

PRACTICAL APPLICATIONS OF PULSE OXIMETRY

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INTRODUCTION

Pulse oximetry is a useful method of monitoring patients in many circumstances, and in the face of limited resources, the pulse oximeter may represent a wise choice of monitor, as with training it allows for the assessment of several different patient parameters.

Pulse oximeters are now a standard part of perioperative monitoring which give the operator a non-invasive indication of the patient's cardio-respiratory status. Having been successfully used in intensive care, the recovery room and during anaesthesia, they have been introduced in other areas of medicine such as general wards apparently without staff undergoing adequate training in their use⁽¹⁾. The technique of pulse oximetry does have pitfalls and limitations and it is possible that patient safety may be compromised with untrained staff. This article is therefore intended for the 'occasional' user of pulse oximetry.

Pulse oximeters measure the arterial oxygen saturation of haemoglobin. The technology involved⁽²⁾ is complicated but there are two basic physical principles. First, the absorption of light at two different wavelengths by haemoglobin differs depending on the degree of oxygenation of haemoglobin. Second, the light signal following transmission through the tissues has a pulsatile component, resulting from the changing volume of arterial blood with each pulse beat. This can be distinguished by the microprocessor from the non-pulsatile component resulting from venous, capillary and tissue light absorption.

The function of a pulse oximeter is affected by many variables, including: ambient light; shivering; abnormal haemoglobins; pulse rate and rhythm; vasoconstriction and cardiac function. A pulse oximeter gives no indication of a patient's ventilation, only of their oxygenation, and thus can give a false sense of security if supplemental oxygen is being given. In addition, there may be a delay between the occurrence of a potentially hypoxic event such as respiratory obstruction and a pulse oximeter detecting low oxygen saturation. However, oximetry is a useful non-invasive monitor of a patient's cardio-respiratory system, which has undoubtedly improved patient safety in many circumstances.

What does a pulse oximeter measure?

1. The oxygen saturation of haemoglobin in arterial blood - which is a measure of the average amount of oxygen bound to each haemoglobin molecule. The percentage saturation is given as a digital readout together with an audible signal varying in pitch depending on the oxygen saturation.
2. The pulse rate - in beats per minute, averaged over 5 to 20 seconds.

A pulse oximeter gives no information on any of these other variables:

- The oxygen content of the blood
- The amount of oxygen dissolved in the blood
- The respiratory rate or tidal volume i.e. ventilation
- The cardiac output or blood pressure

Systolic blood pressure can be estimated by noting the pressure at which the plethysmograph trace reappears during deflation of a proximal non-invasive blood pressure cuff.

Principles of modern pulse oximetry

Oxygen is carried in the bloodstream mainly bound to haemoglobin. One molecule of haemoglobin can carry up to four molecules of oxygen, which is then 100% saturated with oxygen. The average percentage saturation of a population of haemoglobin molecules in a blood sample is the oxygen saturation of the blood. In addition, a very small quantity of oxygen is carried dissolved in the blood, which can become important if the haemoglobin levels are extremely low. The latter, however, is not measured by pulse oximetry.

The relationship between the arterial partial pressure of oxygen (PaO₂) and the oxygen saturation is described by the haemoglobin-oxygen dissociation curve (see figure 1). The sigmoid shape of this curve facilitates unloading of oxygen in the peripheral tissues where the PaO₂ is low and oxygen is required for respiration. The curve may be shifted to the left or right by various patient characteristics e.g. recent blood transfusion, pyrexia.

A pulse oximeter consists of a peripheral probe, together with a microprocessor unit, displaying a waveform, the oxygen saturation and the pulse rate. Most oximeters also have an audible pulse tone, the pitch of which is proportional to the oxygen saturation - useful when one cannot see the oximeter display. The probe is placed on a peripheral part of the body such as a digit, ear lobe or the nose. Within the probe are two light emitting diodes (LED's), one in the visible red spectrum (660nm) and the other in the infrared spectrum (940nm). The beams of light pass through the tissues to a photodetector. During passage through the tissues, some light is absorbed by blood and soft tissues depending on the concentration of haemoglobin. The amount of light absorption at each light frequency depends on the degree of oxygenation of haemoglobin within the tissues.

