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Standards of monitoring revisited, what is the evidence?

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Anaesthesia is routinely performed in millions of patients every year. The amount which anaesthesia itself contributes to peri-operative morbidity and mortality remains controversial. However, it is widely accepted that advances in anaesthetic and peri-operative care have contributed to reduced peri-operative mortality, at least in developed countries [1]. During the past years a number of standards for anaesthesia care and monitoring in anaesthesia had been developed.

General considerations

The presence of an appropriately trained and experienced anaesthesia team is the main determinant of patient safety during anaesthesia. The individual anaesthetist must be familiar with the patient and all the technical devices [1]. Regular observations of the patients and the information provided by monitoring devices must be undertaken and documented. Electronic record keeping is recommended. Monitoring itself cannot prevent adverse reactions during anaesthesia, but basic monitoring reduces the risk of incidents by providing an early warning if the patient's condition worsens. However, human error is inevitable and a number of studies of critical incidents and mortality associated with anaesthesia have shown that adverse events are often attributable to this type of error.

Basic monitoring in anaesthesia

The core monitoring options can be subdivided in monitoring of the anaesthetic equipment ('safety monitoring') and monitoring of the patients physiologic response to anaesthesia ('physiologic monitoring'). Monitoring of anaesthetic equipment comprises the use of an oxygen analyser, capnography, and a disconnection alarm. The use of a vapour analyser is essential if a volatile anaesthetic agent is used. Whenever an infusion device is used, alarm and infusion settings must be verified and set to appropriate levels before commencing anaesthesia. Usually the standards of safety monitoring are defined by guidelines set by national anaesthesia societies (Table 1). The introduction of such routine safety monitoring in anaesthesia occurred together with a number of other improvements likely to affect patient outcome. However, evidence from clinical studies is more circumstantial than proven [1].

Table 1

Monitoring recommendations of the Association of Anaesthetists of Great Britain and Ireland

Essential Monitoring		
Circulation	ECG NIBP	Clinical observation
Respiration	Capnography Airway pressure Pulse oximetry	Clinical observation
Body temperature	Temperature probe	
Available Monitoring		
If muscle relaxants are used	Nerve stimulator	
If volatile anaesthetics are used	In- and expiratory anaesthetic concentration	
Airway gases analysis	Oxygen, carbon dioxide	

Cardiovascular system

Basic physiological monitoring consists of the continuous display of the electrocardiogram (ECG) and intermittent non-invasive measurement of blood pressure (NIBP). Monitoring of heart rate is probably the most simple and least invasive form of cardiac monitoring. The sensitivity and specificity of the detection of myocardial ischaemia depends, at least in part, on the type of ECG monitoring. Myocardial ischaemia can be detected with low sensitivity using a three-lead ECG. However, sensitivity increases when a five-lead ECG is used and leads II and V5 are continuously monitored and routine use of a five-lead ECG is strongly recommended in patients with known or suspected coronary artery disease. However, examining the association between ECG and new echocardiographically detected regional wall motion abnormalities shows that the ECG is a relatively non-specific monitor for myocardial ischaemia.

Measurement of blood pressure should be performed by means of NIBP in every patient. Continuous measurement of blood pressure requires arterial cannulation. This is associated with severe, but rare, complications such as thrombosis, nerve injury, haematoma and infection. Invasive arterial blood pressure monitoring should, therefore, be used with caution. Haemodynamically unstable patients undergoing surgery as a result of trauma or for intra-abdominal pathology frequently require such monitoring. Patients undergoing cardiac, vascular, thoracic, spinal and neurosurgery are subject to rapid changes in blood pressure and intravascular volume status and continuous monitoring should be established to manage hemodynamic parameters within safe margins. Arterial catheters also provide a reliable method for obtaining arterial blood samples facilitating management of blood gas, blood chemistry and coagulation abnormalities. Table 2 gives an overview of indications for invasive blood pressure monitoring, which are based on expert opinion rather than on clinical trials [1].

