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Capnography handbook

Respiratory critical care

CareFusion

About this handbook

This handbook has been prepared as a reference for healthcare professionals who are interested in capnography. It is divided into the following three sections:

- The clinical need for capnography based on the physiology and pathophysiology of respiration
- Technical aspects of capnography
- Examples and clinical interpretations of CO_2 waveforms

We hope this reference can enhance the use of capnography in the clinical setting.

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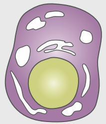
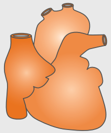
Respiration

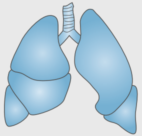
The big picture: The respiratory process consists of three main events:



Cellular metabolism of food into energy—O_2 consumption and CO_2 production.



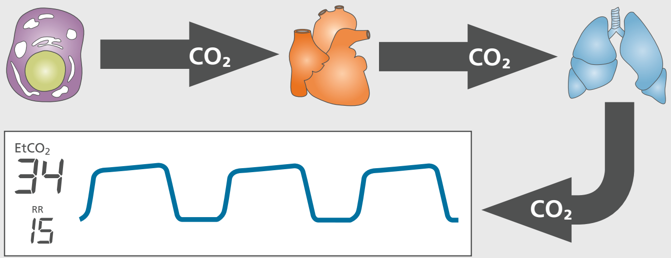
Transport of O_2 and CO_2 between cells and pulmonary capillaries, and diffusion from/into alveoli.



Ventilation between alveoli and atmosphere.

Capnography depicts respiration

As all three components of respiration (metabolism, transport and ventilation) are involved in the appearance of CO_2 in exhaled gas, capnography gives an excellent picture of the respiratory process.

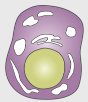


Note: *Of course, oxygenation is a major part of respiration and therefore must also be monitored in order to complete the picture. This may be accomplished through pulse oximetry, which is not covered in this handbook.*

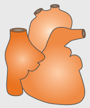
Factors affecting capnographic readings

The factors that may affect capnographic readings can be classified as follows:

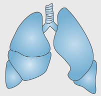
Physiologic



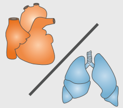
Factors which can affect CO_2 production include substrate metabolism, drug therapy and core temperature.



Factors affecting CO_2 transport include cardiac output and pulmonary perfusion.



Factors which can affect ventilation include obstructive and restrictive diseases, and respiratory rate.



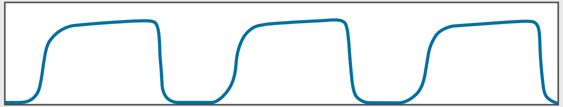
Ventilation-perfusion ratios (described on page 9) can also affect capnographic readings.

Factors affecting capnographic readings *(continued)*

Equipment

Ventilator settings and malfunctions, tubing obstructions, disconnections and leaks can all affect capnographic readings.

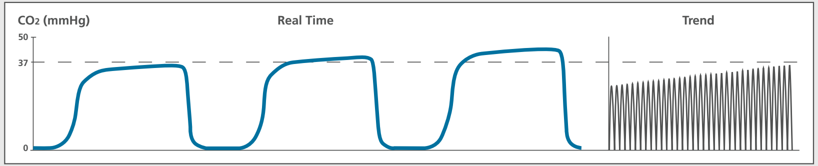
Sampling method and site, sample rate (if sidestream) and monitor (capnograph) malfunctions can affect capnographic readings.



Physiologic factors affecting $EtCO_2$ levels

Increase in $EtCO_2$

- Increased muscular activity (shivering)
- Malignant hyperthermia
- Increased cardiac output (during resuscitation)
- Bicarbonate infusion
- Tourniquet release
- Effective drug therapy for bronchospasm
- Decreased minute ventilation

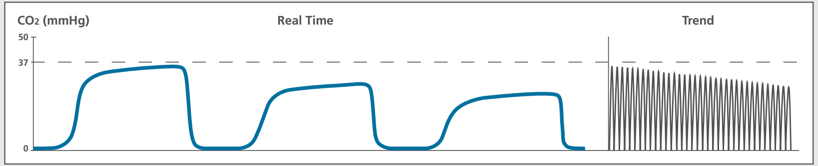


Factors affecting capnographic readings *(continued)*

Physiologic factors affecting $EtCO_2$ levels (continued)

