The Respiratory System

Part 1. Lung Volumes and Capacities

Objectives

1. Obtain graphical representation of lung capacities and volumes.
2. Compare lung volumes between males and females.
3. Correlate lung volumes with clinical conditions.
4. Determine the effect of exercise on tidal volume and respiratory frequency.

Background

Measurement of lung volumes provides a tool for understanding normal function of the lungs as well as disease states. The breathing cycle is initiated by expansion of the chest. Contraction of the diaphragm causes it to flatten downward. If chest muscles are used, the ribs expand outward. The resulting increase in chest volume creates a negative pressure that draws air in through the nose and mouth. Normal exhalation is passive, resulting from “recoil” of the chest wall, diaphragm, and lung tissue.

In normal breathing at rest, approximately one-tenth of the total lung capacity is used. Greater amounts are used as needed (i.e., with exercise). The following terms are used to describe lung volumes (see Figure 1):

- **Tidal Volume (TV):** The volume of air breathed in and out without conscious effort
- **Inspiratory Reserve Volume (IRV):** The additional volume of air that can be inhaled with maximum effort after a normal inspiration
- **Expiratory Reserve Volume (ERV):** The additional volume of air that can be forcibly exhaled after normal exhalation
- **Vital Capacity (VC):** The total volume of air that can be exhaled after a maximum inhalation: \[ VC = TV + IRV + ERV \]
- **Residual Volume (RV):** The volume of air remaining in the lungs after maximum exhalation (the lungs can never be completely emptied)
Total Lung Capacity (TLC): \[= VC + RV\]

Minute Ventilation: The volume of air breathed in 1 minute: \[(TV) \text{ (breaths/minute)}\]

In this experiment, you will measure lung volumes during normal breathing and with maximum effort. You will correlate lung volumes with a variety of clinical scenarios. You will also determine how exercise impacts both tidal volume and breathing frequency to ensure sufficient delivery of air during periods of increased activity.

**Procedure**

*Important:* Do not attempt this experiment if you are currently suffering from a respiratory ailment such as the cold or flu.

1. Connect the Spirometer to the Vernier computer interface. Open the *Bio131* folder on the desktop, then open the *Vernier Physiology* folder. Double-click the file *19 Lung Volumes*.

2. Attach the larger diameter side of a bacterial filter to the “Inlet” side of the Spirometer. Attach a gray disposable mouthpiece to the other end of the bacterial filter (see Figure 2).
3. Hold the Spirometer in one or both hands. Brace your arm(s) against a solid surface, such as a table, and click [Zero] to zero the sensor. **Note:** The Spirometer must be held straight up and down, as in Figure 2, and not moved during data collection.

4. Collect inhalation and exhalation data.
   a. Put on the nose plug.
   b. Click [Collect] to begin data collection.
   c. Taking normal breaths, begin data collection with an inhalation and continue to breathe in and out. After 4 cycles of normal inspirations and expirations, fill your lungs as deeply as possible (maximum inspiration) and exhale as fully as possible (maximum expiration). **It is essential that maximum effort be expended when performing tests of lung volumes.**
   d. Follow this with at least one additional recovery breath.

5. Click [Stop] to end data collection.

6. Click the Next Page button, [Next], to see the lung volume data. If the baseline on your graph has drifted, use the Baseline Adjustment feature to bring the baseline volumes closer to zero, as in Figure 3.

7. Select a representative peak and valley in the Tidal Volume portion of your graph. Place the cursor on the peak and click and drag down to the valley that follows it. Enter the Δy value displayed in the lower left corner of the graph to the nearest 0.1 L as Tidal Volume in Table 1.

8. Move the cursor to the peak that represents your maximum inspiration. Click and drag down the side of the peak until you reach the level of the peaks graphed during normal breathing. Enter the Δy value displayed in the lower left corner of the graph to the nearest 0.1 L as Inspiratory Reserve Volume in Table 1.

9. Move the cursor to the valley that represents your maximum expiration. Click and drag up the side of the peak until you reach the level of the valleys graphed during normal breathing. Enter the Δy value displayed in the lower left corner of the graph to the nearest 0.1 L as Expiratory Reserve Volume in Table 1.

10. Calculate the Vital Capacity and enter the total to the nearest 0.1 L in Table 1.
    
    \[ VC = TV + IRV + ERV \]

11. Calculate the Total Lung Capacity and enter the total to the nearest 0.1 L in Table 1. (Use the value of 1.5 L for the RV.)
    
    \[ TLC = VC + RV \]

12. Share your data with your classmates and complete the Class Average columns in Table 1.
Effect of Exercise on respiration

13. As you have just discovered the inflow of air into the lungs is affected by both tidal volume and by your breathing frequency. Which of these will change with exercise? In this part of the lab you will assess whether tidal volume or breathing frequency varies in response to different levels of exercise. First, select one or two subjects from your group to serve as the “athletes”.

