

Pulse Oximetry Laboratory



Introduction

Measuring the arterial oxygen saturation (SpO_2^*) levels of patients is very beneficial to healthcare providers and has, in the past 20 years, become one of the most vital and easiest parameters to obtain and analyze. SpO_2 levels can provide valuable information including the efficiency of pulmonary gas exchange and the adequacy of alveolar ventilation, blood-gas transport, and tissue oxygenation. In the past, SpO_2 levels were measured by taking periodic blood samples and analyzing them several times a day using large, expensive laboratory equipment. This method was not only inconvenient for doctors, nurses, and patients, but it failed to provide accurate real-time measurements of SpO_2 . During the 1970's much attention was paid to developing a cheaper, more efficient way of measuring SpO_2 . This led to the introduction of non-invasive pulse oximetry in the early 1980's. Pulse oximetry is a non-invasive method to determine SpO_2 by utilizing light emitting diode (LED) technology to measure the differences in red and infrared light absorption or reflection of oxygenated and deoxygenated hemoglobin.

Since its inception, pulse oximetry has become a standard in the clinical environment because of its ease of use and the importance of the information it provides. Pulse oximetry is especially useful in surgical procedures and emergency situations, where the SpO_2 levels can be monitored to ensure that the brain is receiving adequate amounts of oxygen. In the following laboratory session, you will obtain heart rate, SpO_2 , respiration effort, and one channel of electrocardiography (ECG) data in order to gain a better understanding of the basics of pulse oximetry

* Arterial oxygen saturation is referred to as SpO_2 when measured using a pulse oximeter as opposed to SaO_2 when measured in a lab.

Equipment required:

- CleveLabs kit
- CleveLabs Course Software
- Three (3) Snap Leads, Three (3) Snap Electrodes
- Respiratory Effort Belt
- SpO_2 Finger Sensor
- Microsoft® Excel, MATLAB®, or LabVIEW™

Background

In order to understand how SpO_2 is obtained through pulse oximetry, one must be familiar with the underlying technology. Photoplethysmography is an optical method for measuring volume changes in tissue by analyzing changing volumes of an optically absorbent/transmitting substance such as blood. As arterial pulsations fill a capillary bed, the changes in blood volume modify the absorbance/transmittance of light passing through. These changing light characteristics can be measured and used to determine the heart rate of a patient. Furthermore, understanding the characteristics of oxygenated and deoxygenated blood, this technology can be extended for use as a non-invasive method to determine SpO_2 .

Most of the oxygen carried by the blood (~98%) is reversibly bound to a protein molecule called hemoglobin that is found in erythrocytes (red blood cells). Hemoglobin has the ability to bind one oxygen molecule to each of its four subunits that are composed of a single heme group containing a central iron atom where oxygen binding takes place. At any time, depending on the SpO_2 , there are varying amounts of completely oxygenated (4 molecules of oxygen bound), partially oxygenated (1-3 molecules of oxygen bound), and deoxygenated (0 molecules of oxygen bound) hemoglobin circulating in the blood stream. Oxygenated and deoxygenated hemoglobin possess unique optical characteristics when exposed to red and infrared wavelengths of light. More specifically, oxygenated hemoglobin absorbs infrared light and transmits red light, while deoxygenated hemoglobin absorbs red light and transmits infrared light. This phenomenon can be utilized to obtain an accurate, non-invasive measurement of SpO_2 .

Pulse oximetry can be performed in two ways, absorbance pulse oximetry and reflection pulse oximetry (Figure 1). In absorption pulse oximetry, two LEDs at two separate wavelengths (red: 660 nm, infrared: 940 nm) are cycled on and off at up to 480 times per second. After the transmitted red and infrared signals pass through the test site (usually a reasonably translucent area with good blood flow, such as a finger or earlobe) they are received at the photo diode. The ratios of transmitted red and infrared light are calculated and compared to tables provided by the manufacturer that are based on a calibration curve derived from various known SpO_2 levels. The numeric SpO_2 value returned by the pulse oximeter is the hemoglobin saturation percentage, or the percent of hemoglobin passing through the test area that is completely saturated with oxygen. Normal arterial hemoglobin saturation percentages are anywhere from 95 to 100%. In reflection pulse oximetry, the only difference lies in the fact that the photo diode is on the same side as the LEDs. The reflection of the light from test area is measured instead of the transmitted light through the test area as in absorbance measuring. Similarly, the ratios of the lights detected are calculated and compared to a calibration curve made from normal healthy subjects.

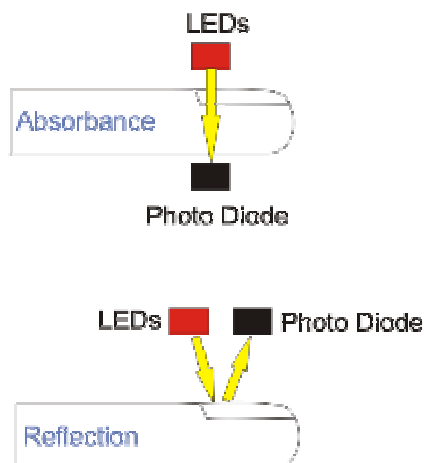


Figure 1. Absorbance and reflection pulse oximetry.

