Pulse Oximetry: Uses and Limitations

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ABSTRACT

Pulse oximetry is a useful noninvasive tool in the assessment of a patient suspected of hypoxia. On literature review, few medical and nursing articles explain how to properly use this tool. This article reviews the basic physics of the pulse oximeter machine and proper use of the oximeter. Limitations and sources of error in pulse oximeter technology are also delineated. Finally, correct interpretation and application of information obtained by pulse oximetry are explained.

Keywords: hypoxia, noninvasive monitoring, pulse oximetry

The human eye is not very trustworthy when it comes to detecting hypoxemia. The traditional sign of circumoral cyanosis is a late indicator of decreased oxygenation and is subjective, depending on the experience and eyesight of the observer, as well as the ambient lighting and the patient's skin pigmentation. Pulse oximetry is an objective measurement of oxygenation and is simple, reliable, and accurate when used appropriately.

Pulse oximetry is a useful tool in the evaluation of a patient's oxygenation status and may be used routinely in many areas of clinical practice. Through use of pulse oximetry, oxygenation can be monitored easily and noninvasively. Advances in microprocessor technology, along with improvements in light-emitting diodes and photoelectric sensors, have improved the accuracy and reliability of pulse oximetry.[1] However, because of the inherent limitations of noninvasive technology, it is important to know how to interpret the information received from oximetry.

Pulse oximetry has gained wide clinical acceptance in many areas. Small portable systems are available for use virtually anywhere. Almost every patient that has oxygen or mechanical ventilation requirements would benefit from clinical monitoring of their oxygen status by pulse oximetry. This may be in the form of continuous monitoring or by intermittent testing.[2]

The oxygen saturation as calculated by pulse oximetry has a 95% confidence rate of ±4%, so oximetry is considered to be reliable at readings that range between 70% and 100% SpO_2.[3] This means that, although pulse oximetry is not a replacement for blood gas testing, it can be used as a screening tool when poor oxygen saturation is suspected (Table 1).

Table 1. Common Areas for Use of Pulse Oximetry

1	During anesthesia and postanesthesia care, including both general and conscious sedation
2	Intensive care units
3	Neonatal care units, including delivery, nursery, and neonatal intensive care unit
4	Hospital medical units
5	Transportation within the hospital and during ambulance or air ambulance transportation
6	Diagnostic testing, such as pulmonary function testing, exercise testing, and during sleep studies
7	Subacute care centers, such as nursing homes and rehabilitation centers
8	Home care patients

PHYSICS

The pulse oximeter measures and displays the pulse rate and the saturation of hemoglobin in arterial blood. The oximeter uses a sensor device consisting of two light sources (red and infrared) and a photo detector to measure absorption of visible light. The photo detector then measures light absorption as it moves through the tissue. The amount of dissolved oxygen in the blood dictates the number of oxygen molecules bound to hemoglobin, or how saturated the hemoglobin is with oxygen. The ratio between the amplitude of the red and infrared wavelength is used to determine oxygen saturation by the pulse oximeter.[2]

Pulse oximeters measure the difference in light absorption of oxygenated and reduced hemoglobin, and then calculate the percentage of hemoglobin that is saturated with oxygen. Oxygen saturation is defined as the ratio of oxyhemoglobin (HbO_2) to the total concentration of hemoglobin in the blood.[4] When an arterial blood gas (ABG) measures arterial oxyhemoglobin saturation, it is referred to as SaO_2 [SaO_2 = $HbO_2/(HbO_2 + Hb)$].[4] When arterial oxyhemoglobin saturation is measured noninvasively by pulse oximetry, it is referred to as SpO_2.

The pulse oximeter uses two sensors and a light source to determine the percentage of oxygen saturation in the blood. The two sensors measure the color of both oxygenated blood and unoxygenated blood by detecting different shades of light transmitted through the tissue from the light source. The oxygenated blood is a brighter shade of red than the unoxygenated blood. The pulse oximeter calculates the difference between the two measurements to determine the percentage of oxygen saturation.[5]

The pulse oximeter uses empirical calibration curves developed from studies of healthy volunteers to calculate SpO_2.[2] The partial pressure of oxygen dissolved in the plasma is measured as the PaO_2. The oxygen dissociation curve shows the relation between SpO_2 and PaO_2. An SpO_2 greater than 95% correlates to the normal range of PaO_2, which is 80 to 100 mm Hg. A PaO_2 of 60 mm Hg or less correlates to a SpO_2 of less than 90% per the dissociation curve.[6] Changes in temperature and pH cause a shift in this relation. As

pH increases (alkalosis) or temperature decreases (hypothermia), the shift is to the left as hemoglobin binds more tightly with oxygen delaying its release to tissues. Acidosis (low pH) and fever shift the curve to the right, as the hemoglobin molecule loosens its affinity for oxygen, making it easier for oxygen to be released to the tissues.[7]

The pulse oximeter consists of a peripheral probe, together with a microprocessor unit, which displays a waveform, the calculated oxygen saturation percentage, and the averaged pulse rate.

