

Pulse oximetry: technology to reduce child mortality in developing countries

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Abstract The causes of hypoxaemia in children include the commonest causes of childhood illness: pneumonia and other acute respiratory infections, and neonatal illness, particularly sepsis, low birthweight, birth asphyxia and aspiration syndromes. The systematic use of pulse oximetry to monitor and treat children in resource-poor developing countries, when coupled with a reliable oxygen supply, improves quality of care and reduces mortality. Oximetry also has a well established role in surgery and anaesthesia, but in many countries children undergo surgery without the safety of oximetry monitoring. This article reviews pulse oximetry, its technical basis and its application to the medical management of childhood illness to reduce mortality in developing countries. We propose that, as a part of the work towards achieving the Millennium Development Goal 4, there should be a concerted global effort to make pulse oximetry and a reliable oxygen source available in all health facilities where seriously ill children are managed.

Introduction

Acute lower respiratory infection (ALRI), principally pneumonia, is the leading cause of death in children under 5 years of age, causing at least 19% of the 9.7 million annual deaths in this age category.¹ In developing countries, hypoxaemia is the major fatal complication of pneumonia and other acute lower respiratory infections such as bronchiolitis, and also of other major causes of mortality in newborns and children.

In a systematic review of 21 published and unpublished studies representing over

16,000 children with acute lower respiratory infection, the median hypoxaemia prevalence among 13 studies which included children with WHO-defined severe and very severe pneumonia was 13.3% (9.3–37.5%).² Given that 11–20 million children are admitted to hospital each year with pneumonia,³ at least 1.5–2.7 million episodes of hospitalised pneumonia associated with hypoxaemia occur in young children globally each year. Countless more do not access health care.

In neonatal care where congenital pneumonia, respiratory distress syndrome, aspiration syndromes, perinatal asphyxia, apnoea and sepsis are common causes of morbidity and mortality, hypoxaemia is common.⁴ In four studies in developing countries, 18–23% of neonatal hospital presentations had hypoxaemia.^{5–8}

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There is now evidence that using pulse oximetry and having reliable oxygen sources in district and provincial hospitals in developing countries can reduce pneumonia death rates by 35% and reduce overall mortality.^{9,10} In affluent nations, pulse oximetry has had an established place in monitoring during surgery and anaesthesia for the last 2 decades but even this has not been widely adopted in developing countries.

There is a worldwide effort to achieve the Millennium Development Goals (MDG). It has been estimated that full coverage of currently available interventions and technologies can reduce the global burden of child mortality by two-thirds, which is the target of the fourth MDG.¹¹ Unfortunately, priorities in global health expenditure do not reflect this. For example, between 2000 and 2004, 97% of research grants allocated by United States National Institutes of Health and the Bill and Melinda Gates Foundation were for developing new technologies rather than implementing or improving current ones, despite evidence that the latter is likely to reduce three times as many child deaths.¹²

Given the frequency of hypoxaemia across the commonest childhood illnesses, pulse oximetry may be the most useful technology in improving the quality of clinical care in developing countries. This article reviews pulse oximetry, its technical basis and the applications of oximetry to the medical management of childhood illness which can reduce mortality in developing countries.

Predicting Oxygen Requirements in Children

Why not use clinical signs?

Despite its prime importance, hypoxaemia is not widely recognised by healthcare workers. Even the best combinations of clinical signs commonly misdiagnose hypoxaemia in some children with normal oxygen saturation or fail to detect some hypoxaemic

children when compared with pulse oximetry.¹³ Oximetry has been found to correctly identify 20–30% more children with hypoxaemia than using clinical signs alone.^{5,14,15} As not all children with signs sometimes associated with hypoxaemia (such as inability to drink) will have hypoxaemia, the use of oximetry can also reduce unnecessary oxygen use. In this way pulse oximetry can ensure the most efficient use of an expensive resource.

How Does a Pulse Oximeter Work?

