Capnography in the Pediatric Emergency Department: Clinical Applications

Abstract

Capnography, often referred to by emergency clinicians as end-tidal carbon dioxide monitoring, is a noninvasive method of measuring cardiopulmonary and metabolic parameters that can be utilized in many clinical applications. Growing evidence in the literature in support of the use of capnography has led to increased clinical use of this modality in many pediatric subspecialties. Understanding capnography and the literature supporting its practice will advance its use by emergency clinicians in the pediatric emergency department, promoting improved patient care and safety. This issue reviews the technology and physiology involved in measuring exhaled carbon dioxide and the interpretation of waveforms, and it highlights uses for capnography in pediatric patients in the emergency department. Uses include confirmation of intubation, maintenance of ventilation in intubated and nonintubated children, monitoring of effectiveness of cardiopulmonary resuscitation, and as an adjunct for monitoring of sedated children and children with lower respiratory disease and metabolic derangements.

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CME Objectives
Upon completion of this article, you should be able to:
1. Describe the basic technology of capnography.
2. Interpret the components of a basic CO2 waveform and recognize the physiologic reasons for deviation from normal.
3. Use capnography in the management of critically ill or injured pediatric patients who require cardiopulmonary resuscitation and/or intubation.
4. Recognize and correctly classify abnormal or disordered ventilation using capnography when monitoring spontaneously breathing patients.

Prior to beginning this activity, see the back page for faculty disclosures and CME accreditation information.

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Case Presentations

On a weekday afternoon in your pediatric ED, a worried mother brings in her 4-year-old daughter, who fell from a piece of playground equipment at her daycare center. She has an obvious deformity of her left forearm, and radiographs confirm displaced fractures of the distal radius and ulna. You inform the mother that her daughter’s injury will require a closed reduction by your institution’s orthopedic team and that you would like to sedate her for the procedure. While doing your pre-sedation assessment, you note that the patient’s pulse oximetry reading is 93%, breath sounds are decreased over both lung fields, and there is an occasional wheeze. The nurse places a nasal cannula on the child and administers supplemental oxygen at a rate of 2 L/min. Her oximetry reading rises to 98%. The mother informs you that her daughter has had 2 or 3 episodes of wheezing in the past, all related to concurrent upper respiratory infections. How will you evaluate this patient’s current respiratory status? Will you maintain the child on supplemental oxygen during the sedation? How will you monitor her respiratory parameters during the sedation?

Shortly after that, a member of your nursing staff asks you to speak with the parent of an 18-month-old boy you evaluated 30 minutes ago. The patient had a 3-day history of fever, vomiting and diarrhea, and poor fluid intake, and he had not had a wet diaper in almost 24 hours. On your exam, you noted him to be tired appearing, tachycardic for age, with dry lips, and a capillary refill of approximately 3 seconds. His abdomen was soft and nontender. You ordered a serum electrolyte panel and requested that the nurse place an IV catheter for hydration. The nurse tells you that she has been unable to obtain blood or place the IV despite multiple attempts. The mother does not want her child to have any more needle punctures or attempts at IV placement, and she asks you if the blood test and IV are absolutely necessary. How will you respond to this mother? Is there a noninvasive objective measure that can help you to determine the severity of this child’s dehydration?

As you consider your options, EMTs rush in with an intubated teenager. CPR is in progress. They tell you that they were flagged down by a group of the boy’s friends at a nearby park. The boy collapsed during a game of basketball, and he was apneic and pulseless on arrival. The intubating EMT tells you that automated external defibrillator pads were placed immediately, and no shock was indicated. Since the park was very near the hospital, they chose to “scoop and run,” and 1 of the EMTs intubated him in the ambulance en route. The intubating EMT tells you he did appreciate breath sounds in both axillae after the endotracheal tube was placed, although it was difficult to hear in the moving ambulance with the sirens blaring. He reports a “positive color change” on the colorimetric CO₂ detector, but states that the color was more beige than bright yellow. He did see the endotracheal tube go through the vocal cords and some water vapor in the tube while he was bagging, so he is sure he intubated the trachea. A resident working with you takes over the manual ventilations of the patient and directs an intern to take over chest compressions from the EMT team. A nurse places the boy on a monitor and checks the femoral pulse during compressions. She reports that she can palpate a pulse with each compression and tells the intern he is compressing effectively. The resident suggests that the intern stop chest compressions for a moment to check whether there is a cardiac rhythm on the monitor. Is the resuscitation of this patient optimal? Are there more objective indicators that can be used to confirm endotracheal intubation and maximize the quality of the CPR your team is providing?

Introduction

The History Of Capnography

Capnography is the measurement and monitoring of the partial pressure of carbon dioxide (CO₂) in exhaled breaths, and it is often referred to as end-tidal carbon dioxide (ETCO₂) monitoring. The modern-day ability to measure ETCO₂ and the insight it provides into human metabolism and cardiopulmonary physiology has been over a century in the making.¹

Some of the earliest experiments in CO₂ measurement were by John Tyndall, a professor of natural philosophy from the United Kingdom. In the mid-1860s, he experimented with carbonic acid and discovered that CO₂ was superior to oxygen, nitrogen, and hydrogen in the absorption and transmission of radiant heat. In 1905, John Scott Haldane created an early spectrometer that was able to measure the volume and calculate the percentage of CO₂ in a mixture of gases. In his studies of respiratory physiology (often using himself as a subject), he was one of the earliest investigators to suggest that human respiratory drive is exquisitely sensitive to the rising partial pressure of CO₂ in alveolar air.² The first modern capnograph is attributed to Karl Friedrich Luft. The “Luft cell” (1937) made use of infrared technology to measure CO₂ concentration, and it continues to be the technologic basis of modern-day CO₂ measurement.²

Review Of The Technology

The earliest technology used in the clinical application of capnography was mass spectrometry.³ The mass spectrometer separates and counts individual molecules of ionized gas to yield a concentration of exhaled CO₂.⁴ The equipment is large, expensive, and complex, which limits its usage chiefly to operating rooms. Currently, the most common capnography technology used by clinicians is infrared absorption spectroscopy. Capnographs that make use of infrared technology can be incorporated into bedside cardio pulmonary monitors, or they can be lightweight handheld units that are battery operated.
CO₂ absorbs infrared light at a specific wavelength (4.26 μm). The concentration of CO₂ in a sample of mixed gases can be calculated by infrared absorption spectroscopy, whereby a beam of infrared radiation from a light source can be conducted through a sample of air to a photodetector. The greater the concentration of CO₂ in the sample, the more light it absorbs, decreasing the intensity of the light that reaches the detector. The difference between the intensity of infrared light absorbed and that which passes through the sample yields a calculation of CO₂ concentration.

There are 2 types of configurations available for CO₂ measurement by infrared technology: mainstream and sidestream.

Mainstream analyzers contain their infrared sensor in an adapter that is connected inline with the patient’s ventilatory circuit (typically at the hub of the endotracheal tube [ETT]), and it can only be used in intubated patients. The adapter is heavy, tends to lay on the ventilator tubing or on the patient, and can cause kinking or dislodgement of an ETT. The unit is heated to a temperature of 39°C in order to prevent water condensation in the circuit, as vapor can falsely elevate ETCO₂ readings. The weight and heat of the mainstream sensor make it impractical for use in neonates and young infants.

In a sidestream system, the sensor is remote from the patient and is not inline with the ventilator circuit, which makes it useful for both intubated and non-intubated patients. In sidestream systems, a sample of air from the expired breath is aspirated from the circuit through a sampling line and then delivered to the sensor. The line can be connected by a T-piece to an ETT. (See Figure 1.) There are also commercially available nasal cannulas, nasal-oral cannulas, and facemasks with built-in sampling lines.

Newer cannulas aspirate smaller gas samples and can deliver supplemental oxygen (up to 5 L/min) while still measuring the CO₂ accurately. (See Figure 2.) In a nonintubated patient, exhaled gases can mix with the ambient air or other gases, diluting the CO₂ concentration and falsely lowering the capnography reading. Newer cannulas have nasal prongs and a mouthpiece so that positive pressure from the breath exiting the nose or the mouth is directed into the sampling line. This limits the amount of ambient air that enters (potentially diluting the sample) and allows a more accurate measurement of CO₂ in the presence of low tidal volumes.

