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Pulse Oximetry in Adults

Guidelines for monitoring arterial oxygen saturation aren't always followed. When is pulse oximetry indicated?

Overview: Pulse oximetry, a straightforward method for estimating arterial oxygen saturation, can detect hypoxemia early; it's used often and in a variety of settings. But what's not always clear is how frequently—or even whether—patients should be monitored, and unless guidelines are understood and followed, pulse oximetry can be misused or overused. This article reviews the technology and its limitations and discusses current guidelines and their implications for nurses.

Hypoxemia can be present before recognizable signs of respiratory distress—tachycardia, tachypnea, cyanosis, agitation, and lethargy—appear. But it wasn't until the early 1980s that technology allowed for the easy and noninvasive measurement of arterial oxygen saturation.^{1,2} Initially used during surgery to prevent accidental death by oxygen desaturation, pulse oximeters are now found in nearly all settings, from EDs and ICUs to general units, and even in home care. (Before pulse oximetry was available, hypoxemia was detected mainly through skin assessment for cyanosis.¹ An early “ear oxygen meter” was invented between 1939 and 1942 by Glen Millikan, a physiologist seeking a way to measure oxygenation in aviators; he coined the term “oximeter.”)

Although pulse oximeters are nearly ubiquitous in health care, some users may question which

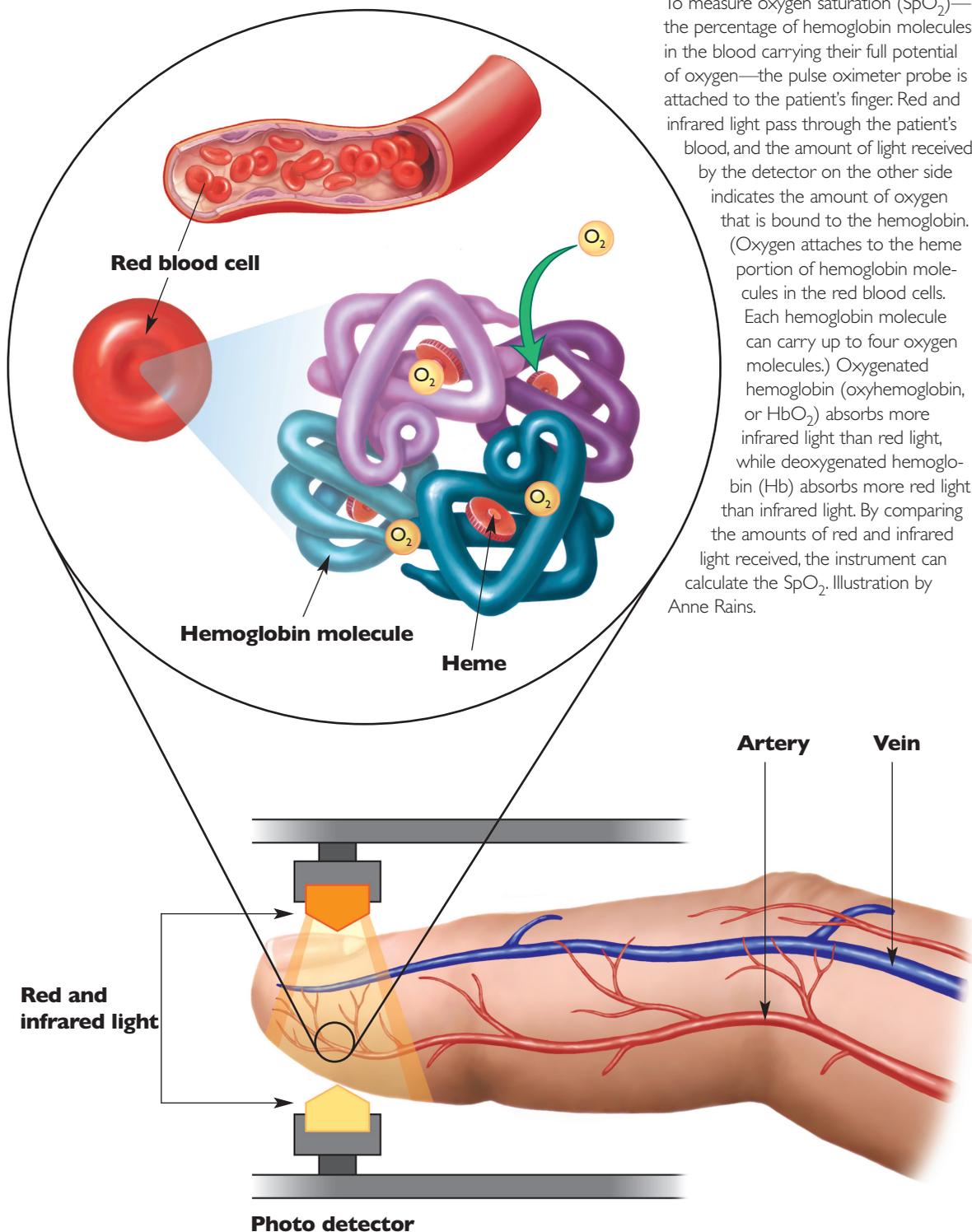
patients should be monitored, and how often. Unless clinicians both understand and follow established guidelines, pulse oximetry can be misused or overused, further straining resources.^{3,4}

