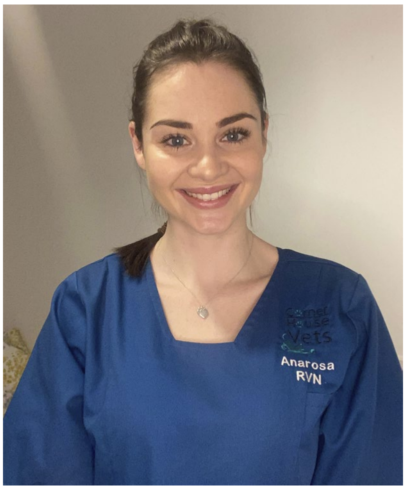

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Capnography: the best anaesthetic monitoring tool?

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ABSTRACT: Currently, there are a wide range of anaesthetic monitoring equipment to aid Registered Veterinary Nurses (RVNs) in closely monitoring their patients under anaesthesia to reduce the risk of mortality and morbidity. Arguably, capnography can be seen as being as the most useful and valuable tool to use, as end tidal carbon dioxide ($ETCO_2$) corresponds to the partial pressure of carbon dioxide in the blood. This gives an indication of ventilation as well as other key pieces of information such as anaesthetic depth, cardiac output and equipment function.

Keywords: Capnography; carbon dioxide; end tidal carbon dioxide; ventilation; anaesthesia

Introduction

Under the Schedule 3 exemption, registered veterinary nurses (RVNs) can assist with the maintenance and monitoring of anaesthesia whilst under direct supervision of a veterinary surgeon (VS) and this is a key part of our job role. Many practices have multi-parameter monitoring machines meaning we are able to use capnography among other equipment to closely monitor and look for abnormalities whilst our patients are anaesthetised. It could be argued that using end tidal carbon dioxide is one of the most valuable monitoring modalities, using carbon dioxide to give an insight into ventilation, anaesthetic depth, cardiac output as well as any malfunctions with equipment. This article will focus on the physiology behind capnography as well as different capnograph traces to help RVNs use capnography to their advantage whilst monitoring patients under anaesthesia.

Physiology behind capnography

Carbon dioxide (CO_2) is made as a result of aerobic respiration when glucose and oxygen react as cells metabolise (Fraser, 2009). The CO_2 is expired after gas exchange occurs in the alveoli. During anaesthesia, capnography measures the amount of carbon dioxide that is expired in one breath and is measured as end tidal carbon dioxide ($ETCO_2$) (Murrell & Ford-Fennah, 2011).

There are three main ways that CO_2 is carried in the blood, these are:

1. In the form of carbonic acid after reacting with water (60–70%)
2. Bound to haemoglobin (20–30%)
3. Dissolved in plasma (5–10%) (Thomas & Lerche, 2011)

As above, CO_2 reacts with water to form carbonic acid. The carbonic acid then rapidly turns into bicarbonate and hydrogen ions. This release of hydrogen ions is key in the role of carbon dioxide and acid-base balance. When there is an increase in CO_2, it leads to an increase in hydrogen ions which lowers the pH of the blood, leading to respiratory acidosis. Conversely, hypocapnia leads to respiratory alkalosis as there are less hydrogen ions (Fraser, 2009).

The level of CO_2 in the blood is measured as the partial pressure of carbon dioxide ($PaCO_2$), this is what is measured during blood gas analysis to give us an indication of how well the patient is ventilating. $PaCO_2$ correlates to the alveolar concentrations of carbon dioxide, meaning $PaCO_2$ and $ETCO_2$ are linked. However, it is estimated that $ETCO_2$ is 2–5mmHg lower than $PaCO_2$ (Thomas & Lerche, 2011). The disparity can be explained by the ventilation perfusion ratio (V/Q ratio) as different aspects of the lungs are ventilated and perfused differently. This means some of the alveoli are ventilated but not perfused so therefore do not take part in gas exchange. This consequently dilutes the expired CO_2 with inspired gas, making the $ETCO_2$ lower (Fraser, 2009). The correspondence between $PaCO_2$ and $ETCO_2$ means RVNs can have an insight into blood levels of CO_2 and the adequacy of ventilation non-invasively rather than using more invasive techniques such as arterial blood gas analysis.