Oximetry uses spectrophotometry—the measurement of the absorbance of red and infra-red light after it has passed through the body tissues—to determine the percentage of haemoglobin that is fully saturated with oxygen (SpO₂). The pulse oximeter consists of a computerised unit and a sensor probe attached to the patient's finger, toe or ear lobe. This sensor probe emits two different wavelengths of light: commonly 650–660 nm (red) and 910–940 nm (infra-red). Oxygenated haemoglobin absorbs more infra-red light and allows more red light to pass through.¹⁶ De-oxygenated (or 'reduced') haemoglobin absorbs more red light and allows more infra-red light to pass through. The ratio of absorbed red to infra-red light indicates the degree of oxygenation of the blood. The pulse oximeter measures 'functional' saturation, which is the ratio of oxyhaemoglobin to the sum of all the functional haemoglobins.¹⁶

The oximeter displays the SpO₂ together with an audible signal for each pulse beat, a pulse rate and, in most models, a graphical display of the blood flow as it passes the probe (the plethysmographic or pulse wave).

Modern pulse oximeters permit accurate measurements during periods of patient movement or low peripheral perfusion. Earlier models' inability to do so was long thought to be an insurmountable limitation of pulse oximetry technology. This technology, the principles of which have now

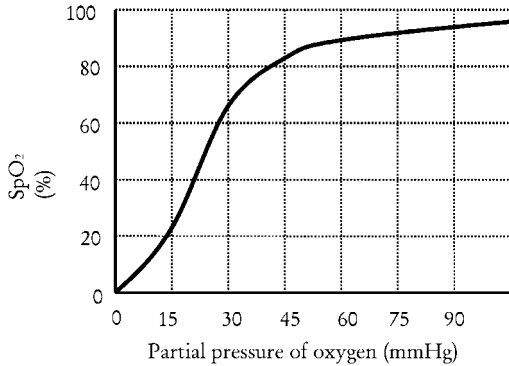


FIG. 1. Haemoglobin-oxygen dissociation curve.

been licensed to some other oximeter manufacturers, was developed in 1996 by a Californian company (Masimo Corporation).

What is Normal Oxygen Saturation?

The mean SpO₂ at sea level is 97–99%, with the lower limits (mean -2 SD) being 94%.^{17,18} Therefore the normal range is 94–100%. The SpO₂ bears a relationship to arterial blood oxygen tension (PaO₂), which

is partly predicated by the haemoglobin–oxygen dissociation curve (Fig. 1). Small changes in SpO₂ between 90 and 100% reflect large changes in PaO₂ because the haemoglobin–oxygen dissociation curve is relatively flat for PaO₂ >60 mmHg. Below an SpO₂ of 90%, the curve is steep. Therefore, small falls in PaO₂ will manifest as large falls in SpO₂. For this reason, many clinicians recommend oxygen supplementation for SpO₂ <90%.

Oxygen transport (the clinically relevant parameter) is a function of SpO₂, haemoglobin concentration and cardiac output. Therefore, children with anaemia or in shock can be hypoxic despite a normal SpO₂.

Baseline SpO₂ levels will also depend on an individual's adaptation to physiological or pathological stresses. Children residing at high altitudes adapt to lower baseline oxygen saturation owing to the lower partial pressure of oxygen at higher altitude. Therefore, the normal range of SpO₂ is progressively lower in populations living in mountainous regions (Fig. 2).¹⁷ Similarly, children with cyanotic congenital heart disease adapt to chronic hypoxia.