14. Repeat the measurements for Tidal Volume as above for your subjects, 1) resting, 2) following a 3 minute walk outside on the road, and 3) following a 3 minute jog/run down the road and back to the lab. It is important to obtain the exercise measurements as soon as the exercise is completed. So the team should be ready with the instruments once the athletes return. As you determine tidal volume, count the number of breaths the subject takes per minute (breathing frequency). Record the data in Table 2.
### Table 1

<table>
<thead>
<tr>
<th>Volume measurement (L)</th>
<th>Individual (L)</th>
<th>Class average (Male) (L)</th>
<th>Class average (Female) (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume (TV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspiratory Reserve (IRV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expiratory Reserve (ERV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vital Capacity (VC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Volume (RV)</td>
<td>≈1.5</td>
<td>≈1.5</td>
<td>≈1.5</td>
</tr>
<tr>
<td>Total Lung Capacity (TLC)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Exercise Level</th>
<th>Rest</th>
<th>Walking</th>
<th>Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume (TV) (Liters)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breathing Frequency (Breaths per minute)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part 2. Effect of “Dead Space” on Oxygen Availability

Objectives

1. Simulate different volumes of dead space.
2. Measure the oxygen concentration within the dead space.
3. Correlate dead space volume with a variety of physiologic challenges.

Background

In the average adult human, approximately 150 mL of the air that is inhaled with each breath never reaches the alveoli. It fills the nose, mouth, larynx, trachea, bronchi, and bronchioles, a volume known as the “anatomical dead space.” This air is not available for gas mixing and exchange. It mixes with newly inhaled air and is “recycled” back to the alveoli. The relative size of the “dead space” as compared to functioning lung tissue impacts the efficiency of the respiratory system. Dead space is important in a variety of medical conditions such as asthma, pneumonia, and emphysema, and must be considered in treatments such as artificial ventilation in an intensive care unit. It is also important in physiologic challenges such as diving and high altitude activities.

In this experiment, you will use an O$_2$ Gas Sensor to analyze inhaled and exhaled air while artificially changing the size of the “dead space.” You will calculate the effect that dead space has on oxygen delivery to the lungs and correlate this with various physiologic challenges.

The majority of oxygen is carried in the blood by hemoglobin molecules. This is dependent upon the partial pressure of oxygen, but the binding of oxygen is efficient over a wide range of oxygen pressures. This relationship is demonstrated in the “Oxygen-Hemoglobin Dissociation Curve” (see Figure 1). In conditions where hemoglobin concentration is low (anemias), oxygen delivery to the tissues is proportionately decreased. Blood transfusions, rather than supplemental oxygen, will increase oxygen delivery to the tissues.

![Figure 1](image-url)
Procedure

Part A. The Effect of Increasing Dead Space on Oxygen Concentration

1. Connect the O₂ Gas Sensor to Channel 1 of the Vernier computer interface. Open the file 24 Effect of Dead Space from the Vernier Physiology folder.

2. Insert the Vernier O₂ Gas Sensor into the CO₂-O₂ Tee as shown in Figure 2.

3. Click [Collect] to begin data collection. Place your mouth on the smaller end of the CO₂-O₂ Tee and begin normal breathing. Data will be collected for 60 s.

4. Store this run by choosing Store Latest Run from the Experiment menu.

5. Remove the O₂ Gas Sensor from the CO₂-O₂ Tee and allow readings to return to ambient levels. Monitor oxygen levels by observing the readings on the screen. Once ambient levels have been reached, re-attach the sensor to the CO₂-O₂ Tee.

6. Attach the 15 cm PVC pipe to the larger end of the CO₂-O₂ Tee as shown in Figure 3.

7. Click [Collect] to begin data collection. Place your mouth on the smaller end of the CO₂-O₂ Tee and begin normal breathing. Data will be collected for 60 s.

8. Store this run by choosing Store Latest Run from the Experiment menu.

9. Remove the O₂ Gas Sensor from the CO₂-O₂ Tee and allow readings to return to ambient levels. Monitor oxygen levels by observing the readings on the screen. Once ambient levels have been reached, re-attach the sensor to the CO₂-O₂ Tee.

10. Attach the 30 cm PVC pipe to the larger end of the CO₂-O₂ Tee as shown in Figure 3.

11. Click [Collect] to begin data collection. Place your mouth on the smaller end of the CO₂-O₂ Tee and begin normal breathing. Data will be collected for 60 s.

