Estimating of end-tidal carbon dioxide partial pressure in patients with cardiovascular diseases at rest and during physical activity: minireview

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Abstract.
End-tidal partial pressure of carbon dioxide (PetCO2) indicates the efficiency of respiratory function and gas exchange. It plays quite an important role in assessing patient’s condition and optimal treatment planning. The current article examines changes in PetCO2 as an important indicator for monitoring patients with cardiovascular disease (CVD), namely heart failure, coronary artery disease, arterial hypertension, and pulmonary hypertension. Such methods of PetCO2 monitoring, like capnometry in comparison with transcutaneous PCO2 measurement, are analyzed, and the diagnostic significance of these changes, and clinical application in the context of CVDs, are discussed. It provides high accuracy and speed of measurement, which is critical for effective monitoring of patients with CVDs. The methodology of capnogram registration by capnography and its phases for interpretation are described. Physiological mechanisms regulating changes in PetCO2 and the possibilities of using this indicator for individualized therapy implementation improvement of outcomes in patients with CVD are also being investigated. Changes in PetCO2 during exercise in patients with CVD are noted, as well as the effect of different types of physical exertion on PetCO2.

Keywords:
carbon dioxide
capnography
monitoring indicator
cardiovascular system
physical exertion
Introduction

The partial pressure of end-tidal carbon dioxide (PetCO2) in the respiratory tract is an important indicator that reflects the efficiency of ventilation and the body’s metabolic activity. Normally, the value of PetCO2 is approximately 35-45 mm Hg. This parameter depends on alveolar ventilation, blood flow in the lungs and general metabolism [1].

Capnography is widely-used non-invasive continuously available instrumental method for PetCO2 measurements. Carbon dioxide concentration in exhaled air during the respiratory cycle is demonstrated graphically. This method represents the state of ventilation and blood flow in the lungs. Capnography allows not only to determine PetCO2, but also while evaluating the shape of the capnogram provides additional information about ventilation-perfusion ratio in the lungs. Capnography measures the level of CO2 in exhaled air using an infrared analyzer. As the patient exhales, the air passes through the capnograph sensor, which detects the concentration of CO2 in each exhale [2].

The capnogram consists of four phases [3]:
- phase I is the beginning of exhalation, when air from the dead space that does not participate in gas exchange leaves the lungs and the CO2 level is zero;
- phase II is a rapid increase in CO2 concentration as air from the alveoli mixes with air from the dead space;
- phase III is the alveolar gas plateau, when the CO2 concentration reaches its maximum and remains stable until the end of exhalation. The end of this phase corresponds to the value of PetCO2;
- phase IV – inhalation, when the CO2 level drops back to zero.

Capnography is of great clinical importance, as it provides information about the state of the patient's respiratory system and the effectiveness of ventilation [4]. It is particularly useful in clinical settings for monitoring patients during surgery [5], in general care [6] and in intensive care units [7], and even while resuscitation [8].

PetCO2 is a surrogate marker for arterial CO2 levels. However, this relationship may vary depending on the patient's
condition. For example, with an increase in ventilation that is not compensated by an adequate increase in cardiac output, PetCO2 may decrease. On the other hand, with normal ventilation but reduced lung perfusion, as can occur in heart failure, PetCO2 may also be reduced. Therefore, the analysis of this indicator requires a comprehensive approach [9].

Transcutaneous PCO2 measurement is another practical and reliable way of PCO2 registration. It is promising for judging steady state values for PaCO2 unless there is overt vasoconstriction of the skin. Moreover, it can be useful in conditions where capnography fails (high-frequency ventilation) or where arterial blood gas analysis is burdensome (clinic or home management of mechanical ventilation) [9].

For patients with cardiovascular disease (CVD), the value of PetCO2 can change significantly, particularly while physical exertion which requires detailed investigation to optimize diagnosis and treatment. We provided literature search in such Data base as PubMed using key words “partial pressure of end-tidal carbon dioxide”, “capnography”, “cardiovascular disease”, “cardiopulmonary exercise testing”, “exercising” and its combinations.

Main part

The heart and lungs are intimately linked. Hence, impaired function of one organ may lead to changes in the other. Accordingly, most of CVDs is associated with airway obstruction, loss of lung volume, impaired gas exchange, and abnormal ventilatory control [10].

Physical activity causes an increase in metabolic activity, which leads to an increase in CO2 production and, accordingly, to changes in PetCO2. In healthy individuals, PetCO2 may rise slightly or remain stable during exercise due to increased ventilation and lung perfusion. However, the situation may be different in patients with CVD. The ability to perform physical exercise is dependent on the cardiovascular system's ability to deliver oxygen to the tissues and eliminate the metabolic by-products produced. Three processes occur in the body to supply O2 and remove CO2, namely external respiration, circulation, internal respiration (oxidative phosphorylation in mitochondria in
order to produce ATP) [10]. Notably, PetCO2 has been suggested as a noninvasive index reflecting cardiac output under constant ventilation [11].

In health, the near-eucapnic, highly efficient hyperpnea during mild-to-moderate intensity exercise is driven by three obligatory contributions, namely, feedforward central command from supra-medullary locomotor centers, feedback from limb muscle afferents, and respiratory CO2 exchange (VCO2). Inhibiting each of these stimuli during exercise elicits a reduction in hyperpnea even in the continuing presence of the other major stimuli. However, the relative contribution of each stimulus to the hyperpnea remains unknown as does the means by which VCO2 is sensed. Mediation of the hyperventilatory response to exercise in health is attributed to the multiple feedback and feedforward stimuli resulting from muscle fatigue [12].

