Decoding the oxyhemoglobin dissociation curve

Understanding the curve helps you put pulse oximetry in context.

By Julia Hooley, MSN, RN

Mrs. Glenn, a 72-year-old female on a medical-surgical floor, was hospitalized 3 days ago for pneumonia. Since her admission, she has been on continuous pulse oximetry and is receiving oxygen (2 L/minute by nasal cannula) and antibiotics. A chest X-ray taken earlier today showed little change in her pneumonia. She has a history of chronic lung disease.

At the beginning of the shift, the nurse hears the low alarm of Mrs. Glenn's pulse oximeter sound, indicating a reading of 89% to 90%. On assessment, the nurse finds the patient alert, oriented, and in no apparent distress. Mrs. Glenn's heart rate is 96 beats/minute; respiratory rate, 24 breaths/minute with diminished breath sounds; blood pressure, 124/80 mm Hg; and temperature, 38.1° C (100.6° F).

Because the nurse is unfamiliar with Mrs. Glenn, she consults the respiratory therapist (RT), who's preparing to administer a breathing treatment. The RT assures her that Mrs. Glenn's pulse oximetry values are always low, close to her baseline of 92%.

The nurse wonders how to interpret the patient's pulse oximetry values in this context. She vaguely remembers something about the oxyhemoglobin dissociation curve and wonders if a better understanding of the curve would aid her assessment.

The oxyhemoglobin dissociation curve (OHDC) indicates the relationship between the oxygen saturation of hemoglobin (SaO_2) and the partial pressure of arterial oxygen (PaO_2). Neither linear nor static, the curve can change or shift depending on various factors. Yet understanding the curve and its implications for patient care can be challenging.

Pulse oximetry has become an essential tool in various settings for monitoring a patient's oxygenation status. It indirectly indicates arterial hemoglobin saturation, measured as oxygen saturation by pulse oximetry (SpO_2). However, this technique is limited because oximetry measures just one component of oxygenation. For a more accurate picture of the patient's overall oxygenation status, you need to assess pulse oximetry values in the context of the OHDC. This article decodes the curve to make it more understandable and discusses the benefits and limitations of pulse oximetry.

CNE
1.42 contact hours

Learning Objectives

1. Recall the physiologic basis for the oxyhemoglobin dissociation curve (OHDC).
2. Describe the shifts that can occur in the OHDC.
3. Discuss the relationship between the OHDC and pulse oximetry.

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Expiration: 1/1/18

The curve: Just the basics

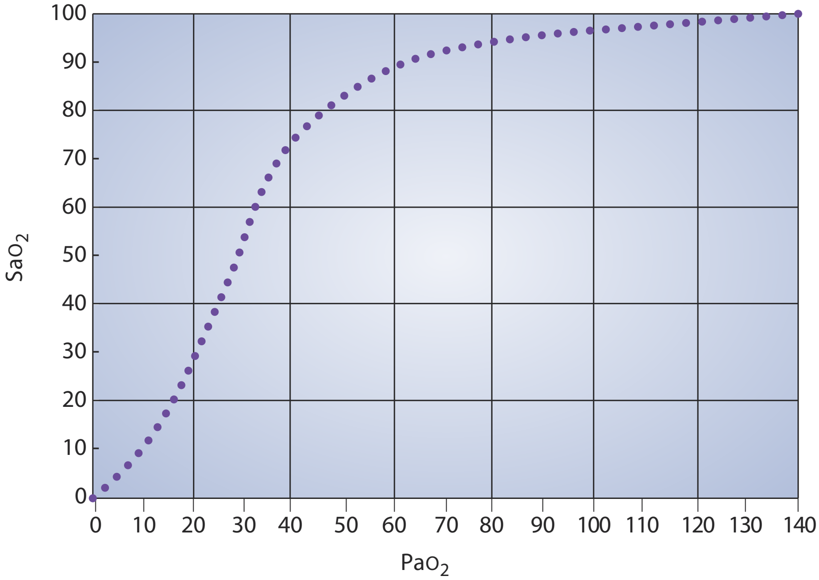
No doubt you remember learning about the OHDC as a nursing student. It's discussed in nearly every nursing textbook. Nonetheless, it can be a somewhat puzzling concept to grasp and apply in clinical practice. To understand it, think about the oxygenation process occurring in the body. Staying alive hinges on adequate oxygen moving from the lungs to body tissues and cells. For this to occur, the lungs, blood, and environment within the body must be functioning properly:

- The lungs must receive enough oxygen to be perfused and ventilated optimally.
- Oxygen must be transported via the blood to the tissues.

Only 2% to 3% of the oxygen going to the tissues dissolves in plasma; the remainder travels in the plasma by attaching to hemoglobin molecules. The most important factor in the amount of oxygen that binds (attaches) to hemoglobin molecules is the partial pressure of arterial oxygen (PaO_2); the higher the pressure, the more readily oxy-

The curve: Relating SaO_2 to PaO_2

The oxyhemoglobin dissociation curve graphically represents the affinity between oxygen and hemoglobin—specifically, how the oxygen saturation of hemoglobin (SaO_2) relates to the partial pressure of arterial oxygen (PaO_2). The curve's position and overall shape (shown in purple below) depend on various factors, including the partial pressure of carbon dioxide ($PaCO_2$), body temperature, and blood pH.



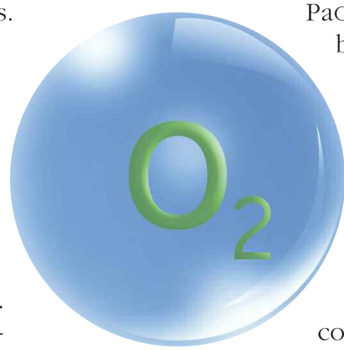
gen combines with hemoglobin in red blood cells. This hemoglobin-oxygen linkage is called oxyhemoglobin.

Hemoglobin is made up of four strands of amino acids. If oxygen is linked fully to all four strands, hemoglobin is 100% saturated with oxygen. Transport of sufficient oxygen to the tissues depends on an adequate number of hemoglobin molecules, as well as sufficient blood volume and circulation (cardiac output and blood pressure). Once hemoglobin transports oxygen to the tissues, the body's environment determines how much (or how little) of the oxygen dissociates (unloads) from hemoglobin for use. Oxygen dissociation from hemoglobin is determined by tissue demand for oxygen. That's where the OHDC comes in.

Relationship between PaO_2 and SaO_2

The OHDC represents the relationship between PaO_2 and SaO_2. Normal PaO_2 ranges from 80 to 100 mm Hg. Normal SaO_2 measures about 97% but may range from 93% to 97%. (See *The curve: Relating SaO_2 to PaO_2.*)

The OHDC isn't a straight line. Instead, it's S-shaped. The flat upper portion where the curve is more horizontal depicts oxygen loading onto hemoglobin in the lungs. The pressure of oxygen entering the lungs exceeds the oxygen concentration in blood returning to the lungs. This enables oxygen to bind more easily to hemoglobin.



A significant PaO_2 change in this relatively flat part of the curve produces only a small change in SaO_2. Thus, a patient's oxygenation status is better protected at this flat portion. For example, if PaO_2 drops from 96 to 70 mm Hg, hemoglobin saturation decreases from 97% to approximately 92%. Clinically, this means that if the patient receives supplemental oxygen, PaO_2 will increase—but with little effect on SaO_2. Hemoglobin can't be saturated more than 100%, but PaO_2 can rise significantly above 100 mm Hg if the patient receives high oxygen concentrations (as occurs with a hyperbaric oxygen chamber).

