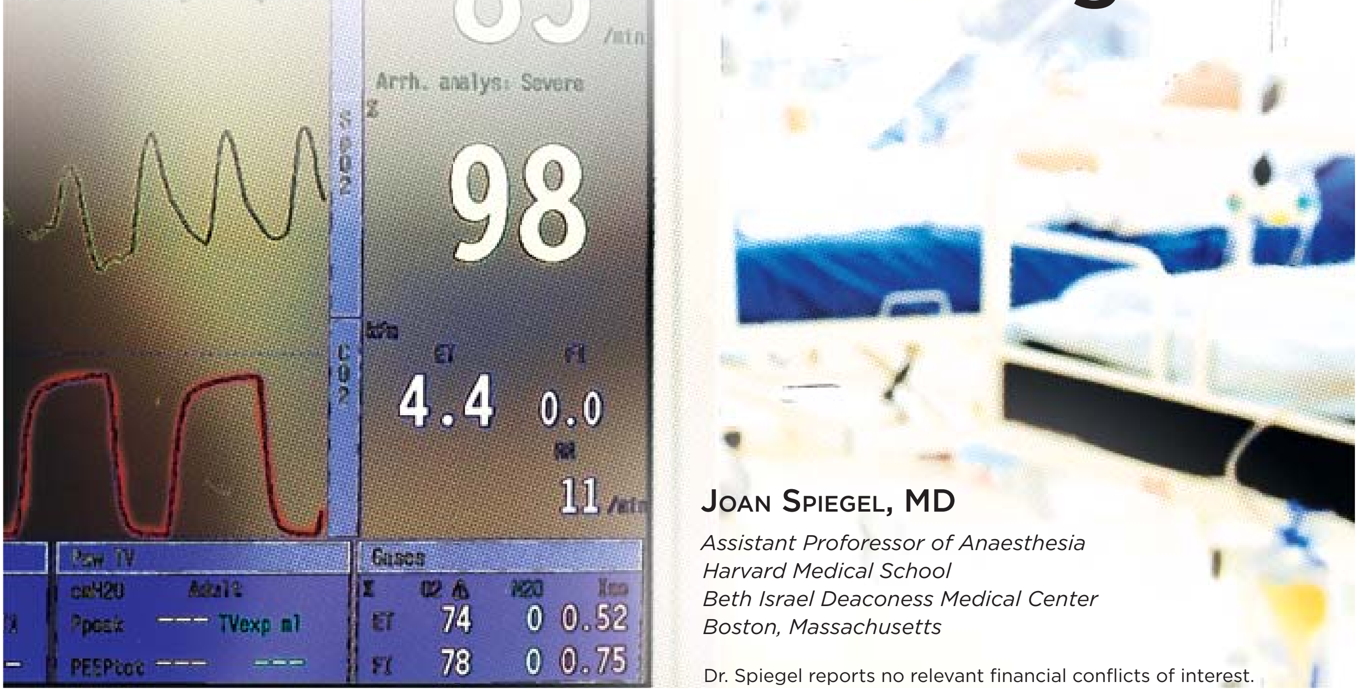
End-Tidal Carbon Dioxide: The Most Vital of Vital Signs



JOAN SPIEGEL, MD

Assistant Proforessor of Anaesthesia
Harvard Medical School
Beth Israel Deaconess Medical Center
Boston, Massachusetts

Dr. Spiegel reports no relevant financial conflicts of interest.

The alveolar concentration of carbon dioxide (CO_2) is the result of ventilation, perfusion, metabolism, and their interactions. Change in the concentration of CO_2 reflects perturbations in any or all of these factors. Detection of CO_2 in an exhaled breath by monitoring end-tidal CO_2 ($etCO_2$) via capnography has long been clinically invaluable in providing immediate information about CO_2 production, ventilation/perfusion (V/Q) status, elimination of CO_2 from the circuit and lungs, and patency and function of the breathing circuit itself.

