Review Article

Technological advances in perioperative monitoring: Current concepts and clinical perspectives

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Abstract

Minimal mandatory monitoring in the perioperative period recommended by Association of Anesthetists of Great Britain and Ireland and American Society of Anesthesiologists are universally acknowledged and has become an integral part of the anesthesia practice. The technologies in perioperative monitoring have advanced, and the availability and clinical applications have multiplied exponentially. Newer monitoring techniques include depth of anesthesia monitoring, goal-directed fluid therapy, transesophageal echocardiography, advanced neurological monitoring, improved alarm system and technological advancement in objective pain assessment. Various factors that need to be considered with the use of improved monitoring techniques are their validation data, patient outcome, safety profile, cost-effectiveness, awareness of the possible adverse events, knowledge of technical principle and ability of the convenient routine handling. In this review, we will discuss the new monitoring techniques in anesthesia, their advantages, deficiencies, limitations, their comparison to the conventional methods and their effect on patient outcome, if any.

Key words: Adverse events, improved outcome, limitations, technological advancement in perioperative monitoring

Introduction

Monitoring in anesthesia is a subject of a lot of research and development. Association of Anesthetists of Great Britain and Ireland (AAGBI) and American Society of Anesthesiologists (ASA) recommended minimal mandatory monitors that is, electrocardiography (ECG), noninvasive blood pressure (NIBP), end-tidal CO_2, pulse oximetry, and temperature which are universally acknowledged and have now become an indispensible part of the anesthesia practice.[1] Some patients may require additional invasive monitoring, e.g., vascular or intracranial pressure (ICP), cardiac output (CO) or biochemical variables. Over the last two decades, an increased numbers of medical litigations with subsequent increased attention to patient safety coupled with the advancements in technology have led to enhanced need for improved monitoring. Newer perioperative monitoring techniques include depth of anesthesia (DOA) monitoring; goal-directed fluid therapy (GDFT), transesophageal echocardiography (TOE), neurological monitoring, the advancement in the alarm system and technological advancement in perioperative pain assessment. Whether an overreliance on new technologies in perioperative monitoring has improved the patient outcome continues to be a topic of debate.[2]

An extensive literature search was performed through Medline, PubMed, Google Scholar and textbooks using the key words "DOA monitoring," "GDFT," "improved perioperative monitoring," "neurological monitoring," "neuromuscular monitoring (NMM)," "perioperative mortality," "temperature monitoring," "alarms and cognition" and "objective pain assessment." Moreover, the "adverse events or limitations" of each monitoring technique were searched separately. In this narrative review, we have discussed the studies and evidences related to the new monitoring techniques in anesthesia, their advantages, their limitations and their comparison to the conventional methods and their effect on patient outcome, if any.

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Anesthesia related morbidity and mortality

The mortality directly attributed to anesthesia has reduced over the last 25 years from 1 death in 2680 anesthetics in 1950s to 1 death in 10,000 anesthetics in 1980s.[3,4] In 1990s, the anesthesia induced cardiac arrest rate and death were observed to be 15/20,080 and 1 in 2500-3000 respectively.[4] The perioperative risk of death after general anesthesia (GA) may range from 1% to as high as 33% in high risk individuals.[4,5] The recent data on anesthesia mortality from the triennial reports of anesthetic mortality review committee, Australia have shown that anesthesia has become safer over time and that the risk of death directly attributable to it in healthy patients undergoing minor or moderate surgical procedures is nearly 1 in 200,000.[4] Various studies of mortality associated with anesthesia have shown that adverse incidents are frequently attributed to human errors.[6,7] Anesthesiologist's vigilance and experience about to the continuous display of data on the monitor is of paramount importance. In fact, "vigilance" is the motto of the ASA. As far as the anesthesiologist's experience is concerned, a recent retrospective analysis have evaluated the effect of experience in providing deep sedation for endoscopic retrograde cholangiopancreatography on safety and cost, and it was observed that anesthesiologist on a regular basis performed better than those on *ad-hoc* basis.[8] Monitoring can significantly reduce the risk of accidents by giving warning of the patients changing condition or by detecting the consequences of errors. Medications-related cardio-circulatory events and airway complications are few of the major causes of anesthesia related morbidity and mortality.[9] However, it is difficult to sort out the mortality due to surgery and patient disease from that due to the technical errors. Many anesthesiologists cite improved monitoring as the reason for the reduction in anesthetic-related mortality over the years. Better monitoring could have been only one of the reasons for the downward trend in anesthetic mortality. There are many other factors which have influenced the anesthesia related mortality over the years like improved training, availability of safer anesthetic agents and change in population anesthetized as a result of changes in surgical practice.[4]