Staff nurses at one children's hospital recently voiced such concerns to doctoral nursing students during a research project. (Two of us, CV-L and SAG, were among those students.) The nurses were first asked to identify practices they had questions about; the students then searched the literature for the best ways to improve those practices. One investigated practice was the use of pulse oximetry in a pediatric population. The nurses felt it wasn't clear when or how often it was appropriate and asked whether there were specific practice guidelines. They were concerned that children were being monitored too frequently and unnecessarily. (Some were being monitored continuously until discharge.) The students found scant literature on such monitoring in children, but abundant literature (although much of it more than five years old) on its use in adults.

Several studies show that there's a knowledge deficit about pulse oximetry among medical and nursing staff.⁵⁻⁷ In one study, researchers administered a 17-question survey on pulse oximetry to 442 nurses, physicians, and respiratory therapists; the respondents' mean score was just 66%.⁶ Another study of 50 nursing and medical staff found “an alarming deficit” in their understanding of pulse

Figure 1. How Pulse Oximetry Works

To measure oxygen saturation (SpO_2)—the percentage of hemoglobin molecules in the blood carrying their full potential of oxygen—the pulse oximeter probe is attached to the patient's finger. Red and infrared light pass through the patient's blood, and the amount of light received by the detector on the other side indicates the amount of oxygen that is bound to the hemoglobin. (Oxygen attaches to the heme portion of hemoglobin molecules in the red blood cells. Each hemoglobin molecule can carry up to four oxygen molecules.) Oxygenated hemoglobin (oxyhemoglobin, or HbO_2) absorbs more infrared light than red light, while deoxygenated hemoglobin (Hb) absorbs more red light than infrared light. By comparing the amounts of red and infrared light received, the instrument can calculate the SpO_2 . Illustration by Anne Rains.



Pulse Oximetry in Children

- Know your equipment and the child's weight. As with adults, the correct sensor size is determined by the patient's weight, and different manufacturers specify different ranges. The accuracy of readings depends on using a device in keeping with its manufacturer's recommendations.^{1,2}
- Consider whether the child is active when deciding on the type of sensor to be used and the frequency of monitoring. Otherwise, nuisance alarms are likely, with the accompanying potential for staff desensitization to the alarms.²
- Children being monitored continuously should be located in an area of the unit where the alarms will be heard.² The reason for continuous monitoring should be documented in the chart, as should oxygen saturation (SpO₂) readings.
- Provide education for family members who remain at the bedside; it's important for them to understand the reason for monitoring and how to respond to alarms.²

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oximetry.⁷ To address this deficit, this article will review the technology and the current guidelines for its use in adults. (For considerations relevant to pediatric populations, see *Pulse Oximetry in Children*.)

HOW PULSE OXIMETRY WORKS

Before the advent of pulse oximetry, arterial oxygen saturation (SaO₂) was measured directly using blood gas analysis. Now that it's measured indirectly using pulse oximetry, it's referred to as SpO₂. Pulse oximetry uses a sensor (sometimes called a probe) and a monitoring unit that analyzes the data and displays the results. The sensor directs light at two wavelengths—red and infrared—through a pulsating capillary bed at a site (often a finger, but the forehead, an earlobe, or a toe can also be used) and detects how much is absorbed. Figure 1 shows the process in more detail.

Each wavelength is absorbed differently: oxygenated hemoglobin (known as oxyhemoglobin) is more transparent to red light and absorbs more infrared light than does deoxygenated hemoglobin. The unit then compares the amounts of red and infrared light absorbed to calculate the

percentage of oxyhemoglobin present. Tissue, venous blood, and bone absorb light at constant levels, but arterial blood absorption fluctuates slightly with the pulse, allowing the oximeter to isolate these readings from those of tissue, bone, and venous blood. Although all oximeters work on the same principles, various configurations (including all-in-one “fingertip,” handheld, and tabletop models) are available. Many models display both digital SpO₂ values and a pulsatile waveform that shows blood volume changes at the site.^{8,9} Pulse oximeters are calibrated by the manufacturer.

Sensors may be disposable or reusable, and attachment methods vary. In general, disposable adhesive or foam-wrap sensors should be considered when there's a risk for cross-contamination of microbial pathogens, when monitoring continuously for more than 10 minutes, and when patients are active.¹⁰ Reusable clip-on sensors tend to be best for spot checks, when monitoring continuously for less than 10 minutes, and when monitoring patients who are immobile.

SaO₂, SpO₂, and PaO₂. A fit, healthy person should have an SpO₂ level of 97% to 99% on room air; most experts consider a reading as low as 95% to be “clinically acceptable” in someone with a normal hemoglobin level.¹¹ As one review states, a reading of 90% should be considered “a red flag”; anything less indicates hypoxemia.¹¹

Also, arterial oxygen saturation is not the same as arterial oxygen tension, also known as arterial partial pressure of oxygen (PaO₂). SaO₂ is an indicator of arterial oxygenation, whereas PaO₂ is an indicator of tissue oxygenation. (Confusion about these two values may be why the terms “hypoxemia” and “hypoxia” are often confused. They aren't synonymous: hypoxemia refers to subnormal oxygenation of arterial blood, whereas hypoxia refers to subnormal oxygenation of tissue.) PaO₂ is measurable by blood gas analysis but *not* by pulse oximetry, and its assessment is essential to a complete evaluation of oxygenation status.

That said, SpO₂ levels have been shown to correlate with PaO₂ values. For example, an SpO₂ level above 95% correlates to a PaO₂ value in the normal range of 80 to 100 mmHg; an SpO₂ of 90% or below correlates to a PaO₂ below 60 mmHg.^{11,12}

GUIDELINES

Several professional groups have developed practice guidelines for the use of pulse oximetry. (Although most guidelines in use were formulated during the 1990s, they haven't been updated.) For example, both the Technology Assessment Task Force of the Society of Critical Care Medicine (SCCM) and the American Association for Respiratory Care (AARC) recommend pulse

oximetry for two broad uses: as a real-time “warning system” in patients at risk for arterial desaturation and as a measure for evaluating response to a therapeutic intervention or a diagnostic procedure.^{13,14} The AARC guidelines further recommend the use of pulse oximetry when there is a need “to comply with mandated regulations or recommendations by authoritative groups.”¹⁴

Professional groups such as the American Society of Anesthesiologists and the American Society for Gastrointestinal Endoscopy, as well as the Consortium on Respiratory Monitoring on the General Care Floor, have also addressed the need for pulse oximetry; see *Other Guidelines Relevant to Pulse Oximetry*.

INDICATIONS FOR USE

The AARC guidelines state that decisions about monitoring frequency—whether continuous or intermittent, and if the latter, how often—should be based on the patient’s clinical condition, as well as on “the indications for performing the procedure and recommended guidelines.”¹⁴ The SCCM guidelines provide similar recommendations for monitoring frequency according to the patient’s condition and status.¹³ (The AARC guidelines also call for first establishing agreement between the patient’s SaO₂ and SpO₂ readings; however, they were written in 1992, and blood gas analysis is no longer standard in patients who aren’t acutely ill.)