At the steep lower part of the curve (under the "knee"), where PaO_2 measures between 40 and 60 mm Hg, oxygen is released from hemoglobin to the capillaries at the tissue level due to increased oxygen demand. At this part of the curve, an increase or decrease in PaO_2 leads to a large SaO_2 change. This means giving supplemental oxygen will significantly increase the patient's SaO_2.

A shift to the left or right

Now comes the more complicated part. The OHDC isn't static or constant, because certain factors can alter hemoglobin's affinity for oxygen. Depending on oxygen demand at the tissue level, oxygen will bind to hemoglobin more or less readily than normal. Various factors cause the curve to shift to the left or right of its normal position. (See *Why the curve shifts* and *How 2,3-DPG affects the curve.*)

Connecting the curve with pulse oximetry readings

PaO_2 and SaO_2 values can be obtained only from an arterial blood gas (ABG) sample. But although ABG studies are the gold standard for obtaining PaO_2 and SaO_2 values, frequent ABG sampling isn't always feasible or cost effective. For ongoing monitoring, pulse oximetry provides a convenient, continuous, and noninvasive way to measure SaO_2 indirectly and monitor trends in the patient's oxygenation status.

Be sure to check for subtle or sudden changes in oximetry values. Changes in oxygenation status can precede clinical signs and symptoms. By detecting these changes early, clinicians can make timely modifications to the plan of care.

Generally speaking, a pulse oximetry value of 95% or higher is clinically acceptable, whereas a value of 90% or lower is a red flag. On the OHDC, a SaO_2 value of 90% correlates to a PaO_2 level of 60 mm Hg. PaO_2 pushes or loads the oxygen onto hemoglobin. So if this level isn't adequate, suspect the patient's overall oxygenation is abnormally low.

What pulse oximetry values *can't* tell you

Pulse oximetry can't tell you the patient's hemoglobin level or identify nonfunctional hemoglobin. In an anemic patient, hemoglobin may be fully saturated and SpO_2 may be normal—yet the patient may be hypoxic due to lack of available hemoglobin to carry oxygen to the tissues.

Likewise, hemoglobin may be fully saturated but with dysfunctional strands, such as carboxyhemoglobin or methemoglobin strands. Hemoglobin binds much more readily to carbon monoxide than to oxygen. Hemoglobin may be fully saturated and the pulse oximetry value may be 98%, yet hemoglobin may be saturated with carbon monoxide instead of oxygen. Carboxyhemoglobin levels are elevated in heavy smokers. Methemoglobinemia may occur in patients receiving nitrate or lidocaine therapy.

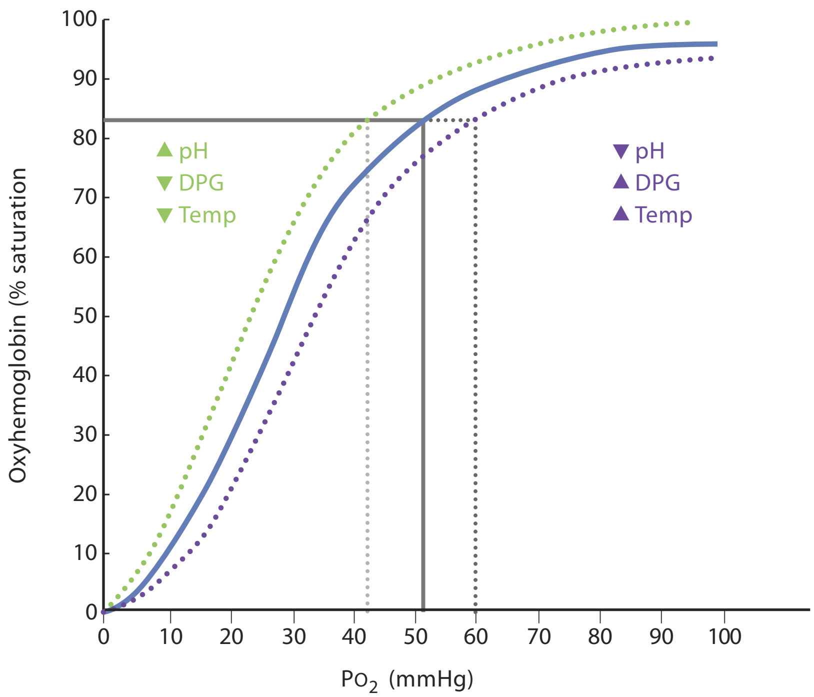
Pulse oximetry also reveals nothing about the patient's partial pressure of arterial carbon dioxide ($PaCO_2$) or ventilation status. Say, for example, a patient's receiving a high percentage of supplemental oxygen by face mask for several hours after surgery. If the patient is too sedated to breathe effectively, $PaCO_2$ may rise to a dangerous level even though SaO_2 may be near normal from the supplemental oxygen. So be sure to obtain baseline ABG values and recheck them periodically.