Table 2

Indications for invasive blood pressure monitoring

Patient dependent factors	Type of surgery
Haemodynamic instability (shock)	Cardiac surgery
Cardiac disease	Abdominal surgery
Respiratory insufficiency	Craniotomy
Increased intracranial pressure	Major thoracic surgery
Multiple trauma	Major abdominal surgery

Respiratory system

Basic monitoring of the respiratory system is used routinely in all patients undergoing anaesthesia. Two methods are used - capnometry and pulse oximetry. Capnometry should be used in all ventilated patients and whenever possible in spontaneously breathing patients. Pulse oximetry should be used on all anaesthetised patients and also on awake patients undergoing regional anaesthesia. A capnometer measures end-tidal carbon dioxide concentration (ET CO₂) during inspiration and expiration. Capnography graphically displays the end-tidal carbon dioxide curve. Capnometry and capnography should be combined as the shape of the curve provides important information on potential causes of insufficient ventilation. Information on typical pathologic conditions and technical failures can be easily obtained by careful reading of the capnogram. Furthermore, missed oesophageal intubation remains one of the most dramatic and potential disastrous complications of anaesthesia. The measurement of carbon dioxide in the expiratory period is an important sign of intubation.

Pulse oximetry enables in-vivo measurement of the arterial oxygen saturation (SaO₂) by detecting the differences in absorption of oxygenated and de-oxygenated haemoglobin. The variation (two-standard deviations) of SaO₂ values obtained by commercial available pulse oximeters is ± 2% between 80-100% oxygen saturation. When the SaO₂ decreases below 80%, an error of up to 5% is possible. It is widely accepted that pulse oximetry should be used in all patients during anaesthesia and in the recovery area. The information obtained is of great importance in avoiding serious, potentially life threatening complications. The value depicted on the monitor represents an average of about 8-15 measurement cycles. The response time to a hypoxic event is, therefore, about 10-35 s.

In 1993, Moller et al published the results of a randomised trial in which they compared the use of pulse oximetry in more than 20 000 patients undergoing anaesthesia [2, 3]. During anaesthesia and in the recovery area, significantly more patients in the monitoring group had at least one respiratory event than control patients. This finding was the result of a 19-fold increase in the incidence of diagnosed hypoxaemia in the oximetry group compared with the control group. Despite these findings, no significant difference in clinical outcome could be identified [2-6]. However, despite the lack of evidence, most clinicians agree that pulse oximetry is essential for the safe conduct of anaesthesia. The results of this study and others conducted in the field of basic patient monitoring have shown that given the relatively small number of patients studied and the rarity of the events being sought, the studies were not able to show an improvement in various clinical endpoints. In summary, there are no prospective, randomised clinical studies on the outcome relevance of monitoring in anaesthesia that prove that patient outcome is influenced by basic physiological monitoring. Most clinicians believe that such a study would be unethical.

Despite no the lack of concrete evidence, the available circumstantial evidence indicates that the routine use of basic monitoring improves patient safety. The numbers of serious accidents and deaths were substantially reduced after implementation of basic monitoring during the 1980's in the 'Harvard Hospitals' [5, 6]. The Australian incident study showed that 52% of anaesthesia-related incidents were detected by a monitor first. In more than 50% of these cases, pulse oximetry or capnography detected the first pathological changes [7-9].

Guidelines and recommendations for monitoring standards are defined by national societies of anaesthesia. An example for such a standard is shown in Table 1 which summarises the monitoring guidelines published by the Association of Anaesthetists of Great Britain and Ireland (AAGBI) in 2007. The same standard must apply when an anaesthetist is responsible for a local anaesthetic or sedative technique for a surgical procedure. It is essential that monitoring and standard care during transfer from the operating room to the ICU is as high as in the operating room and that experienced persons accompany the patient.

Advanced monitoring of the cardiovascular system

In contrast to the accepted standards in basic safety and physiologic monitoring, the definition of and indication for advanced monitoring remains a matter for discussion. In Table 3 commonly used advanced monitoring devices are listed. For the same type of anaesthesia, performed in patients with comparable disease severity undergoing the same procedures, patients can be managed with different monitoring approach in different institutions or even by different staff in the same institution. Moreover, it not known if the variability in monitoring is related to, or even associated with, outcome because large scale studies are still not available. Most of the recommendations or guidelines are based solely on expert opinion. This results in discrimination between 'believers' and 'non-believers'. At least in part, this situation is the result of the prolonged discussion on the role of pulmonary artery catheters (PAC). PACs first became available as a practical diagnostic tool in 1970. They enable measurement of quantitative haemodynamic and metabolic data, such as cardiac output, pulmonary capillary wedge pressure and mixed venous oxygen saturation at the bedside. Many physicians assumed that these numbers could guide treatment and reduce mortality in critically ill patients. Within several years PACs were widely used. In the 1980's 20-43% of seriously ill patients who were hospitalised were underwent pulmonary artery catheterisation. In 1985, Robin described the lack of randomised trials demonstrating the benefit of PACs [10]. Early attempts to conduct randomised trials were handicapped by physicians' opinion that PACs were ethically mandatory in severely ill patients. The turning point was the publication of a multicenter observational trial suggesting increased mortality in the PAC group by Connors et al in 1996 [11]. This article was accompanied by an editorial calling for a moratorium on the use of the PAC until randomised controlled trials were conducted [12]. Although there are still proponents of the PAC, a number of randomised trials [13-19] and one Cochrane Collaboration meta-analysis [16] have shown that this technology has no impact on mortality in diverse populations of critically ill patients.

