Pulse Oximetry in Pediatric Practice
Sotirios Fouzas, Kostas N. Priftis and Michael B. Anthracopoulos

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abstract

The introduction of pulse oximetry in clinical practice has allowed for simple, noninvasive, and reasonably accurate estimation of arterial oxygen saturation. Pulse oximetry is routinely used in the emergency department, the pediatric ward, and in pediatric intensive and perioperative care. However, clinically relevant principles and inherent limitations of the method are not always well understood by health care professionals caring for children. The calculation of the percentage of arterial oxyhemoglobin is based on the distinct characteristics of light absorption in the red and infrared spectra by oxygenated versus deoxygenated hemoglobin and takes advantage of the variation in light absorption caused by the pulsatility of arterial blood. Computation of oxygen saturation is achieved with the use of calibration algorithms. Safe use of pulse oximetry requires knowledge of its limitations, which include motion artifacts, poor perfusion at the site of measurement, irregular rhythms, ambient light or electromagnetic interference, skin pigmentation, nail polish, calibration assumptions, probe positioning, time lag in detecting hypoxic events, venous pulsation, intravenous dyes, and presence of abnormal hemoglobin molecules. In this review we describe the physiologic principles and limitations of pulse oximetry, discuss normal values, and highlight its importance in common pediatric diseases, in which the principle mechanism of hypoxemia is ventilation/perfusion mismatch (eg, asthma exacerbation, acute bronchiolitis, pneumonia) versus hypoventilation (eg, laryngotracheitis, vocal cord dysfunction, foreign-body aspiration in the larynx or trachea). Additional technologic advancements in pulse oximetry and its incorporation into evidence-based clinical algorithms will improve the efficiency of the method in daily pediatric practice. Pediatrics 2011;128:740–752

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KEY WORDS
pulse oximetry, children, hemoglobin oxygen saturation

ABBREVIATIONS
SaO2—arterial blood oxygen saturation
SPO2—arterial hemoglobin oxygen saturation by pulse oximetry
ODC—oxyhemoglobin dissociation curve
COHb—carboxyhemoglobin

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The clinical assessment of hypoxemia is notoriously unreliable because it depends on many factors, including ambient lighting, skin pigmentation, tissue perfusion, and hemoglobin concentration. Even under optimal conditions, arterial blood oxygen saturation ($\text{SaO}_2$) of $\sim75\%$ is required before central cyanosis becomes clinically detectable.\textsuperscript{1,2}

The introduction of pulse oximetry in clinical practice has led to a revolutionary advancement in patient assessment and monitoring, because it allows for a simple, noninvasive, and reasonably accurate estimation of arterial oxygen saturation. Pulse oximeters have become available for widespread application in pediatric care, and oxygen saturation has even been proposed as the “fifth vital sign.”\textsuperscript{3,4} However, clinically relevant principles and inherent limitations of pulse oximetry are not always well understood by health care professionals.\textsuperscript{5,6}

In this review we describe the physiologic principles, limitations, and common applications of pulse oximetry in daily pediatric practice.

**HISTORY OF PULSE OXIMETRY**

The theoretical background for noninvasive assessment of blood oxygenation was set in the early 1900s when it was observed that spectral changes of light absorbance in vivo are related to tissue perfusion.\textsuperscript{7} Great advancements in the development of related instruments occurred during World War II in an effort to monitor oxygenation of military pilots.\textsuperscript{7} In 1940, Squire\textsuperscript{8} reported on a “blood-oxygenimeter” for use on the hand, and in 1942, Millikan\textsuperscript{9} coined the word “oximeter” for a portable ear device that read energy absorption in the red and infrared light spectra. Important subsequent work was presented by Wood,\textsuperscript{10} who managed to measure oxygen saturation by suspending tissue perfusion. However, all these “early” oximeters relied either on compression and reperfusion of the measuring site or on the “arterialization” of capillary blood through heating; consequently, they were inconveniently large, difficult to use, and, most importantly, inaccurate.\textsuperscript{7,11}