Why the curve shifts

The normal oxyhemoglobin dissociation curve (OHDC), shown here by the solid blue line, indicates that when the partial pressure of arterial oxygen (PaO_2) is 40 mm Hg, oxygen saturation of hemoglobin (SaO_2) is 75%. At the tissue or capillary level, a PaO_2 of 40 mm Hg is normal. At this point, about 25% of the oxygen carried on hemoglobin from the tissues to the lungs has been unloaded and used at the tissue level. Much of the oxygen still remains on the hemoglobin molecule, indicating an oxygen reserve isn't normally used at the tissue level. However, this reserve is available when extra oxygen is needed, as during strenuous exercise or high metabolic demand.

Conditions that alter hemoglobin's affinity for oxygen can shift the OHDC to the right or left.

- A *shift to the right* (dotted purple line) decreases hemoglobin's affinity for oxygen for a given PaO_2 value, and the SaO_2 value decreases below normal. Hemoglobin releases oxygen to the tissues more readily in an effort to keep tissues well-oxygenated (because oxygen demand is higher than normal). Causes of a shift to the right include increased body temperature, acidosis, exercise, and elevated 2,3-diphosphoglycerate (2,3-DPG) or partial pressure of arterial carbon dioxide ($PaCO_2$) levels.
- A *shift to the left* (dotted green line) increases hemoglobin's affinity for oxygen. It can result from increased blood pH, decreased body temperature, or reduced 2,3-DPG or $PaCO_2$ levels. In a leftward shift, less oxygen is released to the tissues but more oxygen is bound to hemoglobin in the lungs; the SaO_2 value is higher than normal for a given PaO_2 value.



Factors that can reduce pulse oximetry accuracy

Certain technical and patient variables can reduce the accuracy of pulse oximetry.

- *Technical variables:* Motion artifact, ambient light, dark nail polish, improperly placed sensors, and patient movement can cause inaccurate readings. Clinicians should try to control these variables to the extent possible.
- *Patient variables:* Pulse oximetry is less accurate when SpO_2 values are below 70%, limiting its effectiveness in severely hypoxic patients. Values also may vary in

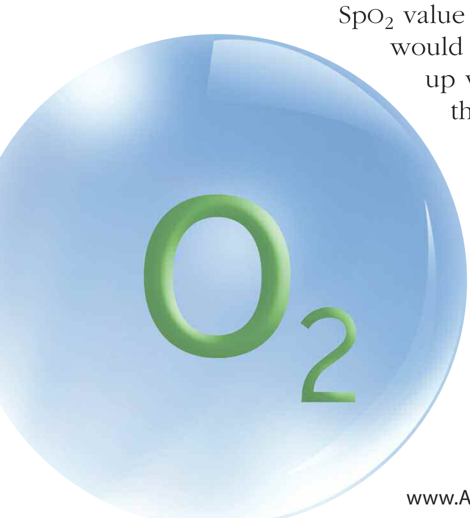
patients with poor perfusion (as from arrhythmias, hypotension, or heart failure) or vasoconstrictive conditions (such as sickle cell anemia, hypothermia, smoking, or certain medications). To determine if low perfusion is interfering with oximetry readings, compare the pulse rate displayed on the oximeter to a good electrocardiographic waveform that correlates to a palpated pulse.