**Introduction To Carbon Dioxide Waveform Interpretation**

Capnography graphically displays the exhaled CO₂ concentration as a function of volume or time as a waveform, referred to as the capnogram. Waveforms to measure CO₂ were first used in 1928 to quantify dead space (the air within the respiratory system that is not involved in gas exchange). In 1974, Smalhout and Kalenda published an atlas of waveforms that were derived from clinical use of capnography.

**Figure 3 (see page 4)** is an example of an ideal, normal capnogram representing a single tidal breath. As the cycle of ventilation continues, each
waveform will connect to the next as an uninterrupt-
ed chain. The y-axis represents the partial pressure of expired \( \text{CO}_2 \) which is zero at the beginning of exhalation. The segment A-B (also known as phase I) represents the beginning of exhalation as the first gases leave the airway from the anatomic dead space of the respiratory tract. Segment B-C (phase II) slopes upward rapidly as the patient begins to exhale gas from the alveoli mixed with residual dead space gas. The measured CO\(_2\) levels off during the phase represented by C-D, which is often referred to as the alveolar plateau (phase III). This represents expired gas emanating mainly from the alveoli toward the end of exhalation. The ETCO\(_2\) (the maximum measured CO\(_2\) concentration) is reached at point D, which is represented on the monitor as a numerical value and is denoted by a dot on the waveform in Figure 3. Normal ETCO\(_2\) is 38 mm Hg at sea level, although for clinical purposes, an acceptable ETCO\(_2\) range is between 35 and 45 mm Hg.\(^6\) The amount of exhaled CO\(_2\) detected decreases quickly in segment D-E (phase IV), which represents inhalation. The waveform returns to baseline, another exhalation is initiated, and the cycle continues.

Aberrations from the normal shape and height of the waveform can provide important and useful information about a patient’s respiratory mechanics and physiologic state. For instance, the Q-angle is the angle formed by the linear representations of phase II and phase III (the alveolar plateau). A widening of the Q-angle, due to an upward-sloping segment C-D may indicate the presence of lower airway obstruction or bronchospasm. Changes in the Q-angle and other departures from the normal shape of the waveform will be described in more detail in subsequent sections of this review.

Critical Appraisal Of The Literature

While capnography was pioneered and principally used by anesthesiologists to monitor intubated patients during general anesthesia, there have been growing numbers of clinical applications evident in the literature. A PubMed search for the terms capnography, capnometry, end-tidal carbon dioxide, and colorimetric capnography yielded 5127 articles dating back to 1950. Since the 1980s, there has been a steady increase in the number of articles pertaining to capnography, averaging between 160 and 215 published articles per year in the last decade. Capnography is now used in emergency medicine, critical care, gastroenterology, and other specialties, with new indications frequently arising. Furthermore, many professional societies and policy statements recommend or mandate its use for specific clinical indications.\(^8\)-\(^{18}\)

Applications Of Capnography

Endotracheal Tube Placement Confirmation

Subjective And Qualitative Confirmation Measures

While direct visualization of the ETT passing through the vocal cords is considered one of the most reliable indicators of a properly placed ETT, it is not completely dependable. The ETT can become dislodged after the removal of the laryngoscope, with repositioning of the patient, or if the ETT is not immediately and sufficiently secured.\(^9\) Cases of esophageal intubation have been reported even when the operator was certain that the ETT passed through the vocal cords.\(^{20,21}\) Auscultation and visualization of chest rise and of vapor in the ETT are all subjective measures and can be falsely reassuring; esophageal intubation can result in some chest rise, and air in the esophagus can produce sounds that are misleading.\(^{19,22-25}\) One study noted that auscultation of breath sounds in the axillae were appreciated in 15% of cases where the ETT was placed in the esophagus.\(^{22,26}\) Because CO\(_2\) is present in the trachea on exhalation and is not present (to an appreciable extent) in the esophagus, capnography is an excellent and objective measure of successful ETT placement.

Colorimetric ETCO\(_2\) detectors are simple and commonly used in prehospital intubation and emergency settings to quickly confirm tracheal placement of an ETT. Small and portable, the single-use colorimetric ETCO\(_2\) detector contains a pH-sensitive disc that changes color from purple to bright yellow in the presence of a concentration of CO\(_2\) > 2.0% (15 mm Hg). (See Figure 4.) Below 0.3% CO\(_2\), the device will remain purple, but it may show subtle color change (beige) in concentrations between 0.5% and 1.0%.\(^{27}\) Nonetheless, these detectors are a qualitative measure of the presence of CO\(_2\) gas, and they give no information about the effectiveness of ventilation. While very useful in confirming endotracheal intubation, they are less reliable when the ETT is incorrectly placed in the esophagus or during cardiac

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**Figure 3. Normal Carbon Dioxide Waveform On Capnography**

To view a full-color version of this photo, go to: www.ebmedicine.net/Capnographyimages

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arrest.\textsuperscript{28} Interestingly, ingestion of a carbonated beverage – even as little as 2 ounces – prior to intubation has been shown to cause false-positive results with colorimetric detectors when the ETT was actually in the esophagus.\textsuperscript{29}

**Quantitative Confirmation Measures**

Quantitative CO\textsubscript{2} measurement (capnometry) and capnography are excellent methods to confirm proper ETT placement. A properly placed ETT should reveal a characteristic waveform that would not be present in an esophageal intubation. There is concern that a patient in cardiac arrest may have a properly placed ETT removed by a clinician who has been misled by an extremely low capnography reading; however, current devices are so sensitive that a subtle waveform may detect residual CO\textsubscript{2} in the trachea, signaling a properly placed tube.\textsuperscript{30} In 1 study comparing auscultation to capnography in a prehospital setting, capnography was found to be extremely sensitive and specific for proper placement of ETTs, even in cases of cardiac arrest.\textsuperscript{31} Capnography is also faster and more reliable than pulse oximetry in detecting proper ETT placement in the setting of preoxygenation of the patient prior to intubation.\textsuperscript{32,33} The American Society of Anesthesiologists considers capnography (by infrared or mass spectrometry technology) to be the accepted standard of care in confirmation of ETT placement, and multiple professional organizations also recommend the use of capnography for this purpose.\textsuperscript{8,9,11,15,34}

**Maintenance Of Endotracheal Intubation**

Once endotracheal intubation has been established, it is important for the emergency clinician to ensure that the ETT is properly secured and to monitor that the ETT – the patient’s critical airway – remains in place. Dislodgement of the ETT can occur due to movement by the patient, copious secretions, or the handling of the patient by healthcare providers. In children, even slight movements of the head can cause the ETT to become displaced into the hypopharynx due to the short distance between the vocal cords and the carina. Unrecognized ETT displacement can be catastrophic for the patient. The issue of ETT dislodgment is important for prehospital providers, who move intubated patients multiple times during transport and must monitor patients in noisy and chaotic conditions. Indicators of ETT dislodgment can include clinical findings such as loss of chest rise or decreased or unequal breath sounds over the lung fields. Dropping oxygen saturation (as indicated by pulse oximetry) can also be a clue that the ETT is clogged or has moved out of the trachea. However, clinical findings are subjective, not continuously measured, and may not always be reliable.\textsuperscript{21,35} While pulse oximetry is objective, it may take several minutes for the monitor to indicate a change in value.\textsuperscript{32,33} Furthermore, most intubated patients receive supplemental oxygen, and in this situation, it may take up to 4 minutes for the pulse oximeter to begin to demonstrate a decline in oxygenation.\textsuperscript{35,36}

In contrast, continuous ETCO\textsubscript{2} monitoring can display both numerically and graphically the adequacy of ventilation, and it can detect ETT obstruction or dislodgement in seconds.\textsuperscript{36} The rapid loss of the capnography waveform or a drop in the numerical value of the ETCO\textsubscript{2} to a very low number (or to zero) can be indicative of ineffective ventilation that is due to a dislodged ETT or ventilator disconnection. In studies using simulated patients, hospital clinicians and prehospital personnel were able to quickly detect ETT dislodgement prior to changes in pulse oximetry.\textsuperscript{37,38} Silvestri et al showed that the rate of unrecognized misplaced intubations among paramedics transporting intubated patients using continuous ETCO\textsubscript{2} monitoring was 0% (95% confidence interval [CI], 0%, 4.0%) as compared to 23% (95% CI, 13.4%, 36%) among those who did not use the device.\textsuperscript{39} The American Society of Anesthesiology was the first organization to include a recommendation for the use of continuous ETCO\textsubscript{2} monitoring for the entire course of intubation in their official professional policy statement on basic anesthesia monitoring.\textsuperscript{11} Currently, the American Heart Association guidelines for both adult and pediatric life support recommend the use of ETCO\textsubscript{2} to continuously monitor the position of an ETT, and the use of capnography in intensive care units and emergency departments (EDs) is now considered invaluable in identifying early dislodgement of an ETT.\textsuperscript{9,40}

