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# Respiratory Monitoring for Anesthesia and Sedation

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This article reviews the theory and practice of routine respiratory monitoring during anesthesia and sedation. Oxygen monitoring and capnography methods are reviewed. The current ventilation monitoring system of choice is considered a combination of the pulse oximeter and capnography. Guidelines are provided for monitoring standards.

Risk management is of foremost importance to anesthesiologists and has been the topic of much research and attention over the past several years. A major component of risk management is the area of physiologic monitoring. Monitoring is the collection and/or observation of data, often from specific organ systems, that are evaluated and interpreted in order to provide the safest care possible. The stresses imposed by anesthesia and surgery require that vigilant monitoring be carried out continuously to allow the prompt recognition of a deleterious trend or an acute problem, as well as the evaluation of responses to therapeutic interventions. Ideal monitors should be accurate, continuous, noninvasive, convenient, and not overly expensive. The primary systems monitored are the circulatory, respiratory, renal, central nervous, and neuromuscular systems. Monitoring also includes evaluating the fluid and electrolyte status, blood loss, and depth of anesthesia.

Monitoring may be divided into "routine" monitoring for all patients undergoing anesthesia, and specialized monitoring for those more complex cases requiring more intensive evaluation of organ function. This discussion will focus on routine monitoring of the respiratory system during anesthesia and sedation. It is not universally agreed as to what should constitute routine monitoring for all anesthetics. At the outset it should be emphasized, however, that the primary and most crucial monitor for any anesthetic is the vigilant senses of a well-trained anesthesiologist. For many years general anesthetics were administered with no monitors except the anesthesiologist's eyes, ears, and touch. Newer technologies have been developed to allow for much more sophisticated monitoring. This, however, does not in any way lessen the need for the anesthesiologist's vigilance. One must remember to "look at the patient" despite the often overwhelming distraction of sophisticated monitors and anesthesia equipment.

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## RESPIRATORY MONITORING

The routine monitoring of the respiratory system has traditionally been much less sophisticated than that of the cardiovascular system, primarily due to a lack of technology. In fact, the respiratory system is perhaps the area where vigilance in monitoring is most needed. Because hypoxia has been noted to be the leading cause of morbidity and mortality during anesthesia,[1] and it has been clearly demonstrated that hypoxia is very difficult to detect clinically until very late in its course,[2] the need for continuous and accurate respiratory monitoring is paramount. The primary questions that need to be assessed with respiratory monitoring are: "is the patient exchanging air?" (ie, is there airway obstruction or apnea), and "is air exchange adequate?" (ie, are oxygen and carbon dioxide being exchanged). The "gold standard" for assessing respiratory function is arterial blood gas analysis. Adequacy of ventilation is classically assessed via the $Pa{CO_2}$ value. Hypoventilation is manifested by a high $Pa{CO_2}$ and vice-versa. Oxygenation is evaluated via the $Pa{O_2}$ in relation to the inspired oxygen concentration. Blood gas analysis, although very accurate, cannot be used at this time as a continuous monitoring device during anesthesia because the data obtained is retrospective (at best several minutes will intervene between sampling and obtaining results), as well as being invasive, relatively inconvenient, and expensive.

The "standard" methods used routinely to monitor the respiratory system continuously have been the use of the precordial or esophageal stethoscope and visual assessment of chest wall movement and patient appearance for obvious signs and symptoms of hypoxia or hypercarbia. These methods are used to assess respiratory pattern, rate, depth, and adequacy. While these time-tested methods are essential, problems exist in that during surgery the operating room noise can make auscultation difficult and the presence of drapes, instruments, and equipment can obscure visual assessment, making accurate monitoring of ventilation very difficult. This is especially true during outpatient general anesthesia for oral surgery with nonintubated patients. The signs and symptoms of hypoxemia have been shown to occur late in the development of respiratory compromise, and, therefore, are not helpful in detecting a respiratory problem until quite late.[2,3] It is, therefore, desirable that a more ideal system for respiratory monitoring be developed and made widely available for routine use during anesthesia. Two monitors that are becoming widely used for these purposes are pulse oximetry and capnography.

