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Captivating Capnography – The Basics of End-Tidal CO₂

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Capnography is most known for its use in confirming endotracheal tube placement and assessing the effectiveness of CPR. However, there are several other clinical scenarios where end tidal CO₂ (ET-CO₂) can provide us useful information.

Anatomy of an ET-CO₂ waveform

Before discussing uses of ET-CO₂, we must understand the normal capnography waveform. A normal ET-CO₂ waveform can be divided into four separate phases reflecting different stages of both inhalation and exhalation (Fig. 1a). The waveform takes on a quadrangular-shaped appearance. In the first phase, baseline CO₂ is near zero with inhalation of gas entering the airway. As exhalation begins, so does phase 2, with CO₂ levels rising from the mixing of gases between the anatomical dead space and alveolar dead/ventilated space. The most clinically relevant phase is phase 3 since this is where the actual ET-CO₂ is measured.

Phase 3 represents the alveolar plateau where there is a balance between ventilation and perfusion thus maintaining constant CO₂ levels. The last portion of phase 3 is the plateau. This is the maximum concentration of CO₂ and is also where the measured value for ET-CO₂ is obtained. In phase 4, CO₂ levels fall rapidly after the onset of the next inspiration. Understanding the basic waveform is important because any deviation could indicate a variety of potential problems involving cardiac output and respiratory function, for which we will now explore further.¹⁻⁵

Confirmation of endotracheal tube placement

Capnography is a rapid and effective method of confirming endotracheal tube placement when compared to other methods. Pulse oximetry, for example, takes a longer time to detect oxygen desaturation.^{2,6} Observing for endotracheal tube condensation can also be inaccurate, since it is present in up to 80% of esophageal intubations.⁷ Failure of proper tube placement is a common problem in the emergent care setting since as many as 5-10% of intubation attempts result in misplacement of the tube into the esophagus, causing increased morbidity and mortality.⁸ Proper tube placement can be confirmed within seconds using waveform capnography, by observing elevated CO₂ levels and a rectangular waveform. This indicates proper wave placement as compared to absent CO₂ levels and lack of waveform as occurs with esophageal intubation.^{3,5,6} (Fig. 1b)

Effectiveness of CPR

Interruptions in CPR to assess rhythm and return of pulse worsen outcomes.⁴ In accordance with 2020 American Heart Association ACLS guidelines, capnography can be an important quantitative method, in addition to clinical assessments, to provide real time feedback on the quality of CPR and return of spontaneous circulation.⁹ Waveforms with an ET-CO₂ of greater than 20 mmHg indicate adequate chest compressions, in a patient that still viable tissues, while an ET-CO₂ less than 10 mmHg signals inadequate technique or possible provider

fatigue.^{3,4} If ET-CO₂ levels remain below 10 mmHg for a prolonged period, despite good compressions, then return of spontaneous circulation is highly unlikely. This can be taken into account when determining futility of further resuscitative efforts.¹⁰ However, factors that affect cardiac output or the effectiveness of ventilation must be taken into consideration if there is a low ET-CO₂ during CPR. These include myocardial infarction, hemorrhagic shock, and pneumothorax.³ If ET-CO₂ levels rapidly rise to normal values (35-45 mmHg) then return of spontaneous circulation is likely.¹¹ The use of capnography for CPR should be used in addition to other management methods and not alone.¹²

Cardiac Output

Methods such as the passive leg raise (PLR) have been shown to be effective in monitoring fluid response in cases of shock. However, PLR requires a direct measure of cardiac index and relies on multiple factors such as echocardiography, arterial line waveforms or other invasive monitoring.^{4,13} If no instrument is accessible to analyze the effects of PLR on cardiac index, then ET-CO₂ can be an alternative method.^{3,13} ET-CO₂ changes caused by PLR have been shown to be better predictors of fluid responsiveness compared to arterial pulse pressure variations caused by PLR.^{3,4,13-15} Studies have shown that mechanically ventilated patients who are responsive to fluids, will have an ET-CO₂ increase of more than 5 percent.^{3,4,13-16} Additional studies exploring the relationship between capnography and fluid response will likely be an area of future investigation.

Respiratory

Capnography has been shown to have a potential role when it comes to recognizing COPD and

pulmonary embolism (PE). Difficulties exist with diagnosing a PE in both the ICU and emergency department, which often CTA scan is the gold standard and test of choice.^{3,4} Potential risks such as new cardiopulmonary complications can arise while waiting and transporting patients to get a CT scan.⁴ Other CT limitations include contrast use being relatively contraindicated in pregnancy, renal disease, and allergic reactions.¹⁷ Thus, capnography can be used as a potential, noninvasive, alternative method to increase suspicion of PE. When using capnography in evaluating a PE, the ET-CO₂ is expected to decrease due to the increase in alveolar dead space thereby decreasing the amount of CO₂ exhaled.^{3,4} In patients with relatively normal pulmonary physiology at baseline, using the differences between the displayed ET-CO₂ and PaCO₂ obtained from an ABG (late dead space fraction) could be suggestive of PE if this fraction exceeds 12 to 15 percent.^{3,18-20} (Fig. 1c) This fraction has further potential to be applied as a method of further assessment in low-risk PE patients as determined by Wells score.^{3,21,22}