Decrease in $EtCO_2$

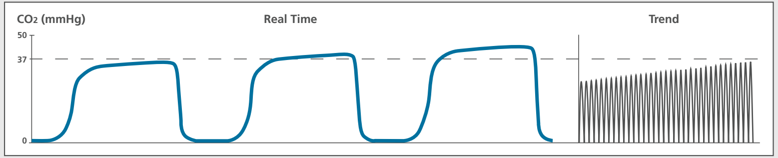
- Decreased muscular activity (muscle relaxants)
- Hypothermia
- Decreased cardiac output
- Pulmonary embolism
- Bronchospasm
- Increased minute ventilation



Equipment related factors affecting $EtCO_2$ levels

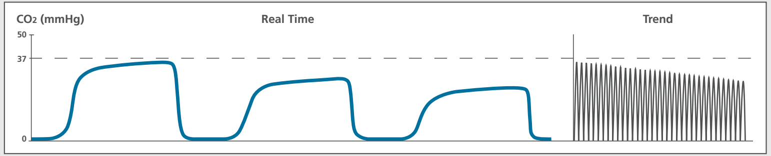
Increase in $EtCO_2$

- Malfunctioning exhalation valve
- Decreased minute ventilation settings



Decrease in $EtCO_2$

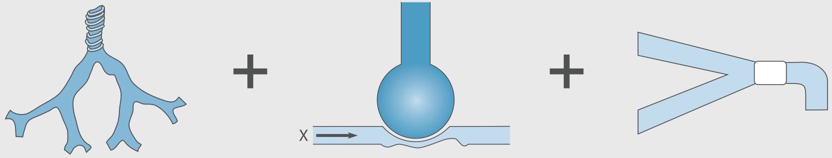
- Circuit leak or partial obstruction
- Increased minute ventilation settings
- Poor sampling technique



Dead space

Dead space refers to ventilated areas that do not participate in gas exchange. Total, or physiologic, dead space refers to the sum of the three components of dead space as described below:

Total (physiological) dead space =



Anatomic dead space refers to the dead space caused by anatomical structures (the airways leading to the alveoli). These areas are not associated with pulmonary perfusion and therefore do not participate in gas exchange.

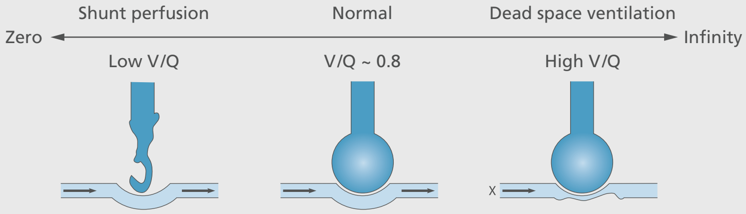
Alveolar dead space refers to ventilated areas that are designed for gas exchange (alveoli), but do not actually participate. This can be caused by lack of perfusion due to pulmonary embolism, blockage of gas exchange, cystic fibrosis or other pathologies.

Mechanical dead space refers to external artificial airways and circuits that may add to the total dead space during mechanical ventilation. Mechanical dead space is an extension of anatomic dead space.

Ventilation-perfusion relationships

The ventilation-perfusion ratio (V/Q) describes the relationship between air flow in the alveoli and blood flow in the pulmonary capillaries. If ventilation is perfectly matched to perfusion, then V/Q is 1. However, both ventilation and perfusion are unevenly distributed throughout the normal lung, resulting in the normal overall V/Q being 0.8.

Ventilation-perfusion spectrum



Shunt perfusion occurs under conditions in which alveoli are perfused but not ventilated, such as:

- Mucus plugging
- ET tube in mainstream bronchus
- Atelectasis

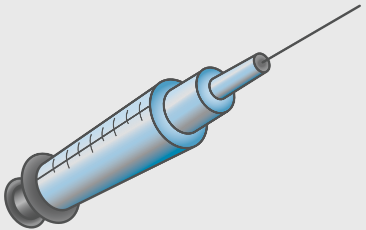
Dead space ventilation occurs under conditions in which alveoli are ventilated but not perfused, such as:

- Pulmonary embolism
- Hypovolemia
- Cardiac arrest

Normal arterial and end-tidal CO_2 values

Arterial CO_2 ($PaCO_2$)

from arterial blood gas sample (ABG)

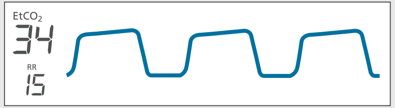


Normal $PaCO_2$ values:

35 to 45 mmHg

End-tidal CO_2 ($EtCO_2$)

from capnograph



Normal $EtCO_2$ values:

30 to 43 mmHg

4.0 to 5.7 kPa

4.0 to 5.6%

Note: Numbers shown correspond to sea level.

