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Patient monitoring is a key element in the provision of anaesthetic care. The word “monitor“ is derived from the Latin verb *monere* - to warn. As its derivation indicates, a monitor can only warn. No mechanical or electrical device can replace conscientious observation of the patient by the anaesthetist. Information from monitoring equipment always requires clinical interpretation. As anaesthesiology has become more sophisticated and complex, so have the monitors and the data they produce. The anaesthetist's senses of sight, hearing, and touch, extended using the stethoscope, electrocardiograph, and sphygmomanometer, are now supplemented by the pulse oximeter, expired gas analyser, neuromuscular monitoring, EEG monitoring, and transesophageal and the echocardiograph.

The purpose of a monitoring device is to indicate trends of change in physiological variables induced by anaesthesia, surgery, or patients underlying disease(s) i.e. **physiological monitoring**; thus, enabling appropriate therapeutic action to be taken. In addition, monitoring should also detect potentially hazardous problems as early as possible, thus allowing correction in appropriate time, i.e. **safety monitoring**. This includes not only monitoring patients, but also devices which interfere with physiological functions, such as the anaesthesia machine or drug administration systems. Similar to the registration procedure for drugs, it is now generally accepted that a **technology assessment** is mandatory for new monitoring devices before its clinical use can be recommended [1] The first step in such a technology assessment should be the evaluation of physical and technical aspects of the technology: Is the method or the device appropriate to measure the respective parameter exactly and reliably? Thus, questions concerning sensitivity, stability of the measurement, reliability and the degree of invasiveness of the method are examined. Thereafter, the efficacy has to be assessed under clinical conditions. This entails a comparison with the “gold standard“, the definition of possible indications, as well as the determination of therapeutically consequences. Theoretically, randomised controlled trials are most appropriate. This is not always possible or practicable. Therefore alternative approaches such as data bases of clinical incidents or closed claims, metaanalyses or consensus conferences are used. Then, the consequences of the new monitoring on patients' outcome has to be investigated. Typically mortality and morbidity as primary outcome parameters are assessed. If these are not relevant or applicable, secondary outcome parameters including hypoxemia, hypotension, or hypothermia are chosen. Finally a cost/benefit analysis is mandatory. Such technology assessment should lead to the definition of recommendations, standards, and guidelines for intraoperative monitoring.

Technological enthusiasm, entrepreneurial involvement, and a sincere desire to know as much as possible about our patients has led to the view that “more is better“. It is argued that additional information acquired from a extensive array of new monitors must surely benefit the patient [2]. Until recently, there has been little evidence to support this hypothesis. Relatively small studies now indicate that a decrease in anaesthetic risk can be associated with the use of certain monitors. The combination of pulse oximetry (27%) and capnography (24%) detected more than half of the incidents that were detected by monitors; the ECG (19%), various BP monitors (12%), low pressure circuit alarm (8%), and the circuit oxygen analyser (4%) were also helpful. The remaining monitors each detected < 1% of the incidents [3].

To date, the association between the number of variables monitored and the probability of satisfactory outcome has not been defined. Interestingly, Eichhorn et al. reported, that least 50% of the intraoperative accidents were not preventable, even with the implementation of adequate monitoring [4]. Thus, the main question that still remains unanswered is “how much anaesthesia morbidity and mortality can be prevented by use of state of the art monitoring?”

Based on the “**Harvard standards**“ of 1986, the American Society of Anesthesiologists (ASA) published guidelines for intraoperative monitoring [5]. According to these guidelines, qualified anaesthesia personnel must be present during all general, regional, and monitored anaesthesia care to continuously monitor oxygenation, ventilation, circulation, and temperature. When an anaesthesia machine is used, the concentration of oxygen in the patient's breathing system must be measured by an oxygen analyser. In addition, during treatment with all

anaesthetics, a quantitative method for assessing oxygenation (pulse oximetry) must be employed. Ventilation must be evaluated continually (observation of chest-excursion, auscultation) and quantitative monitoring of carbon dioxide content and/or volume of expired gas is encouraged. However, if an endotracheal tube or laryngeal mask airway is used, then correct positioning in the airway must be verified by continuous quantitative end-tidal carbon dioxide analysis. When ventilation is controlled by a mechanical ventilator, continuous monitoring with a device capable of detecting disconnection of the breathing system must also be used. Every patient having anaesthesia must have a continuously displayed ECG and have arterial blood pressure and heart rate determined and evaluated at least every 5 min. In addition, circulatory function must be evaluated continually by at least one of the following: palpation of a pulse, auscultation of a pulse, auscultation of heart sounds, monitoring of a tracing of intra-arterial pressure, ultrasound peripheral pulse monitoring or pulse plethysmography. Finally, a means must also be available to measure body temperature. These, however, are minimal standards for every patient. Similar recommendations have been made by national bodies or the European Community (s.a. Norme Européene EN 740). Recently, the routine use of neuromuscular monitoring intraoperatively has been strongly recommended for all patients who receive neuromuscular blocking agents [6].

