**Introduction to Capnography**

**Goal**
The purpose of this offering is to assist the registered nurse to understand the use of capnography during procedural sedation to assess respiratory status, during intubation to determine successful tube placement and during resuscitation to evaluate effectiveness of compressions and to detect return of spontaneous circulation.

**Objectives**
After completion, student will be able to:
- define capnography, EtCO$_2$ and related terms,
- Identify a normal capnograph and recite normal EtCO$_2$ levels
- Recognize abnormal EtCO$_2$ levels in sedated patients
- Recognize ET tube misplacement or displacement using EtCO$_2$
- Evaluate effectiveness of compressions using EtCO$_2$
- Detect return of spontaneous circulation using EtCO$_2$

A patient with a dislocated shoulder requires procedural sedation for reduction. At the end of the procedure, the nurse is preparing to place a sling on the patient when the pulse oximeter alarms. The nurse notices apnea and cyanosis, calls for help and manually ventilates the patient. The physician decides to admit the patient.

A teenager is hit in the head with a bat during a baseball game. There is no external injury, breathing is spontaneous with O$_2$ saturation 95% and pupils are equal and reactive, but the patient is unresponsive. Since the Glasgow Coma Scale is less than 8, the paramedic decides to intubate. Upon arrival to the ER 18 minutes later, it is discovered that the tube in in the esophagus. The CT scan of the head indicates no traumatic injury, yet the patient has brain damage from hypoxia.

Staff begins CPR on a visitor who experienced cardiac arrest. There is disagreement among staff about the effectiveness of compressions. One person proclaims that since there is a regular rhythm on the monitor, the CPR is effective and there is no need to press harder. When a defibrillator arrives 8 minutes later, the rhythm is asystole.

**Definition**

Capnography has been used by anesthesiology for over three decades to confirm tracheal intubation and assess ventilations but is relatively new in the pre-hospital setting and even newer in hospital settings outside of the operating suites.

Capnography is the measurement and graphic display of carbon dioxide (CO$_2$) levels in the airways. End-Tidal CO$_2$ is the concentration of carbon dioxide in exhaled air at the end of expiration.
It is typically expressed as partial pressure in mmHg and sometimes called PetCO\textsubscript{2} or EtCO\textsubscript{2}.

\begin{center}
\begin{tabular}{|l|}
\hline
CO\textsubscript{2}=carbon dioxide \\
PCO\textsubscript{2}=partial pressure of CO\textsubscript{2} \\
PaCO\textsubscript{2}=partial pressure of CO\textsubscript{2} in arterial blood \\
PACO\textsubscript{2}=partial pressure of CO\textsubscript{2} in alveolar gas \\
PetCO\textsubscript{2}=partial pressure of CO\textsubscript{2} at end-tidal \\
EtCO\textsubscript{2}= partial pressure of CO\textsubscript{2} at end-tidal \\
\hline
\end{tabular}
\end{center}

The numeric measurement is called capnometry, the graphic waveform is called a capnogram.

During inspiration, PCO\textsubscript{2} is zero as the amount of CO\textsubscript{2} in the air is negligible and is not measured. Then, as alveolar gas mixes with dead space gas during exhalation, it sharply rises. During most of exhalation, the curve levels and forms a plateau. The PCO\textsubscript{2} at the end of the alveolar plateau is called end-tidal PCO\textsubscript{2} (EtCO\textsubscript{2}). The shape of the capnogram is abnormal in patients with abnormal lung function.

![Normal Capnogram](image)

SEE FIGURE 1 normal capnogram

The levels of CO\textsubscript{2} in the body can inform a health care provider about many different things. The most obvious is the adequacy of breathing—no breathing, no exhaled gas to measure. Hyperventilation or hypoventilation will affect the capnometry. The next is the adequacy of perfusion—CO\textsubscript{2} is being produced, but not transported to the lungs for exhalation which is the case in cardiac arrest. Other factors which affect CO\textsubscript{2} levels in exhaled air are inadequate production and the effects of CO\textsubscript{2} on the body, which will not be covered here.

Desired values can vary between sources; the 2010 American Heart Association Guidelines for CPR and ECC (AHA) indicates that in a patient with a perfusing rhythm the optimal values include EtCO\textsubscript{2} of 35-40 mmHg while the Journal of Emergency Medical Services and the International Trauma Life Support for Emergency Care Providers textbook indicates normal values will range from 35 to 45 mmHg.
For the purposes of this discussion, the use of EtCO₂ in procedural sedation, endotracheal tube confirmation and cardiopulmonary resuscitation will be covered.

**Equipment**

End-tidal measurements of exhaled gases can be captured in intubated patients and in spontaneously breathing patients with different disposable devices and a monitor designed to measure and display EtCO₂ levels. For non-intubated patients there are several styles, but all are designed to capture exhaled air for analysis. Some allow for the simultaneous administration of oxygen. Figure 2

In intubated patients, the collection device fits between the ET tube and the resuscitation bag or the ventilator. Figure 3 and Figure 4

Tubing from the device connects to the monitoring equipment which displays capnometry or continuous waveform capnogram or both.

