Applied physiology at the bedside: Volumetric capnography

23.04.2019

Author: Jean-Michel Arnal, Senior Intensivist, Ste Musse Hospital, Toulon, France, Reviewer: David Grooms

Volumetric capnography is the graphical representation of the partial pressure of carbon dioxide (CO2) versus exhaled volume. This measurement is made noninvasively at every breath by a combination of flow and CO2 sensors, which are positioned together at the Y-piece of the ventilator circuit and well synchronized. Volumetric capnography provides much more information than time capnography, primarily about the metabolism, cardiovascular function, ventilation, and ventilation/perfusion (V/Q) ratio.

Takeaway messages

Volumetric capnography is the graphical representation of the partial pressure of carbon dioxide (CO2) versus exhaled volume, and provides more information than time capnography.

A volumetric capnogram is divided into three phases that correspond with the changing dynamics of gas as the lung empties.

A number of physiological variables can be measured and calculated from volumetric capnography, including anatomical or airway dead space, alveolar dead space, end-tidal CO2, the volume of CO2 exhaled at each breath, and the slope of Phase III.

These variables provide information about the metabolism, cardiovascular function, ventilation, and the ventilation/perfusion (V/Q) ratio.

Physiological meaning

The volumetric capnogram is divided into several phases that correspond with the changing dynamics of gas as the lung empties (1, 2):

Phase I is the first gas exhaled that comes from the conducting airways and contains no CO2.

Phase II is shaped like an S with a rapid increase in CO2. This phase represents gas exhaled from conducting airways mixed with gas from fast-emptying alveoli.

Phase III is plateau-shaped with a positive slope. This phase represents gas exhaled from the alveoli, and the slope represents the changing time constant of the emptying alveoli; i.e., alveoli with a low V/Q ratio empty last and contain the highest amount of CO2 (3).

From volumetric capnography, a number of physiological variables can be measured and calculated:
The anatomical or airway dead space (VDaw in ml) is measured as the volume from the beginning of exhalation through to a vertical line that bisects Phase II (4). Based on VDaw, the ratio VDaw/VT (%), the alveolar ventilation (Valv in ml = VT x VDaw), and the alveolar minute ventilation (Valv in ml/min = VDaw x respiratory rate) can be calculated. The physiological dead space is the sum of VDaw and alveolar dead space (VDalv in ml). VDalv can be calculated using the measurement of PaCO2 and the Bohr-Enghoff equation, and corresponds with the area between the volumetric capnogram and the horizontal line of PaCO2 (5, 6). End-tidal CO2 (PetCO2 in mmHg) is measured at the end of Phase III and represents the CO2 content of the alveoli with the lowest V̇/Q̇ ratio. PetCO2 is usually several mmHg lower than PaCO2; the CO2 gradient (PaCO2-PetCO2) reflects the V/Q inequalities (7). The volume of CO2 exhaled at each breath is calculated as the area underneath the curve of the volumetric capnogram (VeCO2 in ml). VeCO2 multiplied by the respiratory rate equals the total CO2 exhaled per minute, which is assumed to be equal to CO2 production (V'CO2 in ml/min) in a steady, stable condition of circulation and ventilation. The slope of Phase III represents V/Q mismatching (SlopeCO2 in %CO2/l). Airflow obstruction and lung inhomogeneity increase the slope of Phase III (1, 3, 8).

Clinical applications

Metabolism: If the cardiovascular function and ventilation remain stable, a change in V'CO2 represents a change in CO2 production, i.e., a metabolic change. V'CO2 increases in the case of fever, sepsis, shivering, seizures, bicarbonate infusion, hyperthyroidism, or insulin therapy. The first symptom of sepsis is generally an increase in V'CO2 that occurs before the onset of fever. Conversely, V'CO2 decreases in the case of hypothermia, sedation, paralysis, or brain death. When the patient’s condition evolves to brain death, the cessation of brain perfusion may be demonstrated by a sudden decrease in V'CO2.

Cardiovascular function: If CO2 production and ventilation remain stable, V'CO2 changes according to cardiac output and lung perfusion. Therefore, V'CO2 increases in the case of peripheral vasodilatation and cardiac output increase. An increase in V'CO2 during passive leg rising can probably be used as a predictor of fluid responsiveness (9). In addition, a PEEP-induced decrease in V'CO2 by more than 10% predicts volume responsiveness (10). Conversely, V'CO2 decreases in the case of low cardiac output, shock, and pulmonary embolism. In the case of pulmonary embolism, the CO2 gradient increases.

Ventilation: If CO2 production and cardiovascular function remain stable, a change in V'CO2 occurs as a change in alveolar ventilation. V'CO2 increases transiently in the case of hyperventilation and decreases transiently in the case of pulmonary edema, pneumothorax, V/Q inequalities and ARDS. However, the time required for V'CO2 to return to baseline is shorter in the case of hyperventilation than in that of hypoventilation (7).

Ventilation/perfusion mismatching: If CO2 production, cardiovascular function, and ventilation remain stable, a change in ventilator settings that potentially modify the V/Q ratio can be monitored using V'CO2. For example, an increase of PEEP in an ARDS patient may recruit and homogenize the lung on the one hand, but may impair lung perfusion on the other. The net effect on ventilation/perfusion can be assessed by the rapid change in VeCO2.
and SlopeCO2 (11). In morbidly obese patients, the highest dynamic compliance during decremental PEEP titration after a recruitment maneuver occurs at the PEEP level producing the lowest SlopeCO2 (12).

Volumetric capnography is available on almost all Hamilton Medical ventilators*. The volumetric capnogram can be displayed on the screen and the ventilator automatically calculates VDaw, VDaw/VTe, Valv, PetCO2, SlopeCO2, VeCO2, and V'CO2 at every breath.

* Standard feature on the HAMILTON-S1, optional on all other models except the HAMILTON-MR1

References:


