

Pulse Oximeter

It is difficult to imagine the era which ended 30 years ago, when the only practical assessment of a patient's oxygenation was by the presence or absence of cyanosis. The introduction of the first blood gas analysers in the late 1950's rapidly revolutionized medical practice. Until recently, measurement of arterial blood oxygen saturation required the direct sampling of arterial blood, which though not difficult was invasive and potentially risky. Furthermore arterial blood gas sampling provides only intermittent monitoring and remains relatively expensive. Fortunately, a major advancement in this field was the development of pulse-oximetry to determine percent saturation of haemoglobin with oxygen.

Pulse-oximetry technology was available in 1930's but was limited in its use, as it was cumbersome and bulky. It became widely available only in the 1980's with advances in the Light Emitting Diode (LED), microprocessors, optical plethysmography and spectro-photometry. Today pulse-oximetry provides a simple, non-invasive, portable and inexpensive method to continuously monitor oxygen saturation and heart rate with good accuracy.

Physics of Pulse-oximetry

The concept of pulse-oximetry is based on the Beer-Lambert law, which states that the concentration of an unknown solute in a solvent can be determined by light absorption i.e.

$$L(\text{out}) = L(\text{in}) - (D.C.a)$$

where, L = Intensity of light

C = concentration of solution

D = distance the light travels through the solution

a = absorption coefficient of solute.

As we are interested in whether oxygen is attached to haemoglobin or not, the relevant solutes are oxyhaemoglobin and reduced haemoglobin. The absorption characteristics of these two are at two different wavelengths of 940 nm (infrared) and 660 nm (red) respectively (i.e.). Reduced haemoglobin absorbs *more red than infrared light and oxygenated haemoglobin absorbs more infrared than red*. Pulse-oximetry uses these two wavelengths to measure arterial oxygen saturation. Further, only the pulsatile change in light transmission through living tissue is measured to calculate arterial saturation with the understanding that such a change in light transmission would solely be due to change in intervening blood volume. Thus absorption of

light by venous blood, skin pigments, tissue and bone is automatically eliminated from consideration. (Fig 7.1, 7.2).

Practical working of pulse-oximeter

Probe of pulse oximeter consists of two diodes which emit equal intensities of red and infrared light sequentially into pulsatile tissue bed. Variable amount of these lights are absorbed by oxygenated and reduced haemoglobin. A photodetector placed on the opposite side senses the ratio of red and infrared light based on which the proportion of oxygenated and reduced haemoglobin is estimated and displayed.

Correlation with P_aO_2

The P_aO_2 at any given saturation is a function of the “oxyhaemoglobin dissociation curve”. P50 of adult haemoglobin is 27 mm of Hg (this means 50% of haemoglobin is saturated once P_aO_2 is 27 mm of Hg). (Fig. 7.3). As this curve reaches flat upper end, further increase in P_aO_2 causes little change in saturation. If pulse oximeter shows high saturation (around 100%), one never knows how high the actual P_aO_2 might be. This poor discrimination at the upper end of the curve is accentuated by any shift in the curve itself. A shift to right means less saturation at given P_aO_2 . Factors which shift the curve to the right are acidosis, high P_aCO_2 , increased temperature and high concentration of 2, 3-DPG and adult haemoglobin.

Calibration

Since a ratio rather than absolute value is measured, photosensors do not need any calibration. However, calibration curves programmed into the software vary from manufacturer to manufacturer and can be different in various pulse oximeters of the same manufacturer. Apart from this there could be some error in the wave length of the light emitted by the LEDs. For these reasons, same pulse oximeter and probe should be used for all saturation determination in a given patient.

Usefulness of pulse-oximetry

1. In newborns it would provide the fifth "vital parameter" (i.e) oxygen saturation (SpO_2), besides temperature, pulse, respiration and blood pressure.
2. It is a useful adjunct in the assessment of response to resuscitation.
3. It is an important measurement to aid in titration of oxygen therapy in newborns.
4. It can act as apnea monitor (indicating bradycardia and desaturation).
5. It is a valuable companion during transport of newborns
6. It may be useful in addition to Allen's test to detect ulnar artery patency.

