Week 8: Pulmonary Function (PF) I

BIOE 320 Systems Physiology Laboratory

Objectives

1. To observe experimentally, record, and calculate selected pulmonary volumes and capacities.
2. To model and analyze the relationship between vital capacity and variables such as age, height, and smoking habits.
3. To observe experimentally, record, and calculate Forced Expiratory Volume (FEV) and Maximal Voluntary Ventilation (MVV).
4. To compare the observed values with average or predicted values.

Background

The lungs are the primary functioning organ of the respiratory system. They are divided into right and left lobes. Branching segments bring air from the trachea to the alveoli and back. Fig. 1 shows the basic anatomy of the lung.

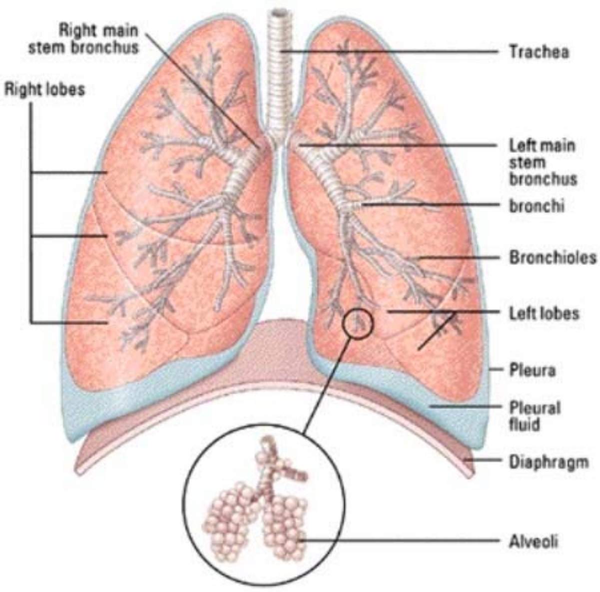

Figure 1: Diagram of lung anatomy

The main role of the respiratory system is to provide oxygen (O_2) to the body, while removing carbon dioxide (CO_2) as waste. When air is breathed into the body, it travels through the oral cavities, throat, larynx, and trachea. It then enters the lungs, and after flowing through the bronchioles, it enters millions of alveoli. In the alveolar space, the gas exchange occurs through a simple diffusion process that is fueled by the partial pressure gradients of O_2) and CO_2). The air that has been inhaled has a higher concentration of O_2) than that in the capillary blood. As a result, O_2) travels down the pressure gradient and into the blood stream (Fig. 2). A similar process occurs with CO_2) in the reverse direction.

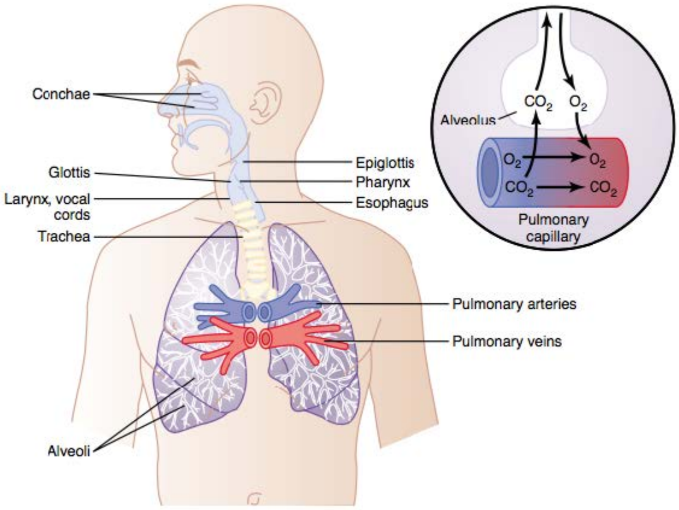

Figure 2: Pulmonary gas exchange

Inspiration (inhalation) is an active process, during which the diaphragm contracts and the rib cage expands to increase lung volume. As modeled by Boyle's Law, an increase in volume is correlated with a decrease in pressure. As the intrapulmonary pressure drops below atmospheric pressure (760 mmHg), a pressure gradient is formed and air flows into the lungs. At this point, gas exchange occurs. **Expiration** (exhalation), however, is mostly passive. The diaphragm and external intercostals relax as the abdominals contract. This causes a decrease in lung volume, an increase in intrapulmonary pressure, and the subsequent outflow of air.

