Capnography and Minute Volume. What’s it all about?
Why is capnography so useful?

• CO2 path involves 3 systems
  • Production – body (cellular respiration)
  • Delivery to lungs - circulation
  • Elimination from lungs - lungs

• If changes occur in one process, with little change in the other two then information can be determined about the cause

• Capnography gives an indication of the adequacy of the patient’s Minute Volume
Why is capnography so useful?

- For example, if there is no change in cardiac output (Delivery) and no change in Production, then a change in CO2 output must be due to changes in Elimination, such as hyper or hypo-ventilation.
Capnography – CO2 production

• For 99% of the time CO2 production will be constant
  • Patient's anaesthetised
  • Steady state of metabolism
  • Constant temperature

• Hyperthermia leads to increased CO2 production
  • Malignant hyperthermia in greyhounds, pigs.
  • Heatstroke

• Hypothermia leads to decreased CO2 production
  • Dogs that fall through ice in winter
  • Shocked, cold animals
CO2 Delivery & The role of the lungs

- In terms of CO2, what is the role of the lungs?
- If the end-tidal CO2 is 40mm Hg, what is the CO2 content in blood leaving the lungs?
  - 40 mmHg
  - 30 mmHg
  - 20 mmHg
  - 0 mmHg
CO2 Delivery & The role of the lungs

• Blood flowing to lungs is rich in CO2: 50-55 mm Hg
• Blood leaving the lungs still has 40mm Hg
• CO2 can only enter lungs down a concentration gradient: high $\rightarrow$ low
• Alveolar concentration matches pulmonary vein concentration
• Pulmonary vein $\rightarrow$ L. Atrium/Ventricle $\rightarrow$ Aorta $\rightarrow$ Arterial circulation
• So, CO2 content in lungs is very close to arterial circulation
• And End-tidal CO2 (alveolar gas) is therefore a good measure of arterial CO2
Maybe rethink the role of CO2

- CO2 is essential for maintenance/regulation of pH
- Regulation of pH is a very finely controlled mechanism: 7.35 to 7.45
- Deviations from this pH band upset many processes at cellular level
- Metabolism → CO2 + Energy
  - Energy → movement, heat
  - CO2 → carbonic acid → maintain ECF pH
- Body closely regulates CO2 content in blood
- Do not want to get rid of all CO2 only surplus CO2. BIG difference
- Consider the body to be like a steam engine...
Capnography – careful maintenance of CO2

Steam engine analogy

The engine works best when pressure is at a given level and maintained
Too much steam/pressure $\rightarrow$ engine damage
Too little steam/pressure $\rightarrow$ poor performance/weakness

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Capnography – careful maintenance of CO2

Too much CO2 → acidic (pH < 7.35) → upset enzymes and cellular metabolism
Too little CO2 → alkalosis (pH > 7.45) → upset enzymes and cellular metabolism
Capnography – the role of the lungs

• Lungs are for fine regulation of CO2 and subsequent control of blood and ECF pH
• If we keep end-tidal CO2 in limits (35-45mmHg) then we will keep CO2 balance in blood correct and hence blood pH
Elimination – removal of CO2 from Lungs

• 2 factors
  • Depth of breathing – Tidal Volume (TV)
  • Rate of breathing – Respiratory Rate (RR)

• Elimination simply depends on how big the breaths are and how frequent they are. Their sum is the Minute Volume
  • Minute Volume = TV x RR and is expressed in litres/minute

• Minute Volume is a very important concept and we will use this term a lot. It is good to start thinking in terms of Minute Volumes rather than just Tidal Volumes.
Measuring CO2 – how do we do it?

- Mainstream or Sidestream methods
Measuring CO2

• Where should you place the capnograph?

• For example, if you have an HME, should that be fitted on the patient side of the capnograph or the circuit side?
Where should the capnograph be placed?

• Place as close to the end of the ET tube as possible, so that any additional dead space will be ‘seen’ by the capnograph.

The position will not change the end-tidal value, it will be the same in both instances, but the waveform will be very different between the two and the rebreathing that occurs with the added dead space will be missed if the sampling point is at the Y-piece.
What do we expect from our capnograph?

• Numbers and a trace

• Numbers tell us...
  • RR
  • FiCO2 (inspired)
  • FeCO2 (expired)

• The trace tells us..
Idealised capnogram

• Parts 0, I, II, III
• The higher the level of phase III the higher the end-tidal CO2 value

Important:
No indication of volume – Cat waveform looks exactly the same as that of a horse
No indication of direction of gas flow – you cannot tell if gas is being breathed in, out, or is stationary.
We will come back to traces shortly after we have looked at the meaning of the numbers.
Normal values of End-Tidal CO2

For numbers to be of any use we need to know what normal values are.
Numbers come in different units, which can be confusing
For this talk the units used will be mm Hg.
Alternative units are: % and kPa.
Not many people use kPa but (unless atmospheric pressure is very low) kPa is approximately %, i.e 5kPa~ 5%

As a rough conversion, 1% is the same as 8mm Hg

- Normal inspired CO2 : 0 mmHg (0%)
- Normal expired CO2 : 35-45 mmHg (4.5-6%)
- Normocapnia = 35-45mmHg
- Hypocapnia < 30mmHg
- Hypercapnia > 50 mmHg
Normal values of End-Tidal CO2

• When the patient breathes out CO2 will go from zero (fresh gas in trachea) to alveolar concentration/End-Tidal which will be held until the patient breathes in, when it will fall to zero again.

