

Capnography for the Nonintubated Patient in the Emergency Setting

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Abstract and Introduction

Abstract

Background Multiple studies illustrate the benefits of waveform capnography in the nonintubated patient. This type of monitoring is routinely used by anesthesia providers to recognize ventilation issues. Its role in the administration of deep sedation is well defined. Prehospital providers embrace the ease and benefit of monitoring capnography. Currently, few community-based emergency physicians utilize capnography with the nonintubated patient.

Objective This article will identify clinical areas where monitoring end-tidal carbon dioxide is beneficial to the emergency provider and patient.

Discussion Capnography provides real-time data to aid in the diagnosis and patient monitoring for patient states beyond procedural sedation and bronchospasm. Capnographic changes provide valuable information in such processes as diabetic ketoacidosis, seizures, pulmonary embolism, and malignant hyperthermia.

Conclusions Capnography is a quick, low-cost method of enhancing patient safety with the potential to improve the clinician's diagnostic power.

Introduction

Waveform capnography is widely recognized as a tool for confirmation of endotracheal intubation in the emergent setting. Many studies identified the benefits of monitoring end-tidal carbon dioxide (EtCO₂) in the intubated patient.^[1,2] Recent technological advances provide the ability to reliably measure and monitor EtCO₂ in the nonintubated patient.^[3] Sidestream collection and analysis allow the provider to noninvasively monitor ventilation parameters quickly and reliably. EtCO₂ monitoring allows clinicians to actively monitor patients for clinical changes and rapidly correct abnormal ventilatory concerns, such as airway obstruction, congestive heart failure, pulmonary embolism, asthma, chronic obstructive pulmonary disease (COPD), diabetic ketoacidosis, seizure, etc. This technique enhances patient safety by providing continuous data on airway patency, ventilatory rate and quality, and circulatory sufficiency.^[4] Capnography is the noninvasive measurement of the partial pressure of CO₂ in the exhaled breath. Capnography provides continuous minute to minute objective data to qualify and quantify metabolism, circulation, and ventilation. A capnometer is a CO₂ monitor displaying a numeric value. A capnograph is a CO₂ monitor that displays both a number and a waveform. The waveform, or capnogram, displays the change in CO₂ concentration during the respiratory cycle. It is commonly displayed as a function of time (i.e., CO₂ concentration over time).^[5]

For noninvasive capnography, the airway interface is typically a nasal-oral cannula allowing concomitant CO₂ sampling and low-flow O₂ delivery.^[5] This process allows the

technology to be utilized in spontaneously breathing patients. Current devices use very low flow rates (~50 mL/min) to preserve the accuracy and resolution of the waveform. Additionally, special filters decrease moisture-related occlusions associated with older detection devices.^[6,7]

McNulty reviewed the relationship between arterial (PaCO₂) and EtCO₂ obtained via sidestream nasal cannula in 20 healthy preoperative patients. This study found a direct and clinically acceptable correlation unaffected by varying rates of oxygen administration.^[8]

Multiple studies illustrate the benefits of waveform capnography in the nonintubated patient.^[5,9–13] This type of monitoring is routinely used by anesthesia providers in order to recognize ventilation changes, such as obstruction or hypopnea/apnea. Its role in the administration of deep sedation is well defined. Prehospital providers embrace the ease and benefit of monitoring capnography. Currently, few community-based emergency physicians utilize capnography with the nonintubated patient. We hope to identify clinical areas where monitoring EtCO₂ is beneficial to the emergency provider and patient. Sedation and analgesia, commonly performed in the emergency setting, is an excellent area to use this technology. In a 1991 article, Wright identified multiple "silent" hypoxic events in a small observational study in which patients underwent benzodiazepine or narcotic administration for painful procedures. The authors observed an increase in EtCO₂ and changes in the waveform before hypoxemia was identified.^[14]

The "normal" capnogram is shown in Figure 1. Abnormalities from the baseline capnogram are associated with clinical entities easily identified by assimilating the waveform analysis and clinical interpretation. A slow upstroke of Phase II can be due to delayed delivery of CO₂ from lungs to the sampling device and can be due to bronchospasm, upper airway obstruction, kinking of the endotracheal tube, or slow sampling rate. Rising Phase II with no plateau (shark fin) is suggestive of prolonged expiration (asthma, chronic obstructive pulmonary disease). A prolonged drop to the baseline in Phase IV might indicate air leak from a deflated cuff or tube that is too small,^[6,15,16] (Figures 2 and 3).

