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Capnography: a guide for veterinary nurses

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ABSTRACT: Capnography allows us to measure the amount of expired (end tidal) carbon dioxide (CO_2) and has become a vital monitoring tool when anaesthetising our veterinary patients. Knowledge and understanding of the information it provides is essential to the veterinary nurse (VN) anaesthetist. This article provides a brief history of this technology's development, the information capnography provides us, the varying waveforms commonly seen and how its use is an important contributor to the safety and stability of the anaesthetised patient. The waveforms encountered on the monitoring screen are also included and a brief description of what they may be demonstrating.

Keywords: Capnography; mainstream; sidestream; $ETCO_2$; $inCO_2$

Measuring carbon dioxide and the history of capnography

The first practical means of measuring the volume of carbon dioxide (CO_2) in a mixture of gases was described in 1905 by John Scott Haldane, who conducted many experiments in respiratory physiology (often subjecting himself to study). Interestingly, he was also able to show that the respiratory centre is sensitive to a rise in alveolar CO_2 (where gaseous exchange of CO_2 takes place) pressure. This discovery highlights that the respiratory reflex is triggered by an excess of CO_2 in the blood, rather than a lack of oxygen as previously thought (Sekhar & Rao, 2014). The development of the modern infrared capnography is generally credited to Karl Friedrich Luft in 1937 (Westhorpe & Ball, 2010). Following further contributions and developments, rapid responding point-of-care CO_2 analysers were originally designed for medical use in response to needs expressed by clinicians so that mechanical ventilation could be more optimally delivered; in the 1950s, mainstream and sidestream devices were introduced (Jaffe, 2011). In many veterinary practices today, capnography is routinely used as a monitoring tool during anaesthesia.

What is capnography?

Capnography estimates arterial CO_2 ($PaCO_2$) by measuring the concentration of CO_2 in the expired gas. The most common method of measurement is by infrared light absorption; mainstream and sidestream measurements are two of the methods available. Raman spectroscopy is another method of measurement (Clarke et al., 2014), but is not discussed in this article.

With mainstream capnometers, the patient breathes through a cell attached directly in the airway between the endotracheal tube (ETT) and the breathing circuit (Haskins, 2015) (**Figures 1a** and **1b**). An infrared sensor emits light through windows in the cell and a photodetector on the opposite side of the sensor measures the amount of CO_2 present and displays this on the monitor in real time (Barter, 2012). Mainstream capnography has a quicker response time compared with the sidestream method and gives a more accurate measurement in patients with high respiration rates and small tidal volumes. However, its use increases apparatus dead space and the sensors are often bulky and can be prone to malfunction due to the accumulation of water vapour and dirt present in the sample (Clarke et al., 2014; Schauvliege, 2016).

Sidestream capnometers continuously aspirate small volumes of gas through a sample line attached to an airway adaptor which connects between the ETT and breathing circuit (**Figures 2a** and **2b**); dead space reducers are available for smaller patients (**Figure 2c**). The line connects to a water trap to remove any exhaled water

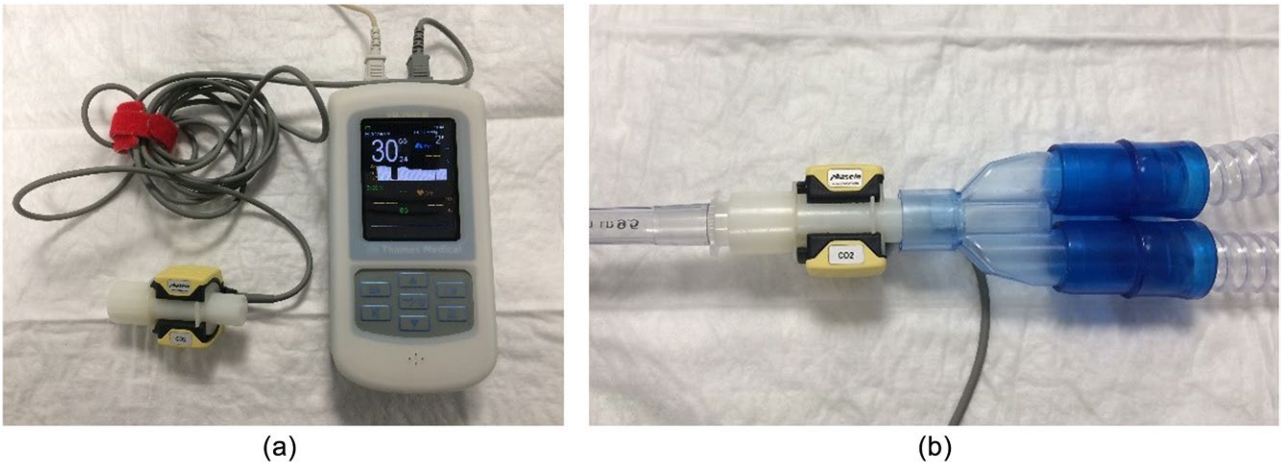

Figure 1. (a) Mainstream Capnometer. (b) The cell is connected between the ETT and breathing circuit.