Monitoring standards in anesthesia

The minimum mandatory monitoring by ASA and the AAGBI includes ECG, NIBP, pulse oximetry, and capnography while a nerve stimulator and temperature monitor should be immediately available.[1] The utility of ASA recommended minimal mandatory monitoring or basic monitoring is universally acknowledged. In our country, the Indian Society of Anaesthesiologists (ISA) recommended mandatory peri-operative monitors are considered as national standards.[10] Additional monitoring like continuous invasive arterial blood pressure, central venous pressure (CVP) monitoring, TOE, NMM etc., may be necessary as deemed appropriate by the anesthesiologists. The first landmark advancement in monitoring technology occurred in 1980's with the advent of pulse oximetry in clinical practice. A significant Cochrane review highlighted data from four trials including 21,000 patients and confirmed that pulse oximetry could detect hypoxaemia and related events, but there was little evidence that it affects the perioperative mortality and morbidity.[11] However the role of basic monitoring like pulse oximetry is proven despite lack of robust randomized controlled trials (RCTs) comparing pulse oximetry, a basic monitoring with no monitoring.

Monitoring in anesthesia practice usually refers to the display of both the patient's physiological variables and the variables assessing the anesthesia machine function. Continuous monitoring is believed to cause an early recognition and thus the correction of any physiological abnormalities. But continuous electronic patient monitoring may not always be beneficial. Rapid recognition of the altered condition is of help only if there is a treatment for the underlying cause. Even if the treatment is available, early detection is of help only if treatment is more effective when delivered quickly.[12] More information may bring more ways of misinterpretation.

If we really wish to evaluate that the reduction in perioperative morbidity and mortality is attributable to improve monitoring, we have two ways to rely upon. First, we can find studies looking at the trends of anesthetic mishaps over time and correlate this with the trends in the monitoring. But it is difficult to differentiate the mortality due to deficient monitoring from that due to various other factors. Second, the best method would be to compare the conventional monitoring with or without a new device in a clinical trial.[11] Hence in this review we shall discuss the studies related to new monitoring techniques in anesthesia, their comparison to the conventional gold standard technique and effect on patient outcome, if any.

The continuous monitoring of ASA recommended minimal monitors are a must in the intraoperative period.[13] Temperature monitoring is an important aspect of perioperative monitoring both under general or regional anesthesia. Various RCTs have shown that the mild hypothermia considerably increases the risk of surgical wound infection,[14] morbid myocardial outcomes,[15] blood loss and transfusion requirement[16] and prolongs recovery [17] in a wide variety of surgical procedures. Recently updated "American Heart Association-American College of Cardiology 2007 guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery" includes a level 1 recommendation for maintenance of perioperative normothermia in patients undergoing surgical or therapeutic procedures under general or regional anesthesia exceeding 60 min by use of active warming measures or by achievement of target temperature of 26°C in the operating room and the postanesthesia care unit.[18] Despite the strong level of recommendation and easy to implement measures of temperature monitoring, there lies a substantial gap in the thermal management practice. Thus, perioperative thermal management has now emerged as an ideal area for performance measurement and improvement as with minimal effort and cost it can markedly improve the surgical and patient outcome.

