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# Educating the Educator: Use of Pulse Oximetry in Athletic Training

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## INTRODUCTION

The 5th edition of the Athletic Training Education Competencies expanded the scope of knowledge and skill set of entry-level athletic trainers related to the domain of Acute Care of Injuries and Illnesses.[1] One of these major changes includes the introduction of adjunct airway techniques,[1,2] such as oropharyngeal and nasopharyngeal airways and suction. Another new addition includes the use of pulse oximetry to assess oxygen saturation levels (Table 1). The addition of these acute care knowledge and skill competencies were incorporated into the athletic training curriculum to reflect the National Athletic Trainers' Association's currently published position statement recommendations, as well as those in development.[1] The purpose of this column is to provide athletic training educators (ATE) with a resource on how to use and teach pulse oximetry within their educational programs.

## WHAT IS PULSE OXIMETRY?

Pulse oximetry in the pre-hospital setting provides a rapid, noninvasive measurement and monitoring technique to estimate peripheral oxygen saturation ($SpO_2$) of hemoglobin,[3-5] and provides a measure of cardio-respiratory function.[6,7] The use of pulse oximetry also establishes the effectiveness of medical interventions[8-10] through identifiable improvements in baseline $SpO_2$ levels and can quickly detect hypoxemia[6] (ie, insufficient oxygenation of arterial blood). However, "unlike the thermometer, pulse oximeters are complex machines and the physiological processes they assess are also complex."[4 (p. 24)] Thus, it is necessary to understand the underlying physiology of oxygenation that affects arterial oxygen saturation in order to properly interpret the results and guide clinical decision-making. Athletic trainers must understand that oxygen saturation values obtained from pulse oximetry are only ONE component of a complete assessment of the patient's oxygenation status.[5]

## BLOOD GASES AND OXYGENATION

### Oxygen and Carbon Dioxide

Blood gases assist with determining oxygenation, or the exchange of oxygen ($O_2$) molecules (moving into the blood from the lungs) and carbon dioxide ($CO_2$) molecules (moving into the lungs from the blood), and acid/base (pH) balance. The measurement of blood gases is important in cases of poor oxygenation or pH imbalances where patients demonstrate dyspnea, apnea, nausea or vomiting. These measurements are obtained either noninvasively, with the use of a pulse oximeter to estimate only peripheral oxygen saturation, or invasively (outside the scope of practice of an athletic trainer), with an arterial blood gas measurement, an authentic measurement of respiratory function.

Table 1. Acute Care of Injuries and Illnesses Competencies focusing on Pulse Oximetry

| Number | Competency |
|---|---|
| AC-6 | When appropriate, obtain and monitor signs of basic body functions including pulse, blood pressure, respiration, pulse oximetry, pain and core temperature. Relate changes in vital signs to the patient's status. |
| AC-18 | Access oxygen saturation using a pulse oximeter and interpret the results to guide decision-making. |

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Several specific blood gas measurements are possible when drawing arterial blood, making it the gold standard in determining oxygenation. These measures are interrelated with other component tests of blood gases and the results must be considered together when assessing the overall status of a patient. The first value, Partial Pressure of Oxygen In Arterial Blood, or $PaO_2$, is used to assess the pressure of oxygen dissolved in blood and the ability of oxygen to move from the alveoli sac of the lungs into the blood (ie, measurement of gas exchange). Second, Partial Pressure of Carbon Dioxide, or $PaCO_2$, measures the amount of carbon dioxide dissolved in the blood and how well carbon dioxide moves out of the body (ie, assesses adequacy of ventilations). Third, Arterial Oxygen Saturation, or $SaO_2$ (oxygen saturation), is a direct measure of the percent of oxygen bound to hemoglobin via a blood draw. Finally, $SpO_2$ is the estimated oxygen saturation of hemoglobin as measured by a pulse oximeter and given as a percentage, with normal around 96%. The relationship of $PaO_2$, $PaCO_2$ and $SaO_2$ is outlined in Table 2. Several other blood gases values do exist, but are beyond the scope of this article.

Table 2. Normal Blood Gas Values

| Gas | Definition | Normal Values |
|---|---|---|
| $PaO_2$ | Partial pressure of oxygen that is dissolved in arterial blood | 80 to 100 mm Hg |
| $PaCO_2$ | Amount of carbon dioxide dissolved in arterial blood | 35-45 mm Hg |
| $SaO_2$ | Arterial oxygen saturation | 95% to 100% |
| $SpO_2$ | Estimated of arterial oxygen saturation | 95% to 100% |

These are average reference ranges. Values may vary between analyzers, laboratories, and reference manuals.

