An Update on End-Tidal CO_2 Monitoring

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Abstract: End-tidal CO_2 ($ETCO_2$) monitoring is not a new modality in the pediatric emergency department (PED) and emergency department. It is the standard of care during certain procedures such as intubations and sedations and can be used in variety of clinical situations. However, $ETCO_2$ may be underused in the PED setting. The implementation of $ETCO_2$ monitoring may be accomplished many ways, but a foundation of capnography principles specifically in ventilation, cardiac output, and current literature regarding its application is essential to successful implementation. It is the intention of this article to briefly review the principles of $ETCO_2$ monitoring and its clinical applications in the PED setting.

Key Words: pediatric emergency department, end-tidal CO_2 monitoring, sedation, intubation

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TARGET AUDIENCE

This CME activity is intended for pediatric emergency medicine practitioners, pediatric critical care physicians, and pediatric anesthesiologists.

LEARNING OBJECTIVES

After completing this CME activity, the reader should be able to:

1. Propose applications for and accurately interpret end-tidal CO_2 monitoring in the ED setting.
2. Assess the limitations of end-tidal CO_2 monitoring.
3. Evaluate current literature and future direction regarding the application and utility of end-tidal CO_2 monitoring.

CASES

Case 1

An adolescent boy is being actively coded in your emergency department (ED). You have secured an advanced airway (endotracheal tube) and have confirmed placement with direct visualization through the cords and good chest rise. How can capnography guide your resuscitative efforts?

Case 2

A 5-year-old girl is undergoing planned procedural sedation in the pediatric ED for a laceration repair. How can capnography assist you in your sedation?

Case 3

An 18-month-old child arrives by emergency medical service with active generalized seizures soon progressing to focal left sided seizures. What role can capnography play in the management for this patient?

Case 4

A 5-year-old patient is being transported to your ED after being struck by a vehicle. His Glasgow Coma Scale score on scene was 8 with noted apnea, and he was intubated by emergency medical service. Upon arrival, his end-tidal CO_2 reading is 27 and a bedside venous blood gas reveals a pCO_2 of 65 mm Hg. How do you use this knowledge to guide your assessment?

Case 5

An 18-month-old nonimmunized child is brought to your ED with a fever of 101°F. On initial examination, her heart rate is 170 beats/minute, blood pressure was 80/34 mm Hg, and capillary refill is 6 seconds despite a fluid bolus. End-tidal CO_2 ($ETCO_2$) is placed and is reading 29 mm Hg with a good waveform. How has capnography assisted your assessment of this patient?

Case 6

A 11-year-old girl with type 1 diabetes presents with several days of vomiting, diarrhea, and weight loss. Her parents are out of town, and friends she is staying with are unsure if she has been taking her medications properly. She was brought in today because at home she began acting strangely and sleeping more. On examination, you see a lethargic girl who has deep periodic breathing and is hard to arouse. Nursing staff is working on intravenous access but is having trouble because of her severe dehydration. She is put on monitors including $ETCO_2$, which is reading 55 to 60. Before getting any further imaging or laboratory tests, how has your clinical examination and $ETCO_2$ assisted your assessment of this child?

End-tidal CO_2 ($ETCO_2$) monitoring is not a new modality in the pediatric emergency department (PED) and emergency department (ED). It is the standard of care during certain procedures such as intubations and sedations and can be used in variety of clinical situations. However, $ETCO_2$ may be underused in the PED setting.[1,2] The implementation of $ETCO_2$ monitoring may be accomplished many ways, but a foundation of capnography principles specifically in ventilation, cardiac output, and current literature regarding its application is essential to successful implementation.[3] It is the intention of this article to briefly review the principles of $ETCO_2$ monitoring and its clinical applications in the PED setting.