The measure of arterial and exhaled CO_2 provides a metric for management and diagnosis in both normal and pathophysiologic states, and as a tool to guide clinical practice both within and outside the operating room. In non-OR procedural environments, such as the emergency room or gastrointestinal (GI) suite, capnography is more lifesaving than the use of pulse oximetry alone because it provides more rapid detection of respiratory depression or apnea leading to hypoxia than pulse oximetry (Table 1).[1]

With the increasing portability of CO_2 analyzers, capnography likely will become the standard of care in many more locations and situations. Recently introduced recommendations and practice standards for capnography include resuscitation for cardiac arrest, continuous $etCO_2$ monitoring in the ICU, patient transport, and for moderate sedation practices.

Capnography (derived from the Greek *kapnos* ("smoke") and *graphein* ("to write")) is the graphic display of the measurement of CO_2 in the respiratory gases and has become an integral part of anesthesia monitoring. In 1978, the Netherlands became the first country to adopt capnography as a standard monitor during anesthesia.[2] Time-based capnography, the most commonly displayed measure of $etCO_2$, displays the respiratory phases in inspiration and expiration. Volumetric capnography can measure the volume of

Table 1. Uses for Capnography

Adequacy of fresh gas flow
Adequacy of mechanical ventilation
Adequate reversal of neuromuscular blockade
Asthma/chronic obstructive pulmonary disease
CO_2 absorption (laparoscopic)
Cardiac arrest/evaluation of cardiac compressions
Detection of blocked or kinked tracheal tube
Detection of breathing/sampling circuit leak
Detecting circuit disconnection
Detection of dead space
Detection of pulmonary embolism
Endotracheal intubation
Evaluation of dual lumen endotracheal tubes
Feeding tube insertion
Functional analysis of rebreathing apparatus
Indirect estimate of cardiac output/cardiac index (fluid responsiveness)
Measurement of cardiac output
Metabolic acidosis
Non-OR deep sedation, conscious sedation
Nutritional support
Onset or waning of neuromuscular blockade
Patient transport
Shunts in cyanotic heart diseases
Ventilator management (titration of PEEP/weaning and extubation)

OR, operating room; **PEEP,** positive end-expiratory pressure

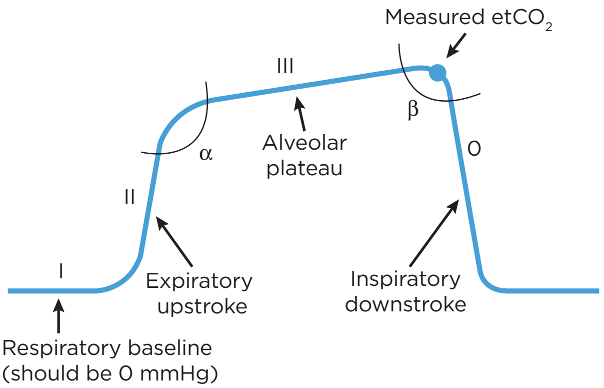


Figure 1. Typical time-based capnography.

expired CO_2 over time and provide information about physiologic dead space and the effects of positive end-expiratory pressure (PEEP) on expiratory phase morphology.

Basic Physiology

At the end of inspiration, assuming no rebreathing, the airway and lungs are filled with CO_2-free gases. Carbon dioxide diffuses into the alveoli and equilibrates with the end-alveolar capillary blood. The concentration of CO_2 in the alveoli is determined by the V/Q ratio. Alveoli with a higher V/Q ratio have lower CO_2 than low V/Q alveoli. During exhalation, CO_2 is evident on the capnogram, reflecting dead space, but gradually a peak appears. At the end of exhalation with inhalation of CO_2-free gases, the capnogram goes to baseline (0) and the end result is a characteristic shape of the CO_2 curve (Figure 1).

The 2 segments of the capnogram are expiration and inspiration. During inspiration, the graph represents the amount of CO_2 in the inspirate. Rebreathing of dead space volume and exhaustion of CO_2 absorber elevate the normal baseline of inspired CO_2. The expiration segment of the capnogram is more complex and provides more clinical information. It is divided into 3 phases: Phase I represents physiologic dead space and contains no sampled CO_2. Phases II (plateau) and III represent the evolution of CO_2 from an exhaled breath measured at frequent intervals and displayed over time. For simplicity, many capnograms appear to exhibit a flattened plateau, but the dynamic removal of CO_2 from the alveoli and thus the CO_2 partial pressure is not uniform, and should have an upward rather than flat slope (Table 2).

