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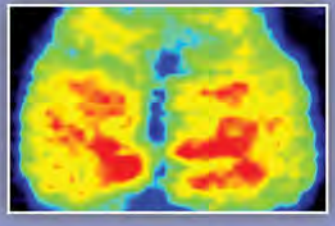
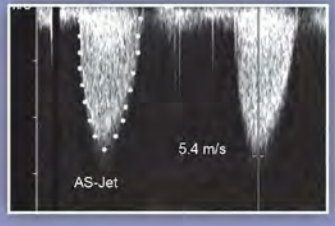
Monitoring in
ANESTHESIA AND CRITICAL CARE



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CHAPTER 3

Minimum Monitoring Standards

Surender K Malhotra, Kamal Kajal

INTRODUCTION

Presence of skillful and experienced anesthesiologist is pivotal in the perioperative management of an anesthetized patient but human error is unavoidable. Plethora of studies in relation to critical incidents has suggested the role of human errors in some ways. Administration of any form of anesthesia to a patient undergoing surgery is associated with inherent dangers and complications. Use of anesthetic drugs, unpredictable nature of complex surgical procedures, and coexisting medical problems often aggravate the risks to the patient. There is substantial evidence that continuous monitoring reduces such critical incidents and cut down human errors by giving an early warning regarding the deterioration of patient situation and subsequent mishaps.

Former practice of monitoring comprises of clinical observation of pulse, blood pressure, respiratory rate, and cyanosis. These modalities were nevertheless unsatisfactory in appreciating hypoxia and hypoventilation. Furthermore, good illumination is needed to acknowledge the color of skin or mucous membrane for cyanosis. It is clearly established that these modalities did not indicate the true nature of the patient condition and changes observed were late and often the clinical condition has sometimes deteriorated to an irreversible state. The development of sophisticated instruments by the technological advances, have resulted in faster detection of impending adverse events so that the subsequent corrective measures could be started at earlier moments.

Advancements in technology lead to the development of number of monitors for clinical use that provided more accurate and comprehensive information about the condition of patient that was not possible earlier. Various monitors ranging from detection of hypoxia (pulse oximeter, oxygen analyzer), hypoventilation (capnometer), cardiac status [electrocardiogram (ECG), noninvasive blood pressure (NIBP), and invasive blood pressure (IBP)], abnormal temperature to a specialized monitoring like bispectral index (BIS), stroke volume variation, transesophageal echocardiography, intracranial pressure (ICP), monitor and transcranial Doppler (TCD) are available and the list seems to be endless. However, it is well-accepted that monitors may not improve patient outcomes. Attributes of ideal monitor are that it should be reliable, cost-effective, and improve patient's safety that translates to better patient outcomes.

Young and Griffiths[1] in their review suggested that the primary intention of monitoring under anesthesia is regulation and control when physiological monitoring of patients is usually justified, not because it is central to the process of anesthesia but suggesting it reduces serious adverse events. Thus, availability of more information is not always better and it benefits only when it is collected at the right time, interpreted correctly, and appropriately acted to get good patient outcomes. Monitors themselves do not prevent an adverse outcome but provides early warning of impending mishaps. Ultimately, it is the man behind the

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machine. It is an anesthesiologist who has the responsibility of properly interpreting the parameters and acting accordingly. Australian incident monitoring[2] has clearly shown that some of the adverse outcomes are attributed to at least partly to human mistakes. Thus, for favorable outcomes, monitors are indispensable. Sets of minimum monitors or core standard monitors are, therefore, essential for the safe anesthetic practice.

Apart from operation theaters, monitoring is extensible used in (level III) critical care units and (level II) high dependency units and in high-risk patients in wards.

GUIDELINES

Depending upon the medicolegal, cultural, racial, and other disparities, an International Task Force (ITF) in 1992 was constituted for assistance to anesthesia providers, hospital administration and government in improvising minimum mandatory standards. World Federation of Society of Anesthesia accepted ITF recommendations in 1992.

"Eternal Vigilance" is the slogan of American Society of Anesthesiologists (ASA). First ASA guidelines on the standards for basic anesthetic monitoring were approved on October 21, 1986 and subsequently amended in October 2010 and last affirmed in October 2015.[3] Association of Anaesthetists of Great Britain and Ireland (AAGBI) guidelines for standards of monitoring during anesthesia and recovery were also published in 2007.[4] The same has been acknowledged and practiced worldwide, including Indian Society of Anaesthesiologists (ISA) in 1999 and was amended in March 2010. Summary is present in table 1.