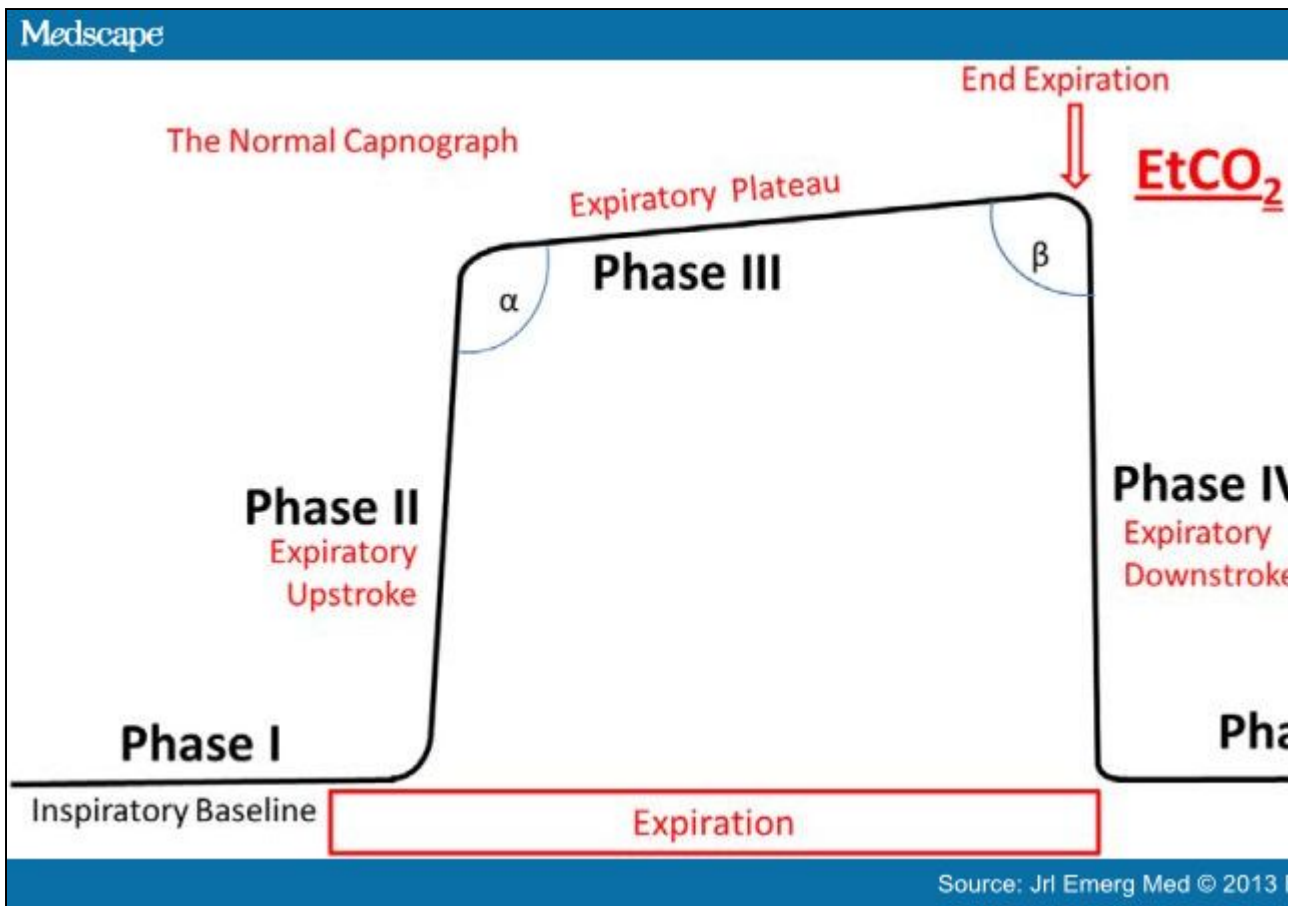


Figure 1.

The morphology of the "normal" capnogram. Phase I represents the inspiratory baseline. Then, upon exhalation, Phase II represents the rapid rise in CO_2 . Once the exhaled breath has resolved from mostly dead space air to mostly alveolar air, Phase III represents the expiratory plateau. The end of the expiratory cycle results in a rapid decrease in the CO_2 concentration (Phase IV) at the detector with the inhalation of atmospheric air, thus returning to the inspiratory baseline. EtCO_2 = end-tidal carbon dioxide.