The pulse oximeter readings lag behind the patient's condition because there is a response delay as a result of signal averaging in the monitor. The length of signal averaging can be set on some machines for 4, 8, or 16 seconds, with most oximeters having a common default setting of 8 seconds. This means there is an interval after the actual arterial blood oxygen saturation starts to fall before it is detected by oximetry because the signal is averaged over several seconds. The PaO_2 could potentially decrease to a critical level before the decreased SpO is displayed by the oximeter. The clinician needs to be aware of this time delay between a potentially hypoxic event such as a respiratory obstruction and the pulse oximeter registering a low oxygen saturation.[8]

USAGE

The pulse oximeter consists of a peripheral probe, together with a microprocessor unit, which displays a waveform, the calculated oxygen saturation percentage, and the averaged pulse rate. Alarms are available which sound when a low SpO_2 level is detected, or when the pulse rate is either tachycardic or bradycardic.

The probe must be placed on a pulsing vascular bed. A sharp waveform with a clear dicrotic notch indicates a good signal. The machine then reads and averages the values that the waveform receives from the vascular bed, which are read over 5 to 20 seconds, depending on the machine's internal setting. Averaging the signal reduces erroneous readings and distinguishes artifact from true signal. A pulse rate and percentage of oxygen saturation are interpreted from these averaged values.[9]

Correct use of the pulse oximeter includes proper placement of the probe. The emitter and detectors must be opposite each other, and light must not reach the detector other than through the tissue. Care must be used to ensure that the digit is fully inserted into the probe.

The finger should be the first choice of site used for measurement. A nondisposable clip-type probe is adequate for most purposes, especially when a single or spot reading is being taken. Self-adhesive probes are more useful for long-term monitoring or when motion artifact is expected. Toes may be used instead of fingers, but poor signal because of decreased perfusion is more likely. The lobe or pinna of the ear can be used with a clip-type probe. Care must be taken when using the ear so that pressure from the clip does not impair perfusion. Forehead or nasal sensors may also be used but, depending on clinical area of use, may not be as readily available as finger probes.[2]

LIMITATIONS

Pulse oximeters do not require user calibration. Thus, it is important that users of the device are aware of the inherent limitations that may give false readings. The pulse oximeter will function properly only if it is able to detect a modulation in transmitted light. If perfusion is decreased and pulse amplitude is small, the signal will be decreased, and the device will be liable to error or be unable to obtain a reading.[2]

Several conditions adversely affect pulse oximetry readings. Poor peripheral perfusion because of cold or hypotension is the principal cause for failure to obtain a satisfactory signal, mainly because of an inadequate pulse wave. Hypothermia, cold extremities, and poor peripheral perfusion may cause the oximeter to fail to

Table 2. Troubleshooting the Pulse Oximeter[2]

Problem	Possible Cause	Possible Solution
No signal, SpO_2 of zero	• Probe is not plugged into unit	• Check unit plugs
	• Probe is not properly placed on patient	• Check probe placement, or change to another probe
	• Light transmission is blocked (eg, blue or black nail polish)	• Remove obstacle to light (eg, remove nail polish)
Erratic signal	• Poor perfusion	• Choose another site
	• Motion artifact	• Minimize probe motion; choose another site
	• Unstable hemodynamics (irregular pulse)	• Adjust signal-averaging time
		• Consider ABGs
SpO_2 is much different than measured SaO_2	• Dyshemoglobinemia (COHb or METHb)	• Check COHb and METHb
Heart rate on the pulse oximeter is different from the apical heart rate	• Poor perfusion	• Choose another site
	• Irregular heartbeat	• Adjust signal-averaging time
	• Motion artifact	• Consider ABGs

ABGs indicate arterial blood gases; METHb, methemoglobin; COHb, carboxyhemoglobin.

register a signal. During cardiac arrest peripheral pulses may be so weak that the device cannot detect them, so monitoring SpO_2 by pulse oximetry could be contraindicated.[10]

Pulse oximetry has been found to be reliable with systolic blood pressure readings greater than 80 mm Hg. Hypotensive systolic blood pressure readings less than 80 mm Hg cause inaccurate and unreliable pulse oximetry readings.[10] Hypotension, low cardiac output, vasoconstriction, vasoactive drugs (dobutamine or dopamine), and hypothermia all reduce tissue blood flow.[11] These low perfusion states produce a low signal-to-noise ratio and create a signal that can be altered by artifact.[8] Lowered perfusion reduces the signal strength, and the oximeter may not be able to adequately differentiate between arterial pulsations and background noise.[2] This causes inaccurate readings, because the sensor is unable to distinguish the true signal.[12]

Motion artifact can interfere with signal detection and interpretation of the signal by the device because of an unstable waveform. Improperly seated sensors, shivering, seizures, or parkinsonian tremors can cause movement, creating an inaccurate reading. Adjustment of the device to a longer signal averaging time may reduce the effects of motion artifact.[2] The pulse oximeter may also be inaccurate in bradycardia and irregular cardiac rhythms, because the device is not able to average the signal waveform in the set amount of time. Edema or venous congestion of the limb can also interfere with readings because of decreased signal.[6,13]

Because pulse oximeters use two-wavelength spectrophotometry, readings are inaccurate in the presence of abnormal hemoglobin levels. Thus, carbon monoxide poisoning will result in an erroneous SpO_2 reading as a result of carboxyhemoglobin. Smokers will often have artificially high readings after smoking a cigarette because cigarette smoke contains carbon monoxide. The presence of methemoglobin will also give an unreliable oximeter reading[2] (Table 2).