The routine use of NMM has been controversial despite the presence of adequate scientific evidence in its favor. Residual neuromuscular blockade is a common complication following use of neuromuscular blockers and is a major cause of morbidity and mortality in the immediate postoperative period.[19] An Australian survey has shown that the incidence of residual neuromuscular blockade has increased from 21% in 1986-31% in 2010.[20] NMM improves the quality of intubation, is helpful in maintaining adequate neuromuscular blockade intraoperatively and for diagnosing residual paralysis in the immediate postoperative period.[21] Acceleromyography (AMG) is the most versatile method in the clinical setting because of its applicability at various muscles and ease of use as it lacks technical difficulties of the traditional methods.[22] Despite the increased incidence of residual paralysis, advanced understanding of the physiology of neuromuscular transmission by anesthesiologist, and the scientific evidence in favor of NMM, it continues to be an optional monitor in the perioperative period.[23] In the year 2000, Baillard *et al.*, showed that intraoperative NMM using AMG as an objective method, in conjunction with an effort to educate the clinicians, led to a reduction of residual paralysis from 62% to very low levels.[24] This landmark finding contributed to the provision of routine use of NMM in all the operating rooms. Later, a survey in United kingdom among 718 anesthetists have shown that only10% used NMM routinely, and 28% used it occasionally and 68% had never used it.[25] Even according to the "ASA task force on the postanesthetic care" the assessment of neuromuscular function includes NMM only occasionally.[23] The probable causes for the occasional use of NMM are that the clinicians are not convinced of the benefits provided by the monitors, lacks adequate training and knowledge of the inherent technical factors.[24,25] So, the controversy whether NMM is used routinely continues despite the presence of adequate scientific evidence.

The new high standard anesthesia work stations, e.g. Drager provides a new level of efficient performance, safety and allows the anesthesiologist to focus on the primary task – the patient. These advanced anesthesia work stations have distinctive features like auto self-check, open architecture, and incorporate flexible monitoring which include continuous measurement of exhaled CO_2, oxygen, anesthetic-gas monitoring, pulmonary functions and various ventilation parameters. Continuous monitoring of these parameters may not be required in all and should be considered depending upon its availability, and patient population anaesthetized. Monitoring of these parameters has been an integral part of the newer anesthesia workstations, but no trials have been attempted for comparing the patient outcome with or without their use.

Newer monitors also incorporate software like anesthesia information system which has completely replaced the paper recording system.[26] Electronic anesthesia record is more contemporaneous, complete, and legible than the handwritten records. A feared problem with its use may be increased malpractice exposure as some evanescent perioperative physiological changes and the artifactual data from the monitors may be misinterpreted in the event of unfavorable patient outcome.[27,28] Hence, although introduced almost 25 years ago, its use in clinical practice is still limited, due to which there is no evidence of improved patient outcome with its use.

Neurological monitoring

Intracranial pressure monitoring continues to be an essential monitor in neurosurgery. Till 2006, only an observational study by Steiner and Andrews had suggested that ICP oriented therapy increases the treatment intensity without any improvement in outcome.[29] In 2012, Meyfroidt highlighted the need of RCTs in this regard[30] and finally recently, a multi-centric RCT involving 324 patients with severe traumatic brain injury, have shown that ICP monitoring does not show superior results when compared to the care based on imaging and clinical examination.[31] Moreover, there is still the controversy concerning the critical thresholds for ICP in children.[32] Moreover, the gold standard for assessing ICP is an intraventricular catheter, but its use in clinical practice is limited as the risk of infections is in the range of 6-11%. The accuracy of alternative devices that is, intraparenchymal, subarachnoid, subdural and epidural devices have been found to be lower than the intraventricular catheter.[29] High ICP and cerebral hypoxia shows a strong correlation with poor outcome. Thus cerebral perfusion pressure (CPP) should be optimized. CPP when used as a target for therapy, there is further controversy as to which threshold should be used.[29,30] CPP would also depend upon the monitored levels of cerebral oxygenation and should be optimized individually.

Various monitors of cerebral oxygenation include imaging methods like positron emission tomography (PET), magnetic resonance spectroscopy (MRS) and nonimaging methods like jugular venous oximetry (SjO_2), near-infrared spectroscopy, intracerebral microdialysis and brain tissue oxygen tension (PbO_2). PET is regarded as the gold standard despite its many limitations such as radiation exposure, limited availability, snapshot nature of the technique, and poor spatial resolution. Similarly, the routine use of MRS is limited due to postprocessing and nonuniform availability.[33]

Jugular venous oximetry (SjO_2) is considered to be an integral part of the neurological monitoring as it gives information on the adequacy of cerebral blood flow in relation to the metabolic demand of the brain.[34] SjO_2 monitoring is highly sensitive in the presence of global hypoxemia or ischemia, but the shortcoming is the inability to detect focal ischemia. Despite the many limitations of the method and the lack of grade 1 evidence, interest is still being focused on SjO_2 monitoring.[35] Brain tissue oxygen partial pressure (PbO_2) has emerged as a reliable monitor of cerebral oxygenation more so during the course of interventions such as CPP manipulations and hyperventilation. The invasiveness of the PbO_2 monitor has limited its usefulness, but combining parameters such as ICP and PbO_2 into a single probe have now reduced the number of probes inserted.

