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Intraoperative cardiovascular monitoring in hypertensive patients

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Abstract

Bacground and Purpose: *Hypertensive patients are more prone to perioperative ischaemia, arrythmias and cardiovascular instability. Attention should be paid to the presence of target organ damage, such as coronary artery disease.*

Material and Method: *Haemodynamically unstable patients undergoing major surgery require more complex haemodynamic monitoring. Multiple studies have demonstrated the favourable outcome achieved by goal-directed fluid management during the intraoperative period.*

Conclusion: *The trend in intraoperative haemodynamic monitoring, a key feature of anaesthetic practice is towards less invasive systems that provide continuous information. A balance is needed between the hazards of an invasive approach and the desire for a continuous stream of accurate information that is robust enough to withstand the surgical and physiological challenges in hypertensive patients. In spite of its importance for anaesthetists, there is no consensus as to which system is best. This review examines the recent developments in haemodynamic monitoring.*

INTRODUCTION

Hypertension is associated with increased levels of afterload and cardiac work. This may predispose to myocardial ishaemia and infarction, especially in the presence of coronary artery disease and left ventricular hypertrophy. The anaesthetic goal aims at prevention of acute rises and wide swings in arterial pressure in the perioperative period. It is also imperative to ensure prevention of acute reductions in arterial pressure which may be fraught with risk *(1)*.

The many factors that may contribute to intra-operative haemodynamic instability include coexistent cardiovascular disease, anaesthetic agents, mechanical ventilation, hypothermia, surgical stress and manipulation, rapid fluid shift, bleeding, renal failure etc. Tissue hypoperfusion during surgery is associated with poor outcome and consequently a cornerstone of management is maintenance of adequate volume.

Goal-directed fluid management involving the maximisation of stroke volume by optimal fluid loading during high-risk surgery has been shown to decrease both the incidence of postoperative complications and length of stay in intensive care *(2)*. On the other hand, administration of excess fluid can cause several problems including an increase in demand in cardiac function as a result of extreme shift to the right on the Starling myocardial performance curve. Fluid accumulation in the lungs predispose to pneumonia and respiratory failure along with other sequelae include inhibition of gastric motility and poor wound healing *(2)*. Therefore, haemodynamic monitoring is essential if fluid therapy is to be managed accurately to prevent the deleterious effects of inadequate tissue blood flow and also the harmful effect of fluid overload. Monitoring should continue in postoperative period until it is clear that the patient is cardiovascularly stable. It might be appropriate to manage the patient in a high dependency area in the immediate postoperative period *(1)*.

Effective and detailed haemodynamic monitoring is necessary to provide the anaesthetist with a continuous overview of cardiovascular status. This in turn, allows rapid identification of problems with accurate direction of treatment strategies, and subsequent improved outcome.

There is an abundance of literature supporting the use of a wide variety of monitoring modalities, with each modality potentially generating several parameters *(2)*.

There is no consensus amongst anaesthetists as to the best form of haemodynamic monitoring despite its importance for intraoperative management. The various forms of monitoring techniques currently available are considered below. They have been classified into the basic and the advanced monitoring techniques for the sake of clarity.

BASIC HAEMODYNAMIC MONITORING

Electrocardiography (ECG)

Continuous ECG monitoring is essential in hypertensive patients to detect arrythmias as well as signs of myocardial ischaemia such as ST segment changes. Multilead ECG monitoring with a combination of lead V5 with an inferior lead (II, III, AVF) improves detection of myocardial ischaemia. Automated ST segment analysis is now available for tracking ischaemic changes. However, one must be aware this analysis does not give accurate information in the presence of underlying intraventricular conduction delays and bundle branch blocks.

Invasive Arterial Blood Pressure Monitoring

Hypertensive patients with well controlled disease with no end organ damage undergoing routine surgery can be managed with standard intraoperative monitoring. However, patients with uncontrolled or labile hypertension warrant the need for invasive arterial blood pressure monitoring for detection and management of acute rise or fall in blood pressure. Patients on multiple antihypertensive drugs undergoing major surgery would also benefit with invasive arterial blood pressure monitoring.

Central Venous Pressure (CVP)

CVP monitoring provides an indirect measurement of intravascular volume and right heart function. In addition, it provides a reliable access for infusion of fluids, inotopes and vasopressors. It can prove invaluable in hypertensive patients undergoing major surgery involving massive blood loss. However, CVP is a static measurement of fluid responsiveness and may not be entirely accurate (*4*).

