Monitoring Oxygen Saturation With Pulse Oximetry

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Introduction

Pulse oximetry has provided a safe and simple method of assessing a patient's arterial blood oxygenation since the early 1980s. Around this time, pulse oximetry monitoring was initiated in the anesthesia setting in an effort to optimize patient safety. The goal was to minimize unrecognized episodes of hypoxemia associated with growing malpractice claims. Episodes of hypoxemia diminished during this adoption period; and the use of pulse oximetry expanded to various inpatient care settings, such as post-anesthesia care, critical care and the general care floor. Today, pulse oximetry reaches many healthcare arenas, including subacute care, long-term care, outpatient clinics, procedure areas, physician offices and the home.

Understanding the information that a pulse oximeter provides, and making appropriate assessments and decisions about patient oxygenation, improves patient care. This improved care is evident in two areas: First, by allowing early identification of hypoxemic episodes that can impact patient safety; second, by facilitating clinical management of the patient. This monograph is intended to support the understanding of critical clinical concepts related to pulse oximetry, and support appropriate applications of this technology.

Behavior Objectives

By the end of this monograph, you will be able to:

1. Describe how oxygen is carried in the blood.
2. Define the relationship of oxygen saturation to total oxygen content.
3. Review the clinical significance and incidence of hypoxemia.
4. Discuss the basics of pulse oximetry technology.
5. Review three factors that may cause arterial blood oxygen saturation (SpO_2) to differ from arterial hemoglobin oxygen saturation (SaO_2).
6. Analyze the utility of the SpO_2 value in patients with anemia, dysfunctional hemoglobin, venous pulsations and edema.
7. Describe three considerations for sensor selection for patients being monitored with pulse oximetry.
8. Identify the role of pulse oximetry in monitoring patients for hypoxemia.
9. Identify three possible applications for the use of pulse oximetry in your clinical setting.

Review of Oxygen Transport Physiology

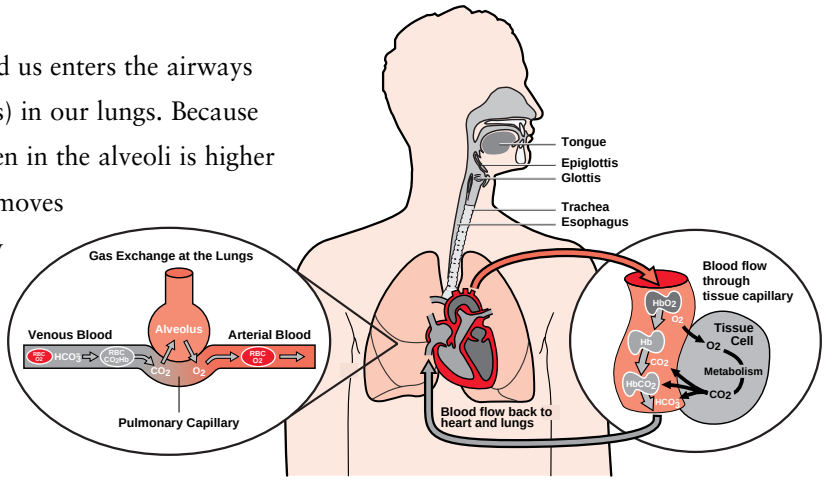
To ensure adequate oxygenation, several physiologic mechanisms must occur:

1. The blood must have adequate amounts of oxygen.
2. There must be adequate amounts of oxygen carriers, or hemoglobin molecules.
3. There must be adequate cardiac output to carry the oxygen to the tissues.
4. The cells must be able to adequately use the oxygen that is delivered.

This monograph focuses on the first two mechanisms of ensuring adequate oxygenation.

How Oxygen Enters the Blood

During inspiration, oxygen from the air around us enters the airways and is transported down to the alveoli (air sacs) in our lungs. Because the concentration, or partial pressure, of oxygen in the alveoli is higher than in the pulmonary capillaries, the oxygen moves across the alveoli. It then enters the pulmonary capillary bloodstream for transport to the tissues in our body. This movement of oxygen from an area of higher concentration to an area of lower concentration is called "diffusion."

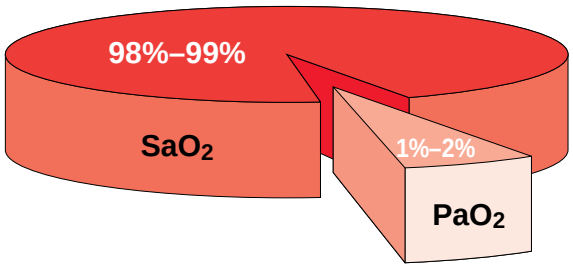


How Oxygen is Carried in the Blood

Once oxygen enters the blood, it is carried in two forms. A small amount of oxygen is dissolved in the arterial plasma, and is measured and reported as PaO_2, which represents the partial pressure of oxygen in the arterial plasma. About 1% to 2% of all oxygen present in the blood is carried this way. However, because the oxygen concentration dissolved in the blood is so high, much of the oxygen moves from the plasma and is carried bound to hemoglobin molecules. Hemoglobins are proteins in the red blood cells.

This combined oxygen and hemoglobin is referred to as "oxyhemoglobin." Hemoglobin not bound with anything is called "deoxyhemoglobin" or "reduced hemoglobin." Normally, 98% to 99% of oxygen in the blood is carried as oxyhemoglobin. Oxygen carried on the arterial hemoglobin is measured and reported as SaO_2, which is the arterial hemoglobin oxygen saturation.