Transcranial Doppler ultrasonography was introduced in 1982 as a noninvasive technique for monitoring blood flow velocity, CPP, vascular reactivity, and the emboli in the basal cerebral arteries. It is also being used as an intra-operative monitor in anesthesia for the management of patients undergoing neuro-vascular surgery and carotid end-arterectomy as it detects microemboli and postsurgical blood flow velocity. However, its reliability as a perioperative monitor is still under investigation.[36]

Cerebral microdialysis has been in use since 1992 and provided useful information for the management of critical neurological patients as it analyzes a broad range of metabolites and mediators of brain damage in anaesthetized patients.[37] This technique till now is reserved only for research purpose as it is expensive, requires technical resources, results are not immediate or continuous and moreover, the interpretation of the resulting information into clinical practice is not easy.[38]

Depth of anesthesia monitoring

The second-step change in monitoring occurred recently in the last decade when the DOA monitoring using the processed electroencephalography (EEG) signal became so simple to be used as routine monitor. The first DOA monitor was bispectral index (BIS) monitor and was introduced in 1992 and after few years, various others were introduced like Narcotrend index, auditory evoked potential (AEP) monitor, patient state analyzer (PSA), entropy, cerebral state monitor (CSM) etc. All DOA monitor calculates an index or a value derived from the EEG, which can measure the hypnotic component of anesthesia. The use of DOA monitor can help in detecting awareness and thus titrate anesthetic agents and keeps a balance between anesthetic requirement and anesthetic drug administration. The reported incidence of intraoperative awareness varies from 0.2% to 2%.[39] The inflated incidence, as reported by various trials may also be reflected by various factors that is, underlying physiologic variation, alternative anesthetic technique, differential reporting and substantial inflation due to false memories.[40] On the contrary, Sebel *et al.* in a multicentric trial have reported an incidence of awareness to be as low as 0.13-0.18%.[41] Moreover, a recent national survey by Pandit *et al.*, reported an intra the-operative awareness of 1: 15,000 under GA which approximately translates to 180 cases in UK annually, the audit also prompted reconsideration of detection and incidence of awareness.[42] The result of this survey was found to be dramatically different from 1 to 2: 1000 established in the previous studies.[39,43] But the real incidence of awareness during anesthesia remains unknown as there has been a lot of variation in the reported incidence of awareness worldwide.

The main limitations of DOA monitoring are that various physiological factors influence EEG; moreover, it may have diverse outcome measures. Physiological factors such as age, race, gender, low body temperature, acid base imbalances, low blood glucose, or cerebral ischemia have significant influence on EEG.[44,45] The outcome measures with DOA monitoring are diverse that is, probability of awareness, consumption of anesthetic agents, time to extubation or discharge from the recovery room, and other sequelae resulting from the awareness during surgeries like postoperative cognitive dysfunction and mortality.

There are many practical limitations with DOA monitoring. Firstly, not all are validated to the same extent except BIS. Secondly, the clinical ranges of various DOA monitors are not identical across the devices. Thirdly, now there is enough evidence that awareness can still occur even with DOA monitoring. A large study in Australia popularly known as the "B-aware study" has clearly demonstrated that the use of BIS can reduce the awareness but does not prevent it with number needed to treat 138.[46] Recently, Avidan *et al.*, compared BIS with end tidal anesthetic gas monitoring in 6000 patients and concluded that no difference in awareness was found with the use of BIS.[47] Liu in a meta-analysis of RCTs s of 1380 ambulatory patients reported that BIS monitoring reduced the anesthesia requirement by 19% and the risk of postoperative nausea and vomiting by 6%, but reduced the time spent in postanesthesia care unit by only 4 min.[48] Fourthly, the DOA monitoring when used intraoperatively, although reduces the drug consumption and accelerate recovery but it does not translate into early discharge or improved outcome.[49] Moreover, the cost savings made by DOA monitoring were entirely cancelled out by the cost of disposables required for the monitoring.[50] In addition, titration of hypnotic agents using DOA monitors is mainly the manufacturer recommendation and good substantiation of this recommendation are lacking.[51] So, the use of DOA monitor in all patients remains an economic decision, and cost benefits analysis needs to be done. There are various other DOA monitoring techniques, e.g., AEP monitor, PSA-4000 monitors, CSM and entropy [Table 1]. All of them have been studied to a very limited extent due to various limitations and nonuniform availability.

