Pulse oximetry: SpO_2 and SaO_2

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This article looks at the measurement of oxygen in the blood. It discusses how this essential observation is carried out in the pre-hospital environment, and its uses and limitations. The article will also take a brief look at the history and technology of the pulse oximeter.

History

Arterial oxygen saturation or the discovered oxygen level in arterial blood (SaO2) is invasive, and it is difficult to monitor trends in a practice setting. In 1972, the idea of a non- invasive pulse oximeter to measure peripheral oxygen level (SpO2) was conceived, with a prototype completed by 1974 (Aoygi, 2003). Prior to this, a number of monitoring methods for hypoxaemia have been described by Severinghaus (2011). Up until the 1930s, dentists were using pure N2O (unlike the 50:50 N2O:O2 mix in Entonox®) to anaesthetise patients for teeth extraction. The cyanosis, or shade of blue of the patient, was used to monitor how long they could stay in this state. While the drugs improved in the 1930s, such as the use of thiopental, the monitoring did not. Respirations were impaired by the new exploration of anaesthetics, and the only change to monitoring was observing chest movement. Deaths inevitably followed.

In 1939, the oxyhemoglobinograph was developed by McClure and Hartman after the publication of their paper on anoxia during surgery (McClure et al, 1939), although this
product was never made commercially available. The next iteration was a heavy device with an ear probe with the intention of monitoring aircraft pilots after World War II—the Millikan Oximeter. However, this was still too heavy and bulky to be a useful commercial product.

In 1947, there was an attempt at the measuring SpO2 using the Millikan ear oximeter to consider the usefulness of cyanosis as a clinical indicator of hypoxia (Comroe and Bothelho, 1947). In 50% of patients, cyanosis did not occur until SaO2 was below 80%; in 25% of patients, it occurred below 75% SaO2. With this knowledge in hand, the recommendation of cyanosis as lone clinical indicator during anaesthesia would result in a high mortality rate. This brought on the pursuit of a commercially viable pulse oximeter.

The pulse oximeter

The principle behind the current approach towards pulse oximetry is that oxygenated blood absorbs light at a certain wavelength (a shade of red), and deoxygenated blood, another (infrared) (Nitzan, 2014). By shining these two light wavelengths through a peripheral area on a body and comparing the ratio of absorbencies against a calibration curve, the SpO2 can be obtained. This is in turn used as an approximation for the patient's SaO2.

A probe is used comprised of two parts sitting either side of the periphery: a light emitter, and a light receiver. The difference in colour between oxygenated and deoxygenated blood was commented on as early as 1864 (Stokes, 1864) as shown on the newly invented absorbance spectrometer by Kirchoff and Buncen (1860).

This estimation of SaO2 by gaining the SpO2 value from pulse oximetry is highly accurate, with a mean difference of less than 2% variation from SaO2 samples over 90%. Below 90% SaO2, this accuracy decreases (Jubran, 2015).

Despite these high-accuracy single- point estimates, changes in SaO2 are not reliably predicted. If rapid changes towards hypoxaemia are expected, the probe attached to the earlobe may show these changes earlier than if used on a finger (Lindholm et al, 2007). This slow change is observable with a steady decline in SpO2 on apnoea, compared with a sudden decline of EtCO2.

Owing to the pulse and changes in blood flow, absorption varies throughout the pulse cycle. The changes in amplitude of the absorption not only allow for the pulse to be measured, but also for the distinction between venous and arterial blood, giving us the SpO2 of arterial blood (Chan et al, 2013).

Application

As with all patient assessment, excellent hand and equipment hygiene (Bradley and Fraise, 2009) and an informed patient consent are of the upmost importance, with an explanation of the procedure and reasoning behind it.

- Select a site that is well perfused with a proximal palpable pulse; warm; with a brisk capillary refill; immobile; comfortable; and easily accessible (Welch et al, 2017)
- This is commonly either the fingers or earlobes, but other sites such as the tongue, cheeks, toes, or nose may be used in a patient with low peripheral perfusion (Barnett et al, 2012)
- Select an appropriately sized pulse oximeter probe so that it comfortably fits the patient (*Figure 1*). If it is too loose, the probe is likely to fall off; too tight, and venous pulsations may occur. This is an especially important consideration when using the adhesive probes—this type of probe may be more stable if not too tight

Figure 1. *An appropriately sized pulse oximeter probe must be selected for comfort and access*

- In paediatric patients weighing less than 3 kg, the ball of the foot can be considered; above this weight, the nail bed of the big toe is recommended (*Figure 2*). The same methods for pulse oximetry in adults can be adopted for older paediatric patients (Trigg and Mohammed, 2014). When using the toe, orientate the cable medially, and replace the sock to stabilise and ensure a strong signal

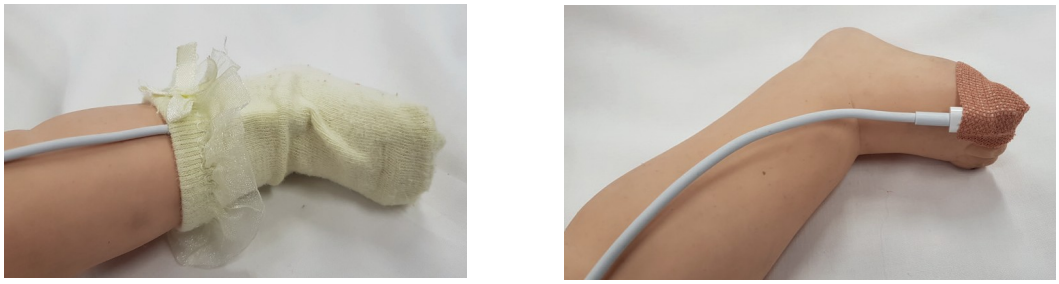

Figure 2*. The nail bed of the big toe is recommended for paediatric patients weighing more than 3kg*