• Typical capnogram therefore looks like a bit like a square wave.
Hypercapnia

• Definition – an end-tidal CO2 value in excess of 50mmHg

• What makes a patient hypercapnic?
  • Increased production - hyperthermia
  • Increased delivery – after restricted delivery by e.g. surgeon
  • Reduced elimination – apnoea, infrequent or small breaths

• Needs an increase in MV to remove the extra CO2
  • If the patient is anesthetised it won’t respond to the increased CO2 and so we will see the end-tidal value rising
Hypercapnia

• How do we increase the MV? Two options:
  • Increase Tidal Volume
  • Increase respiratory rate

• A lot will depend on whether the animal is spontaneously breathing or is being ventilated
  • Spontaneous – give extra manual breath between breaths
  • Ventilated – increase TV slightly or increase the Respiratory Rate
What is wrong with hypercapnia?

- Increased HR
- Increased RR
- Resp Acidosis and decreased blood pH
- Increased BP
- Acidosis causes a Hyperkalaemia and resulting ventricular arrhythmias
- Bradycardia if CO2 > 60mmHg

Generally, the effects are more pronounced the higher the CO2 content and generally the high CO2 is having a stimulant effect
But if it gets too high, get a bradycardia and narcosis

All this is going to lead to increased morbidity and a greater anaesthetic risk
To some extent the details of what happens is not important.
Using capnography will help to avoid the situation
Hypocapnia

• Definition – levels of arterial CO2 < 30mmHg

• What makes a patient hypocapnic?
  • Increased Elimination - MV too high, usually from IPPV
  • Decreased production - hypothermia
  • Reduced Delivery – reduced cardiac output or restricted pulmonary artery

• Needs a reduction in Minute Volume to reduce Elimination and allow end-tidal CO2 values to rise
Hypocapnia

- How do we reduce the MV? Two options:
  - Decrease Tidal Volume
  - Decrease respiratory rate

- Hypocapnia is very rare in spontaneously breathing animals so the problem is mainly seen with ventilated animals
  - Decrease the TV slightly or decrease the Respiratory Rate
What’s wrong with hypocapnia?

• Respiratory alkalosis
• Reduced respiratory drive
• Reduced myocardial contractility
• Cardiac arrhythmias

Generally, the effects are more pronounced the lower the CO2 content and generally the low CO2 is having a depressant effect. The resulting cardiac arrhythmias are a significant concern.

All this is going to lead to increased morbidity and a greater anaesthetic risk.
To some extent the details of what happens is not important.
Using capnography will help to avoid the situation.
Fine control

• Both hypocapnia and hypercapnia are undesirable conditions
• Ventilation and capnography provide the tools to avoid them

• Consider the body as a very finely tuned, tightly controlled, perfectly balanced system. As an anaesthetist it is your task to maintain that balance when normal homeostatic mechanisms are lost.

Finely tuned balanced system

How changes in each compartment affects ETCO2
Trace information from the Capnograph

• Lots of information in the waveform/trace
• Typically we have a capnogram that looks like this:
What do the parts of the Capnogram represent?

- Phase 0: Inspiration:
  Usually a rapid fall to zero. Non-zero levels in this phase can indicate inspiration of low levels of CO2
What do the parts of the Capnogram represent?

**Phase I**

- Phase I: Start of expiration. Because the first part of the breath is involved with expelling dead space gas from the major airways it is not possible on a time capnogram to tell when inspiration ends and phase I starts.
What do the parts of the Capnogram represent?

Phase II

• Phase II:

In this phase there is mixing of alveolar and dead space gas. Phase II should have a steep rise and be linear over its length. Phase II ends when the mixing is complete and only alveolar gas is being exhaled.

• Disturbances in Phase II can indicate problems with expiration particularly when there is obstruction to expiration, either from the lungs themselves or from the anaesthetic apparatus.
What do the parts of the Capnogram represent?

Phase III

- Phase III
  Here, alveolar gas is leaving the lungs. Phase III is usually flat or has a slight rise. Phase III starts when all dead space gas has been eliminated and just alveolar gas is leaving the lungs.
Reading a Capnogram

• Evaluate a Capnogram in the same way you would evaluate an ECG, i.e. in a step by step methodical manner.

1. Can you identify phases 0, I, II and III?
2. Do all waveforms look the same or do they differ?
3. Is Phase 0 nice and steep?
4. Is Phase II nice and steep
5. Is Phase I at zero?
6. Is Phase III flat or slowly increasing with a slight rise?
Reading a Capnogram

• The capnogram here is bad because:
  A) Phase II is not steep
  B) Phase 0 is not steep
  C) Phase III is not flat, but domed and indistinct

This is typical of a capnogram where there is significant gas mixing occurring so the CO2 boundaries are not clear:
  Mainstream – when volume of adaptor is too large for the animal’s TV
  Sidestream – when mixing is occurring in the circuit and/or sampling line
Capnography Summary

- CO2 levels are a balance between production, delivery to lungs and elimination
- Normal End-Tidal CO2 is between 35-45 mmHg
- Capnography method can markedly affect the results
- Capnogram gives information on patient circuit
- Capnogram does NOT indicate volume or direction of CO2, only its presence
- Evaluate a capnogram before interpreting any results
- Use capnography to adjust your patient’s Minute Volume