## Oxygen Dissociation and Its Effects on Pulse Oximetry

As a foundation for utilizing pulse oximetry, a review of tissue perfusion physiology is also warranted. In addition to an adequate availability of oxygen, 3 other factors impact pulmonary perfusion: (1) an adequate blood volume, (2) intact pulmonary capillaries, and (3) the efficient pumping of blood by the heart.[11] Oxygen is transported in the blood by red blood cells bound to hemoglobin (oxyhemoglobin or $HbO_2$), or is dissolved in the plasma (deoxyhemoglobin), 98% and 2% respectively.

Oxygen dissociation describes the equilibrium of oxyhemoglobin and deoxyhemoglobin. In areas containing a high partial pressure of $O_2$ (ie, lungs), $O_2$ binds to hemoglobin to form oxyhemoglobin. The partial pressure of $O_2$ will decrease as oxyhemoglobin moves into body tissues that are deprived of oxygen, releasing $O_2$ for metabolic use and acquiring $CO_2$ for transport back to the alveoli sac. While a strong positive correlation between the percentage of available hemoglobin that is bound to oxygen ($SaO_2$) and $SpO_2$ exists,[12] the assurance of adequate ventilation (carbon dioxide and acid base balance) must be continually monitored in the acutely ill or injured patient in order to avoid overestimation of $SpO_2$, especially in the presence of hypoxemia.[13]

In the presence of increased blood carbon dioxide ($PaCO_2$), hemoglobin will lose its affinity for oxygen. As $CO_2$ levels increase in the tissues, more $O_2$ is released from hemoglobin, thus decreasing oxyhemoglobin levels and lowering the pulse oximeter reading (right shift on the oxygen dissociation curve). A loss of affinity for oxygen is also noted with an increase in body temperature, an increase in 2,3-diphosphoglycerate (2,3-DPG), an organic phosphate salt found in red blood cells, or a decrease of blood pH (hydrogen ion concentration). A shift in the oxygen dissociation curve to the left indicates opposite conditions exist. Figure 1 represents the relationship between the partial pressure of $O_2$ and oxyhemoglobin, and Table 3 outlines the interpretation for $SpO_2$ readings.

Table 3. Interpretation of Pulse Oximetry Readings.[11]

| SpO2 Reading % | Interpretation |
|---|---|
| 95-100 | Normal |
| 91-94 | Mild Hypoxemia |
| 86-90 | Moderate Hypoxemia |
| <85 | Severe Hypoxemia |

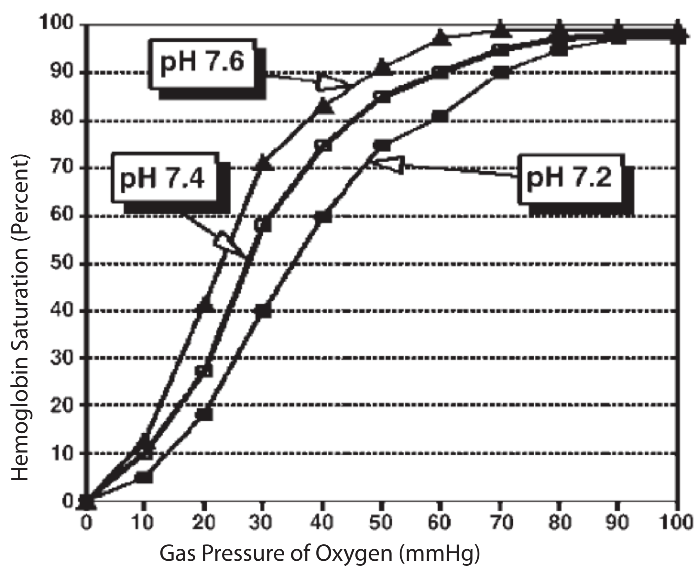



Figure 1. Oxygen Dissociation Curve.[11]

Note: A shift in the curve to the right indicates a decrease in available oxyhemoglobin. Reproduced, with kind permission, from Dr. David McShaffrey, Marietta College, Marietta, OH http://www.marietta.edu/~mcshaffd/index.html