Continuous monitoring. The SCCM guidelines recommend continuous monitoring in all patients with a critical or unstable airway or with lung dysfunction, as well as in those undergoing diagnostic procedures that might trigger airway compromise or hypoxia (such as bronchoscopy, upper or lower gastrointestinal endoscopy, cardiac catheterization, and liver or kidney biopsy).¹³ Continuous monitoring is also indicated during transport of critically ill or unstable patients, during and immediately after surgery, and during hemodialysis. For a more detailed list of indications for continuous monitoring, see Table 1.

Intermittent (spot-check) monitoring is recommended by the SCCM in most patients on supplemental oxygen (some might benefit from continuous monitoring) and in those with a tracheostomy who are on long-term mechanical ventilation for stable, chronic respiratory failure.¹³ For a more detailed list of indications for intermittent monitoring, see Table 2.

Contraindications. Pulse oximetry monitoring should not be used during cardiopulmonary resuscitation, during adjustment of ventilatory support, or in patients with hypovolemia.¹³ These conditions all require blood gas analysis and other laboratory tests for diagnosis and monitoring. For a more detailed list of contraindications, see Table 3.

Table 1. Indications for Continuous Monitoring

Pulse oximetry should be used continuously

- when the patient has a critical or unstable airway.^{1,2}
- during and immediately after surgery.^{3,4} (Some minor procedures performed with minimal sedation might not require continuous pulse oximetry.)
- when the patient is receiving conscious sedation for diagnostic procedures.^{2,5-7}
- when the patient has a condition or history, such as preexisting pulmonary disease, that suggests a risk of significant desaturation.⁷
- when there is known lung dysfunction.²
- when the patient has obstructive sleep apnea or is morbidly obese.^{7,8}
- when the patient with acute pain is receiving analgesics “at a dose or by a route of administration likely to produce ventilatory depression.”⁷
- when there is cardiopulmonary disorder severe enough to cause at least one documented episode of desaturation treated with supplemental oxygen.⁷
- when the patient is at risk for desaturation at the time of discharge from an ICU or postanesthesia care unit.⁷
- during intra- and interhospital transfer of critically ill patients.^{2,9}
- during hemodialysis.²

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POSSIBLE CAUSES OF ERRONEOUS READINGS

Patient-related factors. *Motion artifact* is a common cause of erroneously low readings and false alarms.^{8, 12} Movement such as that caused by shivering or by conditions marked by seizures or tremors can hamper the sensor's ability to accurately detect the amounts of light absorbed. Improper fit of the sensor (too loose or too tight), as well as venous pulsations associated with tricuspid regurgitation or an intraaortic balloon, can also cause motion artifact.¹⁵ Recently, "motion-tolerant" pulse oximeters have been developed. One review concluded that these produce fewer false alarms and more accurate readings than do conventional devices, but the authors cautioned that more research was needed.¹

Higher than normal levels of carboxyhemoglobin (carbon monoxide-bound hemoglobin) or methemoglobin (created when the iron in hemoglobin oxidizes) also skew pulse oximetry readings. These substances absorb the oximeter's red and infrared wavelengths similarly to hemoglobin and oxyhemoglobin. Patients who have suffered *smoke inhalation* or *carbon monoxide poisoning* will have higher levels of carboxyhemoglobin. And higher levels of methemoglobin may occur with *overexposure to various substances*, such as nitrites and some topical anesthetics. Patients so exposed should be monitored by alternative methods.¹⁵ Certain dyes used in diagnostic imaging, including methylene blue, indocyanine green, and indigo carmine, can also raise methemoglobin levels for up to 20 minutes after injection.⁸ Newer pulse oximeters have been developed that use eight wavelengths of light and can measure the amounts



Pulse oximetry

monitoring should not be used during cardiopulmonary resuscitation, during adjustment of ventilatory support, or in patients with hypovolemia.

of carboxyhemoglobin and methemoglobin present. It's not clear how effective these devices are. One expert recommends their use in heavy smokers, who also have higher than normal carboxyhemoglobin levels¹⁶; but another small study found that these devices still failed to accurately measure oxygen saturation.¹⁷

Conditions that cause *low blood flow* or *decreased perfusion* will affect pulse oximetry readings. If the arterial pulse is weak, the oximeter will have difficulty isolating its signal from those of the surrounding venous blood, bone, and tissue.^{4, 18} Causes of low perfusion include cardiac arrhythmias, heart failure, peripheral vascular disease, and hypotension. Vasoconstriction caused by hypothermia, smoking, or medication can also result in low perfusion.¹⁸ Altered pulse oximetry readings may be seen during acute vasoocclusive crises, such as those that occur in patients with sickle cell disease.¹⁹