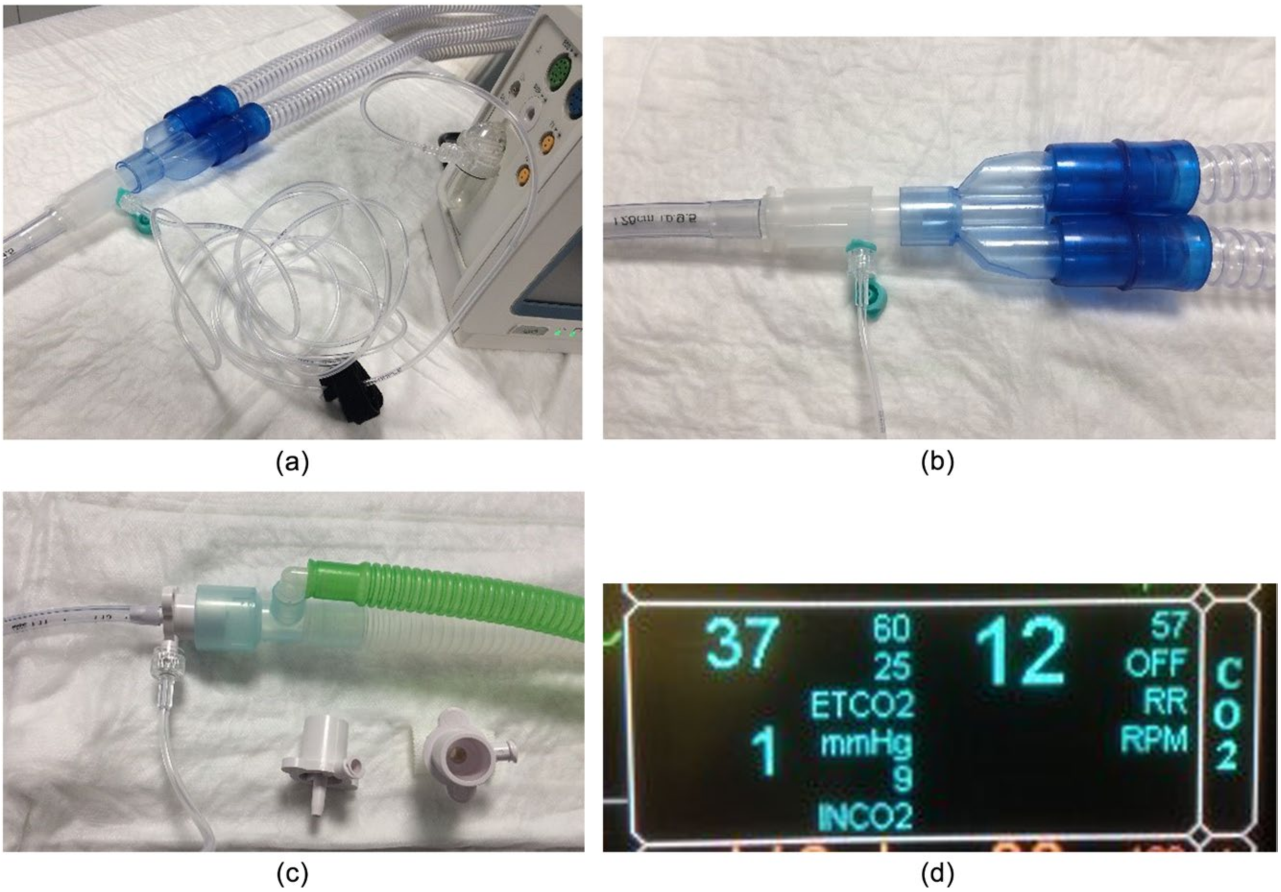

Figure 2. (a) Sidestream Capnometer. (b) Airway adaptor connected between the ETT and breathing circuit. (c) Dead space reducers used for smaller patients. (d) Numerical $ETCO_2$ reading.

vapour, ensuring the sample is dry before entering the monitor; the gas sample is then analysed and a waveform and numerical measurement is displayed on the screen (**Figure 2d**). There is a delay with this technique depending on the length of sample line and the speed at which the monitor makes an analysis, but it is rarely longer than a few seconds (Schauvliege, 2016).

