Capnography – What can it tell us?

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What is Capnography?

- Capnography is the science of monitoring carbon-dioxide levels in the respiratory gases of an animal.
- Capno = Greek for smoke/vapour
- Two main equipment variants:
  - Capnometer
  - Capnograph
Capnography – Sidestream or Mainstream

- Mainstream Unit – a device that samples the CO2 levels in-line. There is no delay in the capnogram trace. Gives a fast response. Fixed volume of dead space

- Sidestream Unit – a device that extracts a sample of the airway gas and performs the analysis inside the machine. Can be very small dead space. Needs a low sampling rate for tiny animals.
Capnography – Sidestream
Capnography –Mainstream

IRMA mainstream CO2 Monitor
Why look at CO$_2$?

- Measurement is a relatively non-invasive technique and depending on the method used can be performed with conscious animals.
- Exhaled carbon dioxide levels give an easy way of assessing the state of the respiratory and or cardiovascular system.
- Capnography is probably the single most useful monitoring modality.
- Virtually no false errors – high reliability.
What information do we get?

- Information from Capnography can be broken down into 4 levels, each with increasing degrees of information.
Capnography - Information

Level 1:
- Breathing or not, i.e. apnoea monitor
- Respiratory rate
Capnography - Information

- Level 2:
  - Expired CO2 levels
  - Inspired CO2 levels

- From these parameters we can now begin to deduce the state of the patient with regard to respiration i.e normocapnic, hypocapnic or hypercapnic

- Expired CO2 is taken to be equivalent to arterial CO2 levels
Capnography - Information

Level 3:

- Waveform profile
- There are 4 recognised parts to a typical capnogram, each one having characteristics that impart specific information
- The waveform can be referenced to time as a time capnogram, or to volume (SBT)
Capnography - Information

- Level 4:
  - Combination of level 2 or level 3 information with blood gas information
  - Can determine e.g. lung dead space using Bohr's equation or take it a stage further and look at components of the lung dead space, e.g. alveolar dead space using the SBT
Capnography - Information

- So there is a huge amount of information available from a standard capnograph.
- In viewing the wealth of information from a capnograph we should not lose sight of the most basic information.
Capnography – the science

- Boils down to the fundamental fact that respiring cells consume oxygen and produce carbon dioxide as a by-product and that this carbon dioxide is removed by the lungs.
- This continuous production of carbon dioxide is the essence of determining patient status.
- The summary of the above is that all situations can be reduced to a balance of production and removal of CO2.
Capnography – the science

- Essentially for a resting animal the rate of production of CO2 is constant. It is varied by the metabolic rate of the animal, so in some circumstances can change.
- Hyperthermia will lead to an increase in CO2 production.
- Conversely hypothermia will lead to a reduction in CO2 production.
Capnography - visualisation

- Consider the production of CO2 as an open water tap filling a large vessel.
- In this concept the vessel is the lungs and the open tap is the constant production of CO2.
- Consider the removal of CO2 as a man removing water from the vessel with a bucket.
Capnography - visualisation

Rate of removal = rate of delivery

NORMOCAPNOEA
Capnography - visualisation

In the previous slide:

- The running tap represents a constant delivery of CO2
- The big bucket represents the level of CO2 in the lungs
- The men represent the rate of removal of CO2 from the lungs
Capnography - visualisation

Rate of removal = rate of delivery  NORMOCAPNOEA
Capnography – the science

- Therefore to keep an animal normocapnic we must ensure that the rate of breathing is sufficient to remove the CO2 delivered to the lungs
- We will return to this concept later
Capnography

- Now that we understand where the information is coming from, what can we do with this information, and what does it mean for the animal?
Capnography – Level 2 information

- Normal values

- Inspired CO2: 0%
- Expired CO2: 4.5% (35 mmHg)

- The following slides assume a zero level for inspired CO2. We will come to the effects of increased inspired CO2 later
Capnography – Hypercapnia

- Increased levels of end-tidal (alveolar) CO2.
  - 5-6% begin to question why
  - > 6% take some action
- This means that the level of CO2 in the lungs after equilibration with pulmonary blood is too high, which itself means that the removal of CO2 is insufficient
- This usually means that the animal is under-ventilated. This may indicate respiratory depression or some other cause (lung pathology)
- Rarely does it reflect an increase in metabolic CO2 production
Capnography - Hypercapnia

Rate of removal < rate of delivery: Hypercapnia
Capnography - Hypercapnia

- What’s wrong with hypercapnia?
  - Indicates hypo-ventilation, so reduced oxygen exchange, and anaesthetic exchange
  - Cerebral vasodilation increasing cerebral blood flow and intracranial pressure
  - Peripheral vasodilation by direct effect on vessels
  - Cellular acidosis develops rapidly affecting cellular function
  - Central depression at very high levels of pCO2
  - Stimulation of the sympathetic nervous system resulting in tachycardia, peripheral vasoconstriction and sweating
Capnography - Hypercapnia

- In a clinical situation this indicates a patient that has insufficient minute volume ventilation.
- It can indicate a patient is too deep
- This patient needs an increase in minute volume ventilation: Give supplementary breaths by hand by squeezing the bag or begin mechanical ventilation
Capnography - Hypocapnia

- Decreased levels of end-tidal (alveolar) CO2.

