PULSE OXIMETRY AND CO-OXIMETRY: A GUIDE FOR EMTS AND FIRST RESPONDERS

EDUCATIONAL CURRICULUM

Bryan E. Bledsoe, DO, FACEP
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EDUCATIONAL OBJECTIVES

TERMINAL OBJECTIVE
Upon completing this presentation the student will be able to clinically apply pulse oximetry and CO-oximetry in the out-of-hospital setting in order to enhance patient assessment skills and provide optimal interventions in patient care.

COGNITIVE OBJECTIVES
Upon completing this presentation the student will be able to:

1. List the principal gases found in the earth’s atmosphere.
2. List the two principal respiratory gases.
3. List the physical characteristics of oxygen.
4. List the physical characteristics of carbon dioxide.
5. Describe the two methods by which the human body transports oxygen.
6. Describe the three methods by which the human body transports carbon dioxide.
7. Describe hemoglobin and detail its function in respiratory gas transport.
8. Describe the structure of hemoglobin.
9. Detail the relationship between hemoglobin oxygen saturation and the partial pressure of oxygen in the arterial blood.
10. Describe the binding of carbon dioxide to hemoglobin and contrast that to the binding of oxygen.

11. Compare and contrast arterial blood gas sampling with pulse oximetry.

12. Describe the benefits of pulse oximetry in out-of-hospital care.

13. Describe how pulse oximetry works.


15. Describe the perfusion index and its role in prehospital respiratory gas monitoring.

16. Describe what a provider can learn from pulse oximetry.

17. Detail what cannot be learned from use of pulse oximetry.

18. List personnel in the prehospital setting who should and should not use pulse oximetry.

19. List and detail the out-of-hospital indications for pulse oximetry.

20. List and describe the out-of-hospital contraindications for pulse oximetry.

21. List and detail the limitations of pulse oximetry.

22. Compare and contrast the limitations and benefits of first-generation and second-generation pulse oximeters.
23. List common myths associated with pulse oximetry and discuss the reasons that these are false.

24. Detail the physiological parameters discerned from pulse oximetry.

25. List the categories of abnormal pulse oximetry findings and describe the clinical significance of each.

26. Discuss suggested interventions for abnormal pulse oximetry readings.

27. Detail why oximetry measurement methods will not work with carbon dioxide.

28. Describe the incidence and pathophysiology of carbon monoxide poisoning.

29. List the signs and symptoms of carbon monoxide poisoning.

30. Describe why red skin discoloration is an unreliable sign of carbon monoxide poisoning.

31. Describe methods for detection of carbon monoxide levels in the blood including CO-oximetry.

32. Describe why screening for carbon monoxide poisoning should be routine in out-of-hospital care.

33. Describe treatment strategies for carbon monoxide poisoning.
34. Describe why the fetus of a pregnant woman is at increased risk of serious carbon monoxide poisoning.
35. Describe how routine CO-oximetry can be a risk management tool in EMS and the fire service.
36. Describe the importance of detecting concomitant cyanide and carbon monoxide poisoning.
37. Discuss the role of cyanide poisoning treatment and methemoglobinemia.
38. Detail why hydroxocobalamin is preferred over the nitrites in mixed carbon monoxide/cyanide poisonings.

AFFECTIVE OBJECTIVES

Upon completing this presentation the student will be able to:

39. Recognize the value and role of pulse oximetry as an adjunct in the assessment of the out-of-hospital patient.
40. Understand the uses and limitations of pulse oximetry.
41. Recognize the value of screening for carboxyhemoglobin and methemoglobin in the out-of-hospital setting.
42. Demonstrate an appreciation for the role additional respiratory gas information plays in developing an accurate field diagnosis/impression of the out-of-hospital patient.
PSYCHOMOTOR OBJECTIVES

Upon completing this presentation the student will be able to:

43. Demonstrate a comprehensive patient assessment using pulse oximetry.
44. Demonstrate a comprehensive patient assessment using CO-oximetry.
45. Demonstrate a comprehensive patient assessment using capnography.
46. Demonstrate appropriate interventions for simulated abnormal oximetry readings.
47. Demonstrate appropriate interventions for simulated abnormal CO-oximetry readings.
48. Troubleshoot problems occurring when monitoring with pulse oximetry.
49. Troubleshoot problems occurring when monitoring with pulse CO-oximetry.
50. Demonstrate proper documentation of oximetry and CO-oximetry readings.
I. Introduction:
   A. The respiratory gasses are essential for life. The ability of out-of-hospital emergency care providers to monitor these gasses is essential to quality out-of-hospital care. Pulse oximetry has been the standard method for monitoring peripheral arterial oxygen saturation. Newer methodologies now allow the monitoring of carbon dioxide through capnography and carbon monoxide through CO-oximetry.

II. Respiratory gas physiology:
   A. The earth’s atmosphere contains several gasses:
      1. Oxygen (O₂).
      2. Carbon dioxide (CO₂).
      4. Water vapor (H₂O).
      5. Trace gasses:
         a. Argon (Ar).
         b. Neon (Ne).
         c. Helium (He).
   B. When gasses are present in a mixture, such as occurs in the earth’s atmosphere, the individual gasses are often represented based upon their partial pressures:
      1. Dalton’s Law.
      2. Determining partial pressure using Dalton’s law.
   C. Biological life depends primarily upon three gasses:
      1. Oxygen (O₂)
         a. Odorless.
         b. Tasteless.
         c. Colorless.
         d. Supports combustion.
         e. Present as a diatomic gas.
         f. Oxygen atoms must share electrons for stability.
         g. Necessary for animal life.
         h. Derived from plant photosynthesis:
            i. Algae (75%).
            ii. Terrestrial plants (25%).
2. Carbon Dioxide (CO₂)
   a. Colorless.
   b. Sour taste at high concentrations.
   c. Very low concentrations in fresh air.
   d. Asphyxiating.
   e. Waste product of animal life.
   f. Contains 2 atoms of oxygen and 1 atom of carbon.

3. Nitrogen (N₂)
   a. Most abundant gas in atmosphere (78%)
   b. Extremely stable
   c. Not a respiratory gas—but important in biological systems
   d. N₂ is very stable and must be converted to other nitrogen forms—usually by nitrogen-fixing bacteria in the soil.

Abnormal respiratory gases:

4. Carbon monoxide (CO).
   a. Colorless.
   b. Odorless.
   c. Tasteless.
   d. Results from incomplete combustion of carbon-containing compounds.

D. Respiratory gas transport:

1. Oxygen:
   a. 97% reversibly bound to hemoglobin.
   b. 3% dissolved in plasma.

2. Carbon dioxide:
   a. 70% as bicarbonate (HCO₃⁻).
   b. 23% reversibly bound to hemoglobin.
   c. 7% dissolved as plasma.

E. Hemoglobin:

1. Protein-iron complex.
2. Transports oxygen to peripheral tissues.
3. Removes a limited amount of carbon dioxide from peripheral tissues via carbaminohemoglobin.
4. Binding sites
   a. Heme structures:
   b. Non-oxygen-containing hemoglobin called deoxyhemoglobin (Hb).
c. Oxygen-oxygen containing hemoglobin called oxyhemoglobin (O₂Hb).
d. Binding of oxygen to hemoglobin changes the shape (conformation) and color of the molecule.

F. Oxygen saturation:
1. Oxygen saturation of oxygen is directly related to the partial pressure of oxygen in the blood (PO₂).
2. Venous blood saturation normally 30-40 mm Hg.
3. Arterial oxygen saturation normally 85-100 mm Hg.
4. Factors that decrease oxygen saturation:
   a. Decreased pH (acidosis).
   b. Increased carbon dioxide.
   c. Increased temperature.
   d. Increased 2,3-biphosphoglycerate.
5. Factors that increase oxygen saturation:
   a. Increased pH (alkalosis).
   b. Decreased carbon dioxide.
   c. Decreased temperature.
   d. Decreased 2,3-biphosphoglycerate.

