CAPNOGRAPHY: CLINICAL ASPECTS

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CARBON DIOXIDE OVER TIME AND VOLUME

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PREFACE

This work explores carbon dioxide from physiology to clinical application of capnography. Included are discussions of physiological concepts and traditional uses of intra-operative and non-operative capnography. We have considered both applications where capnography has gained a foothold and is fast becoming a standard of care as well as the newer emerging applications. This calls for expertise in diverse fields. We persuaded over 40 specialists to give account of their findings and applications in essays that could stand as independent reports. As a consequence, this book is in some respects more of a symposium than a textbook while it covers a comprehensive range of topics relating to the application of capnography in health care. For the readers' comfort we have accepted some overlap and repetition. We have also allowed for differences in perspectives inherent in the background of the author. We are particularly pleased with the historical section of the book, which comprises unique contributions from some of the pioneers of capnography.

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COMMONLY USED ABBREVIATIONS

Abbreviation: Subscripts

A, alv	alveolar
a	arterial
aw	airway
B, b	barometric
d, ds	dead space
E, exp	expiratory
I, insp	inspiratory
Fx,i	fractional concentration of component i in medium x
Px,i	partial pressure of component i in medium x
V	gas volume
ATP	ambient temperature and barometric pressure
ATPD	ambient temperature and barometric pressure, dry
ATPS	ambient temperature and barometric pressure, saturated with water vapor under these conditions
BTPS	body temperature, barometric pressure and saturation with water vapor under these conditions

Examples

P_aCO_2	partial pressure of carbon dioxide in arterial blood
$P_{et}CO_2$	partial pressure of carbon dioxide at end-tidal
P_ACO_2	partial pressure of carbon dioxide in alveolar gas
F_ECO_2	fractional concentration of carbon dioxide in expired gas

Reference

Quanjer, P.H., Sly, P.D. & Stocks, J. (1995). Respiratory function measurements in infants: symbols, abbreviations and units. *Eur. Respir. J.*, **8(6)**: 1039–1056.

INTRODUCTION

The American Society of Anesthesiologists (ASA) says in its standards for basic anesthetic monitoring:

> *To ensure adequate ventilation of the patient during all anesthetics … every patient receiving general anesthesia shall have the adequacy of ventilation continually evaluated … Continual monitoring for the presence of expired carbon dioxide shall be performed unless invalidated by the nature of the patient, procedure or equipment. Quantitative monitoring of the volume of expired gas is strongly encouraged. When an endotracheal tube or laryngeal mask is inserted, its correct positioning must be verified by clinical assessment and by identification of carbon dioxide in the expired gas. Continual end-tidal carbon dioxide analysis, in use from the time of endotracheal tube/laryngeal mask placement, until extubation/removal or initiating transfer to a postoperative care location, shall be performed using a quantitative method, such as capnography, capnometry, or mass spectroscopy*[1].

This ringing endorsement and requirement of capnography by the ASA as well as other medical societies focuses our attention on the successful ventilation of the lungs, as documented by the appearance of carbon dioxide (CO_2) with every exhalation. However, the traditional time-based capnography says nothing about the volumes of gas that delivered the CO_2. Volumetric capnography, which provides a volume-based view of ventilation, as such brings us wonderful additional intelligence.

The current spotlight on and the growing recognition of the clinical value of time- and volume-based capnography are well deserved. Too many patients have died because of ventilation-related problems. But capnography has much more to offer. For example, a readily available sign of a severe pulmonary embolism is the decrease in end-tidal CO_2 at constant tidal volume and minute ventilation. This directs our attention to the delivery of CO_2 to the alveoli and thus to pulmonary blood flow. In consequence, capnography tells a story not only about ventilation but it can also provide crucial information on circulation, specifically pulmonary blood flow.

And that is not all. In malignant hyperthermia oxygen consumption and CO_2 production go into overdrive. Long before the fever sets in, CO_2 production is racing ahead and its concentration in the expired gas rises dramatically, best seen when we can combine the measurements of volume and CO_2 so that we can calculate the volume of CO_2. Thus, capnography generates early warning signs of a rare but treacherous complication of metabolism. This is but one example of how capnography can alert us to the unexpected appearance of CO_2 in the body, or to its decrease.

When we take stock of capnography, we recognize that these measurements can provide important insight and crucial information on ventilation *and* on circulation *and* on metabolism. How these three factors interact will be an important aspect of the book before you.

In a patient who has suffered trauma to the brain or who undergoes an intracranial operation or who has a mass occupying lesion in the brain, the arterial CO_2 levels must be carefully controlled in order to avoid a devastating rise in intracranial pressure or damaging hyperventilation. While we want to monitor arterial CO_2 tension in such patients, the management of ventilation will be greatly assisted by capnography, exemplifying another value of capnography.

To recapitulate: The data provided by capnography must be interpreted with a keen awareness that ventilation *and* circulation *and* metabolism can affect end-tidal values. Interpretation of the data is greatly aided by volumetric capnography. Furthermore, the effects of CO_2 on organs such as the brain make control of ventilation and consequently of arterial CO_2 tension an essential component of good clinical management.

In view of these four perspectives on capnography, we have decided to collate much of the leading *clinical section* of this book in four subsections that concentrate on ventilation, circulation, metabolism and organ effects. In each of these subsections you will find clinical examples and much practical information. We follow the *clinical section* with a look at the basic physiology of CO_2, a history of CO_2 measurements with perspectives from the fathers of time and volumetric capnography and end it with a detailed examination of the technology that makes all of this possible.

[1] www.asahq.org/publicationsAndServices/standards/02.pdf