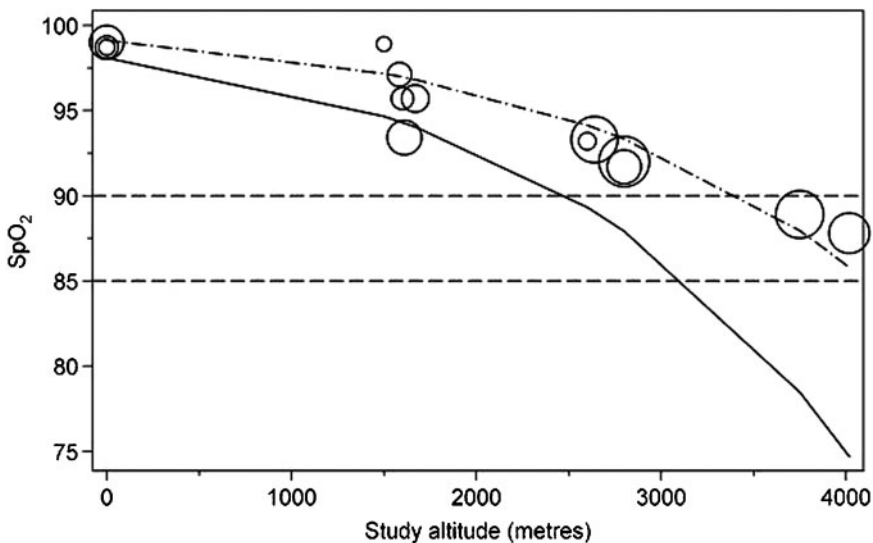


FIG. 2. Threshold of hypoxaemia at different altitudes.¹⁸ The continuous line predicts the level of SpO₂ below which oxygen should be given at different altitudes (--- mean SpO₂, — hypoxaemia threshold; circle size is proportional to the precision of transformed study SpO₂ estimate).

Using Pulse Oximetry

In developing countries, oximeters may be used in several ways to manage sick children. The major uses for daily clinical care are for screening and monitoring. These are described below. If used for multiple purposes in several patient groups, oximeters can offer a cost-effective way of allocating oxygen resources and improving patient monitoring.^{9,10}

Screening for hypoxaemia

Oximetry may be undertaken for selected children during triage (in outpatient or emergency departments) and all children admitted to the inpatient ward. There have been no trials of the efficacy of screening all outpatient children with oximetry but, with the exception of children with clinical signs of respiratory distress and neonates, the prevalence of hypoxaemia in the overall outpatient population is generally quite low. In addition, screening children who are clinically at low risk of hypoxaemia will result in some falsely low readings owing to movement artefact in active children, might

TABLE 1. *Emergency and priority signs (adapted from WHO Pocketbook of Hospital Care for Children).*¹⁹

Emergency signs

- Obstructed breathing
- Severe respiratory distress
- Central cyanosis
- Shock
- Coma
- Convulsions
- Severe dehydration in a child with diarrhoea

Priority signs

- Small infant or any sick child <2 months
- Restless, continuously irritable or lethargic
- Temperature >38.5°C
- Trauma or other urgent surgical condition
- Severe anaemia
- Poisoning
- Pain (severe)
- Respiratory distress
- Burns (major)
- Severe malnutrition
- Oedema of both feet



FIG. 3. A nurse checks an infant for hypoxaemia using a pulse oximeter at the time of hospital admission. Illustration by David Woodroffe from a photograph by Rami Subhi.

upset some children and wastes time in processing patients through a busy outpatient clinic.

One way to select children at the time of triage is to screen by oximetry all children with any emergency or priority signs (Table 1).¹⁹ This will identify children in whom hypoxaemia is most likely. Where only one oximeter is available in a district hospital, it is best to use it in the inpatient ward to screen all children on admission (Fig. 3). This means that the pulse oximeter will also be available to monitor inpatients.

Monitoring the progress of inpatients

Monitoring can be done in several ways. In most resource-limited hospitals, the most appropriate form of monitoring will be one-off ('spot') checks on children who are likely to need oxygen, are already on oxygen, have developed respiratory distress, or who show other clinical signs of deterioration. Oximetry should also be used to determine how long children require to be treated with oxygen. In children with severe pneumonia, the duration of hypoxaemia can range from several hours to several weeks, with a median in two studies of 5 days.^{10,20} For a

given pneumonia severity, the duration of hypoxaemia may be longer at higher altitudes than at sea level.²¹

Children who are receiving oxygen should be monitored clinically and with pulse oximetry at least twice a day. Also, children in a stable condition should be taken off supplemental oxygen once a day to determine if they still require it (see below).

Oximetry in neonatal care

Hyperoxia in premature neonates causes retinopathy of prematurity and increases the risk of bronchopulmonary dysplasia and brain injury.²² On the other hand, prolonged severe hypoxaemia, especially if combined with low cardiac output, can lead acutely to hypoxic brain injury, renal failure and pulmonary hypertension, and can predispose to necrotising enterocolitis²³ and long-term cognitive and intellectual impairment. Since the 1980s, use of pulse oximetry has become widespread for non-invasive monitoring of oxygenation in neonatal care, despite uncertainty about the levels of SpO₂ to target (see below). In developing countries, oximetry has a place in neonatal care in district and provincial hospitals. In a provincial hospital in Papua New Guinea, the implementation of a package of measures, including intermittent monitoring with pulse oximetry and apnoea monitoring to improve the quality of neonatal care, markedly reduced neonatal mortality from very low birthweight, pneumonia and sepsis.²⁴

