Video Article

Expired CO_2 Measurement in Intubated or Spontaneously Breathing Patients from the Emergency Department

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Abstract

Carbon dioxide (CO_2) along with oxygen (O_2) share the role of being the most important gases in the human body. The measuring of expired CO_2 at the mouth has solicited growing clinical interest among physicians in the emergency department for various indications: (1) surveillance et monitoring of the intubated patient; (2) verification of the correct positioning of an endotracheal tube; (3) monitoring of a patient in cardiac arrest; (4) achieving normocapnia in intubated head trauma patients; (5) monitoring ventilation during procedural sedation. The video allows physicians to familiarize themselves with the use of capnography and the text offers a review of the theory and principals involved. In particular, the importance of CO_2 for the organism, the relevance of measuring expired CO_2, the differences between arterial and expired CO_2, the material used in capnography with their artifacts and traps, will be reviewed. Since the main reluctance in the use of expired CO_2 measurement is due to lack of correct knowledge concerning the physiopathology of CO_2 by the physician, we hope that this explanation and the video sequences accompanying will help resolve this limitation.

Video Link

The video component of this article can be found at http://www.jove.com/video/2508/

Protocol

Material Used in Capnography

One of the obstacles to the utilization of expired CO_2 monitoring resides in the disparity of the material used by emergency physicians. To clarify this situation, it is important to distinguish whether the patient is artificially ventilated or breathing spontaneously. As for the rest, the different techniques used for analysis no longer have an implication on clinical results and efficiency.

This statement stands in the case of the traditional distinction between sidestream and mainstream capnography. These two techniques measure CO_2 using infrared waves; the sidestream system uses an aspiration pump to transport CO_2 from the mouth to the detector situated in the monitor, while the mainstream system measures CO_2 directly in a small chamber situated at the mouth of the patient and connected to the monitor by a cable. Traditionally, the sidestream system is used for patients breathing spontaneously as the system is lighter, and the mainstream system, a little bulkier, is connected directly to the endotracheal tube in intubated patients. Technological advances in the last years have fundamentally reduced the differences between mainstream and sidestream systems. New technology is pointing towards the microstream system, which is a sort of 'enhanced sidestream system' in which CO2 travels along a thin tube before reaching the chamber where the detector is located, allowing a smaller transition period between the mouth and the detection chamber and thus a capnography curve that is almost synchronized with the passage of air at the mouth. So, let us have a look at what distinguishes the choice of material, as explained in the second half of the video sequence:

- If the physician wishes to monitor a patient in spontaneous ventilation so as to precocely detect apnea (during procedural sedation, or after medical intoxication), then only the form of the curve is essential, the actual value of $ETCO_2$ being of less importance. In this case, he physician can choose between nasal prongs or a capnomask combining oxygen administration and CO_2 aspiration, or a thin CO_2 aspiration tube that can be placed under a classical mask.
- If the physician wishes to precisely analyse $ETCO_2$ in order to adapt the parameters on a respirator, to verify the correct positioning of an endotracheal tube, or to evaluate the prognosis during cardiac arrest, he must use the material than can be adapted for use with an endotracheal tube (always placed behind the filter so as secretions from the patient do not block the tube).

The Capnography Curve

A typical capnography curve during three expirations is given in Figure 1. The curve regains the x-axis (0 value) at each inspiration, as there is virtually no CO_2 in inspired air.

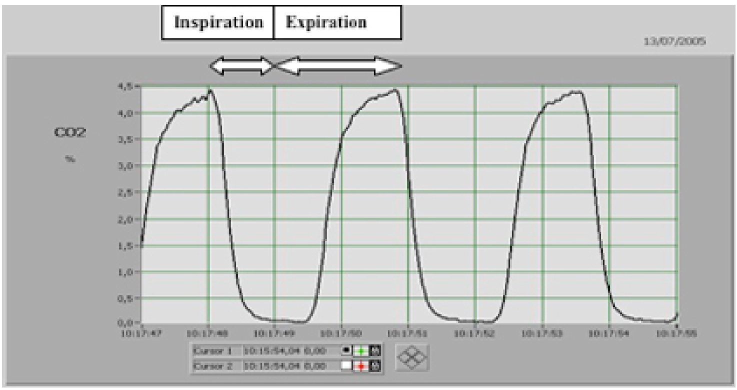

Figure 1: alternance inspiration-expiration

Differences Between $PaCO_2$ and $ETCO_2$

It would be eutopic to believe that non-invasive monitoring of expired CO_2 can replace in all circumstances the need for arterial blood gas (ABG) measures, considered to be the gold standard for the measurement of $PaCO_2$. All depends on the indications for the measurement of expired CO_2 and the patient's cardio-respiratory condition. If the indication is the monitoring of respiratory activity to prevent hypoventilation and apnea during sedation, a simple analysis of the curve is sufficient, whatever the value of $ETCO_2$. On the other hand, if the indication is to monitor the adequate ventilation of a head trauma patient with no history of cardio-respiratory disorders, we can expect the $ETCO_2$ value to be close to the PaO_2 value, though the necessity of a precise $PaCO_2$ value imposes at least one ABG sample, which also allows us to confirm that indeed $ETCO_2$ is close to $PaCO_2$ in the present case.

Finally, if we are faced with the case of a patient that is intubated and ventilated due to respiratory distress, $ETCO_2$ values will evidently not be a good approximation of $PaCO_2$. The reason is simple; as soon as there is a disturbance in ventilation-perfusion ratios, regardless of what the cardio-pulmonary disorder present is, an obstacle to the correct elimination of CO_2 by the lungs is created. As a result, CO_2 accumulates in the blood, and naso-buccal elimination is reduced, creating a $PaCO_2$ - $ETCO_2$ gradient. In this circumstance, it is crucial to know the value of $PaCO_2$ before any interpretation of the $ETCO_2$ value.