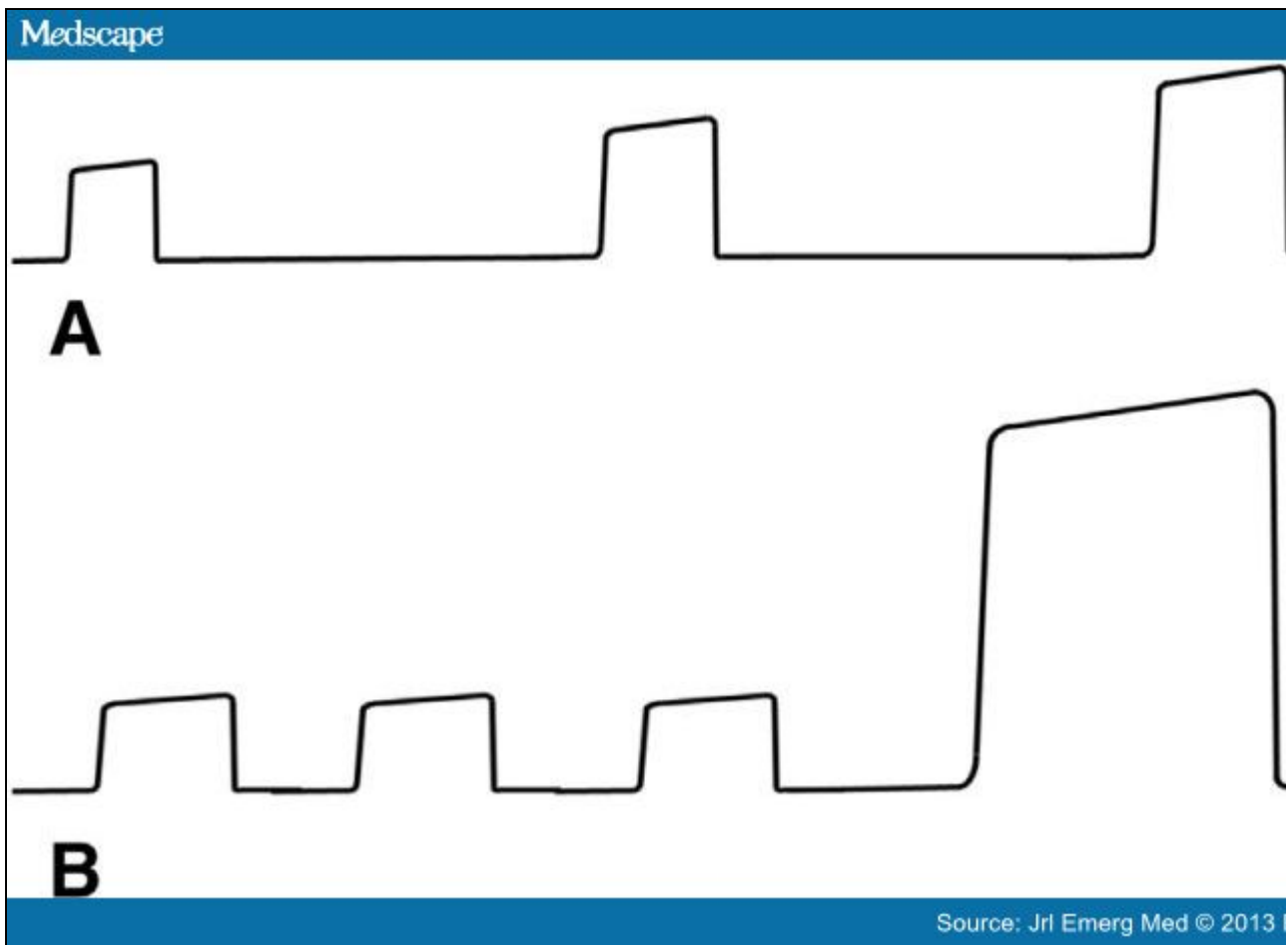


Figure 2.

(A) Hypoventilation resulting from central nervous system depression. Note the increasing end-tidal CO₂ (EtCO₂) levels and the waveform still has a normal morphology.

