New Clinical Perspectives in Pulse Oximetry

Topics for Discussion

• Impact of pulse oximetry
• Oxygen transport physiology
• Knowledge gap in use of pulse oximetry
• Impact of physiology at sensor location in pulse oximetry
• Technology changes in pulse oximetry

OBJECTIVES

At the conclusion of this course, the learner will:

• Describe the basic physics of pulse oximetry monitoring
• Differentiate between functional and fractional saturation
• List three limitations to pulse oximetry
• Describe proper application of the sensor to the patient
• List two technological improvements in pulse oximeters

Pulse Oximetry: The 5th Vital Sign

• Continuous, noninvasive assessment of arterial oxygen saturation (SpO2) and pulse rate
• Patient safety monitor: helps prevent hypoxemia and hypoxia

Pulse Oximetry vs. Arterial Blood Gas (ABG) Analysis

<table>
<thead>
<tr>
<th>Pulse Oximetry</th>
<th>ABG</th>
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<td>Noninvasive</td>
<td>Invasive</td>
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<td>Continuous, real-time data</td>
<td>Single, point-in-time measurement</td>
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<td>Delay in obtaining results from lab</td>
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Clinical Care Scenario

Patient Factors:
– Respiratory distress
– Septic shock
– Poor peripheral circulation

Monitoring Data:
• Pulse oximeter - SpO2 = 80%
• ABG: SaO2 = 94%
• PaO2 = 78 mm Hg
Pulse Oximetry
Clinician Knowledge Gap

442 clinicians from UCLA Medical Center were interviewed:
- 331 registered nurses (RN’s)
- 82 physicians
- 29 respiratory therapists (RT’s)

Percentage of those surveyed who were unaware that “pulse oximetry is not an indicator of adequacy of ventilation”:
- 44% of the RN’s
- 18% of the physicians
- 7% of the RT’s


Pulse Oximetry
Clinician Knowledge Gap

- PACU Nurses
  - 21% thought that a pulse oximetry value (SpO₂) was the same as the partial pressure of arterial oxygen (PaO₂).
  - 89% thought that a pulse oximeter was accurate to within 1% of actual arterial saturation.
  - 89% thought that the arterial oxygen saturation in a healthy adult ranged from 93 to 100%.
  - 37% thought that the finger sensor could be used on the same extremity as a blood pressure cuff.

How Pulse Oximetry Works

Varied Light Absorption Helps Distinguish Arterial Blood

Pulse Oximetry Sensors

Accuracy of Pulse Oximetry Measurements

Typical accuracy specifications are reported as ±2 (adults) or ±3 (neonates) at one standard deviation for the 70% to 100% SpO₂ range.

Statistically, about 95% of readings will fall within 4% of true saturation, which means if the SaO₂ is 94%, SpO₂ readings will range from 90% to 98%.

Statistically, about 67% of readings will be within 2% of true saturation, which means if the SaO₂ is 94%, SpO₂ readings will range from 92% to 96%.

Most hospitals consider SpO₂ levels above 92% as “safe.”

Oxygen Transport

- \( P_a O_2 = \) O\(_2\) dissolved in arterial plasma
- \( S_a O_2 = \) Fraction of functional hemoglobin in arterial blood saturated with oxygen
- \( S_p O_2 = \) Arterial blood oxygen saturation measured by a pulse oximeter

Dysfunctional Hemoglobins

- Carboxyhemoglobin (COHb)
  - CO poisoning
- Methemoglobin (MetHb)
  - e.g. excessive nitrate therapy

Pulse oximetry readings may appear normal when oxygen content is reduced; therefore, assess oxygenation using an arterial blood gas sample and CO-oximetry.

Oxyhemoglobin Dissociation Curve

Left Shift of the ODC

Right Shift of the ODC

Clinical Scenario

You are working in the Emergency Department treating a patient with abdominal pain and a suspected aortic aneurysm.
- BP = 116/74
- f = 32 / min
- P = 120 / min
- \( S_p O_2 = \) 96% and he is not on any oxygen
- Patient complains of light headedness and seems a bit confused
- Routine labwork is pending.

What would your next step be?
Clinical Scenario

• The patient is in distress and it appears that oxygen delivery is reduced.

• The pulse oximetry reading is a distracter.

• Further patient assessment is needed including evaluation of the patient’s hemoglobin level.

