



CAPNOGRAPHY IN RESUSCITATION:

PEAKS, VALLEYS, AND TRENDS—DO THEY SIGNAL THE END?



INTRODUCTION

Ninety-six minutes and 12 shocks. Those are the stats from a record-setting resuscitation effort that paid off. In January 2011, trained bystanders and paramedics performed CPR for more than an hour and a half and delivered a dozen shocks to a 54-year-old Minnesota man who collapsed outside a grocery store. They were inspired to keep going long after resuscitation efforts would normally have ceased because of the humble capnograph. The CO₂ readings from the machine indicated that CPR was working well, getting a good level of oxygen to the brain and other organs. The man, Howard Snitzer, survived neurologically intact and has gained a level of fame for sustaining the longest duration of pulselessness in an out-of-hospital cardiac arrest that resulted in a good outcome.

Documented in the Mayo Clinic Proceedings¹ Snitzer's story also appeared in The Wall Street Journal². In the first 35 minutes after his arrest, Snitzer received a total of 11 shocks. At that point, a helicopter dispatched from the Mayo Clinic and equipped with a capnograph arrived. Snitzer's CO₂ reading remained in the low 30s, not far from the low end of the normal range. At the 90-minute mark, the helicopter team made their fourth call to Mayo physician Roger White, an expert in the management of sudden cardiac arrest. The plan of action: one more dose of amiodarone and one more shock. If no change, the efforts would be halted. At 96 minutes post-arrest: success. A pulse was restored.

UBIQUITOUS, FAMILIAR, AND IMPORTANT: CO₂

We all know that carbon dioxide is an odorless, colorless gas. It gives carbonated drinks their fizz, can be used to extinguish fires, and is created as a byproduct of cellular metabolism.

Once metabolized, the CO₂ produced in our tissues diffuses into the venous blood, where it travels through the right side of the heart and eventually reaches the lungs. The primary function of the respiratory system is to exchange carbon dioxide for oxygen, with the CO₂ level peaking at the end of exhalation. This maximum concentration, known, as the end-tidal CO₂ (EtCO₂) level, can be measured noninvasively with a quick, disposable method or continuously with capnography.

Disposable monitoring methods, which rely on a color change to indicate CO₂ level, provide a snapshot. Capnography uses infrared technology to provide a continuous waveform (capnogram) and a digital readout of EtCO₂.

Figure 1

Normal capnography waveform

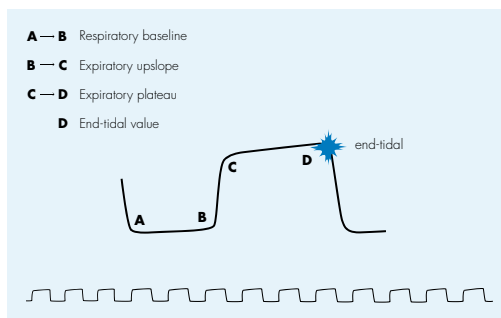
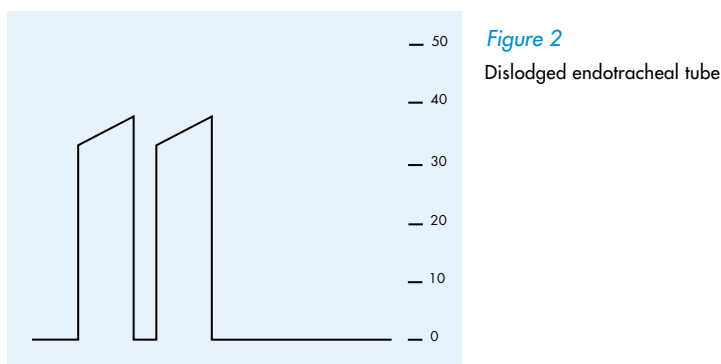


Figure 1 shows a textbook normal capnography waveform. Although disposable methods can be useful, the litmus paper responsible for the color change may be rendered useless by moisture in secretions from the patient. Alternatively, ventilation status can be gauged directly by measuring PaCO₂, the partial pressure of CO₂ in the arterial blood, but this is an invasive test and the data are not continuous. In addition, because of patient oxygenation, the pulse oximetry reading can remain artificially high for a period of minutes even though the airway is compromised.

The clinical focus on capnography started in the 1970s, and today, for patients who require intubation, it is the gold standard for confirming that the endotracheal tube has been placed correctly—and that it remains correctly placed.



If the tube does come out of place while transporting the patient, for example, the waveform will resemble that shown in Figure 2. A 2005 study evaluated the effectiveness of capnography in evaluating out-of-hospital intubation success. In the group that did not use continuous EtCO₂ monitoring, 23% of all endotracheal tubes were found to be misplaced when the patient reached the hospital, while in the group that used capnography, 0% were misplaced³.