**Figure 4. Colorimetric Carbon Dioxide Detector**

![Colorimetric Carbon Dioxide Detector](www.ebmedicine.net/Capnographyimages)
Maintenance Of Normal Ventilation
Prior to capnography, in order to determine the adequacy of ventilation in a spontaneously breathing or mechanically ventilated patient, blood gas sampling was required to measure the partial pressure of carbon dioxide in arterial blood (\(\text{PaCO}_2\)). While \(\text{ETCO}_2\) cannot measure \(\text{PaCO}_2\), the measure of \(\text{ETCO}_2\) by infrared spectroscopy has been shown to provide an accurate estimation of \(\text{PaCO}_2\) in children with and without respiratory disease.\(^{41,42}\) Capnography gives a noninvasive continuous visual indication of the patient’s ventilatory status without the need to draw blood samples or wait for results. Changes in \(\text{ETCO}_2\) values can signal the emergency clinician that the patient is not being ventilated appropriately, prompting immediate changes in ventilator settings. Loss of the \(\text{CO}_2\) waveform can indicate that the patient is apneic, or it can signal the emergency clinician to a possible disconnection or equipment problem in the ventilatory circuit.

Capnography can be invaluable to healthcare providers in maintaining normal ventilation during the transport of intubated patients. Studies have shown that these patients are often unintentionally hypoventilated or hyperventilated.\(^{43-46}\) Two studies involving prehospital transport of intubated trauma patients showed that providers who had access to capnography monitoring were significantly more likely to normoventilate their patients compared to providers who did not.\(^{43,44}\) In the 2004 prospective study of 420 patients by Davis et al, paramedics who had access to \(\text{ETCO}_2\) monitoring had a lower incidence of severe hyperventilation of head-injured intubated patients than those who did not have access to capnography (odds ratio [OR], 2.64; 95% CI, 1.12-6.20). Severe hyperventilation may lead to decreased cerebral perfusion, and this study revealed that patients in both groups who were severely hyperventilated had a higher mortality rate (OR, 2.9; 95% CI, 1.3-6.6).\(^{43}\) The 2003 randomized controlled study of 97 patients by Helm et al (which was carried out in the United Kingdom, where anesthetists are included on the transport team) compared transport anesthetists who did not have access to capnography (versus those who did have capnography monitoring available. The incidence of normal ventilation (determined by the \(\text{PaCO}_2\) on arterial blood gas upon arrival at the hospital) was significantly higher (63.2% vs 20%, \(P < 0.0001\)) and the incidence of hypoventilation was significantly lower (5.2% vs 37.5%, \(P < 0.0001\)) in patients cared for by the anesthetists who could see the \(\text{PaCO}_2\) monitor compared to those who could not.\(^{44}\)

Use Of Capnography In Cardiopulmonary Resuscitation
The presence of \(\text{CO}_2\) in expired air is dependent on ventilation at the level of the alveoli as well as the delivery of blood to the pulmonary vasculature. \(\text{ETCO}_2\) is, therefore, affected by both of these variables. If perfusion of the lungs is maintained at a constant rate and there is no disease process affecting the diffusion of \(\text{CO}_2\) at the level of the alveoli, \(\text{ETCO}_2\) will reflect changes in \(\text{CO}_2\) production: an increase in \(\text{ETCO}_2\) will indicate hyperventilation, and a decrease can indicate either hyperventilation or hyperventilation.\(^{47}\) In the case of cardiac arrest, pulmonary perfusion will be decreased due to lack of cardiac output, and the \(\text{ETCO}_2\) will drop abruptly. The relationship between \(\text{ETCO}_2\) and cardiac output has been demonstrated in both animal and human models, all of which indicate that a drop in cardiac output corresponds to a drop in the \(\text{ETCO}_2\) concentration.\(^{47-52}\)

Endotracheal Tube Placement Confirmation In Cardiorespiratory Arrest
Studies using animal models and humans indicate that cardiac arrest patients will have low \(\text{ETCO}_2\) readings even when tracheally intubated.\(^{47,49,50}\) Using a canine model, Sayah et al found that, when an ETT was properly placed in the trachea during cardiac arrest, a characteristic waveform was noted immediately (within 1 breath), whereas dogs esophageally intubated had no recognizable waveform on capnography.\(^{53}\) In a study by Grmec, intubation by prehospital providers was evaluated by both capnometry (the \(\text{ETCO}_2\) numerical reading in mm Hg with no visible waveform) and capnography. Infrared capnography technology was used to measure both. When intubating patients in cardiac arrest, capnometry was 88% sensitive and 100% specific in determining tracheal placement of ETTs, and it was accurate at an \(\text{ETCO}_2\) level > 5 mm Hg after 7 breaths. In the same study, waveform capnography provided immediate data and was 100% sensitive and specific in determining proper ETT placement in patients in cardiac arrest.\(^{31}\) The 2010 American Heart Association guidelines for CPR now recommend quantitative waveform capnography to confirm ETT placement.\(^{39}\) A flat tracing on capnography monitoring during ongoing CPR should alert the healthcare team that the tracheal tube may be misplaced.\(^{31,49,54}\)

Assessment Of Efficacy Of Cardiopulmonary Resuscitation
Palpation of central pulses produced during CPR was historically used as a subjective measure of the adequacy of chest compressions. As early as the 1970s, Kalenda searched for a more objective measure of pulmonary and systemic perfusion and subsequently described the use of capnography to monitor and guide the effectiveness of resuscitation by cardiac massage.\(^{55}\) If ventilation is maintained relatively constant during CPR, \(\text{ETCO}_2\) should cor-
relate well with cardiac output, and a waveform should be displayed on the capnography tracing. A study by Ward et al compared a mechanical chest compressor to compressions provided manually and found that ETCO₂ tracings could be a useful objective measure to indicate effectiveness of compressions as well as signs of human compressor fatigue. (See Figure 5.) After measuring ETCO₂ in adult patients immediately after cardiac arrest and during CPR, Falk et al concluded that capnography can provide a quantitative measure of the volume of blood flow that is being generated by compressions and that ETCO₂ is a reliable and noninvasive way to measure the effectiveness of CPR. Throughout the 1980s and early 1990s, numerous studies in animals and humans confirmed this correlation between ETCO₂ and cardiac output during CPR, supporting Falk’s conclusion. Twenty years later, the 2010 American Heart Association guidelines recommend the use of capnography to monitor and optimize the effectiveness of chest compressions.

**Detection Of Return Of Spontaneous Circulation**

Capnography used during CPR has also been shown to be a very sensitive indicator of the return of spontaneous circulation (ROSC) in successful resuscitation. (See Figure 6.) Using a porcine model, studies by Trevino et al and Gudipati et al found striking increases in ETCO₂ levels in animals that responded to CPR. The ETCO₂ in animals who had ROSC was nearly double the value of the ETCO₂ readings in the animals that did not respond to resuscitation, and, in many cases, the ETCO₂ in animals with ROSC returned to prearrest levels. Human studies by Garnett et al and Falk et al had similar findings. ROSC was heralded by an almost immediate increase in ETCO₂, and it was the first clinical indication that ROSC had occurred. ETCO₂ has been shown to correlate with increases in measured coronary and cerebral perfusion pressure during CPR, and research suggests that a sustained waveform at a normal or higher-than-normal ETCO₂ level during CPR is a signal that ROSC has occurred and cardiac compressions may be stopped. Further, monitoring ongoing CPR with capnography may obviate the need to periodically stop compressions to check for pulses, as the sustained rise in ETCO₂ will indicate when ROSC has occurred.