Oximetry in peri-operative monitoring

A Cochrane review of pulse oximetry in peri-operative monitoring of adult patients found that oximetry improved the detection and management of hypoxaemia but had no effect on patient morbidity or mortality.²⁵ There is expert consensus, however, that oximetry should be standard practice in developing countries to ensure patient safety

during and following anaesthesia.²⁶ The Global Oximetry Project, an initiative by the World Federation of Societies of Anaesthesiologists and the Association of Anaesthetists of Great Britain and Ireland, aims to increase uptake of pulse oximetry as standard practice in anaesthesia in low-income countries.²⁶ We propose that a similar initiative is needed for paediatric and neonatal care.

Monitoring ventilation (compared with oxygenation)

Pulse oximeters provide no information on carbon dioxide concentration in blood and thus no direct information on ventilation sufficiency. While it is unlikely that a child with normal oxygen saturation while breathing room air has impaired ventilation, once oxygen is administered, SpO₂ can be maintained at normal levels despite severe hypercarbia, such as may occur with croup or other forms of airway obstruction. In a child receiving supplemental oxygen, oximetry *cannot* be used to monitor the adequacy of ventilation. For children receiving oxygen, therefore, clinical observation of respiratory effort, respiratory rate and level of consciousness can indicate CO₂ retention and is a better guide to the adequacy of ventilation.

In a small hospital setting, any concern over the adequacy of ventilation should prompt efforts to ensure the airway is clear and protected, the stomach is deflated by passing a nasogastric tube, and that the patient is positioned to facilitate chest expansion, i.e. sitting in a semi-recumbent position with the head up at 20–30 degrees to reduce diaphragmatic splinting if there is abdominal distension. It is also important to minimise any upset to the child. If there is an inadequate response to basic measures, nursing the child in a high-dependency or intensive care unit should be arranged if continuous positive airway pressure or mechanical support is available.

When to Give Oxygen

Children with acute illness but no co-morbidities impairing tissue oxygenation

As a general rule, any child with an $\text{SpO}_2 < 90\%$ should receive oxygen.¹⁹ Because the normal SpO_2 range is lower (see Fig. 2) at very high altitudes, it might be appropriate to give oxygen only for an $\text{SpO}_2 \leq 85\%$ to children at an altitude above 2500 m if oxygen supplies are limited (e.g. when using oxygen cylinders and when supply is limited by transport difficulties or cost).^{18,27} Oxygen concentrators, which provide continuous, unlimited oxygen to an individual or group of children, largely overcome the problem of supply.

Special cases in children

Some children should certainly receive oxygen when their SpO_2 is in the range of 90–93%: those with very severe anaemia, severe heart failure, septic shock and acute neurological illness. These children will be much less able to withstand moderately low oxygen levels than children with only lung disease and they can deteriorate rapidly.

Premature neonates

Currently, there is limited consensus as to the level of oxygen saturation that should be targeted for premature neonates to avoid oxygen toxicity while ensuring sufficient oxygenation. However, there are two approaches: giving oxygen liberally to achieve saturations within a 'normal' range for healthy term neonates (which is lower than infants older than 1 month of age)⁵ or restricting oxygen supplementation to achieve a lower yet 'safe' level of oxygen saturation. To date, the evidence is not conclusive but observational studies provide the strongest support for an approach that targets SpO_2 in the range of 85–89%.²²

How to Stop Oxygen Therapy

Trials of taking the patient off supplemental oxygen

At least once a day, any child on the wards on supplemental oxygen who appears clinically stable should be disconnected from oxygen for 10–15 minutes and carefully examined for changes in clinical signs and SpO_2 to assess whether supplemental oxygen is still required. Before doing so, however, the SpO_2 should be checked to determine if the trial is safe (i.e. the SpO_2 is $> 90\%$). The child should then be disconnected from the oxygen source and observed carefully to avoid any adverse complications of hypoxaemia. If hypoxaemia ($\text{SpO}_2 < 90\%$), apnoea or severe respiratory distress occurs, children should be immediately restarted on oxygen. Some children will become hypoxaemic very rapidly when they are taken off oxygen, and this is a marker of very severe disease and a high risk of death. Trials on room air should not be done for children who have an $\text{SpO}_2 < 90\%$ while still on oxygen, or who are unstable or clinically too unwell.

