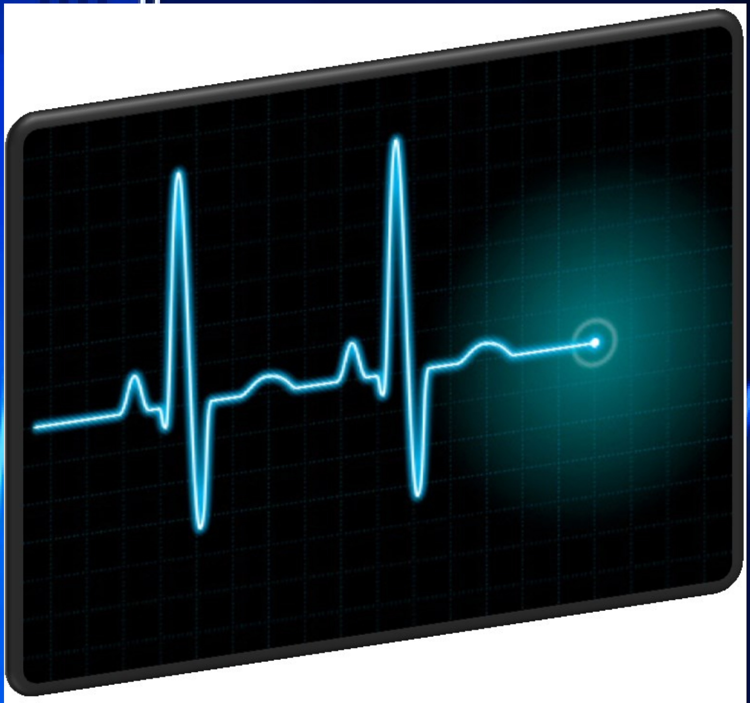
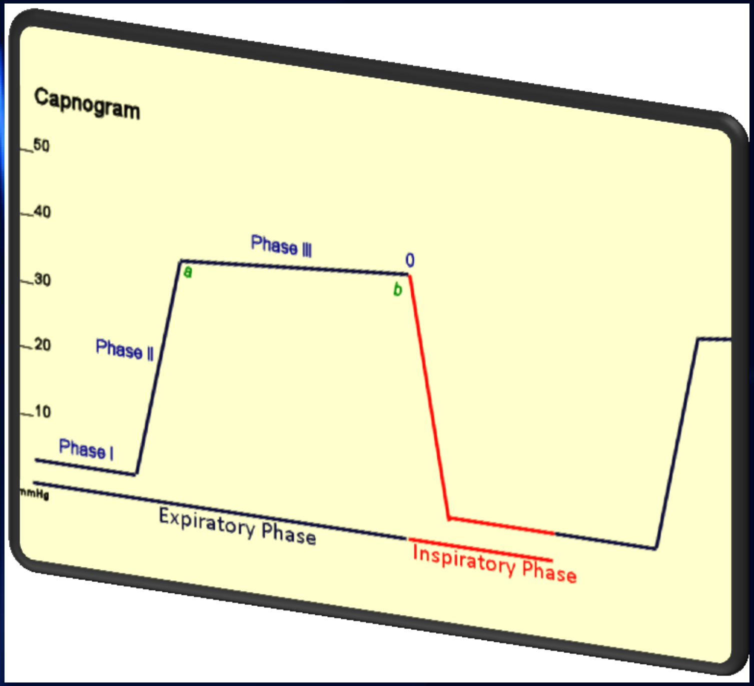
Capnography

The "Other" Vital Sign

4th Edition





Capnography

Capnography

BreathSounds

Because at the Head of Every Team

IS a

Respiratory Therapist

Capnography

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Capnography

Welcome to the 4th Edition of Capnography – The "Other" Vital Sign

For many years taking your patients vital signs has been a standard of practice in all areas of healthcare, from pre-hospital to extended care, and everywhere in between. In today's world of advanced medical education and technology a new vital sign has been gaining popularity in almost all patient care settings. It is the vital sign of ventilation – Capnography…

In earlier years capnography was widely misunderstood by healthcare professionals. It was believed by many that capnography was intended to provide an estimate of P_aCO^2, but that was never the intention. In the years to follow that *misconception* has earned capnography a *bad-rap* in almost all areas of the healthcare community. The purpose of this program is to give you a more accurate understanding of what capnography really is, what kind of information you can learn from it, and how you can use that information to better care for your patient.

Capnography

- Capnography refers to the study and measurement of carbon dioxide in exhaled gas.
- Capnography was first introduced by Karl Luft, a German bioengineer, in 1943 with an infrared CO^2 (*carbon dioxide*) measuring device he called URAS, or "Ultra Rot Absorption Schreiber" (Infrared Absorption Writer)
- It was big, heavy, and very impractical to use.
- Over the years capnography has evolved many times, as did the technology used to measure it.
- According to a study by the American Society of Anesthesiologists 93% of all avoidable anesthesia related incidents could have been prevented with the use of capnography in conjunction of pulse oxymetry.
- In 1998 the ASA (*American Society of Anesthesiologists*) Committee on Standards of Care deemed it mandatory that all patients receiving general anesthesia be continuously monitored for $P_{ET}CO^2$ (Partial Pressure of *End Tidal Carbon Dioxide*)
- Today capnography is successfully used in almost all areas of health care.

Capnography

- *Pre-Hospital* – Paramedics frequently use carbon dioxide detection devices to assist them in assuring an endotracheal tube is properly placed.
- *Emergency Medicine* – Capnography is frequently used to assure proper ET tube placement, trend for adequate ventilation during mechanical ventilation, and that the heart rhythm on the monitor is not PEA.
- *Critical Care Medicine* – In the ICU capnography can be used to trend ventilation during mechanical ventilation, watch for changes in dead space ventilation, and watch the progress of many pulmonary related disease processes.
- *Cardiopulmonary Arrest* – During CPR capnography can be used as a predictor of survivability, to check for adequate cardiac output during chest compressions, and as an indicator of PEA if a heart rhythm return on the monitor.
- *Procedural Sedation* – During conscious sedation capnography is a much faster indicator of changes in respiratory status than pulse-oxymetry. It can take several minutes for SaO^2 to change, but E_TCO^2 changes almost immediately.
- *Anesthesia* – Capnography in the OR has been a standard of care since 1998. It is used to maintain adequate ventilation, watch for drastic changes in dead space ventilation, and assure the presence of adequate cardiac output during surgery.

Capnography

Definitions

- Capnography – A graphical display of CO^2 concentration over time or expired volume.
- Capnogram – CO^2 waveform either plotted against a volume (CO^2 expirogram) or against time (time capnogram).
- P_ACO^2 – Partial pressure of carbon dioxide in the alveoli.
- P_aCO^2 – Partial pressure of carbon dioxide in arterial blood.
- $P_{ET}CO^2$ – Partial pressure of carbon dioxide at the end of expiration.
- $P_{(a\text{-}ET)}CO^2$ – The difference between P_aCO^2 and $P_{ET}CO^2$. Sometimes called the "CO^2-diff", or "CO^2 gradient".
- P_VCO^2 – Partial pressure of carbon dioxide in venous blood.

Capnography

- To understand capnography you MUST understand that "*Oxygenation*" and "*Ventilation*" are two entirely different mechanisms that both rely on the respiratory cycle.
- Oxygenation relies on the *inspiratory* phase and refers to the amount of oxygen (O^2) available and utilized.
- Ventilation relies on the *expiratory* phase and refers to the amount of carbon dioxide (CO^2) produced during the metabolic cycle of the cells, and exhaled from the body.
- Oxygenation and ventilation are BOTH needed, in proper proportion, to sustain an adequate and safe quality of life.

Capnography

Determination of Oxygenation Status:

Invasively an arterial blood gas (ABG) can be obtained which measures, among other things, the P_aO^2 (Partial Pressure of Oxygen dissolved in the blood plasma of arterial blood).

Non-Invasively a pulse oxymetry can be obtained which measures the amount of oxygen that is bound to the hemoglobin.