There are numerous studies that have evaluated the prognostic value of ETCO₂ values in cardiac arrest and successful resuscitation in adults. Many studies suggest that adult patients who experience ROSC after cardiac arrest have higher initial ETCO₂ values at the onset of CPR than those who do not. Some studies indicated that adults with average ETCO₂ levels ≤ 10 mm Hg during CPR would not survive their arrest. Cantineau et al studied 120 adult patients presenting with asystole and found that an ETCO₂ > 10 mm Hg had 100% sensitivity and 67% specificity for predicting ROSC (P < .05), whether it was the initial value or the maximal value reached during CPR. A prospective cohort study of 55 adults with prehospital arrest indicated that an initial ETCO₂ of 15 mm Hg predicted ROSC with both a positive and negative predictive value of 91%. A prospective study of survival in 150 adult victims of out-of-hospital cardiac arrest suggested 100% mortality in patients whose ETCO₂ did not rise above 10 mm Hg within 20 minutes of CPR. A mathematical modeling study that tried to correlate real-time ETCO₂ data with outcomes of resuscitation in 30 patients with cardiac arrest indicated that a maximum ETCO₂ value > 20 mm Hg at any time between 5 and 10 minutes of CPR is likely to predict ROSC, with a sensitivity of 88% and a specificity of 77% (P < .001).

There is some debate as to whether these prognostic values can be extended for use in determining the chances of ROSC and a correlation with mortality in pediatric patients presenting in arrest. While cardiac arrest in adult patients is most often due to cardiac causes (such as ventricular fibrillation), pediatric patients are more likely to arrest secondary to respiratory failure. In contrast to arrest secondary to cardiac causes, it has been shown that cardiac arrest caused by asphyxia (a pediatric model) may initially cause a very elevated ETCO₂. This is likely due to a brief period of continued cardiac activity prior to arrest and exhaled CO₂ that is still present due to lack

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**Figure 5. Capnogram Trend During Cardiopulmonary Resuscitation**

Capnogram demonstrates the effect of rescuer fatigue (point A) and changing to a fresh rescuer (point B) to perform chest compressions.

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**Figure 6. Capnogram Trend Indicating Return Of Spontaneous Circulation**

During cardiopulmonary resuscitation, an abrupt rise in ETCO₂ to normal or greater-than-normal levels indicates improved cardiac output and ROSC.
of ventilation and delayed “washout” of CO₂ from the alveoli. \(^6\, ^6\) An animal study by Berg et al indicated that the measured ETCO₂ in piglets with asphyxial arrest was significantly higher than that of piglets with arrest due to ventricular fibrillation: 91 ± 20 mm Hg versus 34 ± 14 mm Hg. \(^6\, ^6\) Grmec et al studied 155 human adult patients in arrest and confirmed that the initial ETCO₂ is significantly higher in patients who experience cardiac arrest secondary to asphyxia than in patients with cardiac arrest due to ventricular fibrillation. \(^6\, ^7\) While all the patients in this study who experienced ROSC during CPR had an initial ETCO₂ > 10 mm Hg, there was no difference in the initial ETCO₂ value of asphyxia patients with and without ROSC. \(^6\, ^7\) However, a later study by the same researchers found that, while patients with asphyxia had higher ETCO₂ in the first 2 minutes of CPR, after the fifth minute of CPR, an ETCO₂ value of 10 mm Hg was prognostic of ROSC in both asphyxia and primary cardiac arrest patients. \(^6\, ^8\)

In summary, capnography can be a sensitive indicator of ROSC in a successful resuscitation, but using an ETCO₂ value as a prognostic indicator for successful resuscitation remains controversial.

### Applications Of Capnography In The Nonintubated Patient

Respiratory depression or hypoventilation occurs when the alveoli do not receive adequate ventilation due to a reduction in minute ventilation. This can lead to a buildup of CO₂ in the body. Unlike other monitors of respiration or physical examination findings, capnography can detect and differentiate between types of hypoventilation that can occur. In the case of apnea, where the patient ceases to make any respiratory effort, there will be a sudden cessation (or flat-lining) of the capnography waveform, and ETCO₂ values fall to zero.

#### Bradypneic Hypoventilation

Bradypneic hypoventilation develops when a patient’s respiratory rate falls below the normal range and is depressed proportionally greater than tidal volume. While the normal range for respiratory rate varies by age, the emergency clinician may follow trends in respiratory rate during procedural sedation. During bradypneic hypoventilation, ETCO₂ values slowly rise to > 50 mm Hg, as alveoli are still being ventilated with each breath and CO₂ builds within the body. With capnography, the emergency clinician may note both the rising ETCO₂ level and a heightened amplitude of the waveform.

### Hypopneic Hypoventilation

Hypopneic hypoventilation occurs when the patient has a decline in tidal volume proportionally greater than respiratory rate. During hypopneic hypoventilation, ETCO₂ values decline to < 30 mm Hg due to an increasing proportion of dead space ventilation as tidal volume declines. Since a larger proportion of the patient’s ventilation is now coming from dead space volume, the ETCO₂ values will decrease while the arterial CO₂ concentrations will rise. In this circumstance, the capnography monitor will demonstrate decreased amplitude of the waveforms and a decline in the ETCO₂ value while the overall rate remains the same. While bradypnea and apnea can be observed by changes in respiratory rate, physical examination or respiratory monitors do not easily detect hypopneic hypoventilation, and clinicians often do not detect this type of altered ventilation. \(^6\, ^9\) These findings are summarized in Table 1.

### Procedural Sedation

Children are commonly seen in the ED for injuries such as minor head trauma, lacerations, and fractures. In order to best complete diagnostic and therapeutic procedures needed for these patients, medications that provide anxiolysis and pain relief are often necessary. This is commonly known as moderate sedation or procedural sedation and analgesia (PSA), a drug-induced depression of consciousness during which patients respond purposefully to verbal commands. PSA is commonly administered by nonanesthesiologists in pediatric EDs. \(^7\, ^2\) While PSA is relatively safe, hypventilation and hypoxia may occur and threaten the safety of patients.

It is important to remember that ventilation is separate from oxygenation, in that ventilation

| Table 1. Summary Of Ventilation Patterns In Nonintubated Patients\(^7\) |
|------------------|------------------|------------------|------------------|------------------|------------------|
| Type of Ventilation             | Respiratory Rate | Tidal Volume | ETCO₂ (mm Hg) | Capnography Waveform | Arterial CO₂ |
| Normal ventilation             | Normal           | Normal        | Normal (35-45)  | Normal, square     | Normal         |
| Apnea                          | Absent           | Absent        | Absent (0)      | Flat-line          | Elevated      |
| Bradypneic hypoventilation     | Low              | Normal        | High (> 50)     | Increased amplitude | Elevated      |
| Hypopneic hypoventilation      | Normal           | Low           | Low (< 30)      | Decreased amplitude | Elevated      |

Abbreviations: CO₂, carbon dioxide; ETCO₂, end-tidal carbon dioxide monitoring.
involves the adequacy of respiratory effort and oxygenation involves the concentration of oxygen being delivered to the lungs and bodily tissues. These processes are monitored in different ways, and one process can be abnormal without abnormalities of the other. This is particularly important to recall when supplemental oxygen is being provided during PSA. A study by Fu et al demonstrated that pulse oximetry could not reliably detect respiratory depression in the presence of even low levels of supplemental oxygen.\(^\text{74}\) In this study, only 1 of 20 adult patients receiving supplemental oxygen experienced a decline in pulse oximetry < 90% during 10 minutes of deliberate hypventilation compared to immediate changes in the pulse oximetry of 25 patients maintained on room air.\(^\text{74}\) Even with patients on room air, the detection of apnea or hypventilation can be significantly delayed when determined by pulse oximetry alone.\(^\text{75}\) Evidence derived from computer modeling, animal models, and human studies indicate that when a subject experiences inadequate oxygenation, ventilation, or apnea, the onset of desaturation (as measured by pulse oximetry) can vary greatly and may be delayed up to 3 minutes.\(^\text{35,36,76-79}\) Unlike with pulse oximetry, there is no delay between the changes in the patient’s ventilation and the detection of that change by capnography, which can indicate a change within 1 breath.