For a numerical display, $etCO_2$ is read at the end of phase II and represents the maximum amount of CO_2 measured. If the observer is serious about obtaining dead space and flow mechanics, however, volumetric capnography should be employed (Figure 2).

In contrast to time-based capnography, volumetric capnography is essentially an $etCO_2$ curve plus flow and volume. Whereas time-based capnography records partial pressure of CO_2, $etCO_2$, and respiratory rate, volumetric capnography records the gas fraction and time-based measurements plus VCO_2, dead space, and other respiratory mechanics, including flow and airway pressure. Volumetric capnography is more informative than time-based capnography as it provides a measure of not only respiratory rate, but a more in-depth understanding of the ventilation–perfusion relationships of the lung as exhibited by the slope of phase III of the capnogram, as long as the ventilation system is not leaking, including a pneumothorax or leaks from the cuff of an endotracheal tube (ETT). Volumetric capnography is more complicated to employ and interpret, and therefore is not used routinely.

Physics of Capnography

There are 5 methods for detecting CO_2: infrared (IR) spectroscopy, molecular correlation spectroscopy

(MCS), Raman spectroscopy, mass spectroscopy, and photoacoustic spectroscopy (PAS).

Infrared Spectroscopy. In IR spectroscopy, beams are emitted from a light source into a sample. As the beam passes through the sample, CO_2 absorbs a specific wavelength of light (4.3 mcm). This measurement is used to calculate the amount of CO_2 in the sample. IR spectroscopy is the most widely used and cost-effective method for detecting CO_2 and is found in most portable etCO_2 devices.

Molecular Correlation Spectroscopy. MCS is a laser-based technology that generates an IR emission that precisely matches the CO_2 wavelength. This precision can be important if the spectrometer must differentiate perfectly between nitrous oxide (N_2O) and other gases that absorb at ranges close to that of CO_2. The technology allows for refined measurements of small sample size. Because MCS is highly specific with all gas samples, the monitor does not require special algorithms to correct for high concentrations of oxygen, N_2O, or other anesthetic gases, as required by other capnography technologies.

Raman Spectroscopy. This technology uses the principle of Raman scattering, whereby a laser illuminates a sample of gas such as CO_2 or N_2O, or water vapor. As CO_2 selectively absorbs specific wavelengths of IR light, the amount absorbed is proportional to the amount of CO_2 in the sample.

Photoacoustic Spectroscopy. PAS is based on the same principle as IR-based analyzers: The CO_2 molecules absorb the IR light. However, whereas IR spectroscopy uses optical methods of detection, PAS records acoustic signals. A CO_2 sample is bombarded with pulses of IR waves, making the sample rapidly expand and contract, producing sound waves. A sensitive microphone picks up these sound waves, which vary according to how much CO_2 is present in the sample.

Mass Spectroscopy. This is a bulky and expensive technique that measures the charge-to-mass relationship of molecules in sample. It is not commonly used clinically.

It is possible also to detect CO_2 with calorimetry. An indicator treated with chemical foam is contained in a plastic housing that attaches to the ETT following intubation. A color change from purple to yellow indicates the presence of CO_2. This technique cannot provide continuous or numeric information and thus has limited utility other than for confirming the placement of an ETT.

Pathophysiologic States Detected by Capnography

As etCO_2 measurements generally reflect ventilation, perfusion, and metabolism, change in etCO_2 is an invaluable aid in the diagnosis of a range of pathophysiologic states. A sudden or gradual increase in etCO_2 can signal fever associated with sepsis, malignant hyperthermia, decreased ventilation, venous pulmonary embolus (with CO_2), increased carbon monoxide, return of circulation following cardiopulmonary resuscitation (CPR), and chronic obstructive pulmonary disease. Decreasing CO_2 may indicate pulmonary embolism, cardiac arrest, hypothermia, excess ventilation, hypometabolic state, hypotension, low cardiac output, esophageal intubation, and a disconnected ventilator.