For the correct interpretation of changes in PetCO2, it is necessary to take into account the type of physical activity. Aerobic exercise, such as running, swimming or cycling, usually causes a significant increase in metabolic activity. This leads to an increase in the production of CO2 and, accordingly, to an increase in ventilation for its removal. In the case of CVDs, aerobic exercise may show changes in PetCO2, which depend on the degree of compensation of the cardiovascular system. Strenuous exercises, such as weightlifting or intense interval training, lead to rapid loss of muscle oxygen, production of lactic acid and additional CO2 [13, 14].

During exercise, efficient pulmonary gas exchange is characterized by uniform matching of lung ventilation with perfusion. By contrast, mismatching is marked by inefficient pulmonary gas exchange, requiring increased ventilation for a given CO2 production. The etiology of increased and inefficient ventilatory response to exercise in CVD is multifactorial, involving both peripheral and central mechanisms [15].

In patients with heart failure (HF) besides the widely accepted peak oxygen consumption (peak VO2) and VEN/VCO2 slope, other exercise variables - exercise oscillatory ventilation and PetCO2 - should gain attention in the
interpretation of cardiopulmonary exercise testing. Reduced cardiac output results in decreased pulmonary perfusion, which can cause a decrease in PetCO2. During exercise, such patients may experience a significant decrease in PetCO2 due to the inability of the cardiovascular system to provide adequate blood flow. This can be an indicator of the severity of the condition and the need for correction of treatment. Studies have shown that in patients with HF, a low PetCO2 value correlates with a high risk of mortality and complications. Thus, PetCO2 can be a useful tool for risk stratification and monitoring the effectiveness of therapy. Moreover, studies have shown that PetCO2 can be used as a prognostic indicator of survival in patients with HF. Low PetCO2 values during exercise are associated with a higher risk of mortality and complications [15, 16].

In coronary artery disease (CAD), blood flow disturbances can affect the efficiency of ventilation by changing the level of PetCO2. Patients with CAD may experience a decrease in PetCO2 during exercise, which may be a consequence of both decreased perfusion and possible changes in the ventilation characteristics of the lungs. This can be useful in detecting the degree of ischemia and evaluating the effectiveness of anti-ischemic therapy. Rocco et al. demonstrated that both continuous exercise training and interval exercise training modalities showed similar increases in PetCO2 levels during a graded exercise test in patients with CAD, which may be associated with an improvement in ventilatory efficiency and cardiorespiratory fitness [17]. Eto et al. established that aerobic exercise training early after the onset of AMI significantly increased PetCO2 during exercise, which may reflect an improvement in cardiac output during exercise in response to physical training via a decreased ventilation-perfusion mismatch [11].

Hypertensive patients may have increased vascular resistance, which can affect blood flow efficiency and, consequently, PetCO2. During physical exertion, such patients may have both an increase and a decrease in PetCO2, depending on the stage and control of the disease. PetCO2 monitoring can help determine the optimal level of exercise and evaluate the effectiveness of antihypertensive therapy.
Freeberg et al. suggests high-resistance inspiratory muscle strength training as a novel, time-efficient (5-10 min/day) form of physical training that may increase cerebrovascular reactivity to CO₂ leading to mild normalization of blood pressure in midlife/older adults with initial above-normal blood pressure [18,19].

To sum up abovementioned data, cardiopulmonary fitness testing with option of PetCO₂ measurement is a durable and versatile tool that provides valuable diagnostic and prognostic information regarding patients with cardiovascular and pulmonary disease. When combined with adjunctive imaging modalities, it provides additional information regarding cardiac function and also helps in providing prognostic information [20]. PetCO₂ can be used to evaluate the effectiveness of treatment in patients with CVD. For example, an increase in PetCO₂ during exercise after drug therapy, surgery, resuscitation may indicate an improvement in the patient's condition. A decrease in this indicator may signal deterioration of cardiac function or the need to correct therapy while increase in PetCO₂ is strongly associated with improvement of patient's condition [21]. PetCO₂ may also be useful in the differential diagnosis of various types of CVD during cardiopulmonary exercise test in complex with working muscle near-infrared spectroscopy, transthoracic echocardiography, thoracic ultrasound, and lung diffusion analysis [22]. Thus, for instance, patients with primary pulmonary hypertension may have different PetCO₂ values compared to patients with heart HF or CAD, which can help in making an accurate diagnosis and choosing optimal treatment. In comparison with chronic left HF, patients with right HF have a significantly lower PetCO₂, a lower peak PetCO₂ during exercise. Patients with right HF have more changes in ∆PetCO₂ from rest to exercise [23].

Regular monitoring of PetCO₂ can be incorporated into a CVD rehabilitation program to help determine optimal exercise levels. In addition, PetCO₂ can be used to evaluate the effectiveness of new therapeutic approaches and medications, providing objective data for clinical trials [11, 24, 25, 26].
In clinical practice, PetCO2 monitoring can be useful not only for cardiologists, but also for doctors in other specialties, such as pulmonologists and anesthesiologists. For example, in intensive care units, this indicator can be used to monitor patients after operations and in critical conditions [5, 7, 9, 27].

Conclusions

The use of capnography in clinical practice provides significant opportunities for monitoring and assessing the condition of patients with CVD. PetCO2 is an important indicator that allows timely detection of changes in the functional state of the cardiovascular system and correction of treatment.

PetCO2 is an important indicator for assessing the condition of patients with CVD during exercise. Its use allows timely detection of changes in the functional state of the cardiovascular system and adjustment of treatment. PetCO2 is used as a prognostic indicator of survival, risk stratification, monitoring of the patients and therapy effectiveness as well as rehabilitation. Additional research may help expand the use of PetCO2 in clinical practice, which will improve the quality of care for patients with CVD.

References:


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