ADVANCED HAEMODYNAMIC MONITORING

Uncontrolled and prolonged elevation of blood pressure can lead to hypertensive heart disease which includes left ventricular hypertrophy, coronary artery disease, cardiac arrythmias, systolic and diastolic dysfunction of the myocardium and even congestive heart failure. These may be preexisting but may also develop perioperatively in response to acute elevation of blood pressure. This group of patients would benefit with the advanced haemodynamic monitoring specially those undergoing major surgery involving major fluid shifts. Advanced haemodynamic monitoring may be classified into invasive and minimally invasive techniques.

Invasive monitoring

Pulmonary artery catheter

The flow-directed balloon-tipped pulmonary artery catheter (PAC) has been used as a »gold standard« to guide fluid management and vasoactive therapy *(3)*. Relevant haemodynamic variables measured by the PAC are pulmonary artery pressures (PAP), mixed venous oxygen saturation (SvO_2) and cardiac output (CO). The latter two are the main determinants of oxygen delivery. CO measurement with the intermittent thermodilution technique requires injection of a known quantity of cold indicator through the proximal lumen of the PAC into the right atrium. The indicator mixes with the surrounding circulation in the right ventricle (RV) and enters the PA where the change in temperature is detected by a thermistor located near the catheter tip, to produce a thermodilution curve. From this the CO is calculated by an equation *(5)*.

PA catheterisation is being used less frequently because of better appreciation of its shortcomings as well as advent of newer monitoring technology *(6, 7)*. The current generation of modified PAC, introduced in the late 1990s (*8, 9, 10),* allows continuous monitoring of CO (CCO), right ventricular ejection fraction (RVEF) and right ventricular end diastolic volume (RVEDV). CCO monitoring is based on the same intermittent thermodilution principle Instead of applying cool saline in a bolus fashion, blood flowing through the superior vena cava is heated intermittently by an electric filament attached to the PAC some 15 to 25 cm away from its tip. The resulting heat signals from the thermistor on the tip of the PAC are analysed stochastically to determine a single thermodilution curve *(5)*. A proprietary averaging algorithm is applied to reduce the influence of thermal noise. The monitoring system automatically repeats measurements at regular intervals and displays the current CO with trends.

RVEDVI is a promising tool in intraoperative fluid management but several problems with the clinical applicability of RVEDV and RVEF have yet to be resolved. The advanced PAC catheter shows delayed reactivity to rapid changes of intravascular volume and accuracy of data is dependent on catheter position with respect to the tricuspid valve, and the proximity of the thermistor to the pulmonary valve. Right ventricular (RV) monitoring using RV volumetric catheters may be unreliable with irregular or high heart rates (HR) (HR>130–150 beats/min), because the R-R interval becomes too short to identify the ejection fraction. Finally the RVEDV is calculated from stroke volume, which in turn is derived from cardiac output measurements, raising concerns about mathematical coupling as a potential limitation to its use as a preload index.

Using the PAC and SvO_2 for continuous monitoring of oxygen supply and demand might be another useful haemodynamic tool. The main problems when promoting SvO_2 measurement are difficulties in interpreting whether changes result from variations in cardiac output, oxygen supply or demand, or carrying capacity variations.

Pulmonary artery catheterisation and its clinical value in terms of outcome benefit have been under debate now for more than a decade *(11)*. Minor and major complications associated with PAC use have been reported to occur in 23% and 4.4% of insertions, respectively *(12)*. Ventricular arrhythmias during catheterisation have occurred *(13)*. Among fatal complications related to the PAC use, rupture of the pulmonary artery is the most common, with rare cases of myocardium perforation *(14)*. The failure to show improved outcome with the PAC, the delay in recognition of rapid changes when monitoring cardiac output, the costs of the advanced PAC and the complications associated with insertion, may all be responsible for the decline in popularity of PAC as a standard monitoring tool *(11)*. Diagnosis and treatment of pulmonary hypertension (PPH) remain the strongest indications for the insertion of a PAC *(15)*. Therefore, patients with hypertensive heart disease and right heart dysfunction leading to pulmonary hypertension would be ideal candidates for PAC insertion.

Minimally invasive monitoring

Trans-oesophageal echocardiography

During the last decade, TEE has become increasingly popular for monitoring myocardial function. The principle advantage of TEE is that its real-time images provide immediate visual information about the structural nature of the heart and its dynamic function *(16)*. It is less adept at providing the numerical data that we are used to receiving from PAC, but in reality the information from the latter on cardiac filling gives the identical message to that provided by the real time images of TEE *(16)*. Among the factors that can influence pressure readings are intermittent positive pressure ventilation, pulmonary hypertension, valvular dysfunction and ventricular failure. TEE offers more accurate interpretation of myocardial wall tension than PAC pressure measurement *(16)*.