EtCO₂ or SPO₂

For endotracheal placement and other applications, capnography has a number of advantages over another common monitoring method, pulse oximetry. EtCO₂ reflects ventilation. Pulse oximetry measures oxygen saturation levels, or SPO₂. Changes in EtCO₂ are seen rapidly because CO₂ diffuses across the capillary membrane in less than 0.5 seconds; you see what happened just half a second ago. Monitoring the level enables one to immediately detect apnea or hypoventilation. With pulse oximetry, there can be a 30- to 60-second delay in detecting either condition, and SPO₂ measurements can be affected by temperature and carbon monoxide. But monitoring should not be an either/or situation. Ventilation and oxygenation are equally important; capnography should be used in tandem with pulse oximetry.

While monitoring end-tidal CO₂ for ventilation issues is standard practice during surgery, that's not the case in the emergency department for patients undergoing procedural sedation and analgesia (PSA), where SPO₂ levels are typically monitored. A 2006 study found that EtCO₂ monitoring was superior to pulse oximetry for detecting acute respiratory events in emergency department patients who require PSA⁴. Abnormal EtCO₂ levels were documented before changes in SPO₂ or clinically observed hypoventilation in 70% of patients who experienced acute respiratory events.

Predicting the Future

The true potential of capnography is just being realized. Until recently, with the exception of respiratory therapists, many medical professionals didn't pay much attention to the EtCO₂ waveforms on the monitor. The fact is that patients frequently experience a slow decline rather than a dramatic dropoff. Capnography is a crystal ball of sorts, capable of picking up on a negative trend before changes are reflected in the patient's vital signs.

Because it indirectly measures cardiac output, capnography is also useful in assessing the efficiency of ongoing cardiopulmonary resuscitation (CPR) and can be an early indicator of return of spontaneous circulation (ROSC), evidenced by a sudden rise in EtCO₂. The 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care designate continuous EtCO₂ monitoring as a Class I recommendation⁵.

A reading between 35 and 45 mm Hg is generally considered normal. Levels above 45 indicate respiratory acidosis, which may be due to inadequate ventilation or over-sedation. Levels below 35 signal respiratory alkalosis, typically caused by hyperventilation.

In addition to cardiac arrest victims and those under sedation, patients who should be monitored with capnography include those with:

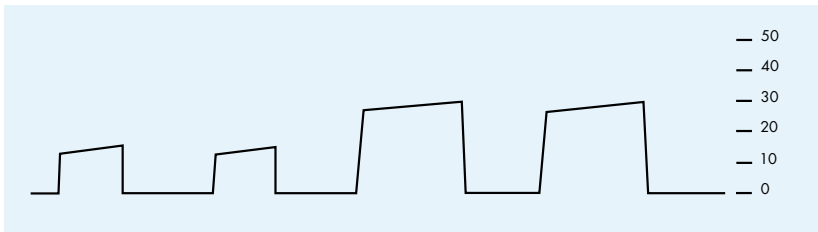
- A decreased level of consciousness
- Head injury
- Congestive heart failure
- Pulmonary embolus
- Asthma
- Chronic obstructive pulmonary disorder (COPD)

For intubated patients, EtCO₂ can be used: to verify endotracheal tube placement, to provide feedback regarding ventilations—too fast or too slow—and as an indicator of perfusion (ROSC, rescuer fatigue, and prediction of survivability).

For non-intubated patients, end-tidal CO₂ can be an early indicator of bronchospasms in patients with asthma, COPD exacerbation, or anaphylaxis. It can also indicate hypoventilation, caused by chronic heart failure, drug intoxication, respiratory fatigue, or circulatory compromise.

Capnometers come in two configurations, sidestream devices, which divert a sample of the patient's respired gas through a tube to a sensor, and mainstream, or nondiverting, devices that measure the gas at the sample site. A mainstream monitor attaches to the tip of the endotracheal tube and is intended for intubated patients, whereas the sidestream configuration can be used with all patients. However, sidestream monitoring may allow mixing of CO_2 with ambient air, and the length of the tubing can affect the reading.

Interpreting CO_2



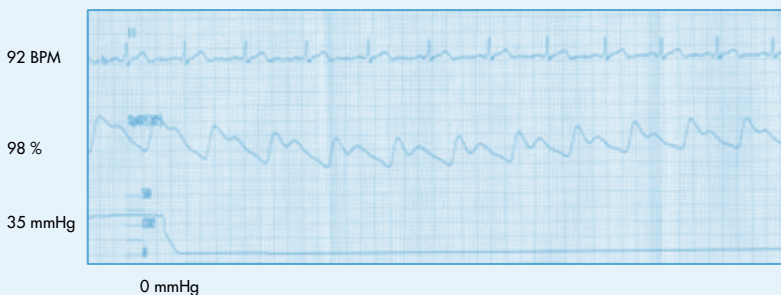
EtCO₂ increases, indicating ROSC

In Figure 3, we see a sudden increase in the end-tidal CO_2 level. This patient has limited CO_2 because her heart isn't beating. Then, all of a sudden, the CO_2 level starts to climb, signaling the return of spontaneous circulation. In one study, cardiac arrest survivors had an average EtCO₂ of 18 mm Hg 20 minutes into an arrest, while non-survivors averaged 6 mm Hg⁶. In another, survivors averaged 19 mm Hg, and non-survivors averaged 5 mm Hg⁷.

