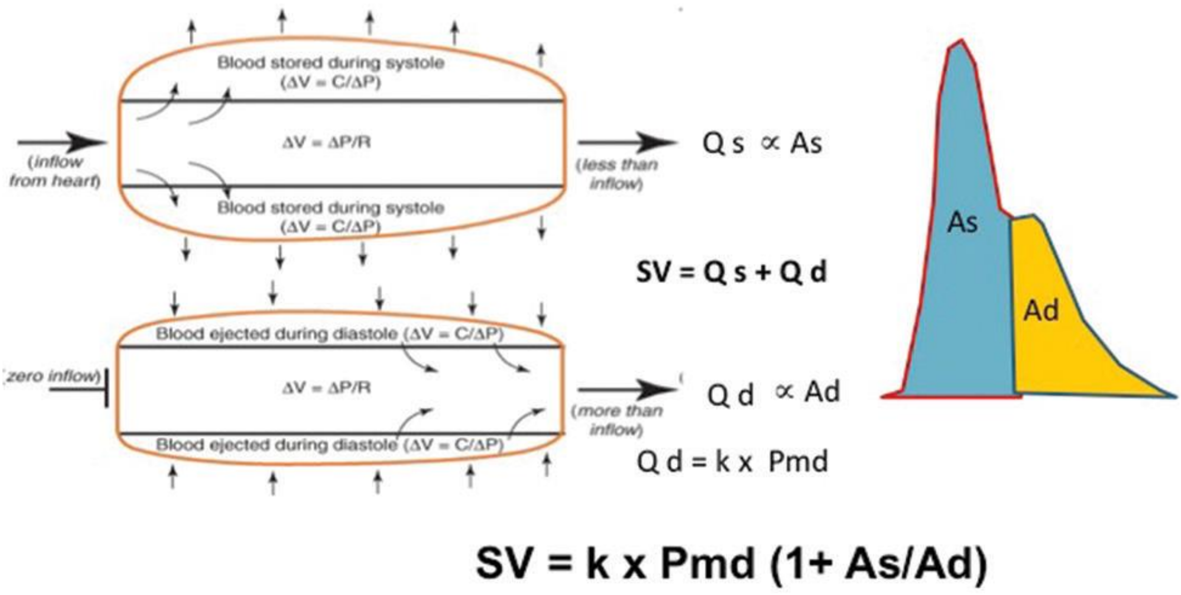

Figure 3:Pulse pressure analysis model to calculate the stoke volume using the arterial waveform (1)

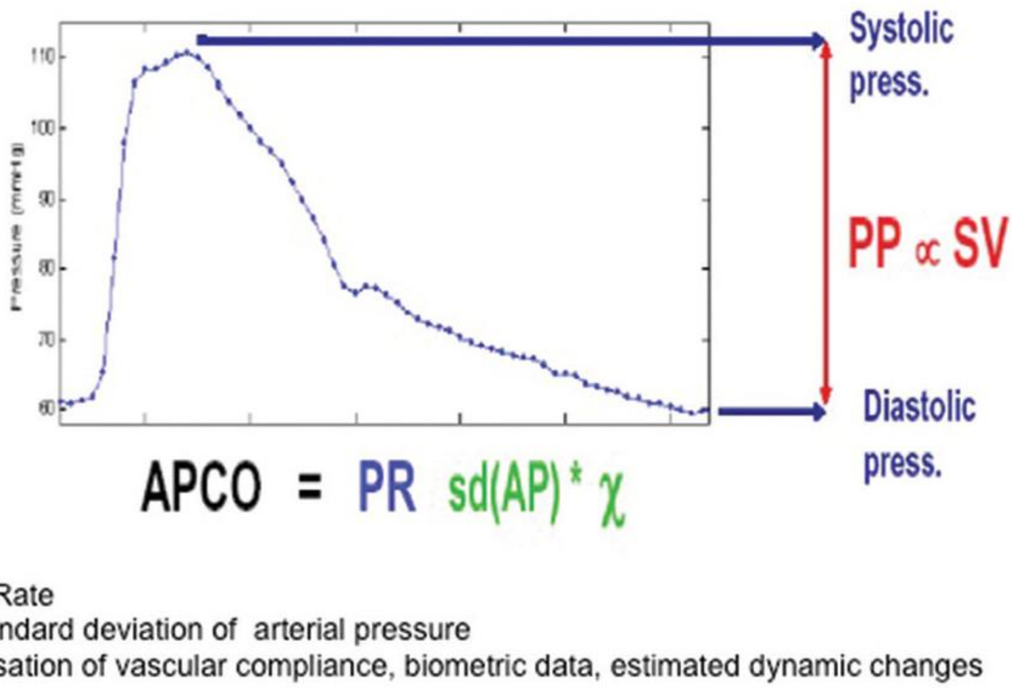

Figure 4:Derivation of cardiac output from the pulse pressure analysis of the arterial waveform (1)

Rodig et al (46), in 1999, and Godje et al (47), in 2002, showed a good correlation between pulse contour analysis and the gold standard pulmonary artery thermodilution technique in their studies of 26 patients undergoing coronary artery bypass surgery and 24 patients in a cardiac surgical intensive care unit, respectively.

In 2007, Manecke and Auger (48) performed a prospective observational study involving 295 measurements from 50 postoperative cardiac surgical patients in the postoperative period following cardiac surgery. It was shown that pulse contour analysis used in the Edwards Vigileo/FloTrac system was not only accurate but also precise when compared to the pulmonary artery catheter, making it suitable for use in clinical settings.

McGee et al (49) performed a multicentre prospective study comparing measurements of cardiac output by arterial pressure-based cardiac output analysis with intermittent thermodilution cardiac output via the pulmonary artery catheter. A total of 84 patients were enrolled from two hospitals in the United States of America, one hospital in France and one hospital in Belgium. The authors concluded that in critically ill patients in the intensive care unit, continuous measurement of cardiac output using arterial pulse analysis is comparable to the gold standard of thermodilution using the pulmonary artery catheter (49).

1.4 Knowledge of advanced haemodynamic monitoring among physicians

Only one study (44) evaluating the knowledge of pulse contour cardiac output monitoring could be identified. The majority of studies evaluating the knowledge of haemodynamic monitoring addressed various aspects of the pulmonary artery catheter. A few of the pulmonary artery catheter studies will be briefly discussed as they highlight the lack of knowledge of advanced haemodynamic monitoring.

Iberti et al (50) in 1990 administered a multiple-choice examination to 496 physicians practising in 13 medical facilities in the United States of America and Canada to assess their knowledge and understanding of the use of the pulmonary artery catheter and interpretation of the data derived. From the 31 questions asked, the mean test score was 66.8%, with a range of 19.4 – 100%. Mean scores varied independently by training, frequency of use of pulmonary artery catheter data in patient treatment, frequency of inserting a pulmonary artery catheter, and whether the respondent's hospital was a primary medical school affiliate. The authors recommended the use of the pulmonary artery catheter be restricted to individuals with documented competency (50).

In 1996 Trottier and Taylor (51) sent a confidential survey to 5 000 physician members of the Society of Critical Care Medicine and 1 095 surveys were returned. The two-part survey consisted of 20 questions regarding the physicians' attitudes towards the pulmonary artery catheter. Thirty-one questions addressed the physicians' knowledge of the pulmonary artery catheter, using the Iberti et al (50) questionnaire. The authors found that the mean test score for the multiple-choice questions was 82.6%, with a range of 9.7 – 100%. The mean score was found to be significantly associated with the following variables: speciality, practice pattern, number of pulmonary artery catheter insertions performed per month and whether or not the physician was trained and/or certified in critical care medicine. At the time of the study, the value of the pulmonary artery catheter was questioned in the intensive care community. The authors recommended that rather than withdrawing the pulmonary artery catheter, the development and maintenance of educational and continuous quality improvement guidelines pertaining to the use of the pulmonary artery catheter should be implemented (51).