The graph is compressed compared to the ECG and pulse oximetry. Since many monitors only display three to five seconds at a time and patients may only breathe once during that time span, having more information on the screen allows the clinician to more easily evaluate the waveforms. Figure 5 and Figure 6

**During Sedation**

A health care provider who depends on a pulse oximetry reading obtained via a probe placed on a finger to evaluate the respiratory status of a patient with strong pulses and healthy perfusion should realize that a delay of several minutes will elapse after the patient becomes apneic and before the oxygen saturation measured in the distal extremity decreases. During those same minutes, the patient with a pulse who is not breathing will continue to circulate blood with ever decreasing oxygen content. By the time the oxygen saturation is low enough in the blood passing under the finger probe to trigger an alarm, the blood circulating in the brain is already desaturated and cell damage can occur during this period of hypoxia.

A healthcare provider using EtCO₂ to evaluate respiratory status will be able to detect apnea by observing the absence of a capnogram immediately, even before there are changes in the exhaled gas composition and the change will be detected a significant time before oxygen saturation in the blood drops.

A patient experiencing respiratory depression will breathe less frequently or take shallower breaths. Hypoventilation allows CO₂ to build up in the lungs between breaths. When breathing is inadequate, the measured exhaled CO₂ level will rise.

If a patient is hyperventilating or is being hyperventilated, the CO₂ levels will fall. Campbell defines EtCO₂ levels of about 30-35 as hyperventilation.
Investigators suggested that EtCO₂ may add to the safety of procedural sedation not readily assessed by other means in the emergency department by quickly detecting hypoventilation. (Gravenstein)

It is presumed that early detection of diminished ventilation as evidenced by an increase in EtCO₂ or apnea, which will correlate with loss of the waveform, will prompt assessment of the patient and steps will be taken as needed to prevent desaturation instead of treating hypoxia after it occurs.

Intervention may include stimulating the patient, especially after the painful procedure or other manipulation is completed, but before the sedative has worn off. Other interventions which may be indicated include repositioning the patient’s head, inserting a nasopharyngeal airway (nasal trumpet or NPA) or an oropharyngeal airway (oral airway or OPA) in an unconscious patient, or initiating positive pressure manual ventilations with a self-inflating resuscitation bag.

Deitch et al declares that “In adults receiving ED propofol sedation, the addition of capnography to standard monitoring reduced hypoxia and provided advance warning for all hypoxic events.”

Proehl et al notes that “Negative outcomes associated with sedation are usually related to airway or respiratory issues. Unfortunately, the usual parameters monitored during sedation in the ED, vital signs and pulse oximetry (SpO₂), are late to respond to hypoventilation.” The authors also note that “It is common to use supplemental oxygen to increase the patient’s oxygen reserves before and during sedation. However, superoxygenated patients desaturate only after prolonged apnea.” In this case, there would be a delay before changes in EtCO₂ would be observed.

None of the measurements discussed here are meant to replace direct observation of a patient while undergoing procedural sedation and during the recovery period. EtCO₂ is a tool that can assist the health care provider to ensure healthy outcomes.

If a sedated patient is not breathing adequately try:

- Verbal or tactile stimulation
- Repositioning: Head Tilt/Chin Lift
- Repositioning: Jaw Thrust
- NPA
- OPA
- Manual ventilation with bag-mask
- Intubation

During intubation

Unrecognized esophageal intubation can be create long term disability or can be lethal.
“It is now clear that the incidence of complication is unacceptable high when intubation is performed by inexperiecned providers or monitoring of tube placement is inadequate” pS732

There have been updates in the standard of care to include additional assessments in intubation protocols. No one assessment is adequate to confirm proper endotracheal tube placement so a combination is indicated.

“Once an advanced airway is inserted, providers should immediately perform a thorough assessment…including visualizing chest expansion bilaterally and listening over the epigastrium and the lung fields bilaterally. A device also should be used to confirm correct placement.” pS731

“Continuous waveform Capnography is recommended in addition to clinical assessment as the most reliable method of confirming and monitoring correct placement of an endotracheal tube.” pS731

“Studies of waveform capnography to verify endotracheal tube position in victims of cardiac arrest have shown 100% sensitivity and 100% specificity in identifying correct endotracheal tube placement ” pS733

Based on the above quotes, it seems one can’t go wrong if capnography is used after intubation, but remember, EtCO₂ is dependent on ventilation and perfusion. The tube may be placed correctly and the patient may be ventilated adequately, but EtCO₂ will remain low when CO₂ is not being delivered to the lungs. This may include poor perfusion related to the arrest state and inadequate CPR, or in association with hypovolemia, acidosis, tamponade, pulmonary or coronary thrombosis, severe airway obstruction or pulmonary edema.

Improvement in a patient’s condition after intubation such as improved color and pulse oximetry readings would be an additional indication of proper tube placement while failure to improve does not mean a misplaced tube, it may be that the patient has diminished delivery of CO₂ to the lungs due to the factors listed above.

