



ASK A SPECIALIST

Capnography: Assessing Ventilation During Anesthesia

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Capnography is the measurement and graphical recording of carbon dioxide (CO_2) concentration in exhaled gases. CO_2 is the major waste product of aerobic metabolism; it is circulated to the lungs for extraction and exhalation. Because CO_2 is highly soluble, it diffuses readily from the blood into alveoli, making arterial (PaCO_2) and alveolar (PACO_2) concentrations almost equivalent in healthy patients. Those concentrations provide information about a patient's metabolism, ventilation, and perfusion.¹ Ventilation is coordinated by the central respiratory center, central and peripheral chemoreceptors, and stretch receptors in the lungs. As PaCO_2 increases, neural outputs from the respiratory center increase alveolar ventilation to compensate, encouraging the exhalation of excess CO_2 . Alveolar ventilation is inversely proportional to PaCO_2 concentrations. As

alveolar ventilation doubles, more CO_2 is expired because of increased gas exchange, thus PaCO_2 is halved.

When a patient is anesthetized with inhalant anesthesia, normal feedback mechanisms are often impaired, which affects ventilation. Many anesthetic agents cause central nervous system depression and muscle relaxation, ultimately decreasing respiration. A patient's ventilation can be assessed by monitoring end-tidal CO_2 (ETCO_2) concentrations.

Other respiration and oxygenation monitoring modalities, such as visual observation and pulse oximetry, are inadequate for assessing ventilation and oxygenation status. Visual monitoring of chest excursions is extremely subjective and indicates only the presence of spontaneous breathing, not the quality

Abstract

Capnography measures the concentration or partial pressure of carbon dioxide in expired gases, which provides valuable information about a patient's ventilation and cardiovascular status. Anesthetic agents used for sedation and induction of general anesthesia often cause central nervous system depression, which can lead to hypoventilation and hypoxemia. Monitoring an anesthetized patient with capnography helps minimize the risk for a general anesthesia adverse event. This article discusses types of capnography systems, common capnograph waveforms, and ways to troubleshoot anesthesia complications associated with expired carbon dioxide.



Take-Home Points

- Many anesthetic agents cause respiratory depression, which commonly leads to hypoventilation, hypercapnia, and potentially hypoxemia.
- Hypoventilation, defined as elevated expired carbon dioxide, may be compounded by anesthesia drugs, obesity, and endocrinopathies.
- Adding capnography to a general anesthesia monitoring protocol can aid in early identification of complications, such as hypoventilation, and guide necessary interventions.
- Capnography waveforms can indicate if a patient is rebreathing carbon dioxide, apneic, or in cardiopulmonary arrest.
- Capnography waveforms can also indicate an airway obstruction and/or a leak in an endotracheal tube.
- The necessary adjustment for a patient that is rebreathing carbon dioxide depends on the type of patient circuit (rebreathing or nonrebreathing circuit).

of respiration. Pulse oximetry measures hemoglobin saturation but not ventilation. For example, in small dogs and cats that are breathing shallowly, pulse oximetry measurement may be within normal limits but the ETCO_2 concentration may be high due to hypoventilation.

Numerous complications can arise from hypoventilation and inadequate gas exchange. CO_2 acts as a sympathomimetic and can increase heart rate and blood pressure. At high levels (>70 mm Hg), CO_2 acts as a depressant and can decrease the amount of inhalant anesthetic needed. If a patient is poorly ventilated and supplemental oxygen is not provided, it will often become hypoxemic from increased PACO_2 . In addition, hypoventilation leads to respiratory acidosis, which

causes cerebral vasodilation and increases the likelihood of cardiac arrhythmias, central nervous system depression, and organ dysfunction.

What are the advantages of capnography?

The gold standard for assessing ventilation and oxygenation is arterial blood gas analysis. However, obtaining an arterial blood sample can be difficult. Furthermore, that analysis provides data from only 1 moment in time. In addition, point-of-care machines are often cost prohibitive.