TABLE 1: American Society of Anesthesiologists standards for basic monitoring[3]

Parameters	Methods
Oxygenation	• Inspired gas oxygen analyzer • Pulse oximetry (with audible tone) • Illumination to assess patient's color
Ventilation	• $PETCO_2$ monitoring: Capnography, capnometry, or mass spectroscopy with audible CO_2 alarm to detect correct placement of endotracheal tube • Utilization of device capable of detecting disconnection of the components of breathing systems
Circulation	• Continuous electrocardiogram • Blood pressure and heart rate determination in every 5 min • Assessment by at least one: Palpation of pulse, intra-arterial tracing of blood pressure, ultrasound peripheral pulse monitoring, pulse plethysmography or oximetry
Temperature	• Indicated when clinical significant changes in body temperature are intended, anticipated, or suspected

$PETCO_2$, partial pressure of end-tidal carbon dioxide; CO_2, carbon dioxide.

MONITORING STANDARDS

Standard monitoring is discussed in following headings:

- Presence of anesthesiologists
- Monitoring parameters:
  - Oxygenation
  - Ventilation
  - Circulation
- Ancillary monitoring recommendations
- Monitoring equipment
- Monitoring during transportation and recovery
- Pediatric monitoring
- Monitoring at remote places or out of hospital setup.

Presence of Anesthesiologists

Well-qualified anesthesia personnel should be present throughout the conduct of anesthesia irrespective of the procedure. The notion is that only the qualified anesthetist is able to appreciate the rapid changes in hemodynamics during anesthesia. Anesthesiologists and monitors together form a complex feedback loop. Monitors provide physiological variables and anesthetist recognizes them and, considering the medical history and stage of operation, takes relevant actions. For example, adjusting ventilation in case of hypo- or hypercapnia by observing capnography, or by giving the fluid bolus in case of tachycardia or hypotension during blood loss or hypovolemia. Availability of assistance in case of mishap should be immediately available. Presence of anesthesiologist is mandatory throughout

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the surgical procedure as well as shifting to postoperative ward or intensive care unit (ICU) with suitable handover to concerned team.

Monitoring Parameters

American Society of Anesthesiologists monitoring standards strongly recommend that every patient undergoing anesthesia should be monitored for oxygenation, ventilation, and circulation.

Oxygenation

- It is mandatory for oxygenation to be monitored by pulse oximetry that displays peripheral capillary oxygen saturation (SpO_2) and heart rate in bold form and it should be equipped with features of low oxygen alarm and variable pitch tone. Apart from these aspects, recent literature also advocates the display of pulse plethysmography
- It is imperative for all the patients to receive an assured inspired concentration of at least 25%. This can be accomplished by legitimate anesthetic machine that incorporates hypoxic defense system with visual and audible oxygen failure alarm and oxygen analyzers for identifying low oxygen concentration in the circuit
- Good illumination must be present in operation theaters to identify color of skin or mucous membrane for cyanosis.

Ventilation

- Clinical observation of chest movement along with appreciation of movement of reservoir bag should be done in routine and they should be supplemented with auscultation of breath sounds
- It is mandatory to monitor end-tidal carbon dioxide (CO_2) by capnography for:
  - Adequate mask ventilation
  - Placement of airway device
  - Diagnosing hypo- or hypercapnia
  - Tracheal tube disconnection.

Circulation

- Clinically palpating the pulse at appropriate sites is critical and should be done frequently
- It is mandatory to continuously monitor the patient's ECG and NIBP, either manually or using a monitor
- Intra-arterial blood pressure tracing or ultrasonography peripheral pulse monitoring or pulse plethysmography can be used in selected situations, where there are extreme and rapid hemodynamic fluctuations
- Central venous pressure or pulmonary artery catheter monitoring is preferred in selected circumstances, for example, major cardiovascular surgeries and thoracic procedures with expected expeditious hemodynamic alterations.

Association of Anaesthetists of Great Britain and Ireland guidelines recommends following monitors during induction and maintenance of anesthesia.[4]

- Pulse oximeter
- Noninvasive blood pressure
- Electrocardiograph
- Airway gases oxygen or CO_2 and anesthetic vapors
- Airway pressure.

Following must be available:

- Neuromuscular monitoring
- Temperature monitoring.