Johnston et al (52) performed a survey in 2008 in 151 participants in Australia and reported an average score of 82.7%, with a range of 53.3 – 100%. The total score was significantly associated with years of experience in intensive care, the number of pulmonary catheters inserted and whether or not the respondent had passed the Joint Faculty of Intensive Care Medicine examination.

In 2014 Hofkens et al (44) performed a web-based survey on the knowledge of pulse contour cardiac output in 252 participants and reported an average score of 58.3% (SD 15.1%). In addition to assessing the knowledge of transpulmonary thermodilution, the survey assessed knowledge, limitations and interpretation of pulse contour intermittent and continuous cardiac output monitoring. A mark of 50% and 70% was required to pass for nurses and doctors, respectively. Having five years of pulse contour cardiac output monitoring experience, which was present in 15.8% of participants correlated with passing the test. Forty-three percent of participants thought that PiCCO was an invasive procedure. The authors noted insufficient basic knowledge on cardiac output calibration, with 23.3% unaware that the temperature of the bolus injectate should be below 8 °C. Only 21.8% correctly stated that the volume of the injectate should be adjusted according to body weight, with a maximum of 20 ml. Sixty-four percent of participants knew the rate of injectate administration of 2.5 ml per second, but 60.7% incorrectly thought the patient needs to be supine while performing transpulmonary thermodilution measurement. Regarding calibration, 54.8% correctly stated that the PiCCO needs to be calibrated only once every shift. Still, only 36.1% knew that a rapid flush test is performed before each measurement, while 36.9% did not know why there is a need to perform a rapid flush test. Pertaining to the application, 41.7% knew that stroke volume variation is unreliable if the patient is not in sinus rhythm, but 26.6% did not recognise atrial fibrillation as an underlying rhythm in the illustrated image (44).

1.5 Summary

Haemodynamic monitoring is the cornerstone in the optimisation of tissue perfusion and the prevention of deteriorating metabolism. Therapeutic decisions derived from these values need to be assessed by an expert physician. In-depth knowledge of the advantages and limitations of the monitoring devices used is required for safe and competent use of these devices.

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Acknowledgements

In a separate section, acknowledge any financial support received or possible conflict of interest. This section may also be used to acknowledge substantial contributions to the research or preparation of the manuscript made by persons other than the authors.

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Cite references in numerical order in the text, in superscript format (Format> Font> Click superscript). Please do not use brackets or do not use the foot note function of MS Word.

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The following are sample references:

1. Jun BC, Song SW, Park CS, Lee DH, Cho KJ, Cho JH. The analysis of maxillary sinus aeration according to aging process: volume assessment by 3-dimensional reconstruction by high-resolutional CT scanning. Otolaryngol Head Neck Surg. 2005 Mar;132(3):429-34.
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4. All author details (Full names, Qualifications and affiliation) must be provided.

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7. References must strictly be in Vancouver format. (Reference numbers must be strictly numerical and be typed in superscript, not be in brackets and must be placed AFTER the full stop or comma.)
8. It must be clear where every figure and table should be placed in the text. If possible, tables and figures must be placed in the text where appropriate. If too large or impractical, they may be featured at the end of the manuscript or uploaded as separate supplementary files.
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Section 3: Draft article

Anaesthetists' knowledge of pulse contour cardiac output monitoring in a department of anaesthesiology

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Keywords: knowledge, pulse contour cardiac output, anaesthetists

Abstract

Background

An acceptable understanding of cardiac output measuring devices is essential for anaesthetists in order to appreciate their limitations and to safely apply their use during patient care. The aim of this study was to describe the knowledge of PiCCO among anaesthetists' working in the Department of Anaesthesiology at the University of the Witwatersrand.

Methods

A cross-sectional, contextual research design was employed in this study using a self-administered questionnaire. The study population consisted of all anaesthetists working in the department. Convenience sampling was used, and completion of the questionnaire implied consent. Adequate knowledge was determined as ≥62% using the Angoff method.

Results

The mean (SD) score obtained was 44.5% (17.6%), with seniors obtaining a significantly higher score than juniors (51.2% vs 39.1, p =0.0001). Of the 21 (14.0%) anaesthetists who had adequate knowledge, more seniors achieved an adequate score than juniors (76.2% vs 23.8%, p=0.0022). Sixteen registrars had adequate knowledge of which 12 (75%) had completed a cardiac rotation and 4 (25%) had not, with those having completed a cardiac rotation significantly achieving an adequate score than those that had not (p=0.0005). All anaesthetists with adequate knowledge had ICU exposure (p=0.0355). Anaesthetists scored the lowest in the performing of the transpulmonary thermodilution section with a mean (SD) score of 41.6% (21.9%).

Conclusion

Knowledge of the PICCO cardiac output monitoring technique was inadequate in a sample of anaesthetists in an academic anaesthesiology department. Seniority, experience in cardiac anaesthesia or ICU are factors improving knowledge adequacy.

Introduction

A key responsibility of the anaesthetist is to ensure adequate global oxygen delivery to a patient undergoing a surgical procedure. During anaesthesia, the inability to clinically determine oxygen delivery accurately necessitates objective variables of cardiac output adequacy. Therefore, it is essential that anaesthetists have adequate knowledge of cardiac output monitoring techniques. The benefits of having a tool that can be utilised to target a specified therapeutic endpoint have repeatedly been shown to improve patient outcomes (1-5). The early detection of pathophysiological haemodynamic derangements through cardiac output monitoring and subsequent appropriate intervention facilitates patient recovery in both the perioperative and critical care settings (1).

The gold standard for cardiac output monitoring has been invasive monitoring with a pulmonary artery catheter (2), however, this fell out of favour due to concerns regarding increased morbidity associated with its use. Alternative minimally invasive cardiac output monitors are now available, such as pulse contour cardiac output monitoring devices, which do not require the insertion of a pulmonary artery catheter. Pulse contour analysis cardiac output monitors analyse the arterial waveform to determine the cardiac output. These monitors can be uncalibrated, which are less accurate, or calibrated with an indicator.

The pulse contour, intermittent and continuous cardiac output (PiCCO) uses the principle of pulse contour analysis calibrated with transpulmonary thermodilution (TPTD). It is a well-validated reference method of transpulmonary thermodilution. The thermal indicator avoids the need for a chemical indicator, such as lithium dilution cardiac output, thus preventing adverse effects or chemical accumulation. TPTD determination of cardiac output can be used in awake or anaesthetised patients, whether ventilated or breathing spontaneously and is not influenced by the ventilator cycle (6, 7). PiCCO, in addition, has predictors of fluid responsiveness for fluid optimisation strategies and is appropriate for use in paediatric patients as well. PiCCO offers numerous other variables allowing for a comprehensive cardiac assessment, and its assessment of extravascular lung water is a predictor of patient outcome in acute respiratory distress syndrome (8, 9).

Understanding the underlying principles of cardiac output measuring devices helps in knowing the limitations of their use and allows more effective and safer utilisation (2, 10, 11). At present, no single cardiac output monitoring device meets all the clinical requirements, considering the limitations of diverse cardiac output monitoring techniques (2). Little is known about health care workers' knowledge of the basic principles and practical implementation of TPTD measurements at the bedside or on the operating table (12). The aim of this study was to describe the knowledge of PiCCO among anaesthetists working in the Department of Anaesthesiology at the University of the Witwatersrand (Wits).