Trials in room air are often best done first thing in the morning when there is likely to be adequate numbers of staff to observe any child who successfully completes the trial and remains off oxygen throughout the day. If done in the late afternoon, there is a risk that children who initially complete the trial successfully might have unrecognised hypoxaemia at night owing to a combination of low staffing and oxygen desaturation which sometimes occurs during sleep.

When to cease oxygen

Where oxygen supplies are ample, children should receive supplemental oxygen until their SpO_2 in room air is $\geq 90\%$. After trials in room air, if the SpO_2 is $\geq 90\%$, they should remain off oxygen and the SpO_2 must be rechecked 1 hour later as sometimes late desaturation can occur. At any time, a child who appears to deteriorate

clinically should have oximetry done to determine whether they need oxygen. Depending on bed-space in the wards, it might be safe to have a rule that children should not be discharged until their SpO₂ is stable at ≥90% while breathing room air for at least 24 hours until all danger signs have resolved and appropriate home treatment can be organised. This does not apply to children with cyanotic congenital heart disease with chronic hypoxaemia. For children with right-to-left intra-cardiac shunts (such as tetralogy of Fallot), oxygen will not be effective in relieving cyanosis or improving SpO₂.

Overcoming Parents' Concerns About Oxygen Use

Many parents are afraid of oxygen and oxygen catheters. Sometimes they will have seen children receive oxygen just before death and might fear that the oxygen caused the death. It can be very useful to show parents the pulse oximeter reading as it is being done and to explain why the child's oxygen levels are low. It is useful also to show them the clinical signs (such as chest indrawing or cyanosis of the gums or tongue). When oxygen is then applied, parents will see that the SpO₂ increases and the child's respiratory distress improves. They will have much more confidence in the treatment and be more likely to accept it. In one hospital in Papua New Guinea, the rate of absconding parents fell significantly (from about 25% to 8%) when daily checking of children using pulse oximetry was introduced. This was mostly the result of explaining the rationale for monitoring and its implications for needing oxygen, needing to stay in hospital and readiness for discharge. Mothers appreciated the daily demonstration that some special attention was being paid to their child and, despite most mothers being illiterate, they were still able to understand the significance of the number generated by the pulse oximeter

TABLE 2. Key points on the clinical use of pulse oximetry.

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- If oximetry is available only in the children's ward, screen all children at the time of admission if time allows, or all children with *emergency* or *priority* signs.
 - If oximetry is used at outpatient triage, screen all children with any *emergency* or *priority* signs.
 - Any child with an SpO₂ <90% should receive oxygen.
 - In some children, particularly those with severe anaemia, heart failure or shock, oxygen should be given if the SpO₂ is ≤93%.
 - For some children living at high altitude (e.g. >2500 m) it will be appropriate to give oxygen when the SpO₂ is <85%, especially when oxygen supplies are limited.
 - Check oximetry *at least* daily on children who are already on oxygen, and screen any child who develops any *emergency* signs or shows other clinical signs of deterioration.
 - Trial children who are clinically stable off oxygen for 10–15 minutes first thing in the morning daily and check oximetry after 10–15 minutes and again within the hour (or sooner if the child becomes distressed). Resume giving oxygen if SpO₂ <90%.
 - Children should not be discharged until their SpO₂ has been stable at ≥90% while breathing room air for at least 24 hours, until all *emergency* signs have resolved, and until appropriate home treatment can be organised.
 - Explain the meaning of oximetry to parents. This will help them understand the importance of oxygen and other treatments and will involve them in their child's care.
 - In a child *on* supplemental oxygen, pulse oximetry *cannot* be used to monitor the adequacy of ventilation. For monitoring ventilation, other clinical signs such as the rate, depth and adequacy of breathing and conscious state are more informative.
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and the thresholds for safe discharge when these were explained in their own language.

