Spirometry: Lung Volumes, Capacities, and Ventilation

Introduction: Pulmonary Volumes and Capacities (text pages 191 – 192)
Lung volumes are the four overlapping components of the total lung capacity and are measured by a technique known as spirometry. Lung capacities are the sum of two or more lung volumes. A few important examples include:

- **Vital Capacity / Forced Vital Capacity (VC / FVC)** – the total amount of air that can be expired after maximal inspiration.
- **Total Lung Capacity (TLC)** – the total amount of air the lungs can hold; TLC = FVC + RV.
- **Residual Volume (RV)** – the amount of air that remains in the lungs after a maximal exhalation.

![Spirogram showing lung volumes and capacities.](image)

<table>
<thead>
<tr>
<th>Average</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC</td>
<td>6.0 L</td>
<td>4.2 L</td>
</tr>
<tr>
<td>VC (FVC)</td>
<td>4.8 L</td>
<td>3.2 L</td>
</tr>
<tr>
<td>RV</td>
<td>1.2 L</td>
<td>1.0 L</td>
</tr>
</tbody>
</table>
I. Introduction: Pulmonary Function (FVC and FEV<sub>1.0</sub> Predicted Values)
Vital capacity can be determined by a slow maximal inhalation then slow maximal exhalation (SVC) or by a slow inhalation and forced, rapid exhalation (FVC). Another useful measure is the forced expiratory volume in one second (FEV<sub>1.0</sub>). It is basically the portion of the FVC that occurs during the first one second of this maximal exhalation. The FVC and FEV<sub>1.0</sub> can be used to give an indication of the overall functional health of the lungs. Specifically, chronic obstructive pulmonary disease (COPD), such as asthma, would result in a reduced FEV<sub>1.0</sub>. Chronic restrictive pulmonary disease, such as pulmonary fibrosis, would result in reduced lung volumes or capacities, such as FVC. With many physiological variables, it is often useful to compare actual measures to predicted measures (i.e. PFVC and PFEV<sub>1.0</sub>), which are based on other physical or physiological parameters. Spirometry measures are good examples. Although these are just predictions, they provide a mark of what is typically expected for a given individual based upon population norms.

### Degrees of Restrictive or Obstructive Lung Disease Based on FVC/PVC, FEV<sub>1.0</sub>/PFEV<sub>1.0</sub>, and FEV<sub>1.0</sub>/FVC

<table>
<thead>
<tr>
<th>Subjective Degree</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&gt;80</td>
</tr>
<tr>
<td>Mild; Borderline</td>
<td>65-80; 70-79</td>
</tr>
<tr>
<td>Moderate</td>
<td>50-64</td>
</tr>
<tr>
<td>Severe</td>
<td>35-49</td>
</tr>
<tr>
<td>Very Severe</td>
<td>&lt;35</td>
</tr>
</tbody>
</table>

- Predicted values for FVC (PFVC) and FEV<sub>1.0</sub> (PFEV<sub>1.0</sub>) can be made from the following equations:

**MEN:**
\[
PFVC (L) = [0.06 \text{ Ht (cm)}] - [0.0214 \text{ Age (yr.)}] - 4.650
\]
\[
PFEV_{1.0} (L) = [0.0414 \text{ Ht (cm)}] - [0.0244 \text{ Age (yr.)}] - 2.190
\]

**WOMEN:**
\[
PFVC (L) = [0.0491 \text{ Ht (cm)}] - [0.0216 \text{ Age (yr.)}] - 3.590
\]
\[
PFEV_{1.0} (L) = [0.0342 \text{ Ht (cm)}] - [0.0255 \text{ Age (yr.)}] - 1.578
\]
Lab Activity IA.
Groups will determine two measures for themselves: (1) the forced vital capacity (FVC) and (2) the forced expired volume in one second (FEV$_{1.0}$). A Micro Spirometer will be used to determine these values. You must make a maximum inspiration and follow it with an expiration that is as fast and forceful as possible for as long as possible. You must exhale until you reach residual volume. Record your values in the data table below. Predicted values will be calculated from the formulas above. The values you measure and predict will be used to calculate the functional capacity of the lungs in regard to ventilation.

Lab Activity IB.
(1) Calculate predicted FVC and FEV$_{1.0}$ (PFVC and PFEV$_{1.0}$) and record them in the data table.
(2) Calculate the (a) FEV$_{1.0}$/FVC ratio (from measured values), (b) FVC/PFVC (from measured and predicted), and (c) PFEV$_{1.0}$/PFEV$_{1.0}$ ratios (from predicted only).

Lab Assignment I.
(1) Turn in a presentation table containing your subjects’ measured values.
(2) Turn in a second presentation table with your calculated results and your ratings for each subject.
(2) Explain the possible reasons for the good health or the impairment of each of the subjects. (You may have to ask the other subjects for information pertaining to their pulmonary health).