Specialised monitors such as pulmonary artery pressure monitoring, cardiac output monitoring, mixed venous oxygen saturation, transesophageal echocardiography or devices for monitoring depth of anaesthesia may be added.

PULMONARY ARTERY PRESSURE MONITORING

Pulmonary artery catheterization (PAC) for hemodynamic monitoring was introduced into clinical practice in 1970 by Swan, Ganz and colleagues [7]. These catheters allowed accurate measurement of important cardiovascular physiologic variables at the bedside, and their popularity soared during the next two decades as they were used in an increasing number of critically ill and surgical patients [8]. Although many complications associated with PAC have been described over the past 25 years, major morbidity specifically associated with PAC use is uncommon. The reported incidence of serious complications due specifically to PAC varied between 0.1 to 0.5 percent of PAC-monitored surgical patients [9,10]. Clearly, proper use of the PAC provides a wide range of useful cardiovascular data that many clinicians cannot accurately predict from standard clinical signs and symptoms. However, no convincing evidence exists to indicate that PAC monitoring improves patient outcome. In reviewing the evidence for efficacy of PAC monitoring, many studies exist either supporting or refuting the benefits of this technique. However, the small number of patients reported limits the validity and applicability of these investigations. Unfortunately, even larger studies currently available have had similar mixed results and marked limitations in study design. Perhaps the most controversial of all these PAC outcome studies is a recently published study, in which Connors et al examined the association between PAC use during the first 24 hours of intensive care and subsequent survival [11]. The patients in this study were seriously ill; entry into the study required a predicted 6-month mortality in excess of 50 percent. Patients who received a PAC were judged to be sicker, but the authors used case-matching analysis and applied a propensity score to adjust for these covariants. PAC-monitored patients, however, had increased mortality, increased durations of hospital stay, and increased costs. Moreover, there was no subgroup who appeared to benefit from PAC monitoring. The controversies surrounding PAC use, however, have helped identify several unanswered key issues related to PAC monitoring and patient outcome. According to Mark et al. these points may be summarised as follows [8]:

- There is large variability in the level of skill and knowledge among physicians who use PACs. It has been proposed that failure to control for this factors has been responsible for the poor performance of PAC in most of the studies.
- Use of PAC varies widely between individual physicians, institutions, and different geographic locations. As in other part of modern medicine, this begs the question whether PAC is overused in many settings or perhaps underused in others.
- Learning bias may be another confounding factor. We now take better care of patients in general because we have learned so much about cardiovascular pathophysiology by using PACs. We now apply this knowledge effectively in the care of patients who do not have PAC monitoring.
- The role of PAC monitoring in improving patient outcome is inextricably tied to the therapies applied based on the data it provides. As several authors have noted, if there is no good treatment for the pathophysiologic state that is identified, there is no expectation of therapeutic benefit from the diagnostic procedure. This may be one of the key issues in our inability to treat effectively a serious illness such as sepsis, even when the cardiovascular problems are clearly identified through PAC monitoring.

Rather than offer a long list of indications for PAC, three factors should guide the physician's decision to employ PAC monitoring, as proposed by Roizen et al. [12].

- 1) The patient is at high risk because of severe underlying cardiopulmonary disease.
- 2) The intended operation places the patient at risk because of the magnitude or extent of the procedure.
- 3) The environment or practice setting is propitious for PAC monitoring.

CARDIAC OUTPUT MONITORING & CONTINUOUS MIXED VENOUS OXIMETRY

Aside from pressure monitoring capabilities, the most important feature of the PAC is its ability to measure **cardiac output** using the thermodilution method. Over the past decade, new technologies were applied to PAC monitoring to allow nearly continuous cardiac output (CCO) monitoring using either hot or cold thermal indicators; the hot thermal techniques are the ones more widely accepted in clinical practice. CCO methods appear to have good agreement with standard bolus thermodilution measurement. In a small, multicenter study, Mihm et al found that CCO provided a clinically reliable measurement. The device performed well in ICU patients with a wide range of cardiac outputs and core temperatures, and the method showed no deterioration in performance of the 72-hour monitoring period [13].

