Capnography: A Feasible Tool in Clinical and Experimental Settings

Capnography is the monitoring of the partial pressure of alveolar carbon dioxide (CO_2) in the respiratory gases. It is a useful noninvasive clinical tool for assessing efficiency and optimizing mechanical ventilation.[1] The use of capnography for monitoring surgical patients during anesthesia and in the emergency department to confirm artificial airway placement is well-established and recommended.[2] Capnography's importance as a standard of monitoring and patient safety in the ICU has been confirmed in recent years.[1,3] Clinical uses of capnography in the ICU also include indirect assessment of cardiac output during weaning from cardiopulmonary bypass in patients without significant lung disease, monitoring of patients during changes in bed positioning, prognostic indicator of outcome in cardiac arrest, adjustment of the trigger sensitivity, and assessment of pulmonary circulation, recognizing the presence of pulmonary embolism as well as the effectiveness of chemical thrombolysis.[4-8]

Expiratory partial pressure of CO_2 can be plotted against time (time-based capnography) or expired volume (volumetric capnography) on each breath. The capnogram is a graphical representation of the concentration or partial pressure of inhaled and exhaled CO_2. Measurement of P_{aCO_2} in arterial blood gas, although a true reflection of ventilatory efficiency, is far from ideal because of its invasive and intermittent nature. The main advantage of capnography over arterial blood gas is the ability to provide continuous CO_2 monitoring, thus making trend assessments feasible. Although capnography does not replace arterial blood gas analysis (P_{aCO_2}), it may decrease the required frequency.

Physiologically based indices derived from the capnographic waveform give direct information about ventilatory misdistributions and functional disturbances. Changes in the morphology of the capnogram indicate ventilation disturbances, and several indices based upon the geometry of the curve were developed in order to quantify ventilation homogeneity distribution.[9-11] Moreover, capnography provides an assessment of ventilation/perfusion ratio ($\dot{V}/\dot{Q}$) mismatch through measurements of end-tidal CO_2 (P_{ETCO_2}). The difference between P_{aCO_2} and P_{ETCO_2} in healthy subjects is very small, so P_{ETCO_2} may reflect P_{aCO_2}.[12] Many clinical situations could change P_{ETCO_2} values, influencing the arterial-alveolar CO_2 difference, which in healthy individuals is <5 mm Hg.[12] This difference can be significantly increased in the presence of lung diseases and some cyanotic heart diseases. Then, in an absence of $\dot{V}/\dot{Q}$ mismatch, the P_{ETCO_2} can be correlated to P_{aCO_2}.

SEE THE ORIGINAL STUDY ON PAGE 1548

P_{ETCO_2} is often used to optimize the ventilatory strategy and to assess potential changes in pulmonary blood flow.[1] P_{ETCO_2} measures the expired gas at the end of tidal volume; therefore, it is more representative of alveolar CO_2 than airway gas. The P_{ETCO_2} obtained from time-based capnography, when associated with arterial blood gas (P_{aCO_2}), can be used to calculate the end-tidal alveolar dead-space fraction (end-tidal alveolar dead-space fraction $= [P_{aCO_2} - P_{ETCO_2}]/P_{aCO_2}$) utilized as an indicator of alveolar V_D. Hardman et al[13] describe the end-tidal alveolar dead-space fraction as a reliable marker to quantify alveolar V_D. According to these authors, the end-tidal alveolar dead-space fraction is easy to obtain, useful, and safe at the bedside of ICU, infirmary, or emergency rooms when used correctly.

The time-based capnogram is the capnography method most commonly used in clinical practice. It provides only a quantitative measurement of P_{ETCO_2}, and it is not able to quantify directly alveolar V_D or anatomic V_D. The volumetric capnogram, besides quantitative monitoring of the P_{ETCO_2}, provides extensive physiological information about production, transportation, and elimination of CO_2 within the lungs through waveform patterns.[9-11,14] Volumetric capnography, unlike time-based capnography, allows identification of CO_2 from sequential emptying of alveoli, and anatomic V_D measures, and evaluation of V_D in each breath. Time-based capnography requires simpler equipment than does volumetric capnography, which involves a pneumotachometer attached to a capnograph, making it a more expensive apparatus. There are few volumetric capnographs commercially available, and most of them are attached to modern mechanical ventilators.