The first part of the video sequencedescribes the procedure to be followed for interpreting the difference between $PaCO_2$ and $ETCO_2$. We see that the measure of $ETCO_2$ is obtained immediately and in a non-invasive manner, but at this stage cannot allow the adaptation of the respirator's parameters. This implies having to measure the $PaCO_2$ that can then be compared with the $ETCO_2$. The $PaCO_2$ value remains the referral value for the appreciation of patient ventilation.

- If $PaCO_2$ measured is higher than the desired value, for example 60mmHg instead of 40mmHg, this signifies that the patient is hypoventilated. The respirator's parameters can then be adapted; either the respiratory rate or the tidal volume can be increased in order to increase the ventilation and thus decrease $PaCO_2$. The objective consists in reducing the $ETCO_2$ by 20mmHg, regardless of the initial $ETCO_2$ value. For example, it can be possible that the $ETCO_2$ value is 50mmHg when the $PaCO_2$ is measured at 60mmHg, due to a $PaCO_2$ -$ETCO_2$ gradient created by the presence of a cardio-respiratory disease. When the adaptation of the respirator's parameters allows the $ETCO_2$ to drop from 50mmHg to 30mmHg, we can safely suppose that the patient is adequately ventilated with a $PaCO_2$ value having dropped from 60mmHg to 40mmHg.
- Inversely, if the $PaCO_2$ is lower than the target value, the patient is hyperventilated and consequently respiratory rate or tidal volume must be reduced to attain the target value. If $PaCO_2$ is 20 mmHg lower than the targeted value, one has to increase the $ETCO_2$ by 20mmHg through modification of the respirator's parameters.

Artifacts and Traps in Capnography.

If the technology for CO_2 measurement has become reliable in terms of precision, reproducibility, response time and curve quality, it still presents, as for any monitored parameter, certain limits:

- The first limitation is due to lack of correct knowledge concerning the physiopathology of CO_2 by the physician, who then is reluctant to use the technique. We hope that this explanation and the video sequences accompanying will help resolve this limitation.
- In the case of the spontaneously breathing patient, the adjunction of oxygenotherapy via the mask will dilute the expired CO_2, which will significantly modify the capnogram and the $ETCO_2$ will drop. The video sequence demonstrates this phenomenon.
- If one wishes to monitor for hypoventilation, or an apnea event, during procedural sedation, we expect $ETCO_2$, in correlation to $PaCO_2$, to increase in parallel to hypoventilation of the patient. Paradoxally, a hypoventilation event in a patient breathing spontaneously is translated by a drop in $ETCO_2$, because the patient is then only breathing with a very small tidal volume, which essentially corresponds to the dead volume of the tracheo-bronchal space; and as we know, this space does not participate in gaseous exchange and thus contains very little CO_2.

- During mechanical ventilation, the pitfall is that one forgets that $ETCO_2$ does not necessarily reflect $PaCO_2$ (see previous chapter).

Discussion

Importance of CO_2 for the Organism

Before exploring expired CO_2 monitoring, it is essential to put into perspective the general role played by CO2 in the human body. Produced at a rate of approximately 200 ml per minute, CO_2 is not just a wasted by-product of cellular metabolism. If our medullar chemoreceptors have the role of maintaining the arterial CO2 partial pressure ($PaCO_2$) at 40mmHg, it is because CO_2 has other functions in the organism that the emergency physician encounters on a daily basis:

- CO_2 constitutes an incredible reserve as a tampon to the continued production of acid by the organism, and thus allows the maintenance of an adequate pH.
- CO_2 values correlate reliably with the patient's ventilation, and its measure is crucial in order to affirm hypo- or hyperventilation of the patient.
- CO_2 plays an important role in the regulation of cerebral perfusion, hypercapnia resulting in vasodilatation and consequently cerebral edema, and inversely hypocapnia provoking vasoconstriction and the risk of ischemia.
- CO_2 values vary in complement to changes in O_2values: the hypocapnia subsequent to hyperventilation constitutes the organism's first reflex reaction to hypoxia when faced with respiratory disease or increase in altitude.

What Expired CO_2 Represents

The CO_2 value as measured at the mouth reflects three fundamental processes: (1) tissular production of CO_2, (2) its transport in the venous system to the pulmonary arteries, and (3) its elimination by the lungs. In emergency medicine, the principal indications for the use of expired CO_2 measurement involves the third process and, more precisely, provides a method of evaluation of the patient's ventilation. An exception is during cardiac arrest, where the measuring of expired CO_2 also reflects the transport of CO_2 in the circulatory system, to the extent that a continuously low value of $ETCO_2$ after 20 minutes of correctly-conducted reanimation conveys the (probably) irreparable absence of blood circulation

Relevance of Measuring Expired CO_2

End tidal CO_2 ($ETCO_2$) values correlate with arterial CO_2 ($PaCO_2$) values, and thus measuring $ETCO_2$ reduces the need for repeated, sometimes difficult and not forgetting painful, arterial blood gas sampling. $EtCO_2$ is typically 3mmHg less than $PaCO_2$. This correlation is only valid if the patient carries no pulmonary disease or defect. For all situations where the ventilation - perfusion ratio is varied, a gradient between the $PaCO_2$ and the $ETCO_2$, and thus $ETCO_2$ measurement has to be combined with ABG sampling in order to obtain the real value of the $PaCO_2$.

Disclosures

No conflicts of interest declared.

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