A true revolution in the development of noninvasive oximetry occurred after the work of the Japanese electrical engineer Aoyagi.\textsuperscript{12} In an experiment aimed to develop a dye-dilution technique to measure cardiac output, he realized that the untoward changes in tissue light absorption caused by the pulsatile nature of the arterial blood flow could be used to compute oxygen saturation. Thus, the “noise” in his experiment became the “signal” for a different application, which led to the development of the first “pulse” oximeter in late 1974.\textsuperscript{11,12} In the next 2 decades, after the explosive development of technologies in light emission and signal processing, pulse oximeters underwent astonishing improvements and became available for widespread application throughout medical practice.\textsuperscript{11,15}

**PRINCIPLES OF OPERATION**

The estimation of arterial hemoglobin oxygen saturation by pulse oximetry ($\text{SpO}_2$) is based on the specific characteristics of oxygenated and deoxygenated hemoglobin (oxyhemoglobin and deoxyhemoglobin, respectively) with regard to light absorption in the red and infrared spectra. Deoxyhemoglobin is characterized by greater red-light absorption (wavelength range: 600–750 nm) in comparison to oxyhemoglobin, whereas oxyhemoglobin exhibits higher absorption in the infrared spectrum (850–1000 nm)\textsuperscript{14,15} (Fig 1). By obtaining the ratio of light absorption in the red and infrared spectra. Deoxyhemoglobin is characterized by greater red-light absorption (wavelength range: 600–750 nm) in comparison to oxyhemoglobin, whereas oxyhemoglobin exhibits higher absorption in the infrared spectrum (850–1000 nm)\textsuperscript{14,15} (Fig 1). By obtaining the ratio of light absorption in the red and infrared spectra and then calculating the ratio of these 2 ratios (ratio of absorption ratios), the percentage of oxyhemoglobin can be calculated.\textsuperscript{12,15}