## UNDERSTANDING THE PULSE OXIMETER

### Unit Design

Developed in the mid-1970s, pulse oximeters are small hand-held devices that indirectly measure (estimate) oxygen saturation levels and heart rate. The pulse oximeter functions based on the principle that saturated hemoglobin and desaturated hemoglobin absorb light at different frequencies.[4,5,14] Pulse oximeter units use light-emitting diodes containing two light sources, visible (red) and infrared light, and a photo sensor. The saturated hemoglobin absorbs visible light, while desaturated hemoglobin absorbs the infrared light. The light source and the photo sensor are placed on either side of an artery (eg, radialis indicis artery of the index finger). When light from the light-emitting diodes is transmitted through an artery's pulsating blood flow (normally for 5 pulses) and surrounding tissues, the hemoglobin (saturated and desaturated) absorbs the different light frequencies.[14] The difference in the amount of light absorbed by the saturated and desaturated hemoglobin, as detected by the photo sensor, is then converted into a digital value representing the percentage of hemoglobin saturated with oxygen. This conversion is based on a complex algorithm for calculating exact saturation and separating arterial pulsation from motion artifact,[14] and is a close estimation to the arterial oxygen saturation in the hemoglobin.[15]

### Pulse Oximetry Measurement Accuracy

#### Non-physiological Factors

The accuracy of $SpO_2$ measurements can be affected by both non-physiological and physiological variables. Two non-physiological variables an athletic trainer (AT) can control are frequency of unit calibration and ensuring proper placement of the unit on the finger or earlobe. New unit measurement accuracy is approximately ±2% for values over 90% and higher when values are reported below 80% saturation.[4] To maintain a high level of accuracy, units should be calibrated on a yearly basis. When a unit is placed improperly on the finger (or other body part being assessed) the light does not pass through the vascular bed correctly when traveling from the light-emitting diode to the photo sensor.[15]

Table 4. Factors Affecting the Placement and Function of a Finger Tip Pulse Oximeter

| |
|---|
| Trauma to the digits (ie, contusion) |
| Decreased peripheral pulses |
| Decreased core temperature |
| Decreased blood pressure |
| Exposure to excessive ambient light (eg, too large of a sensor over a finger) |
| Excessive movement |
| Presence of nail polish |
| Incorrect sensor size (eg, too large sensor will not stay in place, too small of a sensor may constrict arterial flow and provide false low readings). |

Because pulse oximeters use light and color to determine oxygen saturation levels[4] the amount of bright ambient light seen by the photo sensor, a dirty sensor,[7] and dried blood can affect the accuracy of the $SpO_2$ measurement. Patient movement or dislodging the unit (known as motion artifact) experienced with a seizure, hypothermia (ie, shivering), and cardiopulmonary resuscitation also reduces the accuracy of the unit.[15,16] Therefore, when using a pulse oximeter, particularly a figure tip unit, it is necessary to consider when and where to place the unit for the most accurate reading, (Table 4) as a poor signal will result in inaccurate or absent readings.

The effects of nail polish[17-23] and acrylic nails[24] on pulse oximetry have also been studied extensively. Early studies (1980s) on non-hypoxic patients found clinically significant decreases in $SpO_2$ values[19,21,22] particularly with the nail polish colors of blue, black, green, and purple. Later studies (2000s) examining the effects of nail polish color demonstrate more accurate $SpO_2$ measurements, with $SpO_2$ changes less than 2%, compared to the control groups when black, blue, and purple nail-polish were used.[17,18,20] In the mildly hypoxic patient (induced by changes in altitude) nail-polish color (black, blue, purples, green, brown/maroon, white glitter, red, orange, and pink) appear to have no significant effect on $SpO_2$ values.[23] In the presence of artificial nails there appears to be no significant difference in $SpO_2$ values between the unpolished acrylic fingernails (97.53%) and natural unpolished fingernails (97.33%).[24]

#### Physiological Factors

One significant physiological factor affecting the pulse oximeter's measure of cardiorespiratory function is a low perfusion state. Because $SpO_2$ measurements are a function of the artery's pulsating blood flow, a patient must have sufficient perfusion in the monitored area (eg, index finger). Patients with a weak or absent peripheral pulse, such as those with hypotension, hypovolemia, hypothermia, or cardiac arrhythmia may present with inaccurate measurements[15] due to a lack of an adequate peripheral pulse. Additionally, when using an automatic blood pressure cuff a pulse oximeter should not be placed ipsilaterally because blood flow to the finger will be greatly reduced whenever the cuff inflates.[15,25]

