Capnography

Philips clinical considerations in capnography

This application note outlines various clinical considerations on the use of Respironics capnography solutions. It is designed to address the following topics.

- **Selecting and managing the sensing technologies best suited to the clinical environment and application.**
- **Analyzing and interpreting the information provided by the capnography sensors.**

Content

Different **capnography options** for different patients and applications

Capnography monitoring is a quick and accurate method to measure and monitor airway patency, efficacy of ventilation, metabolic activity, and the relationship between ventilation and perfusion. The technology and application of CO_2 monitoring is recommended, or established as a standard of care by many professional organizations[1].

Each application and patient population has specific clinical support needs. Patients requiring airway management, resuscitation, transport, and ventilator management generally require intubation and ventilation, whereas patients undergoing procedural sedation and pain management are non-intubated.

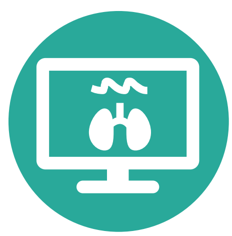
When deciding which capnography sensing technology to use, please consider the following:

- Capnography application
- Patient population
- Current clinical practice
- Current recommended clinical guidelines

The appropriate sensor selection may mitigate nuisance alarms, diminish workflow interruptions, and contain costs related to accessory usage.

Mainstream

Ventilation management



- **Critical care**
- **Emergency department**
- **Operating room**
- **Respiratory therapy**
- **Long-term ventilation centers**

Airway management

Resuscitation

Transport

- **Critical care**
- **Emergency department**
- **Operating room**
- **Pre-hospital**

Procedural sedation

Pain management

- **Endoscopy**
- **Cath lab**
- **Interventional radiology**
- **Bronchoscopy**
- **PACU**
- **Same day surgery clinic**
- **General care floor (PCA)**
- **Emergency department**
- **Critical care**

Sidestream

[1] As listed in the "Global best practices list" (Philips document number: 4522 991 32541)

Deciding between **sidestream and mainstream** technology

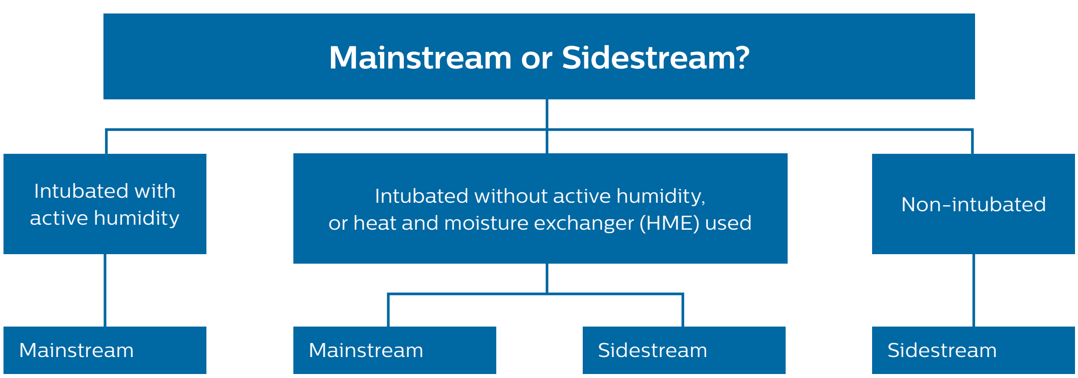
Sidestream and mainstream sampling refers to the two basic styles of CO_2 sensors, and the position of the infrared (IR) measurement device relative to the source of the gas being sampled.

- Sidestream technology uses an airway adapter or nasal / nasal oral sampling line to draw CO_2 for analysis from the patient to a distal monitor.
- Mainstream technology does not require a sampling line to draw the gas sample for analysis because the mainstream sensor takes a direct reading as the CO_2 flows from the patient.
- Sidestream technology is available for intubated and non-intubated patients. However, mainstream is the better match for most intubated patients, especially for long term monitoring and critically ill patients, due to use of active humidity.
- Both technologies use airway adapters for intubated patients which are placed directly in-line with the ventilator circuit to obtain gas samples.