During PSA, hypoxia typically develops secondary to hypventilation or apnea.\(^\text{73,80-83}\) The observational study by Langhan et al of 58 children receiving ketamine revealed that half of the patients experienced hypopneic hypventilation, and when this hypventilation lasted > 30 seconds, patients were more likely to have oxygen desaturations (relative risk [RR], 6.6; 95% CI, 1.4-30.5).\(^\text{70}\) Of the 58 patients in this study, 50% had ETCO\(_2\) values < 30 mm Hg without a rise in respiratory rate (at least transiently), while only 28% had pulse oximetry < 95%. Low ETCO\(_2\) occurred, on average, 3.7 minutes prior to hypoxemia.\(^\text{79}\) Although a 2010 randomized controlled trial of 63 adult patients undergoing PSA did not find any association between abnormal capnography values and hypoxia, this study failed to take into account the low ETCO\(_2\) values indicative of hypopneic hypventilation that appear to be more common among sedated patients.\(^\text{84}\)

Oxygen desaturation has been reported to occur in up to 75% of ED patients undergoing sedation.\(^\text{73,85,86}\) The harm of transient decreases in oxygen saturation are unclear in children.\(^\text{87}\) Both chronic and intermittent hypoxia have been reported to adversely affect development, behavior, and academic achievement in childhood.\(^\text{88}\) More importantly, mild hypoxemia (pulse oximetry < 95% for > 60 sec) has been reported to precede more serious adverse events.\(^\text{89,90}\) Hypoxemia secondary to depressed respiratory activity is a principal risk factor for near misses and death.\(^\text{82,83}\) Since children have a smaller functional residual capacity and higher metabolic demands than adults, they can decompensate faster when subject to respiratory depression. When uncorrected, hypoventilation and apnea can lead to cardiopulmonary arrest in children.

While there still remains controversy about the use of capnography during procedural sedation, there is increasing evidence regarding its benefits.\(^\text{87}\) Capnography provides a superior measure of ventilation and has consistently been shown to detect subclinical respiratory depression during PSA in both children and adults.\(^\text{26,80,81,85,91-95}\) In a meta-analysis by Waugh, respiratory depression was 17.6 times more likely to be detected when capnography was used during PSA (95% CI, 2.5, 122).\(^\text{94}\) More alarmingly, both Lightdale et al and Soto et al found that the capnography monitor detected apnea in 25% and 26% of patients (respectively) undergoing sedation or anesthesia, whereas the staff noted none of these events.\(^\text{70,95}\)

Since capnography can alert an emergency clinician to an airway or respiratory problem within 1 breath, it allows clinicians to intervene earlier, and several studies have demonstrated a reduction in the number of episodes of hypoxia occurring during PSA.\(^\text{69-71,96,97}\) In the Lightdale study, a randomized controlled trial of 163 pediatric patients undergoing sedation for endoscopy, noted that rates of hypoxia dropped from 24% to 11% when capnography was used.\(^\text{70}\) Similarly, in an adult ED population undergoing propofol sedation, rates of hypoxia decreased by 17% in the capnography group (95% CI, 1.3%, 33%).\(^\text{92}\) While respiratory depression is a risk during PSA, one must also consider this risk when administering opioid analgesia alone. This is a crucial issue not only for ED staff, but for prehospital personnel as well.\(^\text{98-100}\)

**Current Guidelines For Monitoring Patients During Sedation**

Since the more-serious adverse events during PSA are rare and the long-term implications of hypoxia are unclear, the actual benefits of using capnography to avert these events has yet to be described.\(^\text{87}\) Clinical practice guidelines for the monitoring and safe practice of moderate sedation vary by specialty and by institution. While anesthesiologists consider capnography essential in the monitoring of their patients, it has not been routinely applied outside the operating room. Although current guidelines do not require the use of capnography to monitor patients receiving sedation, they do suggest that it be considered.\(^\text{13,14,101,102}\)
Clinical Pathway For Capnography In The Emergency Department

Ill or injured child in emergency department

Requires intubation or CPR?

Requires moderate sedation for diagnostic or therapeutic reasons?

Patient has asthma exacerbation or metabolic disturbance

Immediate capnography placement

Monitor for correct placement of ETT (Class II) and effective CPR (Class II)

Establish standard-of-care monitoring as dictated by institution

Consider capnography as an additional adjunct and a more sensitive monitor of ventilation (Class II)

Consider capnography as adjunctive monitor (Class III)

Class Of Evidence Definitions

Each action in the clinical pathway section of Pediatric Emergency Medicine Practice receives a score based on the following definitions.

**Class I**
- Always acceptable, safe
- Definitely useful
- Proven in both efficacy and effectiveness

*Level of Evidence:*
- One or more large prospective studies are present (with rare exceptions)
- High-quality meta-analyses
- Study results consistently positive and compelling

**Class II**
- Safe, acceptable
- Probably useful
- Level of Evidence:
  - Generally higher levels of evidence
  - Non-randomized or retrospective studies: historic, cohort, or case control studies
  - Less robust randomized controlled trials
  - Results consistently positive

**Class III**
- May be acceptable
- Possibly useful
- Considered optional or alternative treatments
- Level of Evidence:
  - Generally lower or intermediate levels of evidence
  - Case series, animal studies, consensus panels
  - Occasionally positive results

**Indeterminate**
- Continuing area of research
- No recommendations until further research
- Level of Evidence:
  - Evidence not available
  - Higher studies in progress
  - Results inconsistent, contradictory
  - Results not compelling


Abbreviations: CPR, cardiopulmonary resuscitation; ETT, endotracheal tube.
Other Applications Of Capnography

Applications In Altered Mental Status And Seizures
There is a scant amount of literature on the use of capnography for nonintubated patients with altered mental status. Emergency clinicians can apply the same concepts discussed for patients undergoing PSA to these populations, since respiratory depression is the central concern. Abnormal ETCO2 levels have been reported in patients with altered mental status secondary to alcohol intoxication, opioid intoxication, drug overdose, head trauma, and seizures. Capnography has been used to monitor response to treatment (either improvement of respiratory status due to administration of drug antagonists or worsening of respiratory status due to treatment with medications that may cause respiratory depression), to monitor changes in mental status, and as a decision-making tool for more aggressive airway support. Abramo et al noted that hyperventilation and hypercapnea were masked in seizing pediatric patients who received supplemental oxygen. Whereas the Glasgow Coma Scale (GCS) is a validated tool for trauma patients, low scores do not always predict the need to intubate patients with altered mental status from medical causes. Thus, capnography may be a useful adjunct to monitor ventilation and airway patency and to guide the need for airway interventions in patients with altered mental status.

Applications In Lower Airway Disease

Asthma
Capnography was first studied in pediatric respiratory disease in the 1990s. One of the first goals of pediatric emergency clinicians was to assess the accuracy of ETCO2 values compared to arterial, venous, and capillary CO2 values in children with conditions such as asthma, croup, and pneumonia. While studies in both adults and children demonstrate an excellent correlation between these measurements, with differences of 1 to 4 mm Hg, on average, (similar to patients without lung disease), many of these studies lacked inclusion of severely ill children.

Measurement Of Airway Obstruction
Capnography is an attractive tool for monitoring respiratory disease, as current measures of asthma severity have limitations in function, reliability, and availability. Clinical scoring systems, spirometry, peak flow measurements, respiratory resistance measures, and measurements of exhaled nitric oxide are all in an emergency clinician’s armamentarium, but they all have limitations. There are over 20 clinical scoring systems in the literature.

Since capnography is independent of effort, it can be used on all patients, regardless of their age or the severity of their disease. In this regard, capnography offers a significant advantage over pulmonary function testing and peak flow meters, which are dependent on effort, are noncontinuous, and are difficult to interpret. Unlike other devices that provide objective measurements of airway obstruction, capnography has a variety of indications for patients in the ED, and it should be available in the majority of these units.

In the setting of bronchospasm or acute asthma, changes in the slope and the Q-angle of the capnography waveform are typically seen and are known as a “shark fin” pattern. As the lower airway obstruction becomes increasingly severe, the slope of the capnogram becomes increasingly steep. It loses its typically square appearance, the alveolar plateau slopes upward, and the Q-angle widens. (See Figure 7.) Overall, the data on the utility of the capnograph or capnometry in bronchospasm have been mixed. Yaron et al noted a significant correlation between the slope of the plateau phase in the capnograph and the log of the percent predicted peak expiratory flow among adults with asthma in the ED (r = .84, P < .001). A comparative study of 40 patients looked at a variety of capnographic indices, all of which were highly correlated with percent predicted peak expiratory flow and forced expiratory volume in 1 second (FEV1) (r = 0.73-0.93). On the other hand, both a smaller study of 12 children and a larger study of 100 adolescents and adults showed no correlation between the slope of the alveolar plateau or the Q-angle and other objective measures of asthma such as FEV1, peak expiratory flow, or clinical scores. Nonetheless, all but 1 of these studies demonstrated significant changes in the slope of the plateau and the Q-angle following beta-agonist treatment, indicating clinical improvement.