Total Oxygen Content

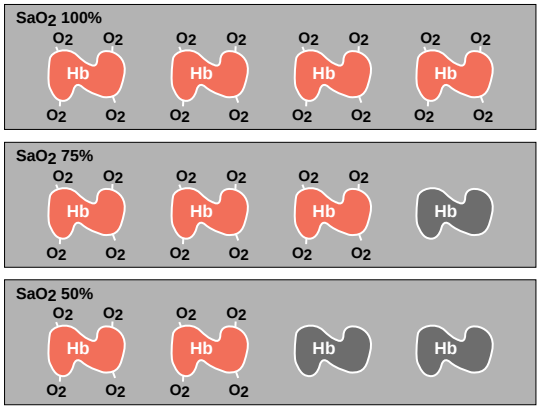


The amount of oxygen dissolved in plasma is an important determinant of the amount of oxygen that is bound with hemoglobin. When there are adequate amounts of oxygen dissolved in the plasma, normally there are greater amounts of oxygen bound with hemoglobin molecules. When inadequate amounts of oxygen are dissolved in the plasma, there may be less oxygen combining with hemoglobin molecules. Therefore, both PaO_2 and SaO_2 are important indicators of blood oxygenation. However, most of the total arterial blood oxygen content is attributed to the oxygen combined with hemoglobin.

Arterial Oxygen Saturation

Arterial hemoglobin oxygen saturation is often determined by a measurement of an arterial blood sample, and reported as SaO_2. The saturation of hemoglobin is the ratio of the number of oxyhemoglobin molecules to the total number of hemoglobin molecules available to bind with oxygen. This number is expressed as a percentage.

$$SaO_2 = \frac{\text{Sites filled}}{\text{Total sites available}} \quad \text{(Expressed as a percentage)}$$

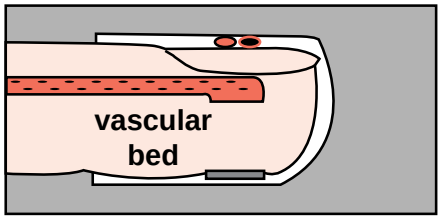


A pulse oximeter also measures arterial blood oxygen saturation. This measurement is often reported as SpO_2. The normal patient range for any arterial hemoglobin oxygen saturation, whether SaO_2 or SpO_2, is 95% to 99%.

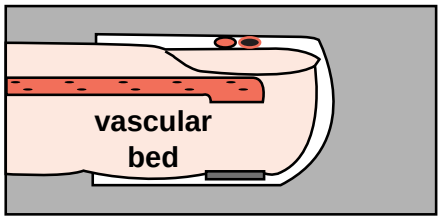
Anemia

Hemoglobin values must be considered when assessing the adequacy of arterial oxygen content. The anemic patient may have the same normal SaO_2 or SpO_2 levels as a patient with a normal hemoglobin value. Although all of the hemoglobin molecules are carrying oxygen, the anemic patient has fewer hemoglobin molecules. The total arterial oxygen content in this patient's blood is therefore lower. The anemic patient may be at greater risk whenever oxygen demand increases or oxygen supply decreases.

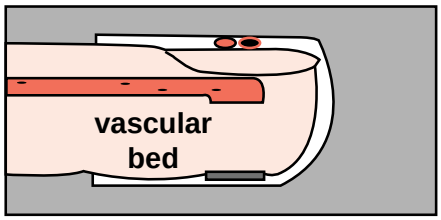
Hb content ~ 15 gm/dl
SpO_2 = 100%



Hb content ~ 8 gm/dl
SpO_2 = 100%



Hb content < 15 gmdl
SpO_2 = ?



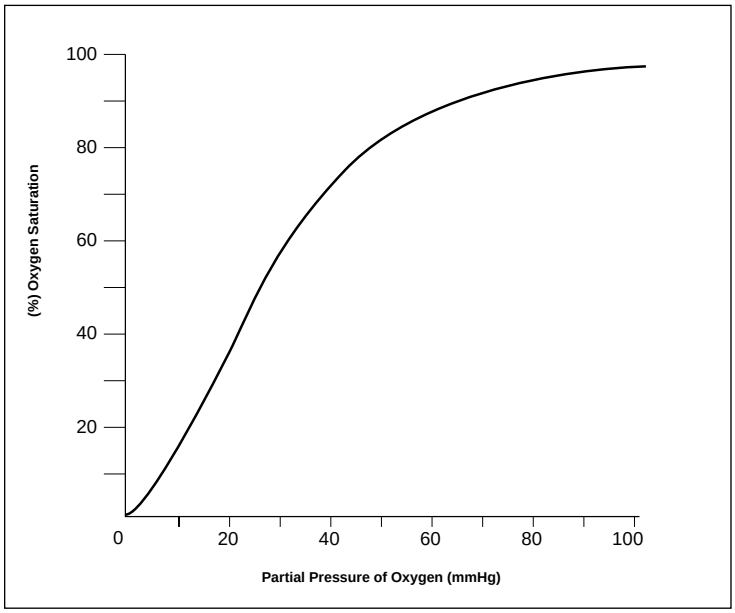
The Oxyhemoglobin Dissociation Curve

The oxyhemoglobin dissociation curve (ODC) is a graphic relationship between hemoglobin oxygen saturation and the partial pressure of oxygen in the blood.

The affinity of hemoglobin for oxygen produces an S-shaped curve representing the way oxygen normally loads onto, and releases from, the hemoglobin molecules. The flat upper portion represents oxygen loading of hemoglobin as blood passes through the lungs. Because the partial pressure of oxygen is high, oxygen binds with the hemoglobin molecule. However, because most hemoglobin molecules are already saturated, additional loading of oxygen onto hemoglobin will not significantly increase as partial pressure continues to increase. The steep lower portion of the curve represents the relationship at the tissue level. Hemoglobin molecules are not well saturated because they have already lost some of their oxygen to tissues. Even with minor reductions in the partial pressure of oxygen, large amounts of oxygen are off-loaded from hemoglobin molecules.

The Normal ODC

The normal ODC, as shown, represents the relationship between changes in hemoglobin saturation and partial pressure of oxygen under certain "normal" conditions. These include a blood pH of 7.4, $PaCO_2$ of 40 mmHG, temperature of 37°C, and normal levels of 2,3-DPG.



2,3-DPG

2,3-DPG is a normal product of red blood cell metabolism. Because of its chemical characteristics, 2,3-DPG plays an important physiologic role in regulating affinity between hemoglobin and oxygen. Some conditions will increase the metabolic production of 2,3-DPG, resulting in decreased affinity of hemoglobin for oxygen. Other conditions, listed in the chart below, may result in lower levels of 2,3-DPG and an increased affinity of hemoglobin for oxygen.