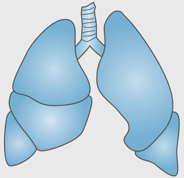
Arterial to end-tidal CO_2 gradient

Under normal physiologic conditions, the difference between arterial PCO_2 (from ABG) and alveolar PCO_2 ($EtCO_2$ from capnograph) is 2 to 5 mmHg. This difference is termed the $PaCO_2$—$PEtCO_2$ gradient or the a—$ADCO_2$ and can be increased by:

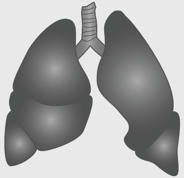
- COPD (causing incomplete alveolar emptying)
- ARDS (causing V/Q mismatch)
- A leak in the sampling system or around the ET tube

Arterial to end-tidal CO_2 gradient *(continued)*

With both healthy and diseased lungs, $EtCO_2$ can be used to detect trends in $PaCO_2$, alert the clinician to changes in a patient's condition and reduce the required number of ABGs.



With **healthy lungs** and normal airway conditions, $EtCO_2$ provides a reasonable estimate of arterial CO_2 (within 2 to 5 mmHg).



With **diseased/injured lungs**, there is an increased arterial to end-tidal CO_2 gradient due to V/Q mismatch. Related changes in the patient's condition will be reflected in a widening or narrowing of the gradient, conveying the V/Q imbalance and therefore the pathophysiological state of the lungs.

Display of CO_2 data

CO_2 data can be displayed in a variety of formats. The next few pages briefly describe:

Capnography vs. capnometry

- Definitions
- Capnography is more than $EtCO_2$

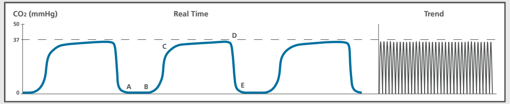
Display formats for end-tidal CO_2

- Quantitative vs. qualitative
- $EtCO_2$ trend graph and histogram

Capnography vs. capnometry

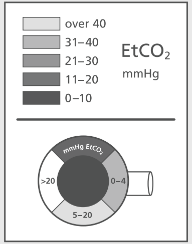
Definitions

Oftentimes, little or no distinction is made between the terms capnography and capnometry. Below is a brief explanation:



Capnography refers to the comprehensive measurement and display of CO_2 including end-tidal, inspired and the capnogram (real-time CO_2 waveform). A capnograph is a device that measures CO_2 and displays a waveform.

Capnometry refers to the measurement and display of CO_2 in numeric form only. A capnometer is a device that performs such a function, displaying end-tidal and sometimes inspired CO_2.



Capnography is more than $EtCO_2$

As previously noted, capnography is comprised of CO_2 measurement and display of the capnogram. The capnograph enhances the clinical application of $EtCO_2$ monitoring.

Value of the capnogram

The capnogram is an extremely valuable clinical tool that can be used in many applications, including, but by no means limited to:

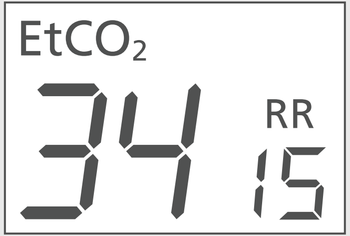
- Validation of reported end-tidal CO_2 values
- Assessment of patient airway integrity
- Assessment of ventilator, breathing circuit and gas sampling integrity
- Verification of proper endotracheal tube placement

Viewing a numerical value for $EtCO_2$ without its associated capnogram is like viewing the heart rate value from an electrocardiogram without the waveform. End-tidal CO_2 monitors that offer both a measurement of $EtCO_2$ and a waveform enhance the clinical application of $EtCO_2$ monitoring. The waveform validates the $EtCO_2$ numerical value.