It's been reported that *anemia* can lead to misinterpretation of pulse oximetry readings, but this remains controversial. One review states that a patient with "significant" anemia can be "fully saturated"—with all hemoglobin molecules fully bound to oxygen—yet suffer from inadequate oxygenation.¹¹ And one study found that the presence of anemia in patients with low oxygen saturation led to a greater degree of error in SpO₂ readings.²⁰ But others have concluded that anemia does not interfere with the accuracy of readings.¹⁸

Early studies indicated that *skin pigmentation* has no significant effect on the accuracy of pulse oximetry.^{21, 22} But one recent study concluded that dark skin pigmentation caused falsely high SpO₂ values, especially at low saturation levels.²³ Another study in patients on mechanical ventilation found that while a target SpO₂ of 92% was predictive of

Table 2. Indications for Intermittent Monitoring

Pulse oximetry should be used intermittently when the patient

- is on supplemental oxygen.^{1,2}
- has a tracheostomy and is on long-term mechanical ventilation for stable, chronic respiratory failure, with the frequency of measurement dependent on the clinical condition of the patient.²

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satisfactory oxygenation in white patients, “black patients required an SpO₂ target of 95%.”⁸

Whether *nail polish* adversely affects pulse oximetry readings taken on the finger also remains unclear. In one early study, researchers found that if the sensor was applied directly over the nail bed and the polish absorbed light differentially at the same wavelengths being transmitted and detected by the sensor—as happened when test subjects wore blue or green polish—the oximeter readings were inaccurate.²⁴ But more recent studies have found otherwise.^{25, 26} In a study of 50 mechanically ventilated ICU patients, investigators polished each of nine fingernails a different color, then obtained SpO₂ readings on all 10 fingers; SaO₂ was measured simultaneously.²⁵ Although some readings were slightly affected by some colors, the effect wasn’t clinically relevant. Similarly, the evidence regarding the effect of artificial acrylic fingernails on pulse oximetry readings is inconclusive. A 1997 study found that artificial acrylic fingernails had no effect on readings.²⁷ But in a more recent study, the investigators found that it did, although results varied according to the oximeter used.²⁸ They recommended removing artificial acrylic nails to ensure accurate readings.

Other factors. Whether *ambient light* affects pulse oximetry readings remains controversial. Some reviews have concluded that light from various sources—including fluorescent lighting, xenon arc surgical lamps, and infrared heating lamps—can cause erroneous readings.^{11, 29} However, a more recent study of 45 healthy adult volunteers found otherwise.³⁰ Testing began with each volunteer situated in complete darkness in a photographic darkroom. Five kinds of ambient light—incandescent, quartz-halogen, infrared, fluorescent, and bilirubin—were then individually introduced and pulse oximetry readings were taken. The researchers found that ambient light has no statistically or clinically significant effect on pulse oximetry readings.

A technical limitation involves the *response delay*, the time required for an oximeter to detect hypoxemia (an SpO₂ reading of less than 90%).^{31, 32} The length of the response delay can be affected by sensor site, poor site perfusion, mild hypothermia, and vasoactive drugs.³¹ One expert states that oximeters respond to a drop in SpO₂ most quickly (in about 10 seconds) when the sensor is placed on the earlobe; with finger placement, the response delay is about 30 to 60 seconds, and with toe placement, the delay may be as long as 90 seconds.¹⁵

Sensor misplacement. If an oximeter fails to display data or a waveform and the patient has a pulse, check that the sensor is functional, adjust its position, or try taking a reading at another site. Keep in mind, though, that sensor designs vary

Table 3. Contraindications for Pulse Oximetry

Pulse oximetry is not recommended¹

- during cardiopulmonary resuscitation.
- when the patient is hypovolemic.
- for assessing the adequacy of ventilatory support.
- for detecting worsening lung function in patients on a high concentration of oxygen.