Methods

Approval to conduct the study was obtained from the Wits Human Research Ethics Committee (Medical) (M200269) and other relevant authorities. A cross-sectional research design was followed.

The study population consisted of anaesthetists working in the Department of Anaesthesiology at Wits. Convenience sampling was used, and the sample size was determined by the number of anaesthetists responding. A minimum response rate of 60% (n=124) was considered acceptable (13). Anaesthetists who decline participation and questionnaires that are less than 80% complete were excluded from the study. A junior anaesthetist was regarded as a medical officer or a registrar with <4 years of training and a senior anaesthetist as a registrar with ≥4 years of training or a consultant.

Based on an extensive literature review, a 2015 questionnaire by Hofkens et al (12) was identified. Permission to use and adapt the questionnaire for the South African context was obtained from the corresponding author. The adapted questionnaire was reviewed by three senior anaesthesiologists with an interest and experience in cardiac output monitoring, thereby ensuring face and content validity. The reviewers' comments were incorporated into the final questionnaire. The final questionnaire contained 40 questions in six sections, namely:

- Section 1: characteristics of the participants
- Section 2: knowledge of the PiCCO
- Section 3: knowledge regarding performing TPTD

- Section 4: knowledge of the limitations of PiCCO
- Section 5: knowledge regarding the interpretation of haemodynamic parameters from the PiCCO
- Section 6: knowledge of the management of haemodynamic problems based on variables derived from cardiac output monitors.

Due to the COVID 19 pandemic, the questionnaire was distributed via Google Forms by the clinical heads of the department to 180 anaesthetists in the department. Questionnaires that were less than 80% completed were included for response rate calculation but not included in the study. Unanswered questions were regarded as incorrect. Adequate knowledge (pass mark) of ≥62% was determined using the modified Angoff method (14).

Data were analysed in consultation with a biostatistician using the statistical program STATA version 15 (StataCorp, USA). Categorical variables were described using frequencies and percentages and compared using Fisher's exact and Chi-squared tests. Continuous variables were normally distributed and reported using means and standard deviations. Comparisons between the two groups (juniors and seniors) were made using unpaired t-tests. A p-value of ≤0.05 was considered statistically significant.

Results

A total of 180 questionnaires were sent out and 152 (84.4%) were returned. Of these, 2 (1.1%) were discarded as they were incomplete, resulting in a sample realisation of 150 (83.3%) anaesthetists. This represents 72.8% of anaesthetists in the department. The characteristics of the anaesthetists are illustrated in Table 1. There were 68 (45.3%) senior and 82 (54.7%) junior anaesthetists.

Table 1: Characteristics of anaesthetists

Characteristics	Number	Percentage
Sex		
Male	58	38.7
Female	92	61.3
Professional designation		
Medical officer	24	16.0
Registrar <4 years	58	38.7
Registrar ≥4 years	34	22.7
Consultant	33	22.0
Critical care fellow	1	0.7

Of the 150 anaesthetists included, 23 (15.3%) had not worked in an ICU, with 101 (67.3%) and 26 (17.3%) having worked in an ICU less than 5 years ago and 5 or more years ago respectively. With regards to the use of cardiac output monitoring 68 (45.3%) used it less frequently than once a month, 31 (20.7%) never used it, 26 (17.3%) a few times a month, 9 (6.0%) once a month, 7 (4.7%) a few times a week, 5 (3.3%) once a week, 2 (1.3%) every day and 2 (1.3%) most days. Regarding utility of cardiac output monitors 110 (73.3%) have used pulse contour cardiac output monitoring (e.g Vigileo), 53 (35.3%) Svo2 or lactate, 48 (32.0%) the PiCCO, 27 (18.0%) have never used any, 26(17.3%) oesophageal doppler and 21 (14.0%) the pulmonary artery catheter. The most preferred method of cardiac output monitoring was pulse contour cardiac output 59 (39.3%), followed by the PiCCO 23 (15.3%), and then oesophageal doppler 14 (9.3%).

The mean (SD) score obtained by the anaesthetists was 44.5% (17.6%), significantly (p=0.0001) juniors obtained 39.1% (17.3%) and seniors 51.2% (15.8%). Only 21 (14.0%) anaesthetists had adequate knowledge (≥62%), of which 5 (23.8%) were juniors and16 (76.2%) were seniors with significantly more seniors achieving an adequate score than juniors (p=0.0022). The scores for the questionnaire overall and per section, the scores for the juniors and seniors and the comparisons of these scores are shown in Table 2. Table 3 shows the comparisons between those who had adequate knowledge and those who did not for the questionnaire overall and per section. Only registrars were included in the cardiac rotation analysis. Sixteen registrars had adequate knowledge of which 12 (75%) had completed a cardiac rotation and 4 (25%) had not, with those having completed a cardiac rotation significantly achieving an adequate score than those that had not (p=0.0005). All anaesthetists with adequate knowledge had ICU exposure (p=0.0355) .Anaesthetists scored the lowest in the performing of the transpulmonary thermodilution section with a mean (SD) score of 41.6% (21.9%).

Table 2: The scores for the questionnaire overall and per section, the scores for the juniors and seniors and the comparisons of these scores

Section (score)	Overall	Juniors	Seniors	p-value
	Mean (SD) Mean (SD) %			
Overall (33)	14.7 (5.8) 44.5 (17.6)	12.9 (5.7) 39.1 (17.3)	16.9 (5.2) 51.2 (15.8)	<0.0001
PiCCO monitoring (5)	2.4 (1.2) 48.1 (23.2)	2.2 (1.1) 43.4 (21.5)	2.7 (1.2) 53.8 (24.0)	0.0032
Performing TPTD (6)	2.5 (1.3) 41.6 (21.9)	2.2 (1.4) 36.0 (22.8)	2.9 (1.1) 48.3 (18.9)	0.0002
PiCCO limitations (8)	3.8 (1.8) 47.8 (22.5)	3.5 (1.8) 44.2 (22.8)	4.2 (1.7) 52.0 (21.6)	0.0165
Interpreting HD parameters (11)	4.6 (2.7) 41.9 (24.8)	3.8 (2.4) 34.5 (21.8)	5.6 (2.8) 50.9 (25.3)	<0.0001
Managing HD parameters (3)	1.3 (1.0) 44.9 (33.4)	1.2 (1.1) 40.2 (35.8)	1.5 (0.9) 50.5 (29.6)	0.0286

Table 3: Comparisons between those who had adequate knowledge and those who did not for the questionnaire overall

Group	N	Score ≥62%	Score <62%	p-value
		n (%)		
Juniors	82	5 (6.1)	77 (93.9)	0.0022
Seniors	68	16 (23.5)	52 (76.4)	
ICU exposure	127	21 (16.5)	106 (83.5)	0.0355
No ICU exposure	23	0	23 (100)	
Cardiac rotation	34	12 (35.3)	22 (64.7)	0.0005
No cardiac rotation	58	4 (6.8)	55(93.2)	

The number of correct answers per question is shown in Table 4.