Active humidity in clinical practice

Intubated patients on mechanical ventilators in the intensive care unit (ICU), emergency department (ED), neonatal ICU or other critical care environment are often supplied active humidity, or are placed in a humid environment, such as an incubator. A known result of active humidity is condensation.

- The sidestream sampling line and filter will collect condensation and other particulates that may come from the patient. This eventually results in clogged sampling lines, which causes a loss of waveform, triggers an occlusion alarm, and requires action by the clinician to troubleshoot and possibly change the sampling line.
- Because mainstream technology does not require a sampling line there is no sampling line to clog, helping to reduce the likelihood of related nuisance alarms.



Philips Respironics capnography offers mainstream and sidestream solutions: The CAPNOSTAT 5 mainstream Sensor, or the LoFlo and CapnoTrak sidestream options. Together they provide a comprehensive ventilation monitoring solution across the care continuum: neonates, pediatrics and adult, and all patient acuities.

For intubated patients requiring long term monitoring, active humidification, or for patients in humid environments, **mainstream** capnography may address nuisance alarms and workflow interruptions, and contain costs through the use of reusable airway adapters, or decreased accessory use.

For short term monitoring where humidity management is not a primary consideration, **sidestream** monitoring is recommended.

CAPNOSTAT 5 mainstream sensor

For intubated patients

- Airway confirmation and management
- Ventilator management
- Resuscitation
- Transport

LoFlo sidestream sensor

Primarily for non-intubated patients
Appropriate for intubated patients for short-term monitoring

- Airway confirmation and management
- Resuscitation
- Transport
- Procedural sedation
- Pain management

Sampling line and airway adapter selection

Sampling lines and airway adapters facilitate the breath sampling during exhalation. Choosing the appropriate technology for the environment and clinical application will optimize the life of the sampling line or airway adapter and may address nuisance alarms, reduce workflow interruptions, and contain costs.

Your considerations when choosing a sampling line or airway adapter include:

1. Will monitoring be on intubated or non-intubated patients?
2. Will monitoring be short- or long-term?
   - If the application is short-term (procedural sedation)
     - Typically, you will not need dehumidification for short-term, low humidity monitoring
     - If you need to capture nasal and oral breaths, you will need nasal/oral sampling lines
   - If the applicaiton is long-term: (ventilator and ventilation management)
     - Typically, you will need dehumidification for long-term, or humid environment monitoring
3. For non-intubated patients, Is oxygen (O_2) delivery part of patient care during capnography monitoring?
   - If yes, then select a sampling line with integrated O_2 delivery
   - If no, then select a sampling line without integrated O_2 delivery
4. What population will be monitored?
   - Adult, pediatric, or neonatal

Humidity management tips

In addition to the selection of the appropriate technology and sampling line or airway adapter, the following actions can aid in prolonging the life of the line by minimizing the accumulation of condensation. These tips may also alleviate nuisance alarms related to excess condensation and clogging of the sampling lines.

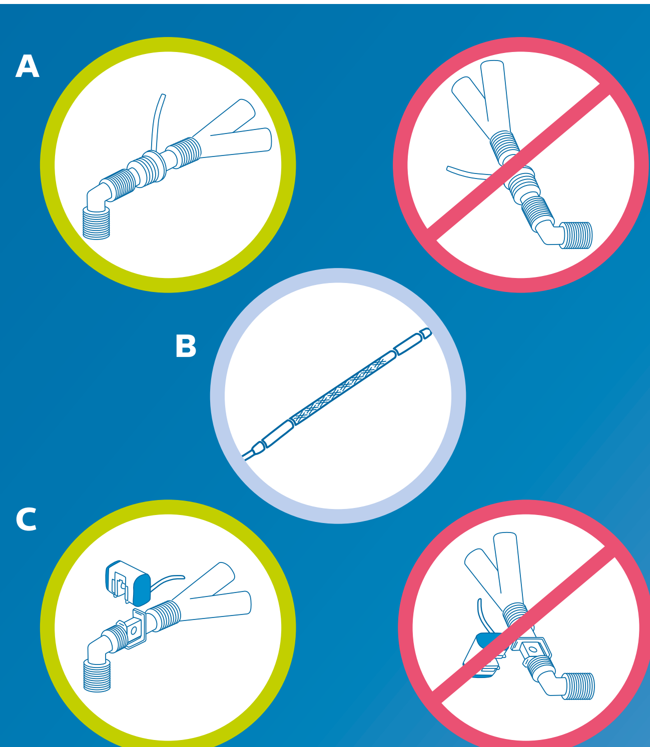
A. Keep LoFlo or CapnoTrak sampling line tubing free of kinks and upright