Narcotrend monitor has less interference with electromyography (EMG) than BIS monitor.[73] The Narcotrend guided sedation demonstrates lower hemodynamic changes and fewer complications when compared to the clinical assessment guided sedation.[52] AEP monitor was introduced in 2000 and were more sensitive in monitoring DOA and in predicting recovery than BIS.[53] AEP features an AEP and the EEG-derived hybrid index of patient's hypnotic state. The monitor uses exogenous input (ARX) to measure the AEP. This monitor calculates the AEP-ARX-Index (AAI index), which is a dimensionless number and is `displayed on two scales, 0-100, and from 0 to 60. The drawback is that the EMG artifacts can influence the values as the EMG also propagates in the same frequency band.[54]

PSA-4000 monitor, calculates the value of the index from four EEG channels which are also a dimensionless number from 100 (awake) -0 (isoelectric).[55] The ability of CSM to monitor DOA is comparable to other available EEG-based devices. The drawback is its slow response to change in sedation.[56] Hoymork *et al*., monitored hypnotic effects in 87% of nonparalyzed patients using CSM and in 13% of patients the values indicated an awake state despite clinical sleep. However, the study was done with the initial version of CSM.[57]

Entropy was introduced in 2003 by the Datex-Ohmeda. This monitor displays two index values, e.g., state entropy (SE) and response entropy (RE) based on EEG and EMG respectively. SE is resistant to facial muscles contraction response and hence SE is a measure of hypnotic effect of AA. No definitive manufacturer recommendation or technical specification is available and result interpretation is at the discretion of the anesthetists and may have inter-individual variation. None of these new DOA monitors has been compared to the BIS, which is a clinically established DOA monitor in terms of its ability to detect awareness.

Another parameter with DOA monitoring is response time to change in the level of sedation or anesthesia as the processing, classification and averaging of EEG derived indices needs time. The response time has not found to be constant and varied from 30 to 100 s for the transition between sedated and awake state for BIS, Narcotrend and CSM.[58]

As we have discussed, awareness can still occur in patients receiving DOA monitoring, if the cause is failure of the monitoring algorithm or artifact detection, specific patient condition, or human error requires further study.[59] Until date, no monitoring system can reliably measure the DOA for all patients and all anesthetic agents.[60] Moreover, all DOA monitor can measure the hypnotic component and not the patient's stress level in response to nociceptive stimulus during GA.[61] Monitoring of the stress response is equally important as prolonged stress response delays recovery and increases the perioperative morbidity.[62] Various other indices like surgical stress index (SSI), the response index of nociception and the noxious stimulation response index have been found to be superior to BIS and AAI index.[63] But has been very little used in clinical practice. The ASA Task force states that brain function monitoring is not routinely indicated for patients undergoing GA, either to decrease the frequency of intra-operative awareness or to monitor the DOA.[64] To conclude, all DOA monitor add another parameter and in no way relieves the anesthesiologist of the need to use clinical judgment and to be vigilant. The development and the future

Table 1: Depth of anesthesia monitors

Depth of anesthesia monitor	Year of introduction	Awake to deep anesthesia (time delay)	Deep anesthesia to awake (time delay)	Electromagnetic interference	Correlation with clinical signs
BIS	1992	61 s	63 s	Moderate	Yes
Entropy	2003	Data not available	Data not available	High	Yes
Narcotrend	2000	26 s	90 s	Moderate	Yes
AEP monitor/2	2001	No data	No data	No data	Yes
PSA 4000	2001	No data	No data	No data	No data
CSM	2004	55 s	106 s	Moderate	Yes

BIS = Bispectral index, AEP = Auditory evoked potential, PSA = Patient state analyzer, CSM = Cerebral state monitor perspective of DOA monitor would definitely depend upon the universal applicability of a single validation protocol.