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somewhat depending on the intended site and that each device is calibrated accordingly. (For example, forehead sensors are usually adhesive, while finger sensors can be adhesive or clip-on.) Using a sensor at a site it wasn’t designed for will result in an erroneous reading.

NURSING CONSIDERATIONS

A variety of pulse oximeters are available. That nurses should be familiar with the manufacturer’s recommendations for the device they’re using is not only common sense but also in keeping with the Joint Commission’s statement that pulse oximeters “should at a minimum be managed following manufacturer’s guidelines.”³³ The commission also says that written policies and procedures should be readily available to staff, who should be trained and competent in their use.

Sensors are sized according to the patient’s weight; different manufacturers specify somewhat different ranges. It’s important to use the correct size to avoid skin complications and ensure accurate readings. Even when the correct size is used, skin breakdown at the placement site, caused by pressure from the sensor, has been reported.⁴ The American Association of Critical-Care Nurses (AACN) recommends assessing the prospective site for signs such as cyanosis, decreased peripheral pulse, and decreased temperature, as these can indicate diminished blood flow and lead to inaccurate SpO₂ readings.³⁴ The AACN further recommends reevaluating the sensor site periodically. When using disposable sensors, assess the site every two to four hours and replace the sensor every 24 hours. When using a reusable sensor, the site should be checked every two hours and changed every four hours. With reusable sensors, the manufacturer’s recommendations regarding cleaning agents should also be followed.

Check that the right type of sensor is being used. The sensor site should be chosen based on which location has the best pulsatile vascular bed.³⁵ Generally the finger is chosen first; however, forehead sensors are particularly useful in patients with poor peripheral circulation.³⁶ Forehead sensors are also a good alternative in patients under general anesthesia whose extremities aren't readily accessible.³⁷

To exclude motion artifact caused by shivering, patients should be kept warm. A study of trauma patients during prehospital transport found that those actively warmed with resistive heating blankets had significantly fewer oximeter alarms than those given wool blankets.³⁸ The researchers attributed this to improved peripheral circulation in the actively warmed group.

To avoid potential interference from ambient light, the sensor can be covered with the patient's linens. Nail polish or artificial nails should be removed.

Beside equipment alarms can be frightening to patients and families, especially if they aren't attended to promptly. Quality assurance studies conducted by member hospitals of the Child Health Corporation of America's Pulse Oximetry Forum indicate that in pediatric populations, the false alarms that occur during continuous pulse oximetry cause needless anxiety for patients and families.³ The studies also suggest that such "nuisance alarms" can cause staff to become desensitized to them or to focus on the monitor instead of the patient. It's likely that similar effects occur in adult populations. Nurses should explain why pulse oximetry is being used, how it works, and what the readings indicate in language the patient and family

can comprehend. The factors that can lead to false alarms should also be explained, as should the importance of frequent site assessment and rotation. Finally, nurses can remind prescribers to change the order from continuous monitoring to intermittent, as appropriate. ▼

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Other Guidelines Relevant to Pulse Oximetry

- American Association for Respiratory Care. Various clinical practice guidelines are available free at www.rcjournal.com/cpgs.
- American Society for Gastrointestinal Endoscopy. Various practice standards and guidelines are available free at www.asge.org/PublicationsProductsindex.aspx?id=352.
- American Society of Anesthesiologists. Various standards, guidelines, and statements are available free at www.asahq.org/publicationsAndServices/sgstoc.htm.
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GENERAL PURPOSE: To present registered professional nurses with information on the technology of pulse oximetry and its limitations, and to describe current guidelines and their implications for nurses.

LEARNING OBJECTIVES: After reading this article and taking the test on the next page, you will be able to

- discuss how pulse oximetry was developed and how it works, as well as its appropriate uses.
- outline the proper interpretation and limitations of pulse oximetry readings.
- plan appropriate interventions for patients who require pulse oximetry.

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- complete the registration information and course evaluation. Mail the completed enrollment form and registration fee of \$21.95 to **Lippincott Williams and Wilkins CE Group**, 2710 Yorktowne Blvd., Brick, NJ 08723, by June 30, 2011. You will receive your certificate in four to six weeks. For faster service, include a fax number and we will fax your certificate within two business days of receiving your enrollment form. You will receive your CE certificate of earned contact hours and an answer key to review your results. There is no minimum passing grade.

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