Pulse oximetry values in the context of the curve

Understanding how to use pulse oximetry in the context of your patient's OHDC can improve outcomes. Used correctly, pulse oximetry gives an overall indication of a patient's oxygenation status and promotes early intervention for high-risk patients. It also allows early recognition of conditions that increase tissue demand for oxygen, helping to ensure that the patient's oxygen supply (hemoglobin saturation) meets demands.

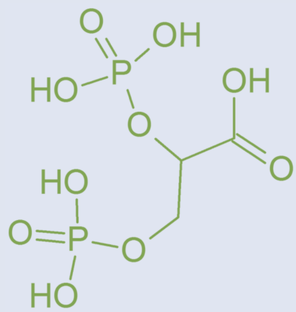
Keep the following key principles in mind when caring for patients like Mrs. Glenn—those with underlying lung disease who've suffered an acute respiratory insult that puts them at risk for impaired gas exchange.

- After assessing the patient's respiratory status and determining that the pulse oximeter is functioning properly, visualize the spot on the OHDC where the SpO_2 value would line up with the PaO_2 value. Is this spot at the flat part or the steep part of the curve?



- When the pulse oximeter's low alarm goes off, don't assume you need to start giving oxygen or increase the oxygen flow. Assess the patient, not the machine: Is the patient in respiratory distress? Check the oxygen supply: Is the oxygen tubing kinked? Is the oximeter applied properly? Does the patient have a disease or condition that increases oxygen demand, such as fever, acidosis, or infection? If so, decreasing SpO_2 values may indicate the need to contact the physician for further orders, in addition to increasing the oxygen flow.
- If the pulse oximetry value is within a normal range, don't assume the patient is adequately oxygenated. Instead, assess respiratory status, especially if the patient's receiving supplemental oxygen. Is the patient breathing adequately? Because of compensatory mechanisms, good SpO_2 values may give false reassurance despite deterioration in the patient' respiratory status. For example, patients in near respiratory failure may be hyperventilating, resulting in respiratory alkalosis. This causes the OHDC to shift to the left, with more hemoglobin hanging on to oxygen instead of releasing it at the tissue level where it's needed.

- Patients with similar SpO_2 values don't necessarily have the same total oxygen content in their blood. Suppose, for instance, Mr. M and Mr. R both have SpO_2 values of 97%, but Mr. M's hemoglobin value is 15 g/dL, whereas Mr. R's hemoglobin value is 8 g/dL. In this case, oxygen-carrying capacity is greater in Mr M than in Mr. R, who may be showing signs of hypoxia.
- Interpret values in light of the patient's overall condition. Patients with chronic disease, such as chronic obstructive pulmonary disease (COPD), may function adequately despite lower SpO_2 values. Be sure to check the patient's baseline ABG and pulse oximetry values, watching for trends. Also remember that PaO_2 values normally decrease with age. Elderly patients typically try to compensate for a low PaO_2 value with a rightward shift of the curve. But this shift doesn't completely compensate for the hypoxic changes and hypercapnia that come with aging. As a result, many older adults have decreased activity tolerance.
- Collaborate with other professionals involved in the patient's care. Review the physician's or-



How 2,3-DPG affects the curve

A phosphate found in the blood, 2,3-diphosphoglycerate (2,3-DPG) forms when red blood cells break down glucose to make adenosine triphosphate. It decreases hemoglobin's affinity for oxygen, promoting oxygen release in the tissues.