Table 2. Checklist for Assessing The Capnogram

The primary usefulness of capnometry is to determine whether there is evidence of patient ventilation.
Is the patient breathing and therefore is there a plateau/onset of the capnogram?
Is there evidence of slow exhalation (slanted upstroke)?
On the horizontal plateau of the capnogram is there uneven emptying of the lungs?
In mechanically ventilated patients, is there evidence of interrupted inspiratory efforts on the horizontal plateau?
Is the down-stroke steep (normal) or is there slow inspiration or rebreathing of CO_2? Could there be an incompetent ventilator inspiratory valve?

Adapted from Capnography in Clinical Practice. Gravenstein, Paulus, Hayes. Anesthesia Patient Safety Foundation. 1988.

Methods for CO_2 Detection

There are 2 types of ways to measure etCO_2: using either a mainstream or a sidestream detector. Sidestream analysis capnography is convenient because a lightweight, inexpensive connector can be attached near a patient's mouth or nares. Delays in sidestream analysis vary with long sampling lines, the rate of air aspiration into the capnometer, and the efficiency of the capnometer itself. The mainstream analyzer generates a capnogram almost instantly as the gas passes through a cuvette almost immediately after exiting the lungs. With mainstream devices, the sensor—consisting of the sample cell and infrared bench—is placed at the airway, revealing an accurate capnogram that reflects in real time the partial pressure of CO_2 within the airway. Sidestream devices aspirate a sample of gas from the breathing circuit through a long (6-8 feet) small-bore tube at a flow rate ranging from 50 to 250 mL per minute. In infants and children, aspiration of large volumes for etCO_2 measurement loses a significant amount of ventilation to the analyzer.

The Microstream (Oridion) can use smaller sampling volumes (30-50 mL/min) to avoid excessive removal of ventilation gases and thus tidal volume.

Safety and Monitoring Trends

Inadequate ventilation of the patient—including failure of the anesthesiologist to adequately

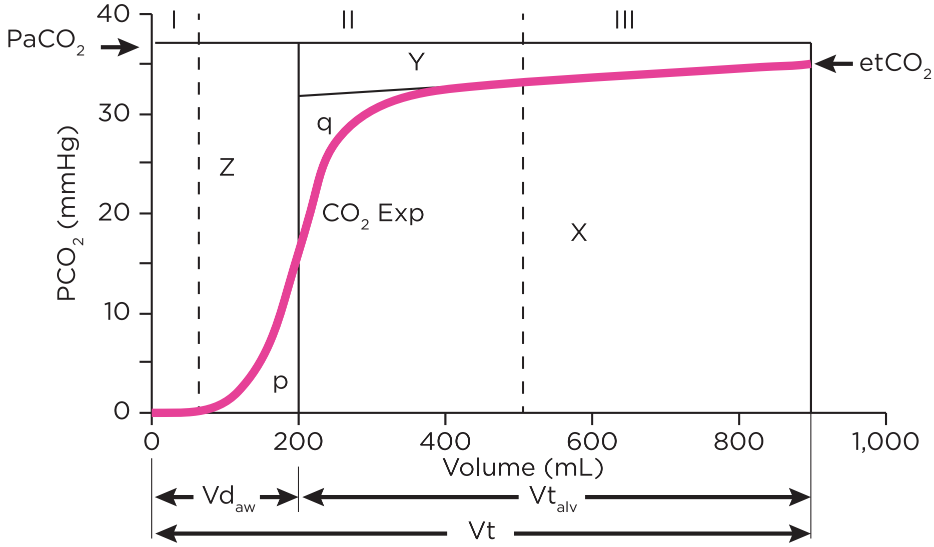


Figure 2. Volumetric capnogram.