III. Monitoring Technologies:
A. Arterial blood gas sampling.
   2. Invasive.
   3. Expensive.
   4. Painful.
   5. Difficult.
   7. Excellent diagnostic test.
   8. Provides:
      a. pH (normal 7.35-7.45)
      b. PO₂ (normal 80-100 mm Hg)
      c. PCO₂ (normal 35-45 mm Hg)
      d. HCO₃⁻ (normal 22-26 mmol/L)
      e. Base excess (-2--+3)
      f. SaO₂ (normal > 95%)
      g. COHb available on most machines.
      h. Total hemoglobin available on most machines.
B. Pulse oximetry
   1. Introduces in 1980s
2. Non-invasive.
3. Safe.
4. Inexpensive.
5. How it works:
   a. Probe is placed over vascular bed (finger, earlobe).
   b. Light-emitting diodes (LEDs) emit light of 2 different wavelengths:
      i. Red = $\lambda$ 660 nm
      ii. Infrared = $\lambda$ 940 nm
   c. Light absorbed by:
      i. Arterial blood.
      ii. Venous blood.
      iii. Other tissues.
   d. Light that passes through the vascular bed is detected by a photodetector.
      i. Photodetectors on opposite side of vascular bed.
      ii. Specialized reflective photodetectors can be on the same side as the LEDs.
   e. Deoxyhemoglobin and oxyhemoglobin each absorb light at different rates due to color and conformation:
      i. Deoxyhemoglobin absorbs more red light than infrared light.
      ii. Oxyhemoglobin absorbs more infrared light than red light.
      iii. Difference in absorption is measured:

\[
R = \frac{AC_{\lambda R} / DC_{\lambda R}}{AC_{\lambda IR} / DC_{\lambda IR}}
\]

Where:
$AC =$ arterial circulation.
$DC =$ venous and other tissue pigments.
$\lambda R =$ red light (660 nm)
$\lambda IR =$ infrared light (940 nm)
f. Only the pulsatile component of arterial blood flow is measured (hence the name “pulse oximetry”).

g. Absorption readings are compared with validated SpO₂ levels in the database for the oximeter.

h. Oxygen saturation:
   i. \( SpO_2 = \frac{Oxygen \ Content}{Oxygen \ Capacity} \)
   ii. Thus:
   \[ SpO_2 = \frac{HbO_2}{Total \ Hb} \times 100 \]
   iii. Thus
   \[ SpO_2 = \frac{Fractional \ Saturation}{100 - (%COHb + %MetHb)} \times 100 \]

i. Perfusion Index (PI):
   i. Found on second-generation oximeters.
   ii. Reflects strength of the pulse at monitoring sites.
   iii. Ranges from 0.02% (very weak) to 20% (very strong).
   iv. Helps determine best site for probe placement.

j. Terminology:
   i. SaO₂ is used for oxygen saturations determined by arterial blood gas analysis.
   ii. SpO₂ is used for saturations determined by pulse oximetry.
   iii. Readings are normally similar.

6. What pulse oximetry can tell you:
   a. SpO₂.
   b. Pulse rate.

7. What pulse oximetry cannot tell you:
   a. Oxygen content of the blood.
   b. Amount of oxygen dissolved in the blood.
   c. Respiratory rate.
   d. Tidal volume
e. Ventilation adequacy.
f. Cardiac output
g. Blood pressure
h. Amount of dyshemoglobinemia

8. Who should use pulse oximetry?
   a. Any level of EMS provider who administers oxygen and has been educated in pulse oximetry usage:
      i. First Responders.
      ii. Emergency Medical Technicians.
      iii. Advanced Emergency Medical Technicians (EMT-Intermediates).
      iv. Paramedics
   b. Always document pulse oximetry readings and communicate these to emergency care providers.

9. Who should not use pulse oximetry:
   a. Persons not trained in use and application of the device.

10. Out-of-hospital indications for pulse oximetry:
    a. To monitor the adequacy of arterial hemoglobin saturation (\(\text{SpO}_2\)).
    b. To quantify the \(\text{SpO}_2\) response to an intervention.
    c. To detect the presence and quality of pulsatile blood flow in an endangered body region (i.e., extremities).