Although the formal Fick cardiac output method is not applied widely in clinical practice, the physiologic relations described by the Fick equation form the basis for another PAC-based monitoring technique termed **continuous mixed venous oximetry**. To the extent that the arterial oxygen saturation, oxygen consumption, and haemoglobin concentration remain stable, mixed venous oxygen saturation may be used as an indirect indicator of the cardiac output. For example, when cardiac output falls, tissue oxygen extraction increases and the mixed venous blood will become more desaturated. However, as noted in this equation, mixed venous oxygen saturation also varies directly with arterial oxygen saturation and haemoglobin concentration and varies inversely with oxygen consumption. When any of these other variables change significantly, one cannot assume that a change in mixed venous oxygen saturation results solely from a change in cardiac output. Although these considerations may confound the use of mixed venous oxygen saturation as an indicator of cardiac output, monitoring this variable provides more comprehensive information about the balance of oxygen delivery and consumption by the body - not just cardiac output, but also the adequacy of cardiac output. Many physicians have used these derived measures of oxygen consumption and oxygen delivery to guide treatment of critically ill patients. Unfortunately, as noted in the earlier discussion of PAC, this has not been shown to result in improved patient outcomes in most instances [8].

TRANSESOPHAGEAL ECHOCARDIOGRAPHY (TEE)

In the mid-1980s, colour flow Doppler technology became commercially available, making it possible for TEE to provide not only high-resolution, real-time images of cardiac structure and function, but also simultaneous, superimposed maps of intracardiac blood flow. With these technical advances, TEE's role was ensured in the perioperative assessment of patients with a wide variety of cardiovascular diseases. As the population of intraoperative TEE increases, however, its impact on surgical and anaesthetic decision-making, clinical outcome, and its role as a monitoring and/or diagnostic tool has been challenged. In clinical scenarios in which TEE is used primarily as a **diagnostic tool** to confirm or identify previously unrecognised cardiac pathophysiology (i.e. tamponade, aortic dissection) its role in influencing clinical management and outcome is easily defensible. In contrast, when TEE is used primarily as a **monitoring device** of cardiac performance or myocardial ischemia, questions regarding its relative independent impact on clinical decision-making and outcome are more difficult to answer. In addition, although relatively non-invasive, advocates of TEE's cost effectiveness and routine use during cardiac surgical procedures must also consider the rare but important procedure-related morbidity (i.e. gastroesophageal injury) [14]. However, the utility of TEE in independently influencing perioperative decision making is indisputably valuable when used to diagnose cardiac valvular pathology, especially valvuloplasty in the immediate post-cardiopulmonary bypass period. In this clinical scenario, the immediate availability of echocardiographic equipment and experienced echocardiographers should be considered a standard [15]. Its application, however, is supported by weaker evidence when used for hemodynamic monitoring or detection of myocardial ischemia in high risk patients.

MONITORING DEPTH OF ANAESTHESIA

In 1952, Faulconer demonstrated that the depth of anaesthesia, based on recognition of **EEG** patterns, correlated with the arterial concentration of ether [16]. Indeed, the EEG is a valuable tool to quantify depth of anaesthesia because it reflects cerebral physiology, it is a continuous and non-invasive measure, and it changes

markedly on administration of anaesthetic drugs. However, the application of the EEG to measure clinical depth of anaesthesia previously failed for several reasons. There has been a lack of understanding of the effects of interactions of several concurrently administered anaesthetic drugs on the EEG. There has not been a standard approach choosing an optimal EEG parameter and finally, a "gold-standard" for the measurement and assessment of clinical depth of anaesthesia has been lacking. Only recently the Bispectral EEG monitoring (BIS, Aspect Medical system) has been developed[17]. This medical device quantitates the anaesthetic effects on the brain, specifically the hypnotic component of anaesthesia, it presents a continuous, EEG parameter, the Bispectral Index, which ranges from awake, no-drug-effect value of 95 - 100 to zero with no detectable EEG activity.

Sensory or nerve stimulation produce a low-amplitude signal, or **evoked response**, within the CNS. This evoked response can be separated by computer signal-averaging techniques, from the underlying, spontaneous EEG. The ability to evoke a response is a measure of the functional integrity of the pathways between the sensory receptor and neuronal generator of peaks in the evoked waveform. The evoked responses are used primarily to monitor the functional integrity of neuronal structures. However, because evoked responses are sensitive to anaesthetic drugs, they have been investigated as possible measures of anaesthetic drug effect and depth of anaesthesia [17]. Many investigations have been performed with evoked potentials, with special emphasis on auditory evoked potentials.

The BIS monitoring device, coupled with observation of surgical stimuli and clinical responses, can be used to adjust the amount of hypnotic and analgesic agents administered to patients. Whether monitoring depth of anaesthesia with any EEG-based technique or evoked responses may decrease the incidence of awareness is matter of current research.

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