Carbon Dioxide - It's not just a gas

Part 1: The basics

In this first of three articles, Martin Betzer of Falck Denmark explains how end tidal carbon dioxide monitoring might guide you in your clinical judgement of the critically ill and why you should never resuscitate without it. This article is the first in a special three part series on Carbon Dioxide.

The background

Prehospital emergency patient assessment often demands clinical decisions based on insufficient information which is retrieved under stressful conditions. As professional clinicians, we trust variables such as blood pressure, pulse oximeter readings, electrocardiogram tracings and respiratory rates to support us in our decision-making process. But what if we could apply one single piece of medico-technical equipment that would provide us with all the information we needed? Behold: End tidal carbon dioxide ($EtCO_2$) monitoring!

$EtCO_2$ monitoring, or capnography, has become increasingly accessible in the prehospital setting over the last decade or more. Capnography provides an overall essential insight to the patient's airway, respiratory, circulatory and metabolic state – a 'one-size-fits-all' parameter that has gained ground among emergency clinicians with some even referring to it as "the superior vital sign".

This article reviews the very basics of $EtCO_2$ monitoring, interpretation and pitfalls, leading to a discussion on the possible benefits of integrating it into patient assessment and management.

The very basic facts

$EtCO_2$ is the partial pressure of expired carbon dioxide (CO_2) gas in the very end of an exhalation[1]. CO_2 itself emerges as a byproduct of cellular metabolism, and its mere presence thereby reveals that some sort of metabolism, circulation and ventilation is going on. Minimising the tech-talk, the overall modern approach to $EtCO_2$ monitoring is through a so-called side or mainstream sampling device. This device is hooked up to a monitor in one end, and an advanced airway or a binasal oxygen catheter in the other. In the monitor-end the $EtCO_2$ tracing comes to life through a real-time, breath-to-breath capnogram waveform visualising airway anatomy. The reference waveform is divided into inspiratory and expiratory phases, one ventilatory cycle being represented as a square-like pattern (*fig. 1*).

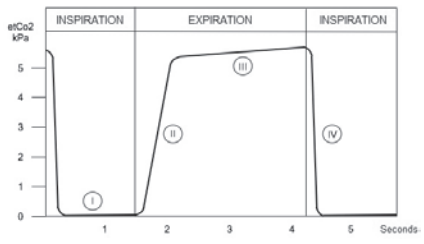

Fig. 1: The one-breath-capnogram has four phases. I: Dead-space expiration, II: the presence of CO_2 mixed with dead-space air during expiration, III: plateau with slightly increasing CO_2 levels during expiration, IV: inspiration, no tracing equals no sampling.

An example of a pathologic capnogram is the "sharkfin" visualised as a sloping expiratory curve due to prolonged expiration – think of the "sharkfin" as a reflection of bronchial constriction as ST-segment elevation reflects myocardial infarction.

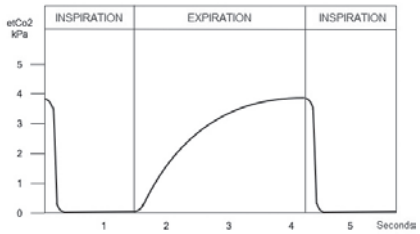

Fig. 2: The capnogram will have a "shark-fin"-like plateau phase in bronchospasm, reflecting prolonged expiration.

Biography: Martin Betzer

Martin Betzer is a Danish ALS-Paramedic with 12 years of experience working in the ambulance service, paramedic rapid response vehicle, emergency physician vehicle, and as emergency call-center operator. Furthermore, Martin has worked for 6 years as instructor at the Danish ambulance technician education. Martin has a Bachelor of Honour's degree in Prehospital Emergency Care from Coventry University, and begins his studies at the University of Stirling this fall in the Master of Research in Health Research.
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The capnogram is in many ways like the ECG or the pulse oximeter curve. You will need a well-shaped waveform to confirm the $EtCO_2$ value, which is measured through the monitor's built-in capnometer. The $EtCO_2$ value is displayed numerically – measured in either kilopascal (kPa), millimetres of mercury (mmHg) or percent (%) with reference intervals within the range of 4.0-5.7 kPa/35-45mmHg or 5-6% [1]. Values below or above reference are indicative of hypo- or hypercapnia – too little or too much CO_2.

The common method of obtaining parts of the information provided by capnography is by invasive arterial blood gas analysis (ABG). Among other relevant things, ABG measures the partial pressure of CO_2 in arterial blood ($PaCO_2$). ABG is a painful, expensive, invasive, time-consuming expert procedure generally only used in-hospital, which solely provides a snapshot of the acid-base balance. Capnography on the other hand, is not painful, relatively cheap, non-invasive, fast, reliable and continuous. But the downside of this apparent wonder-parameter is the interpretation. And this is where your many years of clinical experience kick in!