Ancillary Monitoring Recommendations

Additional monitoring includes:

- Temperature monitoring
- Neuromuscular monitoring
- Anesthetic depth
- ICP/TCD/somatosensory evoked potential/brainstem auditory evoked potentials.

These adjuncts are not included in minimum mandatory requirements. The ASA task force has not incorporated depth of anesthesia monitoring in basic-standard monitoring standards.[5] They are of the opinion that it should be monitored on the discretion of individual anesthetist. The same view has been endorsed by ISA. Patients belonging to pediatric or geriatric or major intra-abdominal procedures should be monitored for core temperature monitoring with esophageal or rectal probes.

Monitoring Equipment

Monitoring the anesthetic equipment in pre-anesthesia period is mandatory and it is the utmost responsibility of an anesthesiologist to ensure that they are accustomed with all the equipment that they want to use and they have followed specific checking protocol recommended in various guidelines.

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Association of Anaesthetists of Great Britain and Ireland and ASA have developed guidelines regarding the monitoring of anesthesia equipment in pre-anesthesia period.[6,7] American Society of Anesthesiologists guidelines for checkout recommendations are shown in table 2.

TABLE 2: Summary of checkout recommendations by American Society of Anesthesiologists[7] (to be done on daily basis)

Item to be completed	Responsible party
Item 1: Verify auxiliary oxygen cylinder and self-inflating manual ventilation device are available and functioning	Provider and technician
Item 2: Verify patient suction is adequate to clear the airway	Provider and technician
Item 3: Turn on anesthesia delivery system and confirm that AC power is available	Provider and technician
Item 4: Verify availability of required monitors, including alarms	Provider and technician
Item 5: Verify that pressure is adequate on the spare oxygen cylinder mounted on the anesthesia machine	Provider and technician
Item 6: Verify that the piped gas pressures are ≥50 psig	Provider and technician
Item 7: Verify that vaporizers are adequately filled and, if applicable that the filler ports are tightly closed	Provider and technician
Item 8: Verify that there are no leaks in the gas supply lines between the flowmeters and the common gas outlet	Provider and technician
Item 9: Test scavenging system function	Provider and technician
Item 10: Calibrate or verify calibration of the oxygen monitor and check the low oxygen alarm	Provider and technician
Item 11: Verify carbon dioxide absorbent is not exhausted	Provider and technician
Item 12: Breathing system pressure and leak testing	Provider and technician
Item 13: Verify that gas flows properly through the breathing circuit during both inspiration and exhalation	Provider and technician
Item 14: Document completion of checkout procedures	Provider and technician
Item 15: Confirm ventilator setting and evaluate readiness to deliver anesthesia care. (anesthesia time out)	Provider and technician

Oxygen Supply

Oxygen analyzers with an audible alarm are prerequisite for giving anesthesia. It is to be placed in such a position so that gas mixture going to the patient is continuously measured. It depends on the breathing system in use. An electrochemical oxygen analyzer has a sensor that is exposed to gas being analyzed.

Instructions for use:

- Calibration: It should be done on a daily basis, before use and at least 8 hours after the first calibration. Method is to expose the sensor to room air and verifying that it displays almost 21%
- Checking alarms: Low oxygen alarm threshold should be set above 21%
- Position: It should be placed in the inspiratory side of the CO_2 canister.

Benefits:

- Detecting hypoxic or hyperoxic mixtures: It gives an early warning of a hypoxemia compared with pulse oximetry. It also helps in prevention of problems relating from hyperoxygenation like damage to lungs or eyes in neonates and fires
- Detecting hypoventilation: A difference between inspired and expired oxygen is 4–5%. Difference of more than 5% after a steady state is a sensitive indicator of hypoventilation.

Breathing Systems

Any type of breathing systems should be checked routinely as recommended in guidelines. It has been mentioned earlier that capnography has an essential role in diagnosing conditions pertaining to ventilation. It provides an important means for assisting metabolism, circulation, and ventilation. Capnometry is the measurement of CO_2 in a gas mixture and capnography is the recording of CO_2 concentration versus time. Box 1 lists some causes of changes in CO_2 levels.

Vapor Analysis

Vapor analysis is essential as part of routine anesthesia, as per AAGBI guidelines. It is not included as a standard of monitoring in ASA guidelines. Infrared bench monitors both anesthetic agents and CO_2. An agent monitor is helpful in determining incorrect contents, provides information on agent uptake and distribution, and detecting disconnections.