One must consider, however, that these waveform analyses cannot be quickly or easily quantified.

Figure 7. Shape Of Capnograph In Obstructive Lower Airway Disease

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in an ED setting, and there have been no advances in the technology to display these alternative measurements. To that end, 2 studies have evaluated using quantitative ETCO2 measures in assessment of asthma severity. Both studies were performed in children in ED settings, and both noted lower ETCO2 values in patients who were admitted to the hospital.124,134 One study of 86 children with acute exacerbations of asthma determined that ETCO2 measured after the first and after the final bronchodilator treatments were significantly associated with both the number of bronchodilator treatments received and the clinical severity score. More specifically, ETCO2 was significantly lower in patients receiving greater numbers of bronchodilator treatments and with a higher clinical severity score.124 Although the number of bronchodilator treatments is an atypical marker of severity, this may indicate that ETCO2 can be used as an effort-independent marker of bronchoconstriction. The other study, by Guthrie et al, showed no correlation between ETCO2 values and other markers of asthma severity (such as peak expiratory flow and clinical scores); however, less than half of the study patients were able to perform the peak expiratory maneuvers.134 Neither of these studies noted any significant change in ETCO2 levels in response to beta-agonist therapy, thereby limiting its use in determining response to treatment.

Bronchiolitis

Bronchiolitis is an acute respiratory illness affecting children aged ≤ 2 years that is caused by a variety of viruses. Similar to asthma, patients with bronchiolitis have been studied in the evaluation of the accuracy of capnography in acute respiratory diseases.42 However, there has only been a single published paper looking at the utility of capnometry in predicting admission among children with bronchiolitis. In this study, a single ETCO2 value and a clinical severity score were measured prior to any treatment in the ED. There was no significant difference in ETCO2 values between children who were admitted and those who were discharged or among children with low, moderate, and severe severity scores at presentation.135 The authors did not provide any information about the ability of the clinical severity score at presentation to predict admission, and no further ETCO2 measurements were made during the ED course of the patients. This single study, looking at a single point in time, cannot provide current evidence for or against using capnography as a predictor of hospitalization in children with bronchiolitis.

A potential benefit of capnography for bronchiolitis would be as a more-sensitive monitor for apnea. There are several risk factors for severe disease and apnea in bronchiolitis.126-139 (See Table 2.) Hypoxia is a driving force in admissions for bronchiolitis. As discussed previously, the use of supplemental oxygen can inhibit the detection of apnea and prolong the time to apparent desaturation with pulse oximetry.74,140 In these cases, capnography could be a useful monitor to alert providers to apnea within a single breath, allowing for interventions to occur before further deterioration of the patient’s condition. This could be particularly helpful during patient transport or in the prehospital setting, where a patient may be in an incubator, and where ambient noise and movement make detection of changes in breath sounds or chest rise difficult.141

Applications In Patients With Metabolic Derangements

While the most common applications of capnography in ED settings involve its use in monitoring cardiopulmonary parameters, there has been recent interest in the use of ETCO2 as a noninvasive measure of systemic metabolism. Barton and Wang’s study of 76 adult nonintubated patients presenting to an ED with a variety of medical conditions found not only good correlation between ETCO2 and PaCO2 (r = 0.772) but also excellent correlation between ETCO2 and the presence of metabolic acidosis (r = 0.899).142 In a recent prospective cross-sectional study using a larger population of nonintubated adult patients (n = 240), the correlation between ETCO2 and serum bicarbonate (HCO3) levels in patients with metabolic disturbance was only moderately significant (r = 0.506). However, ETCO2 was found to be a good predictive tool in identifying metabolic acidosis (defined as an HCO3 of ≤ 21 mmol/L) with an area under the curve of 0.734. At an ETCO2 ≤ 25 mm Hg, the likelihood ratio was 2.7 for identifying metabolic acidosis.143

Diabetic Ketoacidosis

Pediatric patients suffering from diabetic ketoacidosis require careful and continuous monitoring of their metabolic parameters. They are subjected to frequent and multiple venous and/or arterial blood draws, which are painful and invasive. The laboratory testing is both time-intensive and expensive, and it may cause delays in management decisions while awaiting results. Garcia et

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<th>Table 2. Risk Factors For Severe Disease And Apnea In Infants With Bronchiolitis</th>
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<td>• Prematurity (&lt; 37 wk gestational age)</td>
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<td>• Age &lt; 12 wk</td>
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<td>• Postconception age &lt; 48 wk</td>
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<td>• Witnessed episode of apnea</td>
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<td>• Underlying cardiopulmonary disease</td>
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<td>• Immunodeficiency</td>
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<td>• Chronic lung disease</td>
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<td>• Illness caused by respiratory syncytial virus</td>
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al measured ETCO₂ in 120 nonintubated diabetic ketoacidosis patients in a pediatric ED and found excellent correlation between ETCO₂ and venous PCO₂ (r = 0.92); ETCO₂ and serum pH (r = 0.88); and ETCO₂ and respiratory rate (r = -0.79). All had P values of .0001, suggesting that capnography may provide a noninvasive and accurate form of continuous monitoring for these patients.¹⁴⁴

Gastroenteritis
Serum bicarbonate measurement is often used to assist clinicians in determining the severity of dehydration in patients with fluid losses from diarrhea and vomiting. Studies of pediatric patients with acute dehydration have shown that a patient with a serum bicarbonate of > 15 to 17 mmol/L is very unlikely to have severe dehydration.¹⁴⁵,¹⁴⁶ Since the physiologic response to metabolic acidosis is respiratory compensation, ETCO₂ may provide a noninvasive method of determining the severity of dehydration in acute gastroenteritis.

Research in this area is fairly new, but a promising study by Nagler et al of pediatric patients with gastroenteritis found a strong linear correlation between ETCO₂ and serum bicarbonate levels in patients with dehydration (r = 0.80, P < .0001) that was independent of other potential clinical findings and predictors of acidosis in multivariate analysis. An ETCO₂ value of ≤ 31 mm Hg had a positive likelihood ratio of 20.4 in detecting a HCO₃⁻ ≤ 15 mmol/L, suggesting that low ETCO₂ may be useful in “ruling in” metabolic acidosis, thereby prioritizing patients who require IV hydration or possibly identifying those patients who may be at a higher risk for an underlying metabolic disorder.¹⁴⁷

Current Utilization Patterns
Although there has been a steady growth in the literature and an increasing number of applications for capnography, this monitoring device remains most consistently used by anesthesiologists. While pediatric specialists report ease of use and interpretation, capnography is not universally available or utilized for either intubated or nonintubated patients.¹⁴⁸,¹⁴⁹ In 2006, pediatric emergency medicine fellowship programs were surveyed about the availability and use of capnography in a variety of settings. While the majority of programs (88%) had capnography available for intubated patients, only 53% had it available for nonintubated patients.¹⁴⁹

Similarly, in a survey of pediatric emergency medicine physicians, respondents reported that capnography was always used for intubations, but only 54% used it for cardiopulmonary resuscitations, and 61% of respondents never used this device for monitoring during moderate sedations.¹⁴⁹ Reported use for other indications such as trauma and metabolic disturbances was also low. In 2010, a more wide-reaching survey of pediatric emergency medicine subspecialists and fellows queried their use of capnography during sedation and reported that 45% of respondents never used this monitoring device.¹⁵⁰ Most recently, data from close to 115,000 pediatric sedations in 37 institutions within the Pediatric Sedation Research Consortium showed that capnography was only being used in 45% of all sedations.¹⁵¹ Although these data stem from a very select group, it is encouraging to find that, within this report, pediatric emergency medicine physicians reported using capnography in 72% of their sedations.¹⁵¹

In the prehospital setting, the availability of capnography may be linked to regional protocols in a decentralized system. While certain emergency medical service organizations may use this device routinely, others do not use capnography at all.³⁹,¹⁵²

Cost-Effectiveness Of Capnography
There is a paucity of current studies regarding the cost-effectiveness of waveform capnography. The cost of purchase depends on the type of monitor. Units can be self-contained and lightweight hand-held models, or they can be incorporated into bedside cardiopulmonary monitors. A review article written by Ahrens et al in 1999 suggested that the cost of acquiring capnography technology was reasonable, and could be easily recaptured over time secondary to improved clinical practice.¹⁵³ Currently, capnography monitors range in price from $2000 to $5000 per unit; the equipment lasts many years and requires little maintenance.

Disposable single-use nasal/oral capnography cannulas and inline ETT connectors range in price from $10 to $16 each. This is similar to the cost of disposable pediatric pulse oximetry probes, which range from $12 to $30 each. Nasal cannulas that administer supplemental oxygen cost between $2 and $4 per item; however, some capnography cannulas not only monitor ventilation, but can also supply supplemental oxygen to the patient, if necessary. Similarly, the current cost of a colorimetric detector, which is a single-use item that can be useful in confirming endotracheal intubation, is approximately $12 to $15. These are comparable in price to the waveform capnography ETT connectors, but the colorimetric detectors lack the ability to continuously monitor ETT position, and they cannot provide information about ongoing patient ventilation. Ahrens et al suggested that the costs associated with waveform capnography are minimal in comparison to the potential cost of legal action due to the consequences of difficult or improper intubation and the cost associated with futile resuscitation efforts.¹⁵³
Summary

Advancements in capnography have led to increased use of the technology in pediatric emergency medicine as well as in many other fields. Capnography is easy to interpret and can be used to monitor both intubated and nonintubated patients. It is an excellent noninvasive, continuous, and objective measure of cardiopulmonary parameters, and new clinical applications are frequently arising in the literature. Many professional guidelines and policy statements now recommend its use, and the cost of acquiring the technology is reasonable. As capnography becomes more universally available, we expect it will become standard of care for patients of pediatric emergency medicine clinicians and other pediatric subspecialties.

Case Conclusions

As you prepared the 4-year-old patient for procedural sedation to reduce her broken arm, you noted that she was wheezing. As there were no symptoms of a concurrent upper respiratory infection, you considered reactive airway disease in this patient. She was unable to perform peak flow testing secondary to her age. You asked the nurse to give an inhaled...

Risk Management Pitfalls For Pediatric Capnography

(Continued on page 15)

1. “I confirmed placement of an ETT with a colorimetric CO₂ detector, and my patient was on continuous pulse oximetry, so ongoing capnography monitoring was unnecessary.”

While colorimetric capnography is useful to quickly confirm that an ETT is in the trachea, an ETT can become dislodged if the tube is not immediately and sufficiently secured, or if the patient moves, is repositioned, or is transported to another location. In infants and children, even slight movements of the head can cause displacement of an ETT. A displaced ETT that goes unrecognized can be catastrophic for the patient. Continuous infrared capnography can detect ETT dislodgement or obstruction in seconds, whereas pulse oximetry may take several minutes to register a decline in oxygenation. The American Heart Association guidelines for both adult and pediatric life support recommend the use of continuous capnography to monitor the position of an ETT.

2. “When providing CPR, I rely on my coworker, who is providing chest compressions, to let me know when he is getting tired and needs to switch. As long as the compressor is pushing hard and fast and is generating a palpable femoral pulse with each compression, the compressions are effective.”

Numerous studies confirm that ETCO₂ correlates with cardiac output during CPR, and capnography can provide an objective and quantitative measure of the volume of blood flow that is generated by compressions. A drop in the value of ETCO₂ on the capnogram can be indicative of compressor fatigue and the need to switch to another provider. (See Figure 5, page 7.) The 2010 American Heart Association Guidelines for CPR now recommend the use of capnography to monitor and optimize the effectiveness of chest compressions.

3. “The patient was in cardiac arrest, so the ETCO₂ was so low that capnography wouldn’t have been useful in confirming that the ETT was in the trachea.”

Current-day infrared ETCO₂ detectors are extremely sensitive and can detect residual CO₂ in the trachea and reveal a recognizable waveform to indicate the ETT is properly placed. (See Figure 6, page 7.) The 2010 American Heart Association guidelines for CPR recommend quantitative waveform capnography to confirm ETT placement in cardiac arrest.

4. “The only way to know if a cardiac arrest patient is responding to resuscitation is to stop CPR every 2 minutes to check for a pulse.”

The 2010 American Heart Association guidelines encourage the use of capnography to monitor and optimize CPR as well as to indicate ROSC. Pauses in CPR should be minimized in order to maintain perfusion pressure to essential organs. An increase in ETCO₂ noted during resuscitation indicates an increase in pulmonary blood flow. ROSC is recognized by an abrupt increase in ETCO₂ to normal or above-normal levels.

5. “The pulse oximeter said my sedated patient had an oxygen saturation of 100%, so I knew he was breathing effectively.”

While a pulse oximetry reading of 100% is reassuring to the emergency clinician because it indicates oxygen has been effectively delivered to body tissues, it does not reveal any information about how effectively the patient is ventilating. It is possible to have a pulse oximetry reading of 100% in a patient who is hypoventilating.
Pediatric patients have smaller functional residual capacity and higher metabolic demands than adults. If uncorrected, hypoventilation in a child can decompensate quickly to apnea and possibly to cardiac arrest. Continuous capnography monitoring can provide prompt (within 1 breath) objective information about changes in a patient’s ventilatory status. While not yet standard of care, many professional organizations encourage the use of waveform capnography in the monitoring of patients receiving procedural sedation.

6. "My sedated patient had an ETCO$_2$ of 20 mm Hg. That meant he was hyperventilating and I didn't need to worry about respiratory depression."

Although a high ETCO$_2$ (> 50 mm Hg) is always indicative of hypoventilation, it seems intuitive to assume that a patient who is hyperventilating will breathe down his CO$_2$ and have a low ETCO$_2$ reading; however, this is not always true. As the tidal volume declines, a greater proportion of exhaled ventilation is made up from the dead space. These patients will have a low ETCO$_2$ reading (< 30 mm Hg), and the amplitude of the waveform on capnography will be markedly reduced. Since the patient with hypopneic hypoventilation will have a normal respiratory rate, this form of hypoventilation is often undetected by emergency clinicians who do not use capnography monitoring.

7. "I knew that after a seizure, a postictal patient may hypoventilate and become hypoxic, so I kept her on continuous pulse oximetry and a nonrebreather mask to provide supplemental oxygen until she was fully awake."

Postictal patients often have decreased respiratory drive and may have disordered breathing. While it is important to monitor these patients for hypoxia and provide supplemental oxygen as necessary, pulse oximetry will not provide any clinical data about the adequacy of ventilation. Postictal patients receiving supplemental oxygen can have an oximetry reading of 100% and still have significant hypoventilation and acidosis, leading to further neurologic and respiratory compromise. Supplemental oxygen may also increase the time it takes for a pulse oximeter to register a change in respiratory status if the patient becomes apneic. Capnography is very useful as a continuous monitor of ventilation in these patients, and it can give an immediate indication of apnea or severe hypoventilation.

8. “Prehospital providers often inadvertently hyperventilate intubated pediatric patients, but in the case of this head-injured patient, it was probably okay because hyperventilation will help reduce intracranial pressure.”

Current evidence suggests that hyperventilation of head-injured patients may actually lead to decreased cerebral perfusion and ischemia and cause worse neurologic outcomes. Current professional guidelines caution against hyperventilation except in cases of impending herniation. Capnography monitoring can help the clinician in maintaining normal ventilation during resuscitative efforts of head-injured patients. Studies have shown that prehospital providers who had access to ETCO$_2$ monitoring were much more likely to maintain normoventilation in head-injured patients than those providers who did not have access to capnography.
or severe) would be to calculate total fluid losses indicated by a loss of body weight, an accurate pre-illness weight was not available. If blood could have been obtained, an electrolyte panel might have been somewhat useful in determining the degree of dehydration in this child and whether IV hydration would be necessary; however, this parent was strongly opposed to her child being subjected to further painful procedures. You told the mother that, although the evidence is fairly new, you may be able to use capnography, a noninvasive measurement of the CO₂ her child was exhaling, to indicate the severity of his dehydration. If this measured value was reassuring, he could be given an antiemetic medication by mouth and a trial of oral rehydration could be attempted, with the understanding that an IV would need to be placed later if he continued to vomit. The mother was agreeable with this plan, and you placed a capnography cannula on him. A normal-looking waveform was obtained on the monitor, and you waited for a few seconds for the ETCO₂ value to remain constant. Your patient had an ETCO₂ of 35 mm Hg, and you felt reassured that this child did not have severe metabolic acidosis. You proceeded with your antiemetic/oral rehydration plan. The child was able to take fluids orally, and his physical exam findings improved. The patient was discharged home, and the mother thanked you for considering her concerns and including her in the decision-making process for the care of her child.