Capnography can help to diagnose:

- Correct tracheal intubation
- Mechanical problems with the anaesthetic equipment and circuits
- Accidental oesophageal intubation
- Airway obstruction
- Cardiogenic shock

(Clarke et al., 2014).

Increased $ETCO_2$ (hypercapnoea) can be due to hypoventilation, the animal may be in a deep plane of anaesthesia or there is a blockage in the ETT or breathing system. Other possible causes include an increase in the production of CO_2 in the presence of malignant hyperthermia or if the patient is shivering or an increase of CO_2 into the circulation, e.g. during a laporascopic procedure (Schauvliege, 2016). Prolonged periods of hypercapnoea lead to cerebral vasodilation, making the patient more susceptible to the effects of the anaesthetic drugs and gases and in some cases cardiac arrhythmias can occur.

Decreased $ETCO_2$ (hypocapnoea) can be due to hyperventilation, the animal may be in a light plane of anaesthesia or there is a high degree of rebreathing, the ETT cuff is deflated or the sample line has become disconnected. In critical situations hypocapnia may be attributed

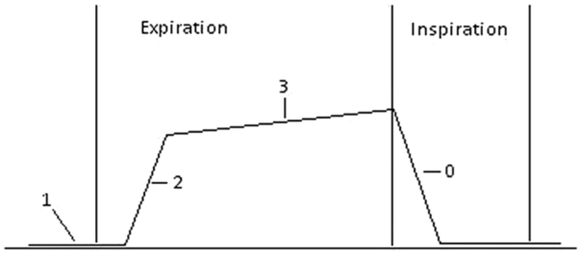

Figure 3. A normal single-breath waveform.

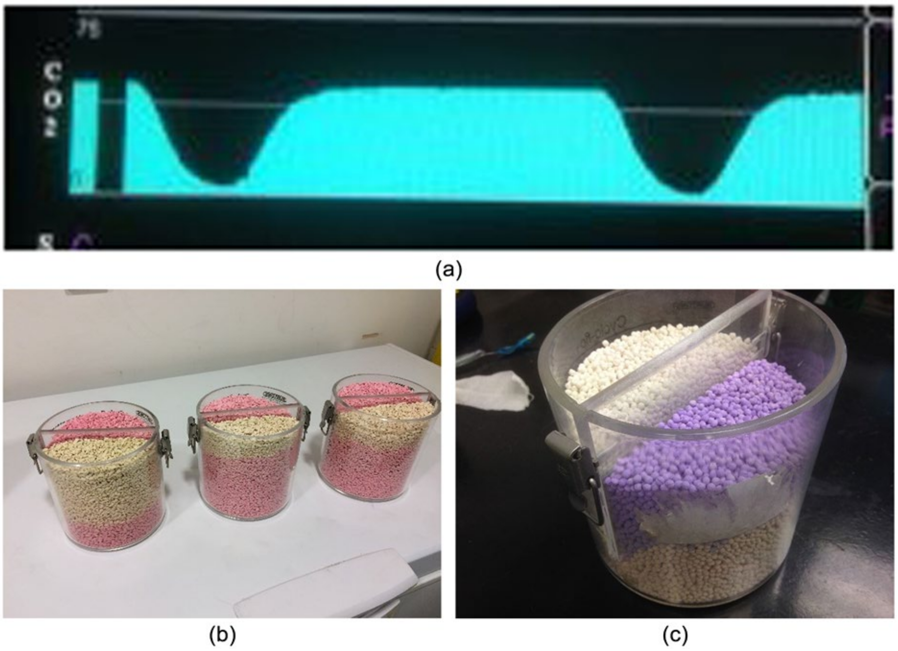

Figure 4. (a) A waveform which does not start or return to the baseline indicative of an increased in CO_2. (b) Circle circuit cannisters, the pink granules turn white when they are exhausted. (c) A circle circuit cannister, the white granules turn purple when exhausted.

Figure 5. Waveform displaying an increased in CO_2 and sloping wave.

Figure 6. Waveform displaying an increased $ETCO_2$.

to cardiovascular depression, e.g. severe hypovolaemia and hypotension, a rapid decline in cardiac output or cardiac arrest (if the lungs are being ventilated). Other possible causes are pulmonary embolism, which obstructs the flow of blood to the lungs and profound hypothermia resulting in poor tissue metabolism (Clarke et al., 2014; Schauvliege, 2016). Prolonged periods of hypocapnoea result in cerebral vasoconstriction and potentially reduced amounts of oxygen reaching the brain. In cases of head trauma a low CO_2 concentration is desirable to reduce the risk of an increase in intracranial pressure.