Patients who smoke and/or who are diagnosed with anemia may have falsely high $SpO_2$ measurements.[4,15] Carbon monoxide, a by-product of smoking, is a colorless and odorless gas that competes for the same binding sites with oxygen on hemoglobin. In fact, the carbon monoxide bind to hemoglobin is approximately 250 times stronger than that of an oxygen molecule.[15] When carbon monoxide binds to hemoglobin it alters the color of hemoglobin making the pulse oximeter unable to accurately detect hemoglobin carrying oxygen and carbon monoxide.[4,15] Anemia affects pulse oximeter measurements in patients during hypoxemia. The causation is not completely understood, but is believed to "be due to photon scattering of light and a shift in red light wavelength increasing its absorption."[26 (p. 43)] Other physiological factors affecting $SpO_2$ measurements can be found in Table 5.

### Indications, Contraindications, and Precautions

The use of pulse oximetry does not preclude the necessity of a thorough comprehensive and ongoing assessment of your patient. A clinical assessment of adequate oxygenation and perfusion status is always required, with treatment based on clinical findings and patient history. Waiting for the pulse oximeter to indicate less

Table 5. Physiological Factors Affecting $SpO_2$ Measurements

| |
|---|
| Arterial blood flow to the vascular bed |
| Hemoglobin level |
| Temperature of the digit or the area where the oximetry sensor is located |
| Patients's oxygenation ability |
| Percentage of inspired oxygen |
| Venous return at the probe location |
| Presence of anemia, carbon monoxide, cyanide or increased $CO_2$ (carbaminohemoglobin) |
| Abnormal pH |
| Increase or decrease in 2, 3-DPH, $CO_2$ or core body temperature |

than optimal tissue oxygenation places you, and the patient, in a reactive versus proactive response situation. As indicated previously, the assurance of adequate ventilation remains a priority regardless of the value obtained by pulse oximetry.

Indications for the use of pulse oximetry include the need to: (1) monitor the adequacy of arterial oxyhemoglobin saturation in any individual who presents with a complaint or assessment findings related to altered mental status, respiratory distress or signs and symptoms of shock, (2) quantify the response of arterial oxyhemoglobin saturation to therapeutic intervention, (3) quantify the response of arterial oxyhemoglobin saturation during a diagnostic procedure, and (4) comply with institutional or facility policies and procedures.[27] Other than the potential for a formation of pressure ulcers secondary to long-term use, no relative contraindications exist.[27]

Even though pulse oximetry is a safe procedure, false-negative results for hypoxemia and/or false-positive results for normoxemia or hyperoxemia can lead to inappropriate patient treatments.[27] Conditions where hemoglobin is bound by carbon monoxide, cyanide, or $CO_2$ (carbaminohemoglobin), may present with tissue hypoxia even with a high measurement reading by the pulse oximeter. Ensure worn probes are replaced with new probes designed specifically for your unit and that the unit is calibrated at least yearly. Injury from an electrical shock and/or burns can occur when incompatible probes are used.[27]

## Application

The steps describing how to properly use a fingertip pulse oximeter are found in Table 6. Once placed on the finger the AT should monitor the position and movement of the pulse oximeter. Excessive movement/shaking of unit can result in unreliable measurements as well as exposure to excessive bright light, which can result in inflated values. If either of these events occurs, consider moving the unit to a different site and shielding the unit with a blanket or towel, respectively. The following information should be documented during the course of care: (1) patient's $SpO_2$ level and location the reading was obtained (finger, earlobe), (2) patient's heart rate, (3) patient's assessment at the time of measurement, and (4) any other factor affecting appropriate assessment. At the conclusion of care, remove the unit and clean according to the manufacturer's directions.

# EDUCATIONAL CONSIDERATIONS

## Equipment

Today there are many different makes and models of pulse oximeters available in the marketplace. Most models provide a visual (bar graph, waveform) digital output and audible display of arterial pulsations and heart rate[15] particularly when the $SpO_2$ or heart rate falls below a predefined level. The size and weight of the pulse oximeter should be considered, as lighter units normally result in less unit movement of the unit and therefore more accurate results. Some models offers resistance to light interference to increase the sensitivity of the oxygen saturation measurement and many manufacturers equip pulse oximeters with a signal quality monitor and alarm.[26] Some models offer software to upload and analyze up to 24 hours of data at a time, while others offer the ability to transmit measurement with Bluetooth wireless technology. The selection of a particular unit will depend on the intended use of the unit and setting in which it is used.[15]

Practicing pulse oximetry in the pre-hospital or educational setting requires very little equipment – normally just a fingertip pulse oximeter and a carrying case to protect the unit. Units can range in price from $69.00 to $385.00. Price is obviously contingent on the features attached to the unit as well as the quality of the light-emitting diodes and photo sensors (Table 7). An Internet search for "finger pulse oximeter" using Google Shopping results in units ranging in price from $22.00-$382.00. The moral of the story here is, "Shoppers beware!"