ventilate—traditionally accounted for the greatest number and most severe anesthesia-related catastrophes. In 1986, the American Society of Anesthesiologists (ASA) first encouraged the use of capnography for certain patients receiving anesthesia. In 1999, the ventilation-monitoring standard was modified to include capnography as a standard for virtually every patient receiving general anesthesia:

"Continual monitoring for the presence of expired carbon dioxide shall be performed unless invalidated by the nature of the patient, procedure, or equipment. Quantitative monitoring of the volume of expired gas is strongly encouraged."[3]

This standard has an asterisk referring to the ability of the responsible anesthesiologist to waive the requirements under extenuating circumstances. Indeed, patients receiving electroconvulsive therapy and cardioversion do not routinely undergo $etCO_2$ monitoring.

Anesthesiologists have taken a step in improving patient safety outside the OR by recognizing capnography as the appropriate measure of adequacy of ventilation during nonintubated procedures requiring moderate or deep sedation. The ASA standards evolved in 2010-2011 in part because of the persistent risk for respiratory compromise in cases of procedural sedation. The past 20 years of ASA Closed Claims data demonstrate that respiratory events and events leading to death occurred twice as often when patients were sedated outside the OR.[4] A 2011 meta-analysis found that respiratory depression was 17.6 times more likely to be detected during sedation cases using capnography.[5] Ironically, the use of a pulse oximeter alone with supplemental oxygen can increase a patient's risk for hypoxic events because supplemental oxygen maintains oxygenation longer during periods of apnea, which frequently goes undetected.

Safety organizations representing cardiology, critical care medicine, pediatrics, and emergency medicine have either mandated or strongly recommended continuous use of capnography for patient monitoring for other purposes including conscious sedation outside the OR, resuscitation, ventilator weaning, and patient transport. A host of organizations besides the ASA also recognize the importance of non-OR monitoring of the adequacy of ventilation, including the Joint Commission, the Anesthesia Patient Safety Foundation, and the Institute for Safe Medication Practices.

Measuring $etCO_2$ via nasal cannula complies with these standards because of its use of qualitative rather than quantitative clinical signs. Accuracy of the $etCO_2$ is not required.

The ASA's new standards on capnography have not gained universal acceptance. The American Gastroenterological Association (AGA) considers the use of capnography for routine, moderate GI sedation cases intrusive, expensive, and unnecessary. According to the AGA, the superior safety in moderate sedation administered by an endoscopist is evidenced by a fatality rate of 8 deaths per 100,000 routine procedures. (The rate when an anesthesiologist administers moderate sedation is as much as one-eighth as high.) Importantly, could those patients have avoided death by the use of properly implemented capnography? The AGA also argues that there are no pertinent randomized trials to support capnography for moderate sedation for routine GI cases. However, the updated ASA standards were in part devised by examining closed claims, and whether deaths or serious claims could have been prevented by the use of a particular monitor.

Expert opinion also is considered important because many studies do not define "near misses," an important subset of clinical experience in anesthesia that is not easily quantifiable in other ways. Claims in the Closed Claims database suggest, for example, that most deaths from erroneous esophageal intubation could have been prevented with the use of capnography. A prospectively designed study to prove this would be unnecessary, and possibly harmful. Nearly one-quarter (24%) of the claims in the Closed Claims database are related to endoscopy; capnography may have prevented many, if not most, of these.[6]

Importantly, the ASA has argued that sedation itself does not neatly fall into a prescribed and orderly response for every patient. Similar drug dosages resulting in moderate sedation for 95% could produce deep sedation for the other 5%. Sedation is a pharmacodynamic continuum rather than a set point. To further complicate matters, the ASA standards for providing anesthesia apply to anesthesiologists and anesthesia providers, but not necessarily to other clinicians, who do not necessarily accept the society's definition of anesthesia. Similarly, the Centers for Medicare & Medicaid Services (CMS) do not consider moderate/conscious sedation to be anesthesia. This remains a political sticking point toward reaching a more acceptable practice for those administering moderate sedation and the use of etCO_2 in such cases (Box 1).