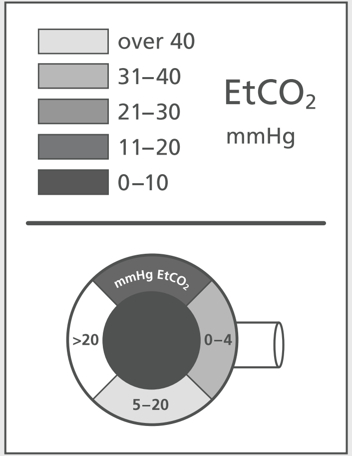
Quantitative vs. qualitative $EtCO_2$

The format for reported end-tidal CO_2 can be classified as quantitative (an actual numeric value) or qualitative (low, medium, high):

Quantitative $EtCO_2$ values are currently associated with electronic devices and usually can be displayed in units of mmHg, % or kPa. Although not absolutely necessary for some applications, such as verification of proper ET tube placement, quantitative $EtCO_2$ is needed in order to take advantage of most of the major benefits of CO_2 measurements.



Qualitative CO_2 measurements are associated with a range of $EtCO_2$ rather than the actual number. Electronic devices usually present this as a bar graph, while colorimetric devices are presented in a percentage range grouped by color. If the ranges are numeric, as is usually the case, it is said to be semiquantitative. These devices are termed CO_2 detectors and their applications are typically limited to ET tube verification.



$EtCO_2$ trend graph and histogram

The trend graph and histogram of $EtCO_2$ are convenient ways to clearly review patient data that has been stored in memory. They are especially useful for:

- Reviewing effectiveness of interventions such as drug therapy or changes in ventilator settings
- Noting significant events from periods when the patient was not continuously supervised
- Keeping records of patient data for future reference

An **$EtCO_2$ trend graph** is shown for a one hour time period.

An **$EtCO_2$ histogram** is shown for an eight hour time period. This format shows a statistical distribution of $EtCO_2$ values recorded during the time period.

Technical aspects of capnography

CO_2 measurement techniques

Various configurations and measurement techniques are currently available in devices that measure CO_2, some of which are briefly described below:

Infrared (IR) absorption

- Principle
- Solid state vs. chopper wheel
- Mainstream vs. sidestream sampling

Colorimetric detectors

- Principle

Other techniques not included in this discussion are mass spectrometry, Raman scattering and gas chromatography.

Infrared (IR) absorption

The infrared absorption technique for monitoring CO_2 has endured and evolved in the clinical setting for more than two decades and remains the most popular and versatile technique today.

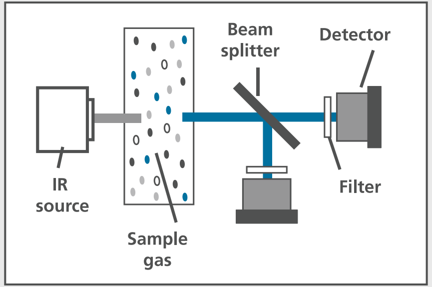
Principle

The principle is based on the fact that CO_2 molecules absorb infrared light energy of specific wavelengths, with the amount of energy absorbed being directly related to the CO_2 concentration. When an IR light beam is passed through a gas sample containing CO_2, the electronic signal from a photodetector (which measures the remaining light energy) can be obtained. This signal is then compared to the energy of the IR source, and calibrated to accurately reflect CO_2 concentration in the sample. To calibrate, the photodetector's response to a known concentration of CO_2 is stored in the monitor's memory.

Solid state vs. chopper wheel

Since the intensity of the IR light source must be known for a CO_2 measurement to be made, some method must be employed to obtain a signal which makes that correlation. This can be done with or without moving parts.

Solid state CO_2 sensors use a beam splitter to simultaneously measure the IR light at two wavelengths: one that is absorbed by CO_2 (data) and one that is not (reference). Also, the IR light source is electronically pulsed (rather than interrupting the IR beam with a chopper wheel) in order to eliminate effects of changes in electronic components. The major advantage of solid state electronics is durability.

