Modern Monitoring in Perioperative Medicine

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Edited by

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FOREWORD

DAVY CHENG

As we navigate the dynamic landscape of anesthesiology and perioperative care in the artificial intelligence (AI) and digital era, we find ourselves at the intersections of cutting-edge technology, patient outcomes, and healthcare providers' well-being. In this rapidly evolving field, monitoring plays a pivotal role in ensuring safe and effective perioperative management. One of the most exciting developments in recent years has been the integration of AI into perioperative monitoring. AI, with its ability to analyze vast amounts of data and recognize patterns, has the potential to revolutionize how we monitor and care for our patients.

This textbook covers a comprehensive systemic approach to monitoring in perioperative medicine written by esteemed authors/experts in their fields into chapters based on organ systems and categories of monitoring, including physician well-being monitoring, and individual provider's performance monitoring. This up-to-date monitoring textbook included evidence of the latest research and clinical trials with 75% of its references within 5 years in most chapters. The latest advancement in technologies of AI and machine learning in perioperative monitoring applicable in organ system monitoring is also discussed, such as AI algorithms in the depth of anesthesia, perioperative risk prediction, ultrasound and echocardiography guidance, pain management, coagulation functions, neonatal/fetal monitoring, and telemonitoring in perioperative medicine.

As clinicians, we must embrace these innovations while remaining vigilant about their limitations in perioperative monitoring. These multi-authored textbook bridges research and practice, providing valuable insights for anesthesiologists, intensivists, trainees, and surgical and perioperative teams. I am sure you will have an informative journey through the pages of Modern Monitoring in Perioperative Medicine, empowering you to deliver exceptional patient care in the modern AI and digital era.

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I. History and Introduction

CHAPTER 1

HISTORY OF PERIOPERATIVE MONITORING

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SHREVEPORT

Abstract

Perioperative monitoring plays a key role in improving health care quality and reducing perioperative mortality and has been a major advancement in improving outcomes in the past century. Today it is relatively safe to undergo through surgery and anesthesia. But this safety level did not come easily. This chapter reviews the history of development of both requirements and techniques in perioperative monitoring in all aspect of perioperative monitoring, including hemodynamic, respiratory, anesthetic volatile agents, temperature, and depth of anesthesia. With never-ending introduction of new technologies into perioperative monitoring, perioperative quality and safety will continue to improve.

Key Words: Anesthesia monitoring, perioperative monitoring, temperature, anesthesia history, capnography, pulse oximetry

Background

Perioperative monitoring is one of the most important factors in ensuring the quality of perioperative care and safeguarding patient safety in modern medicine. The monitoring techniques, requirements, and criteria in various perioperative settings have gone through a long, complex, at times controversial, and even tortuous evolving process. Historically, many of the techniques utilized in patient monitoring in recent times were invented and used long before clinical anesthesia was introduced into medical practice [1,2]. Respiratory patterns were described prior to anesthesia being introduced into clinical medicine. In many cases, there were no prospective randomized clinical trials for perioperative monitoring with only circumstantial evidence showing that vigorous perioperative monitoring improves patient safety and clinical outcome [3]. The introduction of standard/required minimal monitoring by American Society of Anesthesiologists (ASA) in the 1980s substantially reduced previous serious perioperative morbidity and mortality [4]. At present, ASA's recommended obligatory basic and standard perioperative monitoring includes blood pressure measurement, electrocardiography, continuous plethysmography, capnography, measurement of delivered gas concentrations, and temperature monitoring [5]. Other more advanced and sophisticated monitoring techniques and modalities can also be applied in selected patients and specific surgical procedures [3,6].