There are many different types of sensor leads for pulse oximetry. In adults it is most common to obtain the measurement through the tip of the finger using a finger clip pulse oximeter. However in some cases, such as with infants who would constantly pull the lead off, this is not reasonable. In these cases, pulse oximetry measurements can be taken from the earlobe or toe.



Figure 2. Both a finger clip sensor (right) and a finger wrap sensor (left) may be used for pulse oximetry readings. The difference is that the finger clip has all components embedded inside while the disposable finger wrap design requires the user to place the photosensor inside the wrap prior to use.

Regardless of the test area, there are always constant light absorbers such as tissue and venous blood present that add a constant DC component to the detected signal. After each heart beat, there is a surge of blood into the area that momentarily increases the blood volume across the test site. The constant DC signal is subtracted from the time-varying ac component caused by the momentary increase in arterial blood volume. This ensures that only arterial blood is used when calculating SpO_2 levels, eliminating the error that would be caused by the presence of tissue and venous blood.

In early pulse oximetry systems, artifact could be a major problem in obtaining an accurate reading. A common source of artifact was motion. If a subject wearing a finger clip pulse oximeter waved their finger around in space, it would have a turbulent effect on the blood flow

in the finger. This in turn would have an impact on the measurement. However, in recent years, improved algorithms from manufacturers have limited the amount that artifact can corrupt the pulse oximetry measurement.

One unfortunately all too common event which can effect oxygen saturation levels in blood is carbon monoxide poisoning. Carbon monoxide (CO) is a colorless, odorless gas which is produced as a by-product of incomplete combustion of fossil fuels. The burning of gas, oil, coal, and/or wood can produce increased levels of CO without proper ventilation. There are hundreds of deaths each year from carbon monoxide poisoning. CO enters the lungs through normal ventilation. It has a much stronger affinity for hemoglobin than oxygen does. Therefore, it can displace oxygen in the blood. Early effects of CO poisoning include headache, dizziness, and nausea. If left exposed for a long period of time, death can occur. Carbon monoxide detectors should be common fixtures in homes to help prevent exposure.

Experimental Methods

Experimental set-up

1. For this laboratory, you will need the SpO₂ finger sensor, the respiratory effort belt, 3 snap leads, and 3 snap electrodes from the CleveLabs kit.
2. Attach the finger sensor to the index finger of the test subject (Fig 3). Attach the lemo connector end of the pulse oximetry sensor to the BioRadio. (If possible, use a test subject that does not have any type of nail polish or artificial nail surface in the test area as this could cause erroneous results)

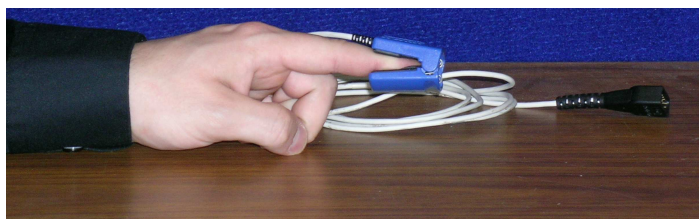


Figure 3. The pulse oximetry sensor attaches to a subject's finger.

3. Place the respiratory belt around the torso of the test subject. Securely fasten the respiratory effort belt around the subject just above the stomach and around the rib cage. Attach the leads from the respiratory effort belt to the + and – inputs of channel 1 of your BioRadio (Fig 4).
4. Attach the 3 snap electrodes to the test subject. One on the inside of the left wrist, one on the inside of the right wrist, and one on the right ankle. For reference, this is described in greater detail in the Electrocardiography I Laboratory. We will only be measuring a one lead (Left Arm, Right Arm, Ground) ECG for this experiment.

5. Attach the snap leads to the electrodes and connect them to channel 2 and the ground (GND) of your BioRadio as shown in Fig 4.
6. Turn the BioRadio on.