Table 4: Number of correct answers per question

Question Description	Number of correct answers		
	Overall n = 150 n (%)	Juniors n = 82 n (%)	Seniors n = 68 n (%)
PiCCO monitoring			
Acronym PiCCO represent	114 (76.0)	58 (70.7)	56 (82.3)
Principles used with PiCCO	94 (62.7)	47 (57.3)	47 (69.1)
Parameters measured by PiCCO	15 (10.0)	5 (6.10)	10 (14.7)
Invasiveness of PiCCO monitoring	71 (47.3)	36 (43.9)	35 (51.4)
Appropriate use of PiCCO	67 (44.7)	32 (39.0)	35 (51.4)
Performing TPTD			
Requirements to perform PiCCO	83 (44.7)	39 (47.6)	44 (64.7)
Injectate temperature	26 (17.3)	18 (22)	8 (11.7)
Determinant of volume injectate	69 (46.0)	36 (43.9)	33 (48.5)

Question Description	Number of correct answers		
	Overall n = 150 n (%)	Juniors n = 82 n (%)	Seniors n = 68 n (%)
Anthropometry requirements	109 (72.7)	49 (59.8)	60 (88.2)
Positioning relative to measurements	9 (6.0)	4 (4.9)	5 (7.4)
Number of measurements required	78 (52.0)	31 (37.8)	47 (69.1)
Limitations of PiCCO monitoring			
Deviation from the mean CO*	46 (30.7)	27 (32.9)	19 (27.9)
Values for volumes and EVLW*	38 (25.3)	12 (14.6)	26 (38.2)
Calibration of PiCCO arterial curve	18 (12.0)	5 (6.1)	13 (19.1)
Indication for rapid flush	94 (62.7)	52 (63.4)	42 (61.8)
Frequency of rapid flush	69 (46.0)	33 (40.2)	36 (52.9)
Curve 1: normal signal	106 (70.7)	56 (68.3)	50 (73.5)
Curve 2: augmented signal	98 (65.3)	54 (65.9)	44 (64.7)
Curve 3: damped signal	104 (69.3)	51 (62.2)	53 (77.9)
Interpretation of haemodynamic parameters			
Placement	128 (85.3)	66 (80.5)	62 (91.2)
Optimal positioning	106 (70.7)	53 (64.6)	53 (77.9)
Rate of Injectate	52 (34.7)	28 (34.1)	24 (35.3)
Delta T	57 (38.0)	23 (28.0)	34 (50.0)
Injectate interpretation	34 (22.7)	14 (17.1)	20 (29.4)
CVP* and PiCCO	35 (23.3)	15 (18.3)	20 (29.4)
Curve 1: incorrect thermodilution curve	49 (32.7)	17 (20.7)	32 (47.1)
Curve 2: correct thermodilution curve	57 (38.0)	22 (26.8)	35 (51.5)
Curve 3: incorrect thermodilution curve	48 (32.0)	17 (20.7)	31 (45.6)
Rhythm determination	85 (56.7)	39 (47.6)	46 (67.6)

Question Description	Number of correct answers		
	Overall n = 150 n (%)	Juniors n = 82 n (%)	Seniors n = 68 n (%)
PiCCO reliability	41 (27.3)	17 (20.7)	24 (35.3)
Management of haemodynamic parameters			
Haemodynamic management	61 (40.7)	30 (36.6)	31 (45.6)
Fluid management	64 (42.7)	33 (40.2)	31 (45.6)
Ventilatory strategy	77 (51.3)	36 (43.9)	41 (60.3)

*CO= cardiac output, EVLW = extravascular lung water, CVP =central venous pressure

Discussion

It is important to be competent with the use and limitations of different cardiac output monitoring techniques (15). In our study, there was inadequate knowledge (44.5%) of pulse contour cardiac output monitoring, specifically related to those monitors calibrated by transpulmonary thermodilution (for example, the PiCCO monitor). This low score may be attributed to a lack of clinical exposure and training in the use of PiCCO. It essential that anaesthetists have adequate knowledge of cardiac output monitoring as it impacts on clinical decision making (2, 10, 12, 16) It was difficult to compare the results with other studies as our study focused on anaesthetists, whereas a previous similar study (12) assessed knowledge of nurses and doctors working in ICU Doctors in the study by Hofkens et al (12), achieved a mean score of 62.7% and nurses a mean score of 57.0%. With an overall score of 58.3% the authors stated that knowledge was suboptimal. Most knowledge studies were based on the pulmonary artery catheter which has fallen out of use due to safety concerns (17-20).

In our study, the section on interpreting haemodynamic parameters had a mean score of 41.9% compared to the study by Hofkens et al (12), who had a mean score of 60.2%. This may be attributed to the fact that nurses and doctors working in ICU use PiCCO more frequently than anaesthetists, implying the effect of experience on knowledge. This is evident in our study as illustrated in the comparison of ICU exposure to no ICU exposure, where no anaesthetist without ICU exposure had adequate knowledge. Registrars were three times more likely to have adequate knowledge if they had completed their cardiac rotation.

The questions obtaining the lowest scores in our study were those pertaining to performing TPTD, with a mean score of 41.6% compared to 61.3% in the study by Hofkens et al (12). Again, this may be due to ICU staff having more exposure to PiCCO than anaesthetists.

The question pertaining to placement of the PiCCO had the most correct responses with, which suggests that insertion of cardiac output monitoring devices is done frequently by anaesthetists in theatre. The question regarding patient positioning during TPTD measurement, however, was poorly answered, which may be due to most patients usually being positioned supine intra-operatively, therefore anaesthetists did not know that patient positioning does not affect TPTD measurement. Positional changes of the patient depending on the clinical situation does not hinder the use of TPTD with PiCCO (12).

Considering the impact of haemodynamic interventions on patient morbidity and mortality, the pass mark of 62% in our study may have been too low. According to a systematic review by Hamilton et al (1), the use of a pre-emptive strategy of haemodynamic monitoring coupled with therapy reduced mortality and morbidity in surgical patients. This raises concern as our study had a mean score of 44.9% in the section regarding the management of haemodynamic problems. Interpretation of haemodynamic parameters generated by a monitor is of little benefit unless the clinical application is weighed against specific goals of directed therapy (21). This suggests that more emphasis needs to be placed on the clinical application of derived haemodynamic parameters. It is important to make sound decisions based on the interpretation of monitor variable outputs (4).

Juniors achieved lower scores than seniors. However, the significance of this result is questionable as both scored well below the pass mark. The difference between juniors and seniors may be attributed to the fact that juniors have had less experience than seniors and that some juniors may not yet have done their ICU rotation where TPTD exposure is more frequent. This is in keeping with the study by Hofkens et al (12) in which they attributed the difference in scores between those with adequate knowledge to those without exposure to PiCCO use. Of concern is that there seems to be a knowledge gap amongst seniors who inevitably need to pass on that knowledge to juniors.

This study was done contextually in the Wits Department of Anaesthesiology and the findings may not necessarily represent the knowledge level of anaesthetists elsewhere. These results may be influenced by the facts that TPTD is not routinely used for all cases and it is very rare that we actually put these monitors in. It may be more relevant to repeat a similar study in centres or groups of anaesthetists where a lot of complicated gastrointestinal surgery is done, which is where these monitors have the greatest impact on outcome.

Conclusion

Knowledge of the PICCO cardiac output monitoring technique was inadequate in a sample of anaesthetists in an academic anaesthesiology department. Seniority, experience in cardiac anaesthesia or ICU are factors improving knowledge adequacy. Knowledge regarding PiCCO among anaesthetists needs to be improved to ensure safe practice, therefore it is essential that anaesthetists have adequate knowledge of cardiac output monitoring. The recommendation of this study is the need for more teaching, training and regular assessment in the form of continued professional development to improve knowledge. It is however, recognised that knowledge does not always translate to practice.

Conflict of interest

The authors declare that we have no financial or personal relationships, which may have inappropriately influenced us in writing this paper.