B. Select dehumidification material (Nafion). This removes water vapor from the patient gas sample, and helps manage moisture and obstruction of sidestream sampling lines.

C. Position the airway adapter vertically to avoid water pooling on the adapter windows.

When suctioning, instilling saline into the endotracheal tube, or when giving a nebulizer treatment

- Do NOT pass a suction catheter through the airway adapter
- Do NOT instill medications or aerosols through the airway adapter
- For LoFlo and CapnoTrak: pause the gas sampling pump, or if that option is not available, disconnect the sampling line from the sensor.



Pictures showing proper placement of airway adapter and positioning.

Understanding the **physiology of capnography**

Physiological and mechanical factors affecting $ETCO_2$

Understanding of the physiological and mechanical factors which may affect $ETCO_2$ is crucial to interpreting $ETCO_2$ trends and alarms. Waveform analysis and interpretation is also part of this process.

Physiological factors
Cellular respiration (metabolism) uses oxygen (O_2) for energy production. During this process CO_2 is produced as a metabolic byproduct. CO_2 then enters the bloodstream, where it is transported (perfusion) to the lungs. CO_2 diffuses across the alveolar membrane to be exhaled out (ventilation) to the atmosphere. If any of these physiologic processes are not functioning properly, the $ETCO_2$ values will trend up or down.

Physiological factors		Increasing $ETCO_2$	Decreasing $ETCO_2$
Metabolism	• Metabolism of food into energy • O_2 consumption • CO_2 production	• Malignant Hyperthermia • Pain • Shivering • Bicarbonate infusion	• NPO status • Hypothermia • Sedation • Anesthesia • Muscle relaxants
Perfusion	• Transport of O_2 and CO_2 between cells and pulmonary capillaries • Diffusion of O_2 and CO_2 to and from alveoli	• Increased cardiac output	• Decreased cardiac output • Hypovolemia • Hypotension • Pulmonary embolism • Cardiac arrest
Ventilation	• Ventilation of CO_2 between alveoli and atmosphere	• Decreased minute ventilation (hypoventilation) • Effective drug therapy for bronchospasm	• Increased minute ventilation (hyperventilation) • Airway obstruction • Shallow breathing

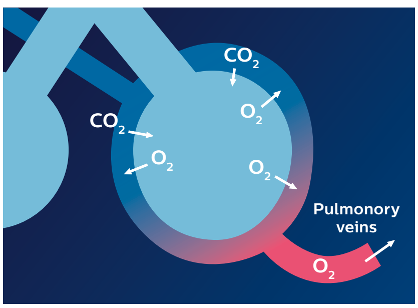
Mechanical factors
In addition to assessing physiological factors which may affect the $ETCO_2$, mechanical factors should also be considered. Kinked or partially occluded artificial airways, faulty ventilator exhaust valves, inadequate seals around the endotracheal tube, or obstruction in the expiratory limb of the ventilator circuit can also impact the $ETCO_2$ level. Trending the $ETCO_2$ level and observing waveform morphology may guide your assessment of mechanical involvement.