Table 3

Parameters and technologies used for advanced cardiovascular monitoring in clinical practice.

Parameter	Technique
Cardiac Output (CO)	Thermodilution, Dye Dilution, Doppler techniques, Lithium dilution, Pulse contour analysis
Central venous pressure (CVP), Pulmonary artery pressure (PAP), Pulmonary artery occlusion pressure (PAOP)	Central venous line, Pulmonary artery catheter
Central (Mixed) venous oxygen saturation (S_{vO_2})	Central venous line, (Pulmonary artery catheter)
Oxygen delivery (DO_2), Oxygen consumption (VO_2)	Calculated
Pulse pressure variation (PPV)	Invasive arterial blood pressure
Stroke volume variation (SVV)	Pulse contour analysis
Intrathoracic blood volume (ITBV) Global end-diastolic volume (GEDV)	Transpulmonary thermodilution
Left ventricular area (EDA-ESA) Left ventricular volume	Transoesophageal echocardiography, Transthoracic echocardiography

Recently Marik et al published an article about the values of CVP monitoring in anaesthesia and intensive care medicine [20]. Central venous pressure is measured routinely in critical ill patients throughout the world and the value frequently used to make decisions regarding the administration of fluids, inotropes or diuretics. Indeed, internationally accepted guidelines such as the surviving sepsis campaign recommend CVP as one end-point of fluid resuscitation. The basis of this opinion is that CVP should reflect intravascular volume. It is widely believed that patients with a low CVP are volume depleted and those with high CVP are 'overfilled'. This opinion is in contrast to recent findings that the CVP is not associated with volume status or fluid responsiveness [21-23]. Consequently, the use of CVP as a guide for fluid replacement is not evidenced-based. The use of cardiac filling pressures such as pulmonary artery occlusion pressure and central venous pressure as guides for fluid therapy is insufficiently supported by the available data. It is unknown if the use of the PAC for specific indications is justified, for example pulmonary hypertension with the need for vasodilator therapy and right heart failure with decreased right ventricular function.

Monitoring of oxygen transport variables

The cardiovascular system is responsible for the transport of substrates and oxygen to and from all the different organ systems. Cardiovascular monitoring should reflect the end-organs and the cardiovascular system. In particular, the availability of oxygen (oxygen delivery, DO_2) seems to be of primary importance. Based on this hypothesis, Shoemaker et al developed a goal-directed therapeutic concept, based on supranormal values for cardiac output and DO_2 [24, 25]. Initially, a decrease in mortality and morbidity was observed when patients were managed this way early in the peri-operative process. Several further studies supported these findings [26]. However, a number of other studies found opposite results. For instance, a recent adequately powered study could not confirm a decrease in mortality and morbidity when applying the concept of supranormal haemodynamic goals in the peri-operative period [14]. However, the attending physicians were not able to reach the set haemodynamic goals in the majority of patients intra-operatively which led to criticism about the validity of the study. Furthermore, it is difficult to compare these studies because the study design, patient population and therapeutic regimen are different. Although the available literature has been analyzed by meta-analyses, no definitive conclusions can be drawn.

Summary

Cardiovascular and respiratory monitoring standards in anaesthesia can be subdivided into safety, basic and advanced monitoring. There is evidence that the introduction of monitoring guidelines has improved safety in anaesthesia. However, the use of basic physiologic monitoring has never been proven in an adequately powered clinical trial. Despite this lack of evidence, the use of basic physiologic monitoring is strongly recommended. In contrast, advanced physiologic monitoring of the cardiovascular system by invasive catheter technologies such as the PAC is not evidence-based. Newer techniques like transpulmonary thermodilution, pulse contour analysis and Doppler techniques for the measurement of cardiac output have shown promising results. However, at present the number of patients included in randomised trials is insufficient.

Key Learning Points

- Basic physiologic monitoring in anaesthesia includes ECG, pulse oximetry and capnography.
- Safety monitoring decreases the number of incidents during anaesthesia.
- The same monitoring must be applied to all patients.
- The use of cardiac filling pressures (CVP and PAOP) to guide fluid therapy is not proven by clinical studies.

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