Correspondence
Lung Investigation Unit
1st Floor Nuffield House
Queen Elizabeth Site
University Hospital Birmingham
West Midlands
United Kingdom
B15 2TH

Email: brendan.cooper@uhb.nhs.uk

MONITORING OXYGEN SATURATION IN THE COMMUNITY

J. Stockley and B. G. Cooper

INTRODUCTION

Pulse oximetry is a well-established, simple, noninvasive method of assessing the arterial oxygen saturation of haemoglobin, both as a single spot-check measurement and as continual monitoring for longer periods.

Initially, pulse oximeters were primarily used in secondary care for peri-operative and post-operative assessment and on intensive care wards [1]. Over time, less expensive models were developed and subsequently introduced for use on general wards. With the more recent development of smaller, portable oximeters, their use has now become more widespread and they have been used in GP practices and the community for monitoring patients with suspected or known hypoxia.

Although the training required to operate a pulse oximeter is minimal, the method is not without limitations and the accuracy is not absolute. In addition, there are a number of factors that can further affect the accuracy of the measurement. However, pulse oximetry has inarguably improved patient care and safety within both the clinical environment and the patient's home.

PRINCIPLES OF OPERATION

Oxygen is transported through the bloodstream almost exclusively by haemoglobin located within red blood corpuscles (erythrocytes). Each haemoglobin molecule can bind to up to four molecules of oxygen and, in this instance, it is said to be 100% saturated with oxygen. The average percentage saturation of the haemoglobin molecules in a particular sample of blood is referred to as its oxygen saturation (SO_2), which is one of the parameters a pulse oximeter measures (SpO_2). In addition, pulse oximeters measure heart rate and the strength of the pulse signal. It is not recommended that a pulse oximeter alone be used to assess heart rate, as tachycardia, bradycardia or a poor signal can lead to inaccurate readings. Initially, the heart rate should always be assessed manually and compared with the oximeter, where a reading within 5 beats·min^{-1} is assumed to be accurate.

A pulse oximeter works on the principle of spectrophotometry. A typical unit comprises two main components: a peripheral probe and a microprocessor unit. The probe is connected to the patient in an area of well-vascularised tissue, most commonly the fingertip. Housed within the top of the probe are two light-emitting diodes (LEDs) of different wavelengths (red and infrared) and an optical sensor (photodiode) directly beneath them. Oxygenated haemoglobin (HbO_2) more readily absorbs infrared light than deoxygenated haemoglobin (Hb), which more readily absorbs red light. By comparing the ratio between the absorbed red and infrared light, the overall oxygen saturation can be determined. Other non-oxygen carrying haemoglobins, such as carboxyhaemoglobin (COHb) and methaemoglobin (MetHb), may also be present in tissue.

There are two forms of oxygen saturation: "functional" saturation, where HbO_2 is expressed as a ratio of all oxygen carrying haemoglobin (equation 1); and "fractional" saturation, where HbO_2 is expressed as a ratio of all present haemoglobins (whether they are capable of carrying oxygen or not) (equation 2).

Equation 1: functional saturation

$$SpO_2 = \frac{HbO_2}{HbO_2 + \text{Hb total}}$$

Equation 2: fractional saturation

$$SpO_2 = \frac{HbO_2}{(HbO_2 + Hb + COHb + MetHb)}$$

The general structure of a standard pulse oximeter finger probe is illustrated in figure 1.

The microprocessor can distinguish between the pulsatile component of the light signal (due to the changing volume of the arterial blood with each heart beat) and the nonpulsatile component of the venous/capillary blood, as well as light absorption by the surrounding tissue. This results in a more accurate estimation of the oxygen saturation of the arterial blood.

The most commonly used finger probe types include the clip-on type and the wrap-around type. Regardless of the probe, it is important that it is fitted correctly with the finger inserted properly and the LEDs directly above the photodiode. Incorrect positioning will most likely lead to poor signal and erroneous measurements. It is also important that the finger is clean and free of nail varnish as this could impair light transition. It has also been suggested that significant movement and even high levels of ambient light can also affect pulse oximeter measurements, though modern probes are designed to minimise interference from ambient light. Another more common source of error includes poor perfusion due to pathology (such as Wegener's Syndrome), cold hands (Raynaud's phenomenom) or abnormal methaemoglobins (after anaesthesia or high plasma nitrate levels) [6, 7]. In cases where the hands are cold, the finger can be warmed by rubbing the hands or by using a topical vasodilator cream.

For spot-checks, the probe should be left in place for a few minutes before the SpO_2 is recorded. There is no agreement on whether skin pigmentation can effect readings but the consensus appears to be that it makes little difference [8, 9]. A summary of common errors associated with oximetry measurements, together with suggested troubleshooting methods, is shown in table 1.