Choosing a Pulse Oximeter for Use in a District or Provincial Hospital

Table 3 summarises issues related to the purchasing and use of pulse oximeters in district and provincial hospitals. In general, they should be robust and mains-powered with a long back-up battery life; they should also have a pulse waveform display, an alarm that indicates a dangerous level of SpO₂ and

TABLE 3. *Key points on the selection of pulse oximeters suitable for children's wards.*

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- Know the voltage range and frequency of the mains power source in which the pulse oximeter will be used. Models are typically available for 240V 50Hz, 240V 60Hz and 120V 60Hz.
 - There are many types of oximeter, including hand-held and table-top devices. Hand-held models may be more liable to theft, and the internal battery may not be re-chargeable from mains power.
 - Weight, operating temperature and operating humidity should all be considered.
 - A hard, robust casing is necessary to prevent damage.
 - Accuracy range is usually $\pm 2\%$ at an SpO₂ of 70–100%.
 - Range of pulse rate measurements should cover 0–250 beats/minute.
 - It is important that the internal battery can be re-charged by the mains power. The oximeter should run on the internal battery for at least 8 hours.
 - A plethysmographic display (either a waveform or a liquid crystal bar-graph) is useful for determining the accuracy of measurement, and an alarm is important to alert the user to dangerously low SpO₂ levels.
 - The pulse oximeter should comply with ISO 9919:2005, IEC 60601-1^{29,30} and carry a CE mark.*
 - The limiting factor to pulse oximetry is the oxygen sensor probes. With appropriate care, good quality probes can last 12 months. Suppliers should be selected on the basis of a guarantee of at least 12 months product use. Oximeters can be bought with a commitment to supply sensor probes for 5 years to ensure machines do not fall into disuse because the probe malfunctions; such a package of oximeter plus sensors with a guaranteed life of 5 years should cost <\$2000, i.e. <\$10/week of use.
 - Sensor probes with soft casings that can be used interchangeably on neonates, infants and older children are available.
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* A conformity mark on products sold in the European Economic Area.

sensor probes with a guaranteed life-span of not less than 12 months.

Size and portability

Various sizes of oximeter are appropriate for district hospitals from very small hand-held devices with in-built sensors to machines about the size of a small portable laptop computer ('bench-top' devices). In many hospital wards where resources are limited,

only one pulse oximeter will be available. It is important that oximeters are portable so that children in any part of the ward may be monitored, although it is best to cohort the sickest children in one 'high-dependency' area. Although the hand-held oximeters are cheaper than the larger models, the battery life of these is shorter and there is a greater risk of theft from hospital wards than with bench-top oximeters. Where theft of hospital equipment is a major risk, it might be sensible to secure the oximeter in one place in the ward within reach of the sickest children, but this will limit its portability. An alternative is to have a locked chain securing the oximeter to a bracket on a wall or bench with the key kept by the nurse in charge of every shift.

Oximeter features

Some SpO₂ monitors are coupled with devices that measure other physiological parameters such as blood pressure, exhaled carbon dioxide (capnography) and an electrocardiograph, but the simpler devices for monitoring SpO₂ and pulse rate have fewer attachments needing replacement over time, require much less training to use and are much less expensive.

Oximeters should have robust, hard plastic casing and be resistant to knocks and vibration. Most function well at high altitudes and in humid and hot environments. Oximeters should have a rechargeable internal battery with a working life of at least 8 hours and an alternating current (AC) power adapter, especially where the cost or logistics of purchasing disposable batteries are prohibitive. Oximeters which use disposable batteries are not recommended. Work is under way to develop oximeters with a battery that can be charged by winding a lever but these are not yet commercially available.

Most oximeters have a visible plethysmographic wave or other graphical displays of the pulse wave detected by the digital probe. The wave is displayed either as a wave

representing the pulse contour or as a liquid crystal light that moves vertically or horizontally with every pulse. This is useful for health workers to ascertain the accuracy of the SpO₂ measurement by observing the shape of this pulse wave which should be regular and consistent. If an oximeter does not have such a plethysmographic display, the pulse rate displayed by the oximeter must be checked with the patient's pulse to ensure that they correspond.

An adjustable in-built low saturation alarm is included in most oximeter models to alert health workers when a child is hypoxaemic. This can be set at any threshold, but it may be sensible to set it at 90% or 85% so that dangerously low saturation levels can be easily identified. A high saturation alarm is useful if there is a need to limit the oxygen saturation achieved by administered oxygen, such as when managing very premature neonates to prevent retinopathy. In term newborns or older infants and children, retinopathy owing to oxygen never occurs, and giving oxygen at a flow rate of 0.5–2 L/minute by nasal prongs or catheter is unlikely to result in levels of oxygen that are very high or damaging to the lungs, so that a high saturation alarm is much less useful.