Mechanical factors	Increasing $ETCO_2$	Decreasing $ETCO_2$
Ventilator	• Malfunctioning exhalation valve • Decreased minute ventilation settings	• Circuit leak or partial obstruction • Increased minute ventilation settings • Poor sampling technique

Arterial to end tidal gradient ($PaCO_2$-$ETCO_2$)

The partial pressure of end-tidal carbon dioxide ($PETCO_2$), also referred to as $ETCO_2$ is a reliable tool for trending the partial pressure of arterial carbon dioxide ($PaCO_2$). The $PaCO_2$ is measured using an arterial blood gas (ABG) test. An ABG test measures the acidity (pH) and the levels of oxygen and carbon dioxide in blood taken from an artery. This test is used to check how well the lungs are able to move oxygen into the blood and remove carbon dioxide from the blood.
To effectively use this tool you should understand that in normal lungs the $PaCO_2$ and $ETCO_2$ will trend very closely. But as the patient experiences more ventilation and perfusion mismatching the gradient will widen. Normal $PaCO_2$ is 35 to 45 mmHg and normal $ETCO_2$ is 30 to 43 mmHg.

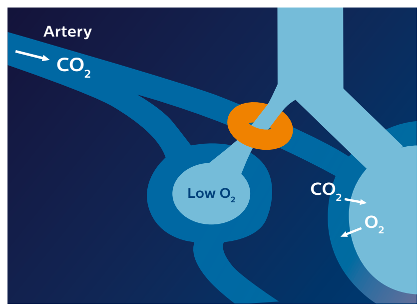
Normal ventilation / perfusion



In a normal, healthy lung a gradient between the $PaCO_2$ and $ETCO_2$ is created by a ventilation-perfusion ratio. Ventilation ($\dot{V}$) is the flow of gas between the alveoli and the atmosphere. Perfusion ($\dot{Q}$) is the blood flow from the body to the pulmonary capillary bed. Ventilation and perfusion are the primary methods the body uses to transport CO_2. Normal, healthy lungs will have a $\dot{V}/\dot{Q}$ ratio of ≈ 0.8, which will be observed as a $PaCO_2$- $ETCO_2$ gradient of ≈ 2 to 5 mmHg. Patients in a diseased state that compromises ventilation or perfusion will have a wider gradient.

The widening $\dot{V}/\dot{Q}$ mismatch may be the result of shunt perfusion or dead space ventilation.

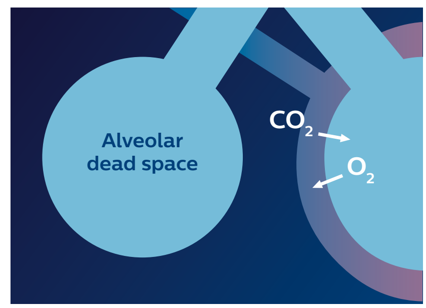
Shunt perfusion



Shunt perfusion refers to alveoli which are perfused, but not effectively ventilated. This mismatch results in a low $\dot{V}/\dot{Q}$ ratio and a widened $PaCO_2$-$ETCO_2$ gradient.

Shunt perfusion may be caused by disease states such as mucus plugging, atelectasis, pneumonia, pulmonary edema, or mainstem bronchus intubation.

Dead space ventilation



Dead space ventilation occurs when alveoli are ventilated, but not adequately perfused. Dead space also refers to any part of the anatomy, or ventilator circuit that does not participate in gas exchange.

Dead space ventilation is not a ventilation abnormality. Perfusion is the problem, and exchange of O_2 and CO_2 is impaired.

This mismatch results in a high $\dot{V}/\dot{Q}$ ratio and a widened $PaCO_2$-$ETCO_2$ gradient.

Dead space ventilation may be caused in disease states such as impaired cardiac output, decreased pulmonary blood flow, pulmonary embolism, hypovolemia, cardiac arrest, and shock. Adding additional components into the ventilator circuit will also increase dead space.