I. PULMONARY FUNCTION

<table>
<thead>
<tr>
<th>Subject</th>
<th>FVC (L)</th>
<th>FEV$_{1.0}$ (L)</th>
<th>PVC (L)</th>
<th>PFEV$_{1.0}$ (L)</th>
<th>FVC/PFVC Ratio</th>
<th>FEV$<em>{1.0}$/PFEV$</em>{1.0}$ Ratio</th>
<th>FEV$_{1.0}$/FVC Ratio</th>
<th>Lung Disease Rating based on FEV$_{1.0}$/FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
II. Introduction: Ventilatory Stimulation

One of the strongest stimulators of ventilation is carbon dioxide. Contrary to what might be thought; low oxygen levels in the blood are not as strong a stimulator of ventilation as high CO₂. Because ventilation causes CO₂ to be “blown off” into the atmosphere, the rate at which CO₂ is removed from the blood can be increased by hyperventilation. This results in lower blood CO₂ (PCO₂) than normal and a decreased ventilatory drive. At the same time, hyperventilation does not allow for excess oxygen to be “loaded” into the blood for use by the body. As arterial blood is almost completely saturated with oxygen under normal conditions, it cannot pick up more, regardless of ventilatory rate or volume.

Lab Activity II.

Each person in the group will use one balloon to capture their expired air after the following conditions:

- **Trial 1:** Deep inhalation and immediate exhalation.
- **Trial 2:** Deep inhalation and breath holding as long as is comfortable.
- **Trial 3:** 4 deep and rapid inhalations and breath holding as long as is comfortable.
- **Trial 4:** 8 deep and rapid inhalations and breath holding as long as is comfortable.
- **Trial 5:** 12 deep and rapid inhalations and breath holding as long as is comfortable.

For each trial you will record the duration of breath holding endured. When the balloon is emptied into the O₂ / CO₂ analyzer, record the % O₂ and % CO₂.

Lab Assignment II.

1. Average the group data for each trial and generate two graphs: Produce one plot (column graph) of the average duration of breath holding (y-axis) against ventilation conditions (x-axis), and one plot of % O₂ and % CO₂ (y-axis values) against ventilation conditions (x-axis).
2. From your results make a conclusion as to the effect of oxygen and carbon dioxide concentrations as stimulators of ventilation.
III. Introduction: Ventilation at Rest and During Exercise

Pulmonary ventilation or volume expired per minute ($V_E$) is the product of tidal volume ($V_T$) and breathing frequency ($F_B$). Since these are not fixed variables, the human has the capacity to manipulate them in order to provide enough air (therefore oxygen) to the body. During exercise more oxygen is used and more carbon dioxide is produced which leads to an increase in ventilation. What is the strategy that is most effective for the human when pulmonary ventilation requirements are high: increase $V_T$ or $F_B$?

Lab Activity III.
One subject from the group will ride the cycle ergometer (50 rpm) at increasing workloads while the rate of volume of air expired $V_E$ and $F_B$ are measured. At the end of the second minute of each stage, obtain $V_E$ from the MMS. Measure $F_B$ by counting ventilations during the stage. Record measurements on the data form.

- Stage 1: 2 minutes of rest (sitting on the ergometer, no pedaling)
- Stage 2: 2 minute at 300 kg m/min
- Stage 3: 2 minute at 600 kg m/min
- Stage 4: 2 minute at 900 kg m/min
- Stage 5: 2 minute at 1200 kg m/min (if possible)

Lab Assignment III.

1. Calculate $V_T$ at rest and for each workload (stage) ($V_T = \frac{V_E}{F_B}$).
2. Generate a line graph by plotting $F_B$ and $V_T$ (y-axis) for each stage (x-axis). This will require you to make a graph with 2 y-axes.
3. Describe the changes in $V_T$ and in $F_B$ as compared to rest. Which had the greatest % increase compared to the other?
   
   \[
   \%\text{ change} = \left[\frac{\text{final-initial}}{\text{initial}}\right] \times 100
   \]
4. Explain the ventilation strategy used by the subject during exercise.
5. Explain why you think that one strategy was used instead of the other.
II. Ventilatory Stimulation

<table>
<thead>
<tr>
<th>Subject</th>
<th>Trial 1 Immediate no holding</th>
<th>Trial 2 No breaths + holding</th>
<th>Trial 3 4 breaths + holding</th>
<th>Trial 4 8 breaths + holding</th>
<th>Trial 5 12 breaths + holding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

III. Ventilation Strategy During Exercise  
\[ \dot{V}_E = V_T \times F_B \]

<table>
<thead>
<tr>
<th>Example Rest</th>
<th>(V_T = 0.5) L</th>
<th>(F_B = 15) bths(\cdot)min(^{-1})</th>
<th>(\dot{V}_E = 7.5) L(\cdot)min(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 (Rest)</td>
<td>(V_T = )</td>
<td>(F_B = )</td>
<td>(\dot{V}_E = )</td>
</tr>
<tr>
<td>Stage 2</td>
<td>(V_T = )</td>
<td>(F_B = )</td>
<td>(\dot{V}_E = )</td>
</tr>
<tr>
<td>Stage 3</td>
<td>(V_T = )</td>
<td>(F_B = )</td>
<td>(\dot{V}_E = )</td>
</tr>
<tr>
<td>Stage 4</td>
<td>(V_T = )</td>
<td>(F_B = )</td>
<td>(\dot{V}_E = )</td>
</tr>
<tr>
<td>Stage 5</td>
<td>(V_T = )</td>
<td>(F_B = )</td>
<td>(\dot{V}_E = )</td>
</tr>
</tbody>
</table>