Situations in which pulse-oximetry does not work

1. Hypovolemic states or low perfusion states.
2. Dyshemoglobinemias – COHb, Meth Hb
3. Dyes and pigments – Methylene blue
4. Optical interference from external light sources (phototherapy unit, fluorescent light, sunlight).

Fetal haemoglobin and bilirubin most probably do not affect the accuracy of the pulse-oximetry.

Pitfalls and precautions

1. Pulse oximeters are accurate mainly when the oxygen saturation is between 80 to 95%.
2. Interference from other light sources, can be avoided by covering the pulse oximeter probe with an opaque material.
3. Movement by the newborn baby may lead to disrupted signal and artefacts.
4. Avoid compromising blood flow to the limb (e.g. by inflating a BP cuff) to which the probe is attached to prevent a false low reading.
5. If probe does not fit properly, the light can be shunted from the LEDs directly to photo-detector affecting the accuracy of the measurement.
6. Pulse oximeter is not reliable in conditions of severe hypotension (in such conditions an ear probe may be more reliable than a finger probe).
7. Currently available pulse-oximeters are unable to distinguish different types of haemoglobins. Hence, in the presence of COHb (carboxyhemoglobin) and MethHb (methemoglobin), the saturation readings may be falsely and significantly elevated, thus masking the presence of hypoxemia.
8. Always remember that pulse-oximetry reflects only the state of oxygenation. It has no value in estimation of adequacy of ventilation (CO₂ removal).
9. Accuracy of pulse-oximetry is about ± 4 to 5% at or above 80% saturation. Accuracy declines below a saturation of 80%.

Signal Extraction Technology (Masimo)

Masimo signal extraction technology (SET) enables accuracy of SpO₂ measurement during low perfusion states and movement . While conventional pulse oximetry employs one or two algorithms to attempt to measure patient arterial saturation , Masimo SET employs five algorithms using adaptive filters, working in parallel to ensure accurate measurement in difficult situations like motion or low perfusion. (Fig. 7.4).

Points to remember

- (i) Desired oxygen saturation will vary according to the infant's condition. Physician should specify the desired range which is as follows:
 - Premature (1-2 week) 90-93%
 - Older neonate, especially with bronchopulmonary dysplasia (BPD) 90-95%
- (ii) Alarm limits are kept 2% higher and lower than the desired saturation range.
- (iii) Inaccurate readings may be due to
 - poor tissue perfusion
 - cool periphery (cold stress/hypothermia)
 - exposure of probe to light sources
 - excessive movement of limb
 - electrical interference from other equipment
 - any obstruction to blood in that limb e.g. a splint tied tightly for IV access or inflated BP cuff)
- (iv) Oxygen saturation monitors are unreliable in detecting hyperoxia at high saturation values.
- (v) The error associated with saturation monitor reading is 2% in the range of 95-100%. Therefore, a saturation reading of 96% may be as low as 94% or as high as 98%.

Complications of pulse-oximetry

These are rare and include finger burns and pressure necrosis due to prolonged contact with probe.

Prerequisites of a good pulse-oximeter

The main consideration when buying a pulse-oximeter is the cost incurred. A good device should have the following features:

1. The display should indicate a pulse-wave form and heart rate with in-built alarm limits for the heart rate and saturation.
2. There can be additional features like adjustments in pulse volumes and alarm volumes.
3. The set should be tropicalised for use in India.
4. It should be small enough to be portable, with an in-built battery back-up, which should be able to provide power for at least 4 to 6 hours. This battery should have a short recharging time.
5. The probe should be flexible (flexiprobe) and there should be at least one or two spare probes.
6. A good back-up/maintenance service is mandatory.

Depending on financial constraints, one can make use of different combinations of features to obtain an inexpensive but useful instrument. Obviously, long duration trends, storage facilities of data and printer options, might make it expensive though useful.

Finally it is important to remember that pulse-oximetry monitoring serves as a useful parameter complementing clinical examination rather than replacing it.