Goal directed fluid therapy and relevant monitoring

The "third-step change" in anesthesia monitoring is the development of simple relatively noninvasive device to measure CO and stroke volume in anaesthetized patients. The GDFT was introduced by Emanuel. Rivers in 2001 and was used in critical care medicine and then in the perioperative period for aggressive management of hemodynamics in high-risk patients undergoing cardiac surgery.[65] Pulmonary artery (PA) catheter was the core technology in the earlier GDFT studies.

The thermodilution technique of determining CO using a PA catheter has been the gold standard technique. In last few years, it has been proven that PA catheterization has no effect on mortality or on hospital stay in high risk surgical patients despite high incidence of adverse events.[66] Intermittent methods such as indicator dilution are widely used, but continuous CO monitoring is required clinically. The devices studied extensively in RCTs s are the esophageal Doppler cardiac output monitor (ODCM), pulse contour cardiac output (PCCO) monitor and TOE. All of these monitoring devices are used as part of a feedback process, to assess the fluid status and replace circulating volume to a target stroke volume or CO. In last one decade, numerous studies were performed with ODCO guided fluid strategies. A systematic review conducted by evidence based practice center in USA tried to conclude that therapeutic management based on ODCO monitor during surgery leads to improved patient outcome when compared to PA based measurement of CO via thermodilution or CVP measurements.[67] This systematic review comprised of total 7 publications involving 583 patients. None of the prospective RCT compared ODCO monitor to thermodilution method that is the gold standard. Moreover, most of the studies used ODCO monitor as a device to be used in complementary to CVP method.[67] Various studies in the past have demonstrated a positive effect of ODCO guided fluid therapy on the length of hospital stay, morbidity and mortality.[68,69] On the contrary, recently Challand *et al*., and Brandstrup *et al*., conferred no additional benefit of ODCO for GDFT over the standard fluid therapy in colorectal surgery in terms of hospital stay and complication rates.[70,71] Cochrane review on the use of ODCO monitor for perioperative fluid volume optimization following proximal femoral fracture has been found to be inconclusive in terms of its effect on patient outcome.[72]

ODCO monitoring, although considered a gold standard for monitoring GDFT perioperatively but it may have limitations. It has been observed that only 37% of patients who have decreased SV perioperatively respond to the fluid bolus[73] and the absolute measurement may also vary by 40%.[74]

NICE[75] and the UK GIFFTASUP[76] guidelines support the use of GDT in high risk surgical patients; however, its use in high risk surgical patients as a routine is highly debatable.[77]

Cardiac output by PCCO monitor calculates CO from the arterial pressure waveform of a peripheral artery using autocorrelation by nonlinear transformation of the input analogue arterial pressure. The first publication on PCCO monitor was in 1904 and preceded Kortokoff's auscultation paper by 1-year.[78] The advantages are that it is less invasive and can detect beat-by-beat CO. However, several calibrations are required intraoperatively to measure the CO. And there can also be a miscalculation of CO by PCCO monitor as the arterial pressure waveform changes with the change in arterial compliance according to sympathetic activity, intravascular blood volume, and patient's position, etc.[79] In view of its limitations, none of the studies has compared PCCO with the gold standard techniques like PA catheter or ODCM.

In late 1980s, TOE was introduced in cardiac anaesthesia and was considered as a noninvasive tool for monitoring the left ventricle function. Since then its use has expanded and now has become a standard intraoperative diagnostic tool for the management of patients undergoing cardiac surgery[80] as well as other major surgical procedures like lung transplantation, liver transplantation, and aortocardiac surgical patients where it often provides new and important information about pathology and may guide both surgical and anesthetic therapy.[81,82] TOE is also useful in guiding therapy in hemodynamically unstable patients in the operating room, and in the Intensive Care Unit (ICU), as simple TOE view can distinguish the hypotensive patients from the one with primary pump failure. But, no evidence supporting this practice is available.[65]