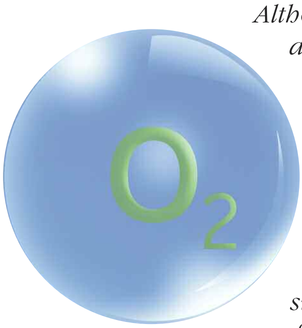
Some hormones, such as thyroxine, human growth hormone, epinephrine, and testosterone, increase 2,3-DPG production and cause the oxyhemoglobin dissociation curve (OHDC) to shift to the right. Also, 2,3-DPG levels are higher in people living in high altitudes. As blood cells age, 2,3-DPG levels decrease, causing oxygen to bind tightly to hemoglobin and the OHDC to shift to the left.

ders to determine the type of monitoring needed and specific protocols to follow. Consult with the respiratory therapist about proper pulse oximetry alarm settings and correct use of the device. Make sure you're familiar with evidence-based practice guidelines for using pulse oximetry, such as those from the American Association of Critical-Care Nurses and the American Association for Respiratory Care.

Clinical scenario revisited

Mrs. Glenn's pulse oximetry values continue to remain low, in the upper 80% range. Her vital signs are unchanged. The physician calls with orders to obtain a urine culture and start another I.V. antibiotic. The nurse clamps the catheter to obtain the culture, but when she returns to collect the culture, she sees that only scant urine has been collected.

Mrs. Glenn remains alert but seems a bit restless. The nurse helps her to the chair to eat dinner. Twenty minutes later, she walks by and sees Mrs. Glenn slumped over in her chair and unresponsive. She calls for help to get her back to bed. Although the nurse attempts oral suctioning, the patient remains unresponsive. Because Mrs. Glenn has "do not resuscitate" orders, no further interventions are taken. The nurse calls the patient's husband. When he arrives 30 minutes later, he tells the nurse, "I know you gave her good care and probably didn't know she was going to die, but I would have liked to have been here when it happened."



Later, the nurse reflects on her experience with Mrs. Glenn. She realizes she missed or ignored clues of quickly developing hypoxia. Although Mrs. Glenn was a COPD patient and thus her pulse oximetry values were lower than normal, the nurse didn't carefully review her ABG values and previous pulse oximetry values. If she had reviewed these in light of the OHDC, she might have realized the Spo_2 decrease from 91% to 88% placed Mrs. Glenn at the steep part of the curve. Her estimated Pao_2 would have been lower than 60 mm Hg. As her Pao_2 continued to drop, her Spo_2 value would have fallen rapidly. Getting her up to eat increased her oxygen demands and contributed to further Spo_2 lowering. Her increased pulse and respiratory rates and decreased blood pressure and urinary output also indicated worsening hypoxia.

The OHDC isn't static or constant, because certain factors can alter hemoglobin's affinity for oxygen. Depending on oxygen demand at the tissue level, oxygen will bind to hemoglobin more or less readily than normal.

Pulse oximetry is used in a wide range of care settings to assess oxygenation status. But it must be correlated with the OHDC to get a full picture of the patient's condition. Correlating Spo_2 with Pao_2 values provides valuable clues about the balance between oxygen supply and demand. When combined with astute assessment, understanding this relationship can lead to earlier detection of oxygenation problems and allow prompt intervention. Ignoring or misinterpreting the relationship between Spo_2 and Pao_2 can lead to disastrous consequences for vulnerable patients, such as Mrs. Glenn. ✯

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Purpose/Goal

To provide nurses with information on how to use the oxyhemoglobin dissociation curve to better assess a patient's oxygenation status.

Learning Objectives

1. Recall the physiologic basis for the oxyhemoglobin dissociation curve (OHDC).
2. Describe the shifts that can occur in the OHDC.
3. Discuss the relationship between the OHDC and pulse oximetry.

Please mark the correct answer online.

1. What percentage of the oxygen going to the tissues dissolves in plasma?

a. 2% to 3%
b. 15% to 18%
c. 20% to 21%
d. 30% to 32%

2. Which statement about hemoglobin is correct?

a. Hemoglobin is made up of four strands of carbohydrates.
b. Hemoglobin is made up of four strands of amino acids.
c. If oxygen is linked fully to two strands, hemoglobin is considered to be 100% saturated with oxygen.
d. If oxygen is linked fully to two strands, hemoglobin is considered to be 10% saturated with oxygen.

