



Let's talk about Capnography

This is one of a series of articles by Keith Simpson BVSc MRCVS MIET (Electronics) discussing the practical aspects of some common monitoring techniques.

Capnometry is the measurement of the levels of exhaled carbon dioxide, which can be measured by a capnometer, which displays the numerical value only. The actual trace is observed on a capnograph and is referred to as a capnogram. Measurement of exhaled CO₂ can be very informative of the patient's condition if you are aware of what is being measured and what deviations from the normal represent. Before getting too involved in the physics and physiology of capnography some explanation of nomenclature and conventions might be helpful.

PetCO₂ is an accurate reflection of the PaCO₂ and normal values are expected to be of the order of 35-40mmHg.

Now what does all that mean!!?

PetCO₂ is an abbreviation for the partial pressure of end-tidal CO₂ and PaCO₂ is an abbreviation for the partial pressure of arterial CO₂.

But what is partial pressure, and isn't it the same as the percentage? Well, no it isn't the same. Partial pressures are a means of expressing a media (normally a gas) as a fraction of another gas. Because the lungs are directly exposed to the atmosphere gas pressures can be related to atmospheric pressure. Atmospheric pressure is nominally 760mmHg (millimetres of mercury). All the partial pressures of the gases that make up air will add up to 760mmHg. For example, say for arguments sake air is 21% oxygen, and 79% nitrogen then the partial pressure of oxygen plus the partial pressure of nitrogen must equal the total pressure, which is 760mmHg. Oxygen in this instance would have a partial pressure of 160mmHg and nitrogen would be 600mmHg. Now it's no coincidence that 160/760 is 21% because that's how you convert from partial pressure to percentage.

So now when we look at the above statement we see that the normal partial pressure of CO₂ in expired breath is 35mmHg or $35/760 \times 100\% = 4.6\%$. The easiest way to remember it is that 1% is equivalent to approximately 8 mmHg. Different machines will display the results differently and some allow you to change between percentage and partial pressures depending on your preference.

Sidestream versus Mainstream

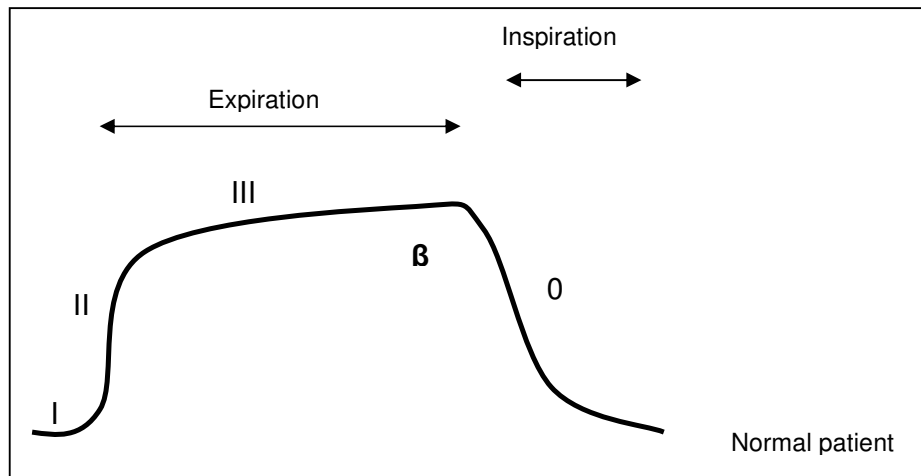
These terms are frequently talked about and deserve some explanation. They refer to the position of the CO₂ sensor.

In a sidestream device a portion of the patient's breath is sucked off down a tiny tube for analysis inside the main unit. This has several implications.