The microprocessor can select out the absorbance of the pulsatile fraction of blood, i.e. that due to arterial blood, from constant absorbance due to non-pulsatile venous or capillary blood and other tissue pigments. Several recent advances in microprocessor technology have reduced the effects of interference on pulse oximeter function. Time division multiplexing, whereby the LED's are cycled: red on, then infrared on, then both off, many times per second,

helps to eliminate background 'noise'. Quadrature division multiplexing is a further advance in which the red and infrared signals are separated in phase rather than time and then recombined in phase later. In this way, an artefact due to motion or electromagnetic interference may be eliminated since it will not be in the same phase of the two LED signals once they are recombined.

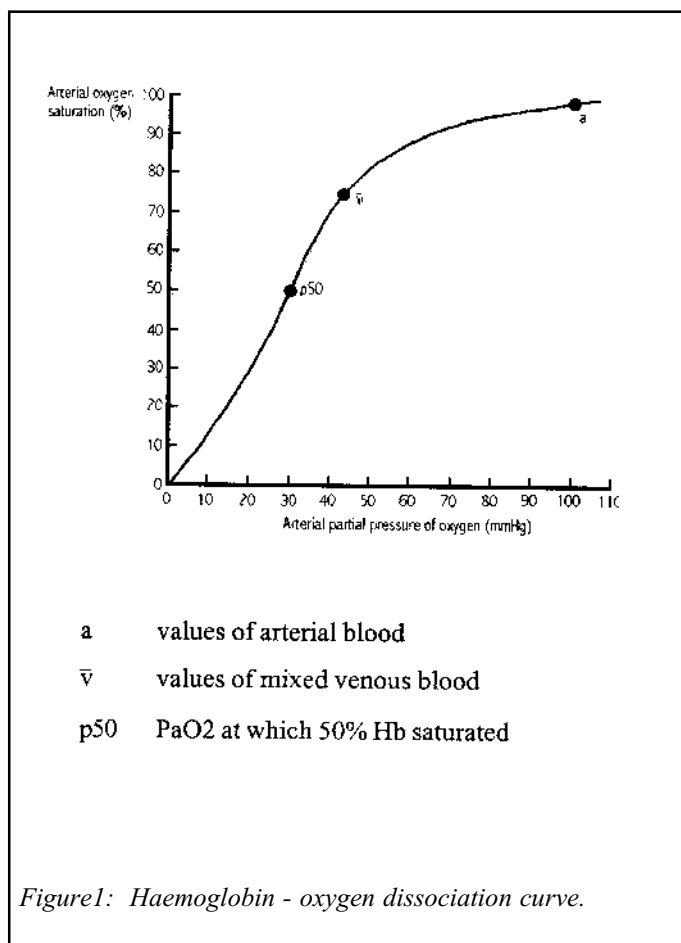
Saturation values are averaged out over 5 to 20 seconds. The pulse rate is also calculated from the number of LED cycles between successive pulsatile signals and averaged out over a similar variable period of time, depending on the particular monitor.

From the proportions of light absorbed at each light frequency, the microprocessor calculates the ratio of the two. Within the oximeter memory is a series of oxygen saturation values obtained from experiments performed in which human volunteers were given increasingly hypoxic mixtures of gases to breath. The microprocessor compares the ratio of absorption at the two light wavelengths measured with these stored values, and then displays the oxygen saturation digitally as a percentage and audibly as a tone of varying pitch. As it is unethical to desaturate human volunteers below 70%, it is vital to appreciate that oxygen saturation values below 70% obtained by pulse oximetry are unreliable.

Reflection pulse oximetry uses reflected rather than transmitted light on a single-sided monitor. It can therefore be used more proximally anatomically e.g. forehead, bowel, although it may be difficult to secure. Other than using specific reflection spectra, the principles are the same as for transmission oximetry.

Practical tips to the successful use of pulse oximetry:

- Plug the pulse oximeter in to an electrical socket, if available, to recharge the batteries.
- Turn the pulse oximeter on and wait for it to go through its calibration and check tests.
- Select the probe you require with particular attention to correct sizing and where it is going to go. The digit should be clean (remove nail varnish).
- Position the probe on the chosen digit, avoiding excess force.
- Allow several seconds for the pulse oximeter to detect the pulse and calculate the oxygen saturation.
- Look for a displayed waveform. Without this, any reading is meaningless.



- Read off the displayed oxygen saturation and pulse rate.

