



Volumetric Capnography: History, Function and Clinical Uses

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Abstract

Introduction: The volumetric capnography (VCap) is a quick, simple, cheap, and effective test for distal airways. The test is based on the volumetric concentration of expired CO₂ and tidal volume (CV) flow over a single exhalation. **Literature Review:** The exam makes it possible to observe the curve of expired CO₂, considering its concentration. These CO₂ curves are plotted, showing the inspired volume point by point, and the dead space volume can be calculated among the elimination of CO₂ with each breath, showing us the different phases of breathing, seen in slopes, from 1 to 3. **Discussion:** Several authors found valuable data when comparing volumetric capnography with other established tests, such as spirometry. **Conclusion:** Despite the countless discoveries using capnography, we still need more tests and comparisons in other pathologies to better understand their most diverse peculiarities. Not forgetting that capnography is a complementary exam. We need other tests, such as computed tomography (CT), to make a diagnosis and define an appropriate treatment for subjects.

Subject Areas

Lung Function, Pulmonary Disorders, Health Care

Keywords

Volumetric Capnography, Airway, Diagnosis

1. Introduction

The volumetric capnography is a quick, simple test and has proven to be of great value when it comes to distal airways. The test is based on the volumetric concentration of expired CO₂ and tidal volume flow over a single exhalation. Changes

in the production and elimination of CO₂ can occur in metabolic and lung diseases. These changes in homeostasis can be detected by the partial pressure of CO₂ in arterial blood. With the difficulties of monitoring and measuring CO₂ levels in arterial blood by blood gas analysis, a convenient solution for CO₂ monitoring can be through non-invasive measurements, by analyzing expired air. The method of analyzing exhaled CO₂ is the absorption of infrared light according to the Lambert-Beer laws, where it is possible to calculate the energy absorption of CO₂ by measuring its concentration through reducing the intensity of light in the passage of the CO₂ sample by the sensor, after a comparison of intensities with a normal sample, made possible by the polyatomic and asymmetric nature of CO₂ [1] [2]. The first measurement of spectrum absorption using infrared was made in the 1860s by the physicist John Tyndall, by measuring expired CO₂, managing to quantitatively measure the physical values of the molecule. From this, it was possible to develop the capnography as we know it today. There is much evidence in the literature of the robustness of spirometry as a marker of severity and prognosis of airway diseases, such as in chronic obstructive pulmonary disease (COPD), some important information may go unnoticed by spirometry. Different evaluation methods can help to elucidate other aspects of the small airways, such as structural changes, how and why there is variability and heterogeneity in some clinical presentations, etc. There are several tools that allow the non-invasive assessment of structural changes in the airways, and here it is essential to mention high-resolution chest tomography. It is an exam that shows the involvement of the small and large airways. The volumetric capnography is also a method that allows us to non-invasively assess airflow. However, with the advantage of being a simple exam, both for the subjects and for the physician, it is lower cost when compared to computed tomography and does not require the subject's effort to obtain results, as in spirometry.

2. Literature Revision

The volumetric capnography device can have a sidestream flow or mainstream flow respiratory gas monitor. The mainstream method has its infrared sensor close to the subject, where it is kept between the Y and the tracheal tube. The sidestream method, on the other hand, is more easily manageable and allows the monitoring of other gases, in addition to CO₂ [3] [4]. The main difference between the methods is that the mainstream flow has a high precision, virtually instantaneous measurement of the CO₂ concentration. While the sidestream flow method has a lower fidelity in the results and also presents a delay of a few seconds in the measurement of the sample compared to that seen in the analysis of the mainstream flow method [3]. The VCap is able to detect changes in dead space volumes, ventilation perfusion rates, pulmonary blood flow, and other respiratory changes. The respiratory system is composed of the physiological dead space (alveolar dead space *plus* anatomical dead space). In the anatomical dead space, CO₂ clearance does not occur, making it possible to quantify the vo-

lume of lungs units that are ventilated but not perfused and capture measurements of the airway. In addition to being in the dead space where most ventilation-perfusion abnormalities occur, the expired nitrogen curve shown is the same as that of CO₂ considered its concentration, allowing to separate the alveolar dead space from the anatomical dead space based on respiration [5]. Such dead space measurements can help us in diagnosis, prognosis and therapeutic applications. These CO₂ concentrations are plotted in a graphic showing the inspired volume point by point, and the dead space volume can be calculated between the elimination of CO₂ with each breath [5] [6]. The slope 1 marks the exhaled tidal volume of the anatomical dead space airways, showing low concentrations of CO₂ or its absence. The slope 2 represents lung units, where we observed a practically linear increase in CO₂ coming from the transition among the anatomical dead space and the alveolar gas compartment, with normal values of 0.36 mmHg/mL 0.40 mmHg/mL. The slope 3 has its volumes attributed to the distribution of ventilation and lung perfusion, CO₂ comes from the alveolar gas compartment, distal airways (characterized by the alveolar plateau, with normal values between 0.007 mmHg/mL 0.017 mmHg/mL [1] [5]).

These assays allow detection of pulmonary ventilation inhomogeneity and also allow an estimation of the anatomic location of the underlying disease process [7].