Types of capnograph

Capnography is a direct and non-invasive way to continuously monitor the patient's end tidal carbon dioxide levels. Carbon dioxide contains atoms that absorb infrared light (Clark, 2009), so higher levels of CO_2 in the blood mean that more infrared is absorbed. A sensor is used to measure how much infrared light is absorbed so therefore, this is directly comparable to the level of CO_2 expired in one breath (Thomas & Lerche, 2011).

There are two main types of analysers that are used in practice. Mainstream analysers have a small piece of tubing with a device that contains a sensor that connects between the endotracheal tube and breathing system (Thomas & Lerche, 2011), with this type of analyser there is no delay in getting a reading as gas is not drawn away from the patient (O'Dwyer, 2015). Most commonly seen in practice is the side stream analyser. Sampling is obtained through a sampling tube where gas is drawn away from the patient. This can be done using an elbow connector (Seen in Figure 1) that allows you to attach the sample line. There are also endotracheal tubes that have been modified to allow the sample line to be attached directly (Seen in Figure 2) (Murrell & Ford-Fennah, 2011). A comparison of the two types can be seen in Table 1.

Figure 1. Elbow connector with sampling line attached.

Table 1. Advantages and disadvantages of mainstream and sidestream capnography analysers (O'Dwyer, 2015).

Mainstream analysers	Sidestream analysers
• No delay in getting a reading • Increases dead space • Water condensation can damage the sensor	• The sensor can measure other units such as oxygen and volatile agents • Less easily damaged as sensor is away from the patient • Delay in $ETCO_2$ readings • Airway secretions can obstruct tubing • Increased dead space can affect measurements

Interpreting capnography readings and traces

When monitoring an anaesthetised patient, it is important to know the normal values of $ETCO_2$ as well as what abnormal levels indicate. Normal and abnormal ranges and in small animals can be shown in Table 2.

Registered Veterinary Nurses can observe the capnograph trace alongside the $ETCO_2$ value to get an overall picture of ventilation. Examples of different capnographs can be seen below.

Figure 3 shows a normal capnograph, it is divided into four phases. Phase I shows a baseline trace, no carbon dioxide is produced here as the expired gas originates from anatomic dead space, meaning it has not undergone gas exchange. The expiratory upstroke is shown in phase II, here the level of carbon dioxide rapidly increases due to it being alveolar gas being expired that has been involved in gas exchange. The third phase (Phase III) is the plateau of the capnograph, this is where expiration ends but the CO_2 levels remain constant as the expired gas in the breathing system is stationary. Lastly, phase IV shows inspiration where there is a rapid downstroke as fresh inspired gas passes the sampling tube (O'Dwyer, 2015).

Figure 2. Endotracheal tube with modification to attach capnography sampling tube.

Table 2. $ETCO_2$ concentrations and their meaning (Murrell & Ford-Fennah, 2011).

$ETCO_2$ Level	Meaning
35–45mmHg	Normocapnia
	Normoventilation
>45mmHg	Hypercapnia
	Hypoventilation
	Hyperthermia
<35mmHg	Hypocapnia
	Hyperventilation
	Decreased cardiac output
	Cardiac arrest
	Hypothermia
	Leak in endotracheal cuff

Figure 3 also highlights the alpha and beta angle, the angle between the second and third stage of is called the alpha angle (α), which is approximately 100–110 degrees. The angle between the third and fourth stage is the beta angle (β) and this should be 90 degrees (O'Dwyer, 2015)

Figure 4 shows a capnograph highlighting a gradual increase in $ETCO_2$. This can be seen when a patient is hypoventilating, leading to hypercapnia where the $ETCO_2$ is above 45 mmHg, as the rate at which CO_2

is removed from the lungs is decreased. This could be due to a deep plane of anaesthesia or due to drugs such as methadone (Comfortan, Dechra) that cause respiratory depression (Clark, 2009). Other causes include shivering, hyperthermia and fever as more carbon dioxide is produced (Thomas & Lerche, 2011).