Capnography

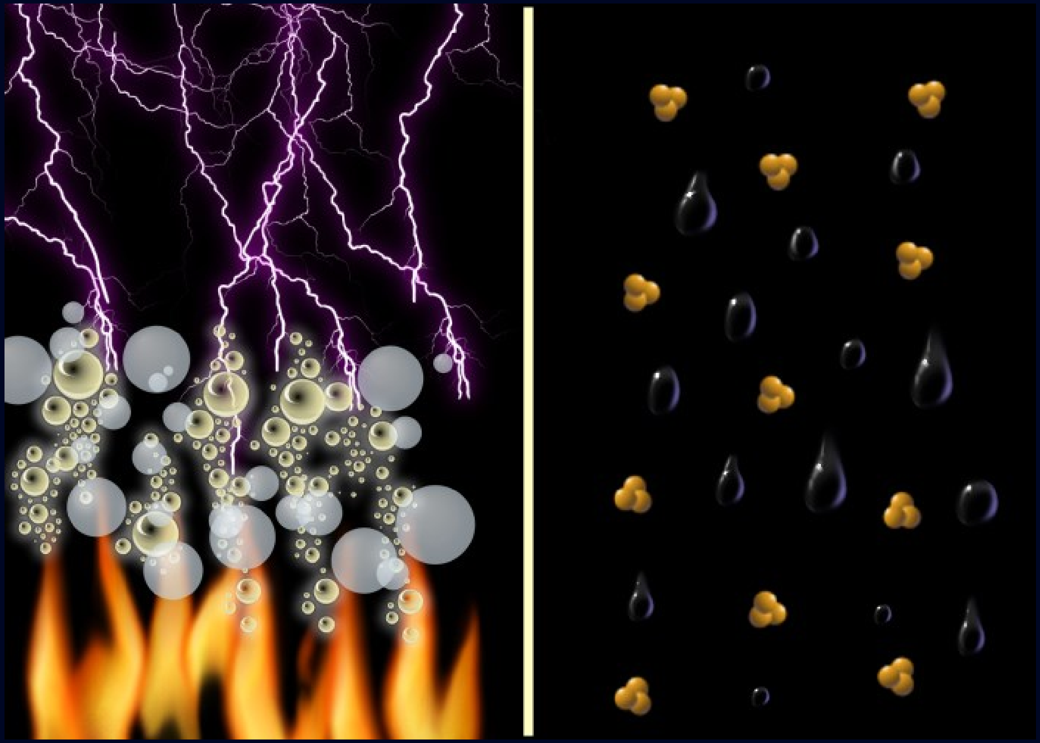
Determination of Ventilation Status:

Invasively the same arterial blood gas (ABG) sample that measures the P_aO^2 also measures the P_aCO^2 (Partial Pressure of carbon dioxide dissolved in blood plasma of arterial blood).

Non-Invasively the $P_{ET}CO^2$ (Partial pressure of carbon dioxide in exhaled gas) can be measured. This is measured breath by breath at the end of the expiratory phase of respiration.

Capnography

Basic Capno-Physiology



Capnography

- Production of carbon dioxide is a result of cellular metabolism.
- During normal aerobic cellular metabolism carbon dioxide is produced when we burn glucose and oxygen to produce energy in the form of adenosine triphosphate (ATP).
- Just like a combustion engine that burns fuel for power, there is also exhaust, or waste, produced.
- The exhaust, or waste products, of aerobic cellular metabolism are mostly water (H^2O) and carbon dioxide (CO^2).
- The excess water is eventually transported to the kidneys where is it converted to urine, which leaves the body during urination.
- The carbon dioxide is transported to the lungs where it diffuses across the alveolar capillary membrane and leaves the body during the expiratory phase of respiration.

Capnography

Methods of Monitoring

The most common methods used for detecting and measuring carbon dioxide in exhaled gas are:

- Chemical colorimetric analysis – Most commonly used in the pre-hospital setting
- Infrared Spectrography – Most commonly used in the hospital setting
- Molecular Correlation Spectrography (Microstream technology)

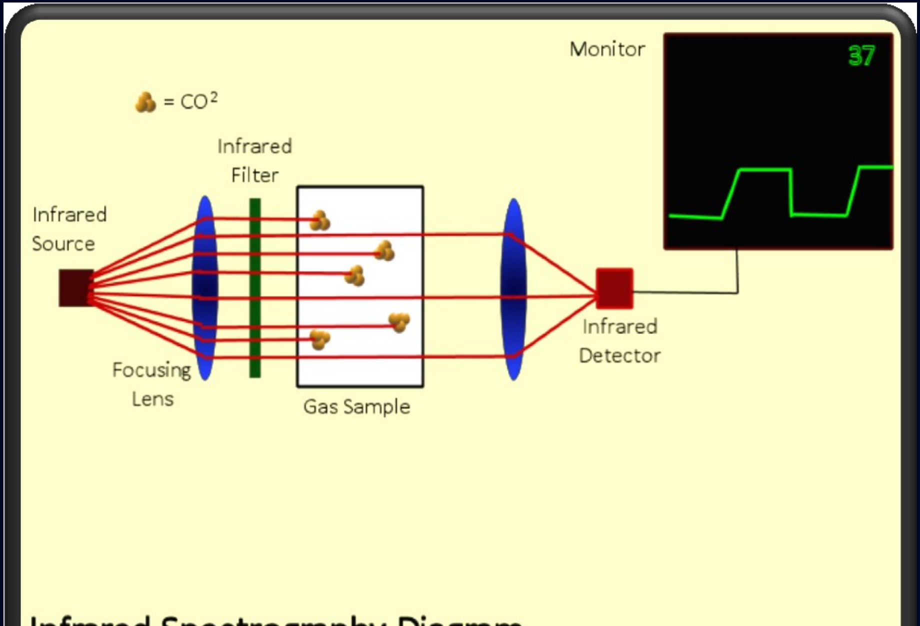
Other methods used are:

- Raman Spectrography
- Mass Spectrography
- Photo-acoustic Spectrography

Capnography

Infrared spectrography, the technology used most CO^2 monitors, works on the principal that carbon dioxide selectively absorbs a known amount of infrared light of a specific wavelength (4.3 milli-microns). The amount of light absorbed is directly proportional to the concentration of carbon dioxide molecules. A predetermined amount of infrared light is sent from the emitting side of the sensor through a gas sample and collected on the receiving side of the sensor (the receiving side of the CO^2 sensor is an IR detector). The infrared light received is compared to the infrared light transmitted. The difference is then converted by calculations into the partial pressure that you see on the monitor. Some models also calculate the difference into a percentage of total gas concentration.

Infrared Spectrography



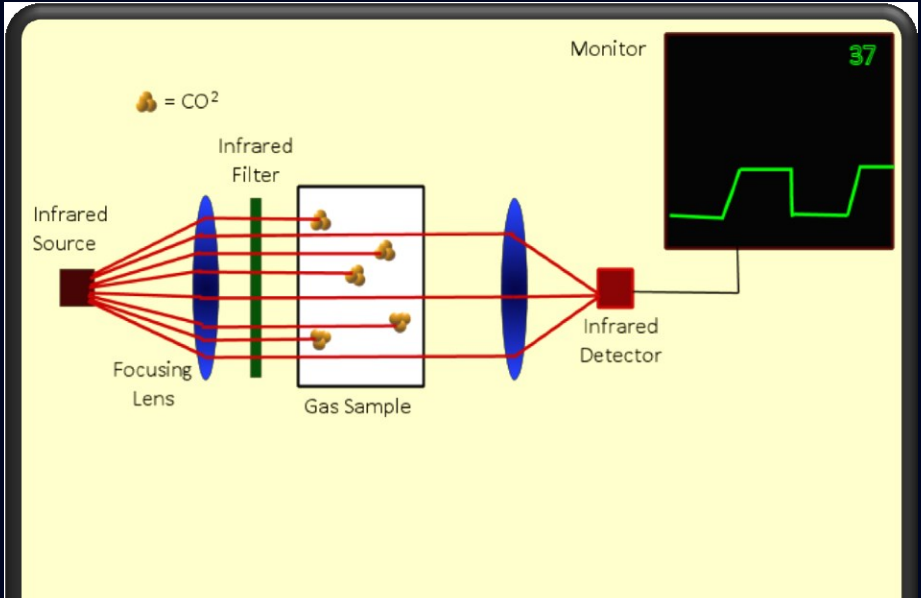
Infrared Spectrography Diagram

Capnography

Advantages of CO^2 Monitors:

- Provides a measured concentration of carbon dioxide present in the gas sample.
- Provides a breath by breath waveform and measurement that can be used to help determine your patients airway and gas exchange condition.
- Waveform and numbers can be trended to monitor patients progress.
- Can detect, measure, and monitor very small amounts of CO^2 in exhaled gas (less than 1%).
- Can accurately measure CO^2 during CPR.
- CO^2 monitors can be used continuously.