3. Discussion

The capnography obtained several interesting results. One of the first results demonstrated by capnography was performed by Romero *et al.* in 1997 [8], where they carried out a study with normal subjects and subjects with Acute Respiratory Distress Syndrome (ARDS) on mechanical ventilation. Concluding that CV index are important to detect heterogeneity in the distribution of ventilation in subjects with ARDS, when compared to normal anesthetized and mechanically ventilated individuals. Among the indices studied, the relationship between effective alveolar ventilation volume and tidal volume seems to be the most sensitive and reproducible to assess ventilatory disorders.

In a study involving peripheral pulmonary obstruction in subjects with cystic fibrosis, volumetric capnography was used as a technique for analysis gas elimination. In an attempt to obtain information on the distribution of pulmonary ventilation in the distal air spaces, involving the multiple-breath washout (MBW) technique. The main finding of volumetric capnography was related to slope 3/CV. Proving to be more sensitive compared to spirometry, which indicated normal results. The slope 3 showed changes regardless of the stage of lung disease, involving subjects with cystic fibrosis [9].

Through an experimental study on near-fatal pulmonary embolism, capnographic variables were tested in comparison with hemodynamic and blood gas measurements. The study involved six pigs intubated with an orotracheal tube to facilitate capnography data collection. The pigs were also sedated with 0.5% ha-

lothane while still maintaining spontaneous breathing in environmental air. Capnography data in the presence of hypercapnia were increased in respiratory variables involving the total minute volume, the minute volume of anatomical dead space, and finally, the alveolar minute volume. In conclusion, that the capnographic variables were effective in the assessment of acute obstructive disease in subjects with pulmonary embolism [10].

Guang-Sheng *et al.* 2014 [11], in a study in which they studied the ability of volumetric capnography to distinguish subjects with COPD from normal individuals, concluded that some of the values determined, such as slope 2, slope 3 and the volume, in which the concentration of CO₂ rises from 25% to 50% of the value of mean end-tidal carbon dioxide pressure (ETCO₂), alone, are able to differentiate patients with COPD from normal individuals.

Schwardt *et al.* in 1994 [12] proposed a method of retrieving information on the dimensions of distal air spaces and on the gas transport properties, from the volumetric spirogram of CO₂ in healthy individuals and in subjects with COPD. The dimensions of the different pulmonary structures used were those proposed by Weibel [13], Hansen and Ampaya [14], who specified the length of the air spaces, their diameter and the total cross-sectional area in each of the 23 (twenty-three) or 26 (twenty-six) generations (z) that start their bifurcation from the pharynx, larynx and trachea (since all these regions contribute to the anatomical dead space), where $z = 0$ and end in the most peripheral of the alveolized generations (23 or 26), depending on the study used, either Weibel [13] or Hansen. [14] The combination of the data obtained in real measurements with the computer simulation of the numerical values of CO₂ transport allowed the development of a computerized method of analysis of the CO₂ spirogram capable of estimating the loss of alveolized tissue and the limitation of gas transport in emphysema. It was able to determine the effects of the variation of acinar morphology in the form of phase 3 of the volumetric CO₂ spirogram. Previous studies by Schwardt *et al.* in 1991 [15] had already demonstrated that small tidal volume, reduction in the cross-sectional area of distal air spaces and any other changes that also produced a decrease in the interface area between the incoming new tidal volume and the volume of gas already present in the lung functional residual capacity, produce an increase in phase 3 slope.

Schwardt *et al.* [12] [15] reached an important conclusion that the reduction in the total cross-sectional area of the peripheral airspaces, when combined with an increase in the length to be traveled by CO₂, until it reaches the mouth, in order to maintain similar volumes moved, causes an increase in phase 3 slope.

Veronez *et al.* [16] in a study carried out with cystic fibrosis and non-cystic fibrosis bronchiectasis subjects, concluded that both groups of subjects showed an increase in slope 3 when compared to the control group, a fact that would probably indicate the presence of diffuse small airway disease in both diseases, cause of ventilation heterogeneities.

The asymmetric branching of the bronchial tree produces parallel units

(acins) that differ in axial length and volume, and this asymmetry explains the slight positive slope of the alveolar plateau at phase 3 of the capnogram in most normal subjects. In bronchiectasis, there is probably an accentuation of this asymmetry, which will be greater, more severe and diffuse the disease [17].

Diniz *et al.* [18] found that the greater the thickness of the bronchial wall, the greater the $ETCO_2$. And that increases in slope 3 indicate major damage to the distal airways and/or lung parenchyma.

Galvão *et al.* [19] volumetric capnography and exercise tolerance and reduction of dyspnea during activities of daily living. The same was observed in subjects grouped according to disease severity, with no differences among groups.

Luiz *et al.* [20], in a study with Duchenne muscular dystrophy, found volumetric capnography parameters referring to higher heart rate and lower slope on slope 2.

4. Conclusion

The capnography provides important data allowing us to have a better understanding of the physiology and pathology of some respiratory diseases. The volumetric capnography is not a substitute for any other exam. It is a way of evaluating the lungs from another perspective. Like what happens in the most distal generations of the bronchi and, with that, makes the treatment of subjects increasingly better and more efficient, consequently, reducing the expenses of the subjects and the health sectors.

Considerations

This present study is a simple literature review. Not involving human or animal participants.

Conflicts of Interest

The author declares no conflicts of interest.

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