If a patient's EtCO₂ level is increasing, CO₂ clearance is decreasing. Besides ROSC, other potential causes include:

- Hypoventilation
- Fever
- Burns
- Hyperthyroidism
- Seizures
- Release of tourniquet/reperfusion

Figure 4



Now look at the strip shown in Figure 4. The heart rate is 92, so this patient is in the middle—not tachycardic or bradycardic. The oxygen saturation is normal at 98%. And the bottom reading, which starts at 35 mm Hg, is end-tidal CO_2 . A reading between 35 and 45 is good. But a few seconds later, it dips down and disappears. Although the heart rate and SpO_2 level are still fine, the EtCO_2 level indicates immediately that something is wrong.

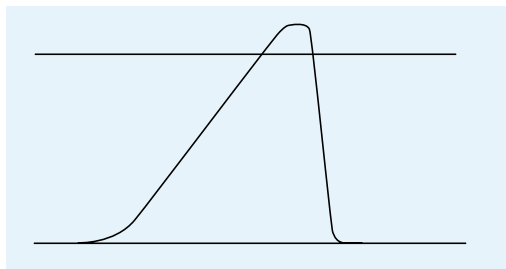


Figure 5

Kinked endotracheal tube

It could be as simple as the endotracheal tube having worked its way out, or it could be due to a wide range of other potential problems. If the endotracheal tube is kinked, the waveform will look like that shown in Figure 5.

*If EtCO_2 is decreasing,
 CO_2 clearance is increasing.
Potential causes include:*

- Hyperventilation
- Hypothermia
- Sedation
- Paralysis
- Decreased cardiac output
- V/Q mismatch

Hyperventilation Kills

Is it possible to hyperventilate a patient at eight breaths a minute? If a healthy person takes eight maximum capacity breaths in a minute for a period of five minutes, that person would be hyperventilated. So it is important not only to focus on the rate but the tidal volume as well. If the ventilator is the cause, vent setting changes are needed.

If you are manually ventilating a patient, it's hard to tell how fast or slow you're pushing air in without a feedback mechanism such as capnography. Studies have found that regardless of training, 37 is the magic number when it comes to ventilations. Paramedics, nurses, and doctors all ventilate an average of 37 times a minutes⁸.

V/Q Mismatch

The V (ventilation)/Q (perfusion) ratio is a measure of the adequacy of gas exchange in the lung—the ratio of the amount of air reaching the alveoli to the amount of blood perfusing them.

There are three types of V/Q mismatch that can lead to inadequate ventilation, inadequate perfusion, or both:

Physiological shunt ($V < Q$)

Alveolar dead space ($V > Q$)

Silent unit ($\downarrow V$ & $\downarrow Q$)

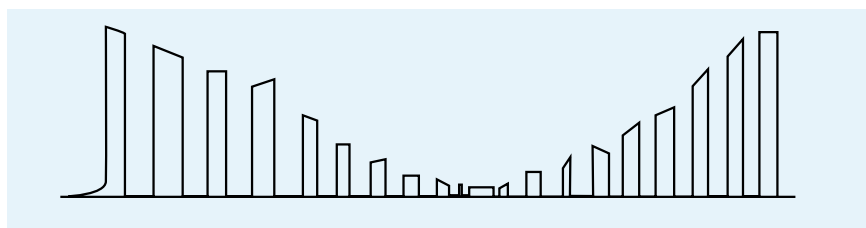
A physiological shunt occurs when blood is passing through the alveoli, but because of a diffusion problem, carbon dioxide is not being exchanged for oxygen. Causes include damaged alveoli, or if the patient has COPD, they may be blocked by mucus. Alveolar dead space often exists as the heart starts to fail; the alveoli are ventilated with fresh oxygen, but they are not perfused by the pulmonary circulation. And with silent V/Q mismatch, the patient is trending downward and is faced with both ventilation and perfusion problems.

As the story of Mr. Snitzer demonstrates, capnography can mean the difference between life and death. But CPR is hard work, and quality matters. In Figure 6, initially, the waveform is strong, with the EtCO_2 level at 10 to 15 mm Hg. But the capnogram is an indicator of fatigue, and as the rescuer who is performing CPR tires, the waveform plunges. If the EtCO_2 level falls below 10 mm Hg during CPR, another rescuer should take over CPR.

If you have a good, steady waveform that suddenly disappears, you can use the DOPE mnemonic to systematically evaluate potential causes. D stands for displaced tube; O for obstruction; P for pneumothorax; and E is for equipment.

Figure 6

This waveform shows that a rescuer performing CPR is getting fatigued and needs to be replaced.



Conclusion

A lot of information can be gleaned by measuring the simple gas exchange process of oxygen in, carbon dioxide out. End-tidal CO_2 has been shown to be superior to pulse oximetry in the early detection of esophageal intubation, especially if patients are preoxygenated with 100% oxygen. And, as the story of Howard Snitzer illustrates, capnography can play an important role in assessing the quality of CPR and determining when it is time to quit. Capnography is an important early warning system that can help us to forecast the future for our patients.

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