Increased 2,3-DPG	Decreased 2,3-DPG
• Residence at high altitudes	• Stored blood bank
• Anemia	• Hypophosphatemia
• Chronic hypoxemia	• Hypothyroidism
• Hyperthyroidism	

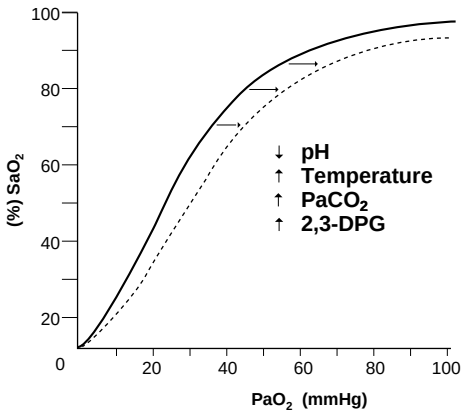
Shifting of the ODC

Under conditions where pH, temperature, $PaCO_2$ and 2,3-DPG are normal, a partial pressure of oxygen at 60 mmHg corresponds with an oxygen saturation value of approximately 90%. However, since many patients have altered pH, $PaCO_2$, temperature and/or 2,3-DPG values, this normal relationship may be altered. In this scenario, ODC is described as being "shifted." These curve shifts reflect altered affinity of hemoglobin for oxygen, which affects oxygen loading and unloading. Normal PaO_2/SaO_2 correlation is affected when the curve is shifted.

Right Shift

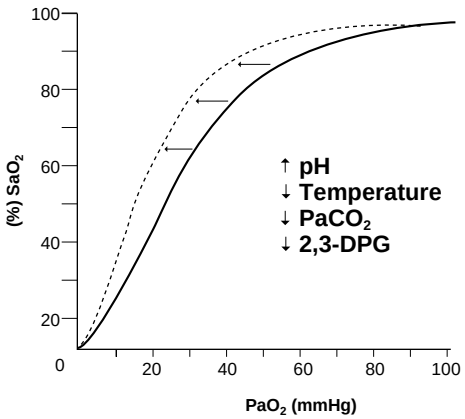
A right shift in the ODC decreases hemoglobin's affinity for oxygen. Hemoglobin does not hold onto oxygen as tightly, and off-loading of oxygen is easier.

Factors Causing a Right ODC Shift	Clinical Conditions Causing a Right ODC Shift
Decreased pH	Acidosis
Increased temperature	Hyperthermia
Increased $PaCO_2$	Alveolar hypoventilation
Increased 2,3-DPG	Anemia



Left Shift

A left shift in the ODC increases hemoglobin's affinity for oxygen. Hemoglobin has a tighter hold on oxygen and off-loading of oxygen is more difficult.



Factors Causing a Left ODC Shift	Clinical Conditions Causing a Left ODC Shift
Increased pH	Alkalosis
Decreased temperature	Hypothermia
Decreased $PaCO_2$	Hyperventilation
Decreased 2,3-DPG	Carboxyhemoglobinemia, hypophosphatemia, fetal hemoglobin

Hypoxemia: The Incidence and Clinical Significance

Recently, a growing body of research has examined the incidence and significance of hypoxemia. Although this research base continues to grow, there have been many relevant findings related to risk factors for hypoxemia and its potential consequences.

Hypoxemia: New Terminology

"Hypoxemia" refers to insufficient oxygenation of the arterial blood. Hypoxemia may lead to "hypoxia," or insufficient oxygenation of the tissues. The consequences of hypoxia can include serious tissue damage, brain damage, and even death. A priority of any healthcare provider is to prevent hypoxemia and ensure adequate oxygenation of patients.

Hypoxemia can occur in an episodic or constant fashion. Episodic hypoxemia is occasionally present and is characterized by sudden changes in SaO_2. The degree of episodic hypoxemia may be mild, moderate or severe. For example, patients may have an episodic hypoxemic event while traveling from the bed to the bathroom, or while climbing stairs in their home. During these episodic events, patients may not have enough oxygen available to meet the metabolic demands required by this activity.

Patients with constant hypoxemia are those who have consistently low oxygen saturation readings. The degree of constant hypoxemia can vary. Constant hypoxemia is often associated with chronic medical conditions, such as chronic obstructive lung disease or cyanotic heart disease.

Patients at Risk for Hypoxemia

Certain patient populations are at greater risk for hypoxemia and should be considered candidates for continuous monitoring of hypoxemia with pulse oximetry. These patient populations include:

Patients at Risk for Hypoxemia	Risk Factors
Patients in Noncritical Care Settings (Hospital and Alternate Care)	Patients cared for in noncritical care areas have complex medical and surgical conditions, which may directly or indirectly affect their cardiorespiratory status. Patient assessment by staff may be less frequent, and patients may be physically located away from the watchful eyes of the caregiver. A decrease in the use of monitoring technologies in these settings may result in hypoxemia being underestimated.
Postoperative Patients	Episodic postoperative hypoxemia can occur in the first few hours after surgery. It can also occur up to five nights postoperative. It can also be associated with sudden unexplained death. Postoperative patients may be at risk for poor oxygenation because of residual effects of anesthesia, pain-inhibited respiratory movement, analgesic-induced respiratory depression and bed rest. Patients who have had major abdominal or thoracic surgeries, or any surgery in the upper airway area, are considered high risk. In addition, those with a significant perioperative oxygenation defect or pre-existing pulmonary disease may be at greater risk during the postoperative period.