Types of Pulse Oximetry Monitors

• Handheld pulse oximeters

• Standalone bedside pulse oximeters

• A module in a bedside critical care/vital signs patient monitor

• A module in a mobile multiparameter monitor

Patient Considerations in Sensor Selection

Factors to consider when choosing a sensor

• Patient body weight
• Patient activity level
• Duration of monitoring
• Infection control concerns
• Skin integrity
• Peripheral perfusion status

Selecting the Right Size Sensor

Choose sensor based on patient’s body weight to ensure:

• Good fit

• Proper alignment of optical components (light emitters and photodetector)

Active Patients

• Single-patient-use, adhesive sensors generally provide a more secure fit.
• Comfortable, “second-skin” fit suitable for long-term monitoring.

Infection Control Concerns

Single-patient-use sensors:

• Typically packaged sterile
• Can be reused on the same patient for prolonged monitoring (in accordance with manufacturer’s directions for use)

Reusable sensors:

• Must be cleaned after use on each patient

Sensor Application Tips & Issues

- Application tips
- Incorrect sensor placement
- Adhesive-related skin trauma
- Neonatal Placement to evaluate presence of Patent Ductus Arteriosus

Sensor Application Tips

- Avoid extremity with an arterial catheter, blood pressure cuff or intravascular infusion line.
- Do not place tape or other constricting materials around sensor.
- Properly position the sensor at the indicated sites according to the manufacturer’s directions for use.

Sensor Applied to Correct Site

Sensor Applied to Incorrect Site

Sensor applied to incorrect site

Physiology at sensor site - Right Sensor – Right Site

- Circulation in the forehead-supraorbital artery off internal carotid artery
- Sensor must be used on right site, designed for anatomical differences
- Note that perfusion is less in the center of the forehead
- Changes in oxygen saturation are accurately measured even under challenging perfusion conditions
- Less movement artifact

Berkenbosh JW and Tobias JD. Comparison of a new forehead reflectance pulse oximeter sensor with a conventional digit sensor in pediatric patients. 2006 Respiratory Care, 51(7): 726-730.
Avoiding Adhesive-Related Skin Trauma

• Skin integrity may be impaired:
  – In newborn infants
  – In the elderly
  – As a result of certain medications

Recommendations:
  – Move sensor to a new site, in accordance with directions for use
  – Use nonadhesive sensors as appropriate

Sensor Placement to Evaluate the Presence of a PDA

• The Ductus Arteriosus may remain open post-delivery and can lead to significant hypoxemia and persistence of fetal circulation.
• Two sensor/monitors can be used
  – Placement of sensor in a pre-ductal location (right hand) and a post-ductal location (left or right foot).
  – In the presence of a PDA, the right hand saturation will be higher than the post-ductal sensor reading.

Troubleshooting

Common conditions that can affect pulse oximetry readings:
• Light interference
• Anemia
• Pigmentation
• Nail polish
• Intravascular dyes

Troubleshooting

Light Interference
• Ambient Light
• Optical Shunt
• Optical Cross-Talk
• Edema

Troubleshooting

Light Interference
• Ambient light
• Optical shunt

Troubleshooting

Light Interference
• Optical cross-talk
• Edema
Troubleshooting

• Anemia

• Skin Pigmentation

Troubleshooting

• Nail polish – especially brown, blue or green


• Intravascular dyes


Clinical Scenario

• 78-year-old female admitted to the general care floor ICU with dyspnea (shortness of breath) and congestive heart failure. She is monitored with pulse oximetry and a noninvasive blood-pressure monitor on the same arm.
  – Receiving O₂ at 3 liters/min via nasal cannula
  – SpO₂ is 92%
  – The pulse oximeter alarms periodically

What would you do to correct the problem?

Technological Improvements in Pulse Oximetry

New-Generation Pulse Oximetry
Reliable performance even in difficult monitoring conditions

Earlier Pulse Oximetry

• Pulse oximetry studies between 1995 and 2003.
  – 17 studies, many of which were flawed in the design making assumptions difficult.
  – “In a lab setting, all new-generation pulse oximeters outperformed conventional devices in their ability to tolerate motion.”
  – “New-generation oximeters have fewer false alarms and higher accuracy than do conventional oximeters.”


Technological Improvement – Signal Processing

• Low perfusion/weak pulsatile signals
• Low blood pressure/blood flow
• Patient motion

Light path

Arterial blood
Venous blood
Bone, tendon, tissue
Sensor light coupling

Time
Clinical Scenario

• You patient in the NICU pulse oximeter monitor’s alarm intermittently goes on. The patient is a 32-week gestation, one-day old baby recently admitted. She is exhibiting periods of normal, quiet breathing with bouts of restlessness. You notice her pulse oximeter alarms during the period of restlessness and stops when she is resting quietly.
• What is the source of the intermittent alarm and how can it be managed?