TOE is relatively safe and noninvasive. The potential injury related to TOE include oral injury, oropharyngeal, laryngeal, esophageal, gastric injury and gastric bleeding, arrhythmia and hemodynamic effects.[83,84] The use of TOE in the intraoperative period poses a higher risk profile in comparison to its use in a nonoperative setting as it requires probe placement and manipulation in intubated patients.[85] Overall TOE related morbidity when used intraoperatively have been found to be similar to nonoperative patients and ranges from 0.2% to 1.2%.[83] Lennon *et al*., surveyed patients for late complications and suggested that the rate of major gastrointestinal (GI) injuries (e.g., gastric lacerations, hemorrhage, or perforation) could be as high as 1.2% and may present after 24 h.[85] They concluded that the underestimation of the overall risk of TOE in the past could have been a reason for possible delay in clinical manifestation of TOE-related GI injury.[86] The other problems with TOE include TOE related endotracheal tube malposition and recurrent laryngeal nerve injury in neurosurgical patients.[83] The familiarization with potential complications of TOE is needed to allow risk benefits analysis on an individual basis.

The improved patient outcome following use of TOE in cardiac patients is an established fact; however, no data suggesting the risk reduction in noncardiac patients is available [Table 2].

American Society of Anesthesiologists task force and the society of cardiovascular anesthesiologists task force on TOE recommends a basic training in perioperative TOE in general anesthetic practice.[87] However, when not used routinely, one may face difficulty in skill retention. It also carries the risks associated with the procedure itself and does require the need of providing training and experience for the practitioner. TOE has resulted in a significant change in the status of anesthesiologists. As now not only can they diagnose any ischemic episode perioperitvely but can also assess the effectiveness and guide the surgical intervention along with the surgeons. The rapid proliferation of TOE may be technology driven but should be used as an accessory tool to have a more comprehensive understanding of the patient's cardiovascular physiology in relation to the disease and surgical intervention. The skill development and retention are deemed essential to enhance the utility of this monitoring technique [Table 3].

Alarms and cognition

Alarms are the integral part of the anesthesia monitor and being used in many clinical applications. Increased attention to safety and numbers of medical litigation following an adverse event in anesthesia practice has led to the widespread use of alarm system. The alarms are observed to be frequently too numerous, confusing, too loud, badly designed resulting in hindrance rather than improved performance.[92] One of the developments in alarm technology is an intelligent alarm system. The key advantage is the low false alarm rates, as it monitors and integrates the output of several parameters at once, or in principle, by a neural net.[93] The various reasons for alarm failure could be a mismatch between technology and the fundamental psychological principles of perception, attention, learning, and memory. Thus, the cognitive capacity and processing mechanism of the user must be considered while designing and implementation of the alarms in clinical practice and is a potential focus for future research. "ASA recommendations for standards for monitoring under anesthesia" states that alarm limits for all equipments must be set before use and all audible alarms must be enabled during anesthesia. However, this

Table 2: Incidence of TOE-related morbidity

Complication	Intraoperative	Pediatric	ICU
Dental injury	Kallmeyer *et al*.[83] 03%		
Severe odynophagia	Kallmeyer *et al*.[83] 0.1%		
Minor pharyngeal bleeding	Kallmeyer *et al*.[83] 0.01%		
Dysphagia	Hogue *et al*.[88] (OR, 4.68) Rousou *et al*.[89] (AO, 7.80)		
Endotracheal tube malposition	Kallmeyer *et al*.[83] 0.03%	Stevenson[91] 0.2%	
Dysrhythmias (AF, VF, VT, NSVT, AVB)		Stevenson[91] 0:1650	Slama *et al*.[84] 1.6%
Perforation	Kallmeyer *et al*.[83] 0.01% Lennon *et al*.[85] 0.3%		
Major bleeding	Kallmeyer *et al*.[83] 0.03% Lennon *et al*.[85] 0.8%	Stevenson[91] 0:1650	
Major morbidity	Kallmeyer *et al*.[83] 0.2% Lennon *et al*.[85] 1.2% Owall *et al*.[90] 0:24		

TOE = Transesophageal echocardiography, ICU = Intensive care unit, AF = Atrial fibrillation, VF = Ventricular fibrillation, VT = Ventricular tachycardia, NSVT = Non-sustained ventricular tachycardia, AVB = Atrio-ventricular block

Table 3: Importance of TOE learning curve

TEE images ↓ Can consume anesthesiologists ↓ Time and attention that they need to attend to other responsibilities	Inaccurate interpretation by inexperienced examiner ↓ Generates incorrect information ↓ Improper clinical decision ↓ Unnecessary peri-operative complication

TOE = Transesophageal echocardiography again is a potential area for performance measurement and improvement.