Patients in Pain/Receiving Pain Management	Both pain and pain management can contribute to hypoxemia. Pain can inhibit expansion of the chest wall, and interfere with patient activity and mobility. Pain management has the potential to cause respiratory depression. The Agency for Healthcare Policy and Research clinical guidelines related to pain management recommend opioids as the drug of choice, with frequent mention of respiratory depression as a serious complication of opioid use.
Confirmed Obstructive Sleep Apnea or Morbidly Obese Patients	Patients often receive little or no assessment of their sleep habits for apnea, yet the presence of sleep apnea is clearly associated with the development of hypoxemia. In the postoperative period, a rebound in REM sleep days after surgery may be a contributing factor to the development of late postoperative hypoxemia. Since hypoventilation is a major respiratory side effect of opiate administration, patients with sleep apnea who receive opioids for pain management may be at greater risk for apnea-associated hypoxemia. However, patients who undergo surgery or receive opioids often have undiagnosed sleep apnea. These patients may be at heightened risk of hypoxemia-related complications. This is especially true if they are not monitored during their postoperative care, and if they have pulmonary comorbidity.

Patients With Pre-existing Cardiopulmonary Disorders	Patients with severe cardiopulmonary disorders, who have had at least one episode of documented oxygen decrease and were treated with oxygen, are candidates for monitoring with pulse oximetry.
Patients Receiving Conscious Sedation	Sedation, with or without analagesia, may result in the loss of protective reflexes. The Joint Commission on Accreditation of Healthcare Organizations requires protocols addressing the use of pulse oximetry equipment whenever sedation is provided in a manner that may be reasonably expected to result in the loss of protective reflexes.
Neonatal, Pediatric and Elderly Patients	The typical pulmonary reserve in neonatal, pediatric and elderly patients is often decreased, especially in relation to their increased oxygen demands. These patients may desaturate more quickly than the average adult, increasing their risk for hypoxemia and related complications.
Obstetric Patients	Pain-induced changes in respiration during labor and delivery, and desaturation from epidural morphine or other narcotics following operative delivery, contribute to the risk of hypoxemia for the obstetric patient. This patient already has diminished pulmonary reserves.
The Technology-Dependent Patient	Whether in the inpatient or home care setting, numerous patients depend on technology. Much of this technology enhances optimal oxygenation. Technology-related failures or complications, such as with invasive and noninvasive ventilators and oxygen therapy, may result in hypoxemia.

Hypoxemia: The Clinical and Economic Significance

In recent years, numerous clinical studies have discussed the possible role of hypoxemia with adverse clinical outcomes.

Hypoxemia and Wound Healing/Infection	Oxygen plays an important role in wound healing and infection. Low tissue oxygen levels can compromise wound healing and resistance to infection, leading to prolonged hospital stays and/or healthcare costs.
Hypoxemia and Ischemia	Postoperative hypoxemia has been associated with myocardial ischemia and arrhythmias in patients, both with and without pre-existing cardiac disease. The risk of myocardial ischemia is related to the degree and duration of hypoxemia, and may contribute to heart attack and subsequent death.
Hypoxemia and Cerebral Function	Hypoxemia can impair cerebral function in a number of ways. These include short-term memory loss, confusion, cognitive dysfunction or permanent impairment. In patients with pre-existing circulatory conditions, hypoxemia can result in cerebral ischemia or stroke, and subsequent death.
Hypoxemia and Unfavorable Healthcare Costs	The consequences of hypoxemia may result in delayed healing and other complications. These can increase the length of stay, rebound to more expensive areas of care, require additional healthcare resources, decrease the functional ability of the patient, and lead to costly malpractice litigation.

Hypoxemia: Traditional Assessment

Although hypoxemia is a well-recognized safety concern across the health-care continuum, it may present itself in a variety of diverse manners and make assessing patients difficult.

One traditional method for assessing oxygen is measuring the patient's respiratory rate. However, respiratory rate is more often estimated than precise. Additionally, counting respirations has been shown to have virtually no value in detecting hypoxemia.

Another method of hypoxemia assessment is evaluating patient skin color. While conventional wisdom holds that if patient skin color changes to a more dusky, bluish or cyanotic tone, the patient is likely hypoxemic, there are several considerations to keep in mind. Cyanosis is in fact a late sign of hypoxemia. Cyanosis may not be detected, even in the presence of hypoxemia, since cyanosis is related to the amount of hemoglobin present in the blood. Patients with severe anemia may never display signs of cyanosis, despite significant hypoxemia. Cyanosis is often difficult to detect in patients with certain skin pigments. The cyanosis detection is considered to be subjective at best, and wide observer variability may occur. Therefore, the predictive value of cyanosis for hypoxemia is poor.

Other assessment parameters, like respiratory effort, mentation and changes in other vital signs, are unreliable indicators of hypoxemia. Respiratory effort may appear unlabored, even in the presence of hypoxemia. Although changes in mentation (such as restlessness and confusion) are associated with hypoxemia, many clinicians don't make the association, and these findings may be attributed to other causes. Changes in other vital signs, including heart rate and ECG, may or may not occur after significant hypoxemia is present.

These assessment parameters – including respiratory rate, color, effort, mentation and other vital signs – usually require the clinician to assess the patient. Even if changes in these parameters result from deteriorating oxygenation status, the clinician is often not present to observe them. Traditional patient assessment activities are usually performed by clinicians when visiting the bedside or home, or at the patient's routine or episodic office visits. Because the oxygenation status of a patient can quickly change, clinicians may not be aware of changes until patient injury or death has occurred. For these reasons, common forms of hypoxemia detection are inadequate.

Pulse Oximetry

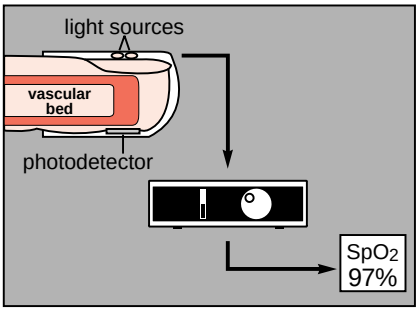
A pulse oximeter is a medical device that provides noninvasive and continuous information about the percent of oxygen that is combined with hemoglobin.