High-intensity lighting, typically fluorescent lights, may lead to false readings. This can be corrected by turning off the bright light. Nail polish and artificial fingernails generally do not interfere with oximetry readings, except in the case of black, blue, or green nail polish.[3,14,15] Age, sex, anemia, jaundice, hyperbilirubinemia, and dark skin have not been shown to cause abnormal readings (Table 3).[16]

INTERPRETATION

Normal arterial oxygen saturation is considered to range between 97% and 99%. Some people, especially long-term smokers, may typically have an SpO_2 between 93% and 95%. Readings of 90% or less may

Table 3. Factors That Affect Pulse Oximetry

Factors	Effect on Pulse Oximetry
Emergent	
Cardiac arrest	Poor signal
Respiratory arrest	Poor signal
Shock	Poor signal
Physiologic	
Jaundice	No interference
Anemia	No interference
Carbon monoxide poisoning	False increase in reading, often reading 100%
Cardiac arrhythmia	Poor signal
Dark skin	No interference
Peripheral vasoconstriction	Poor signal
Edema	Poor signal
Arteriovenous fistula	Poor signal
Environmental	
Nail polish	Poor signal with black, green, blue polish
Bright light or sunshine	False increase in signal (overreading)
Cold room	Poor signal
Shivering, tremors, rigors, motion	Poor signal
Electrical frequencies	Interference with signal
Elevation of probe higher than heart	Poor signal
Mechanical interference with circulation (blood pressure cuff, tourniquet, arterial line)	Poor signal
Dirty sensor	Poor signal

indicate that the patient needs supplemental oxygen and further tests as confirmation of hypoxia.[5]

It is important to remember that pulse oximeters measure and calculate the oxygen saturation of the hemoglobin in arterial blood, not the actual oxygen content of the blood; therefore, they do not provide a measure of actual tissue oxygenation or how well the patient is ventilated. Be cautious interpreting readings when there has been a sudden change in SpO_2. One example would be a sudden decrease from 97% SpO_2 to 85% SpO_2; this is physiologically impossible. Evaluate this information in conjunction with the patient's clinical condition and the above-listed limitations.

Oxygen saturation values below 70% obtained by pulse oximetry are unreliable. Any time hypoxia is suspected, but not confirmed with pulse oximetry, ABGs should be performed.[15] Even when the pulse oximeter reads the SpO_2 as normal, the patient could have undetected carbon dioxide retention. Therefore, it is important not to rely on the information from pulse oximeters alone in the assessment and diagnosis of hypoxemia (Tables 4–6).

SUMMARY

The pulse oximeter, like any clinical monitoring tool, must be used correctly and the results interpreted properly. The oximeter is used throughout health care as a screening tool through intermittent and continuous monitoring of a patient's SpO_2. It is a noninvasive, easy-to-use tool that provides useful information about the oxygenation of a patient's blood.

Clinicians must recognize the limitations of pulse oximetry. The pulse oximeter is an additional assess-

Table 4. Pulse Oximetry: What Do the Numbers Mean?[7]

SpO_2, %	PaO_2, mm Hg	Oxygenation Status
95-100	80-100	Normal
91-94	60-80	Mild hypoxia
86-90	50-60	Moderate hypoxia
Less than 85	Less than 50	Severe hypoxia

Table 5. Patients Who Need Oxygen Regardless of Oxygen Saturation Measurement

1	Patients in cardiac or respiratory arrest
2	Patients with chest pain suspected to be of cardiac origin
3	Patients with multisystem trauma
4	Patients who are apneic or who require assisted ventilation
5	Patients with suspected or confirmed carbon monoxide poisoning or smoke inhalation
6	Neonatal patients in distress
7	Patients with suspected sickle cell crisis
8	Hypotensive patients (SBP < 80 mm Hg)
9	Near drowning patients

Table 6. Case Study

A 62-year-old patient with pneumonia has an SpO_2 of 96% with a heart rate of 90 beats per minute (bpm) at the start of a shift. After a few hours, the SpO_2 decreases to 91%, and the patient seems lethargic. The apical heart rate and oximeter pulse rate correlate at 98 bpm. What does this mean?

Answer: This is a true desaturation. With this decrease in oxygen saturation as read by the oximeter, the PaO_2 has decreased from approximately 90 mm Hg to 60 mm Hg. Making sure the apical heart rate correlates to the oximeter pulse rate is a check on the accuracy of the oximeter reading.

ment tool, not a substitute for other elements of the assessment. Pulse oximeters can increase patient safety by alerting the clinician to hypoxia. However, the reading should always be interpreted in association with the patient's clinical condition. JNP

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1555-4155/07/$ see front matter

doi:10.1016/j.nurpra.2007.02.021