Technological advancement in perioperative pain assessment

Inadequate postoperative pain management may have many undesirable effects like increased hospital stay, impaired quality of life, development of chronic pain and increased morbidity and mortality. Postoperative pain management is one of the most challenging factors for determining patient outcome following surgery. Thus, regular and comprehensive pain assessment in the perioperative period would help in improving the postoperative acute pain management. There are various scales and questionnaires for subjective pain assessment tools and are categorized into uni-dimensional (numerical rating scale, visual analogue scale, faces pain scale) and multidimensional (neuropathic pain assessment NPS, Mc Gill's pain questionnaire. The technological advancement in the objective assessment of pain has occurred recently with the introduction of pain assessment monitors like algesimetry and surgical pleth index (SPI). Algesimeter is a device used to detect the sensitivity of the skin to a painful stimulus and is faster and more sensitive and specific when compared to other objective pain assessment methods. SPI is a parameter based on plethysmographic pulse amplitude and pulse interval and reflects the patients' hemodynamic response to surgical stimuli and analgesic medication during GA. The sensitivity and specificity of algesimetry in the perioperative period is found to be around 90% when compared with clinical stress variables.[94] Whereas, SPI does not show superior results when compared with other hemodynamic variables to assess nociception and anti-nociception balance during GA.[95] Ledowski *et al.*, had observed that skin conductance algesimetry is an efficient perioperative monitor to predict postoperative pain and to assess its intensity.[96,97] Later in 2009, Ledowski *et al.*, also showed the increased specificity and sensitivity of algesimetry in predicting postoperative pain when compared to the SSI.[98] However, in the same year, Storm *et al.*,[99] highlighted the fact that the pain detection sensitivity of this study was markedly different from his own previous studies.[96-98] The limited research and marked variation in the results of the various studies related to algesimetry poses question on its effectivity as a perioperative monitor. Similarly, with SPI, most of the preliminary studies were done in patients undergoing GA with propofol and remifentanyl. These trials showed that SPI-guided remifentanil administration reduces remifentanil and propofol consumption and shortens recovery times in outpatient anesthesia.[100] So, it was concluded that SPI may be used as a bedside tool to measure pain during surgery. But so far, the related studies are limited, and all are performed under GA and till now, no study has investigated SPI or algesimetry under regional anesthesia. All current pain assessment monitors require further development and testing for accuracy and reliability.

Future perspectives and conclusion

The monitoring devices of the future will have an additional advantage that it would enables automated correction of physiological abnormalities simultaneously, e.g., pharmacokinetic-based anesthesia infusion pumps with DOA monitoring or newer ventilators that can automatically adjust the ventilator settings by monitoring lung mechanics. These new monitoring techniques can potentially reduce the element of human error.

To conclude, new and improved monitoring techniques have undoubtedly led to dramatic changes in anesthesia practice. Various factors that need to be considered with the use of improved monitoring techniques are the validation data, patient outcome, safety profile, cost effectiveness, awareness of the possible adverse events, knowledge of technical principle and ability of the convenient routine handling. So far, there is a lack of substantial evidence if these new improved monitoring techniques have improved patient outcome. How often these improved monitors are used for a particular indication also varies from institution to institution. Most of the new monitoring techniques have been evaluated to a limited degree. More over the main barrier to research evaluating the patient outcome with these new monitoring techniques include its non-uniform availability. In developing nation like ours, we must ensure the implementation of minimal mandatory monitoring standards as recommended by ASA and AAGBI. We must reinforce that vigilance is the key and optimal vigilance requires an understanding of the technology of sophisticated monitoring equipments — including the cost benefit consideration. We being anesthesiologists, must be aware of the recent developments in monitoring, must use it where it is indicated and should be in a position to direct them by using our clinical acumen. We should always remember that we must monitor the monitors.

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