Other advantages of TEE include the ability to re-assess cardiopulmonary status immediately prior to surgery *(16)*. TEE may also be of benefit in the occasional situation in which PAC cannot be placed. Finally, TEE allows the visualisation of large vessels such as the inferior vena cava *(17)*.

Transcardiopulmonary thermodilution (tcpid)

Transcardiopulmonary thermodilution (TCPID) is a technique that was introduced as a »minimally invasive« volumetric monitoring system *(18, 19)*. The PiCCOplus (Pulsion Medical System; Munich Germany) system requires central venous and modified femoral or brachial arterial catheters. For determination of CO, a saline bolus is injected through the central venous catheter. The thermistor on the tip of the arterial PiCCO catheter measures the downstream temperature changes. The CO is calculated by means of the Stuart-Hamilton-equation from the area below the transpulmonary thermodilution curve. From the Mean Transit time (MTt) and the Down Slope time (DSt) of the thermodilution curve, preload and lung water are determined. Simultaneously, the arterial pulse contour is analysed and the aortic compliance determined. With this technology, a pulse contour algorithm is calibrated, and this is used to calculate individual values for SV, CO and SVV, a clinically validated fluid responsiveness index in controlled mechanically ventilated patients *(20, 21, 22)*. The TCPID technique also allows estimation of preload indices such as intrathoracic blood volume (ITBV), extravascular lung water (EVLW) and global end diastolic volume (GEDV) *(23)*. It is proved to be safe alternative for advanced haemodynamic monitoring *(24)*.

LiDCO

Recently, new non-invasive cardiovascular monitoring technologies have been introduced and tested. One device based on TPID technique for monitoring CO (LiDCOplus System, LiDCO Ltd, London, UK) needs only a standard peripheral arterial line plus a central or peripheral venous line *(25, 26, 27)*. An established dilution technique is used to define CO using lithium chloride (0.3 mmol; 2 ml) as indicator and a disposable lithium-selective electrode, positioned in the arterial pressure catheter tubing, serves as the sensor (COLi, LiDCO, London, UK). For each COLi measurement, a lithium bolus is given through a central intravenous catheter, whilst a battery-powered roller pump draws arterial blood through the lithium sensor. A lithium concentration washout curve is devised, from which the device derives the CO, and this in turn is used to calibrate a pressure waveform system (PulseCO) that estimates the nominal CO by a nonlinear transformation of the input analogue arterial pressure *(28, 29, 30)*. PulseCO measurements are based on harmonic waveform analysis

(Fourier transformation) and integrate beat duration, ejection duration and mean arterial pressure. Compared with thermodilution, LiDCO is not temperature sensitive, but is influenced by electrolyte and haematocrit concentrations and the maximum recommended daily lithium dose of 3 mMols puts a limit on the number of calibration measurements that can be made. The accuracy and trending ability of the PulseCO algorithm following TCPID calibration, has been confirmed in different patient groups *(28, 29, 30, 31)*.

A comparison of the LiDCO monitor with bolus pulmonary artery catheter thermodilution showed good overall agreement between the two methods ($r^2 = 0.94$). In post-cardiac surgery patients the monitor was at least as accurate as bolus thermodilution, with significantly greater precision *(30)*.

Apart from being non-invasive, LiDCO monitoring provides haemodynamic data continuously through the procedure on a beat-to-beat basis and allows the data to be saved and analysed *(32)*.

Lithium calibration cannot be performed in patients who have received atracurium as a neuromuscular blocker 30 min before calibration because it reacts with the lithium sensor, and the LiDCO system cannot be used in patients receiving lithium therapy. Arrhythmias may make pulse waveform analysis unreliable, as the heart rate can be miscalculated when very large changes are seen in the pressure waveform. Significant fluctuations in the compliance of the arterial vascular system may change the arterial pressure waveform and affect the accuracy of the pulse power analysis performed by PulseCO. Frequent recalibration provides a simple solution but is potentially time consuming. Available evidence suggests that calibration every 6–8 h is sufficient for accurate continuous PulseCO monitoring in the ICU setting *(32)*.

Transoesophageal echo-dopler (ed)

Transoesophageal echo-Doppler (ED) is another non--invasive approach to continuous CO measurement. It is an ultrasound-based technique that measures blood velocity in the descending aorta using an oesophageal transducer *(33)*, which is rotated to obtain a basic image of the aorta with the Doppler sensor. With this monitor it is possible to measure or derive cardiac index (CI), left ventricular (LV) ejection time interval indexed to the heart rate (a measure of LV filling), maximum acceleration (a measure of contractility and global ventricular function), peak velocity, and systemic vascular resistance (SVR). When compared with »gold standard« CO measurements obtained by thermodilution, the Doppler-derived CI values showed significant bias and only moderate clinical agreement in thoracic surgery, but clinically acceptable agreement was found during cardiac surgery *(34, 35)*.

