Capnography-what is it all about?

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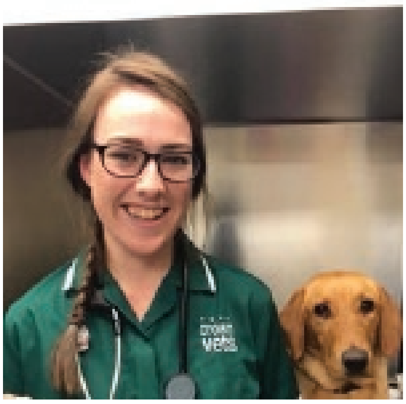
ABSTRACT: Capnography is a gold standard, invaluable tool used to show ventilation under anaesthetic by measuring the volume of exhaled carbon dioxide (CO_2). This article will explore the basics of capnography, how to interpret this information and how to deal with abnormalities. This article will also briefly discuss other methods of obtaining information on a patients CO_2 output and different types of capnographs that are available in practice.

Keywords: capnography; $ETCO_2$; anaesthesia monitoring; general practice; nursing



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Introduction

Capnography allows the continuous measurement of CO_2 in the inspired and expired breath during a respiratory cycle using infrared ray technology (Singh & Kodali, 2017). This non-invasive method measures CO_2 in exhaled respiratory gas and this is presented as the end-tidal carbon dioxide ($ETCO_2$). The measurement of $ETCO_2$ provides us with important information on the status of a patient's ventilation, perfusion, and metabolism (Marshall, 2004). Capnography can also assist in detection of malfunction of anaesthetic equipment and is an invaluable morning tool for the care of the anaesthetised patient.

What is capnography used for?

Measured CO_2 concentration can be displayed in various ways; these are-

- Capnometer- displays $ETCO_2$ as a numerical value. This pressure is most commonly measured in millimetre of mercury (mmHg)
- Capnograph- the graphical representation of CO_2 in the respiratory gas as a waveform (*Figure 1). Time is displayed on the X-axis with expired partial pressure of CO_2 on the Y-axis. This waveform trace is referred to as a capnogram.

The waveform gives an insight into the adequacy of how the patient is ventilating or if they are in respiratory distress and action is needed. The display shows ventilation rather than oxygenation (Welsh, 2009). Ventilation is defined as air exchange between the lungs and environment where CO_2 is exhaled and oxygen (O_2) is inhaled (Shiel, 2018).

Physiology

CO_2 is a waste product of regular aerobic cellular metabolism. CO_2 diffuses from the body tissues and is transported in the blood via the heart to the lungs, where it is then removed from the body by exhalation (Marshall, 2004; Dudley et al., 2015). For this cycle to be effective, there must be adequate return of blood from the body to the heart to be able to pump the blood to the pulmonary circulation, adequate gas exchange across the alveolar-capillary membrane and sufficient ventilatory capacity to expel the CO_2 from the lungs (Bryant, 2010). In this way, the measurement of expired CO_2 can reflect changes in the patient's circulation, metabolism and ventilation.

The measurement of $ETCO_2$ serves as an estimate of arterial CO_2 ($PaCO_2$). However, arterial blood gas analysis is considered gold standard for analysing adequacy of gaseous exchange as it measures $PaCO_2$ and oxygen (O_2) values directly (Topal & Gül, 2006). Arterial blood gas analysis is an invasive monitoring procedure that requires blood sampling, which is best practice, or placement of an arterial catheter to allow for repeated sampling and continuous monitoring. As a result, this method is

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*Figure 1. Multiparameter monitor displaying a normal capnograph trace.

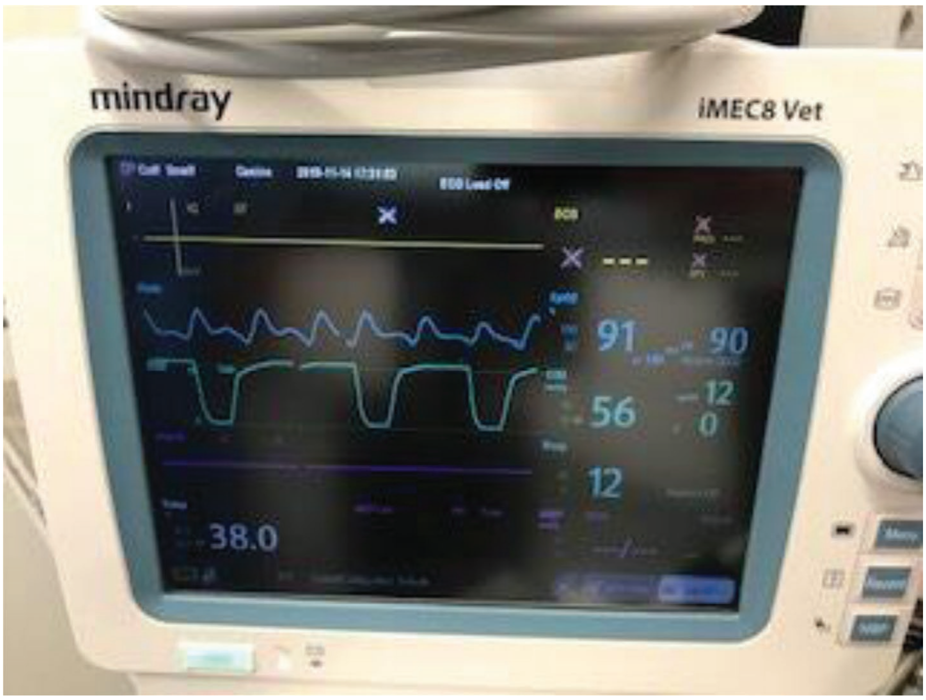

Figure 2. Multiparameter monitor displaying hypercapnia with an $ETCO_2$ of 56mmHG.