Surface tension elastic forces of the alveolar membrane play a large role in the elastic recoil of the lungs. The area between the lung and thoracic wall, called the pleural cavity, contains fluid that helps lubricate movement of lungs within the cavity. The pressure within this space (negative pleural pressure) causes the volume of the lungs to increase and decrease with the expansion and contraction with the thoracic wall. The tendency of htel ungs to contract is called **elasticity**, and the lung's ability to increase in volume in response to an increase in pressure is called **compliance**.

Pulmonary Function Tests (Spirometry)

Lifestyle, body type, disorders, and more can affect pulmonary function. These effects can be quantified for clinical use with a spirometer, which measures the volume and rate of air exhaled and inhaled.

Table 1: Terms related to pulmonary function

Term	Normal value	Definition
Tidal Volume (TV)	500 mL	Volume of air during each normal breath
Inspiratory Reserve Volume (IRV)	3000 mL	Volume of air that can be forcefully inspired after tidal inspiration
Expiratory Reserve Volume (ERV)	1100 mL	Volume of air that can be forcefully expired after tidal expiration
Residual Volume (RV)	1200 mL	Volume of air left in lung following forced expiration (keeps the alveoli from collapsing)
Inspiratory Capacity (IC)	TV + IRV	Maximum amount of air a person can breathe in after normal expiration
Expiratory Capacity (EC)	TV + ERV	Maximum amount of air a person can breathe out after normal inspiration
Functional Residual Capacity (FRC)	ERV + RV	Volume of air left in the lungs after normal expiration
Vital Capacity (VC)	IRV + TV + ERV	Largest volume of air that can be expired after maximum inspiration
Total Lung Capacity (TLC)	IRV + TV + ERV + RV	Maximum volume to which the lungs can be expanded

Volumes and Capacities

Pulmonary volumes can be determined by measuring volumes of inhaled and exhaled air, whereas capacities are derived form the sum of two or more volumes. Total lung capacity is the sum of all of these volumes and represents the maximum volume of air that the lungs can hold. Table 1 and Fig. 3 summarize these terms and their definitions.

Forced Expiratory Volume and Maximum Voluntary Ventilation

In addition to examining lung volumes and capacities, quality of pulmonary function can also be determined by measuring pulmonary flow rates, or the airflow in and out of the lungs. Airflow resistance is a limiting factor in the ability of the lungs to efficiently move air in and out. Forced Expiratory Volume (FEV) and Maximum Voluntary Ventilation (MVV) are both indicative of such resistance. Table 2 describes additional terms to pulmonary function.

Clinical Relevance

There are two main types of pulmonary disease:

- **Restrictive** pulmonary diseases (such as pulmonary fibrosis) are characterized by normal airway resistance, but impaired respiratory movements because abnormalities in the lung tissue, pleura, chest wall, or neuromuscular machinery.
- **Obstructive** pulmonary diseases (such as asthma and COPD) are characterized by difficulty breathing due to increased airflow resistance.