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Section 4: Proposal

Anaesthetists’ knowledge of pulse contour cardiac output monitoring in a department of anaesthesiology

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4.1 Introduction and problem statement

In critically ill patients, there is widespread support for electronic monitoring of physiological variables in the perioperative and intensive care setting. Cardiac output monitoring has increased the awareness and practice of haemodynamic control among anaesthetists (1). Assessment of the underlying haemodynamics, such as cardiac output of acutely ill patients, assist physicians in diagnosing and formulating a treatment plan.

The gold standard for cardiac output monitoring has been invasive monitoring with a pulmonary artery catheter (2). Alternative minimally invasive cardiac output monitors are now available, which do not require the insertion of a pulmonary artery catheter. Studies have shown the use of minimally invasive cardiac output monitors in goal-directed therapy has resulted in improved patient outcomes (3-7).

Minimally invasive cardiac output monitors may be categorised into those that use arterial waveform analysis, Doppler ultrasound, transoesophageal echocardiography, partial carbon dioxide rebreathing systems and electrical impedance (2, 8). These principles and techniques of cardiac output monitoring represent the large armamentarium of cardiac output devices.

The COMET-UK study (9) showed that the three most commonly used validated modalities of minimally invasive cardiac output monitoring were oesophageal Doppler, lithium dilution cardiac output (LiDCO) and pulse contour cardiac output (PiCCO) (9).

The limitations of the oesophageal probe, such as frequent repositioning, specialised training of the operator (10), and patient discomfort restricted its use to anaesthetised or sedated patients. It thus became reserved for use mainly in the intraoperative period and occasionally in the intensive care unit (11, 12).

The LiDCO monitor combines arterial waveform analysis with calibration via lithium dilution (2). Concerns regarding the lithium indicator such as hyponatraemia and interference with non-depolarising muscle relaxants result in unreliable calibration (13, 14). Its use is contraindicated in the first trimester of pregnancy and is unsuitable in patients with severe peripheral vascular disease or vasoconstriction, resulting in its reduced utility in specific patient situations (10, 14).

PiCCO is a continuous cardiac output monitor that uses the principle of pulse contour analysis calibrated with transpulmonary thermodilution (TPTD). Its superiority is noted in its well-validated reference method of transpulmonary thermodilution. The thermal indicator avoids the need for a chemical indicator, such as with the LiDCO, preventing adverse effects or accumulation. It can be used in awake or anaesthetised patients, whether ventilated or spontaneously breathing and is not influenced by the ventilator cycle (15, 16).

PiCCO, in addition, has predictors of fluid responsiveness for fluid optimisation strategies, is appropriate for use in paediatric patients and its assessment of extravascular lung water is a predictor of patient outcome in acute respiratory distress syndrome (17, 18).

Nowak et al (19) used non-invasive cardiac output monitoring to assess emergency physicians' ability to estimate haemodynamic profiles of acutely ill patients. Forty acutely ill patients were monitored and after two hours of testing and therapy, treating emergency physicians were asked to estimate the cardiac output. They concluded that emergency physicians could not accurately estimate the haemodynamic profiles of acutely ill patients when compared to objective measurements (19).

In 2019, Porhomayon et al (1) surveyed the utilisation of cardiac output monitoring devices among anaesthesiolgy programs in the United States of America. Ninety-seven of the 133 anaesthesiologists used cardiac output monitoring for the management of fluid optimisation and vasopressor support. The majority, 84, felt that cardiac output monitoring was clinically beneficial in terms of monitoring response to treatment (1).

Understanding the underlying principles of cardiac output measuring devices helps in knowing the limitations of their use and allows more effective and safer utilisation (2, 8, 20). At present, no single cardiac output monitoring device meets all the clinical requirements considering the limitations of diverse cardiac output monitoring techniques (2).

There are many different types of cardiac output devices, some of which are calibrated, validated and have stood the scrutiny of controlled studies (21). Therefore, knowledge regarding their use as well as the appropriate application of the measured data to each unique situation becomes paramount.

Haemodynamic monitoring with transpulmonary thermodilution is less invasive than with a pulmonary artery catheter and is increasingly used in the intensive care unit and the operating room (22). Optimal treatment of the critically ill patient demands adequate, precise and continuous monitoring of clinical parameters. Little is known about health care workers knowledge of the basic principles and practical implementation of TPTD measurements at the bedside or on the operating table (23).

The importance of knowledge of cardiac output monitoring cannot be over-emphasised. The benefits of having a tool that can be utilised to target a specified therapeutic endpoint have repeatedly been shown to improve patient outcomes (2, 7, 22, 24, 25). The early detection of pathophysiological haemodynamic derangements through cardiac output monitoring and subsequent appropriate intervention facilitates patient recovery both in the perioperative and critical care settings (24).

The optimisation of tissue perfusion by haemodynamic monitoring aids in the preservation of metabolism (26). Therapeutic decisions derived from these values need to be assessed by a physician with appropriate knowledge of the devices and with an appreciation of their functions and limitations.

No research regarding the knowledge of cardiac output monitoring in South Africa could be identified. Studies have shown an established trend in the use of PiCCO globally and its efficacy over most other means of minimally invasive cardiac output monitoring devices (15, 16, 27, 28). Internationally, a study designed to assess the knowledge of transpulmonary thermodilution obtained with the PiCCO haemodynamic device showed the knowledge to be suboptimal with an average score of 58.3% from the 252 participants in the survey (23).

The question, therefore, arises whether anaesthetists in the Department of Anaesthesiology at the University of the Witwatersrand (Wits) are knowledgeable regarding transpulmonary thermodilution as obtained with the PiCCO haemodynamic monitoring device (22).

4.2 Aim and objectives

4.2.1 Aim

The aim of this study is to describe the knowledge of PiCCO among anaesthetists working in the Department of Anaesthesiology at Wits.

4.2.2 Objectives

The primary objectives of this study are to describe the**:**

- knowledge of PiCCO
- knowledge regarding performing TPTD
- knowledge regarding the limitations of the PiCCO monitor
- knowledge regarding the interpretation of haemodynamic parameters from the PiCCO monitor
- knowledge of the management of various haemodynamic problems based on variables derived from cardiac output monitors.

The secondary objectives of this study are to compare the knowledge of PiCCO between**:**

- junior and senior anaesthetists
- anaesthetists with exposure to intensive care and those without
- registrars who have or have not completed a cardiac rotation.

4.3 Research assumptions

The following definitions will be used in this study:

Anaesthetist: is any qualified doctor working in the Department of Anaesthesiology, including medical officers, registrars and consultants.

Medical officer: is a qualified doctor practising in the Department of Anaesthesiology under specialist supervision**.** Medical officers with more than 10 years of experience are career medical officers and are regarded as consultants.

Registrar: is a qualified doctor who is registered with the Health Professions Council of South Africa as a trainee anaesthesiologist.

Specialist anaesthetist: is a qualified doctor registered with the Health Professions Council of South Africa as an anaesthesiologist.

Consultant: is a specialist anaesthetist or career medical officer**.**

Junior anaesthetist: is a medical officer or a registrar with less than four years of training.

Senior anaesthetist: is a registrar with four or more years of training or a consultant.

Adequate knowledge: in this study will be determined by using the modified Angoff method (29).

4.4 Demarcation of study field

The study will be conducted in the Department of Anaesthesiology at Wits. The staff complement of the department is 74 consultants, 110 registrars and 22 medical officers.

The following core hospitals are affiliated with the department's training platform:

- Charlotte Maxeke Johannesburg Academic Hospital, a 1 200-bed central hospital
- Chris Hani Baragwanath Academic Hospital, a 2 880-bed central hospital
- Helen Joseph Hospital, a 500-bed tertiary hospital
- Rahima Moosa Mother and Child Hospital, a 338-bed regional hospital
- Wits Donald Gordon Medical Centre, a public-private hospital with 190 beds.

4.5 Ethical considerations

Approval to conduct the study will be obtained from the Human Research Ethics Committee (Medical) and the Graduate Studies Committee at Wits. Approval to conduct the study was obtained from the Head of the Department of Anaesthesiology (Appendix 1).

The researcher will attend academic meetings where the study will be explained and anaesthetists invited to participate. Those interested will receive an information letter (Appendix 2) and a self-administered questionnaire (Appendix 3). Consent will be implied on the return of the questionnaire.

Questionnaires will be numbered for data collection purposes and will not contain identifying information, thereby ensuring anonymity. The completed questionnaire will be folded in half by the participant and placed into a sealed box at the door of the meeting room. Only the researcher and supervisors will have access to the raw data to ensure confidentiality.

The data will be stored for six years after the completion of the study in a locked cupboard. The study will be conducted in accordance with the Declaration of Helsinki (30) and The South African Guidelines for Good Clinical Practice (31).

If the study demonstrates that the anaesthetists have inadequate knowledge regarding cardiac output monitoring, the researcher will notify the Head of Department.

4.6 Research methodology

4.6.1 Research design

A cross-sectional, contextual research design will be followed in this study.

A cross-sectional study is one where the collection of data takes place at the same time as the measurement of an effect or outcome (32). This study is cross-sectional as data will be collected from participants while simultaneously measuring an outcome.

A contextual study is one where a specific participant context or environment is focussed on (33). The study will be conducted among anaesthetists working in the Department of Anaesthesiology at Wits.

4.6.2 Study population

The study population will consist of all anaesthetists working in the Department of Anaesthesiology at Wits.

4.6.3 Study sample

Sample size

The Department of Anaesthesiology at Wits has 206 anaesthetists. The sample size will thus be determined by the number of anaesthetists attending the departmental academic meetings. A minimum response rate of 60% (n=124 will be considered acceptable (34).

Sampling method

In this study, a convenience sampling method will be used. Convenience sampling, also known as "availability sampling" involves the readily available participants (32), which in this study will be the anaesthetists attending the departmental academic meetings.

Inclusion and exclusion criteria

The inclusion criterion in this study is all the anaesthetists present at departmental academic meetings at the time of data collection.

Exclusion criteria:

- anaesthetists who decline participation
- questionnaires that are less than 80% complete or blank.

4.6.4 Data collection

Questionnaire development

Based on an extensive literature review, a questionnaire by Hofkins et al (23) published in 2015 was identified. The questionnaire was adapted to the South African context. The draft questionnaire was then reviewed by three senior anaesthesiologists with an interest and experience in cardiac output monitoring thereby ensuring face and content validity. The reviewers' comments were incorporated into the final questionnaire. The current questionnaire contains 40 questions.

Permission to use and adapt the questionnaire was obtained from the corresponding author (Appendix 4).

The questionnaire (Appendix 3) consists of five sections, namely:

- Section 1: demographics of the participants
- Section 2: knowledge of the PiCCO
- Section 3: knowledge regarding performing TPTD
- Section 4: knowledge of the limitations of PiCCO
- Section 5: knowledge regarding the interpretation of haemodynamic parameters from the PiCCO
- Section 6: knowledge of the management of haemodynamic problems based on variables derived from cardiac output monitors.

Data collection

To give all the anaesthetists in the department an opportunity to participate in the study, the data will be collected at several departmental academic meetings. Before the meeting, the researcher will approach the chairperson for permission to address the anaesthetists. The study will be explained to the anaesthetists present at the meetings and those who agree to participate will receive an information letter (Appendix 2) and a questionnaire (Appendix 3). Each questionnaire will be assigned a study number.

Questionnaires that are less than 80% completed will be included for response rate calculation but not included in the study. Unanswered questions will be regarded as incorrect.

4.6.5 Data analysis

Adequate knowledge in this study will be determined using the modified Angoff method (29). The Angoff method relies on subject-matter experts who examine the content of each test question and then predict how many minimally-competent candidates would answer the item correctly. The average of the experts' predictions for a test question becomes its predicted difficulty. The sum of the predicted difficulty values for each item averaged across the experts and items on a test is the recommended Angoff cut-off score for passing.

A Microsoft Excel spreadsheet will be used to capture data. Data will be analysed in consultation with a biostatistician using the statistical program STATA version 15 (StataCorp, USA). Categorical variables will be described using frequencies and percentages. The distribution of the data will be determined and the normally distributed continuous variables will be described using means and standard deviations and those not normally distributed using medians and interquartile ranges. Depending on the distribution, the comparisons between the two groups will be made using unpaired t-tests or Mann-Whitney U tests. A p-value of 0.05 or less will be considered statistically significant.

4.7 Significance of the study

Incorrect measurement and interpretation of haemodynamic parameters can result in significant morbidity as a result of incorrect therapy. In critically ill patients, the inappropriate therapy instigated as a result of inadequate knowledge can cause irreversible insult to a physiologically compromised patient and may even cause death. Appropriate depth of knowledge becomes a necessity in the safe utilisation of cardiac output monitoring.

If the results of this study identify knowledge gaps, measures such as PiCCO education and training can be instituted. Improved PiCCO knowledge may contribute to improved cardiac output monitoring and, therefore, safer patient care and improved outcomes.

4.8 Validity and reliability of the study

Validity “refers to the degree to which a measurement represents a true value” and reliability “represents the consistency of the measure achieved” (35).

The validity and reliability of this study will be maintained by:

- using a draft questionnaire based on a previously published questionnaire
- three senior anaesthesiologists reviewing the questionnaire will provide content and face validity
- obtaining a representative sample by targeting a response rate of at least 60% of the department
- reviewing 10% of data entered to ensure that a high quality of data entry is maintained
- analysing data in consultation with a biostatistician.

4.9 Potential limitations

This study will be carried out contextually in the Department of Anaesthesiology at Wits and the results may not be generalisable to other anaesthetic departments.

A convenience sampling method will be used which may result in bias as those included may not accurately represent the whole population of anaesthetists in the department (36).

4.10 Project outline

4.10.1 Time frame

Activity	Jan 2020	Feb 2020	Mar 2020	Jul 2020	Aug 2020	Sept 2020	Jan 2021	Feb 2021	Mar 2021	Apr 2021
Proposal preparation										
Literature review										
Proposal submission										

Ethics approval										
Postgraduate approval										
Data collection										
Data analysis										
Draft article										
Submission										

4.10.2 Budget

Item	Price per page	Number of pages	Copies	Total
Proposal	1	15	10	R 150
Postgraduate form	1	2	6	R 12
Complete report	1	100	4	R 400
Grand total				**R 812**

The Wits Department of Anaesthesiology will incur the costs of paper and printing for the proposal, postgraduate approvals, questionnaire and information letter.

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4.12 Appendices

Appendix 1 Request to the Head of the Department of Anaesthesiology at the University of the Witwatersrand

Dr Takudzwa Mandebvu

Department of Anaesthesiology

University of Witwatersrand

13 January 2020

Attention: The Head of Department of Anaesthesiology

Dear Dr Motshabi

Re: Anaesthetists knowledge of pulse contour cardiac output monitoring

For the research component of my M Med, I would like to assess the knowledge of pulse contour cardiac output monitoring among anaesthetists in the Department. The data will be collected through a self-administered questionnaire.