not as commonly used in general practice. Whereas capnography units are readily available and have the advantage of being non-invasive and simple to use.

Understanding the numbers

The normal range for a patients $ETCO_2$ is 35 mmHg to 45 mmHg (Duckworth, 2017).

Values over 45 mmHg are indicative of high CO_2 levels in the blood also known as hypercapnia (Figure 2). Causes of this can include hyperthermia, rebreathing, exhausted soda lime, too low fresh gas flow rate or the plane of anaesthesia being too deep (O'Dwyer, 2015). If hypercapnia is left untreated, it can lead to respiratory acidosis.

Values less than 35 mmHg indicates low levels of CO_2 in the blood which is known as hypocapnia. This can be caused by

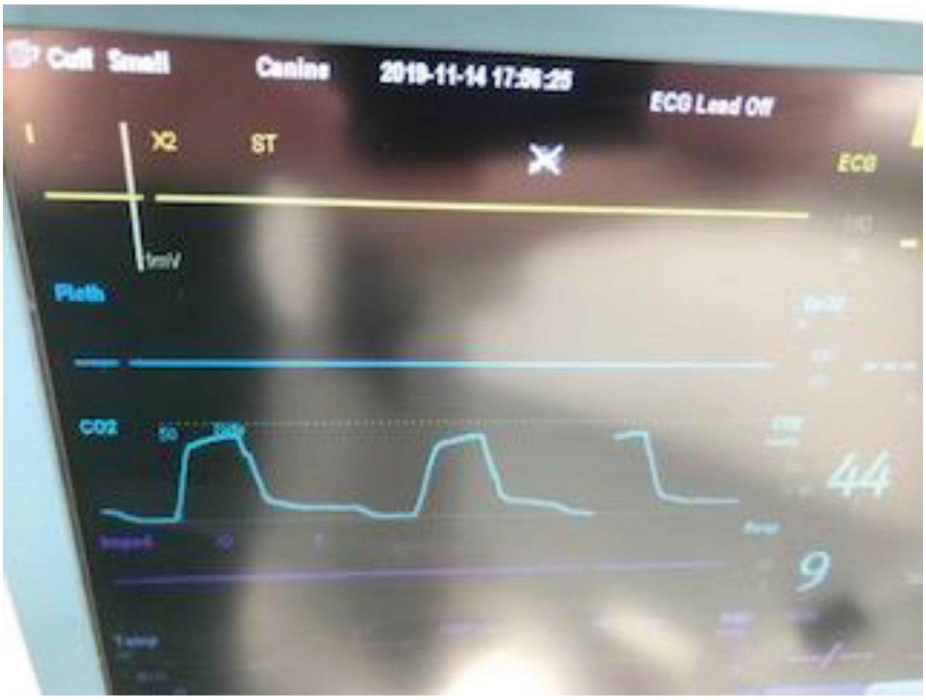

Figure 3. Multiparameter monitor displaying a capnograph trace with an uncuffed ET tube.

Figure 4. Multiparameter monitor displaying re-breathing with the use of a non-rebreathing anaesthetic circuit (note how the wave never returns to baseline).

hypothermia, pain, inadequate anaesthetic depth, a leak in the breathing system or too high a fresh gas flow rate (O'Dwyer, 2015). Prolonged periods of hypocapnia can lead to respiratory alkalosis.

The wave

A normal wave consists of four phases. Phase one is the baseline which should be sitting on zero as this in inhalation and no CO_2 is being released (Simpson, 2014). Phase 2 shows the exhale, the graph will rise upwards as CO_2 is exhaled. This will level off to a plateau which is phase three. At the end of this plateau where the graph is about to fall is the $ETCO_2$ which is recorded on the monitor and is also the point where air from within the alveoli is exhaled. The angle at the end of this phase where the wave starts to decline is known as the β angle (Anderson, 2007). Phase four of the graph is the fall; this is where the patient inhales. When there is an inhale no CO_2 is being produced, this means the graph falls back down to zero and the cycle then starts again (O'Dwyer, 2015).

Dealing with abnormalities

The wave form is telling a story about the patient's respiratory cycle and can indicate whether there is an issue and what may need correcting. If it does not look like a normal wave, interpret it, and take action to correct it (see Table 1). Anaesthesia affects how patients ventilate and drugs given can alter how patients will respond to CO_2 (Thomson, 2018).

