

# Pulse Oximetry and the Oxyhemoglobin Dissociation Curve

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## Course Outline

- I. [Course Objectives](#)
- II. [Introduction](#)
- III. [History](#)
- IV. [Pulse Oximeter Definition](#)
  - A. [What is it?](#)
  - B. [What does it do?](#)
  - C. [How does it do it?](#)
  - D. [What is a normal level?](#)
- V. [Proper Technique](#)
- VI. [Understanding Oxyhemoglobin](#)
- VII. [Oxyhemoglobin Dissociation Curve](#)
  - A. [Definition](#)
  - B. [Oxygen-hemoglobin Affinity Changes](#)
  - C. [Shift to the Left](#)
  - D. [Shift to the Right](#)
- VIII. [Indications](#)
- IX. [Interference/ Device Limitations](#)
- X. [Conclusion](#)

## Course Objectives

Upon completion of this course, the participant will be able to:

- Define pulse oximeter.
- Describe how the pulse oximeter works.
- Differentiate between normal and abnormal values.
- List indications for use of a pulse oximeter.
- State the limitations of a pulse oximeter.
- State proper technique in using the pulse oximeter.
- Identify causes of left or right shift in the oxyhemoglobin dissociation curve.
- Describe what is meant by the hemoglobin's affinity for oxygen.
- List possible sites for the pulse oximeter probe attachment.

## Introduction

A 12-year-old boy is undergoing conscious sedation for reduction of a dislocated shoulder. He is sleeping with shallow respirations. Is his sedation at an appropriate level or is his oxygenation inadequate due to a decrease in respiratory effort?

A 20-year-old woman arrives in the emergency department complaining of shortness of breath and tingling in her fingers and face. Her respiratory rate is 48. Is this hyperventilating due to anxiety or hypoxia?

A 70-year-old man is immediately status post total hip replacement and has recently been extubated. Is his respiratory effort sufficient for adequate oxygenation?

The use of pulse oximetry can help answer these questions and assist healthcare providers in providing the best patient care. The readings obtained in each of these cases will help determine the appropriate medical management.

Pulse oximetry is a simple, non-invasive method of monitoring the oxygen saturation of arterial capillary blood. It is now widely used in a number of healthcare settings and is often referred to as the fifth vital sign. The pulse oximeter is a convenient, cost-effective way to monitor the patient's oxygenation status and determine changes before they are clinically apparent. It is important to know how oximeters work in order to maximize their performance and avoid errors in the interpretation of results.

## **History**

Oximetry measures the percentage of hemoglobin saturated with oxygen by passing specific wavelengths of light through the blood. In 1875 a German physiologist named Karl von Vierordt demonstrated that the oxygen in his hand was consumed when a tourniquet was applied. This was done utilizing transmitted light waves, but the development of the pulse oximeter was still a long way off. In 1936 Karl Matthes developed the first ear saturation meter that used two wavelengths of light. This compensated for the variations in tissue absorption. This idea was improved upon in 1940 when Glen Millikin developed a lightweight oximeter to help the military solve their aviation hypoxia problem.

The modern pulse oximeter was developed in 1972 by Takuo Aoyagi while he was working in Tokyo developing a non-invasive cardiac output measurement, using dye dilution and an ear densitometer. He noticed a correlation in the difference between unabsorbed infrared and red light and the oxygen saturation. This led to the clinical application of the pulse oximeter. It was not until 1980 that Nellcor produced the first commercial pulse oximeter that was reliable, robust, and affordable. In 1988 the use of a pulse oximeter during anesthesia and recovery became mandatory in Australia. Since then, its use has become mandated in many areas from pre-hospital treatment to intensive care units.

## **Pulse Oximeter Definition**

### **What is it?**

A pulse oximeter consists of a computerized monitor and a probe that can be attached to the patient's finger, toe, nose, or earlobe. The monitoring unit displays a digital percentage readout of a calculated estimate of the patient's hemoglobin (Hgb) that is saturated with oxygen (SpO<sub>2</sub>.) A visual waveform indicator is displayed and an audible signal is emitted with each pulse beat, where the tone decreases with a corresponding decrease in saturation. Also displayed is a calculated heart rate. Alarms are available to alert the user to either a high or low saturation level or fast or slow pulse rate.

### **What does it do?**

The device measures two types of hemoglobin: oxygenated and deoxygenated. Since two different substances are being measured, two frequencies of light are necessary. This is called spectrophotometry. The red frequency measures desaturated hemoglobin and the infrared measures oxygenated hemoglobin. If the oximeter measures the greatest absorbance in the red band, it will indicate low saturation. If the greatest absorbance is in the infrared band, it will indicate a high saturation.