Figure 5 shows hyperventilation where there is a gradual decrease in $ETCO_2$, leading to hypocapnia where the $ETCO_2$ is lower than it should be. Pain or light anaesthetic depth can lead to an increase in respiratory rate which causes the patient to have more frequent, shallower breaths meaning less CO_2 is expired. Another reason for hypocapnia could be due to a leak in the endotracheal tube cuff or equipment which is shown on the capngraph as a very narrow phase III on the trace. Additionally, hypocapnia could also be due to decreased CO_2 production or decreased cardiac output, leading to less CO_2 being delivered to the lungs (O'Dwyer, 2015). Therefore, it is important to distinguish whether the hypocapnia is due to a mechanical or physiological issue.

Figure 6 shows rebreathing on a capnograph, here the baseline of the trace does not return back to zero, showing that the patient is inhaling their own CO_2. This can be due to a fresh gas flow rate that is too low in a non-rebreathing system, exhausted carbon dioxide absorbent in a rebreathing system, or as a result of a patient hyperventilating as not enough carbon dioxide is being expired (O'Dwyer, 2015).

Cardiac oscillations are commonly seen and are considered normal (Figure 7). This occurs when cardiac movement caused by contraction of the right ventricle and filling of pulmonary blood vessels causes movement within the airway (O'Dwyer, 2015).

Figure 8 shows a trace that is seen with a patient that has obstructive airway disease or asthma. Here the alpha angle decreases leading to increased resistance at the point of expiration.

Lastly, a capnograph can be used to show the early signs of cardiac arrest, making it an important monitoring tool to use in an unstable patient. A fall in $ETCO_2$ is indicative of failing cardiac output and cardiac arrest. This can be seen as a rapid decrease in $ETCO_2$ as well as a sudden loss of waveform which is shown in Figure 9. Other reasons for a sudden loss of waveform include: apnoea, disconnection of the endotracheal tube, extubation or equipment malfunction.

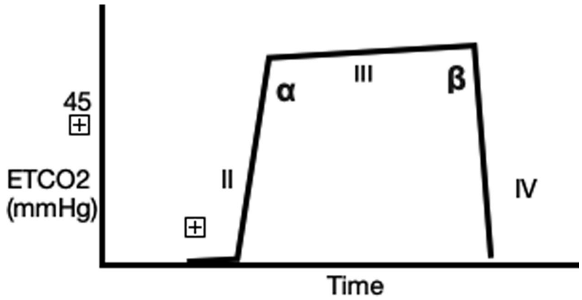

Figure 3. A normal capnograph.

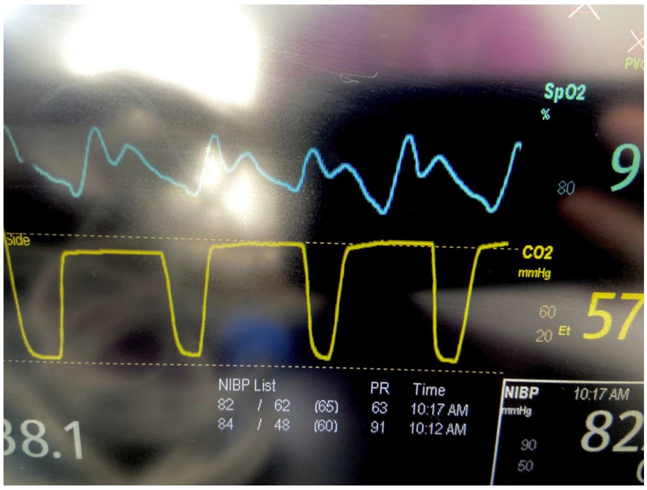

Figure 4. A capnograph showing hypoventilation and hypercapnia.