The questionnaires will be handed out at several departmental academic meetings with permission from the chairperson. Consent will be implied on completion of the questionnaire. There is no identifying information on the questionnaire which will ensure anonymity. Only my supervisors and I will have access to the raw data. A copy of the final report will be made available to you after completion of data collection.

There will be no cost to the department or hospital.

Yours sincerely

Takudzwa Mandebvu (079 629 4350)

mandebvutr@gmail.com

Dr P. Motshabi
HOD

Appendix 2 Information letter

Dear colleague,

Hello, my name is Takudzwa Mandebvu. I am a registrar in the Department of Anaesthesiology at Wits. I would like to invite you to participate in my research study entitled "Anaesthetists' knowledge of pulse contour cardiac output monitoring in a department of anaesthesiolgy". This research report will be submitted to the Faculty of Health Science to fulfil the requirements for my M Med degree.

The aim of the study is to determine the knowledge of anaesthetists regarding cardiac output monitoring using a self-administered questionnaire. It is important to know the latest guidelines and recommendations to help prevent and manage possible complications.

Participation in the study is voluntary and there is no penalty for refusal to do so. By completing the questionnaire, consent is implied. Information will be kept anonymous and confidential as none of your personal details will be required. My supervisors and I are the only people who will have access to the raw data. Completion of the questionnaire should take approximately 15 minutes. Please fold the completed questionnaire and place it in the provided sealed collection box at the door. Please do not share information during the completion of the questionnaire to allow an accurate reflection of anaesthetists' knowledge. If the study demonstrates poor outcomes, then education and training workshops will be facilitated on cardiac output monitoring.

The study has been approved by the Human Research Ethics Committee (Medical) and the Graduate Studies Committee of Wits. Should you require more information, or wish to contact me regarding this study, my mobile number is 079 629 4350. If you have concerns over the way the study is being conducted, please contact the Chairperson of this Committee who is Professor Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail at Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za.

Thank you for your time and for reading this information sheet.

Yours sincerely,

Takudzwa Mandebvu

Appendix 3 Questionnaire

Anaesthetists' knowledge of pulse contour cardiac output monitoring in a department of anaesthesiology

Section 1: Demographics

Please select the correct box

1. Sex	
Female	
Male	

2. Designation	
Medical officer	
Registrar 1st year	
Registrar 2nd year	
Registrar 3rd year	
Registrar 4 or more years	
Consultant or career medical officer (>10 years anaesthetics experience)	
Critical care fellow	
Intensivist	

3. Years of anaesthetic experience	
<4 years	
5 – 10 years	
11 – 20 years	
>20 years	

4. Have you worked or rotated in an Intensive Care Unit?	
No	
Yes <5 years ago	
Yes ≥5 years ago	

5. How frequently, on average, do you use cardiac output monitoring?	
Never used it	
Every day	
Most days	
A few times a week	
Once a week	
A few times a month	
Once a month	
Less frequently than once a month	

6. Please indicate which method(s) you have used from the list below. If more than one, please rank them in order of preference (1 being most preferred used).	
None, never used any	
Pulmonary artery catheter	
Oesophageal Doppler	
PiCCO	
Pulse contour cardiac output monitoring (e.g Vigileo)	
Lithium chloride indicator dilution method (LiDCO)	
Partial carbon dioxide breathing rebreathing systems	
Electrical impedance	
SvO2 and/ lactate levels	
Other methods not listed above:	

Please note: Question 7 is for registrars only.

7. Have you completed your cardiac rotation?	
Yes	
No	

Section 2: Knowledge regarding PiCCO monitoring

1. What does the acronym PiCCO represent?

Please select the most correct answer (only one)

2. What principles are used with the PiCCO measurements?	
Static and continuous CO measurement by arterial pulse contour analysis	
Static by thermodilution and continuous by arterial pulse contour analysis	
Static and continuous measurements by thermodilution	
I'm not sure	

For this question only, you may choose more than one correct option.

3. Which other haemodynamic parameters besides cardiac output can be measured by the PiCCO?	
Preload	
Contractility	
Extravascular lung water	
Filling status	
Wedge pressure	
Afterload	
All answers are correct	
All answers are incorrect	
Other:	

Please select the most correct answer (only one)

4. Haemodynamic monitoring with the PiCCO is:	
Invasive	
Minimal invasive	
Not invasive	
I'm not sure	

Please select the most correct answer (only one)

5. In which patients is the use of the PiCCO appropriate?	
Burned patients	
Patients with septic shock	
Patients undergoing major surgery that need cardiovascular monitoring	

Patients with unknown filling status	
Patients with kidney failure	
Patients with respiratory failure	
All answers above	
I’m not sure	
Other:	

Section 3: Knowledge regarding performing transpulmonary thermodilution (TPTD).

Please select the most correct answer (one only)

1. What do we need to perform a PiCCO measurement?	
Central venous catheter, PiCCO catheter, and a PiCCO kit	
Arterial catheter, PiCCO catheter, and a PiCCO kit	
Only a PiCCO kit	
Pulmonary artery catheter	
I’m not sure	

2. What is the correct injectate temperature (Ti)?	
<5 °C	
<8 °C	
<12 °C	
Ambient temperature	
I’m not sure	

3. Is the volume of the injectate (Vi) dependent on the body weight?	
Yes	
No	
I’m not sure	

4. Is it important to enter information like weight and height of the patient?	
Yes, to present correctly the indexed values	

No, weight and height are not important	
Only length is important because the PiCCO calculates the predicted body weight	
I'm not sure	

5. Should the patient be supine during a TPTD measurement?	
Yes	
No, it is of no importance	
Head of the bed should be elevated at 30 to 40°	
I'm not sure	

6. How many measurements must at least be done to obtain a correct value?	
1 – 2 measurements	
2 – 3 measurements	
4 measurements	
I'm not sure	

Section 4: Knowledge regarding the limitations of pulse contour cardiac output monitoring

Please select the most correct answer (one only)

1. Which deviation from the mean CO is allowed for a thermodilution CO measurement?	
10%	
15%	
20%	
25%	
>25%	

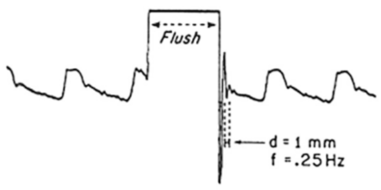
2. What values should be noted for volumes and extravascular lung water?	
The indexed value	
The absolute value	
Both are possible	
I'm not sure	

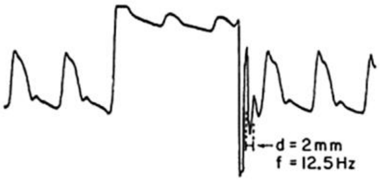
3. How often does the PiCCO arterial curve need to be zeroed/calibrated?	
At least once a day	
Before each measurement	
Only when starting up the PiCCO	
Once per shift	
Once per week	
Once per month	
I'm not sure	

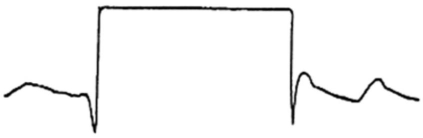
4. Why is a rapid flush test performed?	
To check if the curve is damped	
To check if there is a leak	
To check if the pressure bag is sufficiently inflated	
To measure the CO	
I'm not sure	

5. When is a rapid flush test performed?	
Once a day	
Once per shift	
Before each TPTD measurement	
I'm not sure	

Which of these rapid flush tests are correct or explain the pressure signal?

