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Capnography for veterinary nurses – Part 2: Capnograms and the respiratory cycle

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Introduction

The first part of this series of articles looked at the origin of CO_2 in the body and why it is important. Also discussed were sidestream and mainstream capnographs and how to obtain a good capnogram.

To begin here, let's make the nomenclature clear:

- **capnogram** – the waveform trace seen on a capnograph
- **capnograph** – an instrument that displays a capnogram plus values of inspired/expired CO_2
- **capnometer** – an instrument that measures and displays only numerical values of CO_2

Now we're ready to look at some waveforms and begin to understand what the capnograph is telling us.

A typical capnogram

Figure 1 shows a typical capnogram. The levels of CO_2 in the breath are shown on the y-axis and time is on the x-axis.

- **Phase 0 (Ph 0)** is inspiration. CO_2 levels fall quickly because inspired gas contains no CO_2. The level should go down to zero.
- **Phase I (Ph I)** is the beginning of expiration. Only dead-space gas is being moved at this time. Dead-space gas should be fresh gas and so, again, this has no CO_2.
- **Phase II (Ph II)** is mixing of alveolar gas and dead-space gas.
- **Phase III (Ph III)** is the plateau phase where all alveolar gas is expelled.
- **The α angle** is the angle between Phase II and Phase III.
- **The β angle** is the angle between Phase III and Phase 0.

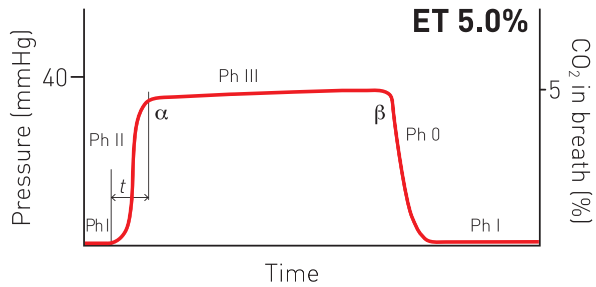


Figure 1. A typical capnogram

Remember that this represents only the CO_2 level. It does not give any information on the depth of the breath. A taller waveform does not mean a bigger breath – it just means that it has more CO_2 in it.

Expiration

If all alveoli emptied at exactly the same time and in the same manner, the graph would be a perfect square wave. The fact that they don't allows us to infer some facts about the breath. If the graph were a square wave, then the rise from zero CO_2 to end-tidal CO_2 would be instantaneous and **Phase II** would just be a line going straight up. But, of course, it takes time for the CO_2 to mix with the fresh gas in the dead-space area so we see a slope to Phase II.

Declaration of Interest

Keith Simpson is Managing Director of Vetronic Services Ltd, a company involved with the design, manufacture and sale of ventilators and monitoring equipment. All information presented in this article relating to equipment is non-specific and does not favour Vetronic Services products over any others. Any photographs in this series of articles in which the Vetronic name appears are used to illustrate a physiological principle rather than for commercial gain.

To cite this article, use either
DOI: 10.1111/vnj.12201 or Veterinary Nursing Journal VOL 29 pp395–397

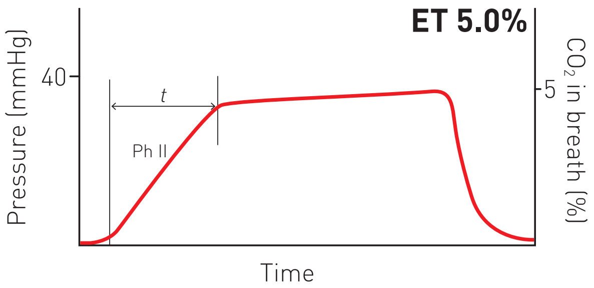


Figure 2. A capnogram showing resistance in a circuit: notice the elongation of Phase II

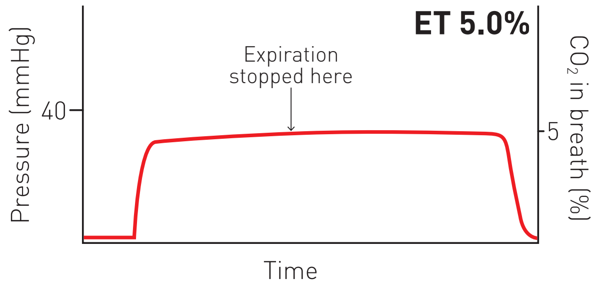


Figure 3. A long gap between expiration and inspiration on a circle system with a mainstream unit

Looking at it another way, the time (*t*) taken for the levels to go from low to high is a measure of how quickly the CO_2 leaves the lungs. If it is quite long, then the passage of breath out of the lungs is restricted. We can therefore use the Phase II slope as an indicator of external resistance, and **Figure 2** shows what we typically see when there is some resistance in the expiratory circuit.