Infrared Spectrography



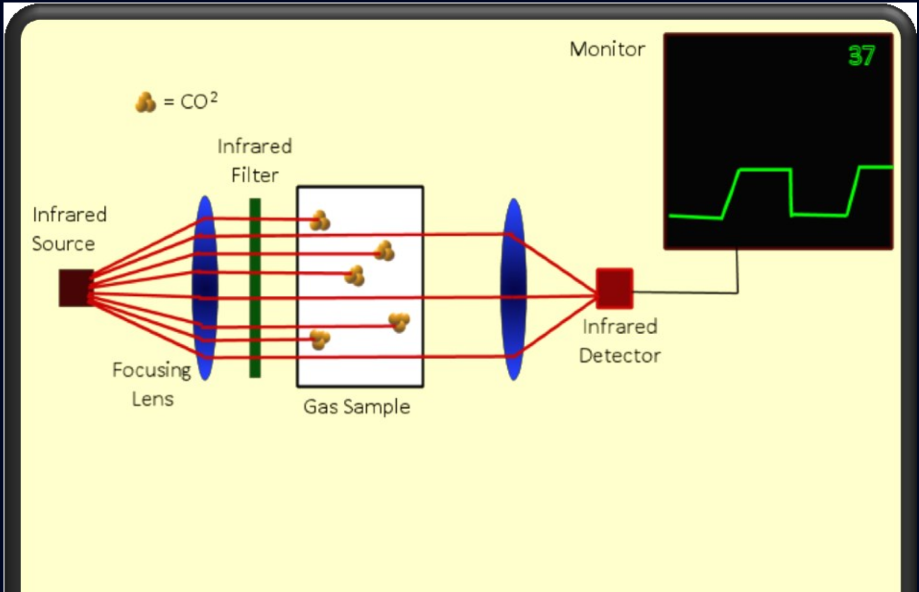
Infrared Spectrography Diagram

Capnography

Disadvantages of CO^2 Monitors:

- Takes longer to show results after endotracheal intubation.
- Sensors can be bulky or heavy on the end of the ET tube.
- Sampling tubing or electrical line attached to the ET tube can increase risk of accidental extubation, creating a sudden unexpected airway emergency.
- Most units require some maintenance and supplies (batteries, airway adapters, etc…).
- Can be expensive.

Infrared Spectrography



Infrared Spectrography Diagram

Capnography

Chemical colorimetric analysis uses a pH-sensitive chemical indicator inside a device that is placed between an endotracheal tube and a breathing circuit, such as a manual respirator or a ventilator circuit. This indicator changes color breath by breath. It turns yellow when it's exposed to a carbon dioxide concentration of 4% or greater, and purple when it's exposed to room air that contains no carbon dioxide.

These devices are good for quick determination of the presence of CO^2 but are not sensitive to low concentrations of CO^2, as is the case during CPR or other low cardiac output situations.

There are also a few disadvantages to using colorimetric devices…

Chemical Colorimetric Analysis

CO^2 Not Present

CO^2 Present

Capnography

Advantages of Colorimetric Devices:

- Very portable devices can easily be stored until needed.
- Quick and easy to use.
- Good for quick determination of ET tube placement during endotracheal intubation.
- Very light weight, putting little to no stress on the end of the ET tube.

Chemical Colorimetric Analysis

CO^2 Not Present

CO^2 Present

Capnography

Disadvantages of Colorimetric Devices:

- Colorimetric devices are for short-term use only (< 30”). When they become too wet from water vapor in exhaled gas they will stop functioning.
- These devices do not measure carbon dioxide. They only respond to the presence of carbon dioxide in the sample.
- In the event of an esophageal intubation a colorimetric CO^2 detection device will show a false positive to carbon dioxide if your victim has consumed carbonated beverages just prior to intubation.

Chemical Colorimetric Analysis

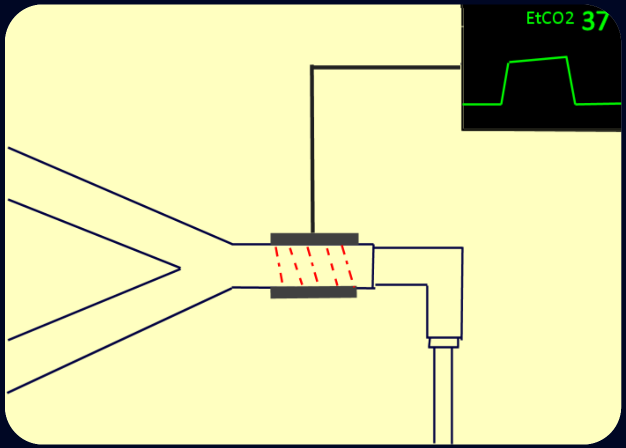
CO^2 Not Present

CO^2 Present

Capnography

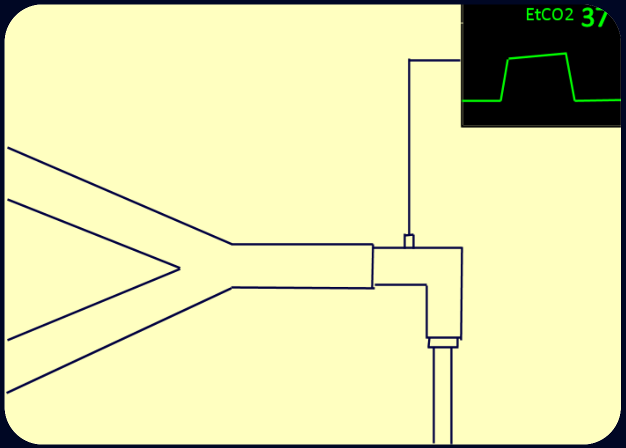
The 2 Types of Capnometers

Mainstream



The infrared sensor is in the direct path of the gas source, and connected to the monitor by an electrical wire.

Sidestream

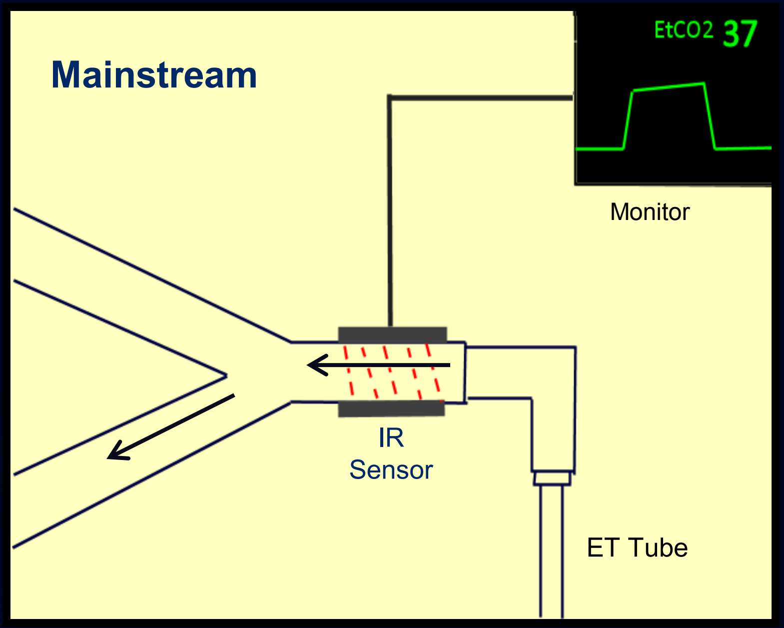


The sample of gas is aspirated into the monitor via a lightweight airway adapter and a 6ft length of tubing. The actual sensor is inside the monitor.