* *Be cautious interpreting figures where there has been an instantaneous change in saturation - for example 99% falling suddenly to 85%. This is physiologically not possible.*

- If in doubt, rely on your clinical judgement, rather than the value the machine gives.

Alarms

- If the Low Oxygen Saturation alarm sounds, check that the patient is conscious if that is appropriate. Check the airway and make sure the patient is breathing adequately. Lift the chin or apply other airway manoeuvres as appropriate. Give oxygen if necessary. Call for help.
- If the Pulse Not Detected alarm sounds, look for the displayed waveform on the pulse oximeter. Feel for a central pulse. If there is no pulse, call for help, start the procedures for Basic and Advanced Life Support. If there is a pulse, try repositioning the probe, or put the probe on a different digit.
- On most pulse oximeters, the alarm limits for oxygen saturation and pulse rate can be altered according to your needs. However, do not alter an alarm just to stop it sounding - it could be telling you something important!

Uses of pulse oximetry

- Simple, portable “all-in-one” monitor of oxygenation, pulse rate and rhythm regularity, suitable for “field” use.
- As a safe, non-invasive monitor of the cardio-respiratory status of high-dependency patients - in the emergency department, during general and regional anaesthesia, postoperatively and in intensive care. This includes procedures such as endoscopy, where often frail patients are given sedative drugs such as midazolam. Pulse oximeters detect the presence of cyanosis more reliably than even the best doctors when using their clinical judgement.
- During the transport of patients - especially when this is noisy - for example in aircraft, helicopters or ambulances. The audible tone and alarms may not be heard, but if a waveform can be seen together with an acceptable oxygen saturation, this gives a global indication of a patient’s cardio-respiratory status.

- To assess the viability of limbs after plastic and orthopaedic surgery and, for example, following vascular grafting, or where there is soft tissue swelling or aortic dissection. As a pulse oximeter requires a pulsatile signal under the sensor, it can detect whether a limb is getting a blood supply.

- As a means of reducing the frequency of blood gas analysis in intensive care patients- especially in paediatric practice where vascular (arterial) access may be more difficult.

- To limit oxygen toxicity in premature neonates supplemental oxygen can be tapered to maintain an oxygen saturation of 90% - thus avoiding the damage to the lungs and retinas of neonates. Although pulse oximeters are calibrated for adult haemoglobin, HbA, the absorption spectra of HbA and HbF are almost identical over the range used in pulse oximetry, so the technique remains reliable in neonates.

- During thoracic anaesthesia - when one lung is being collapsed down - to determine whether oxygenation via the remaining lung is adequate or whether increased concentrations of oxygen must be given.

- Fetal oximetry- a developing technique that uses reflectance oximetry, using LEDs of 735nm and 900nm. The probe is placed over the temple or cheek of the fetus, and needs to be sterile and sterilisable. They are difficult to secure and the readings are variable, for physiological and technical reasons. Hence the trend is more useful than the absolute value.

Limitations of pulse oximetry

- **Not a monitor of ventilation** A recent case report^(3,4) highlighted the false sense of security provided by pulse oximetry. An elderly woman postoperatively in the recovery room was receiving oxygen by face mask. She became increasingly drowsy, despite having an oxygen saturation of 96%. The reason was that her respiratory rate and minute volume were low due to residual neuromuscular block and sedation, yet she was receiving high concentrations of inspired oxygen, so her oxygen saturation was maintained. She ended up with an arterial carbon dioxide concentration of 280 mmHg (normal 40 mmHg) and was ventilated for 24 hours on intensive care. Thus oximetry gives a good estimation of adequate

oxygenation, but no direct information about ventilation, particularly as in this case, when supplemental oxygen is being administered.