### **How does it do it?**

The pulse oximeter utilizes the two wavelengths of light to calculate the saturation of oxyhemoglobin. As a light is shone through the finger, it is picked up by a receiver. Some of the light is absorbed by the tissues, including arterial blood. As the artery fills with blood, the absorption increases; and as the artery empties, the absorption decreases. Since the pulsating blood is the only substance that is changing, the stable substances (skin and tissue) are eliminated from the calculation.

### **What is a normal level?**

The normal SpO<sub>2</sub> value for adults with no lung disease is a saturation greater than 95%, and for children, a level greater

than 96% is normal. This can be misleading as other factors must be considered when determining whether this is normal for the patient. This is discussed below in the oxyhemoglobin dissociation curve. When in doubt, an arterial blood gas (ABG) should be performed to evaluate the correlation between arterial oxygen and pulse oximeter saturation.

### **Proper Technique**

The positioning of the sensor probe is important to obtaining an accurate reading, as is using the appropriate type and size of probe. When using a finger probe, utilize the arm not in use for blood pressures, arterial lines, or having an AV fistula or pressure dressing. The sensor should be placed flush with the skin, and secured without compromising the circulation in the finger. During long term continuous use, the probe site should be checked often to avoid tissue injury. If in doubt of the accuracy of the reading, reposition the sensor or try using another finger.

When assessing accuracy, be sure the pulse readout matches the patient's actual heart rate. The strength of the waveform will assist in determining device accuracy. Ensure the high and low alarms are set to alert the user to any changes immediately.

Probes designed for multiple patient use should be cleaned according to manufacturers specifications between patients to reduce the risk of infection.

### **Understanding Oxyhemoglobin**

The hemoglobin molecule consists of 10,000 atoms, four of which are iron atoms that attract and hold oxygen. Each red blood cell contains about 250 million hemoglobin molecules. There are approximately 5,000 cc's of blood in the average individual and each cc contains five billion red blood cells. When oxygen is bound to the hemoglobin, it is called oxyhemoglobin.

Oxygen is a clear, odorless gas that accounts for 21% of the gases in the air around us. It is essential for the process our body uses to produce the energy needed for metabolism. Too much or too little oxygen (hypoxia) can cause illness or death; therefore, it is necessary to be able to quantify the amount of oxygen in the blood. In the past, the only method of measuring oxygen saturation was via an ABG.

### **Oxyhemoglobin Dissociation curve**

Oxygen can be measured in two forms:

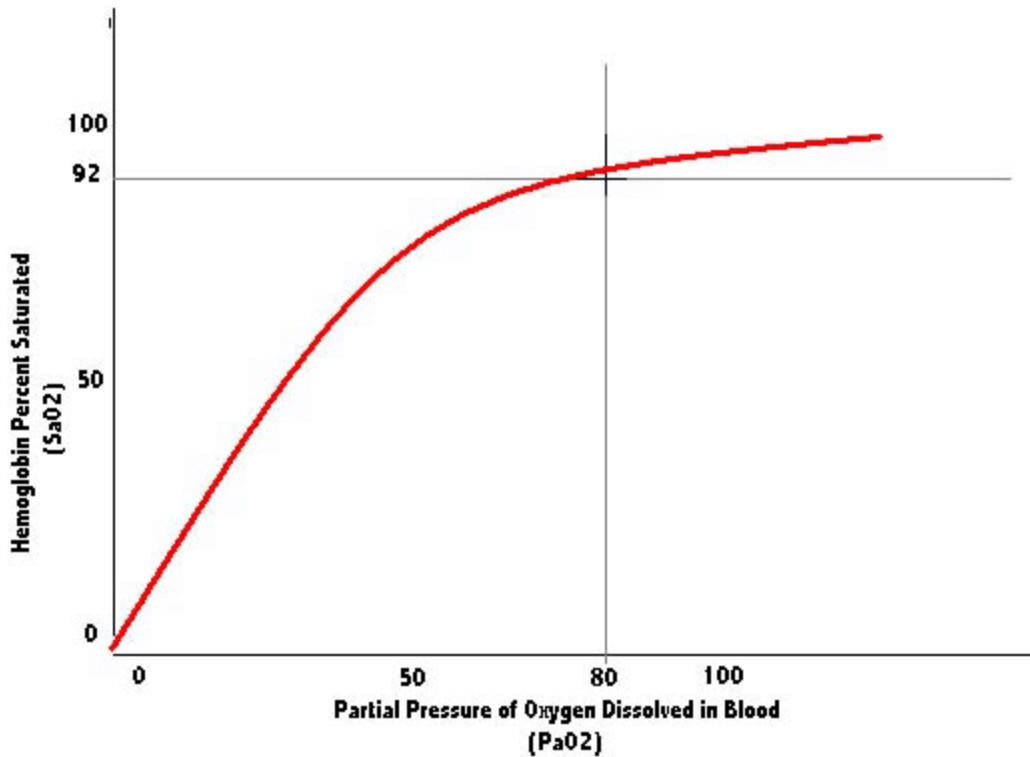
- partial atmospheric pressure of oxygen (PaO<sub>2</sub>)
- oxygen saturation (SaO<sub>2</sub>)
- calculated estimate of oxygen saturation (SpO<sub>2</sub>): an indirect SaO<sub>2</sub>