Important factors to consider include clinical parameters and ensuring they are within normal limits. Look at anaesthetic depth to ensure anaesthetic plane is correct. Other considerations are;

- Pain, are they responding to noxious stimuli?
- Have any drugs such as opioids been given which could alter the patient's homeostasis?
- Check perfusion, is cardiac output adequate-what is their blood pressure measuring?
- Is all the equipment functioning and connected? (See Figure 3)
- Does the soda lime need to be changed? If the soda lime is exhausted, it will no longer absorb CO_2; this can lead to rebreathing and hypercapnia (Figure 4) (Phillips, 2020).

Mainstream vs. sidestream capnography

Currently there are three devices available for $ETCO_2$ measurement. These are mainstream, sidestream and microstream CO_2 sensors, with mainstream and sidestream monitoring being the most commonly used in veterinary patients. Mainstream capnography uses an in line infrared CO_2 sensor connected directly to the anaesthetic equipment, this is usually located between the endotracheal tube and the anaesthetic breathing system (Neto et al., 2002). Sidestream capnography uses an infrared sensor located in the main monitoring unit and CO_2 is constantly aspirated via a sampling tube that is connected to an adapter at the site of the endotracheal tube and the breathing circuit. The flowrate in which respiratory

Table 1. Examples of different wave abnormalities that can be seen on the capnograph.

Abnormality	Cause
The shark fin	Alveoli emptying unevenly will cause the curve to start slopping upwards during phase three. The wave has a sudden and sharp drop in phase four, resembling a shark's fin. This will start to increase the $ETCO_2$ (Duckworth, 2017). A cause of this could be due to bronchi constriction. A scenario which can be seen is in cats with feline asthma. Another cause of shark's fin is mechanical obstruction such as mucus in the endotracheal (ET) tube, in this case the shark's fins will be appearing more quickly (Duckworth, 2017).
High Baseline	Where the wave does not fully return to the baseline, reading a figure above zero. This can indicate rebreathing and causes include exhausted soda line (Welsh, 2009) (Figure 4.).
Cardiac Oscillations	Shows the heart movement which is moving air in the respiratory system (Welsh, 2009) This can be due to an enlarged heart or simply a movement artefact (Yartserv, 2019).
No wave present	This is a cause for serious concern as it is showing apnoea. Patient assessment should be carried out straight away. Causes for this can include the ET tube being placed in the oesophagus, the anaesthetic circuit has become disconnected, the patient has been extubated or there is a total obstruction in the circuit/ET tube (Adshead, 2012). A pending cardiac arrest could also be another possibility.
Sudden drop	This shows a leak in the circuit. Check circuit and ET tube, it can also be caused due to damage in the sample line or hypothermia (Welsh, 2009).
Wave trailing off	Oesophageal intubation will present as the wave decreasing and the $ETCO_2$ getting lower and lower (Yartserv, 2019). Inflating the chest can help to see if the ET tube is in the correct place.
CPR	When doing CPR some $ETCO_2$ will be present which will show up on the graph as a low uneven wave. When carrying out CPR and there is no trace being produced, this indicates that the the ET tube is in the wrong place (Yartserv, 2019). Capnography is a very effective method of measuring the effectiveness of CPR (Aminiahidashti et al., 2018).

gases are aspirated from the adapter varies from 50–400ml/minute. Because the sample aspirated is finite, there is a lower limit to size of patient that can be accurately monitored (Marshall, 2004).

Both devices hold advantages and disadvantages to their use. Mainstream capnography holds the advantage that it gives instant results as it measures the $ETCO_2$ locally, whereas with sidestream capnography there is a slight delay due to the movement of gas from the adapter to the recording unit (Parry, 2017). Other advantages of side stream include that it is easy to use in patients that are in unusual positions as the adapters are lightweight and the sensor is located at the recording unit.

Capnography Tip

Due to the sampling method of sidestream capnography, this can be used in conscious patients where the gas can be sampled directly from nostrils using a nasal adapter or nasal cannula.

Mainstream capnography is beneficial in that there is no effect of pressure changes on $ETCO_2$ results and some designs have limited the issue of dead space meaning it can be used effectively on smaller patients such as cats and rabbits (Chan et al., 2003). Despite the new technology, the additional weight of the infrared sensor may still drag and cause obstruction or kinking of the breathing system. In addition to this, there is a potential risk of facial thermal burns from the heated sensor which has been reported in human medicine (Chan et al., 2003).

Conclusion

$ETCO_2$ is widely used in veterinary patients as an indicator of ventilation, circulation and metabolism during anaesthesia. Capnography is a non-invasive and accurate method of measuring patients $ETCO_2$ and provides critical information regarding patient status. Pros and cons of sidestream and mainstream capnography should be weighed up prior to investment in a capnograph to ensure that the most compatible one is being chosen to suit the caseload seen in practice. It is important for the anaesthetist, most commonly the RVN in general practice, to be comfortable and familiar with the capnograph to be able to utilise this technology to monitor patients as safety and closely as possible.

*N.B. All images in this article are examples of sidestream capnography which are displayed as part of a multiparameter monitor.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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