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Volumetric capnography is considered the best tool to measure dead-space volumes (physiological, alveolar, and anatomic), allowing a functional analysis and providing clinical clues about the efficiency of gas exchange.[3] The V_D increases when the alveolar-capillary interface is compromised (eg, COPD, atelectasis, and ARDS),[15-17] during decreased pulmonary blood flow (eg, pulmonary embolism),[18] or when alveoli are overdistended (eg, high PEEP). Physiological dead space (V_D) involves the sum of anatomic V_D, consisting of the portion of the airways that conducts gas without gas exchange, and alveolar V_D, which consists of alveoli that are ventilated but not well perfused ($\dot{V}/\dot{Q}$ mismatch). The physiological V_D/V_T ranges from 0.30 to 0.35 in healthy children.[19] The $V_D/V_T > 0.4$ can result in hypoxemia or hypercapnia due to $\dot{V}/\dot{Q}$ inequality.

Monitoring the V_D and its ratio to tidal volume (V_D/V_T) has proven to be valuable for monitoring patients on mechanical ventilation and for optimizing ventilatory strategies. V_D/V_T has been studied as a measurement of extubation failure risk in children.[20] Increased V_D fractions also have been demonstrated to be strongly associated with an increased mortality in subjects with ARDS.[21] Almeida-Junior et al[22] monitored V_D/V_T in infants with acute bronchiolitis and reported an association between disease severity and V_D/V_T. Likewise, V_D/V_T could be predictive of survival in ventilated newborn infants with congenital diaphragmatic hernia.[23] Arnold et al[23] claim that $V_D/V_T > 0.6$ is associated with a 15-fold increase in the rate of mortality.

V_D/V_T reflects disturbances in the $\dot{V}/\dot{Q}$ ratio and is affected by any kind of $\dot{V}/\dot{Q}$ mismatch. Volumetric capnography is also used for monitoring the progression of lung diseases and evaluating the response of V_D/V_T after changes in mechanical ventilation parameters, such as PEEP and V_T.[24,25] Furthermore, volumetric capnography can discriminate healthy individuals from those with lung disease, such as cystic fibrosis, bronchiectasis, COPD, lung fibrosis, and asthma, which presents a steeper slope of phase 3 of the capnogram.[9-11]

In this issue of RESPIRATORY CARE, Bhalla et al[26] correlated volumetric capnography versus time-based capnography measurements of V_D and its fractions. Researchers calculated the V_D/V_T and end-tidal alveolar dead-space fraction in 65 mechanically ventilated children and adolescents and found a higher correlation between the end-tidal alveolar dead-space fraction and alveolar V_D/V_T than with V_D/V_T. Monitoring changes in alveolar V_D at the bedside in the ICU with time-based capnography could be simpler and easier than with volumetric capnography. According to Bhalla et al,[26] the end-tidal alveolar dead-space fraction calculated by time-based capnography is as good as alveolar V_D/V_T measured by volumetric capnography.

The interpretation of capnography must take into account the stability of physiologic variables, such as minute ventilation, V_T, cardiac output, and CO_2 body storage. As a result, the evaluation and interpretation of capnographic data in children should be cautious, particularly in a critical care setting. Although the authors have described that data collection was made during a stable period, if capnography data had been recorded in a similar ventilation mode, bias could be reduced. Bhalla et al[26] points out major factors that reduced the correlation between physiological and alveolar V_D/V_T measured by volumetric capnography with time-based capnography (end-tidal alveolar dead-space fraction): high V_D/V_T (>0.6), lower oxygenation ($P_{aO_2}/F_{IO_2} < 200$), a large anatomic V_D (≥ 3 mL/kg), and the administration of inotropes or vasopressors. Those results are probably due to a higher $\dot{V}/\dot{Q}$ mismatch caused by an increase in anatomic V_D in subjects with worse lung disease severity.

To summarize, capnography is promising and feasible in the ICU, emergency room, and anesthesia care unit for monitoring the lungs' ventilation/perfusion in mechanically ventilated patients. Volumetric capnography is the best capnography method to guide ventilatory support according to V_D fractions, but it requires specialized and expensive equipment. As evidenced by Bhalla et al,[26] time-based capnography may be a feasible and less expensive option to assess alveolar V_D during mechanical ventilation in the ICU and reduce it, allowing a better $\dot{V}/\dot{Q}$ match. Despite its potential, capnography remains rarely used because health professionals are unaware of its usefulness in the bedside routine. As stated by Suarez-Sipmann et al,[3] the time has come to take capnography out of the experimental setting and introduce it to guide ventilatory strategies in clinical practice.

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