As you managed the resuscitation of the teenager, you noted that the CO₂ detector that the EMT referred to uses a colorimetric method of capnography, and the presence of exhaled CO₂ should change the color indicator from purple to bright yellow. You also knew that the concentration of CO₂ must be > 2% in order to effect a bright yellow color change, so you had some concerns that the ETT may be misplaced in the esophagus. You were somewhat reassured that the EMT reported seeing the ETT pass through the vocal cords on direct laryngoscopy, but the intubation was performed in a moving vehicle, and the ET could have become dislodged prior to securing the tube. Also, the auscultation of breath sounds is not only subjective and sometimes misleading, but it may also have been masked by the noisy environment of the ambulance. You asked the nurse to attach a sidestream ETCO₂ sampling line to the ETT. A recognizable capnography waveform appeared on the monitor. (See Figure 8.) The appearance of the waveform and the ETCO₂ value of 11 mm Hg reassured you that the ET was in the trachea, and it served as an objective measure of the quality of the cardiac compressions being provided by the intern. After 6 minutes of quality CPR and 2 rounds of epinephrine given intravenously, the ETCO₂ rose to 50 mm Hg. You stopped compressions and noted a perfusing rhythm on the cardiopulmonary monitor. You called the pediatric ICU to arrange admission for this successfully resuscitated patient.

### References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study will be included in bold type following the references, where available. The most informative references cited in this paper, as determined by the author, will be noted by an asterisk (*) next to the number of the reference.

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1. Which of the following statements about capnography technology and monitoring is TRUE?
   a. All capnography monitors are heavy and impractical for use in transporting patients.
   b. Using a nasal cannula to monitor ETCO$_2$ in an unintubated patient means that no supplemental oxygen can be delivered to the patient.
   c. Newer nasal cannulas have a mouthpiece that allows more-accurate measurements of CO$_2$, even when the patient is breathing with low tidal volumes.
   d. It is not possible to measure ETCO$_2$ in a patient receiving bag-valve mask ventilations with a facemask.

2. A healthy child with normal cardiac function and normal ventilation is being monitored by sidestream capnography via nasal cannula. Which of the following statements about the capnography waveform displayed on the monitor is TRUE?
   a. The x-axis of the graphical display represents the partial pressure of expired CO$_2$.
   b. If the respiratory rate remains constant and within normal limits, ETCO$_2$ will likely range between 20 and 30 mm Hg.
   c. The rapidly upward-sloping portion of the waveform represents the patient’s inspiratory phase.
   d. The alveolar plateau represents expired gas coming from the alveoli toward the end of exhalation.
   e. The Q-angle is the angle formed by the alveolar plateau and the descending final phase of the waveform that represents inhalation.
3. A teenage victim of a hit-and-run arrives via EMS. He is tachycardic but normotensive. He seems to be maintaining his airway, but his GCS score is 6. He has obvious head trauma on examination, but his pupils are equal and reactive, and no other injury is recognized on secondary survey. You decide to intubate the patient prior to transport to the radiology suite to obtain head computed tomography. How can you use capnography to assist you in the care and monitoring of this patient?
   a. Colorimetric capnography can be used to confirm tracheal placement of the ETT.
   b. Waveform capnography can be used to confirm tracheal placement of the ETT.
   c. Continuous waveform capnography can be used to ensure that the ETT remains in place during the transport.
   d. Capnography can provide a noninvasive and continuous visual indication of the patient’s ventilatory status, which would be invaluable in maintaining normoventilation.
   e. All of the above

4. All of the following statements regarding the use of capnography in cardiac arrest and CPR are true EXCEPT:
   a. The drop in cardiac output caused by cardiac arrest will cause ETCO₂ to drop abruptly, reflecting decreased delivery of blood to the pulmonary vasculature.
   b. Quantitative waveform capnography is not recommended to confirm ETT placement in patients in cardiac arrest.
   c. ETCO₂ correlates well with cardiac output. A sustained increase in ETCO₂ to a level of 35 mm Hg or higher on continuous waveform capnography indicates ROSC.
   d. Capnography can be used as an objective measure of the effectiveness of cardiac compressions during CPR.

5. Which of the following types of ventilation patterns are correctly matched with the corresponding changes in vital signs and capnography findings for a 6-year-old boy weighing 20 kg?
   a. A respiratory rate of 10 breaths/min, a tidal volume of 150 mL, and an ETCO₂ of 55 mm Hg could represent bradypneic hypoventilation.
   b. A respiratory rate of 10 breaths/min, a tidal volume of 150 mL, and an ETCO₂ of 30 mm Hg could represent bradypneic hypoventilation.
   c. A respiratory rate of 5 breaths/min, a tidal volume of 10 mL, and an ETCO₂ of 80 mm Hg could represent apnea.
   d. A respiratory rate of 10 breaths/min, a tidal volume of 150 mL, and an ETCO₂ of 30 mm Hg could represent bradypneic hypoventilation.

6. You are providing procedural sedation to a 5-year-old patient. You are monitoring the patient using a cardiopulmonary monitor, a continuous pulse oximeter, and waveform capnography. Ten minutes into the sedation, you note that the patient’s respiratory rate is approximately 10 breaths/sec, and you see the following waveform on the display:

   ![Waveform Image]

   How would you describe the current state of ventilation in this patient?
   a. The patient is hypoxic.
   b. The patient is hypoventilating.
   c. The patient is hyperventilating.
   d. The patient is hypocapneic.

7. You are preparing to provide procedural sedation to a patient who requires a painful procedure. You ask the nurse to place a capnography cannula on the patient so that you can continuously monitor the patient’s ETCO₂. This nurse is new to your facility and says that she never used capnography in the hospital where she previously worked. She asks why you need capnography monitoring when the patient has a continuous pulse oximeter in place. What will you tell her?
   a. While pulse oximetry will help you to monitor the patient’s oxygenation, it will not give you any objective information about the adequacy of the patient’s ventilation.
   b. If the patient is not adequately oxygenating or becomes apneic, pulse oximetry may not reflect the change for several minutes, whereas capnography can provide that information within 1 breath.
   c. While bradypnea and apnea can be observed by physical examination changes and a decreasing respiratory rate, altered ventilation caused by hypopneic hypoventilation (small tidal volume in the
setting of a normal respiratory rate) is very hard to appreciate without capnography.

d. While clinical practice guidelines for monitoring and safe practice of moderate sedation vary by specialty and institution, many professional societies and policy statements recognize the increasing evidence on the benefits of capnography and recommend its use for procedural sedation in the ED setting.
e. All of the above

8. The clinical applications for which capnography is currently being used in emergency medicine include its use in confirming intubation, maintaining normoventilation in intubated and nonintubated patients, and confirming successful resuscitation efforts in CPR. Which of the other clinical applications described in this review has been recommended by many professional guidelines for use in the ED setting?
   a. Monitoring patients with altered mental status secondary to intoxication or seizure
   b. Monitoring patients with bronchospasm and reactive airway disease
   c. Monitoring patients receiving procedural sedation and analgesia
   d. Monitoring patients with diabetic ketoacidosis

9. A 2-year old child who was diagnosed with acute gastroenteritis 3 days ago presents to the ED with continued vomiting and diarrhea. Her mother reports decreased urine output and fears that her child may be severely dehydrated. The child looks clinically well and has a capillary refill of < 2 seconds. You place a capnography nasal cannula on the child and obtain an ETCO₂ of 38 mm Hg. Which of the following statements is TRUE?
   a. The patient needs immediate IV hydration.
   b. The patient most likely has a serum bicarbonate of < 15 mmol/L.
   c. The patient likely has an underlying metabolic disorder.
   d. The patient is unlikely to be severely dehydrated, and oral rehydration can be attempted.
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Goals: Upon completion of this activity, you should be able to: (1) demonstrate medical decision-making based on the strongest clinical evidence; (2) cost-effectively diagnose and treat the most critical ED presentations; and (3) describe the most common medicolegal pitfalls for each topic covered.

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