Box 1. ASA Procedural Mandate on Capnography: etCO_2 for Moderate Sedation

Effective July 1, 2011, Basic Anesthetic Monitoring Standard 3.2.4., now reads: "During regional anesthesia (no sedation) or local anesthesia (no sedation), the adequacy of ventilation shall be evaluated by continual observation of qualitative clinical signs. During moderate or deep sedation, the adequacy of ventilation shall be evaluated by continual observation of qualitative clinical signs and monitoring for the presence of exhaled carbon dioxide unless precluded or invalidated by the nature of the patient, procedure, or equipment."

The ASA's former Standard for Basic Anesthesia Monitoring read:

"During regional anesthesia and monitored anesthesia care, the adequacy of ventilation shall be evaluated by continual observation of qualitative clinical signs and/or monitoring for the presence of exhaled carbon dioxide."

Waveform Capnography and Resuscitation

Among the primary interventions of CPR—ventilation, intubation, and electric shocks—the initial and continued act of precordial compressions remains the most effective life-saving measure. Compressions should not be interrupted for long periods, even to perform endotracheal intubation. The utility of continuous etCO_2 during CPR to assess effectiveness of chest compressions has been documented for more than 20 years,[7] but it was not until 2010 that the Advanced Cardiovascular Life Support (ACLS) guidelines incorporated the use of the technology. For the management of cardiac arrest that includes chest compressions, intubation, and the administration of drugs, capnography is considered useful, if not lifesaving. The 2010 ACLS guidelines carry strong recommendations for the use of quantitative waveform capnography for confirmation of ETT placement, to determine the effectiveness of chest compressions, and to determine if a return of spontaneous circulation (ROSC) has occurred. Portability, learning curve for all first responders, and cost of such an endeavor is likely a major factor in hindering the adoption sooner.

In states of very low cardiac output, blood flow rather than content determines oxygen delivery. Invasive arterial monitoring is ideal but highly impractical in most emergent settings, as a measure of effective circulation and monitor of ROSC. Palpation of distal arterial pulses is relatively unreliable as a method for assessing the effectiveness of cardiac compressions.

Using the principal determinants of etCO_2—alveolar ventilation, pulmonary perfusion (cardiac output), and production of CO_2[8]—and by holding alveolar ventilation and CO_2 relatively constant, an increase in etCO_2 for example should reflect ROSC. Specifically, during acutely low cardiac output states such as during cardiac arrest, decreased pulmonary blood flow will manifest as very low etCO_2; and continuous etCO_2 will represent the primary determinant of changes in cardiac output, assuming that ventilation and production of CO_2 are relatively constant. Thus, with chest compressions being relatively constant as well, etCO_2 can be used as a quantitative index in evaluating adequacy of ventilation and pulmonary blood flow during CPR.[7] By extension, continuous etCO_2 monitoring during CPR is a useful gauge of the effectiveness of chest compressions and rescuer exhaustion.

Depending on the type of arrest requiring CPR (asystole, respiratory, etc.), measuring continuous etCO_2 may be a valuable predictor of a positive outcome with ROSC. Patients who experience ROSC during CPR will show a rise in etCO_2 as a first indicator before palpable pulse or blood pressure. On the other hand, with CPR lasting at least 20 minutes, if etCO_2 remains below 10 mm Hg, survival is unlikely (Box 2). However, when etCO_2 remains below 10 mm Hg after 20 minutes of CPR following an asystolic event, the sensitivity and specificity for predicting ROSC are 100% sensitivity and 61%, respectively.[9] Continuous monitoring, therefore, would provide caregivers a more rational approach to prolonged CPR and allow them to assess the adequacy of their efforts without suspending compressions.[9]

Postoperative Patients on Narcotic PCA And Capnography

etCO_2 monitoring also may be used to monitor patients following surgery who are receiving narcotics by patient-controlled analgesia or who may be at significant risk for apnea following surgery. Respiratory