Even in cases where the pulse signal is strong, an allowance for a ±2% error margin for the SpO_2 reading should be considered. At low saturations (<70%), the readings are likely to be inaccurate as there are no control values to compare these readings to. Furthermore, users should be aware that pulse oximetry does not yield information on the oxygen content of the blood, ventilation (breathing rate or carbon dioxide levels), cardiac output or blood pressure.

There are a number of different types of pulse oximeter available, produced by a large number of manufacturers (*e.g.* Konica Minolta (Tokyo, Japan) Nonin (Plymouth, ▶

Table 1. Common sources of error in pulse oximetry and their solutions.

Source of error	**Solution**
Incorrect positioning of probe	Position the finger to the end of the probe with the red/infrared LEDs on the top (nail side) of the finger.
Nail varnish present	Remove nail varnish completely to ensure sufficient light transmission
Poor perfusion	Warm extremity *e.g.* with warm water, rubbing or vasodilator cream
Readings recorded too soon	Leave oximeter probe in place for a few minutes before measurements recorded
Motion artefact	If using a finger probe, the hand should be relaxed at chest level, not held high

LED: light-emitting diode.

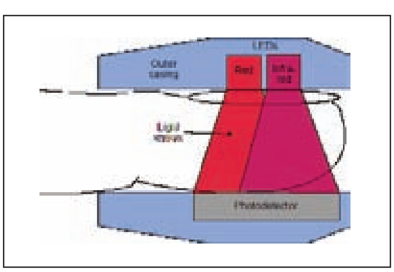

Figure 1. The cross-sectional structure of a pulse oximeter probe (fitted around a finger), including the red and infra red light-emitting diodes (LEDs) and the photodiode.

Figure 2. Two types of oximeters from reputable manufacturers. a) The Minolta PulseOx-2 is used for spot-checks, whereas b) the Nonin 3100 WristOx can be used for serial monitoring.

MN, USA)) and the price range varies considerably. In general, there are two types; those with a memory used for continual measurements that can be downloaded and analysed (for example when performing overnight sleep studies) or those without memory that are used more for spot-checks and tend to be cheaper. It is worth considering exactly what type of pulse oximeter is required and then obtaining information on a number of devices from an independent review site (*e.g.* www.medisave.co.uk) before deciding which oximeter to purchase. Furthermore, as with a lot of medical equipment, the very cheap pulse oximeters are likely to be of poor quality, less robust and possibly inaccurate. Examples of commonly used pulse oximeters are shown in fig. 2.

Once purchased and in regular use, the oximeter must be validated (usually annually) to ensure it is reading correctly. In secondary care, this is usually done by a Medical Engineering Department but the absence of such a facility in primary care suggests that a lot of oximeters within the community may not be validated. As medical equipment, the validation of oximeters is essential and it is worth enquiring at the Medical Engineering Department in a local hospital, who may be willing to do this. This attention to quality has been emphasised elsewhere [10, 11].

NORMAL AND ABNORMAL SpO_2 VALUES

The normal range for SpO_2 in a healthy adult is most commonly stated as 95–99%. It is worth reiterating that a ±2% error margin should be applied to the measurement recorded so, in cases where the SpO_2 is recorded as 95% for example, the true oxygen saturation of the arterial blood could potentially be as low as 93% or as high as 97%. Therefore, SpO_2 is more of an estimation of arterial oxygenation and should always be used in conjunction with further clinical assessment. Whilst SpO_2 can estimate and monitor blood oxygen, it should not be considered a substitute for blood gas analysis.

In general, an SpO_2 value <95% suggests a degree of respiratory compromise may be present. A guide in the form of stratified ranges of normal and hypoxic SpO_2 values, together with recommended management is shown in table 2.

Patients can become hypoxic (both acutely and chronically) for a variety of different reasons. Respiratory failure can result from disease pathology or organ damage *via* other means (such as barbiturate abuse). Common respiratory disorders that can lead to respiratory failure, include chronic obstructive pulmonary disease (COPD), interstitial pulmonary fibrosis (IPF) and chest wall deformities (such as kyphoscoliosis) are common examples. Other disorders, such as muscular dystrophy, myasthenia gravis and even obesity, can lead to hypoventilation and, ultimately, have similar compromising effects on the respiratory system. Respiratory failure can lead to hypoxia (type I respiratory failure) and, with more severe disease, concurrent hypercapnia (type II respiratory failure).

Patients with respiratory failure (and/or cardiac disease) may require supplemental oxygen, as this can improve their health status, quality of life and prognosis. Supplemental oxygen can be given in different ways, depending on the requirements of the individual. For example, a patient may require oxygen only during periods of physical activity (ambulatory oxygen) or they may also require it at rest often for 15–16 $h \cdot day^{-1}$ (*i.e.* long-term oxygen therapy (LTOT)). Other patients may require oxygen only when they sleep, sometimes in conjunction with assisted ventilation in the form of continuous positive airway pressure (CPAP), noninvasive ventilation (NIV) or bilevel positive airway pressure (BiPAP).