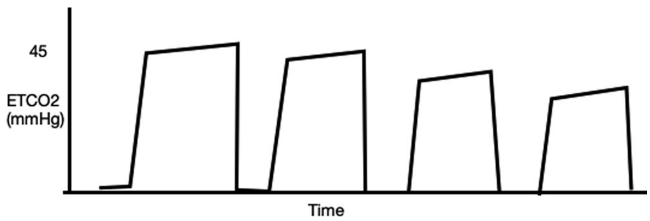

Figure 5. A capnograph showing hyperventilation and hypocapnia.

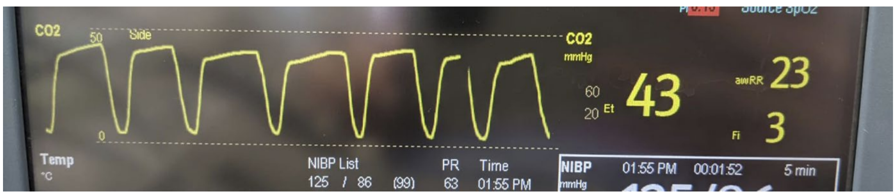

Figure 6. A capnograph showing rebreathing.

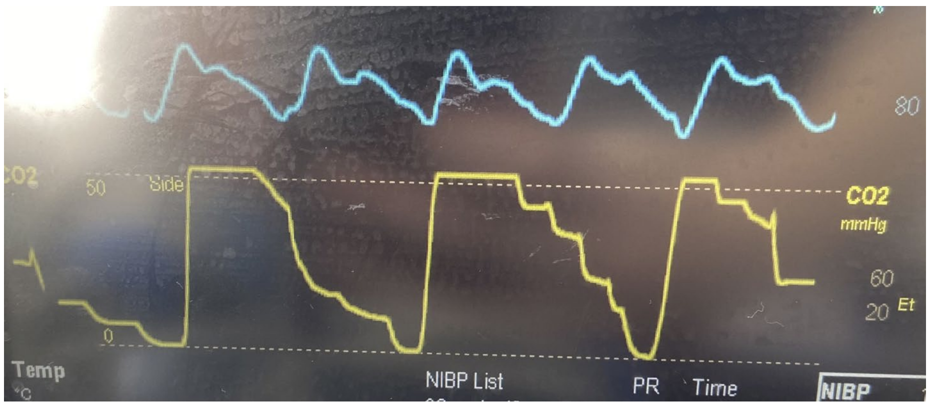

Figure 7. A capnograph showing cardiac oscillations.

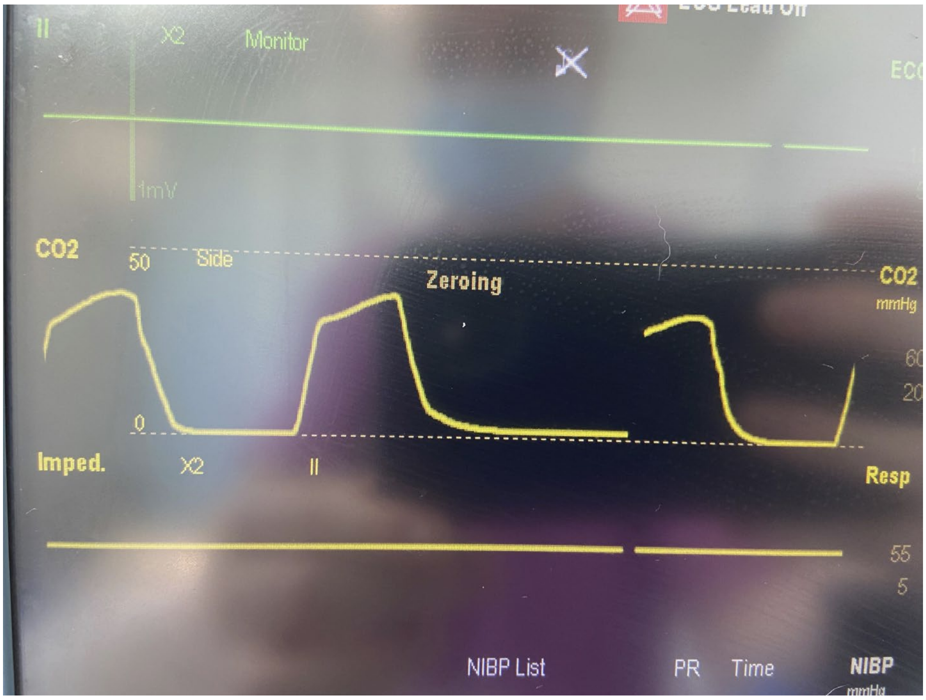

Figure 8. A capnograph showing airway obstruction.