3. The flat upper portion of the S-shaped OHDC represents:

a. oxygen loading onto hemoglobin in the lungs.
b. oxygen exiting hemoglobin in the lungs.
c. oxygen released from hemoglobin to capillaries at the tissue level.
d. oxygen loading onto hemoglobin from capillaries at the tissue level.

4. The steep lower part of the OHDC (under the "knee") represents:

a. oxygen loading onto hemoglobin in the lungs.
b. oxygen exiting hemoglobin in the lungs.
c. oxygen released from hemoglobin to capillaries at the tissue level.
d. oxygen loading onto hemoglobin from capillaries at the tissue level.

5. Which statement about the OHDC and oxygenation is correct?

a. At the flat upper portion where the curve is more horizontal, giving supplemental oxygen will significantly increase the patient's oxygen saturation of hemoglobin (SaO_2).
b. At the very start and very end of the curve, giving supplemental oxygen will significantly increase the patient's SaO_2.
c. At the steep lower part of the curve (under the "knee"), giving supplemental oxygen will have little effect on the patient's SaO_2.
d. At the steep lower part of the curve (under the "knee"), giving supplemental oxygen will significantly increase the patient's SaO_2.

6. Which of the following can cause the OHDC to shift to the right?

a. Alkalosis
b. Increased body temperature
c. Decreased 2,3-diphosphoglycerate (2,3-DPG)
d. Decreased partial pressure of arterial carbon dioxide ($PaCO_2$)

7. Which of the following can cause the OHDC to shift to the left?

a. Increased 2,3-DPG
b. Acidosis
c. Hypothermia
d. Hypercarbia

8. Which statement about shifts in the OHDC is correct?

a. With a shift to the right, hemoglobin releases oxygen to the tissues more readily.
b. With a shift to the right, hemoglobin is less likely to release oxygen to the tissues.
c. With a shift to the left, hemoglobin's affinity for oxygen is decreased.
d. With a shift to the left, hemoglobin is more likely to release oxygen to the tissues.

9. Which statement about 2,3 DPG is accurate?

a. It decreases in the presence of epinephrine.
b. It increases as a person ages.
c. It forms when red blood cells synthesize glucose to make adenosine triphosphate.
d. It forms when red blood cells break down glucose to make adenosine triphosphate.

10. Which statement about pulse oximetry is correct?

a. An SaO_2 level of 70% signifies a PaO_2 level of 60 mm Hg.
b. An acceptable pulse oximetry level is 85%.
c. Pulse oximetry is useful for determining a patient's ventilation status.
d. Pulse oximetry reveals nothing about the patient's $PaCO_2$.

11. Which statement about hemoglobin saturation is correct?

a. A pulse oximetry (SpO_2) value of 100% indicates hemoglobin is fully saturated with oxygen.
b. An SpO_2 value of 98% indicates hemoglobin is fully saturated with oxygen.
c. Hemoglobin may be fully saturated with dysfunctional strands.
d. Hemoglobin binds more readily to oxygen than to carbon monoxide.

12. Which of the following reduces the accuracy of pulse oximetry readings?

a. Smoking
b. Hyperthermia
c. Hypertension
d. SpO_2 value of 85%

13. What key principle should you keep in mind when caring for patients being monitored by pulse oximetry?

a. Patients with chronic obstructive pulmonary disease need higher SpO_2 values to function well.
b. Patients with similar SpO_2 values have the same amount of total oxygen content in their blood.
c. When the pulse oximeter's low alarm goes off, don't assume you need to start giving oxygen or increase the oxygen flow.
d. If the SpO_2 value is within a normal range, you know the patient is adequately oxygenated.