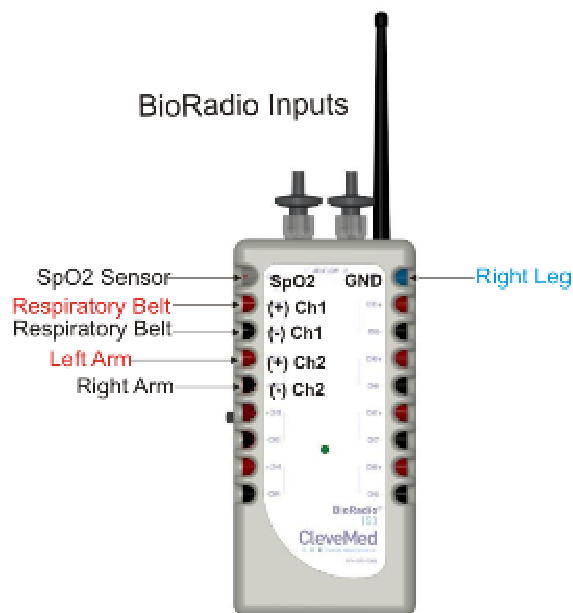


Figure 4. BioRadio set-up for the pulse oximetry laboratory session

Procedure

1. Run the CleveLabs Course software. Log in and select the “Pulse Oximetry Lab” under the “Advanced Physiology” subheading and click the “Begin Lab” button. The CleveLabs software will automatically program the BioRadio to the “PulseOximetry” configuration.
2. Click on the BioRadio data tab and click on the “Start” button. Respiratory effort and one channel of ECG should be scrolling across the screen. Digital displays of the numeric values for SpO₂ and heart rate should also be visible (If the BioRadio™150 is not receiving a good signal from the finger sensor, it will display values of 127 for “%O₂ Saturation” and 511 for “Pulse Rate”. Make sure the test subject’s finger is positioned correctly in the finger sensor. It may take up to 5 seconds for the new signal to be displayed).
3. The first part of this lab will be recording a normal resting SpO₂ and heart rate from the subject.

4. With the subject's signal scrolling across the screen, click on the "Save" button and record approximately 10 seconds of data. Name this file "restingSPO2". After saving data, click on the "Screen Capture" button to capture a screen shot of the scrolling data.
5. Next, we will look at the effects of holding your breath on a resting SpO₂ and heart rate. As in steps two, three, and four start recording a normal resting SpO₂ by clicking on the "Save" button. Approximately 5 seconds into the recording, instruct the test subject to hold his/her breath for as long as possible, but no longer than 30 seconds. Continue recording for approximately 30 seconds after the test subject starts breathing again. Name this file "holdSPO2".
6. Now instruct the subject wearing the finger sensor to wave their arm around in the air for approximately 10 seconds. Record approximately 30 seconds of data for this trial including 10 seconds before, 10 seconds during the arm waving, and 20 seconds after the arm waving. Name this file "SPO2 artifact".
7. Click on the tab labeled "Processing and Application". Utilizing the same concept from the Heart Rate Detection Laboratory, we will now determine the heart rate from the ECG signal and compare that to the heart rate obtained by the commercial pulse oximetry sensor. Set up the simple threshold detection heart rate detector utilizing the same parameters outlined in the *Procedure and Data Collection* section in the Heart Rate Detection Laboratory (steps 9-11). Compare/contrast the two heart rate values.
8. Next, compute the test subject's heart rate by detecting the pulse on the wrist. Compare/contrast the three values of heart rate (pulse oximetry, ECG, and wrist).

Data Analysis

Note: The sampling rate for the SpO₂ and pulse rate was set to 1/10 the sampling rate of the respiratory effort and ECG during the data collection.

1. Using MATLAB, LabVIEW, or the CleveLabs Post Processing toolbox, open your saved data file called "restingSPO2". The four channels of saved data should include ECG, respiratory effort, pulse rate, and SpO₂. Examine any correlations that exist between the ECG and respiratory effort signals.
2. Using MATLAB, LabVIEW, or the CleveLabs Post Processing toolbox, open your saved data file called "holdSPO2". The four channels of saved data should include ECG, respiratory effort, pulse rate, and SpO₂. Examine the impact that holding your breath had on pulse rate and SpO₂.

3. Using MATLAB, LabVIEW, or the CleveLabs Post Processing toolbox, open your saved data file called “artifactSPO2”. If the pulse rate or SpO2 levels were disrupted by the motion artifact, calculate the time it takes for the signals to recover.

Discussion Questions

1. Pulse oximeters can detect and distinguish the pulsatile nature of arterial blood flow in the finger from non-pulsatile venous blood flow located in the same area. This allows the machine to calculate the oxygen saturation of hemoglobin in arterial blood only, eliminating misleading readings caused by light absorption/reflection from the presence of deoxygenated venous blood and the surrounding tissue space. Given this information, can finger movement during pulse oximetry create a misleading SpO₂ value?
2. Why was the development of a pulse oximeter sensor such a large breakthrough in the medical community?
3. Normal resting SpO₂ values for adults are between 95 and 100%. What was the resting SpO₂ of the test subject? What changes (if any) did you observe in SpO₂ when instructing the subject to hold his/her breath? Explain any changes that you observed.
4. What changes did you observe in heart rate when instructing the test subject to hold his/her breath.
5. Why is it important in a clinical setting to measure both ventilation and arterial oxygen saturation?
6. Did the pulse oximetry and ECG heart rate values agree with one another? Why or why not? How did your manual (wrist) heart rate measurement compare to the electronic outputs?
7. Describe the physiological effects of carbon monoxide poisoning.

References

1. Webster, John G. Medical Instrumentation: Application and Design 3rd Edition. 1998 pp 469-472
2. Kästle, Siegfried et al. “A New Family of Sensors for Pulse Oximetry”. Hewlett-Packard Journal. February 1997 pp 1-3.
3. Vander, A., Sherman, J., Luciano, D. Human Physiology: The Mechanisms of Body Function. McGraw Hill. Boston, MA. 2001 pp 484-488.
4. www.carbonmonoxidekills.com