A pulse oximeter is often referred to as a hypoxemia monitor because it can continuously reflect changes in a patient's arterial oxygen saturation. Monitors are electronic devices intended to keep track of certain situations. Because hypoxemia can occur at any time and under any clinical circumstance, pulse oximetry is a valuable tool for patient safety and clinical management. A pulse oximeter used to take intermittent measurements of oxygen saturation is more correctly referred to as a "meter," or measuring device. If pulse oximetry is used intermittently, hypoxemic episodes may be missed.

Pulse Oximetry Technology

Pulse oximetry works by applying a sensor to a pulsating arteriolar vascular bed. The sensor contains a dual light source and photodetector, which are used to measure the amount of oxygen that is combined with hemoglobin. The dual light source has a red and an infrared light. These light sources are used because each is absorbed differently by oxyhemoglobin and deoxyhemoglobin.

Bone, tissue, pigmentation and venous vessels normally absorb a constant amount of light over time. The arteriolar bed, however, pulsates and absorbs variable amounts of light during systole and diastole, as blood volume increases and decreases. The ratio of the amount of each light source absorbed at systole and diastole is translated into an oxygen saturation measurement. An oxygen saturation measurement provided by a pulse oximeter is commonly referred to as SpO_2.



Accuracy

It is important to understand the accuracy level of pulse oximetry measurements. In general, accuracy specifications for pulse oximeters are determined by comparing a saturation obtained from SaO_2 and measured by a laboratory co-oximeter (not an arterial blood gas analyzer) with an SpO_2 measurement. The SpO_2 measurement is taken at the same time arterial blood gas is drawn. This baseline testing is usually performed with healthy adult subjects.

The accuracy specifications for Nellcor® pulse oximeters are usually expressed as "± 2 from 70% to 100% at 1 standard deviation." This means that when the patient's true SaO_2 falls within the 70% to 100% range, the Nellcor pulse oximeter will report a saturation that is within 2% of the true saturation about 68% of the time and 4% of the true saturation about 96% of the time.

Below are certain factors that may cause a greater difference between the SpO_2 and the SaO_2 measured directly from an arterial blood gas.

Factors	Possible Causes/Rationale	Recommendations
Blood Gas Factors	Blood gas is drawn at a different time than the SpO_2 measurement is taken.	Draw ABG at same time oxygen saturation is measured.
	Inaccurate blood gas sampling technique.	Follow proper ABG techniques.
	Blood gas machine is not calibrated accurately.	Ensure ABG equipment is calibrated.
	SaO_2 is calculated from PaO_2 using arterial blood gas analyzer, and not directly measured with laboratory co-oximeter.	Understand whether SaO_2 reports represent measured or calculated SaO_2 values. If SaO_2 is calculated, do not expect SpO_2 value to compare, especially if conditions that cause shifting of the oxyhemoglobin dissociation curve (such as altered temperature, pH, $PaCO_2$ and 2,3-DPG) are present.

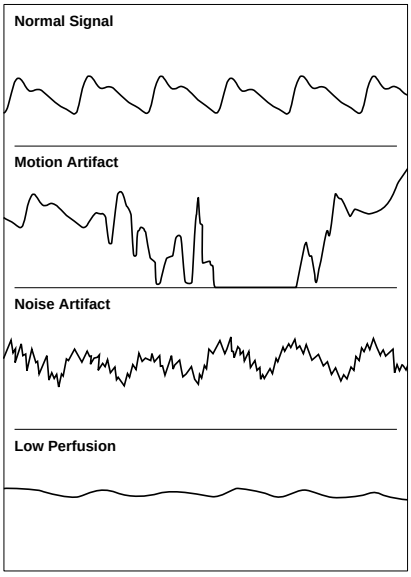
Presence of Dysfunctional Hemoglobins	High levels of carboxyhemoglobin and/or methemoglobin will cause SaO_2 to differ from SpO_2.	Suspect elevated dysfunctional hemoglobins if a measured SaO_2 differs from SpO_2. Assess oxygenation using a measured SaO_2 whenever dysfunctional hemoglobins are suspected.
Intracardiac Shunting	Because of abnormal circulatory conditions, such as some forms of congenital heart disease, different oxygen saturation levels may exist in different parts of the body.	If such conditions are present, be aware that SpO_2 may differ from SaO_2 if measurements are made from different locations.
Intravascular Dyes	The injection of intravascular dyes may result in temporary aberration of the SpO_2 reading.	Be aware that SaO_2 and SpO_2 may differ if measurements are made immediately after injection of a dye.

Innovations in Technology: Oximart and Oximart XL

Traditional pulse oximetry is reliable, especially for immobile and well-perfused patients. However, active patients or those with poor blood flow to a sensor site create challenges for reliable monitoring. Because of motion artifact or because they are weak, pulse signals may be compromised. These conditions may lead to frequent nuisance alarms which can be distracting and time-consuming for clinicians. Because there may be a greater ratio of nuisance alarms to "true" alarms, staff may not respond to every alarm.

The most recent generations of pulse oximetry technology developed by Nellcor address the problem of nuisance alarms common during monitoring conditions of patient motion and low perfusion. Many of the newer models of Nellcor pulse oximeters and multifunction monitors now incorporate *Oximart*® and *Oximart*® *XL* Advanced Digital Signal Processing along with *SatSeconds*™ Alarm Management Technology.

