

Pulse oximetry use in small animals

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Clara Rigotti, Marieke de Vries discuss the benefits of using this technique, and look at how it actually works and any factors that may impede upon its effectiveness

HYPOXAEMIA is one of the most dangerous complications that may be encountered during general anaesthesia and the recovery period.

Even for trained anaesthetists, it can be difficult to accurately assess a patient's oxygenation state by interpreting the colour of the mucous membranes (Comroe and Botelho, 1947; Moller et al, 1992).

The introduction of pulse oximetry in the 1980s revolutionised clinical monitoring, providing a non-invasive instrument that allowed the continuous monitoring of the patient's haemoglobin (Hb) saturation during the perioperative period.

Runciman et al (1993) reported that 82 per cent of anaesthesia-related incidents in human hospitals could have been avoided by the use of a pulse oximeter. For many events in the perioperative period, hypoxaemia is probably the most common mechanism responsible for an eventual adverse outcome.

Pulse oximetry enables early detection and, therefore, correction of perioperative hypoxaemia that may otherwise be potentially life-threatening.

Working principle

Oxygen is carried in the blood in two forms: most of it is combined with Hb in the red blood cells and only a relatively small fraction is dissolved and, therefore, present in the free form.

The majority of Hb is oxygenated (oxyHb), while a small amount is present in the deoxygenated or reduced form (deoxyHb). When normal Hb has its ferrous ion (Fe^{2+}) oxidised to the ferric form (Fe^{3+}), methaemoglobin (MetHb) is formed. Examples of MetHb formation are paracetamol poisoning (cats) or prilocaine overdose (EMLA cream). Carbon monoxide poisoning will result in interference with oxygen transport, as it combines with a very high affinity to Hb to form carboxyhaemoglobin (COHb).

Oxygen saturation is a measure of the percentage of Hb occupied by oxygen molecules, and can either be measured by blood gas analysis or cooximetry (S_aO_2), or by pulse oximetry (S_pO_2). In non-pathological conditions, approximately 97 to 98 per cent of Hb is saturated with oxygen, the remainder being deoxyHb.

Pulse oximeters are bedside monitors designed for measuring S_pO_2 and consist of a peripheral probe and a microprocessor unit, which displays a waveform, oxygen saturation and the pulse rate. Most units have an audible pulse tone, the pitch of which is proportional to the oxygen saturation. The probe consists of two light-emitting diodes (LEDs) and a photodetector.

The principle of pulse oximetry is based on two technologies: infrared spectroscopy and pulse plethysmography.

Infrared spectroscopy

Infrared spectroscopy detects the absorption of light by various tissues at two different wavelengths, namely the visual red and the infrared spectrum.

The theory behind spectroscopy is described by the Beer-Lambert law, which states that the absorption of light by a tissue is proportional to the concentration of the tissue and the path length through that tissue. Therefore, the tissue to which the probe is applied has to be sufficiently thin and translucent. The diodes in the probe emit energy alternately at 660nm (visible red light spectrum) and 940nm (infrared light spectrum).

The absorption of light at these wavelengths by Hb differs, depending on the degree of its oxygenation: reduced Hb absorbs more red light compared to oxyHb, which absorbs more infrared light. The photodetector measures the amount of light absorbed at each wavelength, from which the amount of oxyHb and deoxyHb is calculated by a microprocessor and displayed on the monitor.

Two different types of pulse oximeters exist: reflection and transmission pulse oximeters. In reflection pulse oximetry, the LEDs transmit light that is reflected back to the photodetector placed at the same side of the probe. Examples are forehead probes in humans and rectal or oesophageal

probes sometimes used in reptiles. In transmission pulse oximetry, LEDs transmit light through the tissue to the photodetector placed at the opposite side of the probe – it is this technique that is most commonly used in veterinary practice.

The pulse oximeter is able to differentiate between the absorption of light in the pulsatile (AC – alternating current) and the non-pulsatile (DC – direct current) flow under the probe. The AC component is derived from arterial blood pulsation, whereas the DC component is derived from all other static tissues, where the majority of total absorption occurs ([Figure 1](#)). The photodetector records the light transmitted through both pulsatile and non-pulsatile tissues. The AC component, the signal of interest, represents only up to two per cent of the total absorption (Magee, 2005). This explains how even small interferences, such as movement or vasoconstriction, may have a considerable impact on its accuracy.

Pulse plethysmography

Pulse plethysmography describes the change in light absorption due to the pulsatile variation in volume of arteries and the transformation into a pulse waveform.

Most pulse oximeters display oxygen saturation, heart rate and a plethysmographic trace. The most important function of the plethysmogram is to provide information regarding whether the pulse oximeter is working correctly. Readings displayed are only accurate and, therefore, reliable if this trace resembles an arterial pressure waveform and if the pulse rate displayed equals the actual patient's pulse rate ([Figure 2](#)).

The difference in light absorption depends on variation in the amount of blood flowing underneath the probe, the erythrocyte concentration, local blood velocity and the distance between the light source and the detector. The plethysmogram is also useful as an indicator of cardiac rhythm, as arrhythmias may result in changes in its regularity. Changes in cardiac output may be assessed by a change in amplitude of the trace and the area under the curve ([Figure 3](#)).

Limitations and potential pitfalls

Factors limiting the accuracy of pulse oximeters can be divided into patient-related conditions, to the equipment itself or to external interferences ([Figure 4](#).)