- Remember that the probe measures the absorbency of pulsatile blood, so although a loose probe may have an artificially low SpO2, venous pulsations from a tight probe or tape may also cause an artificially low SpO2 by incorrectly measuring the venous blood (Chan et al, 2013)
- Consider environmental factors to reduce interference and improve signal strength. Electromagnetic radiation such as that produced by mobile phones can cause artefacts (Ortega et al, 2011)
- Patient or probe movements including muscular spasms, shivering, seizures or an inconsolable infant can also cause interference (Clarke et al, 2014).

Limitations

Despite the usefulness of this tool, there are limitations as a result of physiology, pathology or physical

changes. Changes to the colour of the haemoglobin, such as in the case of methemoglobin, which is blue/ brown, can affect absorbency ratios. This form normally represents 2% of haemoglobin. In higher ratios, this has been shown to artificially maintain an SpO2 of 85% in dogs, regardless of the correct SaO2 (Barker et al, 1989). This can be genetically inherited, or caused by oxidising drugs such as nitrates.

In carbon monoxide poisoning, the irreversible carboxyheamaglobin complex is formed, which is the same colour as oxyheamaglobin. This will then not accurately reflect the SpO2 as the absorbency ratio may be artificially altered (Fouzas et al, 2011).

Absorbance of the red light does not account for how freely the oxygen molecules can leave the haemoglobin link they have formed, and move to where they are required for aerobic respiration. Oxygen is more readily released when there is a drop in pH and an increase in carbon dioxide in the surrounding tissue, such as in muscles being used for physical activity having a higher cellular respiration rate.

If there were any concerns about a patient with a shifted dissociation curve, use of the probe on the ear lobe goes some way to counteract this over a finger placement, giving a truer reflection of central PO2 (amount of oxygen dissolved in the blood away from haemoglobin that is available for cellular respiration) (Lindholm et al, 2007).

In patients with sickle cell crisis, evidence of hypoxaemia can be useful in determining the severity of the patient condition. SaO2 can be underestimated with the SpO2 reading gained by a pulse oximeter, showing accuracy only with an SpO2 over 94% (Holbrook and Quinn, 2008; Zheng et al, 2016).

Nail polish or poor hygiene can affect how much light gets through. The light needs to be absorbed through the finger for the absorbance ratio to be produced. Nail varnish might seem like an obvious hindrance, but this has been challenged and there are arguments to both support and disregard the effect of the patient wearing nail varnish being clinically significant (Rodden et al, 2007). The finger (*Figure 3*) or whichever site chosen, may need to be cleaned prior to attempting the reading using the pulse oximeter.

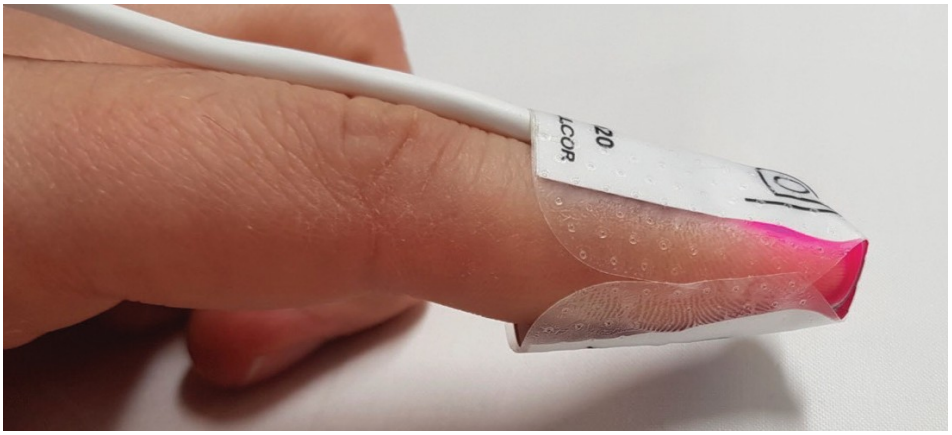

Figure 3. *A taped finger probe is another example of a pulse oximeter*

When the SpO2 reading reduces to below 80%, the comparability to SaO2 starts to suffer. Feiner et al (2007) discovered up to a 3.6% mean bias for some brands of SpO2 pulse oximeters, with a maximum discrepancy of 10% away from the actual SaO2. The paper describes how pigmented skin can cause an over-estimate of SaO2 in individuals with an SaO2 of below 80%. Feiner et al (2007) also describes discrepancies based on gender.

Treat your patient

With all these limitations, the use of an SpO2 pulse oximeter for the estimation of SaO2 for a diagnosis of hypoxaemia should be used with caution. It can be seen that excessive hypoxia, or over- oxygenation in patients, can cause significant harm, both in the short and long term (Martin and Grocott, 2013). Reading the physical characteristics of the patient are more important than what can be read on the monitor— returning to the old dictum of ‘treat the patient, not the machine.’ JPP

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