Oximart technology is designed to identify and reject artifacts that could be otherwise mistaken for a pulse. It can also distinguish between actual loss of pulse and a pulse that is obscured by low perfusion, motion artifact, and electronic or optical noise. *Oximart* technology does this by putting



The effect of artifact on a pulsatile signal from an oximetry sensor

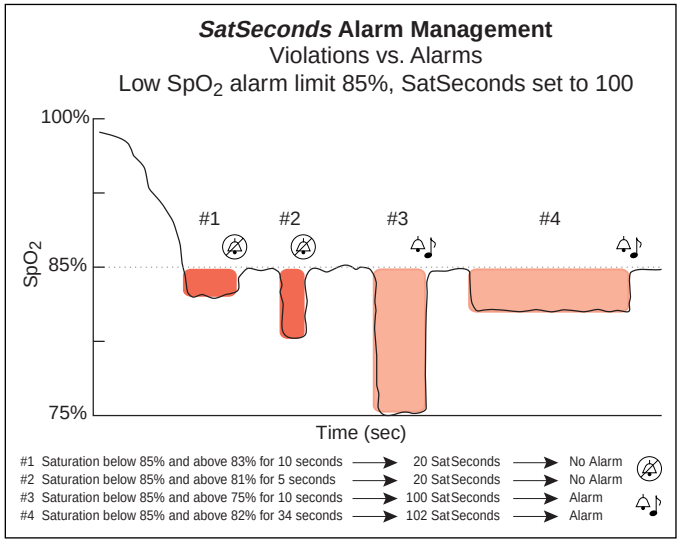
the waveform generated from the pulse through a series of qualifying tests. These tests look at the shape of the waveform, compare it to previously known good pulses, and then determine if it is physiologically plausible. If the waveform passes these tests, the oximeter accepts it and updates the SpO_2 display. *Oximart* technology is designed for environments where the quality of the pulsatile signal can be obscured by artifact, which is typically a brief occurrence.

Because a spontaneously moving patient can be assumed to have a pulse, *Oximart* continues to search for a pulse as long as continuous motion artifact is detected. If the pulse oximeter fails to detect at least one qualified pulse in a ten-second period, the display will alternate between data and dashes, and a data evaluation period begins. During this period, if the patient is not moving and has no qualified pulse for six seconds, an audible alarm is triggered and the display flashes zeros. If the patient is constantly moving, the monitor will search for qualified pulses for up to 50 seconds and update the display each time one is detected. If a qualified pulse signal cannot be detected during this time, an audible alarm sounds and zeros are displayed in the data windows. If an adequate number of qualified pulses are detected, the monitor returns to its normal operating mode and displays updated data on a beat-to-beat basis.

Oximart XL builds on the breakthroughs made with *Oximart* to take pulse oximetry monitoring to a new level. While earlier technologies followed a serial approach to processing patient signals, *Oximart XL* employs parallel engines that run simultaneously to qualify pulses, calculate saturation and pulse rate values, and sound a beep tone. Additionally, where *Oximart* qualifies a pulse by evaluating the waveform, *Oximart XL* also tracks the pulse using technology similar to that developed for submarine sonar devices. This technology, called Adaptive Comb Filtering, enables the oximeter to read through challenging motion. *Oximart XL* also uses an additional method for calculating SpO_2 and pulse rate as an adjunct to that of *Oximart*. This dual approach serves to cover the broadest range of patient monitoring situations. The technological features behind *Oximart XL* translate into more accurate and reliable monitoring of oxygen saturation and pulse rate values during challenging motion and low perfusion conditions.

In addition to *Oximart* and *Oximart XL*, Nellcor made another significant advancement in pulse oximetry with a new alarm management process called *SatSeconds*. *SatSeconds* Alarm Management is present in monitors

powered by *Oximart XL* engines. This new technology tracks desaturations more accurately and quickly than was previously possible. True alarms, although transient and in many cases insignificant, may occur frequently when a patient's measured saturation is near the alarm threshold. Clinicians often manage these kinds of alarms by waiting them out, by ignoring them or turning off the alarms or monitor, or by widening the alarm limits. *SatSeconds* Alarm Management addresses alarm limit violations that are short in duration or small in magnitude without sacrificing safety. The process allows for the clinician to set a *SatSeconds* threshold of 10, 25, 50, or 100 *SatSeconds*. Only if the fall in percentage points of saturation multiplied by the duration in seconds exceeds this threshold would the alarm sound. As a "safety net," an alarm will sound whenever three alarm limit violations occur in a sixty-second period, even if a *SatSeconds* violation did not occur.



The development of *Oximart* and *Oximart XL* technology and *SatSeconds* Alarm Management technology makes safety monitoring for hypoxemia more reliable and reduces the incidence of nuisance alarms. Clinicians are now better able to identify and manage hypoxemia in any setting where pulse oximetry is used.

Optimizing Pulse Oximetry

Certain conditions may result in pulse oximetry readings that are unreliable, incorrect or less informative. These considerations and associated recommendations for more reliable monitoring are listed below.

Consideration	Recommendation
Motion	Move sensor to less active site, or replace adhesive. A reflectance sensor may be placed on the forehead, if the patient is not on a ventilator, or is not placed in a Trendelenburg or supine position. Adjust averaging time on pulse oximeter, if possible. Use *Oximart* technology to enhance the reliability of measurements during motion.

Poor Perfusion	Use an adhesive digit sensor or, if the poorly perfused patient is also immobile, apply an R-15 Nasal Sensor. In some situations, an ear sensor may be appropriate. Protect sensor site from heat loss or rewarm sensor site as permitted by your clinical policies. Use *Oximart* technology to improve the reliability of measurements during poor perfusion.
Venous Pulsation	Position digit sensor at heart level. Avoid restrictive taping. Use care when interpreting SpO_2 values in patients with elevated venous pressure.
Dysfunctional Hemoglobins	Dysfunctional hemoglobins, such as carboxy-hemoglobin or methemoglobin, are unable to carry oxygen. However, SpO_2 values only report functional saturation — oxygenated hemoglobin as a percentage of functional hemoglobin. Therefore, SpO_2 values reported by a pulse oximeter may appear normal when dysfunctional hemoglobins are elevated, although total oxygen content may be compromised due to decreased oxygen carriers. A more complete assessment of oxygenation beyond pulse oximetry is recommended whenever dysfunctional hemoglobins are suspected.
Anemia	Anemia causes decreased arterial oxygen content by reducing the number of hemo-globin molecules that are available to carry oxygen. Although SpO_2 percentages may be in the "normal" range, an anemic patient may be hypoxic due to reduced hemoglobin levels and therefore reduced total oxygen content. Correcting anemia can improve arterial oxygen content. The pulse oximeter may fail to provide an SpO_2 reading if hemoglobin levels fall below 5 gm/dl.
Nail Polish	Remove nail polish (especially brown, blue, green) or apply sensor to unpolished site.
Intravascular Dyes	Use care when interpreting SpO_2 values after injection of intravascular dyes, which may temporarily affect the reading.