COLORIMETRY VERSUS CAPNOMETRY

End-tidal CO_2 monitoring is typically performed 2 ways: colorimetric or capnometry monitoring. Colorimetry involves a semiquantitative measurement of exhaled CO_2.[4] Colorimetric devices use a pH strip, which changes color in proportion to the concentration of CO_2 exhaled. Levels of interpretation typically

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include less than 0.5%, 0.5% to 2%, and 2% to 5%. Colorimetric devices are widespread and readily available. The magnitude of change from purple to yellow indicates the relative CO_2 concentration exhaled.[5] Advantages of colorimetry include the following: it is inexpensive, disposable, lightweight, transportable, and readily available. Disadvantages include their relatively short duration because they expire after a few hours of use. Another disadvantage is the tidal volume required for CO_2 detection. Small tidal volumes may not allow for the detection chamber to completely fill, thus underestimating the CO_2 concentration. This can be partially ameliorated by using a pediatric size device.

Another way to measure $ETCO_2$ is achieved by capnometry involving continuous quantitative measurements of exhaled air. The measured CO_2 concentration (expressed in millimeter of mercury) over time is then displayed numerically (capnometry) and/or graphically (capnography). The maximum exhaled CO_2 at the end respiratory cycle is known as the end-tidal CO_2 ($ETCO_2$; Fig. 1). This number is thought to represent the alveolar concentration of carbon dioxide (CO_2), which in a healthy patient closely approximates arterial CO_2 ($PaCO_2$) levels.[2] Capnometry uses infrared light absorption of CO_2 to measure the concentration of CO_2 in a sample. CO_2 samples are obtained 1 of 1 ways: inline or sidestream.

Inline devices, also known as mainstream, measure the entire sample being exhaled. These devices have the advantage of providing real-time data and are less prone to washout from supplemental oxygen administration or obstruction from vapor condensation. Also, because they are in line with the respiratory circuit, the device does not affect tidal volume by siphoning gas samples. Disadvantages include the bulkiness and weight of these devices, which may cause kinking of the endotracheal (ET) tube and/or increase the rate of extubations, especially in the pediatric and neonatal populations. These mainstream devices can be used in both intubated and nonintubated patients, and with appropriate-sized patient masks and proper seal, an $ETCO_2$ waveform can be obtained during patient bag-valve-mask ventilation.

The next and more common way to obtain capnography in the pediatric ED involves sidestream devices. These devices aspirate a small volume of expired air into a reservoir where infrared light measures the CO_2 concentration.[5] Advantages of these devices include their lightweight and ease of use in nonintubated patients. Many devices can be worn like a nasal cannula, with some allowing for concurrent oxygen administration. Disadvantages include a small lag time in the sample analysis (1–2 seconds) as it travels through the tubing to the machine; errors can also result from dilution of the sampled air with incoming air or interference from moisture/condensation in the sample tubing.

The capnographic waveform provides a wealth of information to the ED practitioner. Each exhaled breath should have CO_2, which is detected by the monitor and plotted in CO_2 concentration over time. Machines typically display several seconds worth of capnographic readings as well as the end-tidal CO_2 number on the screen.

The anatomy of a capnography tracing is straightforward and can be interpreted at bedside (Fig. 1):

Phase 1: consists of the first part of the expiratory cycle involving dead space. The reading should be 0, as no expired CO_2 should be detected.
Phase 2: is the initial mixing of dead space and alveolar gas (containing CO_2), which causes a sharp increase in the tracing.
Phase 3: is a plateau during which alveolar gases become dominate. It is at the end of this alveolar-emptying phase that $ETCO_2$ is calculated.
Phase 0: involves a sharp decline at the end of the plateau and the initial part of the lower horizontal line representing inspiration.
Alpha angle (α): is the measured angle between phases 2 and 3 representing alveolar-emptying efficiency. In normal physiology, the angle is typically around 100 degrees.

PHYSIOLOGY

Understanding $ETCO_2$ monitoring requires understanding basic cardiopulmonary physiology. CO_2 is a product of aerobic metabolism that occurs in human tissue.[5] This waste product must move from cells and tissue via the cardiovascular system to the lungs where ventilation expels the CO_2 with each breath.