(B) The increased intrinsic circulation recruits CO₂ from poorly perfused tissues; this results in a large increase in EtCO₂ after return of spontaneous circulation with normal wave morphology.

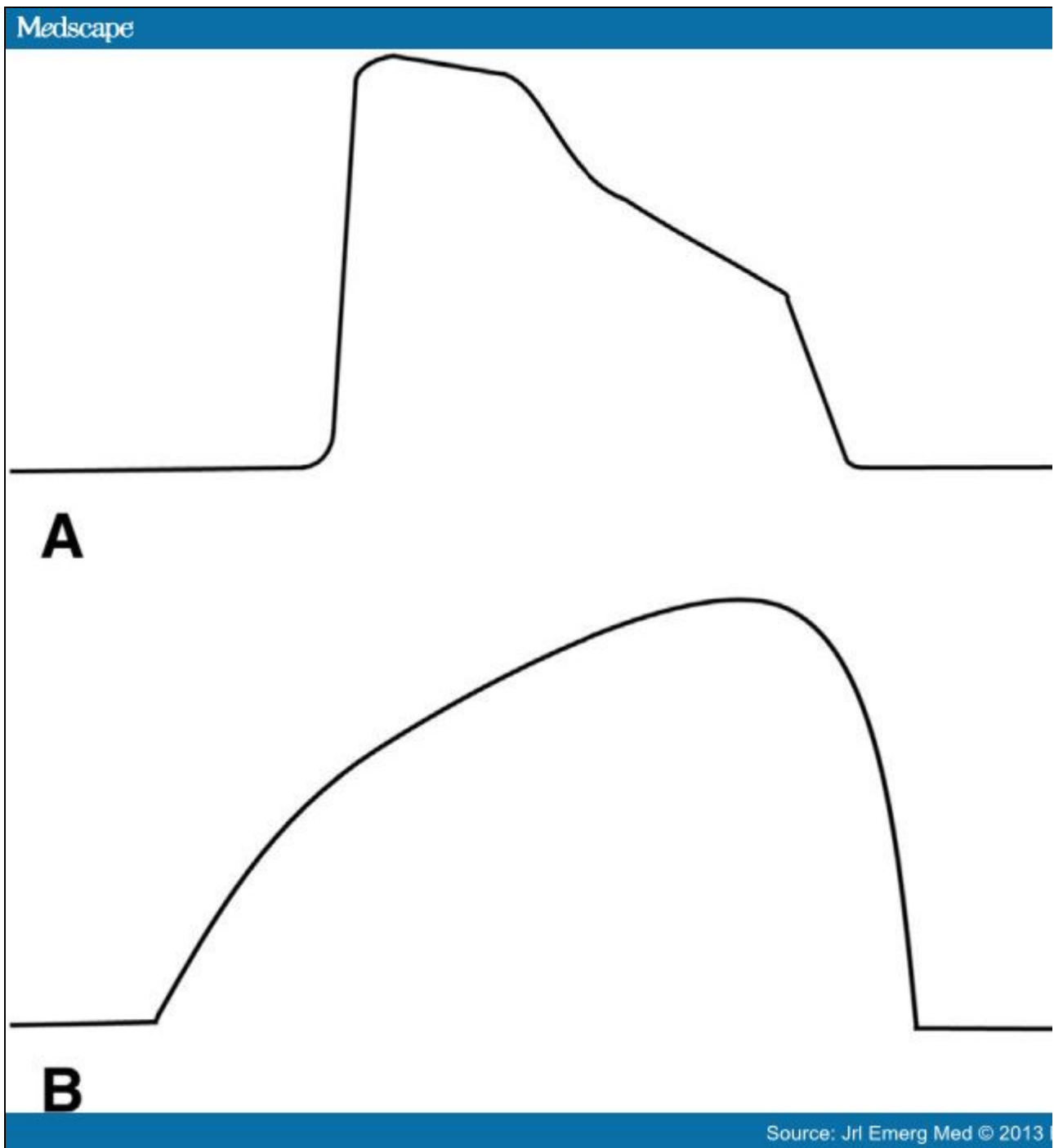


Figure 3.