Edema	Light from the sensor's light sources may scatter through edematous tissue, although the degree to which this may affect the SpO_2 reading is unknown. Position the sensor on non-edematous sites. If peripheral edema is extensive, try the RS-15 Nasal Sensor, the Adult Reflectance Sensor, or the D-YSE Ear Clip.
Optical Shunt	Optical shunting occurs when some light from the sensor's light sources reaches the photodetector without first passing through the vascular beds. Choose an appropriate sensor for the patient's size, and ensure the sensor remains securely in position with the light sources opposite the photodetector. Replace the sensor when its adhesive is no longer effective.
Light Interference	Light interference may result in erratic or inaccurate SpO_2 measurements. Cover the sensor with an opaque material in the presence of bright light sources, including direct sunlight, surgical lamps, infrared warming lamps and phototherapy lights.
Electrical Interference	Any electrical device, including wall outlets, electrical instruments (such as an electrocautery device), ECG monitors and ventilators, release electrical impulses that may interfere with signal acquisition at the sensor site. This interference can inhibit the pulse oximeter's ability to track the true pulse and result in inaccurate or erratic measurements. Plug the pulse oximeter into a wall outlet that is separate from other devices. Run the sensor cable away from, and perpendicular to, other electrical cables. Shield the sensor site. Newer generation pulse oximetry technology may help minimize electrical interference.

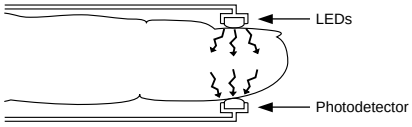
Sensor Selection and Use

One of the most critical factors for ensuring reliable pulse oximetry readings is proper sensor selection and application. No single sensor is capable of monitoring all patients under all monitoring conditions. Consider the following when choosing a sensor for your patient:

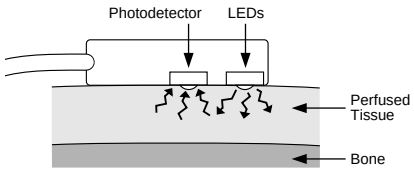
- Patient's body weight
- Duration of use (long term, short term, spot check)
- Patient activity
- Infection control concerns

Mallinckrodt Inc. offers a wide range of Nellcor adhesive and reusable sensors. A Sensor Recycling Program is available in the United States for specific adhesive sensor models.

Sensor Application



Transmission sensor



Reflectance sensor

Always apply a sensor according to the Directions for Use. Transmittance sensors must have the light source properly aligned with the photodetector. Reflectance sensors require proper alignment of the sensor against the surface of the skin. Tape is provided with the sensor. Do not apply additional tape to the sensor.

Sensor Site Change

Nellcor reusable sensors should be moved to another site at least every 4 hours to preserve skin integrity. Nellcor adhesive sensor sites should be checked at least every 8 hours. The clinician should document sensor site checks and changes. To protect circulation at the sensor site, use only the adhesive that comes with the sensor. Do not wrap additional tape or other material around the sensor.

Infection Control

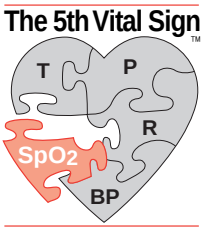
Sterile, patient-dedicated sensors offer an infection control advantage over reusable sensors. Reusable sensors require cleaning between patients with 70% alcohol to minimize the risk of cross-contamination. Consider sterile, patient-dedicated sensors for infected patients or those at increased risk for infection, such as neonates or immunosuppressed patients.

Summary of Tips

- Ensure the light sources and photodetector of the sensor are properly aligned, as outlined in the Directions for Use.
- Check adhesive sensor site at least every 8 hours and move to a new site, if necessary. Move reusable sensors to a new site at least every 4 hours.
- Adhesive digit sensors may be reused on the same patient, if the adhesive tape adheres without slipping. Replace the sensor whenever the adhesive quality is depleted. Do not apply additional tape.
- When selecting a sensor site, priority should be given to an extremity that is free from an arterial catheter, blood pressure cuff, or intravascular infusion line.
- Reusable sensors should be thoroughly cleaned between patients. Refer to Directions for Use.

Detection of Hypoxemia Using Pulse Oximetry

Pulse oximetry is a tool that measures arterial oxygen saturation, an important indicator of total arterial oxygen content. Its use as both a safety monitor and clinical management tool has become so significant to patient care that SpO_2 is often referred to as the 5th vital sign.



To provide early recognition of hypoxemia, monitoring with pulse oximetry should be continuous. Spot checks of SpO_2 may be used in low-risk patients to verify clinical status and define the potential need for continuous monitoring. Telemetry systems for pulse oximetry allow communication of SpO_2 information from the bedside or other remote setting to the caregiver, providing faster identification of changes in oxygen status. These systems are described further in the following section.

Specific clinical applications for pulse oximetry across the continuum of care include:

- To improve patient safety, clinical management and lower the total cost of care by providing continuous safety monitoring for high risk patients in any care setting.
- To safely monitor the patient during medical procedures.
- To provide continuous safety monitoring during sedation or pain management.
- When used with telemetry, to allow for care of patients in less expensive care settings, especially if they do not require intensive interventions.

- To measure the 5th vital sign in vital signs assessment for patients in any location, including inpatient areas, home and physician offices.
- To determine the need to wean from oxygen therapy, which may result in lowered care costs.
- To determine effectiveness of treatments, such as bronchodilators, positioning and suctioning.
- To determine the need for further treatment, such as intubation.
- To assess patient response and tolerance to activities, such as stress testing and activities of daily life.
- To monitor rehabilitation progress.
- To triage patients in the emergency department or clinic.
- To assess admission/transfer/discharge potential of patients.
- To spot check patients for intermittent assessment of oxygenation.