## Monitoring Oxygenation

Because hypoxia is the leading cause of morbidity and mortality during anesthesia and the signs and symptoms of hypoxemia do not occur until late, a sensitive continuous method of monitoring the state of oxygenation is desirable. Several monitors have been developed for this purpose including the transcutaneous oxygen monitor and the ear oximeter. The transcutaneous oxygen monitor was developed in the early 1970s and has the theoretic advantage of monitoring $Pa{O_2}$ over the entire range of oxygenation. It is continuous and noninvasive. Operation involves "arterialization" of the skin under the heated polarographic electrode, the heat causing vasodilatation and increased cutaneous capillary blood flow. The oxygen tension at the skin thus increases to a level similar to the $Pa{O_2}$. Oxygen therefore actually diffuses through the skin and reacts with the electrode which measures $P{O_2}$. Several clinical studies have been carried out to evaluate the transcutaneous oxygen monitor for use during anesthesia with conflicting results. For example, Beech and Lytle used the monitor to detect hypoxia during outpatient general anesthesia for oral surgery. They concluded that it was "useful and accurate," although accuracy was tested by only 11 random blood gases.[4] On the other hand, Knill et al assessed the transcutaneous oxygen monitor during anesthesia as well and reported that stable transcutaneous $Ptc{O_2}$ values varied considerably, that trend detection was inconsistent, and that response time was extremely variable and relatively slow, taking as long as 15 minutes to stabilize after changes in inspired oxygen concentration. They concluded that the transcutaneous oxygen monitor was an inadequate monitor of arterial oxygenation during anesthesia.[5]

In a study at the University of North Carolina, we evaluated the transcutaneous oxygen monitor during outpatient general anesthesia for oral surgery.[6] A total of 54 arterial samples were obtained for comparison of $Pa{O_2}$ with simultaneously recorded transcutaneous partial pressure of oxygen ($Ptc{O_2}$) values. A correlation of $r = 0.93$ was observed overall, with values of $P{O_2}$ varying over a wide range (71–397). However, during periods when the $Pa{O_2}$ was rapidly increasing (as during preoxygenation) the $Ptc{O_2}$ lagged behind the $Pa{O_2}$. This occurred even when a five-minute equilibration time was allowed. Also, when $Pa{O_2}$ was rapidly decreasing (when the oxygen nasal hood was removed or during apnea) the changes in $Ptc{O_2}$ lagged behind even after five minutes. This lag time between changes in $Pa{O_2}$ and $Ptc{O_2}$ during any period when $Pa{O_2}$ is rapidly changing is in agreement with other studies.[3,5] Because accurate monitoring of respiratory status during periods of apnea, airway obstruction, and severe respiratory depression is critical, the transcutaneous oxygen monitor does not appear to be optimal for this purpose from our work.[6] This monitor, as well as the ear oximeter, has other major disadvantages including expense, bulkiness, extensive calibration, and the need for lengthy warmup time. Arterialization of skin has been reported to cause burns. These monitors, therefore, have not been widely used for monitoring during anesthesia.

The most recent development in this area is the pulse oximeter that was introduced in the United States in 1981, with an ear probe, and more recently in 1983 with the finger probe. The pulse oximeter works by placing a pulsating vascular bed between a two-wavelength red light source and a photodiode detector. By spectrophotometric analysis of the absorption of the red light as it passes through the blood, the oximeter determines the ratio of oxygenated (red) hemoglobin to deoxygenated (blue) hemoglobin present and displays an oxyhemoglobin saturation. The difference in light absorption created by the arterial pulsation itself is also factored in so that artifacts that would otherwise be created by tissue and venous blood are eliminated. The pulse oximeter is very accurate and easy to use, requires no calibration, warm up time, or arterialization of tissue, and is very rapidly responsive.

The primary disadvantage of the pulse oximeter lies in the fact that it measures oxyhemoglobin saturation rather than $Pa{O_2}$. Therefore changes in oxygenation are not detected until the $Pa{O_2}$ falls below the 70–80 range, that is approaching the steep portion of the oxyhemoglobin dissociation curve. Barker et al[7] recently demonstrated graphically that large decreases in oxygenation may occur without any change being detectable by pulse oximetry. They state: "the $P{O_2}$ must drop to $<70$ mm Hg before significant desaturation will occur, and the pulse oximeter will not warn of downward trends in $Pa_{O_2}$ over the wide range of oxygen tensions above this level."[7] This simply means that even small changes in hemoglobin saturation (eg, 99–95) must be noted quickly and evaluated before further desaturation occurs. Because the "danger zone" for severe hypoxemia is well below this level, it may be argued that the pulse oximeter will detect hypoxemia before any clinical signs and symptoms become evident and is, therefore, (especially considering its other advantages) a very valuable monitor. Despite its initially high cost, the pulse oximeter is rapidly becoming a "routine" monitor for anesthesia. The cost is currently falling dramatically as more companies introduce pulse oximeters.