Light absorption in vivo depends on the characteristics of the tissues across the site of measurement.\textsuperscript{16,17} During short time periods, the absorption by skin, subcutaneous fat, muscles, bones, and capillary and venous blood remains practically constant (constant absorbers). Therefore, any change in light absorption should be attributed to
the variations of the arterial blood volume related to the cardiac cycle\textsuperscript{12,17–19} (Fig 2; Supplemental Movie 1). Currently available pulse oximeters are equipped with 2 light-emitting diodes (LEDs),\textsuperscript{1} emitting at the red spectrum and the other at the infrared spectrum, most commonly at wavelengths of 660 and 940 nm, respectively. Emission of these 2 wavelengths alternates at frequencies of 0.6 to 1.0 kHz\textsuperscript{15,20,21} and the nonabsorbed energy is detected by a semiconductor. A microprocessor subtracts the absorption by constant absorbers, thus rendering the final signal, which is displayed electronically as a plethysmographic wave form. The SPO\textsubscript{2} is calculated from the conversion of the ratio of absorption ratios by using dedicated calibration algorithms stored in the microprocessor of the device. These algorithms are derived through SaO\textsubscript{2} measurements in healthy volunteers breathing mixtures of decreased oxygen concentrations and are usually unique for each manufacturer.\textsuperscript{15,17–21} The displayed SPO\textsubscript{2} represents the mean of the measurements obtained during the previous 3 to 6 seconds, whereas the data are updated every 0.5 to 1.0 second.\textsuperscript{15,18–20} The performance of each device is strictly related to the reliability and complexity of the algorithms used in signal processing and to the speed and quality of the microprocessor. There are numerous studies of the accuracy and precision of pulse oximeters in various adult\textsuperscript{22–24} and pediatric\textsuperscript{25–27} populations. Most manufacturers claim mean differences (bias) of \(\pm 2\%\) with SDs (precision) of \(\pm 4\%.\textsuperscript{15,18–20,28}\) It should be noted, however, that these results have been reported in subjects with SaO\textsubscript{2} levels that exceed 80%\textsuperscript{15,18–20,28}; the performance of pulse oximeters deteriorates remarkably when SaO\textsubscript{2} decreases to <80%.\textsuperscript{17,24,29}\n
The probe of the device must be positioned in such manner that the emitter and the detector are exactly opposite to each other with 5 to 10 mm of tissue between them.\textsuperscript{15,30} Typical measuring sites include the finger, the toe, the pinna, and the lobe of the ear, whereas for neonates and infants measurements are commonly obtained from the palm or the sole by using specially designed probes.\textsuperscript{28,30–32} Less commonly used sites are the cheek and the tongue.\textsuperscript{30}\n
**MISCONCEPTIONS**\n
Safe use of pulse oximetry requires comprehension of the information that the method offers.\textsuperscript{33} SPO\textsubscript{2} is, in fact, an estimate of SaO\textsubscript{2} as derived by arterial blood gas analysis, which in turn does not accurately reflect partial oxygen tension of the arterial blood (PaO\textsubscript{2}). Indeed, although SaO\textsubscript{2} and PaO\textsubscript{2} are related through the oxyhemoglobin dissociation curve (ODC), their relation is not linear. Moreover, a series of factors can further influence the shape of the ODC (Fig 3). Hence, SPO\textsubscript{2} (as well as SaO\textsubscript{2}) does not necessarily provide reliable information regarding the oxygenation status of tissues.\textsuperscript{30,34,35} SPO\textsubscript{2} represents an estimate of functional arterial hemoglobin saturation,
which refers only to the arterial hemoglobin that is capable of transporting oxygen (functional hemoglobin = oxyhemoglobin/oxyhemoglobin + deoxyhemoglobin). Functional saturation differs from fractional hemoglobin saturation (Fractional hemoglobin = oxyhemoglobin/total hemoglobin), which can be measured by most blood gas analyzers with co-oximetry. The total hemoglobin denominator in the calculation of fractional hemoglobin might include abnormal or variant hemoglobin molecules with limited oxygen-carrying properties. Therefore, the terms “functional” and “fractional” hemoglobin saturation are not interchangeable. In situations such as dyshemoglobinemia, pulse-oximetry readings do not adequately reflect the oxygen-carrying properties of arterial blood. It should be noted also that pulse oximetry does not provide information regarding ventilation or acid-base status.

LIMITATIONS OF PULSE OXIMETRY

The limitations of pulse oximetry can be generally classified as safe or potentially unsafe (Table 1). Safe limitations refer to those circumstances in which the inaccuracy in the displayed SpO2 can be suspected, and its cause is recognizable. In this case the observer is usually warned by the device (alarm) about the pitfall. A potentially unsafe limitation is considered to be any situation in which the inaccuracy is difficult to recognize; the displayed SpO2 is erroneous, but the observer is not warned about the pitfall.

Safe Limitations

Motion Artifacts

Motion artifact represents the most common limitation of pulse oximetry. Because the normally pulsatile (arterial) component of light absorption represents no more than 5% of the total absorbed energy, any motion that alters the remaining fraction of absorption (especially when due to venous blood) will affect the signal-to-noise ratio and drive SpO2 to lower than true values. Fortunately, motion artifacts can be recognized by motion alarms or distorted plethysmographic waveforms. However, rhythmic motions or vibrations with a frequency similar to heart rate (0.5–3.5 Hz) can be particularly troublesome. Sophisticated read-through-motion and motion-tolerant technologies continue to evolve and have improved the performance of the new-generation oximeters.

Poor Perfusion

Adequate arterial pulsation at the site of measurement is essential for distinguishing true signal from background noise. Low-perfusion states, such as low cardiac output, shock, hypothermia, vasoconstriction, arterial occlusion, or during blood pressure cuff inflation, might impair the functioning of the device and result in lower SpO2 readings or delayed recognition of acute hypoxemia. For infants with cold extremities, local rubbing or heating before the application of the probe might temporarily improve perfusion; however, for hypothermic patients, monitoring by a forehead probe is an alternative option. New-generation devices are equipped with signal-extraction algorithms and can perform better in low-perfusion states.