Introduction of anesthesia into clinical medicine

Crawford Long (1815-1878) performed the first general anesthetic with ether on March 30, 1842 (the origin of the Doctor's Day) and William T. G. Morton (1819-1868) successfully and publicly demonstrated for the first time the use of ether anesthesia for surgery on October 16, 1846, in Boston Massachusetts. This public event occurred would later be called "The Ether Dome" at Massachusetts General Hospital. Dr. John C. Warren, the surgeon, performed a surgery on the patient Mr. Edward G. Abbott. After the event, Dr. Oliver Holmes, Sr. (1809-1894) suggested the terms "anaesthetic" and "anaesthesia" in a letter to Mr. William Morton (The origin of today's anesthesiology). The news of William Morton's ether demonstration was carried by the paddle steamship Acadia from Boston to Dr. Francis Boott and Dr. James Robinson in England. Dr. Robinson later extracted a tooth on December 19, 1846, under ether anesthesia for the very first time in England. In the letter to the Lancet, Boott described the operation with the following words: "I beg to add, that on Saturday, the 19th, a firmly fixed molar tooth was extracted in my study from Miss Lonsdale, by Mr. Robinson, in the presence of my wife, two of my daughters, and myself, without the least sense of pain, or the movement of a muscle" [7, 8]. In 1847, Dr. Robinson published "A Treatise on the Inhalation of the Vapour of Ether for the Prevention of Pain in Surgical Operations".

In December 1846, Scottish surgeon Dr. William Scott in Dumfries, Scotland and English surgeon Dr. Robert Liston in London amputated limbs of etherized patients [7]. By then, ether's anesthetic effect was recognized by the British medical community. Dr. John Snow (1813-1858), probably the very first fulltime physician anesthetist, popularized obstetric anesthesia with chloroform by applying it on Queen Victoria for the birth of Prince Leopold (1853) and Princess Beatrice (1857). Later Dr. Snow published two books: "On the Inhalation of the Vapour of Ether" and "On Chloroform and Other Anaesthetics", these books enlightened generations of physician-anesthetists [9].

Administration of anesthetic agent(s) may induce various changes to the physiology of the patient and these changes may include significant fluctuation in their vital parameters, and a series of conditions in patients such as hypothermia, shivering, sore throat, nausea, vomiting, headache, delayed unconsciousness, etc., even in modern anesthetic practice. These changes will need to be continually monitored perioperatively [4,10].

History of hemodynamic and cardiac monitoring

Blood pressure

Ever since William Harvey published his De Motu Cordis in 1628 and showed the world how blood circulates in the body, hemodynamic monitoring has been the topic for both experimental and clinical medicine [11]. Earlier animal experiments in Renaissance Europe demonstrated that blood flow alters under different blood pressure conditions [11]. Although in our daily anesthesia practice invasive blood pressure measurement is significantly less commonly used nowadays than non-invasive blood pressure measurement, invasive blood pressure measurement was experimented and used much earlier than non-invasive blood pressure measurement.

In the 18th century, Stephen Hales, then a curate of a small country parish for over fifty years, invented manometer. Hales inserted one end of a brass tube into the artery of a horse and the other end to a vertically positioned glass tube with 9 feet tall. When untying the arterial ligature, blood rose in the tube to a height of eight feet three inches above the left ventricle of the heart. This is the very first recorded demonstration of the measurement of arterial blood pressure. Hales' pioneering studies on blood pressure, peripheral resistance, cardiac capacities and blood velocity were the greatest advances in hemodynamic physiology since Harvey's work over one hundred years earlier [12]. The first well-documented cardiac catheterization in experimental animal was performed by Claude Bernard in 1844 in France [6,13]. In 1929, Forssmann performed the first right heart catheterization on himself, this is the first human cardiac catheterization. In 1956, Forssmann, Cournand, and Richards were awarded the Nobel Prize in Physiology or Medicine for their contribution in right heart catheterization and consequent discoveries in cardiac pathophysiology [6,14].

In 1901, an Italian scientist Scipione Riva-Rocci invented a practical sphygmomanometer for measuring blood pressure indirectly [15], which was recommended by Dr. Cushing to be used routinely to determine blood pressure during anesthesia. Interestingly at the time, blood pressure was overestimated because they used the inner ring of a bicycle and covered significantly less arm circumference. Obviously at the time nobody knew what normal blood pressure should be, the trend of blood pressure this technique offered did help monitoring those patients during surgery. In 1905, Korotkoff found that the sounds heard when blood flow occurs distal to the deflating cuff. Thus, the modern-day non-invasive blood pressure measurement technique was developed after Korotkoff adopted a wide cuff recommended by von Recklinghausen. This technique provides much more accurate measurement of blood pressure and is used to today's medical practice [16]. In 1931, von Recklinghausen invented a semi-automatic technique for the measurement of blood pressure, the oscillotonometer. It is a double-cuffed system with its proximal cuff occluding the artery and the distal cuff functioning as the sensor to detect the onset of arterial pulsations. In 1940, Doppler was introduced into medicine and Doppler can be used to detect blood flow not only volume but also velocity [17]. In the 1980's, the Dinamap 845 blood pressure recorder was developed. The Dinamap 845 can relatively accurately assess blood pressure and considered acceptable for blood pressure determinations perioperatively [18].

Monitoring patient's blood pressure is probably the single most common clinical examination in modern medicine. Blood pressure measure and monitoring are extremely important in the treatment and prevention of hypertensive cardiovascular disease and in prediction of perioperative mortality and morbidity [19]. In acute medicine settings as in intensive care unit and anesthesia, mandatory blood pressure monitoring has played an important role in improving outcome. The progressive advancement in the quality of anesthesia from its birth almost 180 years ago to modern day practice owes enormously to the vigilant monitoring including continual measurements of blood pressure [7,20].

Pulse, Cardiac tone and Electrocardiography

Dr. John Snow, dubbed as the first fulltime physician anesthetist in 1847 in England (and in the world), mentioned his monitoring of patient under anesthesia to include depth and frequency of respiration, muscle movements, skin color, and stages of excitation or sedation. At the time pulse was not palpated and its characteristics were ironically considered unworthy monitoring. In 1855, the Edinburgh surgeon Dr. James Syme believed that chloroform was safer than ether anesthesia if it was administered properly and patient's respiration monitored. Another Scottish surgeon Dr. Joseph Lister, who started the principles of antisepsis in surgery, even protested against palpation of the pulse as "a most serious mistake". He believed that anesthetist should focus all attentions on breathing, should not be distracted to palpating the pulse [7]. However, the English anesthetist Dr. Joseph T. Clover in Victorian England emphasized the importance of palpating pulses during surgery after investigating the chloroform fatalities. In 1864, the Royal Medico-Chirurgical Society established a special committee to investigate chloroform fatalities. Dr. Clover as an expert in the committee described his innovations in apparatus and animal experimentation with anesthetics. Dr. Clover was a strong advocate that pulse should be continually observed during an anesthesia, and any significant irregularities should alert the anesthetist to stop the anesthetic to minimize fatality during anesthesia [7]. By 1903, S. Griffith Davis added pulse and heart to the anesthesia record in England [2,7].

In 1896 auscultation of cardiac tones was first reported by Dr. Robert Kirk in patients in the operating room of the Glasgow Western Infirmary. Initially they used an ordinary binaural stethoscope with an Indian rubber tubing, was first used. Later, Dr. Charles K. Teter reported the advantages of using the flat Kehler stethoscope. The flat stethoscope could be placed precordially without having to hold it all the time. Dr. Cushing as a strong advocate promoted the widespread utilization of routine, continual monitoring of cardiac and respiratory sounds under anesthesia during surgery [21].

The history of electrocardiography (ECG) can be traced back to 1887. Augustus Waller, a British physiologist, used a capillary electrometer to record the cardiac electrical activity. Physiologist and Nobel Prize winner Willem Einthoven later improved on the electrometer and offered the name "electrocardiogram", a name is still being used today [23]. In 1909, ECK was widely used and helped establish diagnosing various dysrhythmic conditions including various arrhythmia; About one year after, the indicators of myocardial ischemia were described. In the meantime, a formula was also created to describe, name, and distinguish between cardiac deflections called P wave, QRS complex, and T wave, the PQRST pattern was nicely described [23]. Modern ECG has several advancements in addition to the functions of the original technique. ECG has advanced from midcentury descriptions of tachycardia to the 1980s era of defining QRS width parameters predictive of heart failure [7], to diagnoses numerous cardiac conditions like coronary occlusion cardiomyopathy, pericarditis or myocarditis, imbalance of electrolytes, previous heart attacks and cardiac arrest, etc [7].

History of respiratory status, capnography & pulse oximetry monitoring

Breathing pattern

The assessment of a patient's cardiopulmonary functional status started with the invention of the stethoscope by Rene Theophile Hyacinthe Laënnec, a French physician [24]. Before stethoscope, doctors usually placed their ears on the patient's chest, this can be embarrassing if a male doctor has a female patient. Stethoscope solved the problem. The traditional binaural stethoscope was later developed and subsequently a series of technical improvements integrated into the original stethoscope. More advanced color spectrographic phonocardiogram analysis and digital subtraction phonocardiography were also developed later on [24]. In current medicine, we still have the need for continuous respiratory monitoring perioperatively. However, simple, reliable and continuous respiratory monitoring technique has been lacking, the closest we have the Masimo system and capnography [24].

Capnography

The history of capnography can be traced back to as early as 1905, when Dr. John Scott Haldane developed the first version of a gas analyzer that employed chemical absorption technique. This provided the very first practical tool to measure the volume of carbon dioxide (CO_2) in a mixture of gases. Sodium or potassium hydroxide was used to absorb the CO_2 in the mixed gases sample. The original Haldane apparatus got modified in 1940's and 1950's, enabling more accurate measurement of smaller sample volumes. However, this technique was very slow and did not measure CO_2 continuously. August Pfund developed an analyzer in 1939 to measure CO_2 and carbon monoxide. He used the radiation from a heated nickel chrome wire and directed it through a sample cell into a detector cell which has a

3% CO_2 mixture. CO_2 in the sample cell caused less radiation to reach the detector cell, thus resulting in less rise in temperature. The modern-day infrared capnograph was developed by Karl Friedrich Luft, when he worked at the BASF company in Germany. Karl Luft was charged to develop a method of measuring butane concentration. Butane absorbs infrared radiation but measurement was hindered by the interference from other gaseous materials such as CO_2 and water vapor. The "Luft cell" then incorporated a reference cell, and a sample cell through which a continuous stream of gas could be passed. The infrared beam then passed through "reception" cells containing butane, and a membrane capacitor between them detected minute pressure differences. Other newer technologies, like photo-acoustic spectroscopy, mass spectrometry and Raman scattering, were integrated into the basic "Luft cell" technique for better accuracy [26]. Point-of-care CO_2 analyzers were originally developed for medical use so that time sensitive management could be timelier delivered. Researches in mainstream gas sensors in late 1980's led to smaller and more robust mainstream CO_2 sensors. The pulsed thick film infrared technique applied coaxial optical design. The volumetric capnography sensors were also developed in the early 1990s, this latest model combined mainstream flow and CO_2 into an integrated airway adapter, in addition to combining mainstream flow and sidestream CO_2 sensors. Advances in sidestream systems techniques continued with newer source designs and novel configurations with removable sample cells and mainstream designs incorporating digital signal processors and miniaturized optics [26].

Pulse oximetry

The German physician Karl Matthes in 1935 developed the first two-wavelength ear O_2 saturation meter with red and green filters initially, later changed to red and infrared filters. Karl Matthes used this device for the measure O_2 saturation [27]. Glenn Allan Millikan also developed an oximeter in 1940s [28], later Earl Wood added a pressure capsule to squeeze blood out of the ear so that a genuine absolute O_2 saturation value was obtained. This was difficult to implement related to unstable photocells and light sources. Shaw assembled the first absolute reading ear oximeter which used eight wavelengths of light in 1964. The very first pulse oximetry device clinically utilized, the Ear Oximeter OLV-5100, was developed bioengineers Takuo Aoyagi and Michio Kishi in 1972 at Japanese medical electronic equipment manufacturer Nihon Kohden in Japan. They used the ratio of red to infrared light absorption of pulsating components of the blood flow at the measuring site. Dr. Susumu Nakajima and his team tested the device in patients and reported the successful use in 1975. Ununderstandably, Nihon Kohden suspended the further development of pulse oximetry and did not apply for a basic patent of pulse oximetry either except in Japan. The further development of pulse oximetry and utilization in clinical patients continued in the United States. Minolta later commercialized the first finger pulse oximeter OXIMET MET-1471 in Japan in 1977, while the first pulse oximetry was commercialized in the United States by Biox in 1980 [29].

Pulse oximetry monitoring was included in the standard of care for the administration of a general anesthetic in the United States in 1987. Subsequently the use of pulse oximetry rapidly spread throughout the hospitals nationwide. Masimo introduced Signal Extraction Technology (SET) in 1995 and SET could measure more accurately than previously during patient's body motion and low arterial perfusion by separating the arterial signal from the venous and other noisy signals. Also in 1995, Masimo introduced perfusion index, quantifying the amplitude of the peripheral plethysmograph waveform to make pulse oximetry more applicable in wider clinical scenarios [30]. Masimo continued their innovations, in 2007 Masimo introduced the pleth variability index (PVI), enabling automatic, noninvasive assessment of responding to fluid administration [31]. In 2011, an expert workgroup recommended that newborn screened with pulse oximetry to early detect critical congenital heart disease (CCHD) [32]. High-resolution pulse oximetry (HRPO) was also developed for in-home sleep apnea screening and testing in patients for whom it is impractical to perform polysomnography [33]. Severinghaus invented the first blood PO2 and PCO2 analyzer and showed it at the American Society of Anesthesiologists 1957 annual meeting, the addition of pH electrode completed the modern arterial blood analysis device [7].

Anesthetic gas

The respiratory and anesthetic gas monitoring provides very useful information to anesthesia and perioperative providers. Monitoring the anesthetic gases delivered by the anesthesia delivery system can promptly alert clinicians to a number of potentially dangerous scenarios such as inadvertent agent overdose, vaporizer filled with incorrect agent, uptake and distribution monitoring, timing to reach awake MAC, and assurance that the intended agent concentration is being delivered, especially when low flow anesthesia is administered.

Mass spectrometers could continuously measure O2, CO2, N2O and anesthetic gases were rarely used until 1975 when methods were introduced to use one mass spectrometer to sequentially measure gases sampled through long catheters from many patients. In the late 1980s, infrared detectors of CO2 and anesthetic vapors were combined with polarographic O2 electrodes to make the modern operating room a gas monitoring device [34].

The Perkin Elmer Company (later called Marquette) introduced a mass spectrometer capable of monitoring anesthetic gases on breath-by-breath basis in 1981. This technique essentially applied a sidestream sampling system, in which gas samples from the various operating rooms were directed into a centrally-located mass spectrometer for analysis via a multiplexing valve. The sample flow rate was 250 mL/min when the operating room was selected. The Perkin Elmer system or later Marquette Advantage 1100 was designed to measure and quantify up to eight unique anesthetic gases. A few years later, the Perkin Elmer Company introduced its 12 A competitive system, the SARA (System for Anesthetic and Respiratory Analysis) and the PPG (Pittsburgh Plate Glass). However, the system has been shown that the mass spectrometer will display erroneous readings if more than one gas mixed with aerosol propellants, helium, and anesthetic agents, for the identification of which it was not designed. Take the model Advantage 1100's effects as a example, if not programmed for desflurane, the system would identify desflurane as isoflurane, and the PPG and SARA would identify desflurane as enflurane. The risk with a centralized multiplexed mass spectrometry system is that if the central processor a part of the system failed, all the rooms served by the system lose that functionality at the institutional level.

Some competing, more affordable, sidestream gas monitoring technologies emerged in 1990's. These new technologies further facilitated the use of stand-alone anesthetic multi-gas monitoring in each and every operating room. These technologies included infrared spectrometry, infrared photoacoustic spectrometry, RAMAN spectrometry, and piezoelectric crystal agent analysis. The importance of agent specificity, or identification, cannot be over-emphasized in cases when vaporizers may have erroneously been misfiled leading to creation of agent mixtures. This may cause anesthetic overdose yet not detectable by agent analyzers lacking an agent identification function. For a variety of technical and commercial reasons, anesthesia gas analyzers based on innovative technologies (Raman spectroscopy, infrared photoacoustic spectrometry, and piezoelectric crystal agent analysis) have not succeeded in the marketplace. The measured shifted wave spectrum, using photomultiplier tubes, quantifies and identifies the gases in the mixture. Raman spectroscopy provides functionality equivalent to mass spectroscopy but at a much lower cost, good examples included Ohmeda RASCAL II which was no longer on the market [34].

Artema AION anesthesia gas analyzer by Mindray is an 8-channel, single-beam, non-dispersive infrared (NDIR) gas analyzer. Its sensor head measures infrared absorbance at 8 different wavelengths. The AION gas analyzer can identify anesthetic agents singly or in a mixture. The sample flow rate for this gas analyzer is 250 mL/min [35]. The Micro-Optical Rotor (MOR) Technology was later introduced to achieve multi-gas measurement capability in an ultra-compact design [35].

Contemporary anesthesia multi-gas analyzer allows charting the anesthetic gas delivery performance and other pertinent features of five most popular anesthesia gases. The Emergency Care Research Institute (ECRI) Institute's recommended specifications can be helpful in providing context to device performance, but did not address the importance of criteria such as size, weight, field calibration requirements, and water removal performance [35]. Anesthetic gas analysis is now available in all anesthesia machines in the United States and the multi-gas analysis is the standard of the industry.

Temperature

The mandatory temperature monitoring for all patient under anesthesia was not specifically included as mandatory requirement in the original ASA Standard monitoring in 1986. After the publication of 1986 version ASA Standard monitoring, the ASA had received extensive inputs over the years, all pointing to suggest that temperature monitoring should be mandatory during all anesthetics. Monitoring of temperature during general anesthesia is not only for the risk of malignant hyperthermia, but also for the prevention of perioperative hypothermia. The ASA committee evaluated the extensive documentation submitted regarding the potentially deleterious effects of accidental hypothermia and eventually agreed that an update of the standard was indicated. Importantly, assertions that the standard should include language about maintaining a minimum acceptable temperature were not adopted because this is a standard specifically for monitoring and not therapy. Temperature has been a monitoring requirement based on the ASA Committee on Standards of Care [4,5].

Anesthesia records

In 1894 Dr. Harvey Cushing and then a medical students E. Amory Codman developed the first anesthesia record. They used the observed respiratory rate and palpated pulse rate, and documented on the chart. Later in 1901, Cushing added blood pressure measurement by using the Riva

Rocci sphygmomanometry. Then in 1903, respiratory rate and heart rate were obtained by auscultation via a precordial stethoscope. Placement of a precordial stethoscope was also pioneered by Dr. Cushing and a physician-anesthetist, S. Griffith Davis. A century later, we now use electronic anesthesia records in most hospitals and ambulatory surgery centers in the United States [7].

History of depth of anesthesia monitoring

Dr. Snow's 5 stages of anesthesia: From the introduction of anesthesia into clinical medicine, the depth of anesthesia has always been paid enough attention by all levels of anesthesia practitioners. Tracing back to 1847, when Dr. John Snow observed his patient's responses to ether and stated that "The point requiring the most skill and care in the administration of the vapour of ether is, undoubtedly, to determine when it has been carried far enough". He even described the five stages of anesthesia, from early excitement to respiratory failure and eventual death. He further recommended that the surgical patients be operated on in the 4th stage when the patients are completely relaxed. However, total insensibility was not always the goal, ether administration was often brief with patients frequently being aware of the closing moments of the operation. Obviously, Dr. Snow studied the depth of anesthesia from ether vapor very thoroughly![7]

Dr. Guedel's 4 phases in Stage 3: During World War I, Dr. Arthur Guedel pioneered using wall charts to assist practitioners to provide anesthesia for the injured soldiers of war after battles. He described the four different planes in the third stage of (surgical) anesthesia and added the eye changes and respiratory signs. This wall chart quickly became an important tool for anesthetists and gained widespread recognition after his book was published in 1937 [36].

Dr. Gray's "Liverpool technique": Depth of anesthesia in paralyzed patients was initially ignored when muscle relaxants were just introduced into anesthesia practice. Dr. Cecil Gray and colleagues reported the so-called "Liverpool Technique". What they did was intentional light anesthesia with profound muscle relaxation. The risks of the technique were soon reported due to intraoperative awareness and perception of surgical pain intraoperatively [37].

The minimum alveolar concentration (MAC): Introduction of MAC concept was a landmark in monitoring depth of anesthesia. In 1963 Drs. Merkel and Eger reported for the very first time the concept of MAC, an anesthetic agent required to produce 50% no movement in experimental animals. Later in 1965, they further suggested MAC be used as a standard and all volatile anesthetic agents could be compared by MAC value. The MAC values of anesthetic agents help anesthesia providers to figure out how much inhalational anesthetic agents delivered to the paralyzed patients. Technical development in measuring the vapor concentration of inhalational agents provided the possibility of displaying end-tidal MAC value on the anesthesia monitors. This is now the industry standard in anesthesia machine and monitors.

Intraoperative awareness: The first published incidence of awareness was 2.78%, which was alarming to the anesthesia community. The Guedel's chart increasingly viewed as irrelevant when muscle relaxants were administered. Depth of anesthesia was monitored largely still relying on clinical signs such as pulse rate, blood pressure and sweating etc. Indirect methods were also developed.

Bispectral spectrometry (BIS) monitoring depth of anesthesia: Soon after the discovery of the electroencephalogram (EEG), EEG was believed useful in anesthesia monitoring. However, data from the early experiments unveiled EEG was too cumbersome as an intraoperative monitor. Mid-latency auditory evoked potentials have the similar issue, providing useful information but cumbersome. The emergence of commercial BIS monitor made intraoperative monitoring depth of anesthesia truly practical. Now BIS monitoring is widely utilized in developed countries [38].

Perioperative Patient safety and monitoring

The practice of anesthesiology set the best example of emphasizing patient safety in medicine. Only 5.2 deaths per million anesthesia occur worldwide due to improper anesthesia, the anesthesia-related mortality in the United States is even much lower. This is almost close to the best possible in medical practice with the quality standard called Six Sigma (3.4 errors per million) [39,40]. To the contrary, there are almost 88000 deaths annually in the USA alone from health care mistakes. All these did not come easily. Harvard University has 9 teaching hospitals in the early 1980s, the number of anesthesiologists constituted only 3% of the total clinical faculty, but anesthesiologists accounted for more than 12% of the malpractice insurance pay-outs in Harvard system, which was inappropriately high in Harvard system among all medical specialties but approximated the national statistics [41]. The ASA House of Delegates in October 1986 adopted the basic monitoring standards as an official policy at the 1986 ASA Annual Meeting. The proposed elements of conduct during all anesthetics for surgery were so logical that the monitoring standards quickly accepted by a majority of American anesthesia professionals [39].

Though ASA standard monitoring requirement has been widely accepted in developed countries, but globally, anesthetic monitoring standards for cardiopulmonary system are mostly consistent, other physiological systems as immobility or unconsciousness are significantly less consistent [42].

Summary

Anesthetic and perioperative monitoring has gone through a very long evolving process, from the very primitive methods used during the introduction period of anesthesia into medicine, to current relatively sophisticated technologies. Many fascinating stories can be told from this developmental process. By establishing standards for all aspects of anesthesia practice, ASA Played very important roles in reducing anesthesia-related mortalities. With the surgical checklist being more and more widely used worldwide [43], with machine learning, virtual reality, and artificial intelligence are gradually introduced into perioperative monitoring, perioperative monitoring quality and patient safety can be expected to continue to improve in the future.

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CHAPTER 2

STANDARDS OF INTRAOPERATIVE MONITORING

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Abstract

Basic monitoring in the perioperative period includes pulse oximetry, EKG, blood pressure, end-tidal CO2 monitoring, and temperature measurement. Noninvasive monitoring of each of these modalities allows for monitoring in any setting, including in the operating room, procedure rooms, and ambulatory surgical centers. Additional invasive monitoring including arterial line, transesophageal echocardiogram, central venous pressure, and pulmonary arterial pressures can be indicated for more complex cases, depending upon the severity of the patient's medical condition and co-morbidities as well as the magnitude of the scheduled surgery. The ability to monitor these patients allows anesthesiologists to deliver safe anesthesia and optimize patient outcomes. The scope of this chapter is to discuss the American Society of Anesthesiologist's standard intraoperative monitoring requirements. Other monitoring techniques, like Bispectral index (BIS), quantitative neuromuscular blockade, are very useful and helpful, but they are not ASA standard monitoring currently.

Key Words: pulse oximetry, end tidal CO2, heart rate, EKG, blood pressure, capnography, thermistor, thermocouple, infrared photo-spectrometry

Introduction/Background

The administration of anesthesia has the potential to create significant hemodynamic and many other physiological changes. To ensure appropriate monitoring of all patients, the American Society of Anesthesiologists (ASA) created a standard for intraoperative monitoring through the Committee on Standards and Practice Parameters[1]. These standards are the framework for intraoperative monitoring for all patients receiving any type of anesthetic including local, monitored anesthesia care, general, and neuraxial anesthesia. These guidelines are also considered to be the same regardless of location of anesthetics administered. The standards created are the minimum requirements, however, there may be additional monitoring techniques applied for specific patients which can be decided by the anesthesia personnel. This chapter will discuss in detail the minimum requirements from the ASA to conduct anesthesia in any setting. This chapter will include circulatory, respiratory, and oxygenation monitoring systems. The monitoring techniques recommended by the ASA are the basic requirements to proceed with any anesthetic type. These are all noninvasive monitoring techniques making it possible to review the patient's condition in any setting including non-operating room anesthesia sites. The primary goal of the standards set forth by the ASA is to prevent patient complications and to administer anesthetics safely. Additional invasive monitoring techniques may be utilized to manage a patient's hemodynamic alterations intraoperatively; however, they are not necessary for all cases. The role of an anesthesiologist is to determine whether the basic intraoperative monitoring which is discussed in this chapter is appropriate for the impending case, or if there is a need for additional monitoring to support the requirements set forth by the ASA.

Basic mechanisms

1) Oxygenation: The ASA defines intraoperative oxygenation monitoring "to ensure adequate oxygen concentration in the inspirated gas and the blood during all anesthetics" [1]. Two systems are in place to assess a patient's oxygenation status. These systems are the pulse oximeter which can monitor blood oxygenation and infrared photo-spectrometry which is utilized when the anesthesia ventilator is connected to the patient. Pulse oximetry is required for all anesthetics in all settings. It is a non-invasive monitor able to use infrared and red-light absorption to calculate the oxygen hemoglobin in a patient's body. Infrared photo-spectrometry is used when a patient is receiving oxygen therapy and has a gas sample line