11. Out-of-hospital contraindications for pulse oximetry:
    a. Usage by personnel with inadequate education in pulse oximetry use.
    b. Persons not prepared or incapable of obtaining, documenting, or communicating results of a pulse oximetry assessment of a patient with a real or potential medical emergency.

12. Limitations of pulse oximetry:
    a. Oximetry is not a measure of ventilation.
    b. Oximetry may lag behind hypoxic events.
c. Oximetry is not a substitute for physical examination.

d. Very low saturation states may cause low oximetry readings due to an absence of measured SpO2 levels in the database.

e. Pulse oximetry cannot detect abnormal forms of hemoglobin (e.g., COHb and METHb).

13. First-generation oximeters:
   a. First-generation oximeters relied primarily on raw absorption measurements and correlated these with known SpO2 reference values in the database.
   b. Limitations found with first-generation technology:
      i. Hypotension can cause false readings.
      ii. Carboxyhemoglobin can falsely elevate SpO2 readings.
      iii. Oximetry unreliable during helicopter transport because of movement and vibration.
      iv. Dyes and pigments (e.g., nail polish) can cause abnormal readings.
      v. Vasoconstriction can cause low or absent readings.
      vi. Hypothermia can cause low or absent readings.
      vii. Bright ambient lighting can cause readings in the absence of a pulse.
      viii. Shivering can cause readings in the absence of a pulse.
      ix. Movement can cause readings in the absence of a pulse.

14. Second-generation oximeters:
   a. Second-generation oximeters use various technologies to minimize artifacts and to minimize the possibility of false readings:
      i. Adaptive filters (noise attenuation).
      ii. Signal processing algorithms.
      iii. Improved sensors.
b. Problems prevented with second-generation technology:
   i. Motion artifact.
   ii. False readings during low-flow states.
   iii. False bradycardias.
   iv. False hypoxemias.
   v. Missed desaturations.
   vi. Missed bradycardias.
   vii. Data dropouts.
   viii. Effects of abnormal hemoglobin.
15. Myths often associated with pulse oximetry:
   a. Age affects oxygen saturation.
   b. Gender affects oxygen saturation.
   c. Anemia affects oxygen saturation.
   d. Oxygen saturation inaccurate in dark-skinned individuals.
   e. Jaundice affects oxygen saturation.
16. Out-of-hospital usage of pulse oximetry:
   a. Assure scene safety.
   b. Perform initial (primary assessment).
   c. Apply oxygen when appropriate (either with or after oximetry).
   d. Perform secondary assessment.
   e. Provide ongoing monitoring.
   f. Always follow local protocols.
17. What do oximetry readings mean?
   a. $\text{SpO}_2 = 95-100\%$ → Normal
   b. $\text{SpO}_2 = 91-94\%$ → Mild hypoxemia
   c. $\text{SpO}_2 = 86-90\%$ → Moderate hypoxemia
   d. $\text{SpO}_2 < 85\%$ → Severe hypoxemia
18. Interventional response:
   a. Normal:
      i. Change inspired oxygen (FiO$_2$) to maintain saturation:
         a. Increase
         b. Decrease
   b. Mild hypoxemia:
      i. Increase inspired oxygen (FiO$_2$) to increase saturation.
c. Moderate hypoxemia:
   i. Increase inspired oxygen (FiO₂) to increase saturation.
   ii. Assess and increase ventilation.

d. Severe hypoxemia:
   i. Increase inspired oxygen (FiO₂) to increase saturation.
   ii. Increase ventilation.

19. Pulse oximetry to assess circulation in endangered tissues (off-label indication):
   a. Oximeter probe can be placed on tissues distal to a possible vascular injury.
   b. Oximetry can monitor distal circulation with fractures, dislocations, and crush injuries.
   c. Clinical correlation always needed.