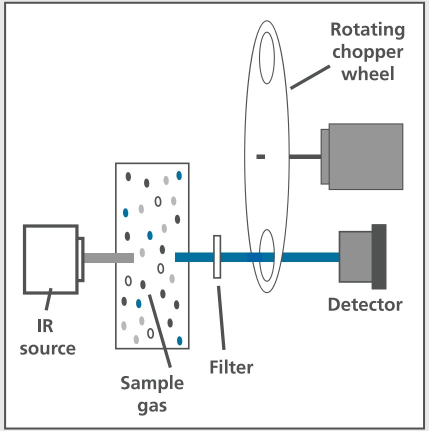


Infrared (IR) absorption *(continued)*

Solid state vs. chopper wheel (continued)

CO_2 sensors that are not solid state employ a spinning disk known as a chopper wheel, which can periodically switch among the following to be measured by the photodetector:

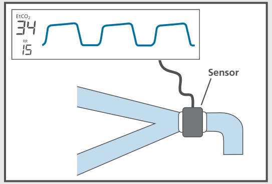
- The gas sample to be measured (data)
- The sample plus a sealed gas cell with a known CO_2 concentration (reference)
- No light at all
- Due to the moving parts, this type of arrangement tends to be fragile



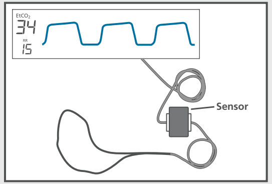
Mainstream vs. sidestream sampling

Mainstream and sidestream sampling refer to the two basic configurations of CO_2 monitors, regarding the position of the actual measurement device (often referred to as "the IR bench") relative to the source of the gas being sampled.

Mainstream CO_2 sensors allow the inspired and expired gas to pass directly across the IR light path. State-of-the-art technology allows this configuration to be durable, small, lightweight and virtually hassle-free. The major advantages of mainstream sensors are fast response time and elimination of water traps.



Sidestream CO_2 sensors are located away from the airway, requiring the gas sample to be continuously aspirated from the breathing circuit and transported to the sensor by means of a pump.

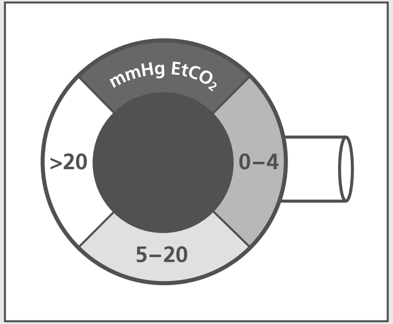


Colorimetric CO_2 detectors

Principle

Colorimetric CO_2 detectors rely on a modified form of litmus paper, which changes color relative to the hydrogen ion concentration (pH) present.

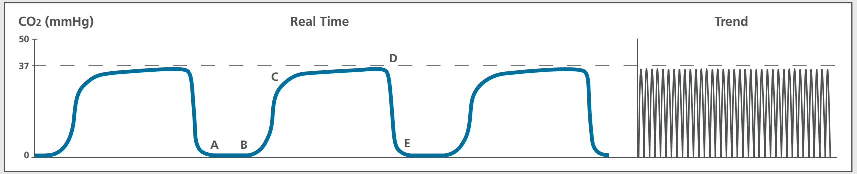
Colorimetric CO_2 detectors actually measure the pH of the carbonic acid that is formed as a product of the reaction between carbon dioxide and water (present as vapor in exhaled breath). Exhaled and inhaled gas is allowed to pass across the surface of the paper and the clinician can then match the color to the color ranges printed on the device. It is usually recommended to wait six breaths before making a determination.



Capnography examples and interpretations

Normal capnogram

The normal capnogram is a waveform that represents the varying CO_2 level throughout the breath cycle.



Waveform characteristics:

A–B Baseline

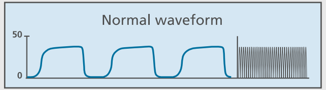
B–C Expiratory upstroke

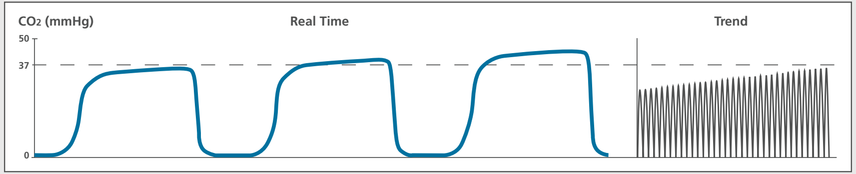
C–D Expiratory plateau

D End–tidal concentration

D–E Inspiration

Increasing $EtCO_2$ level



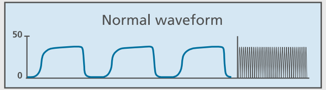


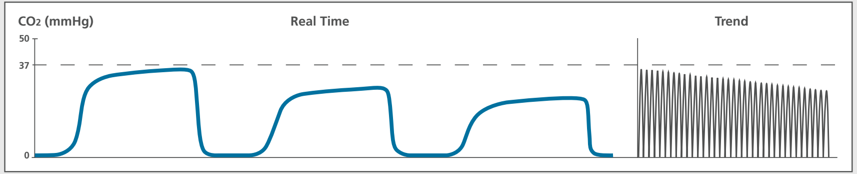
An increase in the level of $EtCO_2$ from previous levels.

Possible causes:

- Decrease in respiratory rate (hypoventilation)
- Decrease in tidal volume (hypoventilation)
- Increase in metabolic rate
- Rapid rise in body temperature (malignant hyperthermia)

Decreasing $EtCO_2$ level



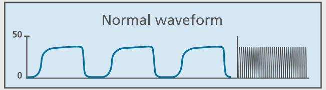


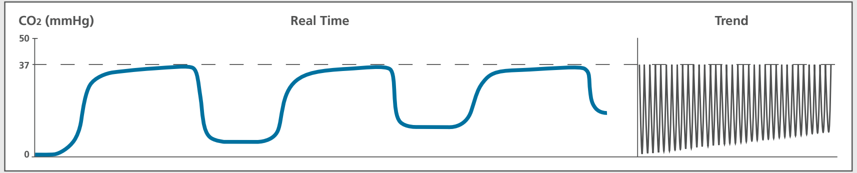
A decrease in the level of $EtCO_2$ from previous levels.

Possible causes:

- Increase in respiratory rate (hyperventilation)
- Increase in tidal volume (hyperventilation)
- Decrease in metabolic rate
- Fall in body temperature

Rebreathing



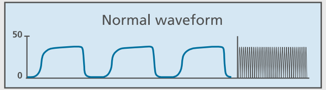


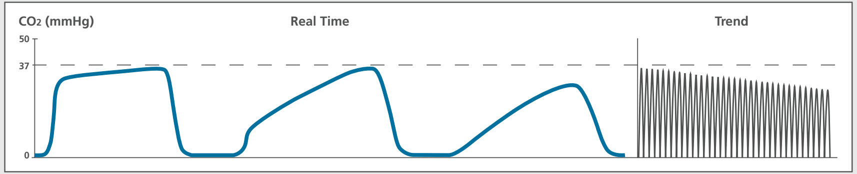
Elevation of the baseline indicates rebreathing (may also show a corresponding increase in $EtCO_2$).

Possible causes:

- Faulty expiratory valve
- Inadequate inspiratory flow
- Malfunction of a CO_2 absorber system
- Partial rebreathing circuits
- Insufficient expiratory time

Obstruction in breathing circuit or airway



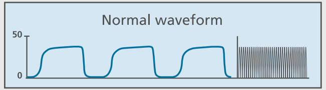


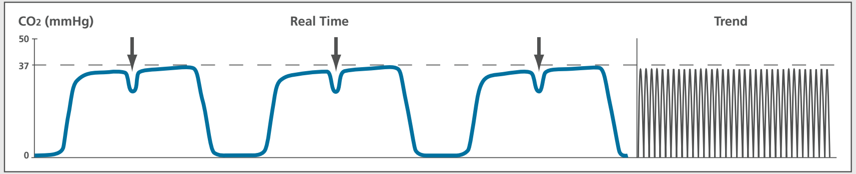
Obstructed expiratory gas flow is noted as a change in the slope of the ascending limb of the capnogram (the expiratory plateau may be absent).

Possible causes:

- Obstruction in the expiratory limb of the breathing circuit
- Presence of a foreign body in the upper airway
- Partially kinked or occluded artificial airway
- Bronchospasm

Muscle relaxants (curare cleft)



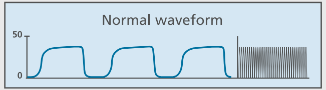


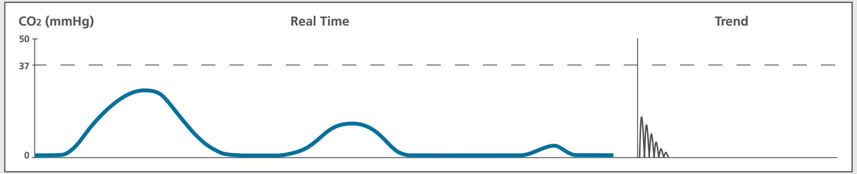
Clefts are seen in the plateau portion of the capnogram. They appear when the action of the muscle relaxant begins to subside and spontaneous ventilation returns.