(A) Cuff leak. Note as the expiratory end-tidal CO₂ (EtCO₂) decreases as exhalation continues, an unexpected drop indicates that the CO₂ is not reaching the detector. (B) Obstruction/bronchospasm. The obstruction pattern is formed as the patient is exhaling through an obstruction creating gradual rise in EtCO₂ caused by the mixing of alveolar and dead space air.

A sudden change to a "flat line" with a quantitative reading approximating zero should alert the clinician to a significant event, such as esophageal intubation, dislodgment of the endotracheal tube, or development of cardiac arrest.^[17] In the mechanically ventilated

patient, it might indicate an obstructed endotracheal tube or disconnected ventilator.

Transient increases in EtCO₂ can result from seizure (increased musculoskeletal metabolism), return of spontaneous circulation (recruitment of previously nonperfused tissue), sodium bicarbonate administration (addition of iatrogenic CO₂), as well as reperfusion of an ischemic limb or removal of tourniquets (recruitment of previously nonperfused tissue).^[18] Increases in EtCO₂ can demonstrate a partial obstruction of the tube, increasing body temperature, or, more importantly, hypoventilation or apnea (Figure 2).

Discussion

Intubation and Capnography

CO₂ measurement is the standard of care for confirmation of endotracheal tube placement in intubated patients.^[1,2,19,20] It is also effective for confirming effective ventilation with supraglottic airways.^[19] Monitoring capnographic waveforms provides rapid detection of loss of proper placement or function in all advanced airway devices. Some concern surrounds confirming intubation in the setting of recently ingested carbonated beverages. In one study, five dogs were administered carbonated beverages while esophageal and endotracheal CO₂ monitoring was conducted. Although CO₂ was detected transtracheally, it was rapidly diminishing and easily distinguishable from physiologic alveolar CO₂ waveforms.^[21] This would appear to be more a theoretical concern than a clinical reality.

Cardiac chest compression effectiveness can be assessed as well as early detection of return of spontaneous circulation^[22,23,24] (Figure 2). EtCO₂ can also be utilized to assist in determining death.^[25] An EtCO₂ of <10 mm Hg after 20 min of advanced life support resuscitation demonstrated 100% mortality. Salen et al. identified that EtCO₂ levels > 16 mm Hg were significantly associated with survival from emergency department resuscitation. No patient survived with a level < 16 mm Hg.^[26] Head injury patients can have their ventilation rates optimized. By doing this, they avoid hyperventilation, which has been shown to increase mortality.^[27,28]

Nonintubated Roles

Plewa et al. reported noninvasive EtCO₂ measured with forced expiration correlated with PaCO₂ levels in nonintubated emergency department (ED) patients with respiratory distress in 1995.^[13]

Respiratory Rate

Reported respiratory rates are inherently inaccurate and can affect emergent patient care. The rapid application and assessment by capnography can provide an accurate interpretation of patient's true respiratory rate within a few seconds, as opposed to a manual count for 30–60 s. This intrinsic value should not be underestimated.^[29]

Plethysmography, which is currently utilized by many vital-sign monitors, relies on transthoracic impedance, which is highly susceptible to patient movements and therefore ineffective and often ignored by clinicians.^[30]

Sedation and Analgesia Utilization

Many studies have reviewed EtCO₂ monitoring in the setting of sedation and analgesia

administration.^[31,32] Supplemental oxygen administration is a common practice and can delay the onset of hypoxia despite hypoventilation and hypercarbia. The American Academy of Pediatrics' guidelines recommend the use of EtCO₂ during deep sedation.^[33] Increases of EtCO₂ were measured from 0.16 to 22.3 mm Hg with a mean increase of 6.7 mm Hg for midazolam and ketamine with a mean increase of 8.8 mm Hg for combinations for midazolam and opiates. This particular study was conducted in children ages 1–16 years old for procedures such as fracture reduction, laceration repair, incision and drainage, and lumbar puncture.^[34] Additional studies demonstrate evidence of hypercarbia in the absence of hypoxia.^[35] In a prospective, randomized clinical trial of 126 pediatric patients who underwent sedation/analgesia procedures in an intensive care unit setting, 6% had hypercarbia (EtCO₂ > 50 mm Hg) without any evidence of hypoxia (oxygen saturation < 90%). Propofol and benzodiazepine/opiate combinations produced a higher incidence of respiratory depression and higher levels of EtCO₂.^[35] An adult study with 132 subjects underwent sedation with propofol in the ED. All patients received supplemental oxygen at 3 L/min. Capnography gave advanced warning for all hypoxic events (SpO₂ < 93% for ≥ 15 s). A median time of 60 s and a range of 5 to 240 s demonstrated capnographic evidence of respiratory depression before hypoxia.^[36] A Spanish study during colonoscopy showed only 38% of hypoventilation episodes were detected by pulse oximetry.^[37] Numerous nonanesthesiologists utilize sedative hypnotics for sedation in outpatient settings. Capnographic monitoring appears to improve patient safety monitoring in these situations.^[38,39]