Clinical Scenario - Solution

• Increased motion leads to artifact which obscures the pulse oximetry signal and leads to inaccurate oxygen saturation readings.
• The solution is to switch to a pulse oximetry system that utilizes new technology designed to read through motion.

Technological Improvement - Faster Microprocessors

• Advances in microprocessor technology.
• Faster speed = Improved algorithms
• Improved algorithms = improved SpO2 readings and less issues with artifact

Technological Improvement - Calibration Systems

EARLIER GENERATION OXIMETRY
Pre-programmed Calibration Choices built into monitor
YICAL pointer

NEW TECHNOLOGY
Calibration Curve stored in digital memory chip

Technological Improvement – Reducing Nuisance Alarms

Problem

• Alarms are turned off
• Alarms are tuned out

Fact or Artifact

• Father relates experience in NICU where his newborn was being cared for.
• Multiple monitors present.
• Staff’s response to an alarms: Ignore them!
• “Why have audible alarms if you always ignore them?”


**Technological Improvement: Reducing Nuisance Alarms**

- **Solution**
  - Improved signal processing algorithms
  - Improved alarm handling capabilities
- Important in NICU

**Technological Advancements: Remote Oximetry Alarm Systems**

- Monitoring of patients during the postoperative period when the risk of hypoxemic complications is greatest and the degree of monitoring is the least.
- A study by Rosenberg at the University Hospital in Copenhagen looked at 22 consecutive adult patients following major surgery.
  - 6 of 22 adult patients had episodes of hypoxemia associated with Tachycardia.
  - 4 of 22 adult patients had episodes of hypoxemia associated with myocardial ischemia (ST segment changes).
  - 3 of 22 adult patients had episodes of hypoxemia associated with 2° AV block.
- Every episode occurred in sleeping patients.
- Remote oximetry monitoring improves patient monitoring and support the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) patient safety goal to improve the effectiveness of alarm systems.

**Remote Oximetry Alarm Systems**

- The monitoring of patients remotely is accomplished with a
  - A computer display at a central station
  - A standalone pulse oximeter at each bedside
  - A transmitter to send oximetry data by radio frequency or hardwire network to the central display.
  - Pager to alert bedside clinician.

**Economic benefits**

- Cost-effective way to better manage higher-acuity patients outside the ICU
- Reduce readmission of patients to the ICU after primary discharge (bounceback)
  - Bounceback leads to increased cost of admission and increased mortality.

**Limitations of Traditional Sites**

- Peripheral pulse oximetry measurements may lag behind acute arterial oxygen saturation changes by a much as 2 minutes.
- Peripheral site use is less accurate in patients who are vasoconstricted due to hypothermia or the infusion of vasoactive medications is less accurate showing significant bias compared to measured arterial oxygen saturation.


**Technological Advancement: Sensor Technology Improvements**

- Poorly perfused patients still a challenge.
- Forehead sensor offers advantage for poorly perfused patients
**Radial Arterial & Various Sensor Sites During Vasoconstriction**

- **Cold Room Vasoconstriction Blood Study**
  - Subject 403
  - Time (sec): 0 200 400 600 800 1000 1200
  - SaO2, SpO2 (%)
  - FIO2 (%)
  - Forehead
  - Radial Artery
  - Fingers
  - Ear


**Finger vs. Forehead**

- During periods of peripheral vasoconstriction, there can be a 3-minute delay in posting a desaturation event from the fingers versus the forehead.
- Improved monitoring through use of a forehead sensor.

**Temperature and Pulse Oximetry**

- **Effect of Cold Environment on Pulse Oximetry**
  - Schramm, Bartunek, and Gilly evaluated the local thermoregulatory control of blood vessels by observing the pulse oximeter’s plethysmographic display.
  - During local hyperthermia, oxygen saturation significantly decreased.
  - During local hypothermia, oxygen saturation increased after immersing the one hand in a warm water bath and the other hand in a cold water bath at the same time.
  - Pulse oximetry readings obtained during periods where the peripheral limb experiences temperature change were subject to some variation.

**Forehead Sensor Advantages**

- Stronger signal integrity than ear sensors
- Easier to access than hands
- Less active site for moving patients

**Critical Care Scenario Revisited**
Conclusion

• Pulse oximetry instrumentation and description of the components of the sensor and monitor.
• Oxygen transport physiology
• Proper sensor application and troubleshooting
• Advantages of newer-generation technology