A low battery alarm is essential to alert health workers when the machine needs to be plugged into a power supply (AC mains). It is very important that the oximeter be connected to mains power when not being used around the ward. If the internal battery discharges, it will only work if plugged into the mains, and its usefulness as a portable monitoring tool will be limited.

Digital probes

A wide range of digital probes is available. Some are disposable but can be re-used on several patients over a week or more until the infra-red light signal fades. However, these are difficult to clean and the adhesive wears off after a few uses. There are several types of longer-life digital probes which,

though initially more expensive, are cost-effective in the long run. For adults, there are hard plastic probes but they do not attach well to infants or children. One ideal type of probe for a wide range of patient ages and sizes is a peg-type device with soft rubber coating or 'shoes'. Because the casing is soft, the probe will mould to the digits of neonates, older children and adults. For very low-birthweight neonates, these soft digital probes can be attached to the foot or hand. These peg-type soft probes are ideal for spot-checks and daily monitoring as they do not need adhesive to attach. The rubber shoes can be removed and easily cleaned. The probes and connecting cables are delicate and easily damaged if stepped on or pulled. However, with proper care, a re-usable, single soft digital probe can be used on hundreds of children and in developing countries it has been found that even with heavy use they can last for over a year. 'Y-sensor' probes are also available but they require some form of attachment to the hand, foot, toe or finger. It is important always to have a spare probe on hand in case one fails. Some probes are designed to attach to the ear lobe but generally these will have less applicability for various ages and for the purposes of spot checks and daily monitoring.

Cost of pulse oximetry

The use of pulse oximetry in low-income countries has been limited by the high initial outlay and the ongoing costs of repairs and spare parts. However, recent reports have highlighted that in settings where oxygen is an expensive resource, improvements in standards of care and long-term cost-saving can be achieved by investing in such accurate diagnostic equipment to effectively 'ration' oxygen to children most in need of it.^{10,28}

The technology is robust and the price of oximeters less than in the past. They can be bought with a commitment to supply sensor probes for 5 years to ensure machines do not

fall into disuse because the probe malfunctions. An oximeter plus sensors with a guaranteed life of 5 years should cost less than \$2000, i.e. <\$10/week of use. Pulse oximetry is a highly cost-effective intervention in hospitals caring for large numbers of children with acute respiratory disease, in neonatal units, and for monitoring children during surgery and anaesthesia.^{9,24,28}

For more information about pulse oximetry and oxygen systems in developing countries, see: <http://www.theunion.org/news/saving-lives-of-children-with-hypoxaemic-pneumonia.html>