Patient-controlled analgesia (PCA) is on the rise in the ED and its use is widespread throughout the inpatient setting. The Veterans Health Administration integrated product team recommends PCA pumps with an integrated EtCO₂ monitor as the pump of choice. Their analysis revealed integrated EtCO₂ could have prevented > 60% of adverse events related to PCA pumps.^[40]

Diabetic Ketoacidosis

Garcia et al. reported the successful noninvasive monitoring of EtCO₂ in diabetic ketoacidosis (DKA) patients.^[41] This allowed continuous monitoring of EtCO₂ as an accurate estimate of PCO₂. One hundred and twenty-one patients were monitored for 6 h. Initial pH values were 7.08, respiratory rate was 35 breaths/min, EtCO₂ 18.6 torr, and venous PCO₂ 20 torr. At the conclusion of the observation period, the pH had improved to 7.29, respiratory rate to 22 breaths/min, EtCO₂ to 35 torr, and the venous PCO₂ to 36 torr. The correlation between EtCO₂ and venous PCO₂ was significant ($r = 0.92$, $p = 0.0001$). Limit of agreements between the two methods established an EtCO₂ 0.8 torr lower than venous PCO₂ with 95% limits of agreement.^[41] This observation may allow the use of noninvasive EtCO₂ monitoring in the clinical setting of DKA, decreasing blood draws and giving a continuous assessment for trending of clinical values.

Seizure Patients

EtCO₂ provides a reliable assessment of a patient's ventilatory status in actively seizing and post-ictal patients. A pediatric ED enrolled 105 patients who were actively seizing and 61 post-ictal patients and monitored EtCO₂, respiratory rates, O₂ saturation, and heart rates. Capillary PCO₂ was compared with EtCO₂ and established 95% limit of agreement ± 4.2 torr. Seventy-nine patients had an oxygenation saturation of <93%. These patients had EtCO₂ > 45 torr. Capnometry was able to reliably detect 5 patients

with respiratory failure. EtCO₂ rose to 70–99 torr despite maintaining O₂ saturations > 97% on 2–4 L/min of oxygen. Each patient required assisted bag-valve mask ventilation and subsequent intubation. An additional 20 patients required brief periods of bag-valve mask ventilation support for significant respiratory compromise not requiring intubation and mean EtCO₂ of 52 torr.^[42] The authors conclude noninvasive capnography was more sensitive than pulse oximetry in predicting a trend toward respiratory failure.^[42]

Trending and Objective Assessment in Respiratory Distress

Characteristic waveform analysis and quantitative measurements can be utilized to monitor response to treatment in patients with asthma, COPD, and congestive heart failure. Bronchospasm and subsequent obstructive disease patterns can demonstrate the "shark-fin" appearance (Figure 3B). During asthma exacerbations, a mild drop in the EtCO₂ level might be noticed as the patient hyperventilates to compensate. When the exacerbation becomes severe, the CO₂ levels will rise to abnormal levels as the patient tires and is unable to effectively ventilate. Effective treatment can be monitored not only by clinical parameters but also by objective findings of quantitative EtCO₂ improvement and waveform analyses, such as the shark-fin appearance normalizing. Approximately 5% of patients with COPD will have a "hypoxic drive." Monitoring EtCO₂ allows the provider to identify when EtCO₂ starts to increase and therefore oxygen flow can be decreased.^[43]

Howe et al. provide preliminary data examining computer analysis of the waveform, specifically observing the slope of Phase II and Phase III and the α angle. Their pre-and post-treatment analysis found a significant difference in the slope of Phase II and the α angle as determined by the computer algorithm in nonintubated patients.^[10] This provides an effort independent process and also promotes continuous monitoring of respiratory status.