Skin Pigmentation, Nail Polish, and Artificial Nails

In theory, skin pigmentation presents a constant level of absorption that is subtracted in the calculation of SpO2 and, therefore, should not influence the performance of the device. However, dark skin pigmentation has been incriminated for erroneous SpO2 readings, especially at SaO2 values of <80%. Although data regarding the impact of nail polish are conflicting, polish of black, blue, or green color and synthetic nails might interfere with pulse oximetry and result in an underestimation of SaO2. This effect can be avoided by mounting the probe on the finger sideways. New-technology pulse oximeters are less susceptible to these limitations.

Irregular Rhythms

Inaccurate oximetry readings can be observed with irregular heart rhythms, especially during tachyarrhythmias. These artifacts can usually be recognized by observing the plethysmographic wave form. Currently available devices possess signal-extraction technologies that are capable of recognizing such events.

Electromagnetic Interference

Electromagnetic energy from electrosurgical cauterization units and cellular phones might interfere with pulse oximeters and lead to erroneous SpO2 readings. Special devices with fiber-optic technology should be used during MRI to avoid both interference with image quality and potentially dangerous heating of the sensor with consequent thermal injury.

Potentially Unsafe Limitations

Calibration Assumptions

As stated already, the displayed SpO2 is the result of the conversion of the ratio...
**TABLE 1 Limitations of Pulse Oximetry**

<table>
<thead>
<tr>
<th>Limitations</th>
<th>Mechanism</th>
<th>Bias</th>
<th>Proposed Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe limitations safe limitations</td>
<td>Sensor movement</td>
<td>Lower SPO2 readings</td>
<td>Evaluate plethysmographic waveform</td>
</tr>
<tr>
<td></td>
<td>Increased noise caused by changes in nonpulsatile component of light absorption</td>
<td>False alarms</td>
<td>Stabilize sensor</td>
</tr>
<tr>
<td>Poor perfusion</td>
<td>Decreased signal caused by decreased pulsatile (arterial) component of light absorption</td>
<td>Lower SPO2 readings</td>
<td>Change sensor position</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Use new-generation pulse oximeters</td>
</tr>
<tr>
<td>Increased noise caused by changes in nonpulsatile component of light absorption</td>
<td></td>
<td></td>
<td>Evaluate plethysmographic waveform</td>
</tr>
<tr>
<td>Poor perfusion</td>
<td>Decreased signal caused by decreased pulsatile (arterial) component of light absorption</td>
<td>Lower SPO2 readings</td>
<td>Check and correct skin temperature and peripheral perfusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Place sensor more centrally</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Use new-generation pulse oximeters</td>
</tr>
<tr>
<td>False alarms</td>
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<td>Change sensor position</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Use new-generation pulse oximeters</td>
</tr>
<tr>
<td>Skin pigmentation</td>
<td>Probably caused by calibration assumptions for dark skin pigmentation</td>
<td>Lower or less reliable SPO2 readings at lower SaO2 values</td>
<td>Use new-generation pulse oximeters</td>
</tr>
<tr>
<td>Nail polish and artificial nails</td>
<td>Decreased signal because of decreased light absorption with artificial nails or nail polish of black, blue, or green color</td>
<td>Lower SPO2 readings</td>
<td>Change sensor position</td>
</tr>
<tr>
<td>Irregular rhythms</td>
<td>Increased noise caused by tachyarrhythmias</td>
<td>Lower or less reliable SPO2 readings</td>
<td>Use new-generation pulse oximeters</td>
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<tr>
<td>Electromagnetic interference</td>
<td>External electromagnetic energy interference caused by electrosurgical cauterization units, cellular phones, or MRI devices</td>
<td>Lower SPO2 readings</td>
<td>Evaluate plethysmographic waveform</td>
</tr>
<tr>
<td>Electromagnetic interference</td>
<td></td>
<td>False alarms</td>
<td>Evaluate plethysmographic waveform</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Avoid external electromagnetic energy sources</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Use pulse oximeters with fiber-optic technology (MRI)</td>
</tr>
<tr>
<td>Potentially unsafe limitations</td>
<td>Device-specific calibration algorithms derived by correlating light absorption ratios over a SaO2 spectrum of 80%–100% in healthy young adults</td>
<td>SPO2 readings of &lt;80%–85% are less accurate especially at the extremes of the age spectrum</td>
<td>Use new-generation pulse oximeters</td>
</tr>
<tr>
<td>Calibration</td>
<td></td>
<td></td>
<td>Do not use pulse oximetry as a substitute for cardiorespiratory monitoring in critically ill patients</td>
</tr>
<tr>
<td>Time lag</td>
<td>Software-related delay between sudden changes in blood oxygenation and SPO2 readings</td>
<td>Delay in detecting clinically important desaturation, which may exceed 15–20 s</td>
<td>Use new-generation pulse oximeters</td>
</tr>
<tr>
<td>Probe positioning</td>
<td>The emitted light energy is projected tangentially to the detector because of inappropriate sensor placement (&quot;penumbra&quot; or &quot;optical shunting&quot; effect)</td>
<td>Lower SPO2 readings</td>
<td>Place sensor with the emitter and the detector exactly opposite to each other</td>
</tr>
<tr>
<td>Ambient light interference</td>
<td>Intense external light energy (as in phototherapy) may interfere with the photodetector (&quot;flooding&quot; effect)</td>
<td>Lower SPO2 readings</td>
<td>Use probes of appropriate size in neonates and infants</td>
</tr>
<tr>
<td>Abnormal hemoglobin molecules</td>
<td>C0Hb presents red-light absorption similar to oxyhemoglobin (COHb absorbs equal amount of energy in the red and infrared spectra, which affects the ratio of absorption)</td>
<td>In carboxyhemoglobinemia pulse oximetry overestimates blood oxygenation, In significant methemoglobinemia, SPO2 tends toward 85%</td>
<td>Use new-generation pulse oximeters</td>
</tr>
<tr>
<td>Pulsatil veins</td>
<td>Increased noise because of pulsations of venous blood (ie, significant tricuspid regurgitation, hyperdynamic circulation states)</td>
<td>Lower or less reliable SPO2 readings</td>
<td>Check arterial SaO2 if abnormal hemoglobin molecules are suspected (ie, carbon monoxide intoxication)</td>
</tr>
<tr>
<td>Intravenous dyes</td>
<td>Intravenous dyes such as methylene blue, indocyanine green, and indigo carmine interfere with light absorption</td>
<td>Lower SPO2 readings</td>
<td>Use new-generation pulse oximeters</td>
</tr>
</tbody>
</table>

**Notes:**

- Safe limitations are circumstances in which a possible inaccuracy in the displayed SPO2 can be easily suspected; the observer is usually warned by the device (alarm) about the pitfall. Potentially unsafe limitations are those situations in which the inaccuracy is difficult to recognize; the displayed SPO2 is erroneous but the observer is not warned about the pitfall.
- New-generation pulse oximeters are less susceptible to these limitations because of more sophisticated calibration and signal-extraction algorithms.
- Pulse co-oximeters are capable of detecting abnormal hemoglobin molecules by using multiwavelength technology.
of absorption ratios into percent saturation by using specific calibration algorithms. These algorithms are derived by correlating the ratio of the absorption ratios with arterial gas SaO₂ measurements in healthy young volunteers over a range of desaturation values. Because it is unethical to desaturate volunteers below SaO₂ levels of ~80%, lower SpO₂ values are derived by extrapolation and, therefore, are less accurate.13,15,24,29,34 Moreover, because the subjects recruited for calibration purposes are healthy young adults, the applicability of calibration data to patients at the age extremes has been questioned.13,15,25,30,34