References

- UNICEF, World Health Organization. *Pneumonia: The Forgotten Killer of Children*. Geneva: WHO, 2006.
- Subhi R, Adamson M, Campbell H, et al. The prevalence of hypoxaemia among ill children in developing countries: a systematic review. *Lancet Infect Dis* 2009; 9:219–227.
- Rudan I, Tomaskovic L, Boschi-Pinto C, Campbell H, WHO Child Health Epidemiology Reference Group. Global estimate of the incidence of clinical pneumonia among children under five years of age. *Bull WHO* 2004; 82:895–903.
- Duke T. Neonatal pneumonia in developing countries. *Arch Dis Child Fetal Neonatal Ed* 2005; 90:211–19.
- Duke T, Blaschke AJ, Sialis S, Bonkowsky JL. Hypoxaemia in acute respiratory and non-respiratory illness in neonates and children in a developing country. *Arch Dis Child* 2002; 86:108–12.
- English M, Ngama M, Musumba C, et al. Causes and outcome of young infant admissions to a Kenyan district hospital. *Arch Dis Child* 2003; 88:438–43.
- Junge S, Palmer A, Greenwald BM, Mulholland EK, Weber MW. The spectrum of hypoxaemia in children admitted to hospital in The Gambia, West Africa. *Trop Med Int Health* 2006; 11:367–72.
- Weber MW, Carlin JB, Gatchalian S, et al. Predictors of neonatal sepsis in developing countries. *Pediatr Infect Dis J* 2003; 22:711–16.
- Duke T, Wandt F, Jonathan M, et al. Improved oxygen systems for childhood pneumonia: a multi-hospital effectiveness study in Papua New Guinea. *Lancet* 2008; 372:1328–33.
- Duke T, Frank D, Mgone J. Hypoxaemia in children with severe pneumonia in Papua New Guinea. *Int J TB Lung Dis* 2000; 5:511–19.
- Jones G, Steketee RW, Black RE, Bhutta ZA, Morris SS, The Bellagio Child Survival Study Group. How many child deaths can we prevent this year? *Lancet* 2003; 362:65–71.
- Leroy JL, Habicht JP, Pelto G, Bertozzi SM. Current priorities in health research funding and lack of impact on the number of child deaths per year. *Am J Pub Health* 2007; 97:219–23.
- Ayieko P, English M. In children aged 2–59 months with pneumonia, which clinical signs best predict hypoxaemia? *J Trop Pediatr* 2006; 52:307–10.
- Usen S, Weber M, Mulholland K, et al. Clinical predictors of hypoxaemia in Gambian children with acute lower respiratory tract infection: prospective cohort study. *Br Med J* 1999; 318:86–91.
- Weber MW, Usen S, Palmer A, Shabbar J, Mulholland EK. Predictors of hypoxaemia in hospital admissions with acute lower respiratory tract infection in a developing country. *Arch Dis Child* 1997; 76:310–14.
- Schnapp L. Uses and abuses of pulse oximetry. *Chest* 1990; 98:1244–50.
- Lozano JM. Epidemiology of hypoxaemia in children with acute lower respiratory infection. *Int J Tuberc Lung Dis* 2001; 5:496–504.
- Subhi R, Smith K, Duke T. When should oxygen be given to children at high altitude? A systematic review to define altitude-specific hypoxaemia. *Arch Dis Child* 2009; 94:6–10.
- World Health Organization. *Hospital Care for Children: Guidelines for the Management of Common Illnesses with Limited Resources*. Geneva: WHO, 2005. ISBN 92 4 154670 0 http://www.who.int/child-adolescent-health/publications/CHILD_HEALTH/PB.htm.
- Duke T, Poka H, Frank D, Michael A, Mgone J, Wal T. Chloramphenicol versus benzylpenicillin and gentamicin for the treatment of severe pneumonia in children in Papua New Guinea: a randomised trial. *Lancet* 2002; 359:474–80.
- Weber MW, Palmer A, Oparaugo A, Mulholland EK. Comparison of nasal prongs and nasopharyngeal catheter for the delivery of oxygen in children with hypoxaemia because of lower respiratory tract infection. *J Pediatr* 1995; 127:378–83.
- Tin W, Gupta S. Optimum oxygen therapy in preterm babies. *Arch Dis Child Fetal Neonatal Ed* 2007; 92:F143–7.
- Bennet L, Booth L, Malpas SC, et al. Acute systemic complications in the preterm fetus after asphyxia: role of cardiovascular and blood flow responses. *Clin Exp Pharm Physiol* 2006; 33:291–9.
- Duke T, Willie L, Mgone JM. The effect of introduction of minimal standards of neonatal care on in-hospital mortality. *PNG Med J* 2000; 43:127–36.

- 25 Pedersen T, Dyrland Pedersen B, Møller AM. Pulse oximetry for perioperative monitoring. *Cochrane Database of Systematic Reviews* 2009, issue 2, CD002013. DOI: 10.1002/14651858.CD002013.
- 26 Thoms GMM, McHugh GA, O'Sullivan E. The Global Oximetry Initiative. *Anaesthesia* 2009; **62** (suppl 1):75-7.
- 27 Duke T. Hypoxaemia in developing countries. *Arch Dis Child* 2003; **88**:365.
- 28 Weber MW, Mulholland EK. Pulse oximetry in developing countries. *Lancet* 1998; **351**:1589.
- 29 International Standards Organization. *Oxygen Concentrators for Medical Use—Safety Requirements*, 1996. http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=22625 (accessed September 2007).
- 30 International Electrotechnical Commission. *Medical Electrical Equipment—Part 1: General Requirements for Basic Safety and Essential Performance*, 2005. <http://www.nssn.org/search/DetailResults.aspx?docid=277847&selnode> (accessed September 2007).