## Capnography

Capnography is the continuous analysis of the carbon dioxide content of respired gases. Gas is continuously suctioned from the airway for analysis, producing a waveform that may be used to detect the presence or absence of ventilation (ie, apnea or airway obstruction) and hypo- or hyperventilation by analysis of the end tidal $CO_2$ ($Pet_{CO_2}$). The end tidal $CO_2$ is the concentration of $CO_2$ measured at the terminal portion of the exhalation curve that represents gas coming from the alveoli. This value has been shown to correlate closely with the $Pa_{CO_2}$. Gases may be sampled at the endotracheal tube connector in intubated patients, or at the nares in the nonintubated patient. Capnography has been shown to be an excellent monitor for:

1) diagnosis of esophageal intubation (no $CO_2$ return with ventilation),
2) apnea and airway obstruction (flat line tracing following a previously normal curve),
3) hypo- or hyperventilation (by $Pet_{CO_2}$),
4) other uses such as detection of malignant hyperthermia (large increase in $Pet_{CO_2}$) and air embolism (sudden decrease in $Pet_{CO_2}$).

At the University of North Carolina at Chapel Hill we evaluated capnography as part of a respiratory monitoring system during outpatient general anesthesia for oral surgery. Because these patients were not intubated, we sampled respired gases via a modified nasal oxygen cannula. We found that the capnogram provided a consistent waveform representing the breath-to-breath ventilatory pattern. In the event of airway obstruction or apnea, the $Pet_{CO_2}$ value dropped immediately to zero and the tracing dropped to zero baseline. This allowed for immediate detection of apnea or airway obstruction in all instances. A total of 66 arterial samples were obtained for comparison of $Pa_{CO_2}$ and simultaneously recorded $Pet_{CO_2}$ (end-tidal $CO_2$) values. $Pa_{CO_2}$ values ranged from 32–47 Torr. When end-tidal $CO_2$ was compared with simultaneously measured $Pa_{CO_2}$ a correlation coefficient of $r = 0.42$ resulted overall. When correlations were analyzed for each patient, however, half of the patients had a correlation coefficient of 0.93–0.99. During the initial moments of hypo- or hyperventilation the $Pa_{CO_2}$ and the $Pet_{CO_2}$ will probably not correlate well. During ultralight general anesthesia with frequent episodes of transient hyperventilation (due to light anesthesia) and hypoventilation (due to intermittent bolus injections of anesthetic agents), a perfect correlation between $Pa_{CO_2}$ and $Pet_{CO_2}$ will probably not occur. Therefore, the absolute value of the $Pet_{CO_2}$ measured via nasal prongs cannot be relied upon to reflect the exact value of the $Pa_{CO_2}$ at any given moment, but seems to provide a relatively good "trend" indicator for the detection of developing hypoventilation as it rises. Thus, our data indicates that capnography provides two valuable parameters for continuous ventilatory monitoring:

1) The continuously displayed $CO_2$ concentration (capnogram) provides a breath-to-breath representation of the presence or absence of air flow (ie, functional respirations) and, therefore, serves as an effective monitor for apnea or airway obstruction.
2) The $Pet_{CO_2}$ value serves as a reasonable trend indicator of hypoventilation as it rises over time. These changes detected by capnography would be expected to occur well before any detectable changes in oxygenation, especially during oxygen supplementation.

This monitor is also becoming increasingly available from various manufacturers and is, therefore, declining in price. In many hospitals it is now part of the "routine" monitoring for all anesthetics.

At this time the most ideal monitoring system for ventilation would appear to be the combination of the pulse oximeter and capnography. These monitors, combined with a precordial or esophageal stethoscope and observation, should answer the two primary questions of "is the patient exchanging air?" and "is gas exchange adequate?" These monitors are accurate, continuous, noninvasive, and quite convenient. The near future will surely see the introduction of monitors that combine these two modalities into one machine at reasonable cost.

The recently introduced "Harvard Standards of Practice in Anesthesia"[8] are becoming widely accepted as guidelines for monitoring during anesthesia. Recommendations made are:

1) that an anesthetist be physically present throughout administration of all anesthetics (except where a hazard exists),
2) that an oxygen analyzer and disconnect monitors be used on all anesthesia machines,

3) use of continuous ECG,
4) blood pressure and heart rate determinations made at least at five-minute intervals,
5) use of "continuous monitoring" of ventilation and circulation,
6) that the ability to measure temperature be available.

These guidelines seem appropriate and an acceptable starting point from which to proceed in establishing one's own personal standards for routine anesthetic monitoring.

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