IV. Oxygen administration.
   A. Supplemental oxygen indicated in many emergency situations.
   B. Airway management, rescue breathing and CPR usually take priority over supplemental oxygen administration.
   C. Administration requires:
      1. Oxygen source
      2. Pressure regulator
      3. Flow meter
      4. Humidifier
      5. Connecting tubing
      6. Delivery device
   D. Delivery devices:
      1. Nasal cannula
      2. Simple face mask
      3. Partial rebreather mask
      4. Non-rebreather mask
      5. Oxygen-powered resuscitator
      6. Continuous positive airway pressure (CPAP)
   E. Procedure for oxygen administration:
      1. Prepare equipment
      2. Assemble equipment
      3. Select delivery device
      4. Explain procedure to patient
      5. Begin oxygen delivery
6. Set flow rate
7. Place delivery device on patient
8. Monitor patient

V. Carbon monoxide and CO-oximetry:

A. Carbon monoxide is the leading cause of poisoning deaths in industrialized countries.
B. At least 3,800 people in the United States die annually from carbon monoxide poisoning.
C. Carbon monoxide results from the combustion of fossil fuels and carbon-containing compounds.
D. Tends to accumulate in poorly-ventilated areas.
E. Carbon monoxide displaces oxygen from hemoglobin.
   1. Hemoglobin has an affinity for carbon monoxide that is 200-250 times that of oxygen.
   2. Only high concentrations of oxygen can displace carbon monoxide from hemoglobin.

F. Symptoms of carbon monoxide poisoning:
   1. Carboxyhemoglobin levels do not always correlate with symptoms nor predict sequelae.
   2. Carbon monoxide poisoning often called the great imitator.
      a. Symptoms:
         i. Mild Severity (COHb <15-20%)
            a. Headache
            b. Nausea
            c. Vomiting
            d. Dizziness
            e. Blurred vision
         ii. Moderate severity (COHb 21-40%)
            a. Confusion
            b. Syncope
            c. Chest pain
            d. Dyspnea
            e. Tachycardia
            f. Tachypnea
            g. Weakness
            h. Rhabdomyolysis
         iii. Severe severity (COHb 41-59%)
            a. Dysrhythmias
            b. Hypotension
c. Cardiac ischemia
d. Palpitations
e. Cardiac arrest
f. Respiratory arrest
g. Pulmonary edema
h. Seizures
i. Coma
iv. Fatal severity (COHb > 60%)
   a. Death
v. Red skin color usually a late finding and unreliable.

G. Detection:
   1. Formerly required hospital-based arterial blood gas sampling.
      a. Clinically requires a high index of suspicion.
      b. Technology available (CO-oximetry) to detect COHb levels in the out-of-hospital and emergency department setting.
         i. Uses 8 wavelengths of light to detect 4 different hemoglobin moieties:
            a. Oxyhemoglobin
            b. Deoxyhemoglobin
            c. Carboxyhemoglobin
            d. Methemoglobin
      ii. Provides:
            a. SpO₂
            b. SpCO
            c. SpMET
            d. Pulse rate
   2. Carbon monoxide evaluation should be routine at all levels of EMS and the fire service.
      a. All field personnel should be educated in use of the oximeter and CO-oximeter.

H. Normal carbon monoxide levels (persons ages 3-74 years):
   1. Nonsmokers = 0.83 ± 0.67%
   2. Smokers = 4.30 ± 2.55%
   3. All persons combined = 1.94 ± 2.24%

I. Treatment of carbon monoxide poisoning:
   1. Treatment is based on severity of symptoms.
2. Treatment generally indicated with SpCO > 12-15%.
3. High-concentration oxygen should be administered to displace carbon monoxide from hemoglobin.
4. Be prepared to treat complications (e.g., seizures, cardiac ischemia).
5. Efficacy of hyperbaric oxygen therapy controversial:
   a. Generally reserved for severe poisonings.
   b. May aid with tissue hypoxia.

