

CHAPTER

2

Monitoring for Oral and Maxillofacial Surgery

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The use of anesthetic agents can alter a patient's physiologic response to disease, injury, stress, or surgical intervention. As health care providers, we depend on various forms of anesthesia to provide care in a painless and compassionate manner. Monitoring is an essential part of that anesthetic care, so that physiologic responses can be evaluated and altered, as necessary, to provide safe and appropriate treatment. A timely response to unfavorable physiologic changes, heralded by monitoring techniques, can prevent the development of serious and possibly irreversible complications.

Outpatient ambulatory anesthesia is the mainstay of many oral and maxillofacial surgery practices, particularly in the performance of dentoalveolar surgery. The expanding scope of our profession is creating new opportunities to use office anesthesia. Additionally, economic pressures are causing a shift of complex surgical cases from the more traditional hospital to an outpatient setting. Patient safety is still the paramount issue, however, and appropriate monitoring during office anesthesia allows us to continue our excellent track record.

Oral and maxillofacial surgeons must be able to continually evaluate the patient's oxygenation, ventilation, circulation, and, when indicated, temperature during office anesthesia procedures. A wide variety of monitoring devices can assist in this evaluation, and individual choices must be made to meet the needs of the patient and the

provider. Monitoring may be manual or automated, have audible and/or visual alarms, contain recording devices, and be invasive or noninvasive. The monitors should be reliable, easy to use and understand, comfortable for the patient, and cost effective. For the monitors to be beneficial, surgeons need to know their functions and limitations, as well as the rules that govern their use. This requires surgeons to review the current literature and stay abreast of advances in technology.

This chapter discusses various aspects of anesthesia monitoring, including its history, safety record, and therapeutic goals. The more common monitoring devices are reviewed, along with recommendations for their use. Current standards for monitoring are included in accordance with the American Society of Anesthesiologists (ASA). Although various monitoring techniques can be used, it is ultimately the surgeon's responsibility to understand the monitors in use, the data they provide, and their limitations and to respond appropriately to that information.

History of Anesthesia Monitoring

Ambulatory anesthesia has its beginnings in the early 20th century with Ralph Waters' Down-town Anesthesia Clinic in Iowa. In this facility, Dr. Waters provided

anesthesia for dental and minor surgical procedures on an outpatient basis. His facility consisted of one waiting area, an operating room with a table, and a recovery area, and he used essentially the same equipment for sterilization that is in use today.¹ Unfortunately, owing to the outbreak of World War I, the idea never caught on with his colleagues. Although there are scattered reports in the literature of attempts at building ambulatory surgery centers, it was not until 1962, when UCLA developed a hospital-based ambulatory surgical program, that the idea received national attention. This culminated in 1969 with the Surgicenter of Phoenix, Arizona, the first freestanding ambulatory surgery center.²

For ambulatory surgery centers to be successful, it was imperative that anesthesia administration be as safe as in the hospital environment. To attain this goal, patient monitoring and standards of care became a focus of the anesthesia community. Before 1980, typical monitoring consisted of only pulse palpation, auscultation with a stethoscope, electrocardiogram (ECG), and intermittent noninvasive blood pressure measurement. With the development of the pulse oximeter in 1983, a new era of more advanced monitoring systems began.

Although various societies and governing institutions attempted to adopt practice standards in the 1970s, these were generally disapproved by the members as being too binding. The Netherlands Health Council was the first to approve monitoring standards in 1978.³ These recommendations specified only what equipment should be used, not how or when it should be used, leaving this determination open to loose interpretation.

In the United States, Harvard Medical School in 1985 was the first to adopt and publish monitoring standards.³ It established specific minimal standards when moni-

toring must be in place and recommended what monitor should be used. These standards had an immediate impact on Harvard's anesthesia department, as major intraoperative anesthetic accidents decreased fivefold and insurance rates for anesthesiologists at Harvard dropped sevenfold.³

In April 1985, the dental community also responded to the call for anesthesia and sedation standards. A conference was held involving the National Institute of Dental Research of the National Institutes of Health (NIH), the Food and Drug Administration, and the NIH Office of Medical Applications of Research to answer various questions regarding anesthesia in the dental office, including appropriate patient monitoring. They determined that for conscious sedation, the heart rate, blood pressure, respiratory rate, and responsiveness of the patient should be checked at specific intervals, including during the recovery period. For deep sedation or general anesthesia, a precordial stethoscope should also be used; in children, an intravenous line, ECG or pulse oximeter, and temperature monitor are desirable. As for personnel, a minimum of two trained people should be involved in the patient's care during conscious sedation and three for deep sedation or general anesthesia. This committee also determined areas in which further research was needed to improve patient monitoring and patient outcome.⁴

In October 1986, the ASA established its own monitoring standards.³ These standards were similar to Harvard's, in that they required adherence to minimal levels of monitoring, and they expounded on the objective of each standard. These standards also delineated what methods were acceptable for monitoring. Owing to the changing medicolegal environment, these standards were accepted by the membership. They are revised periodically to adapt to the changing health care field. The last revision was in October 1996.⁵

AMERICAN SOCIETY OF ANESTHESIOLOGISTS STANDARDS FOR BASIC ANESTHETIC MONITORING

These standards apply to all anesthesia care although, in emergency circumstances, appropriate life support measures take precedence. These standards may be exceeded at any time based on the judgment of the respon-

sible anesthesiologist. They are intended to encourage quality patient care, but observing them cannot guarantee any specific patient outcome. They are subject to revision from time to time, as warranted by the evolution

AMERICAN SOCIETY OF ANESTHESIOLOGISTS STANDARDS FOR BASIC ANESTHETIC MONITORING *Continued*

of technology and practice. They apply to all general anesthetics, regional anesthetics, and monitored anesthesia care. This set of standards addresses only the issue of basic anesthetic monitoring, which is one component of anesthesia care. In certain rare or unusual circumstances, (1) some of these methods of monitoring may be clinically impractical, and (2) appropriate use of the described monitoring methods may fail to detect untoward clinical developments. Brief interruptions of continual* monitoring may be unavoidable. Under extenuating circumstances, the responsible anesthesiologist may waive the requirements marked with an asterisk (*); it is recommended that when this is done, it should be so stated (including the reasons) in a note in the patient's medical record. These standards are not intended for application to the care of the obstetrical patient in labor or in the conduct of pain management.

Standard I

Qualified anesthesia personnel shall be present in the room throughout the conduct of all general anesthetics, regional anesthetics, and monitored anesthesia care.

Objective

Because of the rapid changes in patient status during anesthesia, qualified anesthesia personnel shall be continuously present to monitor the patient and provide anesthesia care. In the event there is a direct known hazard, e.g., radiation, to the anesthesia personnel which might require intermittent remote observation of the patient, some provision for monitoring the patient must be made. In the event that an emergency requires the temporary absence of the person primarily responsible for the anesthetic, the best judgment of the anesthesiologist will be exercised in comparing the emergency with the anesthetized patient's condition and in the selection of the person left responsible for the anesthetic during the temporary absence.

*Note that *continual* is defined as "repeated regularly and frequently in steady rapid succession," whereas *continuous* means "prolonged without any interruption at any time."

Standard II

During all anesthetics, the patient's oxygenation, ventilation, circulation, and temperature shall be continually evaluated.

Oxygenation

OBJECTIVE

To ensure adequate oxygen concentration in the inspired gas and the blood during all anesthetics.

METHODS

1. Inspired gas: During every administration of general anesthesia using an anesthesia machine, the concentration of oxygen in the patient breathing system shall be measured by an oxygen analyzer with a low oxygen concentration limit alarm in use.
2. Blood oxygenation: During all anesthetics, a quantitative method of assessing oxygenation such as pulse oximetry shall be employed. Adequate illumination and exposure of the patient are necessary to assess color.

Ventilation

OBJECTIVE

To ensure adequate ventilation of the patient during all anesthetics.

METHODS

1. Every patient receiving general anesthesia shall have the adequacy of ventilation continually evaluated. While qualitative clinical signs such as chest excursion, observation of the reservoir breathing bag, and auscultation of breath sounds may be useful, quantitative monitoring of the carbon dioxide content and/or volume of expired gas is strongly encouraged.
2. When an endotracheal tube or laryngeal mask is inserted, its correct positioning must be verified by clinical assessment and by identification of carbon dioxide in the expired gas. Continual end-tidal carbon dioxide analysis, in use from the time of endotracheal tube/laryngeal mask placement, until extubation/removal or initiating transfer to a postoperative care location, shall be performed using a quantitative method such as capnography, capnometry or mass spectroscopy.

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3. When ventilation is controlled by a mechanical ventilator, there shall be in continuous use a device that is capable of detecting disconnection of components of the breathing system. The device must give an audible signal when its alarm threshold is exceeded.
4. During regional anesthesia and monitored anesthesia care, the adequacy of ventilation shall be evaluated, at least, by continual observation of qualitative clinical signs.

Circulation

OBJECTIVE

To ensure the adequacy of the patient's circulatory function during all anesthetics.

METHODS

1. Every patient receiving anesthesia shall have the electrocardiogram continuously displayed from the beginning of anesthesia until preparing to leave the anesthetizing location.
2. Every patient receiving anesthesia shall have arterial blood pressure and heart rate determined and evaluated at least every five minutes.

3. Every patient receiving general anesthesia shall have, in addition to the above, circulatory function continually evaluated by at least one of the following: palpation of a pulse, auscultation of heart sounds, monitoring of a tracing of intra-arterial pressure, ultrasound peripheral pulse monitoring, or pulse plethysmography or oximetry.

Body Temperature

OBJECTIVE

To aid in the maintenance of appropriate body temperature during all anesthetics.

METHODS

There shall be readily available a means to continuously measure the patient's temperature. When changes in body temperature are intended, anticipated or suspected, the temperature shall be measured.

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As health care becomes more economically driven, ambulatory surgery will continue to be a viable method of health care delivery. In 1993, more than 16 million ambulatory operations were performed in the United States, and these numbers continue to grow.² Following this trend in health care, more debilitated patients, such as ASA III and geriatric patients, will need to be treated outside the hospital environment. To maintain our excellent safety record, oral and maxillofacial surgeons will need to be proficient in anesthesia techniques and understand the importance of appropriate monitoring.

Safety Record since the Advent of Monitoring

To evaluate the impact of monitoring on anesthesia, it is necessary to investigate

morbidity and mortality data since the inception of anesthesia. Although general anesthesia has been practiced successfully on a routine basis since the 1850s, the early literature is sparse when it comes to morbidity and mortality statistics. Until the 1950s, the literature is filled with only anecdotal case reports of perioperative deaths often assumed to be secondary to anesthesia. Sykes researched anesthesia-related deaths extensively during this 100-year period, only to find gross discrepancies in the record keeping.⁶ He never quoted a morbidity or mortality rate but discussed specific case reports and mechanisms of death. Little is known of morbidity rates during this time because adverse outcomes other than death were seldom reported in the literature. The earliest large multicenter study that investigated mortality rates was by Beecher and Todd in 1954. They found a death rate of 1 in 1560 when anesthesia was

a contributory cause and 1 in 2680 when it was the primary cause.⁷ Multiple studies from various institutions worldwide followed, with widely differing morbidity and mortality rates. Today, reported mortality rates for anesthesia range from 7.9 per 10,000 anesthetic cases⁸ to 1 per 400,000 anesthetic cases.⁹

A mortality or morbidity rate is of no benefit unless the causes of mishaps are evaluated and the rate is ultimately decreased. Multiple studies have investigated these causes, and human error was involved in 65% to 87% of them.¹⁰ The most common problem was failure to properly ventilate the patient. Caplan and associates in 1987 found that 24% of respiratory mishaps could have been prevented with pulse oximetry alone, and 40% with pulse oximetry and capnography.¹¹ Tinker and colleagues in 1989 found that 93% of mistakes could have been prevented with the use of pulse oximetry and capnography.¹² Cooper and coworkers found that equipment failure was implicated in only 14% of accidents.¹⁰ Results of studies like these justify the current trend toward improved training of anesthesia personnel and monitoring standards.

Therapeutic Goals of Anesthesia Monitoring

Monitoring involves data collection about the patient and the anesthesia delivery system, and in turn, these data provide a record of the events occurring during the administration of anesthesia. Although monitoring aids in the efficiency of anesthesia administration, its primary goal is to improve patient outcome by allowing early recognition of potentially life-threatening complications. For a monitor to be useful, it must be cost effective, reliable, user friendly, and compact enough to fit in the work area. It must also provide information rapidly enough to allow intervention before an adverse event ensues.

Oral surgeons are concerned mainly with anesthesia in the office setting. This is different from inpatient anesthesia, because the procedures are usually shorter, the depth of anesthesia is less, and the patients are healthier. Also, the anesthesia is usually administered not because of the complexity

of the procedure but rather to alleviate the anxiety of the patient. Despite these differences, these patients should have the same level of safety as when the procedure is performed in the hospital. Thus, each of the monitors discussed in this chapter needs to be evaluated by the surgeon to determine its utility in his or her practice.

Monitoring Devices

In this section, the most commonly used monitors in the outpatient setting are discussed with respect to their technology, correct use, limitations, and data interpretation. Although there are many other monitors (e.g., central venous pressure monitors, mixed venous oximeters), these are not routinely used in the outpatient environment. If a surgeon plans to use these monitors, however, he or she must be proficient in their use and knowledgeable about their limitations.

HEALTH CARE PROVIDER

The most important monitor in the operating room is the personnel delivering the anesthesia. As already discussed, the majority of mishaps involve human error. A mechanical monitor can only collect and present data to the anesthesia personnel, who must correctly interpret and act on the data in the appropriate manner. For this reason, many people believe that money would be better spent on improving the education of personnel and the ergonomics of the anesthesia workplace rather than making monitors more sophisticated.

Westhorpe and Cass classify monitors based on how much human intervention is required to accumulate and process the information the monitor collects.¹³ Class I monitors rely on human participation to sense, organize, and interpret the data. The only class I monitors are the human senses, which, with the exception of taste, are all routinely used when delivering anesthesia. Pulse palpation, capillary refill, skin color, chest wall excursion, patient movement, and pupillary signs are completely dependent on the provider's senses. Listening for alarms, ensuring that the breathing circuit

is connected properly, and evaluating the rate of the drip chamber are examples of how our senses ensure proper machine operation. Class II monitors use a device to sense the data, but humans must organize and interpret the data. Examples of class II monitors include the stethoscope and sphygmomanometer. Class III monitors use a device to sense and organize the data, but a human must interpret them. Class III monitors include the pulse oximeter, capnograph, and automatic noninvasive sphygmomanometer. Class IV monitors are completely independent of human intervention, but there are none currently available.

PULSE OXIMETER

Most anesthesiologists agree that no invention has had a greater impact on patient safety than the pulse oximeter, which was introduced in 1983. The original oximeter was developed by Millikan in the 1940s. Although his device used essentially the same physics as today's, it required heating of the skin and measurements with the vessel bed compressed and then engorged to give an accurate estimate, which was technically cumbersome. This problem was rectified by Aoyagi in the 1970s when he related arterial hemoglobin saturation to the pulsations of the vessel bed.¹⁴ He separated light absorbers that are constantly changing (arterial blood) from light absorbers that are constant (other living tissues). With the advent of microprocessor chips, the pulse oximeter became compact, reliable, and easy to use.

Pulse oximeters work on the principles of Beer's law, which relates the concentration of a solute to the intensity of light transmitted through a solution. Each solute is assigned an extinction coefficient that is dependent on the wavelength of light used. If two different wavelengths are used, two extinction coefficients are needed. The absorbance at each wavelength is measured and formulated into a ratio, which determines the saturation. In the case of the pulse oximeter, the solute is hemoglobin and the light wavelengths transmitted are red and infrared. Oxygenated hemoglobin absorbs more red wavelengths, and reduced hemoglobin absorbs more infrared wavelengths. Absorbance ratios of 0.4 and 3.4

correlate to saturations of 100% and 0%, respectively. Of note, a ratio of 1.0 equals an oxygen saturation of 85%.¹⁵ Despite their high reliability, pulse oximeters also have many limitations. Their major limitation is that they assume that there are only two types of hemoglobin, oxygenated and reduced. Normally, adult blood contains four types of hemoglobin: oxygenated hemoglobin, reduced hemoglobin, carboxyhemoglobin, and methemoglobin, with the last two found in very small amounts. If they are present in larger amounts, they contribute to the absorbance of light according to their own characteristics but are interpreted by the sensor as oxyhemoglobin or reduced hemoglobin, resulting in a false saturation reading. Carboxyhemoglobin absorbs very little infrared light but as much red light as oxygenated hemoglobin, thus driving the ratio down and the perceived oxygen saturation up.^{16, 17} Methemoglobin readily absorbs both wavelengths, pushing the ratio toward a value of 1.0, which means that the oximeter tends toward a saturation of 85% regardless of the actual saturation.^{18, 19} Fetal hemoglobin has little effect on the pulse oximeter because its extinction coefficient is very similar to that of adult hemoglobin, even though its dissociation curve is shifted to the left.²⁰

Other factors can limit the accuracy of the pulse oximeter. This monitor relies on pulsations being sensed where the transmitter is placed. Low perfusion states such as hypothermia, hypotension, or vasoconstrictive drugs can lead to erroneous readings. This requires a severe reduction in blood flow, however, as oximeters are known to sense pulses when flow is decreased to only 8.6% of baseline.²¹ Other sources of error include motion artifact, patient crying with Valsalva's maneuver, nail polish, ambient light, intravascular dye, and simultaneous use of electrocautery.²² In a large, multicenter, prospective evaluation of pulse oximetry, Moller and colleagues found an overall 2.5% failure rate with oximetry, which increased to 7.2% in ASA IV patients.²³ Failure of pulse oximetry occurs when the oxygen saturation reading is unobtainable for any reason. The failure rate is higher in high-risk patients, who may have vascular problems, altered pulmonary function, or hypothermia. The investigators also found that pulse oximetry can improve an anes-

esthesiologist's ability to detect hypoxic events but does not decrease the rate of postoperative complications, except for myocardial ischemia.²⁴

It is also important to understand the limitations of the information provided by pulse oximetry. Pulse oximetry provides real-time estimates of hemoglobin saturation, but the partial pressure of oxygen must fall below 75 to 90 mm Hg for a change in saturation to be sensed. Thus, there may be large changes in the partial pressure of oxygen that are not sensed by the oximeter. This means that a patient receiving 3 L/min of oxygen by nasal cannula at sea level could have a 50% pulmonary shunt that goes undetected by pulse oximetry. Another limitation is that hemoglobin saturation does not equate with oxygen content of the blood unless a total hemoglobin is also known. This is particularly important in anemic individuals, because their saturation can be normal even when their oxygen content is decreased. Finally, the correlation between absorbance ratios and oxygen saturation was determined in healthy adults with oxygen saturations to 70%. Below this value, the correlation is an extrapolation of values above 70%. Above 70%, the error is generally less than 2%, but below 70%, the error may be increased.¹⁵

BLOOD PRESSURE MONITOR

Blood pressure measurement during anesthesia delivery is considered a standard of care by the ASA. The method of measurement—manual, automated, or invasive—is left to the discretion of the anesthetist. It is important that the provider understand the various methods of measuring blood pressure and their limitations so that appropriate conclusions can be drawn from the data.

Manual blood pressure measurement is the oldest method available. Systolic blood pressure measurement involves placing an occlusive cuff around the arm or thigh and then determining at what pressure a return of flow is detected distal to the cuff. The return of flow can be determined in various ways: listening for Korotkoff sounds with a stethoscope, palpating a distal artery, or using a Doppler probe on a distal artery. Diastolic blood pressure measurement in adults

is determined by listening over a distal artery for the disappearance of the murmur caused by the partially occlusive cuff. In children, determination of the diastolic pressure is less precise because frequently there is no definitive point at which the murmur disappears. In this instance, two measurements are recorded: the point at which the sounds first become muffled, and the point at which there is complete silence.

All noninvasive methods of blood pressure measurement are imprecise, with up to 30% error²⁵; therefore, attention to proper technique is critical. For simplicity, an arm pressure is discussed here. The bladder width should equal 40% of the circumference of the arm, and the length should be twice the width. A cuff that is too large will falsely underestimate the pressures, and a cuff that is too small will falsely elevate the pressures. The cuff should be placed snugly around the upper arm with the lower edge of the cuff 1 inch above the antecubital fossa. The bladder should sit over the brachial artery and be inflated rapidly to 30 mm Hg above the last palpable pulse. Pressure is released at 3 mm Hg per heartbeat (2 to 3 mm Hg/sec) while simultaneously listening over the brachial artery within the antecubital fossa with the diaphragm of a stethoscope. The point at which the first sound is heard is the systolic pressure, and the beginning of persistent silence is the diastolic pressure. If complete silence never occurs, the beginning of muffled sounds is recorded as the diastolic pressure. It is important to continue to listen after the disappearance of sound while still deflating the cuff to ensure that an auscultatory gap is not present. An auscultatory gap is a brief period of silence between the systolic and diastolic pressures that, if not recognized, could be interpreted as a falsely low systolic pressure or a falsely high diastolic pressure.

Since the 1970s, automated blood pressure measurement has been available, and it has become the most popular method to use during anesthesia. It frees the doctor's hands to perform other tasks, and many machines now have the capacity to record each measurement chronologically. Automated blood pressure cuffs work by oscillometry. A transducer within the proximal portion of the bladder senses vibration in the limb of the patient. The first repeatedly sensed vibration marks the systolic

pressure, the mean arterial pressure is signified when the vibrations reach their maximal amplitude, and the diastolic pressure is marked by greatly diminished or absent vibrations.

Although convenient to use, automated cuffs are known to be very inaccurate when compared with invasive blood pressure monitors. In general, at high pressures, automated cuffs tend to underestimate blood pressure; at low pressures, they overestimate blood pressure.²⁵ Thirty percent underestimations and 40% overestimations have been proved.²⁶ This is important to oral surgeons when hypotensive anesthesia is indicated (e.g., orthognathic surgeries). Another limiting factor is that current non-invasive automated systems do not provide continuous data. Pressures can be taken only intermittently to allow blood return to the distal appendage. Other sources of error include patient motion, external compression of the cuff, and air leaks.

Invasive blood pressure monitoring is indicated for seriously ill patients and when large blood loss is expected, cardiac instability is suspected, deliberate manipulation of blood pressure will be performed, or frequent blood gas analysis is anticipated. This is currently the most popular method of continuously recording the blood pressure, especially in high-risk patients. Invasive blood pressure monitoring involves placing a catheter into an artery and then connecting the catheter to tubing and a transducer, which converts the pressure wave into a blood pressure.

Currently, intra-arterial blood pressure measurement is considered the "gold standard" for accuracy, but error can be incorporated into the system. This system follows the principles of fluid mechanics with frequency modulation and damping coefficients. One factor that easily affects frequencies in fluids is the length of the tubing. If it is longer than the transducer is calibrated for, the pressure will tend to be overestimated. Excessive air bubbles in the tubing can overdampen the system, which leads to underestimation of the pressure.²⁷

Complications can also be associated with arterial cannulation. The most significant is ischemia distal to the site of cannulation due to occlusion of the artery by either thrombosis or the cannula. In the past, Allen's test was used to predict ischemic com-

plications. Blood flow to the hand was evaluated by simultaneous compression of the radial and ulnar arteries and then release of pressure on the ulnar artery. More recent research has shown that this test has little predictive value, so it is rarely relied on today.²⁸ Other complications include hemorrhage, thrombosis, embolism, cerebral air embolus, aneurysm, arteriovenous fistula, and infection.²⁸ These complications can be avoided by using the smallest cannula that will still give accurate pressures, minimizing the length of time of cannulation, and minimizing the amount of air in the system.

Although the radial artery is the most common site for cannulation, other sites can be used. These include the ulnar, brachial, axillary, femoral, dorsalis pedis, and superficial temporal arteries. Many of these alternative sites require special catheters.

STETHOSCOPE

Despite being one of the simplest, oldest, most cost efficient noninvasive monitors available, the precordial or esophageal stethoscope is being used less frequently than in the past. Prielipp and associates found that no stethoscope was used in 7% of general anesthesia cases and 60% of monitored anesthesia cases at their institutions. Even when a stethoscope was placed, it was listened to in only 28.5% of cases.²⁹ This situation resulted from the advent of pulse oximetry and capnography, which are believed to be more accurate methods of assessing ventilation and cardiac status.

Nevertheless, the stethoscope provides important information about the cardiac and pulmonary systems. The presence of heart sounds and their quality and rhythm can be continuously evaluated. Listening for breath sounds verifies air movement and allows detection of wheezes, crackles, airway secretions, circuit disconnects, main stem intubations, and abnormal rates. Klepper and coworkers concluded that 54% of critical anesthesia incidents could be detected with an esophageal stethoscope.³⁰ Also, the core temperature can be simultaneously evaluated with many esophageal stethoscopes.

There are also limitations to the information that can be obtained from a precordial or esophageal stethoscope. The most im-

portant is that the presence of breath sounds does not guarantee adequate tidal volume or gas exchange. Pulse oximetry and capnography are more sensitive monitors for these determinations. Second, in many patients, it is difficult to hear breath sounds and heart tones with a precordial stethoscope, and an esophageal stethoscope is impractical in awake patients. To optimize a precordial stethoscope's capabilities, its placement is critical. The bell should be securely attached to the chest wall along a line connecting the sternal notch to the left nipple at the point where breath sounds and heart tones are maximal. Typically, this is close to the sternal notch, so breath sounds are predominant, because all anesthetics are respiratory depressants to some degree.

ECG

The ECG is used for two purposes intraoperatively: to detect ischemia and dysrhythmia. As a dysrhythmia monitor, the ECG should be used in conjunction with the pulse oximeter. The ECG identifies what rhythm the heart is in but gives no information about the effectiveness of the circulation. The pulse oximeter indicates that the heart is pumping blood to the site of the sensor but rarely gives information about the rhythm. (Some may argue that irregular rhythms such as atrial fibrillation can be detected by the pulse oximeter.) Also, the pulse rate recorded by the pulse oximeter can be compared with the rhythm on the ECG to ensure that they coincide. If the waveform has a deep dicrotic notch, the pulse oximeter may erroneously read each beat as two beats, thus doubling the pulse rate and leading to the false belief that the patient is tachycardic. Lead II is most commonly used for monitoring dysrhythmias. This lead most closely parallels the atrial depolarization vector, thus giving the tallest P waves, and it is available with three-lead and five-lead ECGs.

Perioperatively, the ECG is the most common and often the only monitor available to detect myocardial ischemia. As such, it is best to monitor all areas of the heart. A three-lead system allows monitoring of only standard leads I, II, and III without changing lead placement. By adding only two more leads (five-lead system), the standard

leads (I, II, III), augmented limb leads (aVR, aVF, aVL), and one precordial unipolar lead (usually V₅) can be monitored simultaneously. Although a 12-lead system is available, it is often cumbersome and impractical in the operating theater. In 1988, London and colleagues detected 75% of ischemic events intraoperatively with lead V₅. This was increased to 80% by adding lead II and to 96% with leads II, V₄, and V₅.³¹

The most common ECG manifestation of ischemia is ST segment depression. The ST segment extends from the J point to the beginning of the T wave. Flat or downsloping depressed segments are more specific and carry a more serious prognosis than upsloping depressed segments. The ST segment change must be at least 0.1 mV in amplitude (one small box on the standard ECG) at least 60 msec from the J point. Another common indication of ischemia is T wave changes such as flattening, peaking, or inversion. Despite these definitive criteria, they are not specific for ischemia. Other conditions that can mimic ischemia on the monitor include left ventricular hypertrophy, hypothermia, hypoglycemia, electrolyte abnormalities, respiratory alkalosis, digitalis and diuretic use, and Wolff-Parkinson-White syndrome.³² Although these conditions can mimic ischemia, any intraoperative ST segment or T wave changes should be considered ischemia until proved otherwise. Elevation of the ST segment may also occur with acute ischemia and is more specific for ischemia than is ST segment depression, but it can also be seen with ventricular aneurysm and pericarditis and as a normal variant.³³

TEMPERATURE MONITOR

Body temperature should be maintained at or near normal levels for optimal physiologic function. Although not essential in most cases, the ability to monitor body temperature should be readily available and should be used when changes in body temperature are anticipated or suspected. Hypothermia can lead to a compensatory increase in metabolic rate and cardiac work as the body attempts to warm itself. Hypothermia can also decrease drug metabolism and cutaneous blood flow, as well as impair coagulation. Elevations in temperature may

warn of the onset of malignant hyperthermia or create a hypermetabolic state that increases oxygen demand.

Devices available to measure temperature include electric probes (thermistor, thermocouple, platinum wire), liquid crystal strips, and infrared thermometers.³⁴ Electric probes measure changes in electrical resistance or potential, which vary with changes in temperature. These probes are small and accurate, yield rapid continuous information, are disposable, and can be placed inside the body or attached to skin. When used inside the body, they must be insulated to avoid moisture contamination. Liquid crystal strips use organic compounds that become optically active as they are heated and change from solid to liquid form. The strips are generally applied to surface skin and have a black background to avoid reflection of transmitted light. The strips are convenient, noninvasive, inexpensive, and disposable. Skin temperatures determined with liquid crystal strips do not correlate with core temperature and are most useful for following trends rather than revealing specific temperature data.³⁵ Infrared thermometers sense radiation from a warm object and measure the difference between the thermometer and the object. This technology is most commonly used in the auditory canal to measure the temperature at the tympanic membrane, which correlates well with core temperature.³⁶ The monitor is easy to use, is well tolerated, and has disposable covers. Disadvantages include intermittent sampling and the possibility of falsely low readings if improperly placed.

Preferred sites for temperature monitoring that most closely reflect core temperature are the tympanic membrane, lower one-third of the esophagus, or nasopharynx. During conscious sedation, peripheral sites are usually better tolerated by the patient and include the axilla, forehead, or any accessible skin surface. Rectal probes are easily placed but can be inaccurate owing to local bacterial metabolic factors and delays in relation to changes in core temperature. Temperature probes can cause harm via blunt trauma or electrical injury and need to be evaluated for structural flaws and proper placement when in use. Moisture contamination can yield falsely elevated temperatures.³⁷

CAPNOGRAM

Capnography is the continuous measurement and monitoring of carbon dioxide (CO_2) in the breathing circuit. The concentration of carbon dioxide can be rapidly determined using infrared analysis, Raman scattering, mass spectrometry, or chemical colorimetric analysis. Infrared analysis, the most popular method, passes light of a specific wavelength ($4.26 \mu\text{m}$) through expired gas. The light is absorbed in proportion to the concentration of CO_2 present and is usually reported as partial pressure in millimeters of mercury.³⁸ Raman light scattering uses a light source (argon laser) to bombard gas molecules and cause changes in those molecules. This results in the emission of altered wavelength energy and scattering. The new wavelengths and scatter are then used to identify components of the gas mixture. The intensity of the scattered light is proportional to the partial pressure of the gas being measured. Mass spectrometry uses mass-charge ratios to separate the components of a gas mixture and displays them in volumes percent. The colorimetric analyzer uses hygroscopic filter paper to detect changes in pH that relate to the presence of CO_2 . Changes in a color grid give gross estimates about the amount of CO_2 present. Its primary use is in confirming endotracheal intubation or for short-term monitoring when standard capnography machinery is not available or is impractical.

The gas sample can be obtained from sidestream or mainstream analyzers with the port as close to the airway as possible. Sidestream analyzers require a sampling flow rate of at least 150 mL/min. When using a sampling tube of 1 mm diameter, there is a transit time delay of about 1 second.³⁹ Sidestream analyzers are more prone to moisture contamination from condensation than are mainstream analyzers but have the capability of sampling several gases simultaneously. Mainstream analyzers typically evaluate only CO_2 and can be bulky in the circuit.

The most useful display of capnography is the continuous waveform capnogram (Fig. 2-1). An entire tidal breath can be evaluated and the waveform divided into four specific phases: I, baseline pause; II, expiratory upstroke; III, expiratory plateau; and IV, inspiratory downstroke.⁴⁰ Abnormalities

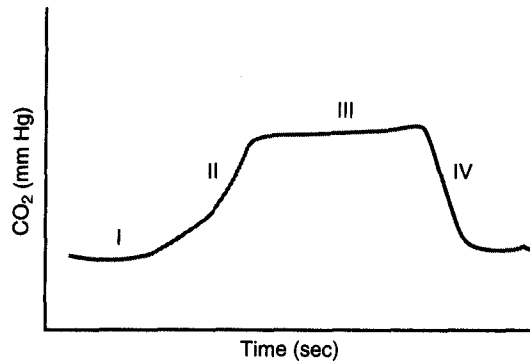


FIGURE 2-1. A standard single-breath capnogram. I, baseline pause; II, expiratory upstroke; III, expiratory plateau; IV, inspiratory downstroke with return to baseline.

in any phase of the capnogram may signal problems requiring intervention. Baseline pause occurs just before an expiration and represents dead space. Normally, there should be no CO_2 present. An elevated baseline may represent CO_2 rebreathing or a mechanical fault in the breathing circuit. The expiratory upstroke represents airflow from the alveoli yielding rapidly rising CO_2 levels. A prolonged upstroke indicates impaired expiratory flow, which may be due to airway obstruction, chronic obstructive pulmonary disease, or moisture in the sampling tube. No CO_2 in the expired gas suggests a lack of effective ventilation, which could be the result of esophageal intubation, circuit disconnection, complete airway obstruction, or cardiac arrest. The expiratory plateau reflects alveolar gas and slowly rises, ending in the peak CO_2 level. The peak CO_2 level is considered to be the end-tidal CO_2 , which best reflects arterial PaCO_2 . When ventilation is normal, end-tidal CO_2 is 5 to 10 mm Hg lower than arterial PaCO_2 , owing to dead space in underventilated alveoli.⁴¹ In situations in which the dead space is increased, the end-tidal CO_2 will decrease, giving a falsely low impression of alveolar PaCO_2 . Elevated CO_2 levels may represent increased production from malignant hyperthermia or tourniquet release, hypoventilation, or rebreathing of CO_2 . Decreased CO_2 levels may indicate hyperventilation, decreased production from hypothyroidism or hypothermia, or pulmonary embolism.⁴²

The greatest benefits of capnography are its use in verifying endotracheal intubation,⁴³ monitoring for apnea or altered venti-

lation frequency, early detection of airway obstruction, and early warning of malignant hyperthermia. Capnography can be useful when monitoring nonintubated patients, but it is then considered an open system and is subject to error.⁴⁴ It is still a good indicator of ventilation and may provide the earliest warning of airway obstruction in a nonintubated patient.⁴⁵

OXYGEN ANALYZER

Oxygen analyzers are used primarily in conjunction with closed-circuit anesthesia delivery machines to ensure that a hypoxic mixture of gas cannot be delivered to the patient. Located at the inspiratory limb of the circuit, they measure the concentration of oxygen delivered and should sound an alarm when the oxygen concentration is less than room air (21%) or when a low-flow situation exists. However, it should be remembered that measuring inspired oxygen does not ensure adequate oxygenation of the patient.⁴⁶

Oxygen analyzers may be paramagnetic, galvanic cell, or polarographic (the most common).⁴⁷ The Clark electrode, an electrochemical cell, is an example of a polarographic sensor that measures changes in current in proportion to oxygen tension. Oxygen analyzers are usually calibrated at the factory to room air and 100% oxygen but require regular maintenance and recalibration when in use. Oxygen analyzers are easy to use but have limited utility outside a controlled breathing system, such as in conscious sedation.

PERIPHERAL NERVE STIMULATOR

The peripheral nerve stimulator is an electronic device that delivers depolarizing current to assess neuromuscular function via an evoked motor response. The motor response is dependent on the presence of a functional neuromuscular junction, the integrity of the muscle, and the electrical characteristics of the stimuli. The nerve stimulator should be compact, easy to use, and capable of delivering stimuli of varying intensity at varying intervals. A constant current is necessary to reliably deliver unchanging stimulation over varying imped-

ance. Nerve stimulators allow for precise dosing of neuromuscular blocking agents perioperatively and aid in determining appropriate recovery from those blocking agents at case completion.

Patterns of nerve stimulation include single twitch, train of four, double-burst stimulation, and tetanic stimulation.⁴⁸ The train-of-four pattern delivers four consecutive single pulses of 2 Hz for 0.2 msec at 0.5-second intervals. When a depolarizing muscle relaxant is used, there is equal depression of all four pulses, but a nondepolarizing block allows for progressive depression of twitch height or fade. The more profound the block, the fewer the number of twitches seen. When the fourth twitch is eliminated, approximately 75% of the receptors are blocked. Loss of the third twitch is an 80% block, and loss of the second twitch is a 90% block. A train-of-four ratio can also be determined that relates the amplitude of the fourth twitch to the amplitude of the first twitch. A ratio of 0.7 or greater indicates that the patient can demonstrate normal force of respiration and appropriate recovery from neuromuscular blockade.⁴⁹ A transducer is required to determine the amplitudes accurately. Tetanic stimulation, a rapidly repeated stimulus, is normally delivered at 50 Hz for 5 seconds and is sustained but decreased with a depolarizing agent and demonstrates fade with a nondepolarizing agent. A sustained tetanic stimulation, when delivered as stated, correlates well with a train-of-four ratio greater than 0.7. The technique of post-tetanic facilitation is useful in cases of deep neuromuscular blockade when no response is seen to train-of-four or tetanic stimulation. A tetanic stimulus is delivered at 50 Hz for 5 seconds, followed by a 3-second pause, and then a 1-Hz stimulus is delivered and the number of twitches counted. This post-tetanic count predicts the return of response to a train-of-four stimulus.⁵⁰

Tactile or visual monitoring is most often used to evaluate the evoked response, but a transducer can be employed if more specific information is needed. Common sites for evaluation are the ulnar nerve, facial nerve, and, less commonly, posterior tibial nerve. The ulnar nerve supplies the adductor pollicis brevis muscle, which adducts the thumb and is usually easily accessible. Tactile monitoring would involve abducting the

patient's thumb and feeling for contractions. The facial nerve can be tested by placing electrodes along the lateral canthus of the eye, and contraction of the facial muscles is easily seen when present. The facial nerve underestimates the degree of block compared with the ulnar nerve.⁵¹ The patient can experience pain with nerve stimulation, especially when higher currents or tetanic stimulation is used.

GAS ANALYSIS

Multiple gases can be monitored during general anesthesia, including both respiratory gases and inhalational anesthetics. Monitoring gases other than oxygen and CO₂ allows evaluation of nitrogen levels, presence of nitrous oxide in the system, and identification of volatile anesthetic agents that may explain prolonged wakeup time following general anesthesia. The principal methods of gas analysis are mass spectrometry, Raman light scattering analysis, and infrared analysis.⁵²

The mass spectrometer separates the components of a gas mixture according to their mass-charge ratios and displays them in volumes percent. Inaccuracies can occur if gases that the spectrometer cannot measure are present.⁵³ Most gases of interest can be measured with mass spectrometry, but the machine must be programmed for the gases to be monitored. Raman light scattering analysis can measure most gases of interest, is fast, and is not prone to the extra gas inaccuracies of the mass spectrometer.⁵⁴ Raman spectroscopy can be inaccurate in pediatric patients with small tidal volumes and high respiratory rates. Infrared analysis is used on gases with two or more dissimilar atoms. The gases have unique absorption patterns of infrared light and are identified in this manner. Nitrogen and oxygen are nonpolar and cannot be measured with this technology.

Gas analysis units may be freestanding and dedicated to a specific anesthesia unit or part of a shared system. Delay time is greater in shared systems, but these are also more cost efficient and practical with regard to space management. Sidestream or mainstream sampling is available, as with capnometry.

The Anesthesia Record

Although no regulatory authority in the United States requires a specific format for the anesthesia record, it serves many purposes and should be designed with these purposes in mind. When making entries on the anesthesia record, one must ensure that concise, important information is recorded rather than notes that will not be helpful later. This section discusses the purposes of the anesthesia record and its proper documentation.

The anesthesia record has many uses to various people. It may be reviewed by the anesthetist, other physicians or nurses, billing clerks, insurance companies, peer review committees, or lawyers. It must be available to these people preoperatively, intraoperatively, postoperatively, and often long after the patient has been discharged. The record may be used in the recovery area or on the ward, for review with future surgeries, for billing or research, or for peer review or legal defense. For this reason, the record must be neat, orderly, coherent, and concise. Additionally, abbreviations used must be comprehensible to anyone who may need to consult the record.

In its most basic form, the record should document the patient demographics and the anesthetist; the preanesthetic evaluation of the patient; the intraoperative events, including all actions taken by the anesthetist and the patient's response to those actions; and the postanesthetic condition of the patient. This documentation should be orderly and logical. The ASA has outlined certain guidelines,⁵ with the record divided into preanesthesia and postanesthesia periods. For the preanesthesia evaluation, the ASA recommends documentation of the patient's medical history, along with the patient interview, physical examination, laboratory studies and consultations, and anesthesia plan. For postanesthesia care, the ASA standards require "an accurate and written report" of the postanesthesia period. Intraoperatively, the ASA recommends the recording of vital signs at various intervals. These are reviewed in the section on standards of monitoring.

Standards of Monitoring

The standard of care is the reasonable level of care that any patient can expect

from a prudent practitioner. Ultimately, the standard of care is whatever a jury believes it to be, but this is more than a legal issue. Standards in monitoring improve the quality of care and help limit risk to the patient but cannot guarantee favorable outcomes. The responsibility for providing reasonable care with reasonable safety, given the known risks and complications of treatment, lies with the practitioner.

Numerous organizations involved in the delivery of anesthesia have determined the need for perioperative monitoring standards. As previously stated, the ASA began publishing standards for intraoperative monitoring in 1986, with the most recent revision taking place in October 1996. The American Association of Oral and Maxillofacial Surgery (AAOMS) published its parameters of care in September 1995, listing indicated therapeutic standards for both conscious sedation and deep sedation or general anesthesia.⁵⁵ The American Dental Society of Anesthesiology (ADSA) adopted guidelines for intraoperative monitoring in 1988 based on the ASA standards, with special concern for sedative and anesthetic procedures in the dental setting.⁵⁶ Additionally, state or local regulations may dictate what must be done to meet the standard of care within a specific community.

The focus of these published standards is on what personnel must be present and which components of physical status should be monitored and documented during the delivery of anesthesia. Patient assessment should address oxygenation, ventilation, and cardiovascular status, along with the ability to monitor temperature when indicated. There are various methods available, allowing for flexibility and personal preference in the monitors used.

Personnel When conscious sedation is delivered, the surgeon and at least one other individual trained in basic cardiac life support (BCLS) or its equivalent must be present. During deep sedation or general anesthesia, a surgeon trained in advanced cardiac life support (ACLS) and at least two other individuals trained in BCLS or its equivalent must be present.

Oxygenation Adequate oxygenation must be ensured throughout the anesthetic period. Observation of skin, mucosa, and the surgical site is fundamental. The use of pulse oximetry during conscious sedation, deep sedation, or general anesthesia is a

therapeutic standard in the AAOMS parameters of care.

Ventilation Adequacy of ventilation must be continually evaluated. Excursions of the chest wall, auscultation for breath sounds, or observation of qualitative signs may be used. During deep sedation or general anesthesia, observation of the reservoir bag or monitoring of expired gases may be employed.

Cardiovascular Status During conscious sedation, blood pressure and pulse should be evaluated periodically. They should be measured and recorded at least every 5 minutes during deep sedation or general anesthesia. An ECG may be used during conscious sedation, is encouraged during deep sedation, and must be used during general anesthesia.

Temperature The ability to monitor body temperature should be available for any level of anesthesia. Monitoring temperature during general anesthesia is encouraged and is indicated when changes are anticipated or suspected.

When conscious sedation, deep sedation, or general anesthesia is delivered, completion of an anesthetic record—including vital signs; types of monitors used; and perioperative information with respect to oxygenation, ventilation, circulation, and, when indicated, temperature—is a therapeutic standard in the AAOMS parameters of care.

Recommendations for Monitoring

Recommendations for monitoring should be closely tied to the preceding standards

and parameters of care. Studies by Tinker and colleagues,⁵⁷ Jastak and Peskin,⁵⁸ and Krippaehne and Montgomery⁵⁹ indicate that adverse respiratory events are the most common problems encountered in anesthesia. Furthermore, most mishaps could be prevented with the use of appropriate monitors, particularly pulse oximetry and capnography, assuming proper evaluation and action by the practitioner. Monitoring and observation do not end with the procedure but must be continued throughout the recovery period. Until the patient is determined to be stable for discharge, the same standards for monitoring and support of physiologic health must be ensured. Table 2-1 gives recommendations for monitors that can be used during different methods of anesthesia in the office setting. The oral/parenteral category refers to patients receiving medication for sedation purposes orally, rectally, nasally, or by intramuscular injection. These would most commonly be pediatric patients but could be adults given oral sedatives before treatment.

It should be remembered that standards of care refer to minimal requirements for monitoring. Additional monitoring or personnel may be indicated, depending on the patient's medical status or events occurring during anesthesia. When circumstances dictate a deviation from the standards of care, documentation in the patient record should reflect why the standards were not followed. There is little objective evidence that the use of additional or more sophisticated monitoring improves patient outcome in conscious sedation.⁶⁰

The earliest warning of an unfavorable event gives the provider the greatest amount of time to identify and correct the

TABLE 2-1. Recommended Monitors

	Stethoscope	Pulse Oximeter	Blood Pressure	ECG	Other
Local anesthesia					A
Oral/parenteral (pediatric)	X	X	X		B
Nitrous oxide/oxygen	X	X	X		B
Conscious sedation	X	X	X		B
Deep sedation/	X	X	X		B
general anesthesia				X	
Postoperative		X	X		B, C

A, any monitors may be used, but observation by the practitioner is the only requirement; B, additional monitoring may be included as indicated; C, observation and monitoring are dictated by the patient's medical condition and to support compliance with discharge criteria established by the facility.

problem before injury to the patient results. The provider is the most important monitor in the room and is the only monitor that can act to correct an unfavorable anesthetic event.

Future of Anesthesia Monitoring

As technology grows, so will the number and complexity of available monitors. This is already being seen with the advent of continuous noninvasive blood pressure monitoring and automated record documentation.

One of the most recent advances in monitoring is the continuous noninvasive blood pressure monitor. This device, commonly called a Finapres, was developed by Wesseling in 1983 and operates by the Penaz method.⁶¹ Essentially, a small cuff is placed around the patient's digit, and changes in cuff pressure are noted as pulsations travel through the artery. When cuff pressure equals arterial pressure, both transmural pressure and artery wall tension are zero. The amplitude of arterial pulsations is maximal at this point and is equal to mean arterial pressure. This is the set-point for future measurements. Simultaneously, a source emits light that is sensed on the opposite side of the arterial bed. As more blood enters the arterial bed, less light is transmitted to the sensor, so the cuff is inflated until the set-point is reached again. The changing cuff pressure is recorded as a waveform, which is then correlated to the arterial pressure.

Although simple in design, the Finapres has limitations. The cuff width is critical to accuracy, and the sensor must be maintained at heart level. Also, movement, hypovolemia, cold, and low cardiac output may give erroneous results.⁶¹

As computers have become more commonplace, so have paperless systems of recording information. Automated systems of anesthesia record keeping are becoming more popular, but they are not universally accepted. Proponents of automated record keeping feel that more time can be spent attending to the patient and that real-time recording of physiologic parameters is more accurate than handwritten records. These records are also more legible and reduce the

doctor's workload. Detractors argue that an automated record reduces the vigilance of the anesthesiologist and does not improve patient care, while escalating costs. The jury remains out over the use of automated recording systems in the anesthesia workplace.

As these systems are developed, care must be taken to ensure that they improve patient care. New monitors must match older monitors' simplicity of use, reliability, cost efficiency, and accuracy. As these monitors are accepted by the anesthesia community, there is a danger that they will become the standard of care. This could make outpatient anesthesia cost prohibitive for oral surgeons.

Despite the technological advances, all monitors still rely on a well-trained health care provider to interpret and act on the data. For this reason, many in the anesthesia community feel that these dollars would be better spent in improving doctors' training. Human error is responsible for the greatest proportion of poor anesthetic outcomes; therefore, improved education would have the greatest impact.

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