Volumetric Capnography – A Brief History

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Abstract

One of the earliest infrared measurements of CO₂ in the expired human breath was reported by John Tyndall in 1855. However, it took another century before those measurements reached the bedside. Notably, some of the earliest measurements of tidal volume by John Hutchinson reported in 1856 preceded the development of devices which permitted continuous measurement of flow (and hence volume) by over 70 years. The importance of measuring volume with carbon dioxide has long been recognized by physiologists and clinicians. Early methods such as the Haldane method and its various derivatives, used chemical absorbents, and served as the reference method for a volumetric measure of CO₂ for many years. Various investigators sought to extend those discrete chemical absorbent-based methods to “continuous” analysis (e.g. Rahn [1933] [2]).

One of the earliest descriptions of the volumetric capnograph and a method to determine “alveolar” dead space in the form of Arrows and Clark Kennedy [1933] [3]. Fowler [1968(1)] in describing the single breath for nitrous oxide (N₂O) curves sought to use similar terminology to clarify the “meaning of dead-space”, and, thus, divided this curve into four phases: I, II, III, and IV. Different methods to sample “alveolar” CO₂ gases were developed, including single and multiple breath methods.

Elam [1955], using newly developed CO₂ gas sensors, was first to publish capnographic profiles of human respiration in the anesthesiology literature [4]. It was not until Fletcher [1960] [5] presented the concept of dead-space and CO₂ elimination in a unified framework known as the single-breath CO₂ curve that this approach began to gain clinical recognition. In 1976 the Model 590 CO₂ analyser (for use with the 900 Servoventilator) offered the first commercial volumetric capnograph, featuring mainstream CO₂ and ventilator derived flow.

In the early 1990s the first to integrate CO₂ and flow from the airway with the introduction of the noninvasive E-tube sensor (Nihonkohden, Helsinki, Finland) combining in a single adapter piece a flow-resistive element for flow and a port to allow sidestream gas sampling. The sidestream approach requires sophisticated computer algorithms to align and compensate the flow and CO₂ signals [6].

The mid-1990s saw the introduction of the first “all-instrument” devices for noninvasive volumetric capnography (Novametrix, Wallingford, CT) [7]. These devices evolved from separate flow and CO₂ sensors connected to separate devices (e.g., Ventum 1590 Capnograph) and became integrated E-tube-flow/airway adapters interfaced to the same host computer (e.g., CO₂, N₂O). The development of this family of flow/ETCO₂ adapters (neonatal, pediatric and adult) required a number of technological developments such as a novel thin film IR sensor, a robust, tight fitting flow sensor, and extremely sensitive low-cost-differential pressure sensors [8]. With the increased recognition of the clinical value of volumetric capnography, it will likely evolve to become the standard of care for all mechanically ventilated patients.

References

1. Aitken JF. Exp. Path. 1 Pneum. 1933; 171: 363.

Timeline

Mainstream CO₂ and ventilator derived flow
Model 930 CO₂ analyzer (for use with the 900 Servoventilator); the first commercial volumetric capnograph (Siemens-Elema)

Combined mainstream CO₂, flow sensors (left to right) adult and pediatric (Respironics)

Philips–Respironics

Ventrac (1994)

Capnography

Introduction of Model 930 CO₂ Analyzers

Early capnography: rise of human respiration (flow and CO₂) in the chest radiograph literature

Two to three phases

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Unlabeled framework: concept of dead space and

Capnography curve into four phases: I, II, III, and IV (Fowler, 1948) [6]

The three phases of left CO₂: Phase I is the CO₂ free part of the breath, the ineffective tidal volume. At the start of phase II, CO₂ appears and the effective volume start. Phase II and III together are the effective tidal volume, Vₐ/total. Relative slope of phase III can be measured between 0.2 and 0.4 effective volume. (Fletcher, 1980) [5]

Combining mainstream CO₂, flow and CO₂ from the airway (E-tube sensor) (Khalil M, Tidwell RJ, 2010)