The interpretation

This is by all means the tricky part. You should possess advanced theoretical background in respiratory physiology in order to recognise the conditions where $PaCO_2$ might not correlate with the end tidal measured equivalent. Remember, that capnography measures the partial pressure of CO_2 in expiratory gas, whereas ABG measures the partial pressure of CO_2 in arterial blood. Interpreting the $EtCO_2$ value, you thereby have to turn your mind around and differentiate between the two different sampling points. Furthermore, multiple factors affect the $EtCO_2$ readings.

The $EtCO_2$ level itself, and the relationship between $PaCO_2$ and $EtCO_2$ might be affected significantly by the patient's ventilatory, hemodynamic and metabolic state. The literature describes a phenomenon named ventilation/perfusion (V/Q) mismatch [2]. In respiratory physiology, V is for ventilation - the amount of air reaching the alveoli, Q is for perfusion - the amount of blood reaching that same alveoli through the capillaries. These two variables – ventilation and perfusion - should be evenly matched to obtain an optimal gas exchange. Pulmonary embolism is a classic example of a V/Q mismatch, where alveoli are being fully ventilated but the surrounding capillaries are not being perfused leading to a decrease in gas exchange, decrease in blood pressure and an increase in ventilatory rate all of which equals low CO_2 values and thus, hypocapnia. $EtCO_2$ and $PaCO_2$ are comparable in the healthy individual but the V/Q mismatch might affect this relationship making comparisons useless. Therefore, you should not apply capnography in order to predict those $PaCO_2$ levels you presume your patient might have. You should use it in order to monitor sudden changes in the $EtCO_2$ readings or to identify extremely abnormal values – as these are the findings relevant for interpretation [3].

The science

The critical relationship of $EtCO_2$ monitoring and clinical decision-making in the intubated patient is well-described, and capnography is therefore the gold standard for continuous verification of endotracheal tube placement and ventilatory monitoring in this cohort [4]. Additionally, capnography is recommended during advanced life support resuscitation [5].

The rationale and benefits from applying $EtCO_2$ monitoring in the non-intubated cohort is, however, inadequately documented and guidelines and recommendations for its application are sparse. There is no doubt that the technology itself is functional and credible, as

well as the theory behind using it in a clinical context making sense. But does $EtCO_2$ monitoring make a difference, compared to regular clinical evaluation and standard vital parameters?

In Falck Emergency, we wanted to answer this question in order to identify categories of spontaneously breathing, non-intubated emergency patients where capnography could be handy in clinical decision-making. In 2016, we therefore conducted a systematic review including studies evaluating the usefulness of capnography in the non-intubated emergency patient [6]. In total, we identified 409 studies through literature search, with 11 being included in our final review.

Six of the studies found that capnography was a meaningful addition to clinical decision making [7-12]. Clinical accuracy in ventilation rate and apnea monitoring was confirmed in three studies [13-15]. Five studies evaluated the beneficial properties of capnography during procedural sedation and they all concluded that hypoventilation and adverse respiratory events were identified faster with capnography than with standard monitoring alone [7, 8, 10-12]. Three studies concluded that improvements in airway diameter in patients

with bronchospasm could be identified by the capnogram [15-17].

So, capnography is apparently meaningful - but does it **make a difference?**

The included studies were of variable quality and strength, which is why their conclusions must be carefully evaluated. None of the studies included true emergency patients as ethical considerations ruled out the sickest. Some studies had technical limitations as their approach to capnography consisted of inconsistent and confusing terms and reference intervals. But our most important finding: no study evaluated the impact of capnography on clinical decision-making in the emergency patient compared to standard monitoring alone.

We therefore concluded, in our systematic review, that there is not enough high-quality scientific evidence to support recommendations and guidelines for capnography as a tool in clinical decision making for the spontaneously breathing, non-intubated emergency patient. Until further research is conducted, exploring this very matter, the clinician should utilise capnography in the non-intubated cohort through a critical approach following the old saying: Treat the patient, not the monitor!

The summary

This article has reviewed the very basics of respiratory physiology, $EtCO_2$ interpretation and capnography application. Capnography is a non-invasive continuous monitoring form providing an instant overview of airway anatomy, ventilation, circulation and metabolism. Capnography and intubation are inseparable interventions and it might also be a valuable addition to clinical evaluation in spontaneously breathing, non-intubated emergency patients, but the science to support this is inadequate.

The next edition

With a critical approach, the usability during cardiopulmonary arrest will be reviewed in the next edition of *Ambulance Today*, leaving the application possibilities in the spontaneously breathing, non-intubated emergency patient for the Winter edition. Hold your breath – until next time!

Take home box

-Capnography interpretation requires substantial knowledge within respiratory physiology

-$EtCO_2$ and $PaCO_2$ are not always equivalent due to V/Q mismatch

-Capnography is the gold standard and a must-have in the intubated patient

- The benefits of capnography in clinical decision-making are not adequately scientifically supported in the spontaneously breathing, non-intubated emergency patient

For comments or feedback to the author, or to find out more about the work of Falck Research, please email: martin.betzer@falck.dk or follow @MartinBetzer on Twitter.

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