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Box 1: Causes of changes in end-tidal carbon dioxide measured by capnography

- Hypercapnia
- Hypoventilation
- Hyperthyroidism
- Malignant hyperthermia
- Rebreathing
- Fever or sepsis
- Other hypermetabolic states
- Hypocapnia
- Hyperventilation
- Hypothermia
- Venous air embolism
- Pulmonary embolism
- Decreased cardiac output
- Hypoperfusion

Infusion Devices

All infusion devices must have their alarm setting and infusion limits checked before initiating anesthesia. It is important that these drugs are delivered to the patient appropriately and infusion site should be visible and secured nicely.

Alarms

The manufacturer often inappropriately sets default alarm setting and it should be reset to upper and lower limits as needed. All alarms should be set at appropriate values and audible alarms must be enabled. With positive pressure ventilation, airway pressure alarms should be used to identify excessive pressure in airway and provide early warning of disconnection and leaks. Maintenance, provision, and renewal of equipment are the responsibility of the institution.

Monitoring Recommendations during Transfer and Recovery Areas

Monitoring standards during transfer of patient to destined area should be as high as that applied in the controlled operation theatre setup and person with acceptable knowledge should accompany the patient. Appropriate monitoring should be initiated before transfer that includes SpO_2 and NIBP along with ECG. Oxygen cylinder of known content sufficient to last the maximum period of transfer should be checked. Airway pressure, tidal volume, and respiratory rate must be monitored in transfer of mechanically ventilated patients.

Very high vigilance is needed in patients recovering from anesthesia in wards. Patients should be stable on departure from operation theater with availability of supplemental oxygen source.

Association of Anaesthetists of Great Britain and Ireland recommendations mandates following minimum monitoring devices in recovery:

- Pulse oximetry
- Noninvasive blood pressure.

Following must be available:

- Electrocardiography
- Nerve stimulator
- Temperature monitoring
- Capnography.

Monitoring in Pediatric Patients

Numerous studies found 3–5-fold higher rate of cardiac arrest among children undergoing anesthesia than adult population.[8] Incidence reported is from 9.2/10,000 to 17/10,000 anesthetics, that is roughly 10 times the adult incidence.[9] Cardiovascular and respiratory causes are most accepted factors. Incidence of cardiac arrest and mortality during noncardiac procedures were 2.9/10,000 and 1.6/10,000, respectably.[10] Above data signifies that pediatric population is a high-risk group for anesthetists and should be monitored with particular attention during cardiovascular surgery.

American Society of Anesthesiologists and AAGBI monitoring hold true for pediatric populations also. Special features are mentioned below.

Physical Examination

It includes observation and auscultation. Enough information can be inferred from observing the child heart rate and pattern of respiration. Respiratory pattern gives clue to the anesthetic depth and airway obstruction can be checked by chest retractions or see-saw paradoxical respiration. Good illumination in the operation theater needed to appreciate the color changes of skin and mucous membranes for confirming adequate oxygen as pulse oximetry has a significant lag time and it is ineffective in vasoconstricted states. Capillary refill time is also an important monitoring parameter for assessing volume status and cardiac output.

Precordial stethoscope is helpful in detecting changes in rate and character of heart and breath sounds. Stethoscope should be placed in left sternal border between second and fourth interspaces.

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Electrocardiography

It is most helpful in tracking of heart rate and to detect intraoperative arrhythmias. Bradycardia and supraventricular tachyarrhythmias are most frequent in pediatrics. Hypoxemia related ECG monitoring detects hypoxemia related bradycardia early before an appreciable drop of saturation in pulse oximetry. Movement related artifacts are less compared with pulse oximetry. Additionally, electrolyte abnormalities can be appreciated by ECG monitoring. Lead II provides better information of atrial activity and detecting arrhythmias. Table 3 presents the resting heart rate of infants and children.

Systemic Arterial Pressure

Oscillotonometry is the method used to measure blood pressure in small infants. It correlates well with the Riva-Rocci mercury column method but it underestimates the diastolic component.[11] It should be done every 3–5 minutes, as too frequent monitoring would lead to limb ischemia. It is usually done on upper arm but other sites like forearm, thigh, or calf can be chosen. Cuff should cover two-thirds of the total length of forearm. Too small a cuff would result in falsely high blood pressure reading and too large would result in low readings.

Indications of direct arterial pressure monitoring are:

- Blood loss more than 50% of Epstein-Barr virus (EBV)
- Acute loss of more than 10% of EBV
- Fluid shifts (third space losses >50% EBV)
- Surgery requiring cardiopulmonary bypass.