Capnography

Mainstream – Advantages

Mainstream

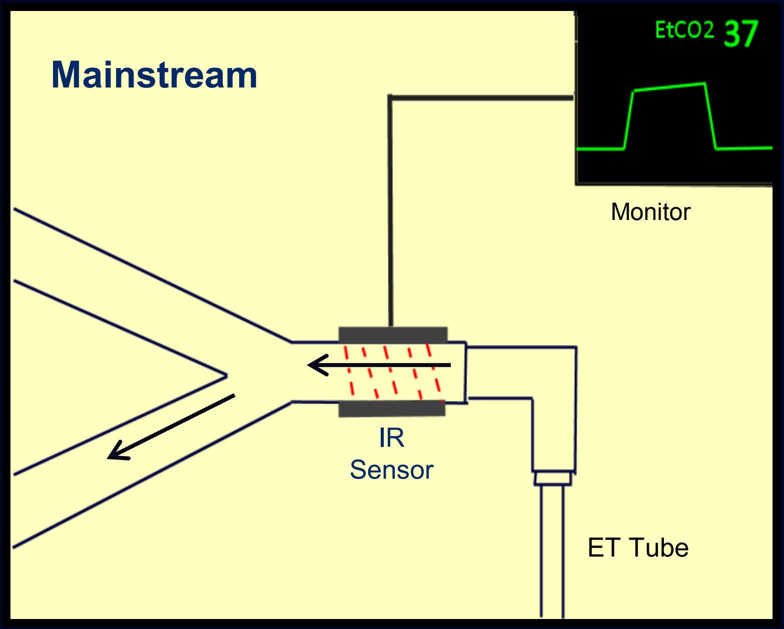


- NO sampling tube to become obstructed.
- No variation due to barometric pressure changes.
- No variation due to humidity changes.
- Direct measurement means waveform and readout are in *'real-time'*. There is no sampling delay.
- Suitable for pediatrics and neonates.

Capnography

Mainstream – Disadvantages

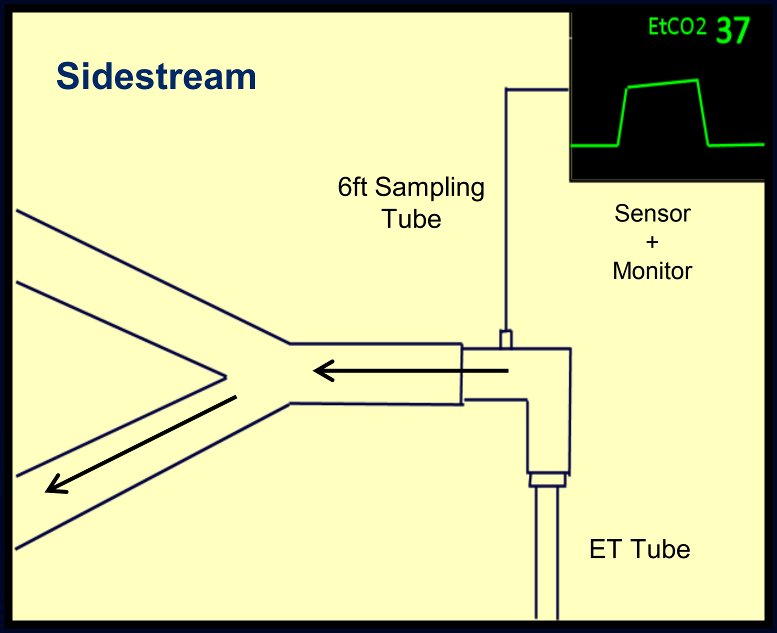
Mainstream



- The airway adapter sensor puts weight at the end of the endotracheal tube that often needs to be supported.
- In older models there were minor facial burns reported.
- The sensor windows can become obstructed with secretions and water rainout.
- Sensor and airway adapter can be positional – difficult to use in unusual positions (prone, etc).

Capnography

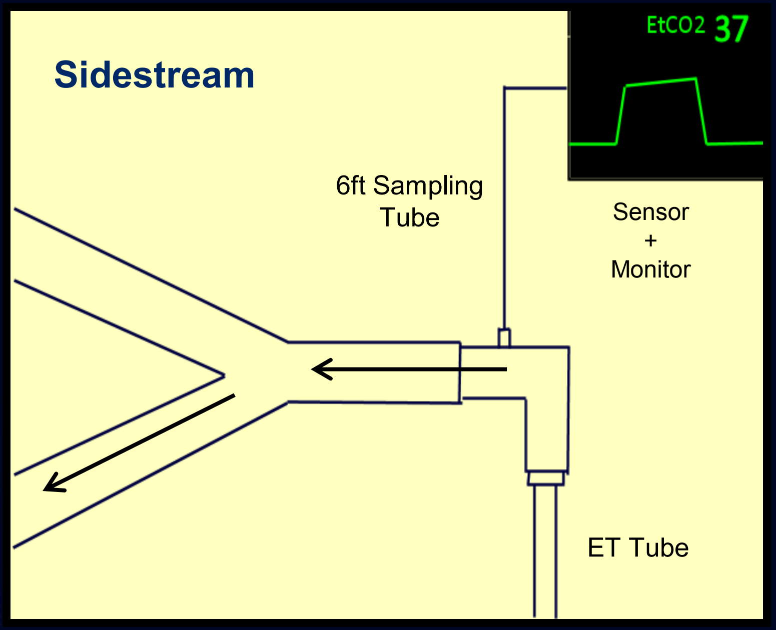
Sidestream – Advantages



- Sampling capillary tube and airway adapter is easy to connect.
- Single patient use sampling – No issues with sterilization.
- Can be used with patient in almost any position (prone, etc…).
- Can be used on awake patients via a special nasal cannula.
- CO^2 reading is unaffected by oxygen flow through the nasal cannula.

Capnography

Sidestream – Disadvantages



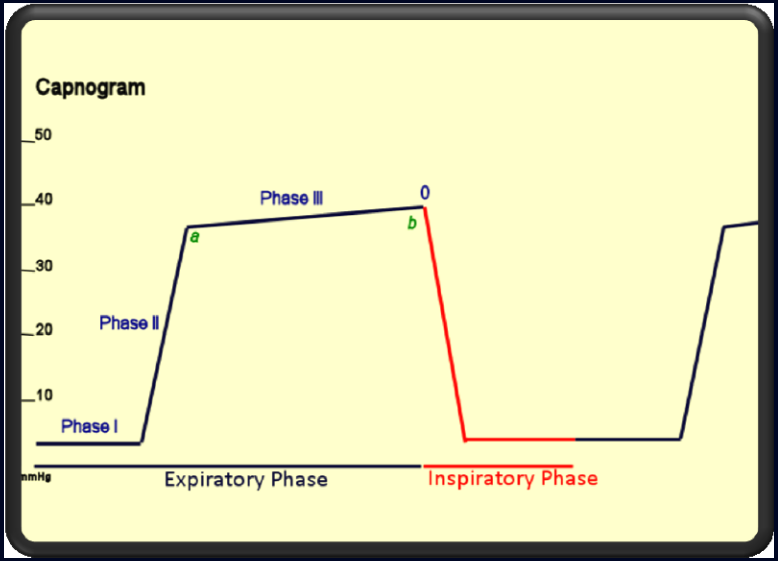
- The sampling capillary tube can easily become obstructed by water or secretions.
- Water vapor pressure changes within the sampling tube can affect CO^2 measurement.
- Waveforms of children are often not clear, deformed.
- Delay in waveform and readout due to the time it takes the gas sample to travel to the sensor within the unit.

Capnography

The Capnogram

I. Phase-I is the onset of expiration which contains only deadspace gas of the upper airway.
II. Phase-II is the upward slope that contains a mixture of deadspace gas and alveolar gas.
III. Phase-III, also called the alveolar plateau, contains only alveolar gas.

- Phase-0 is the onset of inspiration.

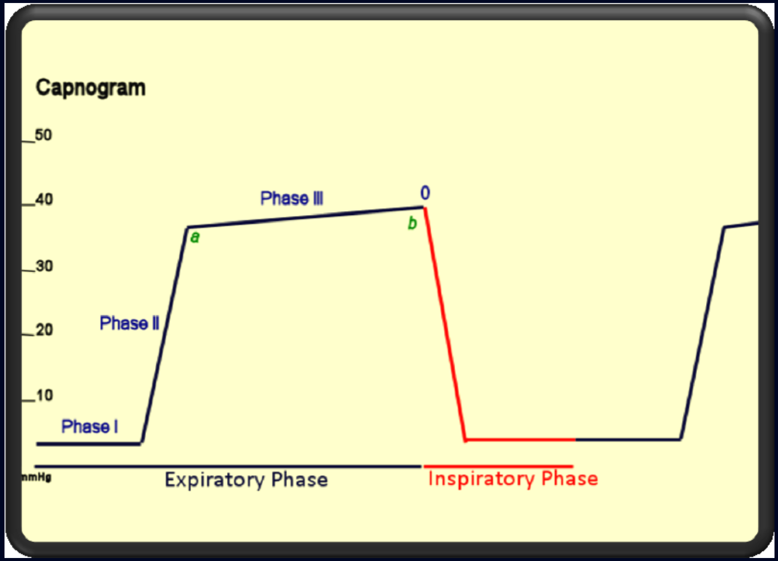


Capnography

The Capnogram

a. The alpha-angle is the angle between Phase-II and Phase-III of the capnogram. A decreased alpha-angle can indicate partial airway obstructions or V/Q mismatching.