**Time Lag in the Detection of Hypoxic Events**

Most conventional pulse oximeters present a clinically significant delay between a sudden change in blood oxygenation and the related change in the displayed SpO₂ values. This time lag depends on the complexity of the algorithms used and might exceed 15 to 20 seconds.34,65–66 Although new-generation devices have improved response times, and desaturation events can be detected earlier if the probe is placed more centrally (eg, at the ear lobe),13,21,65 pulse oximetry should not be used as a substitute for cardiorespiratory monitoring in critically ill patients.30,34

**Probe Positioning**

Lower SpO₂ readings might occur when the probe is inappropriately placed, especially on the small fingers of neonates and infants.15,28 In this case, the emitted light can be projected tangentially to the detector; sometimes without crossing an arterial bed, phenomena which have been described as the “penumbra” and “optical shunting” effects, respectively.50,67 This pitfall can be avoided by positioning the emitter and the detector exactly opposite to each other and by using probes of appropriate size for neonates and infants.13,28,34

**Abnormal Hemoglobin Molecules**

Abnormal or variant hemoglobin molecules might interfere with pulse oximetry and lead to falsely low SpO₂ readings. This phenomenon, known as the “flooding” effect, is caused by the excessive increase of the light energy that literally floods the photodetector and drives the ratio of absorption ratios toward the unit; this corresponds to an SpO₂ of 85%.16 Although new-generation devices can detect light interference,15,21,34,68 health care professionals, particularly those who handle neonates exposed to phototherapy, must be aware of this potential limitation. Ambient light interference can be avoided by simply covering the sensor with nontransparent material.

**Venous Pulsation**

In case of significant tricuspid regurgitation and in hyperdynamic circulation states, the pulsatile variation of venous blood might affect signal-to-noise ratio and result in erroneous SpO₂ readings.85,86

**Intravenous Dyes**

Intravenous dyes such as methylene blue (actually used as a first-line treatment for severe methemoglobinemia), indocyanine green, and indigo carmine might cause lower SpO₂ readings.15,34,87,88
APPLICATIONS OF PULSE OXIMETRY IN PEDIATRIC PRACTICE

Pulse oximetry has become widely available in various aspects of pediatric care. It is routinely found in the emergency department and the pediatric ward, and it is regarded as an essential element of patient monitoring in pediatric intensive and perioperative care. Its use in the assessment of respiratory and hemodynamic parameters in advanced pediatric care settings is beyond the intentions of this review.

Normal Values

Normal pediatric SpO2 values have not yet been established. Pulse-oximetry readings vary with age and altitude.89,90 The substantial variation of normal SpO2 values among studies can be attributed to differences in sample size, instruments used, health of participants, probe positioning, and measurement protocols. Thus, in healthy infants and children, mean SpO2 values at sea level have been reported to be 97% to 99% (−2 SDs, 95%–96%)91–93 and they might be lower in neonates and young infants (range: 93%–100%).93 At moderate altitudes SpO2 values are somewhat lower (mean: 97%–98%; −2 SDs, 93%–96%)94,95 and decrease further at high altitudes (>3000 m; mean: 88%–91%; −2 SDs, 74%–82%).89,96,97,98,99 Authors of a recent systematic review concluded that supplemental oxygen should be administered to children who reside at altitudes of >3000 m if the SpO2 is <85%.99

Most children also exhibit a progressive fluctuation in SpO2 during a 24-hour cycle. Maximal values occur in the late afternoon, whereas minimal values appear in the first morning hours. This pattern is evident regardless of whether children are asleep or awake.100 Basal SpO2 values reported by polysomnography or home monitoring range from 95% to 100%, but normal saturation nadirs can be as low as 84% to 86%.101–105 However, although SpO2 values in the range of 90% to 93% are not uncommon during sleep, they might be associated with poorer academic performance.104