How to calculate the patient's $PaCO_2$-$ETCO_2$ gradient

Trending $PaCO_2$-$ETCO_2$ gradient can provide valuable clinical information about the patient's ventilation and perfusion status. Please follow the following steps:

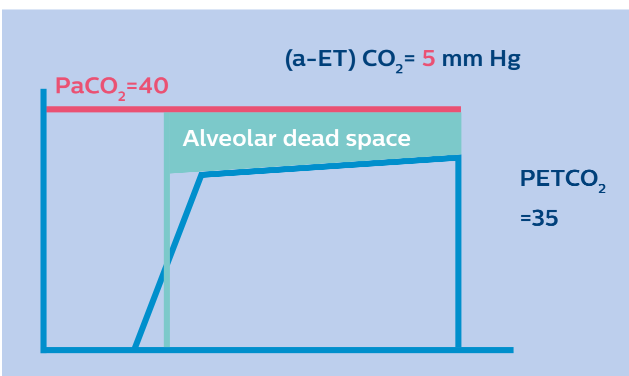
1. Verify that you have a clear stable $ETCO_2$ waveform, as well as a stable $ETCO_2$ value.
2. Record the $ETCO_2$ value at the same time the arterial blood gas sample (ABG) is drawn from the patient. Failure to obtain information simultaneously may not be reflective of the relationship.
3. Once a value for $PaCO_2$ is available, use it in the formula: $PaCO_2$ - $ETCO_2$ to calculate your gradient.
4. Please note that an ABG value reflects the patient's current and the immediate past condition, whereas the $ETCO_2$ value reflects the current moment, trending forward.

Evaluation of $PaCO_2$-$ETCO_2$

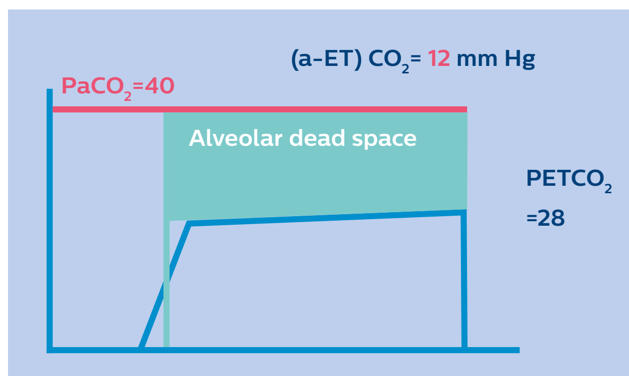
A A gradient within normal limits indicates effective $\dot{V}/\dot{Q}$ status.
B A widening gradient indicates the $\dot{V}/\dot{Q}$ status is deteriorating.
C A narrowing gradient indicates the $\dot{V}/\dot{Q}$ status is improving.

If there is a sudden drop in the $ETCO_2$, with no change in ventilation, then get an ABG to differentiate. This usually indicates a perfusion issue.

A



B



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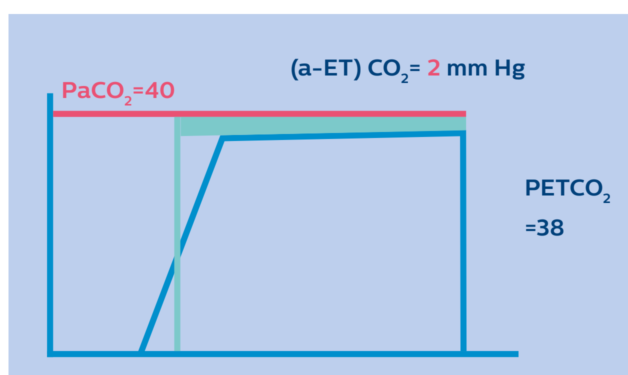
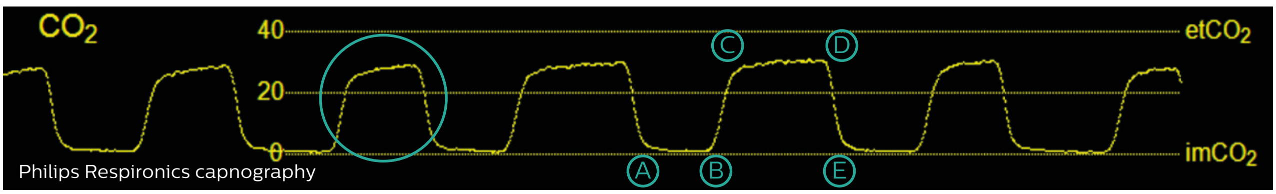


Understanding **capnography waveforms**

Waveform phases and analysis

The capnogram, or waveform generated by the $ETCO_2$ monitor is one of the most useful tools available to assess a patient's ventilation and airway status, and can provide information on metabolism and perfusion.