Firstly it takes time for the gas to arrive at the unit so the patient's breathing movement seem to be out of phase with the capnogram. Depending on the breathing rate and the sidestream withdrawal rate, the capnogram could be a breath or two behind the patient. Secondly because some gas is removed from the airway there is a limit on the low-end resolution. Many capnometers withdraw around 200mls/minute, which is excessive if you have a small animal with a minute volume of less than 500mls/minute. Some capnometers allow you to adjust the withdrawal rate for small animals. This is a help but if the animal has a rapid breathing rate (which the small ones invariably do) distinction of the breaths becomes lost and the capnometer gives the wrong result. This is the major unavoidable limitation of sidestream technology. In a mainstream device the sensor sits right next to the patient and measures the CO₂ levels that pass through the airway to the patient. With a mainstream device the capnogram follows exactly the patient's breathing pattern. When the patient breaths out the capnogram shows a rise in CO₂. It doesn't matter how small the patient is (as long as the tidal volume exceeds the dead space) because there is no gas withdrawn and no dilution effect. These units are nicer to work with but command a much higher price. The downside to a mainstream device is that the patient needs to be intubated, whereas you can use a sidestream device via a nasal tube or a face mask.

Before going too far let's look at a typical capnogram from a CO₂ monitor:





This is a time capnogram. There are other ways of depicting the expiration of CO₂ but for now we will stick with a time capnogram which means that time passes from left to right and the height indicates the CO₂ level. Without getting too technical here the phases of the graph are subdivided into the expiratory phase comprising, Phases I-III plus the alpha angle and the inspiratory phase comprising phase 0 and the beta angle. Phase I represents exhalation of air within the anatomical dead-space and because this is just air that has been sucked in and blown out again it has the same composition as room air. Then air from the lungs begins to be exhaled and the CO₂ level rises and more or less plateau's before falling during inspiration. We'll look at what each phase represents in more detail later.

So how can capnography help?

There are two areas where capnography gives us vital information. Firstly, we have the peak end-tidal CO₂ value, which is simply a numerical expression of the maximum amount of CO₂ detected in that breath. Secondly, and more subtly is the variations within the capnogram itself which give information on the way CO₂ is being eliminated from the lungs. The combination of these two pieces of information is where the real value of capnography lies.

What are we actually measuring?

On the face of it, it looks very simple. We are just measuring the CO₂ produced by the lungs. However, when you start looking at this more closely you realise that what is being measured is the composite exhalation of CO₂ after mixing in the trachea and that because the different parts of the lungs are emptying at different rates and are exposed to differing ventilation perfusion ratios, the actual levels being exhaled vary over the course of the breath, between breaths and with posture. As a quick example, in obese or pregnant patients the effect of diaphragmatic/thoracic compression results in a terminal emptying of the alveoli in excess of the normal. For this reason there is often an upturn at the end of the CO₂ profile.

The end-tidal statement is important. The assumption made is that the last portion of breath at the end of the tidal volume comes from and is representative of the alveoli. Because alveolar CO₂ (PACO₂) is a close approximation to arterial CO₂ (PaCO₂) and because end-tidal CO₂ (PetCO₂) is a close approximation to alveolar CO₂ we can use end-tidal CO₂ as an indicator of arterial CO₂. That way we don't have to take blood to assess the arterial CO₂ level. Capnography gives us a simple way of monitoring arterial CO₂.

When we look at the screen of a typical capnograph we see something like this:

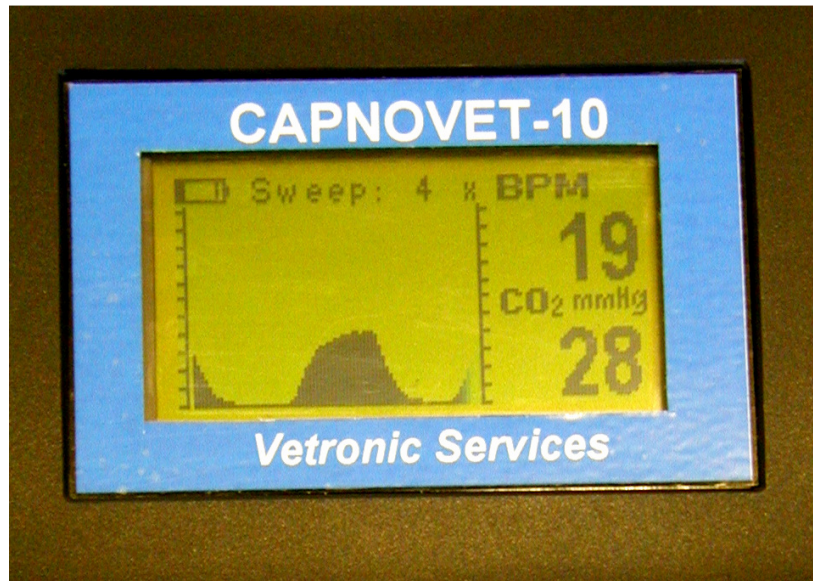
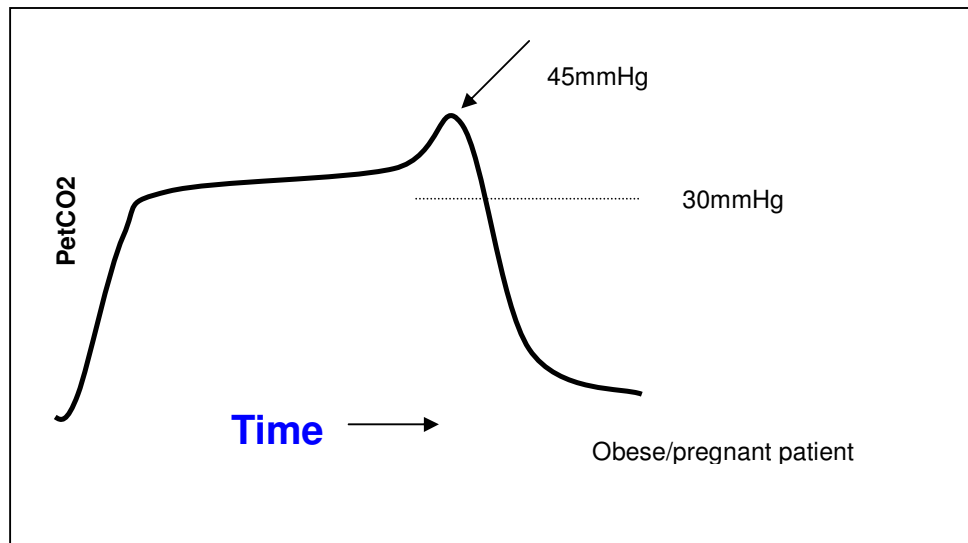


Figure 1.01 – typical display Capnograph machine

We have a CO₂ value, a respiratory rate and a capnogram. The value in using a capnograph is not just with looking at the end-tidal CO₂ value (which of course is helpful) but in understanding exactly what that means and in understanding the capnogram as well.

CO₂ value.

This is the peak or maximum measured CO₂ value in the last breath. This value may be averaged with preceding values or may be a report of the actual last breath measured, depending on the machine. Either way it is just the peak value and in the same way that the systolic blood pressure reading only tells you part of the story so does the PetCO₂ value. Because it's the peak value you don't know how that value is derived or produced. If we go back to our pregnant patient and compare with our normal we see two different capnograms. This graph is an exaggeration of the effect but it does show the principle involved.



What we see is an upturn at the end of expiration that increases the PetCO₂ value by 15mmHg. If we were just looking at the PetCO₂ value this could be misleading because it might seem a bit high. But by looking at the waveform we can see that the average end tidal CO₂ value is 35mmHg and only rises momentarily to 45mmHg because of the extra air being forced from the alveoli. In extreme cases this could rise higher without there necessarily being a cause for concern, as long as the plateau phase (phase III) was normal. The point behind this is that you need to look at the waveform as well as the PetCO₂ value. The increase in this end-tidal value is interesting. As the lungs collapse during expiration their volume decreases, but the addition of CO₂ is relatively constant so the effective CO₂ concentration rises. Also there is late emptying of alveoli with a low ventilation/perfusion ratio which therefore have a higher CO₂ concentration. In normal patients this results in a positive slope to phase III and in obese patients gives us the late emptying effect seen above.