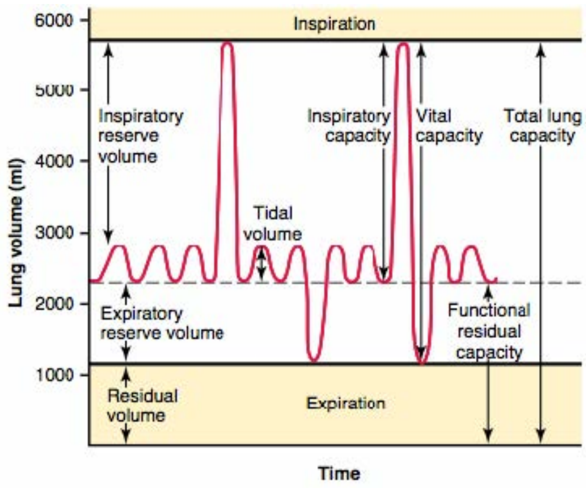

Figure 3: Pulmonary volumes and capacities

Table 2: Additional terms related to pulmonary function

Term	Definition
Forced Expiratory Volume (FEV)	Maximum amount of vital capacity air that can be expelled in a certain number of seconds (e.g. FEV_1, FEV_1, FEV_3)
Forced Vital Capacity (FVC)	Maximum amount of air that a person can forcibly exhale after a maximal inhalation
Maximum Voluntary Ventilation (MVV)	Maximum amount of air that can be inhaled and exhaled in one minute in L/min, breathing as quickly and deeply as possible. This combines volume and flow rates to assess overall pulmonary ventilation

Experiment 1

Hardware and Software Setup

1. Plug the output line from the airflow transducer into channel 1 of the MP3X unit.
2. Insert the filter into the inlet opening of the airflow transducer.
3. Insert the calibration syringe into the other end of the filter (away from the airflow transducer) as seen in Fig. 4
4. Turn the MP3X unit on.
5. From the desktop, open BIOPAC student lab 3.7. Selected L12 - PF 1.

Calibration

1. Make sure to always handle this setup by holding the syringe, rather than the handle of the airflow transducer. This will ensure that the equipment remains properly aligned.

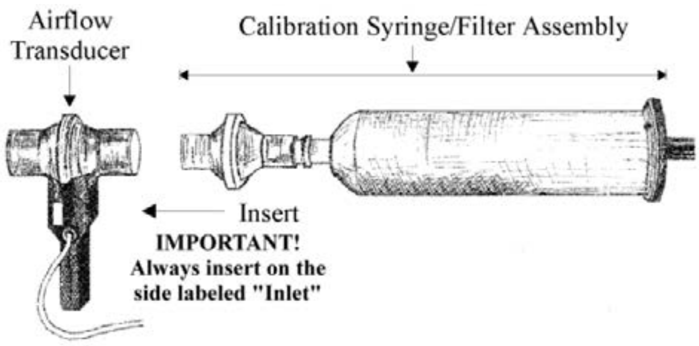

Figure 4: Transducer setup

2. Pull the syringe handle all the way out.
3. Read the instructions below, then click the "Calibrate" button located int he upper left corner of the Setup window.
4. During this recording, simply hold the assembly still and upright. Recording will end after 8 seconds and your screen should display a straight line.
5. During this next part, you will push the syringe plunger in and out for a total of 5 cycles (push in and pull out for a total of 10 strokes). Pace yourself and try to achieve slow, smooth movement. Rest for a short time in between each plunge.
6. Hold the syringe horizontally in one hand and use the other hand to plunge in and out completely.
7. When you are ready to begin, click "OK" to start the calibration.
8. When you finish calibrating, click "End Calibration." Your screen should resemble Fig. 5.

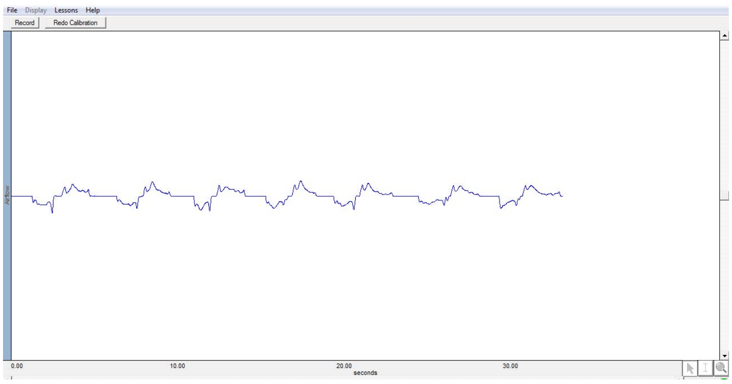

Figure 5: Calibration procedure - plunge cycles

9. If your calibration looks incorrect, click "Redo" and repeat the procedure.

Test Procedure

Info: Keep the airflow transducer upright at all times during the experiment. If you start on an inhale, try to end on an exhale as this increases the accuracy of the airflow to volume calculation. Try not to look at the screen while recording as you may manipulate the results.

1. Remove the calibration syringe and replace it with a disposable mouthpiece.
2. Attach the nose clip to the subject's nose.
3. Breathe normally through the mouthpiece for 20 seconds prior to the start of recording.
4. Select "Record" when the subject is ready (Begin recording on an inhale).
5. The subject must:
   (a) Continue breathing normally for 5 breath cycles.
   (b) After a resting expiration, inhale as deeply as possible.
   (c) Exhale to the point of normal resting expiration and continue breathing normally for 3-5 breaths.
   (d) After a resting inspiration, maximally exhale (as completely as possible).
   (e) Breathe normally for 5 breath cycles.
6. When you are done recording, click on "Stop."
7. If the data resembles Fig. 6, click "Done." Otherwise, click "Redo" and try again.

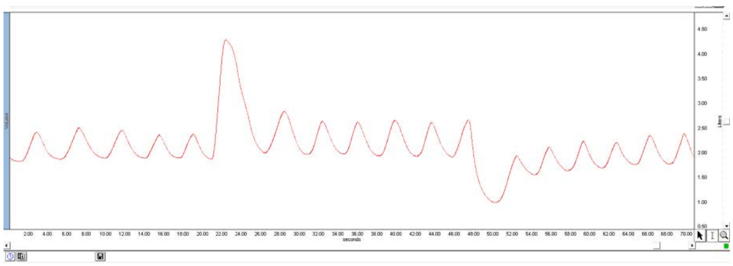

Figure 6: Example pulmonary function data

Info: You will not be able to make additional measurements after this step, so make sure you have all the data needed.

8. From the pop-up window, select "Analyze current data file."

Data Analysis

1. Complete the table in the handout. The tidal volume is the peak-to-peak volume measurement of a normal breath cycle. Calculate the Tidal Volume for three different breaths and take an average. Determine IRV, ERV, and VC for one breath
2. Calculate the capacities listed in the table in the handout assuming a Residual Volume (RV) of 1 L.

3. How would the volume measurements (TV, IRV, and ERV) change if data were collected after vigorous exercise?
4. In this lab, equations for vital capacity (VC) were presented. Using the data provided, determine an equation for VC in the following form:

$$VC = b_0 + b_1x_1 + b_2x_2 + b_3x_3 \tag{1}$$

where b_n is a regression parameter, x_n is a variable (such as height). *Hint: use a program that can perform multiple regression.*

5. Qualitatively assess your equation. How do the variables (such as height) affect the VC? Is each of the parameters positively or negatively correlated to VC? What do the magnitude and sign of the regression parameters imply?

Experiment 2

Hardware and Software Setup

1. Remove the mouthpiece from the airflow transducer and insert the calibration syringe.
2. From the desktop, open BIOPAC Student Lab v3.7 and select L13 - PF II.
3. Follow the calibration procedure described in the previous section.

Test Procedure

> **Info:** Keep the airflow transducer upright at all times during the experiment. If you start on an inhale, try to end on an exhale as this increases the accuracy of the airflow to volume calibration. Try not to look at the screen while recording as you may manipulate the results.

1. Remove the calibration syringe and replace it with a disposable mouthpiece.
2. Attach a nose clip to the subject's nose.
3. Breathe normally through the mouthpiece for 20 seconds prior to the start of recording.
4. Select "Record FEV" when the subject is ready to start recording.
5. The subject must:
   (a) Continue breathing normally for 3 breath cycles.
   (b) After a resting expiration, inhale as deeply as possible.
   (c) Hold their breath for an instant.
   (d) Exhale as quickly and completely as possible.
6. When you have collected your data, click "Stop."
7. If the data does not resemble Fig. 7, click "Redo" and try again.