While reviewing the next steps, please refer to the capnogram picture/sample above.

Is there a waveform present?

- If there is no waveform, then an immediate patient assessment is needed.
- The presence of a waveform verifies a patent airway and that the patient is ventilating. The next steps will help determine the efficacy of ventilation.

Is the shape generally square (please refer to the circled area in the picture above)?

- If the shape is not generally square, then there is a perfusion, ventilation or mechanical issue.

Does the waveform start and end at "zero" baseline (A-B) along the horizontal access?

This segment is the beginning of exhalation

- The first gas to appear at the sampling point is the last gas that was inhaled into the conducting airways.
- This gas has not been subject to gas exchange and is essentially free of CO_2, so remains at the zero baseline.
- This baseline represents the gas occupying the anatomical dead space.
- Anatomical dead space is the internal volume of the upper airways where no gas exchange takes place. This includes the nose, pharynx, trachea, and bronchi.
- Each wave should return to a zero baseline.
- A continuous rise off the horizontal baseline indicates rebreathing of expired CO_2, or mechanical issues in ventilated patients.

Is there a notable expiratory up stroke (B-C) and inspiratory down stroke (D-E)?

The up stroke (B-C) represents gas that is a transition area composed partially of conducting airway volume and partially from alveoli (gas exchange).

- Here we see both a rise in CO_2 concentration and accumulation of volume.
- Failure to demonstrate an upstroke is reflective of ineffective ventilation, either due to low tidal volume/ shallow breathing, or partial airway obstruction.

Inspiration (D-E) is marked by a rapid downward direction of the capnogram.

- This downward stroke corresponds to the fresh gas, which is essentially free of carbon dioxide that passes the CO_2 sensor during inspiration.
- The capnogram will then remain at zero baseline throughout inspiration.
- Decreasing expiratory up stroke and inspiratory down stroke reflect decreasing $ETCO_2$ levels. Assess for metabolic, perfusion, ventilation, or mechanical issues.

Is there an alveolar plateau (C-D)?

All of the gas passing by the CO_2 sensor is alveolar gas which causes the capnogram to flatten out.

- Loss of the alveolar plateau means that there is ineffective ventilation, because CO_2 is not clearing the airway, usually due to shallow breathing, or partial obstruction. Follow practice protocol for assessment and support of patient with potential respiratory compromise.

End-tidal concentration (D)

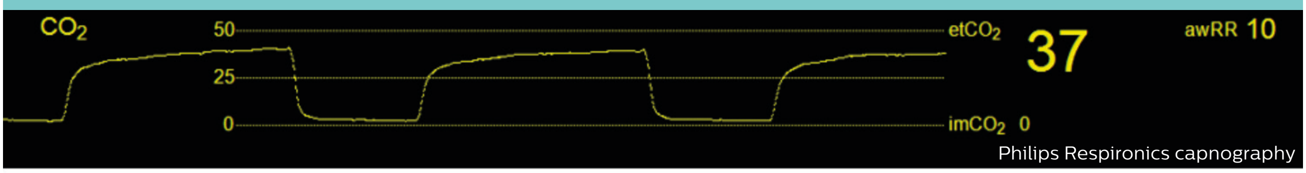
The $ETCO_2$ value displayed on the monitor is the highest value measured during exhalation and usually occurs just prior to inspiration.