12. Click and drag to highlight all data runs from 20–60 s. Click the Statistics button, [ ]. Click the boxes in front of Run 1, Run 2, and Latest and click [OK]. Record the mean values to the nearest 0.1% for all three runs in Table 1.
Part B. The Effect of Increased Effort on Oxygen Consumption

13. Choose Clear All Data from the Data menu.

14. Remove the 30 cm PVC pipe from the CO₂-O₂ Tee and ensure that the Tee is well attached to the O₂ Gas Sensor.

15. Click [Collect] to begin data collection. Place your mouth on the smaller end of the CO₂-O₂ Tee and begin deeply inhaling and exhaling. Allow 3 s for inhalation and 3 s for exhalation to prevent dizziness. Data will be collected for 60 s.

16. Store this run by choosing Store Latest Run from the Experiment Menu.

17. Remove the O₂ Gas Sensor from the CO₂-O₂ Tee and allow readings to return to ambient levels. Monitor oxygen levels by observing the readings in the Logger Pro tool bar. Once ambient levels have been reached, re-attach the sensor to the CO₂-O₂ Tee.

18. Attach the 15 cm PVC pipe to the larger end of the CO₂-O₂ Tee as shown in Figure 3.

19. Click [Collect] to begin data collection. Place your mouth on the smaller end of the CO₂-O₂ Tee and begin deep breathing, as instructed in Step 15. Data will be collected for 60 s.

20. Store this run by choosing Store Latest Run from the Experiment Menu.

21. Remove the O₂ Gas Sensor from the CO₂-O₂ Tee and allow readings to return to ambient levels. Monitor oxygen levels by observing the readings in the Logger Pro tool bar. Once ambient levels have been reached, re-attach the sensor to the CO₂-O₂ Tee.

22. Attach the 30 cm PVC pipe to the larger end of the CO₂-O₂ Tee as shown in Figure 3.

23. Click [Collect] to begin data collection. Place your mouth on the smaller end of the CO₂-O₂ Tee and begin deep breathing, as instructed in Step 15. Data will be collected for 60 s.

24. Click and drag to highlight all data runs from 20–60 s. Click the Statistics button, [Statistics]. Click the boxes in front of Run 1, Run 2, and Latest and click [OK]. Record the mean values for all three runs in Table 2.
### Data

#### Table 1 – Normal Breathing

<table>
<thead>
<tr>
<th>Run</th>
<th>Description</th>
<th>Mean O₂ concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CO₂-O₂ Tee alone</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CO₂-O₂ Tee + 15 cm PVC pipe</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CO₂-O₂ Tee + 30 cm PVC pipe</td>
<td></td>
</tr>
</tbody>
</table>

#### Table 2 – Deep Breathing

<table>
<thead>
<tr>
<th>Run</th>
<th>Description</th>
<th>Mean O₂ concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>CO₂-O₂ Tee + 15 cm PVC pipe</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CO₂-O₂ Tee + 30 cm PVC pipe</td>
<td></td>
</tr>
</tbody>
</table>
DATA ANALYSIS

PART 1. VOLUMES

1. Describe the difference between lung volumes for males and females. What might account for this?

2. Calculate your Minute Volume at rest.

\[(TV \times \text{breaths/minute}) = \text{Minute Volume at rest}\]

If you had to take shallow breaths (TV = 0.20 L) to avoid severe pain from rib fractures, what respiratory rate would be required to achieve the same minute volume?

3. On a separate piece of paper create a bar chart showing a) Tidal volume in relation to exercise intensity, b) Breathing Frequency in relation to exercise intensity, and c) minute volume in relation to exercise intensity. Based on your data, which appears to be more important for increasing the delivery of air as the intensity of exercise increases – increasing tidal volume or increasing breathing frequency?
PART 2. ANATOMICAL DEAD SPACE

1. The varying lengths of PVC pipe act to increase the volume of inhaled air that is not available for gas mixing and exchange – the so-called “dead space.” Calculate the volume of air in the 15 and 30 cm lengths of PVC pipes ($\pi r^2 h$), respectively. To each value, add 30 mL to account for the volume of air present in the CO$_2$-O$_2$ Tee. Record your answers in the table below in the column labeled “Volume” (remember that cm$^3$ = mL). Add these volumes to your anatomical dead space (150 mL), and enter the total values into the table.

<table>
<thead>
<tr>
<th>Calculation of Dead Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe length</td>
</tr>
<tr>
<td>15 cm</td>
</tr>
<tr>
<td>30 cm</td>
</tr>
</tbody>
</table>

2. Using the table you completed in Question 1, estimate the proportion by which your anatomical dead space was artificially increased by

(a) the 15 cm tube.

(b) the 30 cm tube.

3. Describe the trend in mean oxygen concentration seen in the data entered in Table 1 as it relates to the anatomical dead space.

4. The average amount of air breathed in and out during normal respirations is approximately 500 mL (this is called tidal volume). The volume of air inhaled and exhaled during deep breaths is approximately 4000 mL (this is called vital capacity). Use these values to explain the difference in trends seen in Table 1 and Table 2.