Disease-Specific Applications

Respiratory Applications

In pediatric practice, pulse oximetry must be readily available in any situation associated with hypoxemia. Oxygen saturation is a particularly sensitive indicator of disease severity in conditions associated with ventilation/perfusion (V/Q) mismatch, such as exacerbations of asthma or chronic lung disease of prematurity, acute bronchiolitis, and pneumonia.3,4,21,26,105–108 Conversely, SpO2 is not a reliable indicator of disease severity in proximal (laryngeal or tracheal) airway obstruction such as acute laryngotracheitis, foreign-body aspiration, and vocal chord dysfunction.34 The principle mechanism of hypoxemia in such cases is hypoventilation, which primarily leads to an increase in PaCO2. These patients might not present with particularly low SpO2 readings98,38–40 because, per the alveolar gas equation,109 an SpO2 of <90% requires a PaCO2 of ~80 mm Hg. It should be noted that coexistent diffuse peripheral airway obstruction (eg, laryngotracheobronchitis) might cause V/Q mismatch leading to a lower SpO2 level. In the later scenario, however, hemoglobin desaturation reflects a secondary pathophysiological process rather than the primary mechanism of the disorder.

Current guidelines state that oxygen saturation should be monitored by pulse oximetry during asthma exacerbations to assess severity of the disease and response to treatment.110,111 Mild asthma exacerbations are associated with SpO2 values of >95%, moderate exacerbations with values of 90% to 95%, and severe exacerbations with values of <90%.110,111 Although SpO2 values of <92% at presentation have been suggested to predict hospitalization or return to the hospital,112 more recent studies have not confirmed this finding.113–116 Instead, a 1-hour post-treatment SpO2 of <92% to 94% has been shown to be a better predictor of the need for hospitalization.113–115

To date, there is no consensus on the SpO2 thresholds that should be used to admit, treat, and discharge infants with acute bronchiolitis.117–120 The American Academy of Pediatrics guideline recommends administration of supplemental oxygen if SpO2 values fall to <90%.117 The Scottish Intercollegiate Guidelines Network (SIGN) recommends admission for all symptomatic infants with SpO2 values of ≤92%, whereas the decision to admit and/or treat patients with an SpO2 value of 93% to 94% should be made on an individual basis.118 Intermittent is preferred over continuous SpO2 monitoring in hospitalized infants, and patients should be considered for discharge when the SpO2 is >94% in room air after an observation period of 8 to 12 hours.118 SpO2 values of <94% have been shown to increase the likelihood of admission and to predict longer hospital stay121–123; however, small differences in SpO2 (92% vs 94%) might significantly influence the decision to admit or discharge.124 Therefore, it is evident that, on the basis of SpO2 values alone, many infants with bronchiolitis will be hospitalized and treated for prolonged periods of time while all other problems have resolved.125,126

Pulse oximetry is essential for prompt detection and management of pediatric pneumonia, because infants and children might not appear cyanotic despite significant hypoxemia.127 The British Thoracic Society guideline for the management of community-acquired pneumonia recommends that symp-
titration of inspired oxygen concentration, it cannot reliably prevent hyperoxic events.\cite{13,19,30,34} \(\text{SPO}_2\) values of \(>92\%\) do not accurately correlate with \(\text{PaO}_2\), as is clearly depicted by the shape of the ODC (Fig 3). At such high \(\text{SPO}_2\) values, small variations of \(\text{SPO}_2\) might relate to disproportionally wider variations of \(\text{PaO}_2\).\cite{145} Therefore, caution is required when interpreting pulse-oximetry readings in situations in which hyperoxia is to be avoided, especially in case of preterm and low birth weight neonates for whom excessive oxygen administration can be particularly harmful.\cite{146–151} Although a single best range has not been established yet, there is convincing evidence that \(\text{SPO}_2\) values between 85\% and 93\% are sufficient to maintain normoxia\cite{152} and to decrease the incidence of retinopathy of prematurity in infants receiving supplemental oxygen.\cite{148–151} In extremely preterm neonates, however, lower \(\text{SPO}_2\) targets (ie, 85\%–89\%) have been associated with an increased risk of mortality compared with higher \(\text{SPO}_2\) levels (ie, 91\%–95\%).\cite{153} Further ongoing trials on this issue are expected to resolve the uncertainties surrounding optimum \(\text{SPO}_2\) range in premature neonates receiving supplemental oxygen.\cite{154}