Capnography provides a real-time measurement of ventilation with several key advantages. Capnography

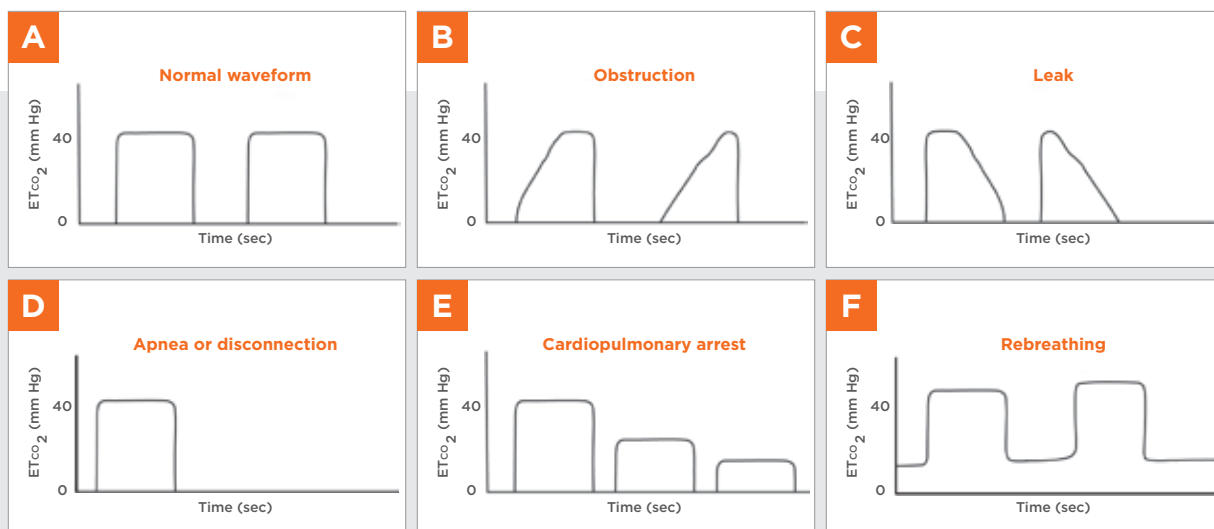


FIGURE 1. Examples of common capnography waveforms. The X-axis is time in seconds and the Y-axis is end-tidal carbon dioxide (ETCO_2) in millimeters of mercury (mm Hg). (A) Normal waveform; (B) obstruction; (C) leak in endotracheal cuff; (D) apnea or disconnection; (E) cardiopulmonary arrest; (F) rebreathing CO_2 .

Early identification of CPA is essential for immediate action and initiation of cardiopulmonary resuscitation.

can confirm correct placement of an endotracheal tube. Very little to no CO₂ is present in the esophagus, and an ETco₂ reading from esophageal intubation will be very low to 0. After intubation, correct tracheal placement can be corroborated by observing a breath and assessing the capnography waveform.

A normal waveform consists of an inspiratory phase, which should return to baseline or 0 mm Hg. An expiratory phase consists of a steep rise in CO₂, then a plateau and rapid return to baseline at the start of inspiration. Overall, a normal wave should resemble the shape of a top hat or square (FIGURE 1A). If the first side of the square is absent or has a sloped appearance (known as a “shark fin”), it indicates an obstruction, potentially from bronchoconstriction or secretions in the endotracheal tube (FIGURE 1B). If the back side of the square is absent, it indicates a leak in the system, often at the endotracheal tube cuff (FIGURE 1C). Early identification of these 2 waveforms can mitigate further complications from a complete airway obstruction and an unprotected airway. Abrupt loss of a waveform can indicate accidental extubation, disconnection from the breathing system, or apnea (FIGURE 1D).



FIGURE 2. A mainstream capnograph, the EMMA, displays the numerical value and capnography waveform.

Removing CO₂ from the lungs requires adequate cardiac output. In an anesthetized patient, substantial changes in cardiac output can result from numerous factors such as anesthesia drugs, vasodilation, bradycardia, and hypovolemia. A sudden decrease in cardiac output leads to decreased venous return to the lungs. That decreased return leads to decreased CO₂ delivery to the lungs, which causes a rapid and continual decrease in ETco₂. A clinical example of that scenario is cardiopulmonary arrest (CPA). An early identifier of CPA in an anesthetized patient is a sudden decrease in ETco₂ (FIGURE 1E). Early identification of CPA is essential for immediate action and initiation of cardiopulmonary resuscitation. During cardiopulmonary resuscitation, capnography can be a valuable monitoring tool for assessing quality of compressions, indicating degree of circulation to the lungs, and identifying return of spontaneous cardiac circulation.² When the heart beats on its own, a sudden increase in cardiac output causes a sudden increase in ETco₂.

Which is better: mainstream or sidestream capnography?

There are 2 common types of capnography devices used to measure CO₂.

With mainstream capnography, the patient breathes through a sensor attached to the endotracheal tube, displaying an almost real-time measurement of CO₂ (FIGURE 2). Disadvantages to mainstream capnography include the weight and bulk of the monitoring device, additional dead space, and potentially increased airflow resistance due to a narrower diameter.³ Dead space is any location in the breathing circuit in which airway gas flow is bidirectional and is between the end of the patient's nose and bifurcation of the Y-piece.

A sidestream capnograph aspirates a sample from the airway. Because CO₂ is measured at the monitoring device, away from the patient, there is a slight delay (2 to 3 seconds) between measurement and display. Also, tubing can become clogged with secretions and condensation. High oxygen flow rates can dilute the sample, leading to a falsely low CO₂ reading. Advantages of sidestream capnography include its lightweight design and better durability (FIGURE 3).

What does increased inspired CO₂ indicate?

Increased inspired CO₂ (> 5 mm Hg) or failure to



return to baseline (0 mm Hg) indicates that a patient is rebreathing CO₂ (**FIGURE 1F**). Rebreathing CO₂ can lead to increased PaCO₂. When troubleshooting an increase in inspired CO₂, consider the type of breathing circuit.

If a patient is rebreathing CO₂ in a rebreathing circuit, there are 3 common causes: exhausted CO₂ absorbent, stuck expiratory valve, and increased airway dead space. In a rebreathing circuit, lower flow rates are acceptable because CO₂ absorbent is within the system. Absorbent should be monitored and changed regularly (e.g., every week if surgery is daily) to avoid exhaustion. Inspiratory and expiratory valves ensure unidirectional airflow through a rebreathing system. These valves are often made of lightweight plastic, which are easily lifted by a patient's exhalation. Condensation can build up on an expiratory valve, causing it to stick and/or not close completely. Increased airway dead space can be caused by the addition of a mainstream capnograph, long endotracheal tubes, elbow tubing connectors, and spirometry sensors (**FIGURE 4**).

In a nonrebreathing circuit, fresh gas flow is essential for the delivery of inhalant anesthetics and oxygen, as well as the washout of expired CO₂. If fresh gas flow is too low, the washout will not be adequate; the patient

will rebreathe expired CO₂. The rate of recommended fresh gas flow for nonrebreathing systems varies slightly but should generally be 200 to 300 mL/kg/min. Increasing the oxygen flow rate until inspired CO₂ reads 0 mm Hg, or the capnography waveform returns to baseline, is the lowest acceptable flow rate.

What does increased ETco₂ (> 45 mm Hg) indicate?