Waveform examples

Hypoventilation

Characteristics
- Increasing $ETCO_2$
- Decreasing awRR
- Prolonged alveolar plateau
- Rectangular shape

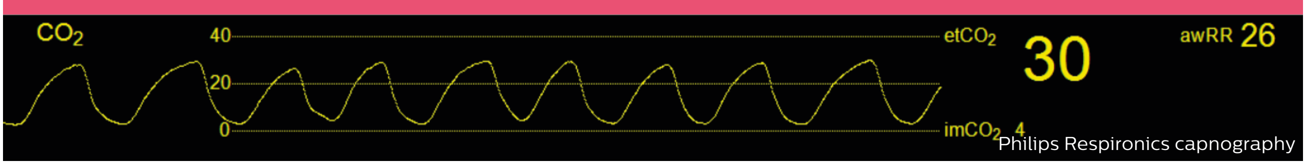
Evaluate patient for
- Respiratory compromise



Hyperventilation and rebreathing

Characteristics
- High awRR
- Failure to return to baseline
- Loss of alveolar plateau
- Decreasing $ETCO_2$

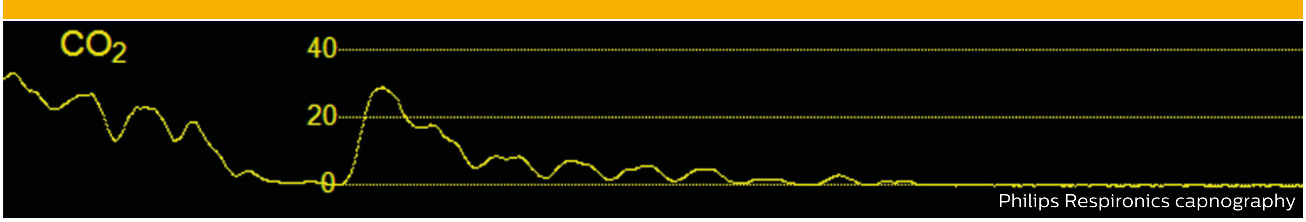
Evaluate patient for
- Pain
- Fever
- Head and neck positioning



Shallow breathing and apnea

Characteristics
- Loss of waveform
- Loss of up stroke and down stroke
- Loss of alveolar plateau

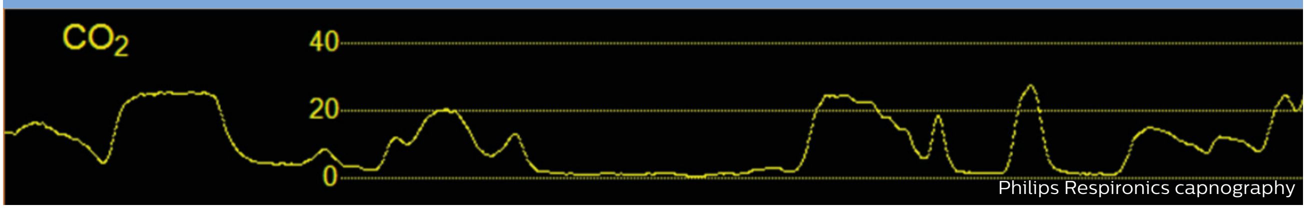
Evaluate patient for
- Respiratory compromise



Erratic waveform

Characteristics
- Loss of alveolar plateau
- Irregular waveform shape

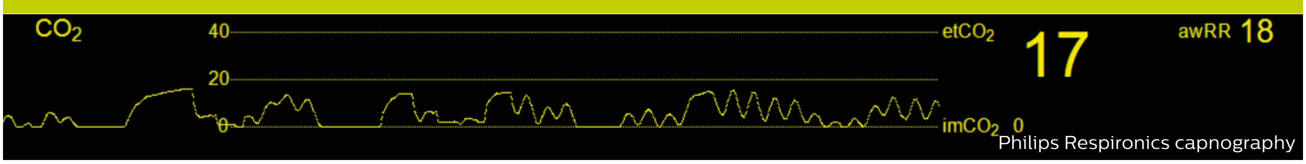
Evaluate patient for
- Talking
- Partial obstruction
- Mouth breathing with nasal only sample line



CPR

Characteristics
- Goal is $ETCO_2$ >10 mmhg

Evaluate patient for
- Return of spontaneous circulation (ROSC)
- Airway placement



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