• Patient-related conditions

As already stated, conventional pulse oximeters are designed to take into account the presence of only two types of Hb: oxyHb and deoxyHb. The presence of other species such as MetHb and COHb will interfere with S_pO_2 readings.

MetHb will provide falsely low readings of around 85 per cent as equal amounts of red and infrared

light are absorbed. On the other hand, COHb will give falsely high readings – even up to 100 per cent – due to its similar absorption in the red light spectrum as oxyHb. In contrast, foetal Hb absorbs light at the same wavelengths as adult Hb, and, therefore, does not influence pulse oximeter readings.

These devices are particularly susceptible to the patient's movements, caused by muscle contractions, tremors and shivering. The plethysmogram will be irregular, and often values of 85 per cent will be displayed.

Decreased blood flow due to vasoconstriction, or hypotension and hypovolaemia, will affect its accuracy (Reich et al, 1996). This has to be taken into account when vasoactive drugs – such as α_2 -adrenoreceptor agonists, adrenaline and phenylephrine – have been administered, or when patients suffer from decreased peripheral perfusion.

Venous stasis, pulsatile venous blood or oedema will also influence its accuracy by decreasing the absorption of light by the AC component.

In theory, skin pigmentation does not interfere with the accuracy of pulse oximetry in humans (Bothma et al, 1996). Unfortunately, this appears to not be true in animals, where dark pigmentation has been suggested to be a source of failure and inaccuracy (Jacobson et al, 1992).

Patient size may also influence S_pO_2 readings, as very small patients, such as cats, show a decreased accuracy compared to dogs and horses (Matthews et al, 2003).

This could be due to the fact that pulse oximeter probes, when applied with moderate pressure, may occlude blood flow in the tissue underneath the probe, decreasing the pulsatile component of light absorption.

It has been demonstrated that the best accuracy in cats is achieved by placing the pulse oximeter probe on a white rear paw, when this is possible (Matthews et al, 2003).

Pulse oximetry does not reveal whether oxygen delivery to the peripheral tissues is adequate, as this depends on both cardiac output and arterial oxygen content. The latter is mainly determined by haemoglobin concentration. Anaemic patients may have optimal S_pO_2 values, as their haemoglobin will be maximally saturated, but may still suffer from low arterial oxygen content caused by reduced haemoglobin concentrations.

• **Equipment and external factors**

First, it should be realised that values displayed are calculated over an average number of beats – any change in arterial saturation of oxygen will not be displayed immediately, but delayed over 10 to 20 seconds.

Another important fact is that with S_pO_2 values of 80 per cent or lower, accuracy decreases as it is unethical to calibrate this type of equipment on individuals exposed to potentially life-threatening hypoxaemia – therefore, lower readings are extrapolated.

Malpositioning of the probe may result in the so-called “penumbra effect”, which occurs when the path length between each of the LEDs and the photodetector are not equal, causing a distortion in absorption, as one of the wavelengths will be “overloaded”. This asymmetric probe placement may produce erroneously low S_pO_2 readings (Guan et al, 2009).

External factors that may limit the accuracy include electromagnetic interference, IV dyes (such as methylene blue and indocyanine green) and ambient light. Shielding the probe from ambient light may help to reduce its interference. Placing a wet swab on the tongue where the probe is applied may also help to decrease possible artefacts.

Care should be taken with probes that are too big, as excessive pressure may be exerted, resulting in hindrance of blood flow – with a potential local ischaemia as a result. Probes with various sizes are available ([Figure 5](#)).

Although a pulse oximeter offers a good objective estimation of arterial oxygenation that is cheap, reliable and non-invasive, it is important to remember it does not provide any indication of the ability of the patient to ventilate properly. It may provide a false sense of security, especially when an increased fraction of inspired oxygen is applied, as normal S_pO_2 values may exist concurrently with high arterial carbon dioxide tensions.

The oxyhaemoglobin dissociation curve describes the nonlinear relationship between the arterial partial pressure of oxygen (P_aO_2) and S_pO_2 ([Figure 6](#)). Under normal conditions and at sea level, arterial blood contains a P_aO_2 of 80mmHg to 100mmHg and is saturated for almost 100 per cent. During the plateau phase, changes in P_aO_2 have hardly any effect on the degree of saturation, while the steep part of the curve demonstrates that once values below 90 per cent are reached, small changes in saturation will result in dramatic changes in P_aO_2 . Because of this shape, the pulse oximeter has also been described as a “sentry standing at the edge of the cliff of desaturation”, because of the potential lag in warning of possible hypoxaemic events. This is particularly important during the initial recovery period, when the patient will be disconnected from the anaesthetic machine and the fraction of inspired oxygen decreases from almost 100 per cent to 21 per cent. At this point, a patient that is hypoventilating due to – for instance – the residual effects of anaesthetic drugs, may easily become hypoxaemic. Early detection of hypoxaemia and rapid correction by providing extra oxygen is fundamental for a positive postoperative outcome.

Conclusion

The use of pulse oximetry in the perioperative period is invaluable, as it will enable an early and rapid detection of hypoxaemia. However, its values should be used in the right context, as it does

not provide any information on the amount of oxygen dissolved in – and, therefore, the oxygen content of – the blood; neither does it provide any information about how well the patient is ventilating.

The use of a pulse oximeter is especially recommended in the early period of recovery, when the patient starts to breathe 21 per cent of oxygen and may still be hypoventilating at the same time, with the risk of developing hypoxaemia.

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