What do the phases represent?

Phase I. This represents the expiration of gas from anatomical dead space.

Phase II. Here alveolar gas is mixing with dead space gas

Phase III. Expired gas consists almost entirely of alveolar gas. This phase typically has a positive slope.

Phase 0. Inspiration.

Alpha angle. The angle between phase II and phase III. The rate of transition from phase II to phase III is an indicator of the ventilation/perfusion ratio of the lungs.

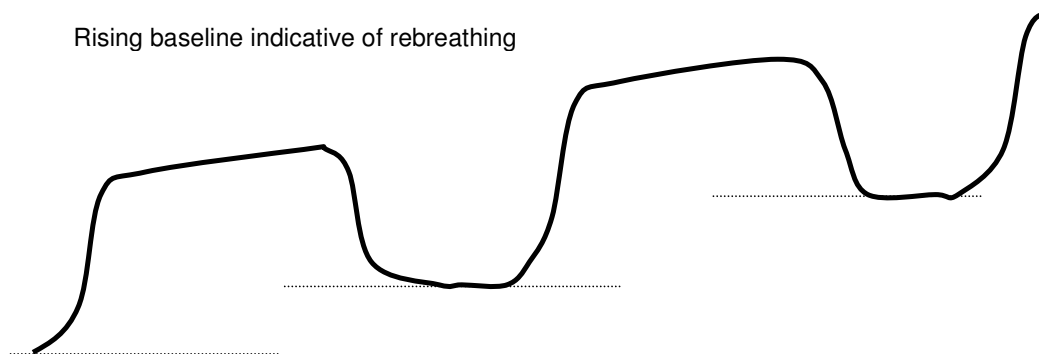


Phase III is the most important as it provides information on how the lungs are emptying and indicates the V/Q status of the lungs. One point that may not be immediately clear is that as the lungs empty blood is continually delivering CO₂ to the alveoli. These alveoli therefore have increasing amounts of CO₂ in them so phase III has a positive slope. Also note that the situation in a dog and a horse is different. With the slow heart rate in a horse perhaps only one pulse perfuses the lungs during expiration whereas with a dog 3 or 4 pulses may perfuse the lung during expiration. This will result in different profiles between the species.

What else can the Capnograph tell us?

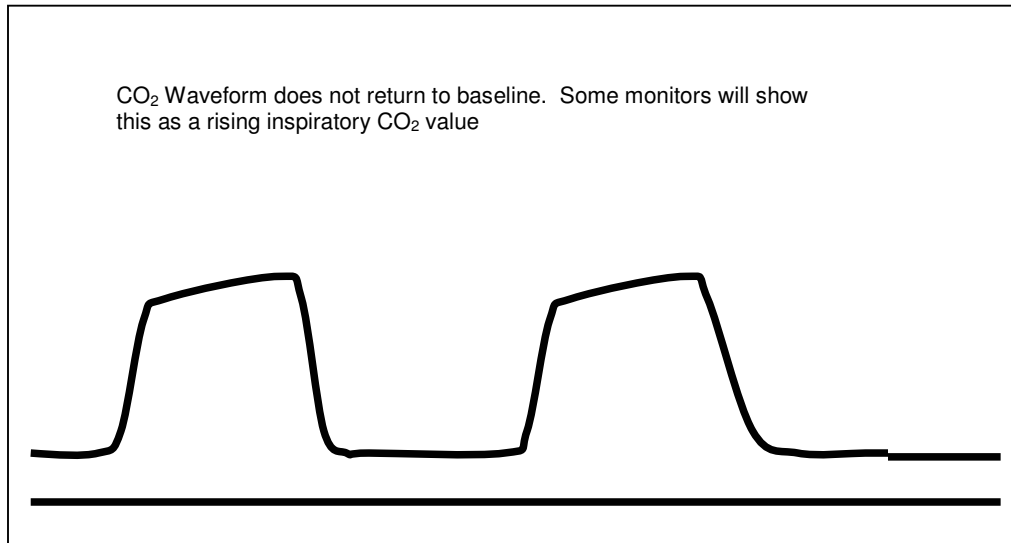
Rebreathing

If a patient is rebreathing its own exhaled gas then the CO₂ levels will rise. Inhaled air will not be free of CO₂ so the baseline will start to rise. The PetCO₂ will also rise but it is more apparent from the capnogram than from the numerical value. This can be extremely valuable for ventilated patients or patients connected to a rebreathing anaesthetic circuit.