When the PaO<sub>2</sub> is determined, we are measuring the actual amount of oxygen that is dissolved in the blood. Since the pressure of 1 atmosphere is 760 mm of Hg and oxygen comprises 21% of the atmosphere at sea level, we find 21% of 760 which is 160. After adjusting for dead airway space, elevation, patient temperature, and water vapor, the range of a normal PaO<sub>2</sub> should be between 90-106 mm of Hg. By administering supplemental oxygen or placing a patient in a hyperbaric chamber, the oxygen level can be increased considerably.

### **Definition**

There is a relationship between the amount of oxygen dissolved in the blood and the amount attached to the hemoglobin. This is called the normal oxyhemoglobin dissociation curve.

### **Normal Oxyhemoglobin Dissociation Curve**



The chart above illustrates that when the PaO<sub>2</sub> is 80, the hemoglobin is 92% saturated with oxygen. As the pressure of oxygen increases, the hemoglobin saturation increases. A pressure of 105 or above will completely saturate the hemoglobin. More oxygen can still be diffused into the blood but the hemoglobin is at its maximum capacity. By using the pulse oximeter we can indirectly assess the PaO<sub>2</sub> by measuring the SpO<sub>2</sub>. For example:

97% saturation = 97 PaO<sub>2</sub> (normal)  
 90% saturation = 60 PaO<sub>2</sub> (danger)  
 80% saturation = 45 PaO<sub>2</sub> (severe hypoxia)

### Oxygen - hemoglobin Affinity Changes.

The functions of hemoglobin are oxygen pickup and delivery. The hemoglobin has an affinity (the strength of bond between oxygen and hemoglobin) that can be increased or decreased due to various situations. If hemoglobin has an increased affinity, it is highly saturated; but oxygen is less available for release to the tissues due to the strong bond. The reverse is also true.

Shifts occur due to an alteration in normal pH, CO<sub>2</sub> levels, temperature, and 2-3-DPG (2-3-diphosphoglycerate). 2-3-DPG is a normal product of red blood cell metabolism.

An increase in 2-3-DPG can be caused by:

- residence at high altitude
- anemia, chronic hypoxemia
- hyperthyroidism
- chronic alkalosis

A decrease in 2-3-DPG can be caused by:

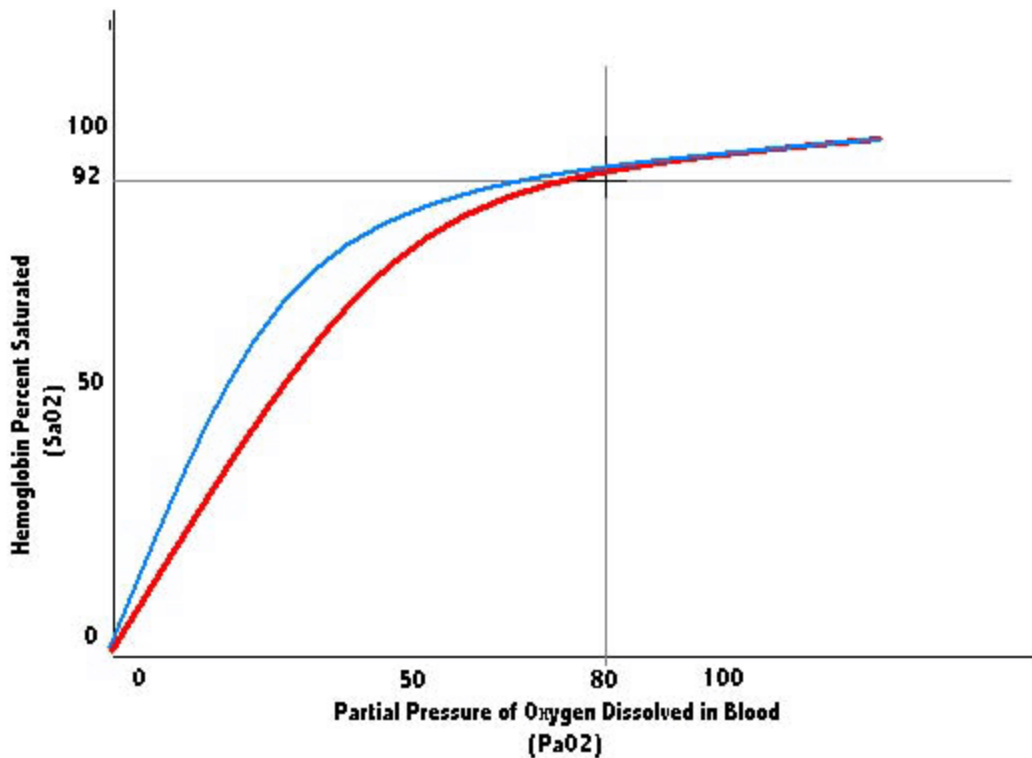
- infusion of stored bank blood
- hypophosphatemia
- hypothyroidism
- chronic acidosis

### Shift to the Left

A shift to the left in the hemoglobin dissociation curve is caused by an increase in hemoglobin's affinity for oxygen. This can be caused by the following:

- alkalosis
- decreased PaCO<sub>2</sub>
- hypothermia
- decreased 2-3-DPG

### Shift to the Left



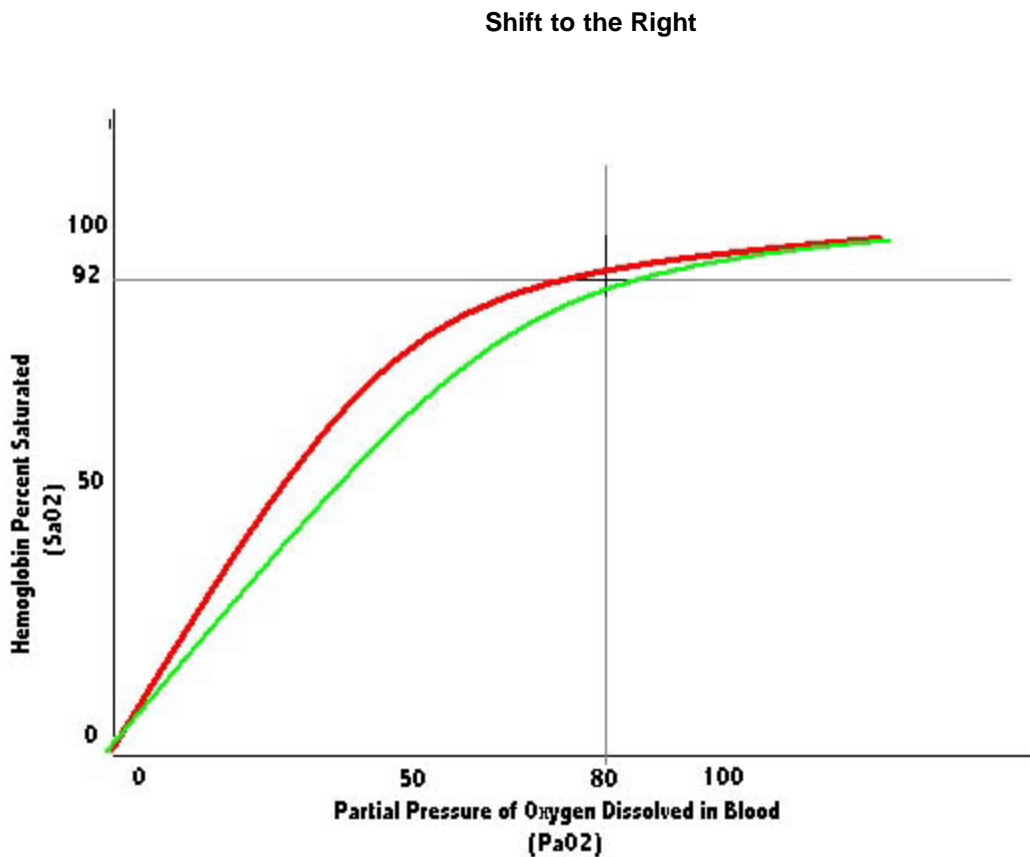
Note that during these circumstances, a pulse oximeter reading of 95% (usually considered normal) denotes a PaO<sub>2</sub> of