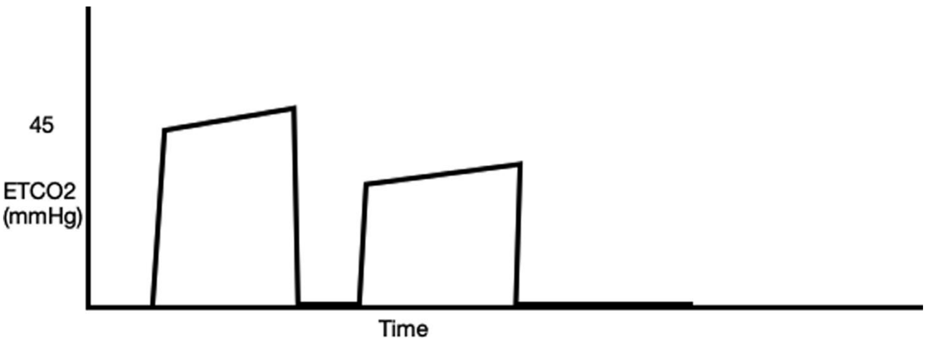

Figure 9. A capnograph showing a fall in $ETCO_2$ indicative of cardiac arrest.

Due to the number of reasons for a sudden loss of waveform it is important for the RVN to troubleshoot by physically checking the patient as well as any equipment such as the breathing system and endotracheal tube. Using capnography is also invaluable during cardiopulmonary resuscitation (CPR), as without a functioning circulation no CO_2 will get back to the lungs and be expired. Therefore, if the waveform re-appears it is an indication of the return of spontaneous circulation, meaning CPR has been successful (Thomas & Lerche, 2011).

A lot can be learnt from capnography, it can highlight whether the patients depth of anaesthesia is inadequate. Inhalant anaesthetic agents such as Isoflurane and Sevoflurane cause dose dependent respiratory depression (Flaherty, 2009). If the patient is hypoventilating and is therefore hypercapnic, it could be a sign of anaesthetic depth that is too deep. By reducing the level of the volatile agent, the degree of respiratory depression will be reduced and the patient will ventilate normally and the $ETCO_2$ will decrease. In cases where the patient is severely hypercapnic the RVN can assist with ventilation using intermittent positive pressure ventilation to help decrease the $ETCO_2$ level. Conversely, if the patient is hyperventilating due to being light under the anaesthetic or due to pain, by increasing the vaporiser level and giving analgesia, the $ETCO_2$ should return to within normal limits. As well as a drop in cardiac output, another cause of hypocapnia is due to a leak in the breathing system or endotracheal tube. If this is the case, the veterinary nurse should check the breathing system for a leak or inflate the cuff of the endotracheal tube to prevent carbon dioxide escaping (Challis & Seymour, 2008).

Conclusion

Capnography is an invaluable tool to monitor patients under anaesthesia. We are able to yield information on a patient's ventilation, depth of anaesthesia and cardiac output non-invasively. Using the waveforms alongside the $ETCO_2$ level can alert the veterinary nurse to problems that may be missed without capnography such as rebreathing, airway obstruction or leaks in the breathing system or anaesthetic machine. As well as being advantageous when monitoring an anaesthetic, capnography is key when performing CPR as the return of the waveform highlights the return of spontaneous circulation, indicating successful CPR. Therefore, capnography can be seen as the best anaesthetic monitoring tool due to the huge wealth of information it can provide.

Disclosure statement

There are no conflicts of interest.

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