Innovations in Detecting Hypoxemia: Remote Oximetry Monitoring

Remote oximetry monitoring uses telemetric capabilities to continuously transfer oxygen saturation and pulse rate values to a monitor at the central station or directly send alarm data to the bedside caregiver via a remote paging notification system. Remote oximetry monitoring addresses the clinical challenge of detecting hypoxemia throughout the non-critical care areas of the hospital where caregivers have multiple patients and cannot be in all places at all times.

As clinicians struggle to provide consistent, quality patient care in today's health care environment, remote monitoring plays an increasingly important role in improving quality of care and reducing the risk of injury to patients. Continuous remote oximetry monitoring systems give clinicians an efficient way to detect changes in oxygenation and pulse rate so they can respond when necessary with timely treatment interventions. Remote paging notification systems use pagers to help caregivers on the unit keep tabs on pulse oximetry alarms, even when they are not right at the bedside. Clinicians view both of these monitoring systems as an extra pair of eyes that assist in optimizing patient care.

Continuous remote oximetry monitoring systems are designed to work with existing pulse oximetry monitors. At each bedside, a standalone pulse oximeter is fitted with a transmitter to send oximetry data by radio or hardwire telemetry to a central monitoring station. Arterial oxygen saturation and pulse rate values are displayed simultaneously on the bedside pulse oximeter and at the central station. The central station display gives the clinician an overview of the entire unit at a glance. It provides audible and color-coded visual alarm notification if saturation or pulse rate moves beyond the individually preset alarm limits. The system also records trends in saturation and pulse rate that clinicians can review over time.

Remote paging notification systems serve as highly effective secondary alarm systems by giving the bedside caregiver critical alarm status information within seconds. These systems also use existing pulse oximetry monitors. Each standalone pulse oximeter is fitted with a small radio transmitter to send oximetry data to an electronic pager carried by the clinician. When the pulse oximeter alarms at a patient's bedside, the pager notifies the clinician directly.

Many types of patients can benefit from remote oximetry monitoring, because many patients—young and old—are at risk for hypoxemia. Pediatric patients might include children with asthma, respiratory syncytial virus, croup, and cystic fibrosis. In some institutions, any child under 12 months of age who has undergone surgery, children with apnea or reflux, and children who receive conscious sedation are routinely placed on a remote oximetry monitoring system. In the adult population, remote oximetry monitoring is applicable for several acute medical conditions, including chronic obstructive pulmonary disease, asthma, neurologic disorders, and cardiovascular disorders. It can also be useful for postoperative patients receiving patient controlled analgesia, patients receiving high concentrations of oxygen and patients with saturation values below 90%.

In addition to its clinical benefits, remote oximetry monitoring also offers economic advantages. It provides a cost-effective means for improving the management of acutely ill patients outside the ICU. In areas of the hospital where architectural design prohibits the close observation of patients, and in areas where staffing is stretched to accommodate the influx of acutely ill patients, remote oximetry monitoring offers a practical solution. Modularity and portability make it simple to move monitors from patient to patient, room to room—providing pulse oximetry monitoring when and where it's needed. Use of remote oximetry monitoring technology may reduce ICU admissions of patients at risk for respiratory compromise and may also reduce readmission of patients to the ICU after primary discharge. In short, remote oximetry monitoring allows the institution to accommodate higher-acuity level patients without significantly increasing the cost of care. Because of its many advantages, institutions have begun to integrate remote pulse oximetry monitoring into their standards of care.

Post Test

1. State two ways oxygen is carried in the blood.
   a. Dissolved in plasma and bound with hemoglobin.
   b. Dissolved in plasma and bound with carboxyhemoglobin.
   c. Bound with hemoglobin and carbon monoxide.
   d. Dissolved in hemoglobin and bound with plasma.

2. Which of the following statements about total oxygen content is true?
   a. The majority of oxygen carried in the blood is dissolved in the plasma.
   b. The majority of oxygen carried in the blood is bound with hemoglobin.
   c. Only 1% to 2 % of oxygen carried in the blood is bound with hemoglobin.
   d. Total oxygen content is determined by hemoglobin ability to release oxygen to the tissues.

3. Which of the following statements about hypoxemia is false?
   a. Obstructive sleep apnea may cause carbon dioxide retention, but not hypoxemia.
   b. Certain postoperative patients are at greater risk for hypoxemia.
   c. Confusion may be a symptom of hypoxemia.
   d. Even the obstetric patient may be at risk for hypoxemia.

4. Pulse oximetry incorporates two technologies that require:
   a. Red and yellow light.
   b. Pulsatile blood flow and light transmittance.
   c. Hemoglobin and methemoglobin.
   d. Veins and arteries.

5. Which of the following defines "SpO_2"?
   a. Partial pressure of oxygen provided by an arterial blood gas.
   b. Oxygen saturation provided by an arterial blood gas.
   c. Oxygen saturation provided by a pulse oximeter.
   d. Partial pressure of oxygen provided by a pulse oximeter.

6. If your patient's oxygen saturation has fallen from 98% to below 90%, after receiving 4 liters O_2 via nasal cannula, the following physiologic changes may be occurring:
   a. Oxygen content is rapidly decreasing.
   b. PaO_2 level is rapidly increasing.
   c. Oxygen content is slowly decreasing.
   d. PaO_2 level is slowly increasing.

7. Pulse oximetry can be used to:
   a. Obtain invasive information about oxygenation.
   b. Provide acid-base profiles.
   c. Noninvasively monitor saturation values during ventilator weaning.
   d. Fully replace arterial blood gas testing.

8. Which of the following clinical conditions may contribute to inaccurate oxygen saturation readings as measured by a pulse oximeter?
   a. Venous pulsations.
   b. Mild anemia.
   c. Sensor placed on a middle finger.
   d. Monitoring a patient during weaning from oxygen.

9. To troubleshoot motion artifact on a finger or toe sensor:
   a. Ensure the light source is directly across from the photodetector.
   b. Position the sensor below the level of the heart.
   c. Cover the sensor with an opaque material.
   d. Apply additional tape to the sensor to secure it in place.

Post-Test Answers

1. a
2. b
3. a
4. b
5. c
6. a
7. c
8. a
9. a

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Notes

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