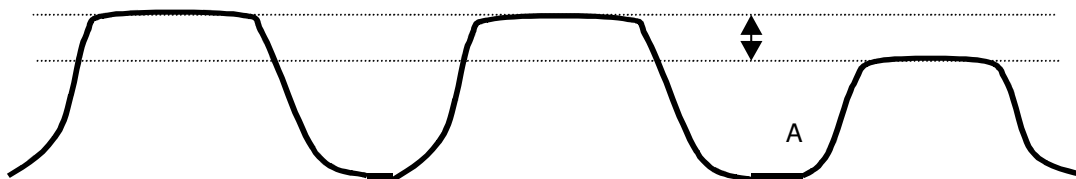
If the effect is slower which it typically is, you will see something similar to the next diagram:



Cardiac output

If all other parameters are stable then changes in CO₂ can indicate cardiac output. A fall in cardiac output and pulmonary flow will result in a fall in PetCO₂ because CO₂ is simply not being delivered back to the lungs at the normal rate. Conversely a rise in cardiac output will be associated with better alveolar perfusion and a rise in PetCO₂. This effect can be clearly seen during procedures that affect pulmonary flow such as during an exploratory thoracotomy and can be very helpful to the anaesthetist.

'A' represents a fall in CO₂ due to reduced cardiac output





Ventilation/perfusion ratio or V/Q ratio

The ventilation/perfusion ratio is a ratio intended to give an indication of how well areas of lung are performing. Values are rarely referred to, anaesthetists preferring to talk about normal, low or high V/Q ratios. The nominator is Ventilation so as Ventilation increases the V/Q ratio increases. A ratio is used because both ventilation and perfusion are elements of successful lung function. A well ventilated but under-perfused lung (high V/Q) will have a low PetCO₂, and conversely a poorly ventilated but well perfused lung (low V/Q) will have a high PetCO₂ level. It is more informative to talk about areas of lung and their V/Q ratios than the lung as a whole because different areas of the lung have differing V/Q ratios. This is the whole essence of determining or interpreting the final capnogram. It is further complicated because the ventilation to a lung area may be adequate and the perfusion of lung area may be adequate, but not at the same time so there is still a V/Q mismatch (temporal mismatch). A spatial mismatch occurs when different areas of lung have differing V/Q ratios. The main points to remember are that the longer an alveolus holds its gas, the higher its CO₂ content will be and that the lower the V/Q ratio for an alveolus the higher its CO₂ content will be. Late emptying alveoli contribute to the rising slope of phase III and by looking at the overall pattern of phase III much information can be learned about lung function and its overall V/Q ratio.

Summary

- 1) End-tidal CO₂ is used as an indicator of arterial CO₂. The two are not equal but PetCO₂ follows PaCO₂ very closely.
- 2) When evaluating a patient's end-tidal CO₂, look at the capnogram as well as the value
- 3) Sidestream technology has limitations with very small patients. This will also apply to mainstream devices depending on the dead space they represent.
- 4) The actual end-tidal CO₂ value tells only part of the story.
- 5) Read the end-tidal value in association with the capnogram.
- 6) A capnograph can give us additional information on rebreathing and cardiac output.
- 7) Understanding the physiology behind the production of the capnogram enables prediction of the causes of changes in the capnogram.
- 8) The area of capnography is a fascinating new area and there are features of capnography that are beyond the scope of this article.



The capnometer and capnograph are relatively new instruments in the field of veterinary medicine but they have the potential to provide an awful lot of information about our patients in new ways and also in faster ways than previous instruments. Using them with an understanding of the principles involved will enhance our care of anaesthetised patients.

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