- This means that the level of CO2 in the lungs after equilibration with pulmonary blood is too low, which itself means either that the removal of CO2 is excessive or that CO2 delivery is reduced.
Capnography - Hypocapnia

Possible causes:

- Excessive ventilation
- Reduced CO2 production – hypothermia
- Reduced delivery of CO2 to the lungs
Capnography - Hypocapnia

Rate of removal > rate of delivery: Hypocapnia
Capnography - Hypocapnia

Reduced delivery of CO2: Hypocapnia
Capnography - Hypocapnia

- Reduced delivery of CO2
  - Can be either reduced cardiac output or decreased production
  - Differentiate between the two by degree of change. With a change in cardiac output the effect on the capnogram is dramatic
Capnography - Hypocapnia

- What’s wrong with Hypocapnia?
  - Inhibition of respiratory drive
  - Shift of the haemoglobin oxygen dissociation curve to the left (impairing peripheral oxygen unloading)
  - Depression of myocardial contractility
  - Cardiac arrhythmias
  - Less of an evil than Hypercapnia
Capnography - waveforms

- So far all the information discussed has been available from a capnometer, i.e. the information has been purely numerical.
- We will now look at the information imparted by the capnogram itself
What can a Capnogram tell us?

- In addition to the End-Tidal value the Capnogram shows the levels of CO2 during the complete respiratory cycle.
- The Capnogram waveforms provide a lot of information.
Typical Capnogram
Typical Capnogram

- Mainstream & Sidestream
- Live demo..
What do the different phases represent?

- Phase 0 – Inspiration. Rapid fall in CO2 levels as new breath taken
Phase I – Beginning of expiration and the elimination of gas from anatomical dead space
Phase II

- Phase II – Alveolar gas mixes with dead space
Phase III

- Phase III – Main component of expiration. Has a typical positive slope
Normal Capnogram

Expired CO2: 5% 38mmHg
Inspired CO2: 0% 0 mmHg
Exp – Insp: 5% 38 mmHg
Capnogram 2

Expired CO2: 7.5% 55 mmHg
Inspired CO2: 0% 0 mmHg
Exp – Insp: 7.5% 55 mmHg
Increasing End-tidal CO2

- CO2 delivery to the lungs exceeds removal
- Need to increase the minute volume to “blow off” more CO2
- If animal is not on a ventilator, then start IPPV
- If animal is on a ventilator then the simplest way to do this is to increase the respiratory rate. Leave Inspiratory time unchanged and decrease the Expiratory time
- Could increase the Tidal Volume but that might change the degree of lung inflation
- Why has this occurred? Was Minute Volume too low or is there another factor? Hyperthermia, changes in Cardiac Output
Capnogram 3

Expired CO2: 3%  25mmHg
Inspired CO2: 0%  0 mmHg
Exp – Insp:    3%  25 mmHg
Falling End-Tidal CO2

- CO2 removal rate exceeds the delivery rate to the lungs
- Need to reduce the minute volume
- If the animal is not on a ventilator then it is probably hyperventilating. Possible response to pain - may need increased depth of anaesthesia
- If the animal is on a ventilator then the minute volume is too high. Reduce the minute volume by decreasing the respiratory rate.
- Another cause could be....
- Fall in cardiac output so delivery of CO2 to the lungs is decreased. Causes – compression of pulmonary artery by surgeon, PEEP, shock
- Hypothermia. Results in reduced CO2 production
Capnogram 4

Expired CO2: 6% 45 mmHg then 3% 25 mmHg
Inspired CO2: 0% 0 mmHg
Dramatic drop in CO2 level between 2 breaths

- Such a sudden fall in CO2 level must be associated with a fall in cardiac output. This can happen when the surgeon “embarrases” heart function or occludes the pulmonary artery.
- Something to look out for in ruptured diaphragm repair
expired CO2: 7% 55 mmHg
inspired CO2: 2% 17 mmHg
exp – insp: 5% 38 mmHg
Delta Capnography - Nonin 9847V

The Model 9847V Veterinary Pulse Oximeter and Carbon Dioxide Detector
Capnogram 6
Skewed Capnogram

- The Capnogram is skewed.
- The total cycle time is unchanged but the time for phase II is extended.
- Phase II is the expiration of gas from the lungs, mixing with dead space gas.
- Elongation of phase II is most commonly caused by obstruction in the expiratory circuit.
Spiked Capnogram
Spiked Capnogram

- The spike represents an isolated pocket of high percentage CO2 gas during the expiratory period.
- Known as gas trapping this can be due to:
  - Single-bronchus intubation
  - Mucus plugs
Capnography - Summary

- Easy to use
- Lots of information available from basic through to detailed
- The single most informative piece of equipment for anaesthetised animals
- Remember to consider production versus removal in all cases where CO2 output changes