The main advantage of ED is that it is fairly simple and does not require any sonographic skills. Furthermore, all studies agree that its short response time and reliability is important *(33, 36)*. Against its use are the limitations described above and loss of the Doppler signal caused by diathermy, gastric tube and surgical traction *(37)*.

Better patient outcome can be achieved by perioperative haemodynamic optimization using oesophageal Doppler monitoring and should be considered for routine use in most types of high-risk surgery *(38)*.

Vigileo CO monitoring

In contrast to the calibrated systems described above, the FloTrac sensor attached to the Vigileo device does not require external calibration, and it uses an algorithm to derive cardiac output from the arterial pressure wave (APCO). The system can use any arterial line already in situ, but the signal needs a specific transducer, the FloTrac. The algorithm gets all the information it needs to calculate the arterial impedance from the analysis of the arterial pressure waveform together with the patient's age, sex, height and weight. For APCO assessment the standard deviation of pulse pressure measured during time windows of 20 s is empirically correlated to the 'normal' stroke volume based on underlying patient data. Aortic compliance is also estimated using these data, whereas resistance is derived by analysing the actual pressure waveform characteristics.

TABLE 1

Comparison of different methods of advanced haemodynamic monitoring.

	PAC	TEE	TCPID	LiDCO	ED	VigileoCO
Accuracy	Good	Good	Good	Good	Good	Poor
Precision	Good	Good	Good	Good	Good/Poor	Poor
Rapid response timeresponse/ Continuous data	Yes	Yes	Yes	Yes	Yes	No
»Real time« updating	Poor	Excellent	Good	Good	Good	Poor
Reproducibility	Good	Good	Good	Good	Good	?
Operator independent	Yes	Yes	Yes	Yes	Yes	Yes
Risk to patient	Serious complications reported	Low	Low	Low	Low	Very low

The Vigileo system represents a genuine revolution in the field of pulse pressure analysis, being a real »plug and play« tool, but assessment of the performance of the algorithms (two versions of the software have already been released in less than three years) is still underway. To date the reception has been mixed, with some finding good agreement between the Vigileo system and intermittent thermodilution, whilst others have reported poor limits of agreement *(39–47)*.

Similarly, vasoactive agents induce changes in vascular impedance and compliance with a subsequent impact on arterial pressure waveform. Intermittent cardiac output measurement may be less susceptible to these influences than APCO.

LiDCOrapid

The LiDCOrapid represents the newest arterial pulse wave analysis device. It uses a nomogram to make an estimate of the calibration factor used in the generalised equation used to scale and transform the nominal maximum aortic volume. The LiDCOrapid nomogram has been derived by the manufacturer from a multivariate analysis of the relationship between aortic volume and age, height, weight and body surface area. In the LiDCOrapid set-up the user only has to input these patient details into the monitor and the scaling factor is automatically estimated. The manufacturer claims that once the patient's details have been entered into the system, the monitor follows cardiac output trends. The bias and precision of the nomogram scaled version of the $PulseCO_{LiR}$ algorithm in 10 liver transplanted patients *(48)* was found to be acceptable measurements when compared to ICO and CCO but percentage error was 30% and 26% respectively.

Increasing attention has been given to the validation of less invasive monitoring tools in hyperdynamic patients, and yet these monitoring devices fail to be applicable for intraoperative monitoring during OLT. Nevertheless, testing their accuracy in this clinical situation is a further step towards their uptake in high-risk surgical patients and critical illness.

CONCLUSION

Hypertensive patients with end organ damage such as hypertensive heart disease, coronary artery disease etc. require intensive haemodynamic monitoring in the perioperative period to avoid worsening of the cardiac status. Monitoring should aim to include invasive arterial pressure monitoring as well as the measurement of the cardiac output and indices reflecting the preload and the afterload. This can then be used to optimise the fluid therapy as well as guide drug therapy. Traditional haemodynamic monitoring is based on pulmonary artery catheter and trans-oesophageal echocardiography. The new developments in PAC technology offer the opportunity to monitor right heart pressures and preload indices with variables such as RVEDV and RVEF that give a better reflection of preload status than the »old« filling pressures. TEE is receiving growing attention because it allows direct visualisation of heart structure, shape and function. The PiCCO system measures transpulmonary thermodilution cardiac output, but to this it adds a preload index through intrathoracic blood volume measurement, and monitors lung function status through extravascular lung water. Uncalibrated less invasive CO monitoring devices do not give reliably accurate information on cardiac output in the hyperdynamic conditions.

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