Table 7.1. Common brands available in market

S.No.	Make	Dealers	Unit cost (Rs.)
1.	Pacotech Model 520 Series 300	Medex	50,000 90,000
2.	Novamatrix Model 511,515 C Oxypleth	Rustagi Surgicals	40,000-60,000 70,000
3.	Nellcor N-180, 185	Instromedix	57,000-80,000
4.	Simed	Oticare	70,000
5.	Oxypal Nihon Khoden	Shibumi Medical System	1,35,000
6.	Apache, Erkadi	Moolaa Technologies	55,000
7.	Criticare 503, 507 series	Criticare India Ltd.	80,000
8.	Dolphin Medical 2100	Rohanika	75,000
9.	Ohmeda Biox – 3700, 3800	Phoenix Medical System	1,75,000
10.	Invivo	Instrument and Machine	70,000
11.	Minolta	Drager Phoenix Medical system	70,000
12.	Pulseox	Methodex	80,000
13.	EMCO	EMCO Meditek	45,000
14.	Pulse sense	Meditrin, Mediserve	50,000
15.	Masimo	Innovative intex Pvt. Ltd.	80,000

Frequently asked questions (FAQ's)

Q1. What are the uses of pulse oximetry?

- This helps clinician in
- Noninvasive arterial oxygen saturation monitoring.
- Pulse rate monitoring.
- Trending of saturation and pulse rate.

Q.2. What are the Common indications for pulse oximetry?

1. To measure oxygenation in infants suffering from hypoxia, apnea, cardio-respiratory disease, broncho-pulmonary dysplasia, etc.
2. To monitor response to therapy during resuscitation
3. Monitoring side-effects of therapy
 - Suctioning
 - Laryngoscopy
4. In extreme LBW babies <1000g – for monitoring oxygenation and heart rate (apneic spells)
5. During neonatal anesthesia to regulate FiO₂

Q.3. Which infants can be monitored using the oxygen saturation monitor?

The oxygen saturation monitor is reliable, practical, and accurate for use in infants with a wide range of birth weights, postnatal ages and heart rates.

Q.4 At what site should the probe be placed for pulse oximetry?

The probe can be positioned on the fingers, toes, hand, foot, or wrist of the neonate. Other sites will depend on the infant's size. Newer probes allow for forehead placement.

Q.5. How do I clean/sterilize the probe after use on one baby and before being used on another?

Cleanse the probe with alcohol and let it dry before using on another baby.

Q.6. Are there any complications from using the oxygen saturation monitor?

In the newborn population, there are no known complications from oxygen saturation monitoring when the neonatal probes are used as indicated.

Q.7. How can I determine the accuracy of the pulse oximeter?

Most transcutaneous pulse oximeters have a visual representation of the pulse intensity as well as a digital display of the pulse. The pulse display should be within three beats per minute of the display on the cardiac monitor. The bar pulse display or pulse waveform must cover at least half of the total display for an accurate reading. Differences greater than this will not reflect accurate oxygen saturation values because the probe is not detecting the arterial pulsations adequately or accurately. Some newer monitors have integrated the ECG complex with the oxygen saturation probe.

Q.8. Can ambient light interfere with pulse oximetry readings?

Yes, ambient light containing the red spectrum may interfere with accurate readings from the oxygen saturation monitor. Light from heat lamps and phototherapy lights has been reported to skew the readings. The high intensity of light emitted from these sources masks the small changes in light transmission from the probe. The remedy is to shield the probe from the ambient light by black paper (e.g. carbon paper) or black polythene.

Q.9. What are the comparative advantages and disadvantages of the transcutaneous oxygen monitor and the oxygen saturation monitor?

A comparison of the two monitoring systems is outlined in the table given below:

Feature	Transcutaneous Oxygen Tension	Pulse Oximetry
1. Calibration	8-10 min. every 4 hours	None
2. Warming time	Approximately 15 minutes after probe application for the skin to reach 43-44°C and capillary bed to "arterialize"	None (displays oxygen saturation level instantly once a pulse is located)
3. Lag time	30-40 seconds.	None (instantaneous) ;
4. Complications	Thermal injuries resulting in first and second degree burns due to heat generated from probe	Compromised skin integrity under the probe (may go unnoticed because the probe does not need repositioning at set intervals)
5. Artifacts (factors causing inaccurate readings)	Membrane wrinkles, air between the membranes and skin, pressure on the probe	Movement of extremity with probe, inflated blood cuff proximal to probe;

light with red spectrum reaching an unshielded probe
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Note: There is no doubt that pulse-oximetry is remarkably more practical and useful option

Q10. What are the responsibilities of staff for using pulse oximetry?