Box 2. The 96-Minute CPR

The dilemma of when to stop performing CPR on a victim suffering an out-of-hospital cardiac arrest remains acute. One case exemplifies how the monitoring of $etCO_2$ was used in a rational albeit prolonged manner to decide the fate of a man who suffered an out-of-hospital cardiac arrest. An astonishing 96 minutes of CPR (chest compression) were administered to save the life of a 54-year-old man in cardiac arrest. In almost any other scenario, cardiac compressions and electrical shocks would have been discontinued after 30 to 40 minutes. What saved this patient was the availability of $etCO_2$ monitoring during CPR. Because the $etCO_2$ monitor consistently showed an $etCO_2$ of more than 30 mm Hg, CPR was continued until the $etCO_2$ rose to 37, suggesting that return of spontaneous circulation was achieved. The man underwent cardiac catheterization and stenting, and unbelievably had no permanent neurologic deficits on discharge from the hospital.

Reported on National Public Radio, Oct. 3, 2011

depression is relatively common postoperatively. When combined with other parameters such as pulse oximetry and heart rate, $etCO_2$ may help discern significant changes in patient status while ruling out false-positives and preventing unnecessary interventions.

Integrated Pulmonary Index

The Integrated Pulmonary Index (IPI; Covidien) is a new technology (FDA-approved in 2009) that uses $etCO_2$, respiration rate, pulse rate, and SpO_2 to provide an uncomplicated, inclusive, real-time assessment of a patient's ventilatory and oxygenation status into a single index value ranging from 1 to 10. Fuzzy logic (mathematical model mimicking human logic) and the input of experienced clinicians developed the algorithms used in the final single numerical output.[10] The clinician can use the trends and changes of the IPI to assess the interrelationships of a patient's respiratory parameters, and to intervene if clinically indicated. The IPI also provides an early indication of changes in a patient's respiratory status that may not be indicated by the values of the individual parameters.[11] Interestingly, the IPI also helps delineate clinically insignificant (false-positive) alarms as well. In short, the IPI theoretically can increase patient safety by indicating the presence of slow-developing patient respiratory issues not easily identified with individual instantaneous data to the caregiver in real time.

Because normal values for the physiologic parameters are different for different age categories, the IPI algorithm differs for different age groups (3 pediatric age groups and adult). The IPI is not available for neonatal and infant patients (up to the age of 1 year).

It remains to be seen how quickly clinicians will adopt the IPI given the expense of the technology, elimination of false-positive and negative alerts, training issues, and other considerations.

Capnography in the ICU and for Transport

Continuous capnography for mechanically ventilated patients in the ICU is uncommon, and particularly rare in North America. However, inadvertent ETT dislodgment and its consequences account for unnecessary deaths in critical care settings. According to a 2011 audit of major airway complications in the United Kingdom, 75% of airway-related deaths or severe neurologic injuries in the ICU could have been prevented with the use of continuous capnography.[12] The authors of the audit strongly encourage continuous waveform capnography for all intubated patients, including those ventilated through tracheostomy tubes.

Continuous capnography seems ideally suited for the ICU, as it aids in detection of misplacement of feeding tubes; gauges changes in metabolic rate; aids in the weaning off the ventilator in patients without serious lung pathology; guides the titration of PEEP (volumetric capnography); and can assess in the kinking, disconnection, or failure of the patient's ETT. In the United States, no specific standards currently address the use of waveform capnography in intubated patients in the ICU.

Transportation of critical intubated patients from one hospital to another does not require the use of continuous capnography. Certainly, airway mishaps can be detected with the use of capnography, but added expense and time for education limit its rapid introduction for emergency medical service providers.

Other Uses for Capnography

Studies suggest that capnography can be used as an indirect estimate of cardiac index/cardiac output. $etCO_2$ has been shown to correlate strongly with changes in cardiac output. In determining fluid responsiveness, passive leg raise (PLR) has been shown to dynamically evaluate cardiac preload. The PLR test has been used in resuscitation of critical patients such as septic patients. Several studies have shown that the PLR can be evaluated using $etCO_2$ in ventilated patients to evaluate for fluid responsiveness. An increase of at least 5% in $etCO_2$ after PLR suggests fluid responsiveness with a sensitivity of 71% to 91% and a specificity of 94% to 100%.