During cardiac arrest, when ventilation continues there is a quick decline in the $ETCO_2$ concentration over a few breaths. This is because the CO_2 produced in the tissues is not being transported to the lungs for excretion due to the failing circulation (Schauvliege, 2016).

Common waveforms

The waveform displayed can provide important information about the patient's physiological status and any equipment malfunction (Clarke et al., 2014). It is important that the VN understands what is being displayed, recognises any potential dangers and can act to maintain the patient's stability.

Figure 3 shows a normal single-breath waveform shape. Phase 1 is the respiratory baseline. Expiration begins prior to phase 2 as the initial part of expiration is dead space gas and contains no CO_2. Phase 2 is the expiratory upstroke, which rises steeply. Phase 3 is the plateau, which has a gradual upslope, the end point being the alveolar CO_2 concentration; it then quickly returns to the baseline in phase 0 as the animal inspires (Schauvliege, 2016).

Figure 4 shows a wave that does not start or return to the baseline. The inspired CO_2 ($inCO_2$) will be increased (ideally it will be zero). If the animal is breathing via a circle circuit the soda lime may be exhausted (Figures 4a and 4b).

Figure 5 also displays an increased $inCO_2$ with a sloping wave, which could suggest a partial airway obstruction or impaired lung deflation (Clarke et al., 2014). The patient is also hyperventilating; a rising $inCO_2$ can exacerbate this (see above: Measuring carbon dioxide and the history of capnography) and the $ETCO_2$ will fall (hypocapnia).

Figure 6 demonstrates an increased $ETCO_2$, usually indicative of hypoventilation; a blockage in the ETT or breathing system can also cause the ETT to increase and this must be addressed immediately.

Figure 7 shows very small, sporadic waves; these small transient waves may suggest a leak – possibly due to an inadequately inflated ETT cuff. These waves are also similar to what is seen with

Figure 7. Small, sporadic waves.

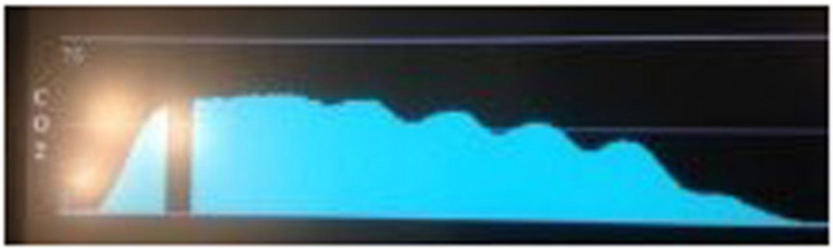

Figure 8. Cardiogenic oscillations.

accidental oesophageal intubation: eventually there are no waves and the ETCO$_2$ figure is zero.

Figure 8 demonstrates the presence of cardiogenic oscillations; these are common when respiration rates are low (Schauvliege, 2016).

Conclusion

General anaesthesia carries an inherent risk for all veterinary patients.

Capnography has become a vital tool to help ensure patient safety and provides the user with a vast amount of information. Central to the process of monitoring anaesthesia is often the VN, and the ability to utilise and interpret the readings from this technology is paramount to its effective use. Together with observation of the patient undergoing anaesthesia, a multiparameter monitor and any other observations will help facilitate any necessary intervention that may be required.

Disclosure statement

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

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Multiple Choice Questions

1. Capnography estimates which of the following?

(a) PaCO$_2$

(b) PaO$_2$

(c) SpO$_2$

(d) SpCO$_2$

2. Which of the following is not detected using capnography?

(a) Correct tracheal intubation

(b) Peripheral oxygenation

(c) Cardiogenic shock

(d) Airway obstruction

3. Hypercapnia may be caused by:

(a) Hyperventilation

(b) A light plane of anaesthesia

(c) Hypoventilation

(d) A deflated endotracheal tube cuff

4. Hypocapnia may be caused by:

(a) Hyperventilation

(b) Hypoventilation

(c) Malignant hyperthermia

(d) Laparoscopic procedures

5. Mainstream capnography has a quicker response time compared with the sidestream capnography method:

(a) True

(b) False

6. When were the first practical means of measuring the volume of carbon dioxide in a mixture of gases first described?

(a) 1905

(b) 1937

(c) 1950

(d) 1979

7. Which is the most common method of capnography measurement?

(a) Raman spectroscopy

(b) Infrared light absorption

(c) Ultra violet light absorption

(d) Piezo electric crystal conduction

8. Sidestream capnography increases apparatus dead space more than mainstream capnography

(a) True

(b) False

For the answers to the MCQs, please go to: **http://www.bvna.org.uk/publications/veterinary-nursing-journal**