- (1) Calibrate with arterial blood gases if applicable for model and brand.
- (2) Select the appropriate sized probes, and locate a position for monitoring.
- (3) Place the probe such that the light source and photo-detector are opposite each other.
- (4) Set monitor alarms in accordance with the unit policy.
- (5) Document monitor readings and FiO_2 every hour and with each blood sample drawn for gas analysis.
- (6) Change probe site to avoid skin breakdown.

Q11. What are the common brands available in the Indian Market?

You may choose anyone of the mentioned above or other brands available in the market. Some may be very cheaps, like a handheld pulse oximeter which runs on battery alone. It does not have display of pulse waveform/bar. The disposable probes will be cheap, but recurring cost will be quite high. Reusable flexiprobe (life 3-6 months), costs only one thirds of finger probe (life 1-2 years; cost Rs. 6,000 to Rs. 10,000/-)

Q12. What are steps involved in setting up a pulse oximeter?

Procedure	Rationale
<ol style="list-style-type: none"> 1. Assemble all necessary equipment. 2. If saturation monitor probe is reusable, cleanse probe with alcohol, let it dry. 3. Turn monitor on. 4. Apply probe to a site that is well perfused. 5. Ensure both sides of probe are directly opposite each other. 6. Secure probe in place. Avoid edematous, bruised sites and applying excessive pressure. 7. Set high and low alarm limits for saturation and heart rate (2% above and below desired limits). 8. Set pulse and alarm volumes. 9. Check for correlation of depicted heart rate on monitor and the actual heart rate by auscultation. 10. Record heart rate, respiratory rate, colour, oxygen saturation and FiO₂ hourly. 11. Observe and change site at least once per shift. 	<p>Decreases risk of nosocomial infection and facilitates transmission of light.</p> <p>Pulse oximetry requires adequate perfusion of tissues and pulsating vessel to transmit red light. One side emits light and the other side has photo-diode that picks up the transmitted light.</p> <p>Warns of excessive or low oxygen saturation and heart rate.</p> <p>Saturation readings are likely to be correct if heart rates on cardio-respiratory and oxygen saturation monitors correlate.</p> <p>Prevents skin breakdown.</p>

Q13. What can go wrong with the pulse oximeter setting?

Problems	Remarks
<ol style="list-style-type: none"> 1. The oximeter continues to “search” but cannot find a pulse or there is a pulse displayed but no % saturation. 	<p>Try readjusting the sensor or applying it to a new site which has better perfusion. Slight readjustments in the position of the light emitter and/or light detector can make the difference between a non-functional and a functioning sensor. Be sure too, that the “windows” are clean. Tiny bits of debris can interfere with the sensor. The sensor may not be plugged in securely to the monitor, or the sensor may be damaged.</p>
<ol style="list-style-type: none"> 2. The heart rate and % saturation readings fluctuate rapidly. 	<p>This is usually motion artifact caused by an active baby, although some of the fluctuations may be real.</p>

<p>3. The % saturation readings are misinterpreted to be the PaO₂, as determined from an arterial blood sample.</p>	<p>Remember that PaO₂ also measures the oxygen dissolved in plasma, which is reported as “mm Hg”. An oximeter measures oxygen bound to hemoglobin, which is reported as “% saturation” Although the two values should correlate (see the oxygen dissociation curve) the exact numbers will not be the same.</p>
<p>4. The oximeter reading seems to be inaccurate.</p>	<p>Check whether the pulse oximeter pulse rate is the same as the heart rate as determined by a cardiac monitor. If they are different the sensor may need to be adjusted. Also, check if the sensor is shielded from bright light.</p>

Q 14. What makes Masimo SET different from conventional pulse oximetry ?

Conventional pulse oximetry assumes that it is only the arterial blood that moves in a pulsatile manner. But practically the venous blood also moves thus measuring the venous oxygen saturation along with arterial saturation. Also, motion artifacts will mimic the pulsatile movement of the blood is also not distinguished by conventional pulse oximetry. Masimo SET, by using 5 adaptive filters, identifies the venous blood signals and ‘noise’ produced by these movements, isolates them and extracts only the arterial signals. Thus, this technology will work during patient motion artifact, low perfusion, at low signal output and during intense ambient light exposure.