In children with normal hearts and lungs, $ETCO_2$ tension is normally within 2 to 5 mm Hg of $PaCO_2$.[5,6] End-tidal CO_2 does evaluate effectiveness of ventilation, but it is also dependent on cardiac output to deliver CO_2 to the pulmonary system. Therefore, a dysfunction in either the respiratory or cardiac system can cause a variation in $ETCO_2$ readings. For example, a patient in cardiac failure or hypovolemia (diabetic ketoacidosis [DKA], septic shock, hemorrhagic shock, etc) may have decreased pulmonary perfusion leading to an increase in alveolar dead space and a ventilation/perfusion mismatch (right to left shunt). This mismatch will result in lower $ETCO_2$ readings.[4] In healthy subjects, however, $ETCO_2$ monitoring is seen as an objective marker of ventilation status and is a reliable indicator of respiratory status in the absence of heart disease.[7] Because of the interdependence of these 2 systems, clinicians must evaluate each patient's cardiovascular and respiratory function when interpreting $ETCO_2$ readings in lieu of blood gas examinations, and correlation with an arterial blood gas is recommended.

Elevated or rising $ETCO_2$ in the context of normal cardiovascular and respiratory systems can indicate several things including an increase production (as in hypermetabolic states), inadequate ventilation, or equipment failure. Elevated $ETCO_2$ almost always indicates an increased $PaCO_2$.[5]

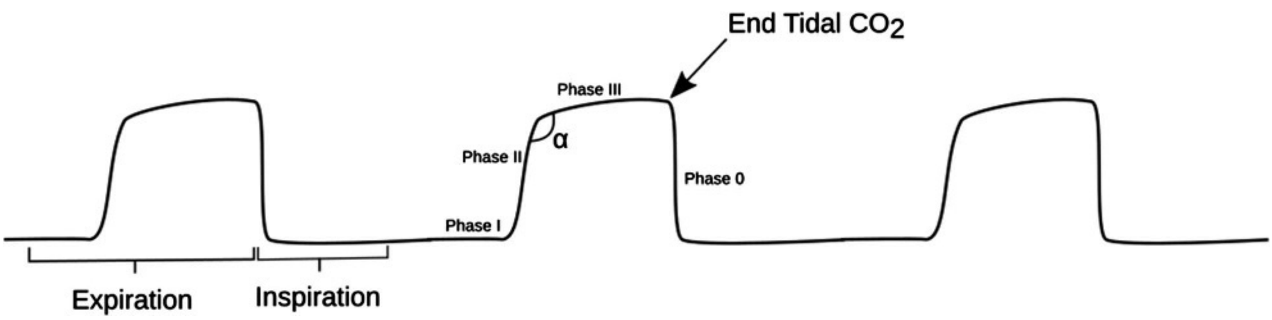

FIGURE 1. End-tidal capnography.

Low $ETCO_2$ may be due to decreased production, decrease in pulmonary blood flow (low cardiac output), excessive ventilation (DKA, salicylate ingestion), or equipment malfunction.[5]

In the case of hemodynamic instability or pulmonary injury, divergence of $ETCO_2$ and $PaCO_2$ may occur. The widening gradient between blood gas and $ETCO_2$ measurements indicates increased pulmonary dead space or decreased cardiac output.[5,8]

False positives in $ETCO_2$ measurements are possible. Situations where clinicians should be aware of such events include recent ingestion of carbonated beverages, mouth-to-mouth ventilation, and inadequate bagging causing gastric distension. False positives are decreased by observing several waveforms (~15 seconds) to ensure that CO_2 present from other sources is adequately washed out.[4] False negatives can occur in defective devices and in instances where no gas exchange is occurring at the alveolar level. For example, in cardiac arrest cases, 25% of adults have no detectable $ETCO_2$.[9]

$ETCO_2$ MONITORING IN THE PED ED

End-tidal CO_2 monitoring is invaluable in the PED and prehospital setting. We will identify both essential and newer applications of this monitoring modality described in the literature.