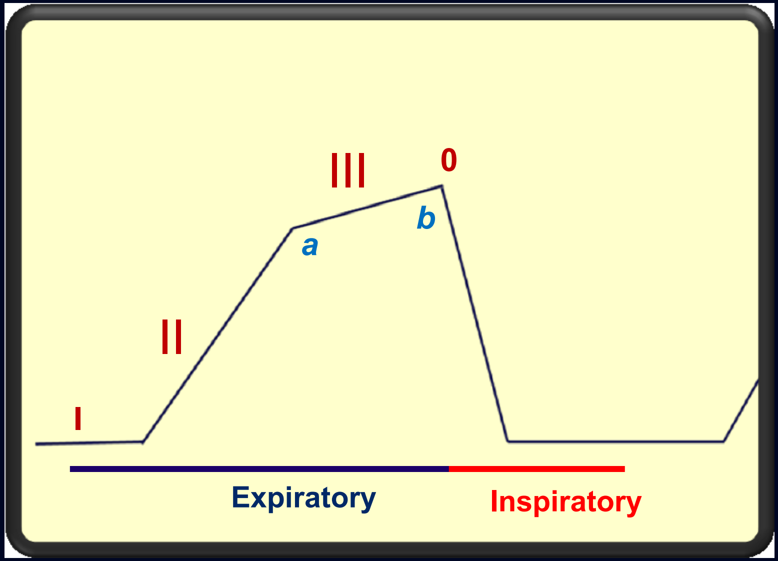
b. The beta-angle is the angle between Phase-III and Phase-0 of the capnogram. A decreased beta-angle can indicate CO² rebreathing



Capnography

The Capnogram

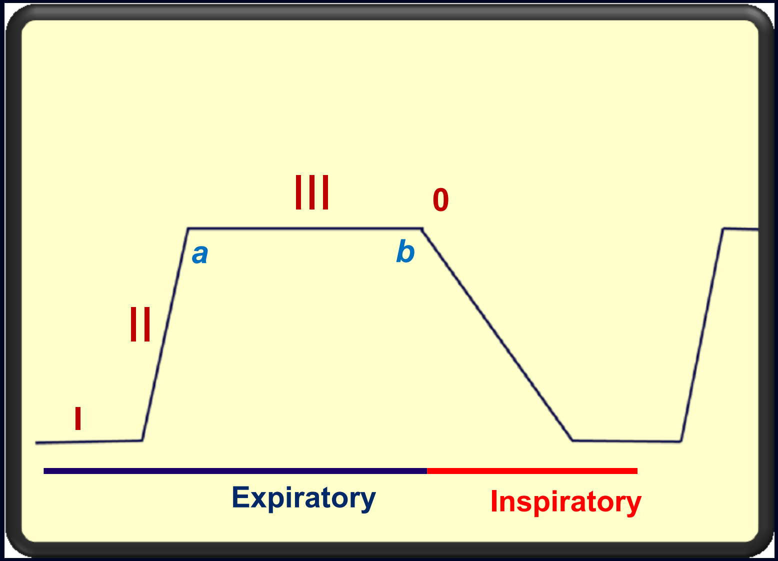
a. The alpha-angle is the angle between Phase-II and Phase-III of the capnogram.
b. A decreases alpha angle indicates a prolonged expiratory phase as is often seen in bronchospasm or partial airway obstruction.



Capnography

The Capnogram

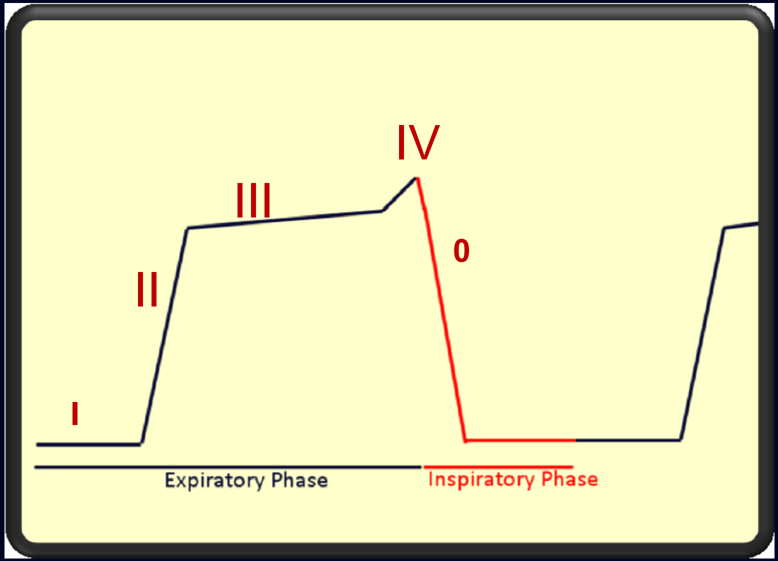
a. The beta-angle is the angle between Phase-III and Phase-0 of the capnogram.
b. A decreased beta angle is indicative of partial rebreathing of exhaled carbon dioxide as is sometimes seen with partial foreign body airway obstruction or laryngospasm.



Capnography

The Capnogram

The presence of Phase-IV on a capnogram indicates an unequal emptying between the left and right lung. This can be caused by a unilateral bronchospasm, or a partial airway obstruction within the left or right bronchial tree.



Capnography

Indications for Use:

- Endotracheal Intubation: Confirmation of proper ET tube placement
- Procedural Sedation: Continuous monitoring of respiratory pattern
- Mechanical Ventilation: Monitoring effects of ventilator setting changes
- General Anesthesia: Monitoring of pulmonary and cardiac output status
- Cardio-Pulmonary Resuscitation: Monitoring effectiveness of chest compressions, and predicting the outcome of CPR

Capnography

Capnography During Endotracheal Intubation:

- ❑ Carbon Dioxide is a waste product of cellular metabolism, and leaves the body during the expiratory phase of respiration.
- ❑ If cardiac output is stable, and the airway is patent, then carbon dioxide is present in exhaled gas.
- ❑ Carbon dioxide is normally NOT present in the stomach. *
- ❑ Capnography should be initiated immediately after endotracheal intubation.
- ❑ The consistent presence of CO^2 after 4 – 5 breaths* indicates a successful endo*tracheal* intubation.
- ❑ The absence of CO^2 in the exhaled gas indicates an esophageal intubation.

** If your patient has consumed a significant amount of carbonated beverages just prior to getting intubated a CO^2 measurement could be positive for the first 4 – 5 breaths.*

Capnography

Capnography During Endotracheal Intubation:

After an inadvertent esophageal intubation a false-positive capnographic reading can be caused by:

- ❑ Resent consumption of carbonated beverages
- ❑ Exhaled gas entering the stomach during aggressive bag-valve-mask ventilation
- ❑ A significant tracheo-esophageal fistula can cause exhaled gas to enter the gastrointestinal tract.

Capnography

Capnography During Procedural Sedation:

- Capnography is a vital sign of ventilation.
- The capnographic waveform DIRECTLY correlates with respiration.
- Changes in respiratory status can be detected instantly when monitored with the proper use of capnography.
- Changes in respiratory status can go undetected for up to 5 minutes when being monitored with pulse-oxymetry alone, even if a cardiac monitor is being used.
- During procedural sedation capnography should be used in conjunction with pulse-oxymetry.

Capnography

Capnography During Mechanical Ventilation:

- When a critically ill patient is on mechanical ventilation oxygenation and ventilation are being continually monitored.
- Invasively this is done by drawing and arterial blood sample and running an arterial blood gas (ABG) at regular intervals, and after changes in ventilator settings.
- Non-Invasively oxygenation is continually monitored with the use of pulse-oxymetry, and ventilation can be continually monitored with the use of capnography.
- Capnography can be used as a trending tool and to aid is determining the effects of changes in mechanical ventilator settings.
- When used properly capnography can help you manage your intubated patients with fewer arterial blood samples.

Capnography

Capnography During General Anesthesia:

- After anesthesia induction capnography is first used to verify ET tube placement after endotracheal intubation.
- During surgery capnography is used to monitor airway status, ventilatory status, and pulmonary perfusion status.
- Airway status: The waveform us closely watched for change in shape, which will alert the anesthesiologist of anything from bronchospasm to dislodgement of the ET tube.
- Ventilatory status: During surgery a sudden decrease in $P_{ET}CO^2$ can alert the anesthesiologist of changes to ventilation status.
  - A sudden decrease in $P_{ET}CO^2$ indicates a sudden increase in alveolar deadspace, leading to the suspicion of an acute pulmonary thromboembolism or air embolism.
- Perfusion status: A sudden decrease in $P_{ET}CO^2$ can also mean an acute decrease in pulmonary perfusion. Pulmonary perfusion is directly proportional to $P_{ET}CO^2$.

Capnography

Capnography During Cardio-Pulmonary Resuscitation:

The benefit of using capnography during cardiopulmonary resuscitation has been known about for many years, and several studies have been published supporting its use.

- We already know that if ventilation is consistent then measured $P_{ET}CO^2$ is directly proportional to cardiac output and pulmonary perfusion status.
- With an intubated patient if manual ventilation is consistent then $P_{ET}CO^2$ help determine if chest compressions are effectively circulating blood to the vital organs.
  - As the person performing chest compressions begins to fatigue chest compressions will not be as effective and $P_{ET}CO^2$ will begin to decline. MOST people can only perform EFFECTIVE chest compressions for a maximum of three (3) minutes before beginning to fatigue.
- Studies show that the initial measured $P_{ET}CO^2$ can also be a predictive indicator of outcome and survivability of CPR.
  - If the initial $P_{ET}CO^2$ is < 8mmHg then the survivability is less than 1%.
  - If the initial $P_{ET}CO^2$ is > 18 then you patient has a 70% greater chance of survival.
  - It MUST be understood that outcome is also dependent on the initial cause of the cardiopulmonary arrest.

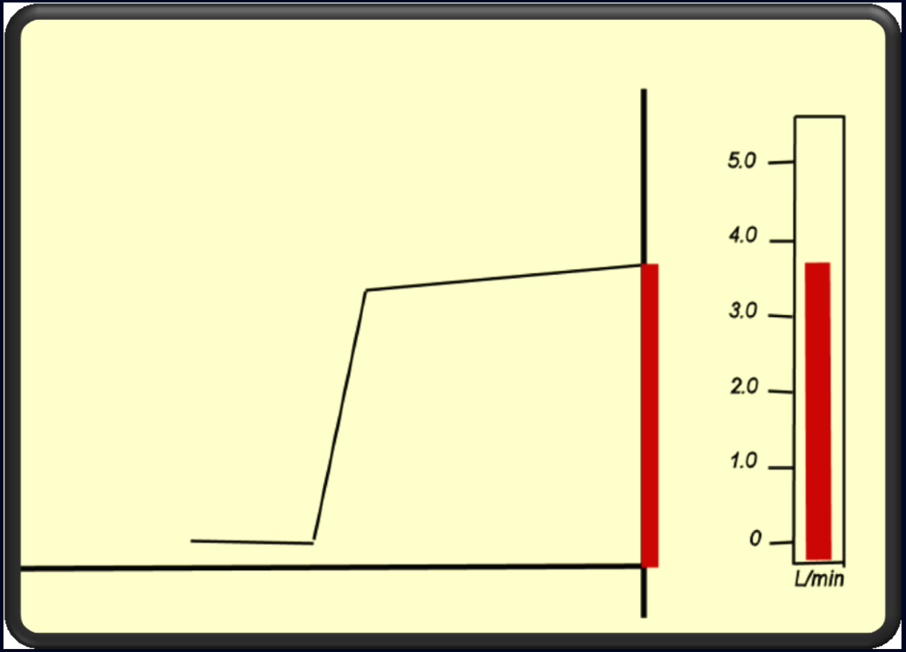
Capnography

- Normal values for $P_{ET}CO^2$ is 30 – 40 mmHg. This is for the text-book patient; 35 year, 6 foot, 165 pound, white male in perfect health.
- In the clinical setting normal $P_{ET}CO^2$ is considered to be 3 – 5 mmHg below the P_aCO^2 via arterial blood gas measurement.
- This calculated measurement is the $P_{(a\text{-}ET)}CO^2$, also called the CO^2-diff, or the CO^2 gradient.
- The $P_{(a\text{-}ET)}CO^2$ is directly proportional to the amount of dead-space ventilation (Ventilation that does not participate in gas exchange).
- There is clinical significance in both measurements – The $P_{ET}CO^2$ and the $P_{(a\text{-}ET)}CO^2$.
- There are numerous conditions and circumstances, acute and chronic, that will effect the $P_{ET}CO^2$ measurement and the $P_{(a\text{-}ET)}CO^2$ measurement. See the tables on the following slides…

Capnography

- $P_{ET}CO^2$ & Cardiac Output:

- $P_{ET}CO^2$ is directly proportional to cardiac output and pulmonary perfusion.
- If ventilation is consistent then any sudden change in cardiac output or pulmonary perfusion will result in a sudden change in $P_{ET}CO^2$.



The above image is a graphical representation of alveolar and deadspace ventilation, and the $E_{(a\text{-}ET)}CO^2$ based on the $P_{ET}CO^2$ capnogram.

Capnography

- $P_{ET}CO^2$ & Cardiac Output:

- $P_{ET}CO^2$ is directly proportional to cardiac output and pulmonary perfusion.
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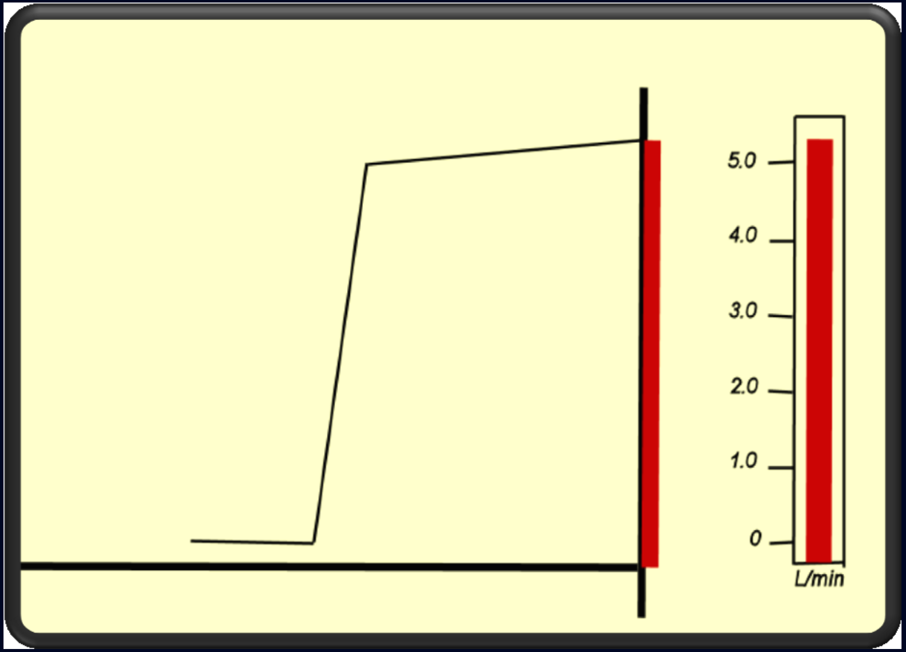

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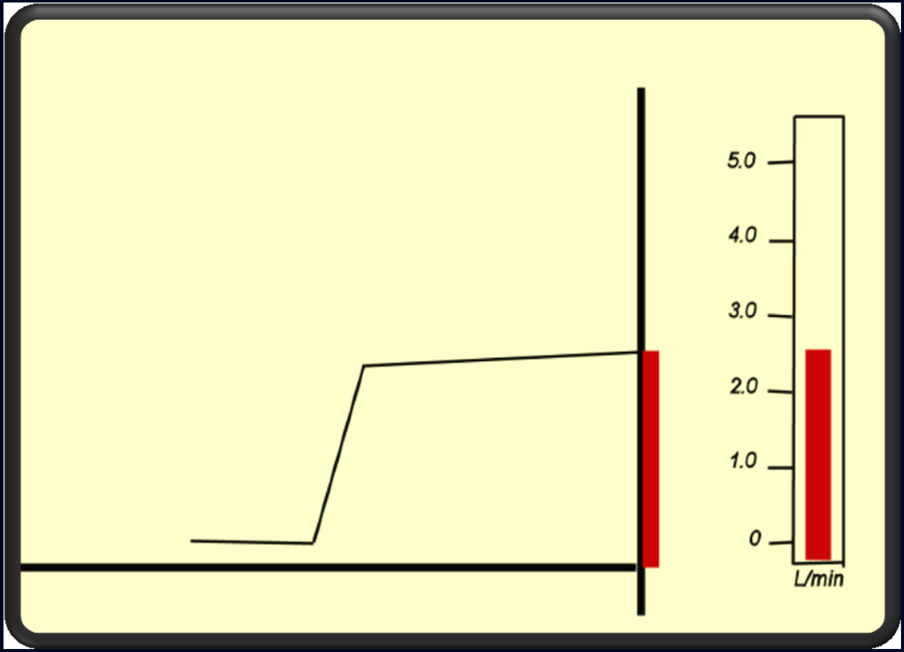
Capnography

- $P_{ET}CO^2$ & Cardiac Output:

- $P_{ET}CO^2$ is directly proportional to cardiac output and pulmonary perfusion.
- If ventilation is consistent then any sudden change in cardiac output or pulmonary perfusion will result in a sudden change in $P_{ET}CO^2$.
- A sudden increase in cardiac output or pulmonary perfusion will result in a sudden increase in $P_{ET}CO^2$.
- A sudden decrease in cardiac output or pulmonary perfusion will result in a sudden decrease in $P_{ET}CO^2$.