76. This patient is hypoxic.

### Shift to the Right

A shift to the right in the hemoglobin dissociation curve is caused by a decrease in the hemoglobin's affinity for oxygen. This can be caused by the following:

- acidosis
- increased PaCO<sub>2</sub>
- fever
- increased 2-3-DPG



When a shift to the right occurs, an SaO<sub>2</sub> of 75% (usually considered severe hypoxia) denotes a PaO<sub>2</sub> of 88. This patient is not nearly as hypoxic as the SaO<sub>2</sub> would lead us to believe.

### Indications

The pulse oximeter may be used in a variety of situations that require monitoring of oxygen status and may be used either continuously or intermittently. It is no substitute for an ABG, but can give clinicians an early warning of decreasing arterial oxyhemoglobin saturation prior to the patient exhibiting clinical signs of hypoxia. Below are the most common uses of a pulse oximeter:

- During general anesthesia and recovery
- During IV conscious sedation or other procedures requiring monitoring of oxygenation status
- During mechanical ventilation
- Guidance for weaning from mechanical ventilation
- Guidance for determining therapeutic oxygen requirement
- Assessing oxygenation during sleep or exercise
- Assessing severity of illness, especially in the emergency department
- Assessing SpO<sub>2</sub> when a direct measurement of PaO<sub>2</sub> or SaO<sub>2</sub> is not immediately available

The pulse oximeter is a useful tool but **the patient must be treated--not the numbers**. As with all monitoring equipment, the reading should be interpreted in association with the patient's clinical condition. If a patient is short of breath and bluish with a saturation reading of 100%, check for possible causes due to artifact. Never withhold therapeutic oxygen from a patient in distress while waiting to get a reading. If the patient appears to be in perfect health and the saturation is reading 70%, this should alert you to the possibility of interference. Never ignore a reading which suggests the patient is becoming hypoxic.

### Interference/ Device Limitations

In order for an accurate reading to be obtained, there must be adequate perfusion at the site of the probe. The pulse oximeter is not effective during cardiac arrest or with extreme heart rates ( less than 30 or over 200.) The patient's blood pressure generally needs to be at least 80 systolic. Results may be affected by any vascular impingement such as:

- AV fistula decreasing distal flow
- Elevation of the extremity in relation to the heart
- Compression of the finger by the probe
- The presence of vasoconstrictors such as cold, fear, hypothermia, and medications

There are a number of factors that limit the use of the pulse oximeter. Due to the fact that the oximeter measures the oxygen saturation of hemoglobin rather than the oxygen content of the blood, it is not as accurate as an ABG. The presence of dysfunctional hemoglobin will cause the readings to be unreliable. Examples of dysfunctional hemoglobin are:

- Anemia
- Carboxyhemoglobin
- Methemoglobinemia
- Sickle Cell Anemia
- Thalassemia
- Fetal hemoglobin

Anemia (a hemoglobin less than 5) will cause the oximeter to display a false high saturation when the patient is actually hypoxic.

With carbon monoxide poisoning (carboxyhemoglobinemia), the pulse oximeter is not able to distinguish oxyhemoglobin from carboxyhemoglobin. Both will be read together and a false high saturation reading will be the result.

Methemoglobin is a form of hemoglobin in which the iron has been oxidized and is no longer capable of transporting oxygen. This can occur with exposure to nitrates, nitrites, phenacetin, pyridium, sulfonamides, or benzocaine. Methemoglobin is equally absorbed by both of the oximeter's light wavelengths. This corresponds to a functional

saturation of 85% on the curve, which means the reading will tend towards 85% regardless of the true saturation. Therefore, if the functional saturation is really less than 85%, the oximeter will read high, and if the functional saturation is really greater than 85%, the oximeter will read low.