Characteristics:

- Depth of the cleft is inversely proportional to the degree of drug activity
- Position is fairly constant on the same patient, but not necessarily present with every breath

Endotracheal tube in the esophagus

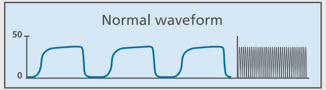


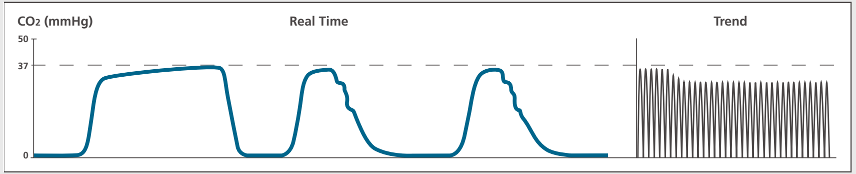


Waveform evaluation:

A normal capnogram is the best available evidence that the ET tube is correctly positioned and that proper ventilation is occurring. When the ET tube is placed in the esophagus, either no CO_2 is sensed or only small transient waveforms are present.

Inadequately sealed endotracheal tube



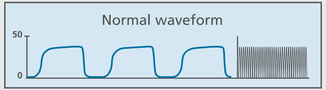


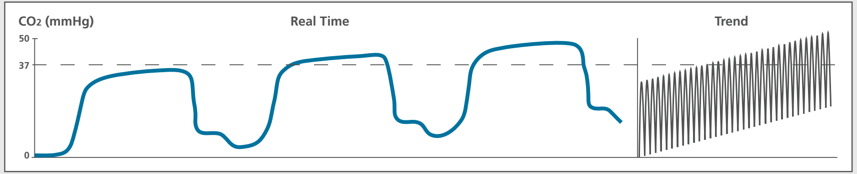
The downward slope of the plateau blends in with the descending limb.

Possible causes:

- An endotracheal or tracheostomy tube without a cuff or one that is leaking or deflated
- An artificial airway that is too small for the patient

Faulty ventilator exhalation valve

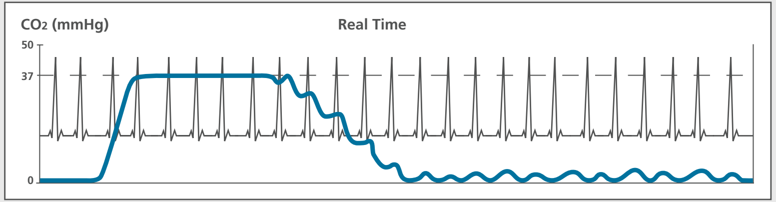




Waveform evaluation:

- Baseline elevated
- Abnormal descending limb of capnogram
- Allows patient to rebreathe exhaled gas

Cardiogenic oscillations



Cardiogenic oscillations appear during the final phase of the alveolar plateau and during the descending limb. They are caused by the heart beating against the lungs.

Characteristics:

- Rhythmic and synchronized to heart rate
- May be observed in pediatric patients who are mechanically ventilated at low respiratory rates with prolonged expiratory times

Glossary of terms

Capnography

Measurement and graphic as well as numeric display of carbon dioxide.

Capnometry

Measurement and numeric display of carbon dioxide.

Dead space

Area of the lungs and airways (including artificial) that do not participate in gas exchange.

End-tidal CO_2 ($EtCO_2$)

Peak concentration of carbon dioxide occurring at the end of expiration.

Pulmonary perfusion

Blood flow through the lungs (pulmonary capillaries).

Glossary of terms *(continued)*

Shunt perfusion

Areas of the lung that are perfused with blood, but not ventilated.

Substrate metabolism

Oxidation of carbohydrate, lipid and protein for energy.

Ventilation-perfusion ratio (V/Q)

Ratio of ventilation (air flow) to perfusion (blood flow).

Notes

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