It is also worth noting that “False-positive readings have been observed in animals after ingestion of large amounts of carbonated liquids before the arrest; however, the waveform does not continue during subsequent breaths”. pS734

The readings can become unreliable if the device becomes contaminated with gastric contents or acidic drugs. Even water vapor can interfere with readings if allowed to obstruct the tubing.
What about the use of other advanced airways or blind insertion airway devices? The studies have not been done but the AHA says, “Effective ventilation through a supraglottic airway device should result in a capnographic waveform during CPR and after return of spontaneous circulation”. S734

Studies of colorimetric exhaled CO2 detectors and non-waveform EtCO2 capnometers indicate that the accuracy of these devices does not exceed that of auscultation and direct visualization for confirming the tracheal position of an endotracheal tube in victims of cardiac arrest. pS733

EtCO2 has become the standard of care in the pre-hospital setting to confirm and monitor ET placement. Unfortunately, in some settings, when the patient arrives at the hospital, EtCO2 is not continued and the continuous waveform monitoring is not utilized. If a health care provider does not have a mechanism to monitor tube placement, it can become displaced or dislodged without the provider noticing for some time, especially if there is dependence on pulse oximetry to detect hypoxia.

If the patient has adequate perfusion and the trachea is correctly intubated, the health care provider will observe a normal capnography tracing and capnometry levels between 35-45 mmHg. Subsequently, if the endotracheal tube becomes displaced sometime after successful intubation is confirmed, it will be reflected immediately in the tracing and the provider will have an opportunity to intervene before the patient becomes hypoxic.

If the endotracheal tube is too deep and the right mainstem is intubated, there will be capnography waveform, but the capnometry levels may be low, therefore it is still important to perform a physical assessment to determine the presence of bilateral breath sounds to confirm proper endotracheal tube placement.

- Direct visualization of the tube passing through the vocal cords
- Visualization of chest rise
- Auscultation of bilateral breath sounds
- Absence of epigastric gurgling
- Use of a confirmation device

“Continuous waveform capnography is recommended in addition to clinical assessment as the most reliable method of confirming and monitoring correct placement of an endotracheal tube.” PS733

**During resuscitation**

A patient in cardiopulmonary arrest has neither perfusion nor ventilation. In the early stages, oxygen is still being used by the cells and CO2 is still being produced but it is not being transported to the lungs and without ventilation, there is no exhalation.
In patients without a pulse and no perfusing rhythm, the EtCO$_2$ will remain flat, unless cardiopulmonary resuscitation is initiated, specifically compressions are performed. With successful resuscitation, including effective compressions and adequate ventilation, CO$_2$ should appear in the lungs and be available for measurement on exhalation.

The effectiveness of perfusion provided by external compressions during arrest can be evaluated by observing the compression depth and rate, adequacy of relaxation and minimization of pauses. A better way to evaluate the effectiveness of compressions includes measuring physiological parameters including ECG assessment, pulse checks, arterial pressure measurements via an arterial line, coronary perfusion pressure (CPP) via a central line, central venous oxygen saturation (Scvo$_2$) sampled via a central line or partial pressure of end-tidal CO$_2$ (EtCO$_2$) as measured via an endotracheal tube.

“If ETCO2 is <10 mm Hg, it is reasonable to consider trying to improve CPR quality by optimizing chest compression parameters.”

A normal EtCO$_2$ level of 34-45 would not be expected during cardiac arrest with manual compressions. Cardiopulmonary resuscitation is not as effective as a spontaneous rhythm but if EtCO$_2$ is less than ten, the compressor should press harder and faster while allowing full chest recoil and ensuring minimal interruptions.

“Although no clinical study has examined whether titrating resuscitative efforts to these or other physiologic parameters improves outcome, it is reasonable to consider using these parameters when feasible to optimize chest compressions and guide vasopressor therapy during cardiac arrest.” pS740

Providers should be aware that some medications can alter EtCO$_2$ readings for a short time after administration. For example, Sodium Bicarbonate is converted to water and CO$_2$ which will cause an increase in EtCO$_2$ readings. Vasopressors, including epinephrine, increase blood pressure and myocardial blood flow but will also decrease cardiac output causing a decrease in EtCO$_2$.

- Is there breathing?
- Is the tube in?
- Did the tube come out?
- Are compressions effective?
- Do we have a pulse?

It has already been discussed that a health care provider can use EtCO$_2$ to evaluate continued respiratory effort in a spontaneously breathing patient, confirm tube placement in a patient who is not breathing, monitor tube placement in ventilated patients and evaluate the effectiveness of manual compressions during cardiac arrest. There is one more instance where EtCO$_2$ can be informative.
When an abrupt and sustained increase in EtCO₂ is observed during CPR, indicating that more CO₂ is being delivered to the lungs, it could be a result of the patient having regained spontaneous circulation. It would be appropriate to assess the patient for an organized perfusing rhythm and to perform a pulse check.

![Figure 7](image_url)

The use of capnography in the pre-hospital setting and within the hospital is expected to increase. The nurse caring for sedated or intubated patients or patients experiencing cardiac arrest can gain valuable information on the status of those patients, in a non-invasive way, that could not be obtained by another method.
References