Interference will also affect the pulse oximeter readings. Causes of interference include:

- Artificial fingernails: False or thickened nails can hinder accurate readings.
- Dark pigmentation: The dark coloring may increase the likelihood of artifact that alters the readings. This is not as much of a problem with finger probes as it is with ear clips.
- Electrical: This includes interference from radio frequencies.
- Intravenous dyes: Any substance in arterial blood which absorbs light at red or infrared wavelengths may cause an error in the reading. Methylene blue will absorb light and will be interpreted as deoxyhemoglobin.
- Movement: Any movement of the patient, sensor, stretcher, or the transporting vehicle. Body movements, such as seizures or shivering, will give a false reading.
- Nail Polish: The colors are non pulsatile, so they are not confused with blood pigments; but they do increase the likelihood of other artifacts. Blue and dark colors affect the readings the most, but all polish should be removed to help ensure correct readings.
- Pulsatile venous system: CPR or tricuspid regurgitation can create venous pulses that may be interpreted by the oximeter as arterial pulses.
- Radiated light: Bright lights, including infrared heat lamps, may interfere and cause a higher SpO<sub>2</sub> and pulse rate than is really occurring.
- Edema: If present in the area of probe attachment, can hinder obtaining an accurate reading.

Whenever a discrepancy exists between the pulse oximeter reading and the ABG, or the reading does not match the patient's clinical presentation, the pulse oximeter should not be used as an evaluation tool.

It is important to remember that pulse oximeters assess oxygen saturation only and give no indication of the level of CO<sub>2</sub>. For this reason they have a limited benefit in patients developing respiratory failure due to CO<sub>2</sub> retention.

## Conclusion

The implementation of the pulse oximeter has changed medical management and improved patient care. Oxygenation can be assessed almost immediately and treatment can be initiated quickly. If the healthcare professional understands the device's operation and the principles behind the oxyhemoglobin dissociation curve, the pulse oximeter can be a useful tool in providing quality patient care.

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### Self-Assessment Questions

## Questions

1. A pulse oximeter measures:

- a. the amount of hemoglobin in the blood.
- b. the amount of hemoglobin that is oxygenated.
- c. the level of carbon dioxide in the blood.
- d. the amount of oxygen dissolved in the blood.

2. Saturation measurements via pulse oximetry are indicated by what abbreviation?

- a. SaO<sub>2</sub>
- b. PaO<sub>2</sub>
- c. SpO<sub>2</sub>
- d. O<sub>2</sub>

3. Which of the following situations utilizes proper finger probe placement?

- a. The arm has an IV present.
- b. The arm has an AV graft.
- c. The arm has a tight dressing over the recent ABG site.
- d. The arm has an automatic blood pressure cuff in use.

4. The pulse oximeter utilizes \_\_\_\_\_ to make measurements.

- a. pressure readings
- b. sound waves
- c. radio frequencies
- d. light waves

5. A pulse oximeter can be useful in the following circumstances:

- a. post anesthesia care unit (PACU)
- b. emergency department
- c. intensive care unit
- d. all of the above
- e. none of the above

6. The primary indication for the use of pulse oximetry is:

- a. monitoring of ventilation status.
- b. monitoring of oxygenation status.
- c. monitoring of acid-base balance.
- d. monitoring pH.

7. Gross anemia (hgb <5 ) will affect the pulse oximeter readings by displaying:

- a. a false high saturation.
- b. a false low saturation.
- c. accurate results.
- d. variable results.

8. Pulse oximetry readings are affected by all of the following types of hemoglobin except:

- a. oxyhemoglobin.
- b. methemoglobin.
- c. carboxyhemoglobin.
- d. oxymethocarbohemoglobin.

9. The hemoglobin's affinity for oxygen can be defined as the:

- a. rate at which hemoglobin repels oxygen.
- b. strength of the bond between oxygen and hemoglobin.
- c. number of hemoglobin molecules that are capable of carrying oxygen.
- d. volume of oxygen in the blood.

10. A shift to the right in the hemoglobin dissociation curve may be caused by:

- a. fever.
- b. alkalosis.
- c. obesity.
- d. colitis.

11. A normal oxygen saturation is:

- a. 97%.
- b. 105%.
- c. 90%.
- d. 92%.

12. Pulse oximetry readings may be affected by all of the following except:

- a. hypothermia.
- b. a heart rate of 220.
- c. the induction of conscious sedation.

- d. administration of vasoconstrictors.

13. Which of the following diseases will limit the accuracy of pulse oximeter readings?

- a. peptic ulcer disease
- b. hypertension
- c. diabetes
- d. sickle cell anemia

14. When a discrepancy between patient presentation, arterial blood gas saturation and pulse oximetry readings exist, which is of the least value in evaluating the patient?

- a. arterial blood gas
- b. patient presentation
- c. pulse oximetry readings
- d. patient respiratory rate

15. Interference can be a contributing factor in all of the following cases except:

- a. CPR.
- b. seizures.
- c. hypertension.
- d. edema.