Formal assessments are essential in determining what dose of oxygen is required (and how it should be delivered) to increase the patient's oxygenation sufficiently while, at the same time, ensuring the level of arterial carbon dioxide does not ▶

Table 2. A table showing normal and abnormal levels of oxygen saturation with grades of hypoxia and suggestive management.

SpO_2	Level of Oxygenation	Management
95–99%	Normal	None
90–95%	Mild Hypoxia	Measure regularly, especially at night. Review trends. May require LTOT
80–90%	Moderate Hypoxia	Will almost certainly require LTOT. Monitor regularly. *N.B.* Blood gas required
<80%	Severe Hypoxia	Oxygen required and ventilatory support should also be considered. Monitor closely. *N.B.* Blood gas required

Sp,O2: oxygen saturation measured by pulse oximetry; LTOT: long-term oxygen therapy.

Table 3. A summary of the uses of pulse oximetry both as spot-check measurements and serial measurements within secondary care and the community.

Spot-checks
Assessment of breathless patients
Screening for respiratory failure
Monitoring COPD patients
Quick assessment of LTOT and NIV patients
Spot-checks during some exercise tests (*e.g.* pulmonary rehabilitation exercise)
Serial measurements
Screening for sleep apnoea
Monitoring during field exercise testing (*e.g.* incremental/6-minute walk tests, ambulatory oxygen assessment)
Monitoring during flight assessments (hypoxic challenge)
Emergency monitoring for patients prior to and during ambulance transport to hospital
Assessing nocturnal oxygen requirements in patients with respiratory failure

COPD: chronic obstructive pulmonary disease; LTOT: long-term oxygen therapy; NIV: noninvasive ventilation.

increase significantly. These oxygen assessments are usually performed in secondary care by fully trained health care specialists, using blood gas analysis. Long-term monitoring of oximetry in primary care can be a useful adjunct to oxygen treatment.

USES OF OXIMETRY IN THE COMMUNITY

There is a growing realisation of the usefulness of pulse oximetry in primary care but little evidence for this other than common sense [12–13]. For patients established on oxygen therapy, it is important to continually monitor their progress, as their oxygen requirements may change over time with improvement or deterioration of health. In addition, it is also important for patients with mild hypoxia to be monitored as they may require oxygen in the future.

Check ups can take the form of a clinic appointment in primary or secondary care, a telephone conversation or a home visit. The latter may be more appropriate for patients who are generally housebound due to severe dyspnoea or other reasons (such as disability). In primary care or during a home visit, detailed analysis of respiratory blood gases (*via* earlobe capillary sampling) may not be possible. In these instances, the use of pulse oximetry to monitor a patient's oxygenation is an integral and important part of their healthcare.

$S\text{p}O_2$ values can be measured easily at the patient's home by pulse oximetry. It can be performed while the patient breathes either room air or their prescribed level of oxygen. It is important to note that the patient must have been breathing either air or oxygen for at least 20 min before the $S\text{p}O_2$ measurement is made, to allow adequate time for the oxyhaemoglobin saturation to stabilise. By measuring $S\text{p}O_2$ in both situations, it is possible to first monitor the patient's oxygenation without therapy (to determine if they have likely worsened or improved) and secondly to check whether the prescribed level of oxygen is still appropriate (as a general guideline, above >90% $S\text{p}O_2$ is adequate).

In cases where an unexpected or significant change in $S\text{p}O_2$ occurs, a more detailed investigation (often by referral to secondary care) may be appropriate but, in general, oximetric assessment within the community is a sufficient starting point.

A summary of these points, together with other uses of pulse oximetry in the community and secondary care is shown in table 3.

There are a variety of conditions where oximetry should be considered as a screening or monitoring tool to inform primary care when to escalate intevention with a blood gas. These include asthma, COPD, IPF and cystic fibrosis. There is a growing trend toward using oximetry in primary

Table 4. Measuring pulse oximetry correctly

Ensure good peripheral circulation
Ensure correct fitting of pulse oximeter probe
Always record the inspired oxygen conditions (eg. room air, LTOT dose, % oxygen)
Check the pulse quality (most common source of error)
Check for errors in measurement
Leave oximeter probe in place for 5 min before recording measurements
Do not rely on pulse oximetry for assessment of pulse rate

LTOT: long-term oxygen therapy.

care to help screen for obstructive sleep apnoea but such services are only beneficial if they link closely with an expert sleep apnoea service in secondary care. There are issues for and against the use of oximetry for sleep apnoea studies in primary care [14, 15].

Oximetry is not helpful in diagnosing pulmonary embolism (unless massive embolisation has occurred), anaemia (very insensitive unless <10% fall) [16] but there is suggestion that it may help in the pathway for managing pandemic influenza [17].

