Capnography in the MICU

Capnometry is the measurement of exhaled carbon dioxide in numerical form, usually measured in mm Hg. **Capnography** is the same information, but in graphical form. In addition, the capnograph will show the pattern of ventilation. Capnography is becoming a widely accepted practice in the ICU.

Physiology: Carbon dioxide is the major product of metabolism, and the exhaled CO_2 tension can be used to make assessments of the body's circulatory and ventilatory status. Most (60-70%) carbon dioxide is carried in the bloodstream in the form of bicarbonate ion—carbonic anhydrase in the RBC accounts for this. 20-30% is carried bound to proteins; hemoglobin is the most prevalent. This leaves 5-10% to exist as dissolved carbon dioxide, which can be measured as the $PaCO_2$. This is the usual measurement of ventilation. The capnograph can provide measurement of the end-tidal CO_2 ($ETCO_2$), which, when used with the $PaCO_2$, can yield a great deal of information.

The Capnograph:

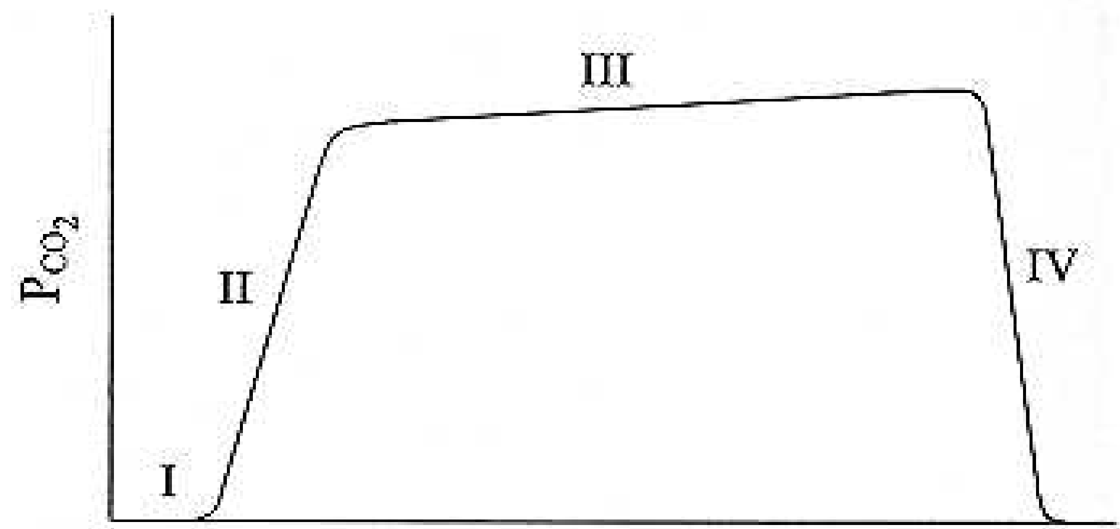


Fig. 3. A normal capnogram, with the labeled segments corresponding to the different phases of the respiratory cycle.

I. Respiratory Baseline: This should be at zero. This part of the capnograph indicates the exhalation of CO_2-free air—the air in the non-ventilated parts of the tracheobronchial tree. Elevation of the baseline indicates rebreathing of exhaled CO_2. When the baseline and the $ETCO_2$ rise, this usually means the sensor is contaminated.

II. Expiratory Upstroke: This should be a steep slope, as it indicates the rapid exhalation of CO_2 from the proximal acini mixed with dead-space gas. When it is less steep, this indicates a prolongation of the time it takes for CO_2 to get from the acini to the sensor. This can be seen in cases of bronchospasm and incomplete obstruction of the endotracheal tube from secretions.

III. Expiratory Plateau: This should be horizontal, or nearly so. The end point of the plateau is the $ETCO_2$. This phase indicates the maximal ventilation of CO_2 from the lungs. An up sloping plateau can represent incomplete alveolar emptying, such as seen in COPD, partial airway obstruction, or obstruction of the endotracheal tube.

IV. Inspiratory Downstroke: The fourth phase represents the inhalation of CO_2-free gas. Leaks in the ventilator system or cuff can cause prolongation of this phase.

Clinical Use:

The first step in interpreting the capnograph should be to assess the presence or absence of a waveform. The absence of a waveform indicates one of two things:

1. Failure to ventilate (esophageal intubation, tube in the hypopharynx, obstruction of the tube, apnea). **THIS IS AN EMERGENCY. FIX THE PROBLEM.**
2. Mechanical mishaps—fix the equipment! This should only be considered after you've *thoroughly* investigated #1, by the way.

Keep in mind that the $ETCO_2$ will never exceed, and rarely match, the $PaCO_2$. The $ETCO_2$ isn't a replacement for the arterial blood gas. Knowing that the $ETCO_2$ never exceeds the $PaCO_2$ is very helpful—it means that whatever the $ETCO_2$, the $PaCO_2$ is at least that high. It could be a little higher, or a lot higher, but it's higher.

For example, if a patient has an $ETCO_2$ of 60, you know that the $PaCO_2$ is at least that. It could be 65, or 105, but it's at least 60. If it's important to the patient to have a $PaCO_2$ in the 35-40 range, then you know to increase the minute ventilation on the ventilator.

The next step is to compare the $ETCO_2$ with the $PaCO_2$. The normal arterial-alveolar CO_2 gradient is usually 3-5 mm Hg. A wide gradient means that there are areas of lung where the ventilation and perfusion aren't matched. Consider the following if there is a large difference between the $PaCO_2$ and $ETCO_2$:

1. Poor cardiac function, leading to low perfusion
2. Pulmonary embolism, leading to an increase in dead space
3. ARDS
4. VQ mismatch from COPD, pneumonitis, or other pulmonary pathology
5. Hypovolemia and/or hemorrhage
6. Air trapping from dynamic hyperinflation
7. Overdistension of alveoli from excessive ventilator pressure

It's just as important to follow trends in the gradient. A gradient of 10 mm Hg represents a significant change in a patient who had a $PaCO_2$-$ETCO_2$ gradient of 4 mm Hg yesterday.

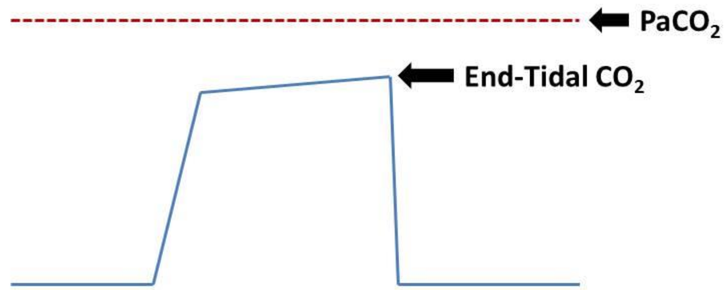
Look at the waveform and its amplitude—a discernable waveform with low amplitude usually represents a sudden increase in dead-space ventilation. However, even cardiac arrest will not drop the plateau to zero—the CO_2 in the lung must be washed out. A zero or near-zero reading, especially with an abnormal waveform, usually indicates a misplaced ETT, obstruction of the tube, or an equipment problem. A waveform with a gradually decreasing amplitude indicates diminishing CO_2 production (hypothermia) or decreasing CO_2 delivery to the lungs (cardiac failure). A sudden increase in the $ETCO_2$ occurs after a seizure, bicarbonate administration, reperfusion of an ischemic limb, or ROSC after cardiac arrest.

CPR:

CPR is often an unscientific, throw-the-book-at-'em procedure. Capnography is a cheap, noninvasive, objective method for assessing the success or failure of various interventions. Cardiac arrest causes a wide a-A DCO_2; narrowing of the gradient, as demonstrated by rising $ETCO_2$, indicates increasing pulmonary circulation and therefore increasing cardiac output. Animal and human studies have shown the correlation between $ETCO_2$ and coronary perfusion pressure, the chief predictor of ROSC (return of spontaneous circulation). It also has been shown to correlate with cerebral blood flow.