Intubations

Intubation placement confirmation and monitoring is the central role of $ETCO_2$ monitoring in the emergency care setting. Children in all settings undergoing ET tube placement should have confirmation with $ETCO_2$ detection.[5,10] End-tidal CO_2 confirms ET tube placement much faster than other standard techniques including auscultation, pulse ox, and observation of chest rise.[3] Pediatric patients, in particular, require quick identification of improper ET tube placement because of their relatively small oxygen reserve. As long as there is cardiac output, CO_2 detection should be present and can be evaluated within seconds of ET tube placement. Several breaths should be observed in case of false positives as mentioned earlier. In a cardiac arrest patient receiving chest compressions, $ETCO_2$ is still helpful at identifying proper tube placement during cardiopulmonary resuscitation (CPR). In one study, providers were able to see capnographic movement (not a flat line), which indicated ET intubation with 100% sensitivity and specificity.[6]

Transport

Transfer of intubated patients (interfacility/intrafacility) is an excellent role for $ETCO_2$ monitoring where the risk of unrecognized tube dislodgement can have devastating effects.[6] Endotracheal tube dislodgement occurs at greater rates in children than in adults. Standard methods of evaluating the patient's ET tube positioning including pulse oximetry, chest rise, and so on, may lag several minutes behind the time the event occurred. Capnography has been shown to be more sensitive at detecting dislodged tubes.[11]

Advanced Life Support

In the clinical setting of cardiac arrest $ETCO_2$ monitoring may be helpful in the evaluation CPR quality and return of spontaneous circulation status. In the most recent American Heart Association Pediatric Advanced Life Support, recommendations were changed to say that $ETCO_2$ monitoring "may be used to evaluate the quality of compressions, but specific values have not been established in children."[10] Several animal, pediatric, and adult studies have shown the benefit of $ETCO_2$ monitoring to guidance of CPR quality and may identify provider fatigue or ineffective compression (due to rate, depth of compression, or lack of recoil).[6,8] Some studies have noted that return of spontaneous circulation may be preceded by an abrupt rise in $ETCO_2$ levels indicating increased blood flow.[6,12] Other studies have shown that the inability to increase $ETCO_2$ greater than 10 mm Hg indicates a poor prognosis for survival; however, this should not be used on its own to guide cessation of resuscitation. Providers should be aware that administration of bicarbonate to severely acidotic patients may cause a falsely elevated $ETCO_2$ level. Another application of $ETCO_2$ during cardiac arrest involves the activation of extracorporeal membrane oxygenation (ECMO). In patients with refractory cardiac arrest, capnography may help practitioners identify and activate ECMO in specific subsets of arrest patients, but further research is needed in this area.[6]

In a Slovenian study by Grmec et al,[13] patients who had cardiac arrest due to drowning showed initial and average $ETCO_2$ levels notably elevated compared with other primary out-of-hospital cardiac arrests. This was likely due to the asphyxia component of the arrest. These patients tended to be younger and have less comorbidities. They also presented more often in nonshockable rhythms such as asystole but had overall better survival rates. Along with other factors, higher initial and average $ETCO_2$ values throughout resuscitation were correlated with higher survival rates.

Sedation

The next area in which capnography plays an essential role is during sedation. The American Association of Pediatrics and The American Society of Anesthesiologists recommend $ETCO_2$ monitoring during sedation.[14] Adult studies have shown that $ETCO_2$ serves as an indicator of respiratory events, with sedation leading to less hypoxic events, but these results are mixed in the pediatric population. With capnography in children, more events are detected, but the significance of these events has been questioned.[3] A recent clinical report by the American Association of Pediatrics on procedural sedation by Cote et al[14] noted that $ETCO_2$ monitoring is a vital sign that "must be documented every 5 minutes" during deep sedation and is "strongly recommended" in moderate sedation. Continuous capnography should be performed to ensure adequate ventilation during the procedure. Pediatric patients have less reserve and may deteriorate quickly in episodes of hypoxia.[3] Thus, $ETCO_2$ monitoring may identify respiratory events/apnea before hypoxic events.[15,16] It is important to realize that oxygenation and ventilation do not always correlate because alveolar hypoventilation may occur in the presence of a normal pulse oximetry reading.[15] Thus, patients may have elevated $ETCO_2$ levels with normal pulse oximetry readings. Some sensing devices and monitors allow patients to have simultaneous oxygen administration and $ETCO_2$ measurements obtained. Although patient cooperation may preclude $ETCO_2$ monitoring before sedation, once sedated, the device can be applied.