It is not recommended that patients purchase their own oximeter to monitor themselves because the devices sold to them may be cheap and of poor quality. Moreover, the patients may misinterpretate an erroneous measurement which could potentially result in an inappropriate call to the emergency services or unnecessary anxiety about their condition.

Whether it is a GP, practice nurse, district nurse, respiratory nurse specialist or case manager that is assessing a patient's SpO_2, a firm underlying knowledge of the limitations of pulse oximetry, through formal training of pulse oximetry measurement and the interpretation of results, is essential. In-house training from experienced healthcare scientists may not be available to healthcare professionals in primary care so it is important for them to seek formal training through other means, such as a lung function department in a local hospital, who may be happy to provide it.

Some may contest the need for such training but helping healthcare staff understand the limitations of even as simple a test as pulse oximetry will protect patients in the long term.

A summary of advice for measuring pulse oximetry correctly in the community is shown in table 4.

FUTURE DEVELOPMENTS

There will inevitably be increased use of pulse oximetry in primary care, as more guidelines recommend the use of pulse oximetry in this arena (British Thoracic Society (BTS) Asthma, BTS COPD, National Institute for Clinical Excellence COPD, PRODIGY, International Primary Care Respiratory Group, *etc.*). The technology is continually developing to improve the quality of the signals (*e.g.* signal processing technology to remove movement artefact) and developments including telemetry with oximetry are under development. The use of "multireflectance" will generate a new generation of more relaible devices. Provided the limitations of the technology are understood by users, these developments present few challenges and an improved quality of services for patients.

CONCLUSION

Oximetry is a relatively simple test, which has a widespread potential to improve respiratory care in the community. It does have some practical limitations; however, with some modest training and explanation, there is no reason why it cannot be used for patient care in the community. As an adjunct to blood gas analysis, it can target which patients need to be "stepped-up" to more complex investigations. ■

REFERENCES

1. Severinghaus JW, Honda Y. History of blood gas analysis VII "History of Pulse Oximetry" *J Clin Monit* 1987; 3: 135–139.
2. Chan MM, Chan MM, Chan ED. What is the effect of fingernail polish on pulse oximetry? *Chest* 2003; 123: 2163–2164.
3. Brand TM, Brand ME, Jay GD. Enamel nail polish does not interfere with pulse oximetry among normoxic volunteers *J Clin Monit Comput.* 2002; 17: 93–96.
4. Barker SJ, Shah NK. The effects of motion on the performance of pulse oximeters in volunteers. *Anesthesiology* 1997; 86: 774–781.
5. Fluck RR Jr, Schroeder C, Frani G, *et al.* Does ambient light affect the accuracy of pulse oximetry? *Respir Care* 2003; 48: 677–680.
6. Bayard M, Farrow J, Tudiver F. Acute methemoglobinemia after endoscopy. *J Am Board Famil Prac* 2004; 17: 227–229.
7. Gupta SK, Gupta RC, Seth AK, *et al*. Methemoglobinemia in areas with high nitrate concentration in drinking water. *Natl Med J India* 2000; 13: 58–65.
8. Adler JN, Hughes LA, Vivilecchia R, *et al*. Effect of skin pigmentation on pulse oximetry accuracy in the emergency department. *Acad Emerg Med* 1998; 5: 965-970.
9. Bickler PE, Feiner JR, Severinghaus JW. Effects of skin pigmentation on pulse oximeter accuracy at low saturation. *Anesthesiology* 2005; 102: 715–719.
10. Chatburn R, Kallstrom T, Volsko T. Evaluation of a commercial standard for checking pulse oximeter performance. *Respiratory Care* 1996; 41: 100–104.
11. Hannhart B, Michalski H, *et al.* Reliability of six pulse oximeters in chronic obstructive pulmonary disease. *Chest* 1991; 99: 842–846.
12. Ingram G, Munro N. The use (or otherwise) of pulse in general practice. *Br J Gen Prac* 2005; 55: 501–502.
13. Blonshine S, Brown R, *et al.* AARC clinical practice guidelines: pulse oximetry. *Respir Care* 1991; 36: 1406–1409.
14. Banham SW. Sleep study, home or office? Pro. *Chron Respir Dis* 2007; 4: 117–118.
15. Garpestad E, D'Ambrosio C, Hill NS. Sleep study, home or office? Con. *Chron Respir Dis* 2007; 4: 119–120.
16. Severinghaus JW, Koh SO. Effect of anemia on pulse oximeter accuracy at low saturation. *J Clin Monit.* 1990; 6: 85–88.
17. K. Challen, J. Bright, A. Bentley *et al.* A physiological–social score for triaging of pandemic influenza patients. *Eur Respir J* 2006: 28; 253–254.