## Teaching the Skill

A tremendous benefit to utilizing this technology resource is the ease of education. From a cognitive aspect, just a couple of questions on what is pulse oximetry, how it works, and how to interpret the information may be easily developed. The psychomotor education component is accomplished through actual application of the device in the classroom and clinical setting. The non-invasive nature along with the ability to alter information output through restriction of blood flow (eg, applied to an extremity while taking a blood pressure) easily demonstrates varying feedback of audio and waveform output as well as digital readouts. Remember, there may be restrictions to utilizing educational equipment in the actual clinical setting dependent upon organizational structure and student policy and procedures. Please refer to your individual biomedical department or administrative resource to determine specific restrictions, if any.

# CONCLUSION

The concepts of pulse oximetry, especially those required by educational competencies, should not be viewed as a challenge; rather they should be viewed as an advancement of the profession. Yes, it does add to already long list of knowledge and skills required for an entry-level AT, however, these are also skills required for proper emergency care of a patient. If ATs are truly going to be the "first" on the scene of an emergency situation, then having the requisite training on one of the most fundamental skills taught in every emergency medical responder course is important.

Table 6.  Using a Fingertip Pulse Oximeter

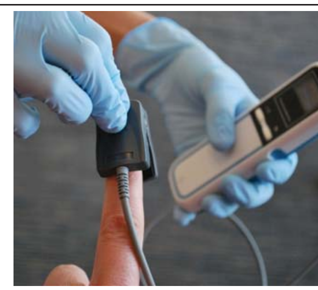
| Steps | Procedure | Image |
|---|---|---|
| 1. | Assume body substance isolation (BSI). | |
| 2. | Select the appropriate size fingertip pulse oximeter and sensor to optimize signal capture and minimizes artifact-related difficulties. |  |
| 3. | Turn on the pulse oximeter and ensure proper functioning of the unit. |  |
| 4. | Select the desired sensor site; normally the index finger of hand without a sphygmomanometer attached. | |
| 5. | Apply the pulse oximeter in a method that allows the light-emitting diodes to be opposite the photo senor and shielded from excessive ambient light.<br><br>Note: Consider removing fingernail polish as needed.  Do not delay immediate care. |  |
| 6. | Allow the unit to measure the pulsating blood flow (normally 5 pulses). | |
| 7. | Determine accuracy of by comparing the manually measured numeric heart rate value to the unit's monitored heart rate. | |
| 8. | Document the baseline results. |  |
| 9. | Monitor changes in the patient pulse oximetry values and respiratory status.<br><br>Do not wait for less-than-optimal tissue oxygenation as reported via the pulse oximeter before providing medical interventions. | |

Table 7. Pulse Oximeter Finger Unit Resources.

| Company | Web Address | Equipment | Retail Price |
|---|---|---|---|
| Savelives.com | http://www.savelives.com | SPO Medical PulseOx 5500 Finger Unit | $189.00 |
| | | SPO5500 Carry Case | $15.00 |
| | | BCI Digit Pulse Oximeter | $380.00 |
| | | BCI Fingerprint Pulse Oximeter | $665.00 |
| | | BCI Fingerprint Nylon Carry Case | $35.00 |
| | | Model 9500 Finger Sized Pulse Oximeter | $385.00 |
| | | Model 9500 Belt Loop Carry Case | $17.50 |
| eNasco | http://www.enasco.com | Fingertip Pulse Oximeter | $88.00 |
| CPR Saver | http://www.cpr-savers.com | Finger Pulse Oximeter – Item - MDC22 | $69.95 |
| | | Digit® Finger Oximeter | $319.00 |
| | | View 02 Fingertip Pulse Oximeter – Item - 180-5055 | $128.25 |
| | | Fingertip Pulse Oximeter - Item - MS-74001 | $225.00 |
| Laerdal | http://www.laerdal.com | Contact Laerdal directly at (877) LAERDAL | |

Note: Speak with a company representative to inquire about educational pricing



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