Respiratory Status in Altered Mental Status and Seizures

As mentioned previously, capnography is a graphical representation of expired CO_2 concentration over time (Fig. 1). Several observations regarding patient ventilatory status can be made from not only the $ETCO_2$ number but also the graph shape.

In asthmatic people, $ETCO_2$ monitoring would be helpful as a screening modality for disease severity because, unlike pulmonary function tests, it is not effort dependent for accurate readings.[17] Unfortunately, studies have tried to correlate $ETCO_2$ readings and asthma severity without success[7]; however, other studies show a correlation between the alpha angle (between phases II and III; Fig. 1) becoming larger (>100 degrees)[6] in obstructive processes.

This widening is due to a delayed emptying of alveoli due to an obstructive process. Although graphical interpretation may correlate with severity of disease status, because of the need to manual calculate these numbers, the utility in a busy ED practice is low.

In patients having epileptic events, several studies have shown the utility of capnography in monitoring patient ventilatory status. Abramo et al[18] showed that patients can develop hypercapnic hypoventilation in the presence of normal oxygen saturations. Capnography was also able to monitor ventilation status and detect patients with possible respiratory failure.

Metabolic

Besides ventilation status, $ETCO_2$ can also be used in patients with metabolic disturbances. In DKA, a linear relationship between $ETCO_2$ and bicarbonate has been described.[19] Noninvasive monitoring of $ETCO_2$ can reduce frequent laboratory testing and inform providers about the effectiveness of their interventions.[20]

Dehydration

Nagler et al[21] describe a linear correlation between $ETCO_2$ and bicarbonate and in children experiencing symptoms of gastroenteritis. Lower $ETCO_2$ readings (<34 mm Hg), much like decreased serum bicarbonate, are highly sensitive in identifying severe dehydration in need of intravenous fluids and even predicting patients who may be more likely to return to the ED after discharge because of worsening symptoms. The decreased $ETCO_2$ readings in this scenario are a compensatory respiratory alkalosis due to the metabolic acidosis from the underlying illness.[22]

Trauma

In trauma, the utility of $ETCO_2$ monitoring can be multifaceted. A study by Deakin et al[23] revealed that lower $ETCO_2$ levels in blunt trauma had a higher rate of mortality. Without ventilation problems, it can be assumed that $ETCO_2$ in trauma victims correlates with cardiac output.[23,24] Patients with higher gradient between $ETCO_2$ and $PaCO_2$ should prompt emergency physicians to investigate for other injuries including hypovolemia from hemorrhage, pulmonary contusions, or other reasons for decreased cardiac output or ventilatory problems.

In patients with severe head trauma, strict $ETCO_2$ monitoring must be used to avoid worsening injury. Hyperventilation has been used acutely to decrease intracranial pressure in patients at risk of herniation, but Bagwell et al[25] showed that excessive hyperventilation with $ETCO_2$ levels less than 30 mm Hg may lead to decreased cerebral blood flow and increase the risk of ischemic injury. Practitioners in the ED setting will find capnography useful in head trauma patients to maintain CO_2 levels in an appropriate range to avoid further injury.

CONCLUSIONS

End-tidal CO_2 monitoring is a helpful tool in the PED setting. It is essential in pediatric airway management and has been accepted universally; however, the utility of this tool in other clinical scenarios has not been as readily adopted. New research and further education regarding the use and interpretation of this tool in various clinical scenarios should be done to help clinicians and their patients who will benefit from the implementation of this invaluable tool.