Notice the elongation of Phase II. Look out for this in circle circuits or ADE systems, where expiratory valves get sticky, or even in non-rebreathing systems where the expiratory gas flow is restricted, such as with a twist in the neck of a T-piece reservoir bag.

The restriction to outflow could be anywhere in the respiratory tract, endotracheal tube (ET tube) or patient circuit. If it's in the respiratory tract, there may be little that can be done about it, but how would you know? There's a very simple test you can do (see box below).

When the CO_2 has mixed with the dead-space gas, the amount of CO_2 levels off; this is **Phase III**. This phase represents the level of CO_2 from the deepest alveoli and typically has a flat or slowly rising appearance. For obvious reasons, this is referred to as the plateau phase.

Phase III is very helpful, especially in determining whether your CO_2 waveform is accurate enough to be diagnostic. If you have a distinct plateau (meaning a straight line, be it flat or rising), then you know that the sampling technique, regardless of whether it is mainstream or sidestream, is accurate. Why? Because a straight line response in Phase III will only be seen when there is no dilution of the sample.

The way mainstream and sidestream systems can lead to dilution of the sample is slightly different in the two systems:

Mainstream: If your patient is too small for the mainstream adaptor placed at the end of the ET tube, the adaptor will represent a large dead space. Excessive dead space leads to dilution and rounding of the waveform so, if you have a plateau, there is no excessive dead space.

Sidestream: If the sidestream sampling rate is excessive compared to the patient's tidal volume, there will be dilution due to sucking in of air from the patient circuit, leading to rounding of the waveform. An excessive sampling rate leads to dilution so, if you have a plateau phase, the sampling rate must be appropriate.

Dilution of the waveform is a major problem in capnography. Being able to spot it will mean that you don't misinterpret the readings presented. We will cover in some detail later in the series how to identify the signs of sample dilution.

End of expiration and transition to Phase 0

Finally, what happens at the end of expiration? Often, inspiration begins immediately and you see the familiar Phase 0 and rapid fall in CO_2. But what if there is a pause between the end of expiration and the start of inspiration? It is not unusual for there to be quite a pause between breaths, particularly after induction or if the patient is on a ventilator. What the capnograph shows then can depend on a number of factors. Let's look, for example, at what you might see if the patient was being monitored by a mainstream device on a circle system.

Once the patient has exhaled, the adaptor of the mainstream device is full of end-tidal CO_2 gas and the capnograph will show a steady flat line as a continuation of the plateau phase. Because a circle system is being used, there is usually insufficient fresh gas flow to start to wash out the air in the adaptor or even dilute it. So you will see normal Phases 0, I, II and III, but Phase III will be extended as a flat line (**Figure 3**). This may be maintained until the patient takes its next breath.

Now look at the same patient on a circle system, but this time on a sidestream unit sampling at 200 ml/minute. Once the patient has exhaled, the adaptor is still full of end-tidal gas, but now it is being removed by the sidestream sampling unit and so fresh gas from the patient circuit flows in to the adaptor and the CO_2 levels drop (**Figure 4**).

Test when outflow is restricted

First, disconnect the Y-piece from the end of the ET tube for one breath and see if the waveform changes. If it does, you've got a problem in the anaesthetic circuit. If it makes no difference, then the problem lies in the ET tube, trachea and/or major airways.

The only thing you can do at this stage is probably replace the ET tube in case it is occluded – check for over-inflation of the cuff before you do that. Let the cuff down and see if the waveform improves.

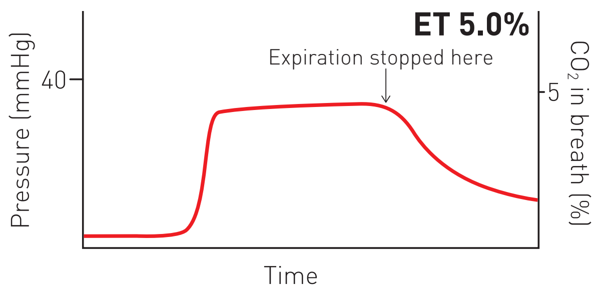
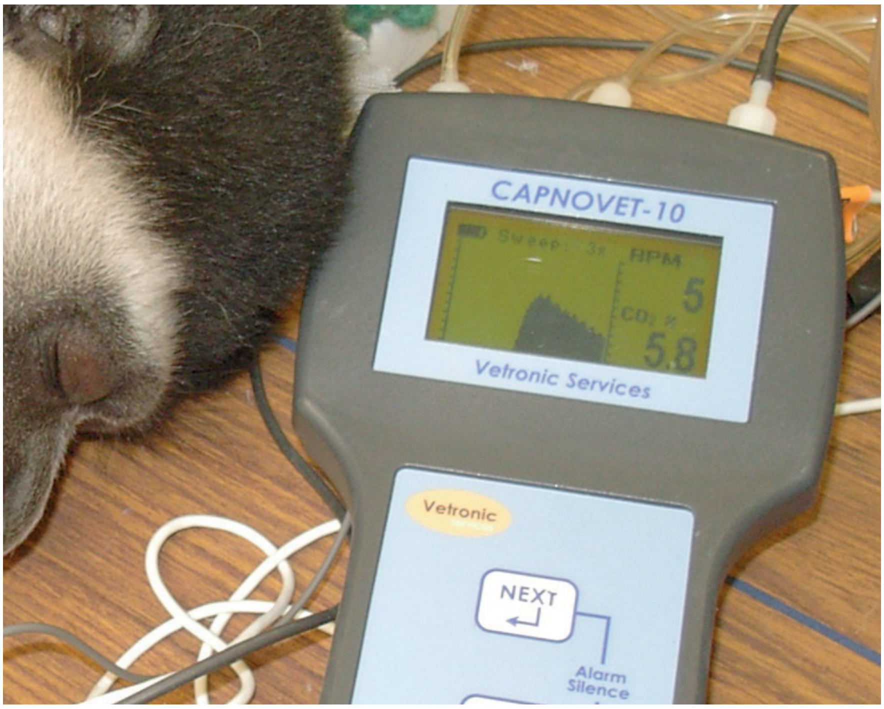