New Devices

Ultraportable waveform capnograph monitors and CPR/defibrillators with mainstream $etCO_2$ attachments are now available. Cost is a major consideration for defibrillators equipped with $etCO_2$ technology, ranging from $10,000 to $20,000. Portable handheld capnograph/oximeters are less expensive—$2,000 to $3,000—but also might carry nontrivial per-use costs.

Innovations to sidestream capnography also include improvements to capturing $etCO_2$ during procedural sedation in nonintubated patients. The Smart Capnoline (Oridion) uses a special cannula that measures exhaled $etCO_2$ from the nose and mouth while delivering oxygen. This feature is useful in endoscopic procedures in which detection of $etCO_2$ can be difficult. Oridion also developed a combination bite block and $etCO_2$ line into the Capnoblock for use primarily in endoscopy.

Conclusion

Capnography allows for the detection of life-threatening conditions of the lungs and cardiovascular system more rapidly than pulse oximetry alone. Studies have expressly validated the usefulness of waveform capnography in saving lives in many clinical environments. Waveform capnography has found its way into clinical practice to confirm and now monitor ETT placement, assess quality and utility of continued CPR, and detect ROSC. It is now standard of care for patients receiving moderate sedation, and is recommended in intubated critically ill patients, for transport of these patients, and for postoperative patients receiving narcotics. The recent change in monitoring standards and recommendations for the use of capnography by the ASA and the American Heart Association for sedation and resuscitation are important, but effective and rational hospital implementation of capnography will require the future collaboration of other societies and regulatory groups.

References

1. Deitch K, Miner J, Chudnofsky CR, Dominici P, Latta D. Does end tidal CO2 monitoring during emergency departmental procedural sedation and analgesia with propofol decrease the incidence of hypoxic events? A randomized, controlled trial. *Ann Emerg Med*. 2010;55(3):258-264.
2. Advisory Report on Anaesthesiology, Part I: Recent developments in Anaesthesiology, Committee of the Health Council of the Netherlands, 1978.
3. American Society of Anesthesiologists (ASA). Basic Standards for Anesthetic Monitoring; Committee of Origin: Standards and Practice Parameters (Approved by the ASA House of Delegates on Oct. 21, 1986, and last amended on Oct. 20, 2010 with an effective date of July 1, 2011).
4. Cravero JP, Blike GT, Beach M, et al. Incidence and nature of adverse events during pediatric sedation/anesthesia for procedures outside the operating room: report from the Pediatric Sedation Research Consortium. *Pediatrics*. 2006;118(3):1087-1096.
5. Waugh JB, Epps CA, Khodneva YA. Capnography enhances surveillance of respiratory events during procedural sedation: a meta analysis. *J Clin Anesth*. 2011;23(3):189-196.
6. Bhananker SM, Posner KL, Cheney FW, Caplan RA, Lee LA, Domino KB. Injury and liability associated with monitored anesthesia care. A closed claims analysis. *Anesthesiology*. 2006;104(2):228-234.
7. Falk JL, Rackow EC, Weil MH. End-tidal carbon dioxide concentration during cardiopulmonary resuscitation. *N Engl J Med*. 1988;318(1):607-611.
8. Benumof JL. Interpretation of capnography. *AANA J*. 1998;66(2)169-176.
9. Cantineau JP, Lambert Y, Merckx P, et al. End-tidal carbon dioxide during cardiopulmonary resuscitation in humans presenting mostly with asystole: a predictor of outcome. *Crit Care Med*. 1996;24(5):791-796.
10. Reliability of the Integrated Pulmonary Index postoperatively. Gozal Y, Gozal D. Society for Technology in Anesthesia annual meeting. January 2009.
11. The Integrated Pulmonary Index: Validity and application in the pediatric population. Gozal D, Gozal Y. Society for Technology in Anesthesia annual meeting. January 2009.
12. Cook TM, Woodall N, Harper J, Benger J; Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 2: intensive care and emergency departments. Fourth National Audit Project. *Br J Anaesth*. 2011;106(5):632-642.

For an excellent and more thorough review of capnography, please visit the website www.capnography.com.