J. Significant and evolving body of scientific literature showing there are numerous long-term and permanent sequelae from CO poisoning.
K. Fetal hemoglobin (HgF) has a much greater affinity for carbon monoxide than adult hemoglobin (HgA).
   1. Pregnant mothers may exhibit mild symptoms, yet the fetus may have devastating outcomes from carbon monoxide poisoning.

L. Risk management:
   1. Carbon monoxide poisoning symptoms are non-specific and easy to miss and can lead to death and disability.
   2. Missed carbon monoxide poisoning is a significant legal risk for out-of-hospital and emergency department personnel.
   3. Carbon monoxide poisoning is a particular occupational risk for firefighters.
   4. A simple COHb reading can be life-saving.
   5. Screening can be quickly performed.

VI. Methemoglobin and methemoglobinemia.
   A. Not a respiratory gas—but has implications with regard to other respiratory gasses and toxins.
   B. Methemoglobin is hemoglobin with the heme in the ferric (Fe³⁺) state.
      1. Cannot bind oxygen.
      2. Reflects hemoglobin at the end of its functional life.
      3. Results in dark reddish-brown blood.
      4. Most frequently seen in children < 4 months of age.
C. As methemoglobin levels increase, a functional anemia results (hemoglobin amounts normal but a significant amount of hemoglobin nonfunctional).

D. Symptoms:
   1. Cyanosis begins around lips with SpMET >10-15%
   2. Organs with high oxygen demands manifest toxicity first.
   3. Symptoms vary with SpMET concentration:
      a. SpMET = 1-3%:
         i. Normal, asymptomatic.
      b. SpMET = 3-15%:
         i. Slight grayish blue skin discoloration.
      c. SpMET = 15-20%:
         i. Asymptomatic, but cyanotic.
      d. SpMET = 25-50%:
         i. Headache
         ii. Dyspnea
         iii. Confusion
         iv. Chest pain
         v. Weakness
      e. SpMET = 50-70%:
         i. Altered mental status
         ii. Delirium

E. Treatment:
   1. Administer oxygen at high concentrations.
   2. Remove offending agents.
   3. Consider methylene blue as an antidote:
      a. Accelerates the enzymatic degradation of METHb.

F. Carbon Monoxide and Cyanide
   1. Parts of cyanide kit (amyl nitrite and sodium nitrite) induce methemoglobinemia.
   2. Cyanide antidotes (nitrites) and carbon monoxide poisoning can lead to elevated levels of COHb and METHb significantly reducing oxygen-carrying capacity of the blood.
   3. Sodium nitrite should not be administered when combination cyanide/carbon monoxide poisonings when SpCO > 10%.
4. Hydroxycobalamin converts cyanide to cyanocobalamin (Vitamin $B_{12}$) which is cleared renally.
   a. Preferred over nitrites in mixed poisonings.
   b. Hydroxycobalamin is the antidote of choice in mixed carbon monoxide/cyanide poisonings,
REFERENCES


Kansas State Board of EMS. “Monitoring Pulse Oximetry”. [Available at: http://www.ksbems.org/curricula.htm]


Non-Invasive respiratory Gas Monitoring: Out-of-Hospital Implications

Course Evaluation Form

Instructor Name_________________________________________

Date__________________ Time ___________________________

Course Location ________________________________________

Directions:
Circle the number that applies. 1) Needs improvement 2) Satisfactory 3) Good 4) Excellent.

The Course:

Provided enough time to clearly present all lesson objectives

1  2  3  4

Provided enough time for students to learn material or learn and practice the skills

1  2  3  4

Contained information necessary for students to be knowledgeable in the lecture topics/practical skills presented

1  2  3  4

Was logical in the progression of instruction

1  2  3  4

Correlated well to the field application of the topics

1  2  3  4
Kept students interested/involved in the course
1 2 3 4

Assessment-based philosophy received a positive reaction from students
1 2 3 4

Assessment-based thinking helped differentiate between critical/non-critical patients.
1 2 3 4

Assessment-based style provided a satisfactory approach to patient care.
1 2 3 4

Prepared the students to properly manage patients
1 2 3 4

Provide any additional comments in the space below: