Volumetric Capnography for Monitoring Lung Function during Mechanical Ventilation

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Ⅰ Introduction

Capnography has become standard of care in monitoring respiratory function during anesthesia [1] and together with pulse oximetry has contributed to a major improvement in safety and reduction in morbidity over the last three decades [2].

Carbon dioxide is an end product of the body’s metabolism and is continuously produced in the cells. In a normal person, about 280 l of CO₂ is produced every day and after its transport by the systemic and pulmonary circulation is eliminated by the lungs via tidal ventilation. The amount of CO₂ reaching the alveoli depends on several factors including the rate of production, the equilibrium between the tissue stores, the venous return, cardiac output and pulmonary perfusion and finally alveolar ventilation.

In intensive care medicine, in contrast to anesthesiology, capnography has gained only limited acceptance as a monitoring tool. However, a better understanding of the pathophysiology of CO₂ kinetics as well as the introduction of new measurement techniques have increased the interest and the potential of capnography. In addition, the introduction of lung protective ventilation strategies [3, 4] in the clinical management of patients with acute lung injury (ALI) requires us to revisit our views of mechanical ventilation as a rather passive and supportive process and start to consider it instead as a highly dynamic and therapeutic intervention. This has increased the demand for improved bedside respiratory monitoring in order to facilitate its adequate and safe implementation.

Breath by breath volumetric capnography represents a very attractive monitoring option that provides the clinician with information not only about the amount of CO₂ eliminated but also about its elimination process, thus adding valuable information about the lung’s physiological condition. In this chapter, we will review some of the theoretical and physiological principles behind volumetric capnography. Finally we will discuss some clinical applications that can be derived from a systematic use of this methodology especially in the context of lung protective ventilation strategies.

Ⅱ Time and Volume Capnography

The first capnographic measurement to be introduced and currently the most widely used is the time based capnogram that is obtained by plotting exhaled CO₂ against time. This measure provides continuous monitoring of end tidal CO₂ (P<sub>ET</sub> CO₂) and, more importantly, changes in the shape of its graphical display assist in
detecting a number of clinically relevant problems during mechanical ventilation such as: esophageal or bronchial intubation, circuit disconnections, spontaneous breathing, ventilator malfunctions, etc.

The synchronous measurement of both the CO₂ and the flow/volume signals measured at the airway opening allowed changes in CO₂ in the volume domain to be studied in real time, this way obtaining the volume capnogram also called expiratory capnogram or single breath test of CO₂ (SBT-CO₂). Figure 1 shows a normal volume capnogram with its components and phases.

The volume capnogram provides all the features of the time based capnogram, supplementing it, however, with important physiologic information related to the dynamics of CO₂ exhalation and the ability to analyze the sequence of tidal ventilation and dead spaces ($V_D$).

**The Normal Capnogram: Definitions of Phases and Derived Variables**

- Phase I begins with the start of expiration and ends when the concentration of CO₂ increases beyond 0.1% from baseline. The volume of gas in phase I comprises airway $V_D$ ($V_Daw$) and represents part of the gas in the proximal airway.
- Phase II, or expiratory upstroke, starts at the end of phase I and ends at the intersection of the predictive slope lines of phases II and III. The midpoint of phase II (50% of the slope) is the limit between $V_Daw$ and alveolar gas, and represents the ‘interface’ where gas transport by convection changes into transport by diffusion within the lung acini. Thus, phase II contains part of both $V_Daw$