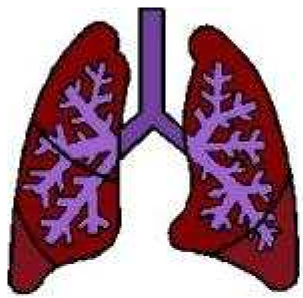
Spirometry Laboratory



CleveLabs Laboratory Course System Version 6.0

Introduction

Respiration consists of ventilation, gas transfer and transport, and the control of breathing. Each of these functions work together to bring air into the body, extract oxygen from the air, and distribute the oxygen to areas of the body that need it to perform physiological functions. The lungs operate in this network of functions by allowing us to inhale a volume of air. The alveoli in the lungs are then responsible for the transfer of oxygen to the blood stream and carbon dioxide out of the blood stream. Finally, the blood and circulatory system is then responsible for carrying oxygen throughout the human body.

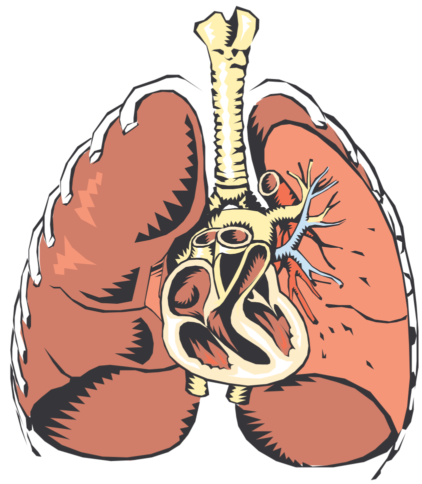


Figure 1. Air enters the lungs and gas exchange is completed in the alveoli.

More specifically, ventilation is the process of moving air in and out of the lungs. The process of ventilation is controlled by many muscles and the inherent mechanical properties of the lungs themselves such as size and elasticity. There are many diseases that can have a negative effect on the properties of the lungs and inhibit oxygen transfer to the body. For example, cigarette smoking can cause emphysema or lung cancer which can decrease the elastic property of the lungs making it harder to fill them with air.

Therefore, ventilation or "airflow" is an important physiological signal to measure. There are several types of electromechanical transducers that can be used to monitor airflow. These include spirometers, pressure sensors, thermocouples, and piezo-electric respiratory effort belts. For the purposes of this laboratory session, you will explore how to use a spirometer. You should have already learned how to use other transducers in the "Respiration" chapter. In this lab you will compare the spirometer output to the piezo-electric respiratory effort belt and determine the tradeoffs and benefits of each type of transducer.

Equipment required:

- CleveLabs Kit
- CleveLabs Course Software
- Piezoelectric Respiratory Effort Belt
- Spirometer and Transducer Interface Cable
- Microsoft® Excel, MATLAB® , or LabVIEW™

Background

The Lungs

The lungs are the main organ of the body responsible for gas exchange, namely the transfer of oxygen into the body and the transfer of carbon dioxide out of the body. The biomechanical properties of the lungs are integral in how well they can transfer air in and out. The gas exchange of oxygen and carbon dioxide in the body takes place in three steps. First, ventilation occurs. Ventilation refers to the moving air in and out of the lungs. Secondly gas diffusion and uptake occurs. Finally, the gas is transported by the blood.

The muscles that control respiration create a difference in lung pressures. This pressure difference, which is also a function of the elasticity of the lungs, causes air to flow. The diaphragm is the main muscle that is used for breathing. When the diaphragm contracts it causes the lungs to inflate and the thoracic cavity becomes enlarged. As a result, the pleural space in the chest cavity enlarges. This increase in space volume causes a decrease in pressure which causes the lung to expand and fill with air. This is an example of Boyle's Law in action. Boyle's Law states that for a constant temperature, the volume of any gas varies inversely with the pressure.

$$\text{Pressure} * \text{Volume} = \text{Constant} \qquad \text{(Boyle's Law)}$$

The volume of air that enters or leaves the lungs during a single breath is known as the tidal volume. The tidal volume is approximately 500mL during normal resting conditions. However, the tidal volume is only a small portion of the amount of air the lungs can actually take in.

An important test that individuals with breathing problems are given is a forced vital capacity (FVC) test. This evaluation monitors the amount of air a person can move in and out of their lungs. In this test, the person is instructed to take a deep breath and then exhale out has hard as they can. The average volume of air that a person can forcefully exhale out of their lungs is approximately 5.0L. A spirometer is an instrument that can be used during this test to measure airflow and the volume of air that is moved in and out of the lungs. FVC is a function of strength of chest and abs, airway resistance, and the size and elasticity of the lungs. Therefore, if FVC is out of the normal range, the clinician can begin trying to determine which of those factors are causing the abnormality.

Another important quantitative test to evaluate lung function is pressure-volume curves. This technique is extremely important for measuring the compliance of the lung. Lung compliance is computed as the slope of the pressure volume curve. A high compliance means that the lungs are very easy to inflate while a low compliance means that the elasticity of the lungs is extremely reduced.

Figure 2. Individuals with asthma may use an inhaler to deliver medication that will open constricted bronchials.

Lung diseases are typically classified as either obstructive or restrictive disorders. An obstructive disorder prevents expiratory flow from the lungs while a restrictive disorder prevents the inflation of the lungs. Examples of obstructive diseases include chronic bronchitis and emphysema. Another example of a respiratory disease is asthma. In asthma, constricted bronchials collapse and lead to a decrease in forced vital capacity compared to normals. An asthmatic may not have more than a 3.0L FVC. An inhaler is used to open the airways again to restore breathing (Fig 2). The inhalers contain brachiodialators which act to open the airway. For those that are too young or unable to use an inhaler, a nebulizer may be used. A nebulizer transforms the medication into a vapor mist that is inhaled through a mask.

There are several medical devices that can be used by individuals who have a decreased capacity for getting oxygen into their body. For example, oxygen concentrators are used for people who cannot get enough oxygen into their body simply from breathing room air. The normal oxygen concentration in the air is approximately 20% oxygen. Oxygen concentrators strip oxygen from the air in the room and deliver a higher concentration of oxygen to the patient. The oxygen is typically delivered through a cannula and the flow rate on the concentrator is adjustable. Oxygen concentrators typically deliver a level of oxygen greater than 90% to a user. Patients may also be on portable oxygen cylinders which are filled with air at high percent oxygen.

Spirometry Transducers

A spirometer is a transducer that measures airflow. There are several designs that have been used to implement a spirometer. In an early design, the recorder included a double-walled cylinder that used an inverted bell immersed in water to create a seal. A pulley attached the bell to a pen that wrote on a rotating drum. As air entered the system, the bell would rise and change the position of the pen in relation to the drum. In more modern devices, computer technology and electronic transducers are used to create a spirometer. The pressure differential across two sides of a membrane can be utilized to measure flow. The relative pressure difference across the membrane is proportional to flow. Therefore, this technique can be used to calibrate an electrical pressure transducer to monitor flow as someone breathes through the membrane.

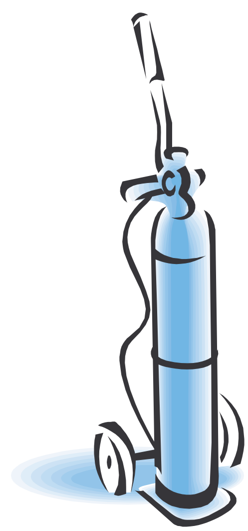


Figure 3. Oxygen cylinders may be used by those with respiratory difficulties.

A piezo-electric respiratory effort belt can also be used to monitor breathing. This transducer outputs a voltage which is proportional to the change in length of the belt. This transducer will be used in this lab to examine the tradeoffs between different transducers for monitoring respiration. For a more detailed description of how this transducer works, please refer to the "Respiration" lab chapter.

Experimental Methods

Experimental Setup

During this laboratory session you will record airflow using a spirometer and respiratory effort using a piezo-electric belt. These experiments will allow you to learn how to record airflow with a new transducer as well as evaluate the tradeoffs and benefits between different types of respiratory transducers. You should be sure to watch the experimental setup movie included with the CleveLabs software before beginning the initial setup in the experiment.

1. For this laboratory you will need to use a piezoelectric respiratory effort belt, a spirometer, and the transducer interface cable from the CleveLabs Kit.

2. Connect the transducer interface cable to input channels 1 and the pulse oximeter input on the BioRadio. The pulse oximeter input provides power to the transducer.

3. Connect the spirometer to the transducer interface cable.

4. Connect the leads from the piezo-electric respiratory effort belt to the inputs on channel 2 of the BioRadio.

5. Be sure to place the plastic white, microguard over the inlet of the spirometer. Additionally, you should place one of the disposable mouthpieces over the microguard. The mouthpiece should be discarded after use by a subject.

6. The respiratory effort belt should wrap snuggly around a subject's torso between their chest and stomach.

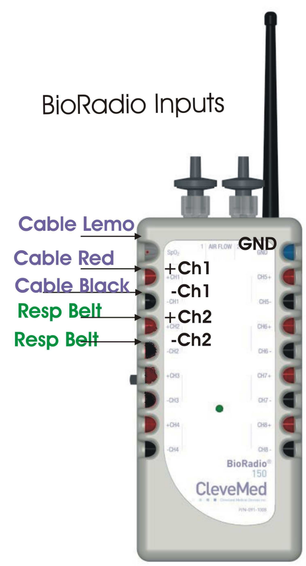


Figure 4: Spirometer and piezo-electric respiratory effort belt setup

Procedure and Data Collection

1. Run the CleveLabs Course software. Log in and select the “Spirometry” laboratory session under the Advanced Physiology subheading and click on the “Begin Lab” button.

2. Turn the BioRadio ON.

3. Click on the Airflow Data Tab and then on the green “Start” button. One channel of airflow and one channel of respiratory effort should begin scrolling across the screen. Your BioRadio should be programmed to the “Spirometry” configuration.

4. Make sure the subject is not breathing into the spirometer. Then click on the “Zero Spirometer Sensor” button to calibrate or zero the transducer.

5. First you will record your respiration at rest. The subject should be sitting in a chair relaxed. The subject should place the spirometer in their mouth and then begin breathing normally. Save about 20 seconds of data to a file named “relaxbreaths”.

6. Repeat step 5 with the subject taking shallow breaths. Name the file “shallowbreaths”.

7. Repeat step 5 with the subject taking very deep breaths. Name the file “deepbreaths”.

8. Now click on the spectral analysis data tab. Click on the frequency domain tab. Change the data collection interval to 500ms. Notice what happens to the peak frequency as you change your breathing patterns from quick shallow breaths to longer spaced deep breaths.

9. Now click on the tab labeled processing and application. Set the filtering parameters to a low pass filter with a 20Hz cutoff.

10. In this application you will measure the subject’s force vital capacity (FVC). Instruct the subject to inhale as large a breath as they can and then hold it for a second. At this point, you should click on the green “Start” button, followed by the “Run” button under the “Forced Volume” label. They should NOT put the spirometer to their mouth until after they inhale. They should then put the spirometer to their mouth and exhale as hard as they can for as long as they can. As soon as they are finished exhaling (you can watch the plot to see it), click on the “Forced Volume” button again to stop the calculation. In other words, the force volume button should only be down during the exhalation part of the subject’s breath.

11. The software will automatically integrate the signal and compute the volume that was exhaled. The plot shows the process of integrating the flow signal. The final value in the plot is also shown to the left. This final value is the volume that was exhaled during the trial. Repeat this exercise three times and note the FVC for each trial.

12. Repeat steps 10 and 11, but this time allow the subject to take a deep breath in with the spirometer after the exhale before you stop the trial.

Data Analysis

1. Using MATLAB, LabVIEW, or Excel, open each of your saved data files. Can you come up with a calibration factor between the two sensors that would allow you to calibrate the piezo-electric respiratory effort belt to output airflow?

2. Using MATLAB, LabVIEW, or Excel, open each of your saved data files. Note the differences in the time and frequency characteristics for the different types of breaths that the subject took.

3. Compute the average FVC for the maximum expiration trials.

4. Compute the average FVC for the maximum expiration trials in which you followed expiration with a deep breath in.

Discussion Questions

1. Describe the quantitative difference in the signals from each of the transducers for the different types of breaths that the subject took, including short, normal, and deep.

2. What are some common respiratory disorders and what impact do they have on the lungs?

3. Were you successfully able to compute a calibration factor for the respiratory effort belt to measure airflow? Describe reasons why or why not.

4. What are the tradeoffs between the different types of transducers?

5. What was the average FVC for a subject during the exhale only trials? Was this close to normal?

6. What was the average FVC for a subject during the exhale and inhale trials? Why?

References

1. Guyton and Hall. Textbook of Medical Physiology, 9th Edition, Saunders, Philadelphia, 1996.

2. Rhoades and Phlanzer. Human Physiology, Third Edition. Saunders College Publishing, Forth Worth, 1996.

3. Kandel ER, Schwartz JH, Jessel, TM. Essentials of Neuroscience and Behavior. Appleton and Lange, Norwalk, Connecticut, 1998