CASE RESOLUTIONS

Case 1: Coding Adolescent Boy

In this case, $ETCO_2$ monitoring can be used at multiple points of the resuscitation. Initially, ET tube placement can be confirmed by observing fine oscillations of the capnography tracing. After 5 to 6 breaths and continued high-quality CPR, CO_2 should be detected if there is not an obstructive lesion. The quality of chest compressions can be evaluated. Decrease $ETCO_2$ levels may indicate compressor fatigue and may signal a time to change. In the case of a successful resuscitation, providers may notice a slight rise in $ETCO_2$ level moments before resumption of spontaneous circulation. Another helpful for the ED provider is when a patient has persistent cardiogenic failure/shock but adequate $ETCO_2$ during the resuscitation. Emergency physicians may consider activating their ECMO team in this scenario. Finally, at this time, $ETCO_2$ should not be relied upon solely when deciding to stop halt resuscitation efforts.

Case 2: 5-Year Old Girl Undergoing Procedural Sedation

In this scenario, the patient should have multiple monitors to provide the practitioner insight to the patient's cardiac and respiratory status. The utility of $ETCO_2$ monitoring lies in the fact that alveolar ventilation and oxygenation do not always correlate. In cases of apnea, $ETCO_2$ may detect changes several minutes before change in pulse oximetry. Because of the smaller reserves in children, emergency physicians will find it helpful to monitor a patient's respiratory status with continuous capnography during sedation procedures.

Case 3: 18-Month-Old With Seizures

Patients with seizure activity are at risk of unrecognized hypoventilation or apnea because of their altered state. In this child, capnography would be helpful in allowing practitioners to recognize if the child had any respiratory effort by the presence of good waveforms. If the child begins hypoventilating, the astute practitioner will recognize an increase in $ETCO_2$ which may indicate compromise of ventilation requiring intervention (repositioning, stimulation, bag-valve-mask, intubation, etc) even in the case of normal oxygen saturation.

Case 4: 5-Year-Old Trauma Patient

In this trauma patient, a discrepancy is noted in the $ETCO_2$ and pCO_2 of the venous blood gas. If the capnography device is properly setup and does not have a build-up of condensation or obstruction (possible in sidestream devices), then the ED practitioner should evaluate other causes of this discrepancy. In the acute stages of trauma, practitioners should be aware of an increased $PaCO_2$-$ETCO_2$ gradient and consider conditions that may be responsible including equipment failure (ie, tube placement in intubated patients) and any condition causing reduced pulmonary blood flow from pulmonary or cardiac origins. Some of these conditions may include hypovolemia (blood loss), cardiac tamponade, tension pneumothorax, pulmonary contusions, and others.

Case 5: 18-Month-Old Febrile Patient

In this patient, the astute physician will note that the $ETCO_2$ (29 mm Hg) is lower than expected. Given this patient's ill appearance, it is necessary to quickly identify and correct potential causes of this poor clinical picture. The most likely cause of this patient's low $ETCO_2$ is likely sepsis and a worsening metabolic acidosis causing this patient to hyperventilate (respiratory alkalosis). However, correlation with blood gas would be helpful. If an increased Pa_{CO_2}-$ETCO_2$ was noted, the physician should also consider other pulmonary or cardiac conditions causing decreased pulmonary blood flow (ie, pneumonia, cardiomyopathy, etc), which may require other interventions.

Case 6: 11-Year-Old Girl in DKA

In this scenario, because of the patient's severe dehydration, intravenous access is an issue and alternative access may be required. On clinical examination the patient is clearly altered, and given her likely DKA, cerebral edema must be high on the list of differential diagnoses. Once connected to monitors, the physician should notice that the $ETCO_2$ readings are higher than the physiologically normal ranges (35–45 mm Hg). Knowing that higher $ETCO_2$ readings typically correlate with increased Pa_{CO_2} levels, the clinician can be fairly sure of a low pH; furthermore, the clinician should be concerned about an increased $ETCO_2$ in this scenario knowing that her underlying diagnosis is likely DKA, which typically causes a decreased $ETCO_2$ reading due to a compensatory respiratory alkalosis created by Kussmaul breathing patterns. Urgently, the clinician should attempt to gain further access and search for causes of her altered mental status such as cerebral edema. Also, the clinician may need to assist the patient's breathing efforts due to her apparent hypoventilation.

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