When looking at the third phase in the waveform for COPD or asthmatic patients, a steeper slope is associated with the severity of airflow obstruction resembling a shark fin waveform appearance.^{3,4} (Fig. 1d) Because of this, capnography could have the potential in distinguishing between COPD and heart failure in an emergency medicine setting, by using a multitude of factors such as exhalation duration, end-exhalation ET-CO₂ slope, and maximum ET-CO₂ duration.^{3,4}

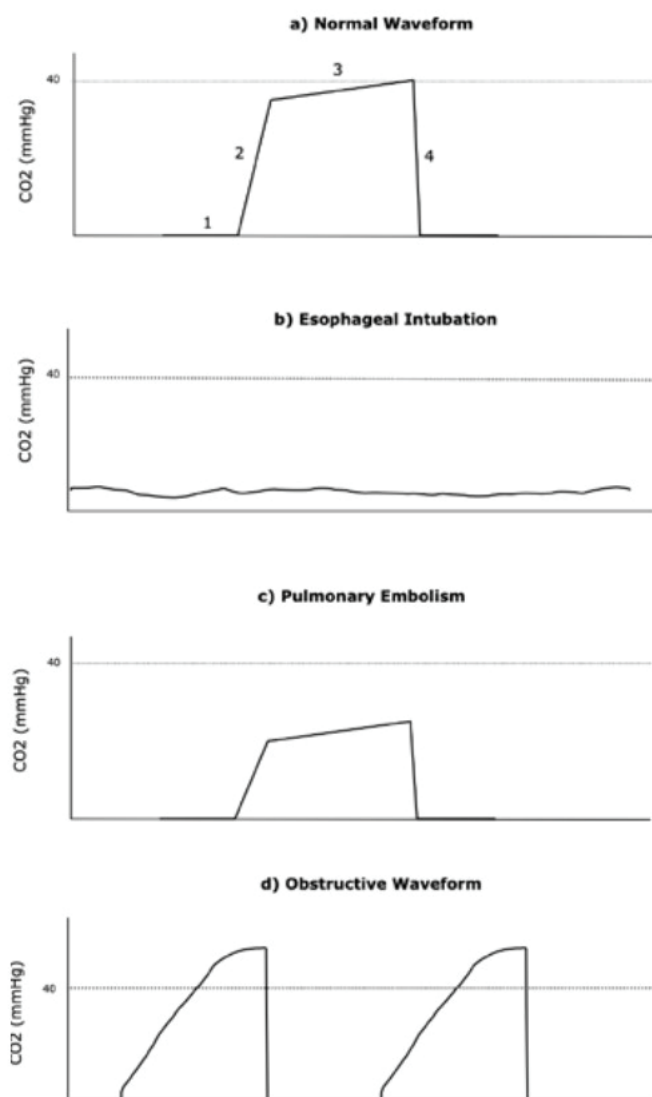


Figure 1 “End-Tidal CO₂ Capnography Waveforms”

Legend: a) displays the normal ET-CO₂ waveform illustrating the four phases. b) esophageal intubation – note the lack of quadrangular waveform, the ET-CO₂ is below the expected 40 mmHg. c) pulmonary embolism – phase 3 plateaus around 25 mmHg, this waveform combined with a normal PaO₂ should raise suspicion for a pulmonary embolism. d) the classic “shark fin” appearance of an obstructive process.

Procedural Sedation

Procedural sedation is a common practice in the emergency department and ICU. Changes in ET-CO₂ of > 10%, loss of capnography waveform or an increase of ET-CO₂ above 50 mmHg has been shown to precede hypoxia by a median time of 60 seconds.²³

It is important to note that although respiratory depression may cause hypercapnia, hypocapnia is equally concerning. Progressive hypocapnia secondary to reduced tidal volumes, specifically a decrease from baseline ET-CO₂ by more than 10 mmHg or loss of waveform are indicative of a patient at risk for developing severe respiratory depression.²⁴

COVID

With the high prevalence of COVID, the need for rapid diagnostic testing has resulted in the development of rapid COVID tests. Although not useful in the rapid detection of COVID, capnography may prove helpful in monitoring the severity and progression of COVID infection. As alluded to above, capnography has already been shown to be able to differentiate between different pulmonary diseases like COPD, asthma, PE and heart failure. Since the initial COVID presentation is often respiratory, capnography holds promise in being a simple, noninvasive method to rapidly assess the severity COVID. Capnography can provide real time monitoring and assessment of COVID patients, by evaluating changes to the waveforms such as slopes, shape changes, and duration at ET-CO₂.²⁵ Many limitations exist such as limited data, distinguishing waveform characteristics of COVID from other pulmonary diseases, requiring further investigation.

CONCLUSION

Capnography is not just limited to CPR and endotracheal tube placement. ET-CO₂ is likely underutilized and developing a basic understanding of the various waveforms will help enhance your clinical practice and care of critically ill ER and ICU patients.

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