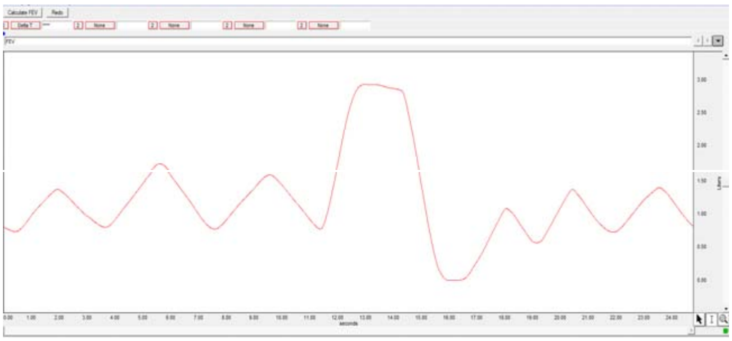

Figure 7: Example pulmonary function data

8. Use the I-beam cursor to select the area of maximal exhale. Start at the exact point where the exhale begins and continue for 3 seconds (use delta T measurements to guarantee at least 3 seconds of data selection).
9. Click on "Calculate FEV." This will automatically plot your data to show a cumulative expired volume over time,
10. If you need to re-select the measurement area, click "Redo." Otherwise, click "Continue."
11. Have the subject reapply nose clip, sit upright, and begin breathing through the airflow transducer.
12. Select "Record MVV" when the subject is ready to start recording.
13. The subject must:
    (a) Continue breathing normally into the airflow transducer for 5 breath cycles.
    (b) Breath quickly and deeply for 12-15 seconds. Stop early if the subject feels dizzy.
    (c) Breathe normally for 5 more cycles.
14. Click on "Stop."
15. Review the data on the screen. If the data does not resemble that in Fig. 8, click on "Redo." Otherwise, click "Done."

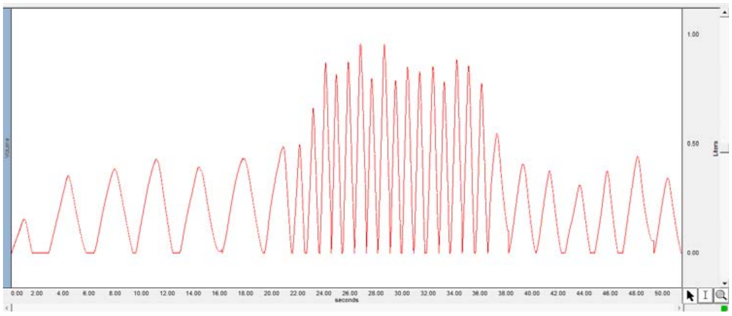

Figure 8: Example pulmonary function data

16. Select Analyze Current or Previous Data File to analyze data from the FEV or the MVV files, respectively. You can also access these files when you first open BIOPAC

lessons, by selecting "Review Saved Data" instead of a specific lesson and looking for the folder where you saved your data.

Data Analysis

1. Estimate the Vital Capacity using a p-p measurement.
2. Calculate FEV_1, FEV_2, and FEV_3.
3. How do your calculated fractions of air expelled during the three listed time intervals compare with "normal" (average) values?
4. Is it possible for a subject to have a vital capacity within normal range, but a value for FEV_1 below normal range? Explain.
5. Using the data collected for the Maximal Voluntary Ventilation (MVV) measurements, calculate the respiratory rate (RR) over a 12-second interval. Do so by calculating the number of cycles in the 12-second interval and *not* by highlighting the whole section and selecting Frequency.
6. Complete the table in the handout with a measurement for each cycle. Complete only for the 12-second interval used above (the table may have more rows than you need). Calculate the average volume per cycle (AVPC).
7. Calculate the MVV using the following formula:

$$MVV = AVPC \times RR \tag{2}$$

8. Bronchodilator drugs open airways and clear mucous. How would these drugs affect the FEV and MVV measurements?
9. MVV decreases with age. Why?