Pulmonary Embolism

Although not able to reliably diagnose a pulmonary embolism (PE), the EtCO₂ decreases secondary to increase in dead-space ventilation. Hemnes et al. reviewed 298 patients and attempted to define an EtCO₂ level that would exclude pulmonary embolism.^[44] They measured EtCO₂ within 24 h of contrast-enhanced helical computed tomography; lower extremity duplex, or ventilation perfusion scan. A PE was diagnosed in 13% of the enrolled patients. Mean EtCO₂ levels in healthy volunteers were not different from patients without PE. End-tidal CO₂ $\geq$ 36 mm Hg had an optimal sensitivity and specificity of 87.2% and 53%, respectively, for identifying patients without PE. A negative predictive value of 96.6% (95% confidence interval [CI] 92.3–98.5) demonstrates the value of this technique. They report this increased to 97.6% (99% CI 93.2–99.2) when combined with a Wells score $\leq$ 4.^[44] The authors determined a CT cost of \$1739 and 120 of the studies could have been avoided for a potential cost savings of \$208,680 in this small study.^[44]

Malignant Hyperthermia

A rare complication of anesthesia administration, and one occasionally associated with hyperadrenergic states, is a dramatic increase in EtCO₂ that can be seen even before a change in temperature. This has been reported to be 3–4 times the patient's previous level. Monitoring a patient's baseline EtCO₂ and recognizing this phenomenon of a rapid rise when succinylcholine or anesthetic agents are administered can be lifesaving.^[45,46]

Triage

Preliminary evaluation of EtCO₂ as a triage tool was presented in an abstract from the University of Florida Jacksonville. A small convenience sample of patients presenting to an urban academic ED demonstrated EtCO₂ could be a sensitive (yet nonspecific) indicator of illness or injury. They showed 1 in 6 subjects presenting with normal vital signs and normal EtCO₂ are admitted, and 1 in 2 subjects with normal vital signs and abnormal EtCO₂ are admitted.^[47] In acute blunt-trauma patients with an EtCO₂ < 26.25 mm Hg after 20 min, only 5% survived to discharge. This time delay of 20 min effectively eliminated those patients who had airway obstruction or the need for assisted ventilations, which might have accounted for an initial elevation in CO₂.^[48] In mass-casualty incidents, it has been suggested that capnography can serve as an effective, rapid assessment and triage tool for victims of chemical exposure.^[48]

Kartal et al. evaluated the use of EtCO₂ to exclude metabolic disturbances.^[11] They enrolled 240 patients and determined the EtCO₂ values of ≥ 37 mm Hg essentially ruled out HCO₃ levels of ≤ 21 mmol/L. This is another example demonstrating EtCO₂ can give rapid predictive information for patients presenting to the emergency setting.^[11]

Anxiety/Hyperventilation

Many authors suggest using EtCO₂ as a means of biofeedback for patients to utilize the waveform and quantitative measurements as visual feedback and coaching.^[49] The patient can be instructed to watch the monitor and visualize their breathing by watching the waveform. Patients can see their EtCO₂ level rise and respiratory rate decrease. Additionally, their symptoms improve. This is a very effective technique for patients with hyperventilation primarily due to anxiety and panic attack.

Intrahospital and Interhospital Transport

Standard practice for intrahospital transport is to provide the same level of care, monitoring, and interventions that are available in the intensive care unit.^[50] EtCO₂ monitoring assists in recognizing or preventing complications during transport of patients. Capnography is also recommended as an additional monitoring tool for minor trauma patients during interhospital transport to an emergency center.^[12]

Patient Safety

Many associations and organizations, including Anesthesia Patient Safety Foundation and the American Society of Anesthesiologists, are incorporating into their guidelines the noninvasive monitoring of EtCO₂ to assess a patient's ventilatory status.^[51] The 2012 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care stress the critical importance of continuous waveform capnography to confirm and monitor endotracheal intubation placement, assess the quality of cardiopulmonary resuscitation, and detect return of spontaneous circulation.^[52]

Conclusions

EtCO₂ is safe, noninvasive, inexpensive, and rapidly performed at the bedside. It is an essential tool for evaluating patients in the emergency setting. Additional study will determine cost-benefit ratios and patient-safety impact. Most consider the use of noninvasive EtCO₂ monitoring for sedation and analgesia administration as a reasonable

practice. Novel uses, such as noninvasive monitoring of DKA and incorporating triage algorithms, might require additional research.

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