Figure 4. The same patient on a sidestream unit

It is removed at about 3 ml/second and the dead space in an adult adaptor is about 4 ml, so within a second or two the CO_2 level will drop significantly. It will not drop suddenly as in Phase 0 but usually much more slowly.

Figure 5 shows a short breath with an end-tidal value of 5.8%. As soon as expiration is complete, the waveform starts to fall off as the sidestream unit brings in diluting fresh gas. This Colobus Monkey is on a sidestream capnograph. Cardiogenic oscillations (which will be described in Part 3 of this series of articles) are just visible in Phase III but more obvious in the fall-off after expiration has finished. The same will be seen if the sidestream unit is sampling at 50 ml/minute, except it will take four times as long, so the fall-off is much slower.

In the mainstream example, if the fresh gas flow (FGF) into the circle system is quite high, then you may also see a faster fall-off. However, it doesn't really matter what the fall-off looks like; the main point is to recognise that it is not a true Phase 0, i.e. not caused by the patient breathing in. If the sidestream system sampling rate and time between breaths is sufficient, the CO_2 may have fallen to zero by the time the patient inspires, so you will not see a proper Phase 0.



Photograph © Keith Simpson

Figure 5. The waveform starts to fall off as the sidestream unit brings in diluting fresh gas

Avoid the trap of trying to analyse part of Phase III after the point at which the patient has stopped exhaling.

Conclusion

We have now looked at the different phases of the capnogram and what they represent. In Part 3 of this series of articles, we will explore what the capnogram can tell us.

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NEWS REVIEW by Jean Turner

'Don't be bone idle,' says Kennel Club

With both human and canine obesity at an all-time high, the Kennel Club has launched an online video of the top five exercises for dog owners to do with their pets.

The exercises were developed as part of the Kennel Club's 'Get Fit With Fido' campaign and were devised by the creators of Wag & Tone, an exercise programme for dogs and their owners. They are designed for people of all ages and abilities as a brief introduction to improving fitness levels of both dog and owner.

Statistics from the NHS show that more than 60% of adults in the UK are overweight or obese, and up to 60% of dogs in the UK are overweight, highlighting the need for action.

The 'Get Fit With Fido' campaign encourages owners to work together with their pets to improve the health and fitness of both of them. In addition, the 'Get Fit With Fido' Challenge rewards the dog and dog owner who jointly and individually lose the most weight, with the help of exercising together.

To find out more about the Kennel Club's 'Get Fit With Fido' campaign and Challenge, visit www.thekennelclub.org.uk/getfitwithfido

New system for diagnosing lymphoma in dogs

Nearly a quarter of dogs will develop cancer in their lifetime. Of these, 20% will be lymphoma cases. A new approach offers fresh hope for beloved family pets.

Researchers from the Mathematics Department of the University of Leicester, led by Professor Alexander Gorban, have partnered up with experts from Avacta Animal Health Ltd to develop a novel electronic system for diagnosing the early stages of lymphoma in dogs and for remission monitoring. The canine lymphoma blood test (cLBT) is the first of its kind to monitor the remission status of a dog after chemotherapy.

Kevin Slater, chief scientific officer at Avacta Animal Health, is extremely encouraged by the results to date:

The collaboration we have with the University of Leicester's Department of Mathematics is having a dramatic impact on the types of new tests that we can offer to vets and their owners. We are already widening the application of multivariate analysis to other diseases which commonly affect our pets and, subsequently, this work could also have benefits to human health.