6. Curve 1	
	
Damped signal	
Normal signal	
Augmented signal	

7. Curve 2	
	
Damped signal	
Normal signal	
Augmented signal	

8. Curve 3	
	
Damped signal	
Normal signal	
Augmented signal	

Section 5: Knowledge regarding the interpretation of haemodynamic parameters

Please select the most correct answer (one only)

1. Is the placement of catheters important for the interpretation of the obtained values?	
Yes	
No	
I'm not sure	

2. Which of the following is the ideal catheter position?	
Right jugular vein/ left or right femoral artery	
Left femoral vein/ right femoral artery	
Left subclavian vein/ left or right femoral artery	
I'm not sure	

3. The injectate should be injected:	
In <7 sec	
In <10 sec	
In <12 sec	
Depending on the amount of injected volume always 5cc/2 sec	

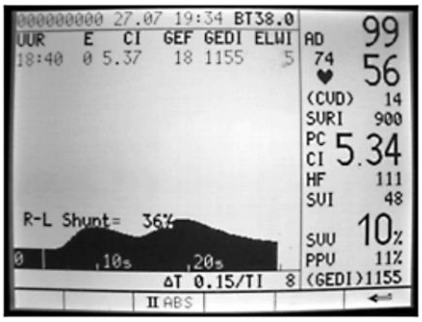
4. What is done if the delta T° is <0.2 °C?	
Increase the cooling of the injectate	
Increase the speed of the injection	
Increase the volume of the injectate	
I’m not sure	

5. What happens if the injectate volume is < the amount expected by the PiCCO?	
False increase of the CO	
False decrease of the EVLWi	
False increase of the CI	
False decrease of the GEDVi	
I’m not sure	

6. Should the CVP be entered in the PiCCO?	
No, it is calculated by PiCCO	
Yes, to calculate the cardiac output	
Yes, to calculate the systemic vascular resistance	
I’m not sure	

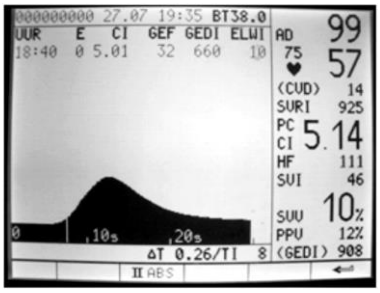
Look at the following thermodilution curves and state if correct.

7. Curve 1

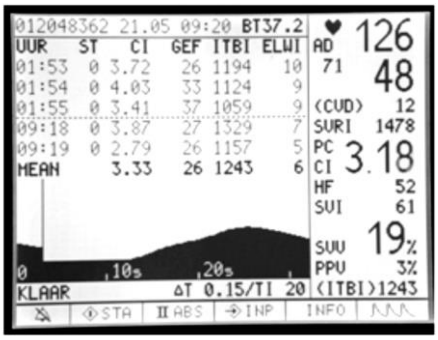


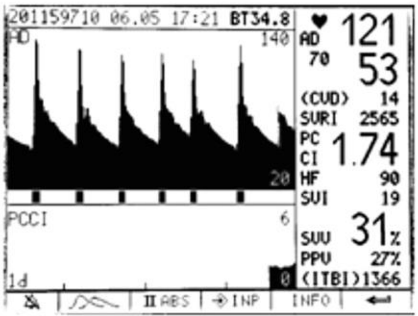
Correct	
Incorrect	
I'm not sure	

8. Curve 2



Correct	
Incorrect	
I'm not sure	

9. Curve 3	
	
Correct	
Incorrect	
I’m not sure	

10. Determine the underlying rhythm	
	
Regular sinus	
Atrial fibrillation	
Irregular	
I’m not sure	

11. Which PiCCO measurements are not reliable if the patient is not in sinus rhythm?	
All measurements are reliable	
All measurements are unreliable	
SVV and PPV are unreliable	
The thermodilution measurements (GEDVi and EVLWi) are reliable	
I’m not sure	

Section 6: Knowledge regarding the management of haemodynamic problems

Please select the most correct answer (one only)

1. A patient with right heart failure is monitored with a pulse contour cardiac output monitor, which gives a SVV of 50%. What is the next appropriate management of the patient?	
Give a directed fluid bolus to improve the SVV	
Start inotropes and titrate to effect	
No specific therapy as this parameter is not appropriate in this patient	
I don’t know, I’ve never used this device	

A 45-year-old man with known alcoholic liver disease, ischaemic heart disease and COPD is intubated in the ICU requiring cardiorespiratory support. On day three, he is on 0.2mcg/kg/min of noradrenaline with a lactate of 4mmol/l, requiring a FiO_2 of 0.8 with bilateral pulmonary infiltrates on chest x-ray. PiCCO readings are PPV 5%, GEDV 870mL/m^2, EVLWI 15mL/kg and PVPI 4.

2. You suspect evolving ARDS and you note that the patient has a positive fluid balance. What is your next step?

3. How would you ventilate the patient?

Thank you for answering this questionnaire. Your time is greatly appreciated.

Appendix 4 Permission to use survey tools

<2068128@students.wits.ac.za>

Good afternoon,

Hello, my name is Takudzwa Mandebvu. I am a doctor in South Africa currently specialising in anaesthesia at the University of the Witwatersrand in Johannesburg. As part of my training I am doing a M Med describing anaesthetists knowledge of cardiac output monitoring. Please may I have permission to use and adapt certain questions from the survey tool referred to as “Appendix 1” in the article entitled “Common pitfalls and tips and tricks to get the most out of your transpulmonary thermodilution device: results of a survey and state-of-the-art-review”?

Kind regards,

Takudzwa Mandebvu (MBChB, DA (SA))

<manu.malbrain@telenet.be>

Hi

Thank you for your message

Sure no problem

Keep me posted regarding final survey you use and the results

Best regards

Manu Malbrain

Section 5: Annexures

5.1 Ethics approval

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

R14/49 Dr T Mandebvu

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M200269

NAME: **(Principal Investigator)**	Dr T Mandebvu
DEPARTMENT:	School of Clinical Medicine Department of Anaesthesiology Medical School University
PROJECT TITLE:	Anaesthetists' knowledge of pulse contour cardiac output monitoring in a department of anaesthesiology
DATE CONSIDERED:	2020/02/28
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Professor J Scribante; Mrs H. Perrie; Dr A. Alli
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	2020/07/02

This clearance certificate is valid for 5 years from the date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on the 3rd Floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to submit details to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **February** and will therefore reports and re-certification will be due early in the month of **February** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

03/07/2020

Date

5.2 Graduate studies approval

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

06 January 2021
Person No: 2068128
PAG

Dr TR Mandebvu
8 Visser Street
Vorna Valley
Midrand
1686
South Africa

Dear Dr Takudzwa Mandebvu

Master of Medicine in Anaesthesia: Approval of Title

We have pleasure in advising that your proposal entitled *Anaesthetists' knowledge of pulse contour cardiac output monitoring in a department of anaesthesiology.* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty'shigher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

5.3 Turnitin report

2068128:MANDEBVU_TURNITIN_DOCUMENT.docx

ORIGINALITY REPORT

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12 July 2021

The Chairperson
Graduate Studies Committee
Faculty of Health Sciences
University of the Witwatersrand

Dear Professor Papathanasopoulos

Re: M Med: **Anaesthetists' knowledge of pulse contour cardiac output monitoring in a department of anaesthesiology.**

Dr Takudzwa Mandebvu, student number: 2068128, has submitted his research report to Turnitin, which revealed a similarity index of 16%. These similarities appear not to be plagiarism but mainly the use of common terminology and phrases specific to the topic of the research.

Yours sincerely,

J. Scribante

Juan Scribante
Supervisor