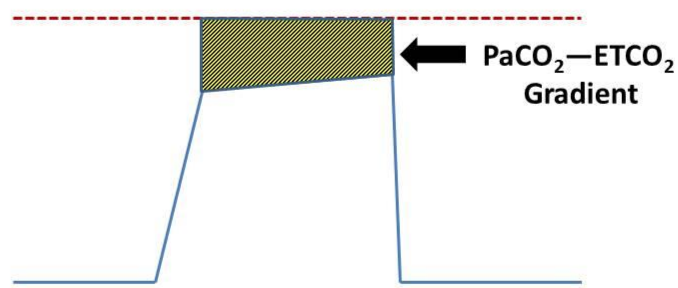
Transient increases in the $ETCO_2$ can be seen with administration of bicarbonate, high-dose epinephrine, and hyperventilation. It is important to maintain constant minute ventilation during CPR. Return of spontaneous circulation will produce a sudden increase in $ETCO_2$, usually to 40 mm Hg or more.

One major advantage of using capnography in CPR is the ability to assess the efficacy of closed chest compressions. A drop in the $ETCO_2$ can be due to rescuer fatigue. $ETCO_2$ can also be used to guide the depth and frequency of chest compressions—objective data, and much more reliable than pulse palpation (usually retrograde venous flow). If the $ETCO_2$ is less than 10 mm Hg, the American Heart Association's ACLS Guideline suggests trying to improve CPR quality by optimizing chest compressions. Additionally, a discernable waveform and $ETCO_2$ can reveal pseudo-EMD, which should be treated with vasopressors and fluid support.



$ETCO_2 \neq PaCO_2$

$ETCO_2$ is <u>always</u> less than the $PaCO_2$

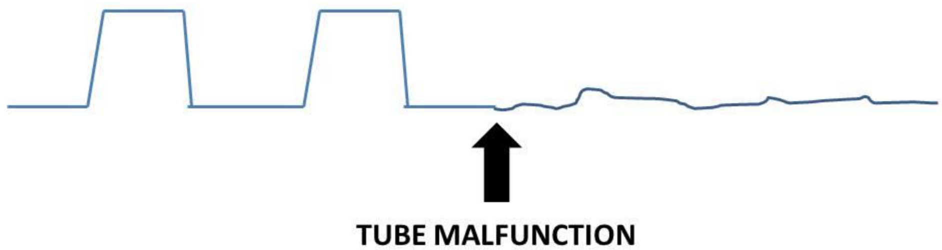


Normal gradient: 3-5 mm Hg

Larger gradient = Dead Space

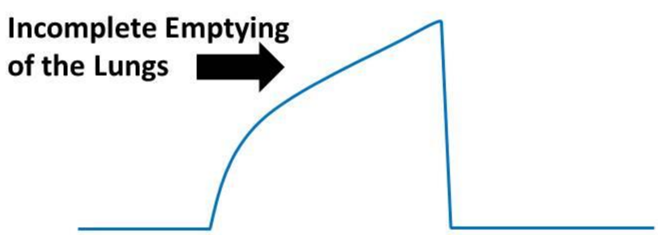
Increased Dead Space:

- Low Cardiac Output
- Pulmonary Embolism
- Air Trapping



No ETCO2 Waveform = Endotracheal Tube NOT WORKING

- **Complete obstruction**
- **Esophageal**
- **Dislodged into the hypopharynx**
- **No matter what—FIX THIS!**



Shark Fins = Bronchospasm

<u>Rising</u> $ETCO_2$
<u>Rising</u> $PaCO_2$

Alveolar Hypoventilation

- Oversedation
- Diminished drive
- Neuromuscular weakness

<u>Falling</u> $ETCO_2$
<u>Falling</u> $PaCO_2$

Alveolar Hyperventilation

- Pain
- Agitation
- Fever

<u>Falling</u> $ETCO_2$
<u>Unchanged or Rising</u> $PaCO_2$

Increased Dead Space

- Pulmonary Embolism
- Worsening cardiac function
- Bleeding
- Air trapping with autoPEEP

Zero $ETCO_2$
Loss of Waveform

TUBE MALFUNCTION

- Esophageal intubation
- Tube dislodgement
- Complete obstruction

EMERGENCY!