- **Critically ill patients** It may be less effective in very sick patients, because tissue perfusion may be poor and thus the oximeter probe may not detect a pulsatile signal.
- **Waveform presence** If there is no waveform visible on a pulse oximeter, any percentage saturation values obtained are meaningless.
- **Inaccuracies** Bright overhead lighting, shivering and motion artefact may give pulsatile waveforms and saturation values when there is no pulse.
 - (i) Abnormal haemoglobins such as methaemoglobinaemia, for example following overdose of prilocaine, cause readings to tend towards 85%.
 - (ii) Carboxyhaemoglobin, caused by carbon monoxide poisoning, causes saturation values to tend towards 100%. A pulse oximeter is extremely misleading in cases of carbon monoxide poisoning for this reason and should not be used. CO-oximetry is the only available method of estimating the severity of carbon monoxide poisoning.
 - (iii) Dyes and pigments, including nail varnish, may give artificially low values.
 - (iv) Vasoconstriction and hypothermia cause reduced tissue perfusion and failure to register a signal.
 - (v) Rare cardiac valvular defects such as tricuspid regurgitation cause venous pulsation and therefore venous oxygen saturation is recorded by the oximeter.
 - (vi) Oxygen saturation values less than 70% are inaccurate as there are no control values to compare them to.
 - (vii) Cardiac arrhythmias may interfere with the oximeter picking up the pulsatile signal properly and with calculation of the pulse rate.

NB. Age, sex, anaemia, jaundice and dark-skin have little or no effects on oximeter function.

- **Lag monitor** This means that the partial pressure of oxygen can have fallen a great deal before the oxygen saturation starts to fall. If a healthy adult patient is given 100% oxygen to breathe for a few

minutes and then ventilation ceases for any reason, several minutes may elapse before the oxygen saturation starts to fall. A pulse oximeter in these circumstances warns of a potentially fatal complication several minutes after it has happened. The pulse oximeter has been described as “a sentry standing at the edge of the cliff of desaturation.” because of this fact. The explanation of this lies in the sigmoid shape of the haemoglobin / oxygen dissociation curve (figure 1).

- **Response delay** due to signal averaging. This means that there is a delay after the actual oxygen saturation starts to drop because the signal is averaged out over 5 to 20 seconds.
- **Patient safety** there have been one or two case reports of skin burns or pressure damage under the probe because some early probes had a heater unit to ensure adequate skin perfusion. The probe should be correctly sized, and should not exert excessive pressure. Special probes are now available for paediatric use.

The penumbra effect re-emphasises the importance of correct probe positioning. This effect causes falsely low readings and occurs when the probe is not symmetrically placed, such that the pathlength between the two LEDs and the photodetector is unequal, causing one wavelength to be “overloaded”. Repositioning of the probe often leads to sudden improvement in saturation readings. The penumbra effect may be compounded by the presence of variable blood flow through cutaneous pulsatile venules. Note that the waveform may appear normal despite the penumbra effect as it measures predominantly one wavelength only.

Alternatives to pulse oximetry?

- Bench CO-oximetry is the gold standard - and is the classic method by which a pulse oximeter is calibrated. The CO-oximeter calculates the actual concentrations of haemoglobin, deoxyhaemoglobin, carboxyhaemoglobin and methaemoglobin in the sample and hence calculates the actual oxygen saturation. CO-oximeters are much more accurate than pulse oximeters - to within 1%, but they give a ‘snapshot’ of oxygen saturation, are bulky, expensive and require constant maintenance as well as requiring a sample of arterial blood to be taken.

- Blood gas analysis - requires an invasive sample of arterial blood. It gives the 'full picture', including arterial partial pressure of oxygen and carbon dioxide, arterial pH, actual and standardised base excess and actual and standardised bicarbonate concentrations. Many blood gas analysers report a calculated saturation which is less accurate than that provided by the pulse oximeter.
- Lag monitor - time delay between potentially hypoxic event such as respiratory obstruction and a pulse oximeter detecting low oxygen saturation.
- Inaccuracies: ambient light; shivering and vasoconstriction; abnormal haemoglobins; and alterations in pulse rate and rhythm.
- Advances in microprocessor have led to improved signal processing.

SUMMARY POINTS

- Pulse oximeters give non-invasive estimation of the arterial haemoglobin oxygen saturation.
- Useful in: anaesthesia, recovery, intensive care (including neonatal), patient transport.
- 2 principles involved:
 - (1) Differential light absorption by haemoglobin and oxyhaemoglobin.
 - (2) Identification of pulsatile component of signal.
- No direct indication of a patient's ventilation, only of their oxygenation.

Further Reading

1. Stoneham MD, Saville GM, Wilson IH. Knowledge about pulse oximetry among medical and nursing staff. *Lancet* 1994;334:1339-1342.
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 4. Hutton P, Clutton-Brock T. The benefits and pitfalls of pulse oximetry. *BMJ* 1993;307:457-458.
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