**NOVEL TECHNOLOGIES AND FUTURE DIRECTIONS**

Pulse oximetry has been proven to be an extremely useful tool in patient assessment and monitoring in pediatric practice. However, its widespread use over the last 3 decades has also revealed its inherent limitations. The theoretical model of conventional pulse oximetry assumes that the arterial blood is the only light-absorbing pulsatile component. However, this assumption has been challenged by \(\text{SPO}_2\) readings during motion that fall to \(<85\%\) (which corresponds to a ratio of absorption ratios equal to 1); this
should not be the case if these desaturations were merely the result of uncharacterized noise. New theoretical models assume that nonarterial absorbers also generate a pulsatile signal when motion occurs and that the ratio of absorption ratios should be considered a composite of arterial and nonarterial pulsatile components. These novel conceptual models are also applicable to situations of low signal-to-noise ratio such as low-perfusion states. Thus, new-generation devices use improved algorithms of signal extraction, which ultimately result in more accurate \( \text{SpO}_2 \) readings, especially under critical conditions.\(^{155,156}\) In addition, new theories of multiwavelength pulse oximetry are expected to further improve the performance and applicability of these devices.\(^{157}\) Reflectance pulse oximeters that are based on absorption analysis of reflected rather than transmitted light have been also introduced into clinical practice.\(^{158}\) In light of these ongoing technological advancements, clinical trials on how to incorporate pulse oximetry into evidence-based diagnostic and management algorithms in daily pediatric practice are urgently required.

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HOW MUCH IS ENOUGH?: Many of my friends exercise all the time, whereas others hardly ever do. When I ask those not exercising why they don’t, most say they don’t have enough time, that it is too hard to start, or that exercising just a few minutes a day is unlikely to be beneficial. Exercise physiologists and others have long wondered just how much aerobic exercise each day or each week is necessary to produce a health benefit in adults. As reported in USA Today (Fitness & Food: August 2, 2011), it turns out that it doesn’t take much at all. Federal guidelines suggest that adults should engage in 150 minutes of moderate-intensity activity each week; this is still a reasonable goal. However, new data suggest that almost any amount of exercise may be beneficial. Adults engaging in as little as 10 to 15 minutes/day of moderate-intensity exercise accrue some benefit in the prevention of heart disease. In studies evaluating the risk of heart disease in sedentary and exercising adults, the most dramatic health benefits were seen in those who went from not exercising at all to exercising a little bit. The data also show that there is an indirect relationship between the amount of exercise and the risk of heart disease. Compared to sedentary people, those who engaged in 150 minutes of moderate-intensity exercise each week had a 14% reduced risk of heart disease. Those who exercised 300 minutes/week had a 20% risk reduction, and a 25% risk reduction if they exercised 750 minutes/week. Women, for unknown reasons, derive a greater benefit from exercise than men. Bursts of activity followed by long periods of inactivity, however, were not beneficial. This suggests that for better health, one needs to keep moving. Although researchers have not been able to quantify the exact health benefit to 75 minutes of weekly moderate-intensity exercise, the American College of Sports Medicine recently revised its guidelines. Although the guidelines still recommend that adults engage in at least 150 minutes of moderate-intensity exercise each week to achieve weight reduction and help maximize the health benefits of exercise, just a little exercise, such as 75 minutes/week, is likely to be beneficial. The data are fairly clear. To borrow a marketing phrase from Nike: just do it.

Noted by WVR, MD