Increased ETco₂ represents hypoventilation, often resulting from respiratory depression caused by anesthesia drugs such as opioids and inhalants. In addition, comorbidities impair ventilation in anesthetized patients. Patients with obesity, hypothyroidism, and hyperadrenocorticism may have increased abdominal fat and/or organomegaly, which can cause cranial displacement of the diaphragm and decrease thoracic wall compliance. These patients may require positive-pressure ventilation to ensure adequate oxygen and inhalant delivery and to reduce CO₂ levels. In healthy patients, mild to moderate hypercapnia (ETco₂ = 50 to 55 mm Hg) can be tolerated and support hemodynamic stability. For patients with

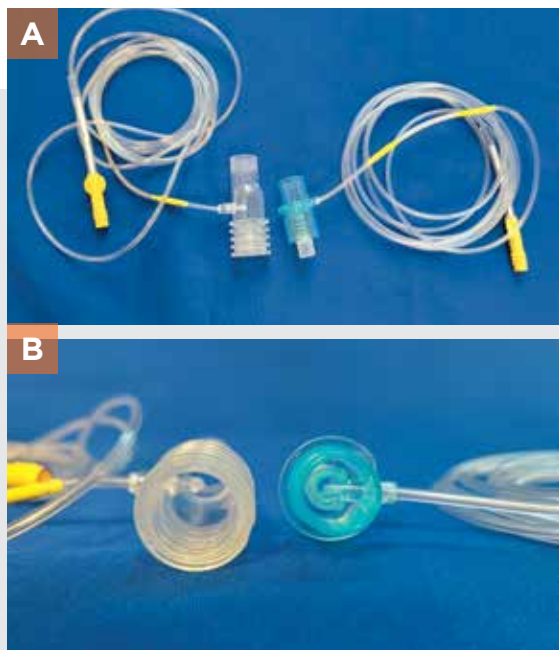


FIGURE 3. Examples of sidestream capnograph adapters. **(A)** Adult on the left and pediatric on the right. **(B)** A view of the inside shows the smaller diameter and decreased dead space of the pediatric adapter.



FIGURE 4. This patient has a large amount of dead space due to a long guarded endotracheal tube, spirometer, and elbow adapter. Equipment dead space can lead to rebreathing expired carbon dioxide.

ETCO₂ > 60 mm Hg, assisted ventilation may be necessary through either manual or mechanical ventilation.

What does decreased ETCO₂ (< 35 mm Hg) indicate?

Decreased ETCO₂ results from the washout of CO₂ in a nonrebreathing system, hyperventilation, or increased alveolar dead space. When a nonrebreathing system is used, a high oxygen flow rate can dilute expired CO₂ before sidestream capnography sampling, which can cause a falsely low ETCO₂ reading. Hyperventilation can result from a light plane of anesthesia, nociception, hyperthermia/fever, or hypoxemia. Troubleshooting hyperventilation requires evaluating anesthesia depth, pain, temperature, and/or oxygen saturation levels. If the suspected cause of hyperventilation is light anesthesia depth or pain, adding a sedative or opioid may help.

A sudden decrease in CO₂ can indicate CPA or pulmonary thromboembolism. Pulmonary

thromboembolism causes a sudden increase in alveolar dead space as a portion of the lung is ventilated but not perfused. Depending on the severity of pulmonary thromboembolism, desaturation, which is often identified by a decreased pulse oximeter reading, may occur after the sudden decrease in CO₂.

SUMMARY

Capnography is an essential monitoring tool. Continuous ETCO₂ monitoring provides a wealth of information about a patient's cardiorespiratory status. Familiarity with common capnography waveforms encourages early detection of potential anesthesia complications, which are more likely in sick patients yet also occur in healthy patients. Displaying references for common waveforms in rooms used for anesthesia may be helpful. By incorporating low-cost, minimally invasive, real-time continuous monitoring of CO₂ with capnography as a standard of care, complications can be detected early and corrections made swiftly, giving veterinary patients the best possible outcome. **TVP**

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Dr. Shippy graduated from the University of Missouri in 2017 where she also completed a master's of public health degree. She completed a rotating internship in small animal medicine and surgery at Louisiana State University. Continuing to pursue her interest in anesthesia, she completed an anesthesiology and pain management residency at the University of Florida where she also completed a master's degree in veterinary sciences in 2022. She has continued to work at the University of Florida as a clinical assistant professor. Her clinical interests include pain management techniques and exotic animal anesthesia.