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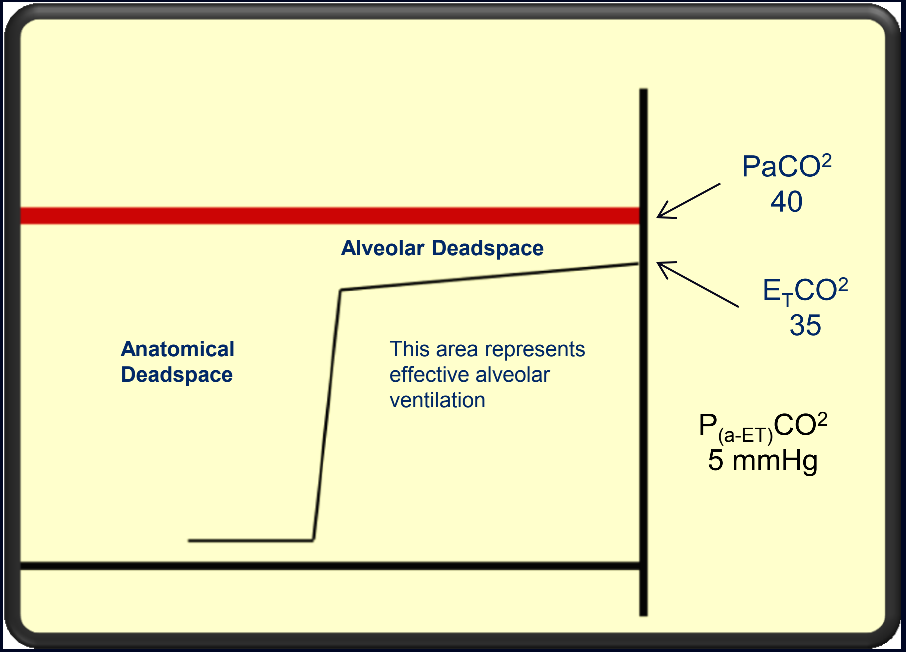
Capnography

- The $P_{(a\text{-}ET)}CO^2$:

- ❑ The difference between the $P_{ET}CO^2$ and the PaO^2 is often referred to as the $P_{(a\text{-}ET)}CO^2$, or the "*CO^2-diff*".
- ❑ There is clinical significance in the $P_{(a\text{-}ET)}CO^2$.
- ❑ The $P_{(a\text{-}ET)}CO^2$ is representative of, and is directly proportional to, alveolar deadspace.



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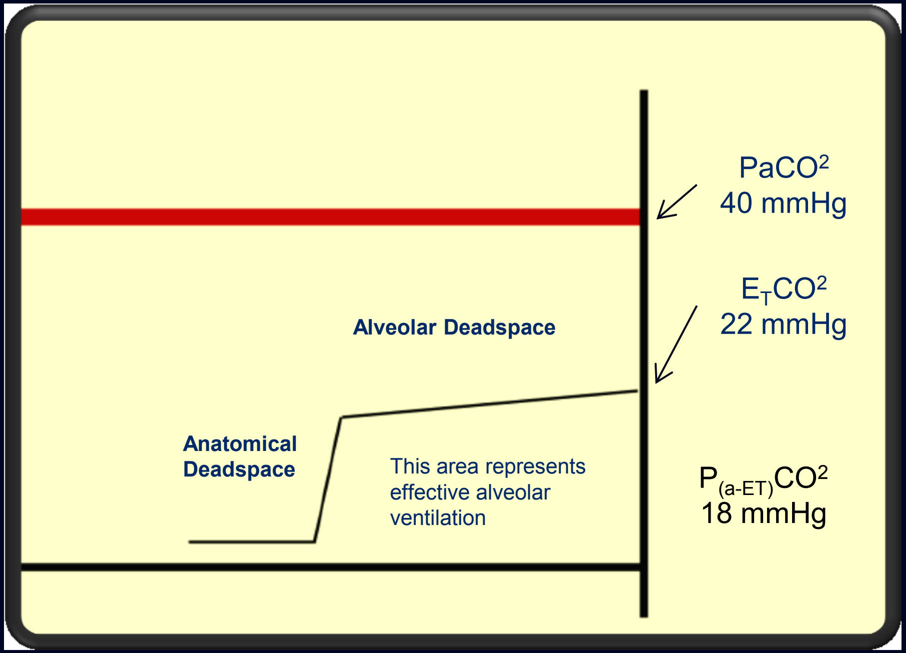
Capnography

- The $P_{(a\text{-}ET)}CO^2$:

There are several conditions or disease states that will cause an increase in the CO^2-diff.

- ❑ Pulmonary embolism
- ❑ Emphysema
- ❑ Low cardiac output states
- ❑ Hypovolemia
- ❑ Slightly increases with age



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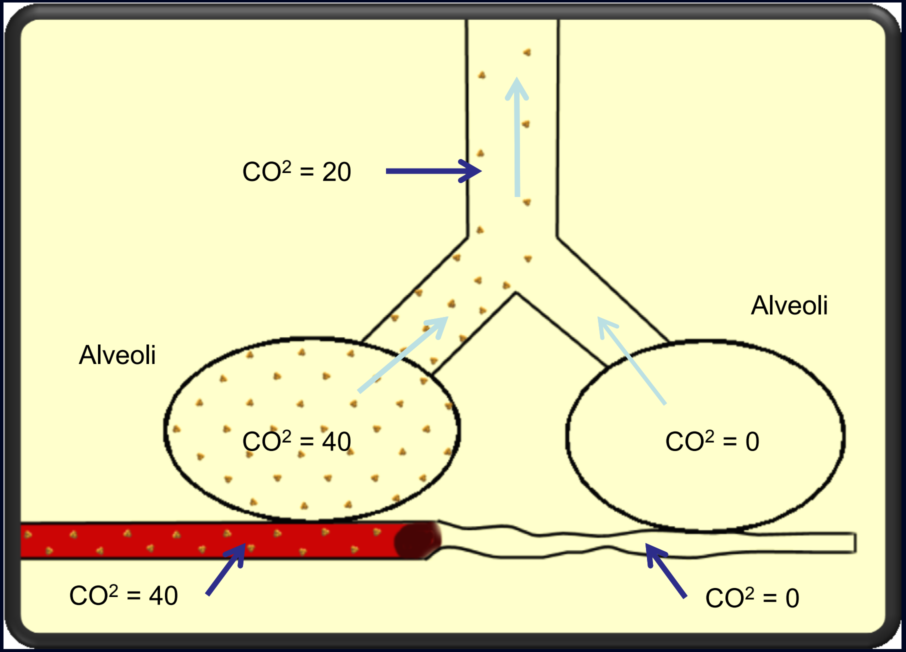
Capnography

- The $P_{(a-ET)}CO^2$:

Pulmonary Embolism:

Air that is rich in CO^2 leaves the alveoli and gets diluted with dead-space air that leaves alveoli with poor perfusion or no perfusion. The result is a lower concentration of CO^2 in exhaled air.



The above image is a graphical representation of alveolar and deadspace ventilation, and the $E_{(a-ET)}CO^2$ based on the $P_{ET}CO^2$ capnogram.