Monitoring Recommendations for Out-of-operation-Theater Settings

There is ever increasing need for anesthesia personnel to provide services for out-of-operating room environments. It requires great deal of flexibility combined with expertise and skill to fraught with challenges faced in these setups. Few studies have shown that adverse events are of higher severity and often result from substandard care including lack of constancy to minimum mandatory guidelines.[12,13]

Magnetic resonance suites pose profound risks to patients as high magnetic field interferes with pacemakers, implants, cardiac valves, or other prosthesis. Other problems in monitoring are:

TABLE 3: Normal resting heart rate in neonates

Age	Range (beats/min)
Newborn	94–145
1–7 days	100–175
8–30 days	115–190
1–3 months	124–190
3–12 months	111–179
1–3 years	98–163
3–5 years	65–132
5–8 years	70–115
8–16 years	55–105

- It is mandatory to have magnetic resonance imaging compatible anesthesia machine along with compatible equipment
- Electrocardiographic monitoring is apt to considerable artifacts from magnetic field
- Pulse oximetry is mandatory but signal may become degraded due to currents in oximetry cable and decreased signal to noise ratio
- Capnography may be helpful and there may be decrease in phase II slope of capnogram due to long circuit pathways.

CONTROVERSIES IN MONITORING

Plenty of studies have been done to determine the competency of monitors to reduce mortality and morbidity. In a systematic review by Pedersen et al. for analyzing the role of pulse oximetry, no evidences of significant difference pertaining to duration of ICU stay, ventilator free days, and postoperative complications were found.[14] They did not find any candid evidence that it affects the outcomes of the patients. Similarly, Mollers et al. in their randomized controlled trial that includes 20,842 patients did not find any convincing impact of pulse oximetry on reducing mortality or hospital stay.[15,16] Cochrane review in 2008 also concluded that its impact on reducing adverse events remains unproven.[17] On the contrary, there are dearth of studies that advocate usefulness of pulse oximetry in facilitating faster detection of arterial desaturation and subsequent implementation of potential life-saving treatment. Randomized controlled trial by Watkinson et al. in conclusion of study mentioned that mandatory vital parameter monitoring had no effect on reducing adverse events in high-risk medical

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and surgical patients.[18] However, this study has been criticized for its abundant limitations that may have lead to high type II error.[17]

Closed claim data analysis studies advocate that the efficient monitoring may be initiated for prompt correction of catastrophic perioperative events.[19] While all the studies mentioned above have significant limitations but they helped to diversify the idea that monitoring even in patients with highly abnormal values does not provide mortality benefit.

Early studies relating to the use of capnography as a supplement during sedative procedures found that this modality might help in early detection of imminent respiratory failure.[20]

CONCLUSION

Prevention of morbidity and mortality is the principal goal of intraoperative monitoring but fundamental aim is to provide information that allows anesthesiologists to give risk-free anesthesia to all patients. At the end, most critical monitor is the anesthesia provider. Continuous monitoring is pivotal for the administration of anesthesia. So, minimum mandatory standards given by various guidelines should be followed in every case. Nonetheless, it is not possible to evaluate monitoring standards using randomized trials. Wide range of monitors and equipment are available for anesthesiologists caring for adults and children. Their use depends upon the patient's illness and the surgery planned. Last but not the least, direct surveillance of each patient during anesthesia and surgery is vital and relying too heavily on these monitoring modalities is not justified.

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Monitoring in
ANESTHESIA AND CRITICAL CARE

Key Features

- This book provides extensive coverage of most primitive to most modern monitoring technologies
- A comprehensive yet concise description of various monitors is included
- The book uniquely includes structured text on obstetric critical care, which we felt was lacking in most textbooks available previously
- Extending beyond clinical realms, the book also focuses on research based upcoming monitoring ideas like quantifying pain, sedation, and maternal-fetal safety improvement
- The book is aptly divided into sections that discuss monitoring technologies of various organ systems like cardiac, respiratory, hematology, and nervous system
- Other special highlight of the book includes a section on monitoring of metabolic parameters (endocrine, arterial blood gases, and biochemical parameters) that clearly make this book distinct from all other books published with similar purview
- Multispecialty global experts spanning intensive care, anesthesia, medicine, and surgery have enriched the book with clinical practical ideas that targets almost all subspecialties readers
- Essentially, the book not only provides relevant material for postgraduate students but also extends out to reach the clinicians in both teaching and nonteaching hospitals.

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