Capnography

Increased $P_{ET}CO^2$:	Decreased $P_{ET}CO^2$:
Decreased Alveolar Ventilation ❑ Decreased respiratory rate ❑ Decreased tidal volume ❑ Increased equipment deadspace	**Increased Alveolar Ventilation** ❑ Increased respiratory rate ❑ Increased tidal volume
Increased CO^2 Production & Delivery ❑ Fever (increases metabolism) ❑ Increased muscular activity ❑ Malignant hyperthermia ❑ Hypercatabolic state	**Reduced CO^2 Production & Delivery** ❑ Hypothermia ❑ Decreased cardiac output ❑ Hypocatabolic state
Increased Inspired CO^2 ❑ Rebreathing ❑ CO^2 absorber exhausted ❑ External source of CO^2	**Increased Alveolar Deadspace** ❑ Pulmonary embolism ❑ High positive end-expiratory pressure (PEEP) during positive pressure ventilation

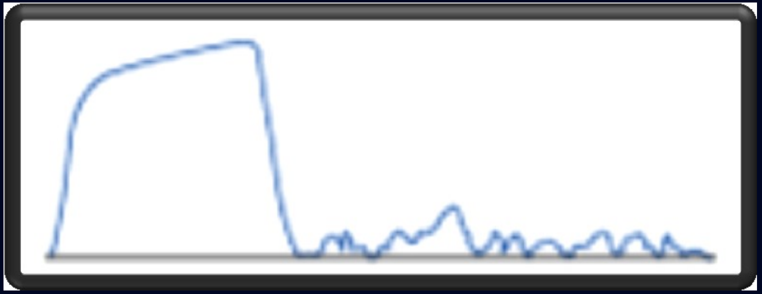
Capnography

Increased $E_{(a-ET)}CO^2$:	Decreased $E_{(a-ET)}CO^2$:
❑ Emphysema ❑ Pulmonary embolism ❑ Low cardiac output states ❑ Hypovolemia ❑ Slightly increases with age	❑ Can occur during pregnancy. ❑ Occurs naturally in young children. ❑ Can occur with a high tidal volume and low set respiratory rate. ✓ Young children and infants normally have less dead-space ventilation than adults because their lungs and airways are much smaller in size.

Capnography

- ✓ Capnography is a very fast indicator of many problems that can arise during artificial ventilation.
- ✓ In most cases capnography responds much faster than pulse-oximetry, which can sometimes take 3 – 4 minutes to show a change in respiratory status.
- ✓ The measured E_TCO^2 alone, while important, is of limited value. In many cases it is the waveform that tells you a lot more about the pulmonary and airway status of your patient.

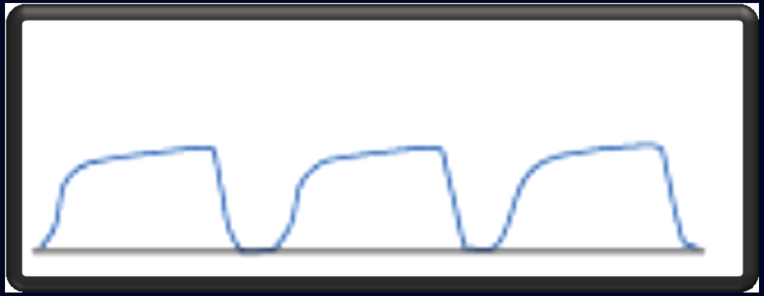
Capnography



Sudden Loss of $P_{ET}CO^2$

- Airway disconnected
- ET Tube kinked
- ET Tube dislodged
- Airway obstruction
- Ventilator malfunction

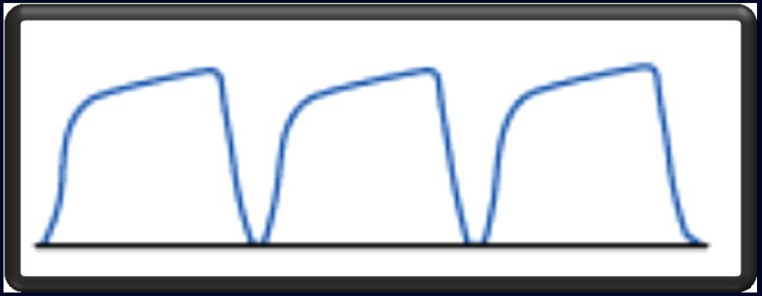
Capnography



Consistently low $P_{ET}CO^2$

- Alveolar hyperventilation
- Hypothermia
- Increased dead space ventilation
- Sedation / Anesthesia

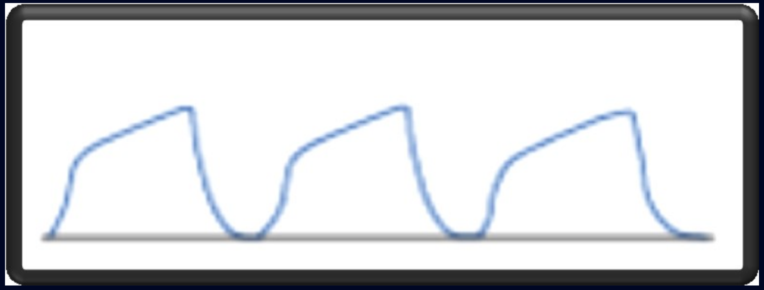
Capnography



Sudden High $P_{ET}CO^2$

- Alveolar hypoventilation
- Inadequate minute volume
- Hyperthermia, pain, shivering
- Respiratory depressant lungs

Capnography

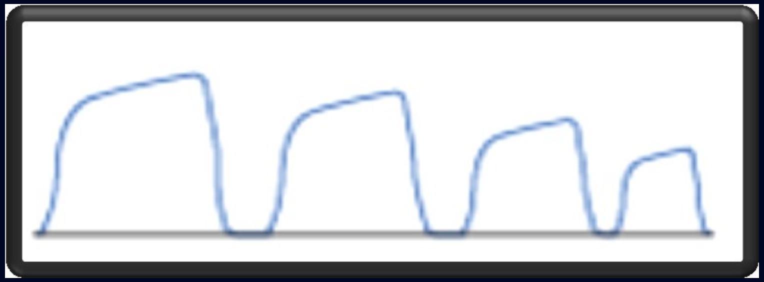


Rising alveolar plateau

(Notice the increased alpha-angle)

- Bronchospasm
- Mucus plugging
- Partial airway obstruction
- Partially kinked ET tube
- Prolonged expiratory phase

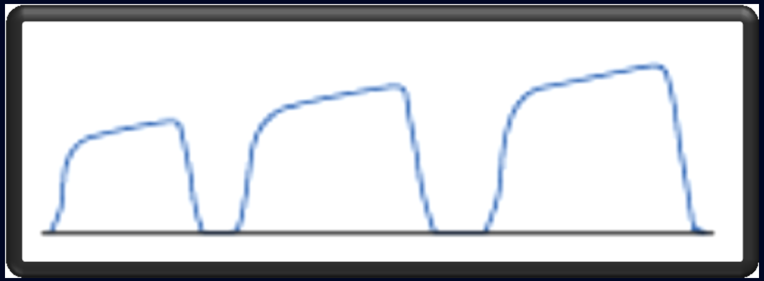
Capnography



Rapidly Decreasing $P_{ET}CO^2$

- Onset of cardiopulmonary arrest
- Developing pulmonary embolus
- Increasing dead space ventilation
- Sudden hypotension / blood loss

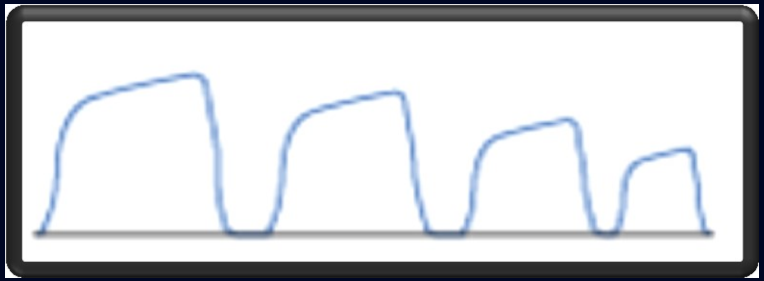
Capnography



Rapidly Rising $P_{ET}CO^2$

- Rising body temperature
- Increased metabolism
- Progressing alveolar hypoventilation
- Partial airway obstruction

Capnography



Rapidly Decreasing $P_{ET}CO^2$

- Onset of cardiopulmonary arrest
- Developing pulmonary embolus
- Increasing dead space ventilation
- Sudden hypotension / blood loss

Capnography

Send questions or comments to:

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Capnography

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Because at the Head of Every Team

Is a

Respiratory Therapist