I. Introduction

All animals require oxygen to carry out cellular processes of energy transformation essential for life. During cellular metabolism, oxygen is consumed when nutrients such as protein, carbohydrate, and fat are oxidized, and carbon dioxide is produced as a gaseous waste product. Collectively, the processes whereby oxygen is taken up from the atmosphere, delivered to body cells, and consumed, and the processes of producing carbon dioxide and delivering it to the lungs for excretion into the atmosphere constitute respiration.

Processes of respiration fall into one of three categories: external respiration, gas transport, and internal respiration. External respiration refers to mechanisms by which a person obtains oxygen from the external environment and eliminates carbon dioxide into the external environment. Gas transport refers to mechanisms used to distribute oxygen to and remove carbon dioxide from cells. Internal respiration refers to the chemical reactions of cellular metabolism in which oxygen is consumed and carbon dioxide is produced. In this lesson we will focus on mechanisms of human external respiration.

The human respiratory system (Fig. 12.1) consists of an upper division and a lower division. The upper division is made up of the nasal and oral cavities, the pharynx (throat), and the larynx (voice box). The lower division consists of a system of sequentially arranged and progressively smaller airways that resemble an inverted tree. Often called the respiratory tree (Fig. 12.2.), it consists of the trachea (windpipe), a right and a left primary bronchus, the lobar bronchi, segmental bronchi, sub-segmental bronchi, terminal bronchioles, respiratory bronchioles, alveolar ducts, alveolar sacs, and individual alveoli. Gas exchange with the blood occurs only in the smaller, thin-walled terminal parts of the tree beginning with the respiratory bronchioles. The remainder of the respiratory tree, and the entire upper division, collectively comprise anatomical dead space, space that is ventilated but plays no direct role in gas exchange.
Expiration begins when the inspiratory muscles relax. The diaphragm returns to its resting dome shape, decreasing thoracic and intrapulmonic volume. Relaxation of the external intercostals allows the ribs to fall to their resting position, thereby reducing the diameter, and thus the volume of the thorax and lungs (Fig. 12.5). A reduction in intrapulmonic volume is accompanied by an increase in intrapulmonic pressure. As soon as intrapulmonic pressure increases above atmospheric pressure, air flows down the pressure gradient from the expanded air spaces in the lung through the airways and back into the atmosphere, continuing to flow until intrapulmonic pressure is again equal to atmospheric pressure (Fig. 12.5).

The volume of air a person inhales (inspires) and exhales (expires) can be measured with a spirometer (spiro = breath, metri = to measure). A bell spirometer consists of a double-walled cylinder in which an inverted bell filled with oxygen-enriched air is immersed in water to form a seal (Fig. 12.6). A pulley attaches the bell to a recording pen that writes on a drum rotating at a constant speed. During inspiration, air is removed from the bell and the pen rises, recording an inspired volume. As expired air enters the bell, the pen falls and an expired volume is recorded. The resultant record of volume change vs. time is called a spirogram.

In this lesson, you will use the BIOPAC airflow transducer and the software will convert airflow to volume, thus approximating the volume measurements from a spirometer. Air flows through a scaled head which is divided in half by a fine mesh screen. The screen creates a slight resistance to airflow resulting in a higher pressure on one side than the other. A Differential Pressure Transducer measures the pressure difference, which is proportional to the airflow, and converts it to a voltage, which is then recorded by the BIOPAC MP unit. After the airflow recording is complete, the software calculates volume by integrating the airflow data. This integration technique is a simple method for obtaining volume but is very sensitive to baseline offset. For this reason the calibration and recording procedures must be followed exactly to obtain accurate results.
II. EXPERIMENTAL OBJECTIVES
1.) To observe experimentally, record and/or calculate selected pulmonary volumes and capacities.
2.) To compare the observed values of volume and capacity with average values.
3.) To compare the normal values of pulmonary volumes and capacities of subjects differing in sex, age, weight, and height.

III. MATERIALS
- BIOPAC Airflow Transducer (SS11LA)
- BIOPAC Bacteriological Filter (AFT1): one per subject. If using calibration syringe, one dedicated to syringe.
- BIOPAC Disposable Mouthpiece (AFT2)
- BIOPAC Noseclip (AFT3)
- BIOPAC Calibration Syringe: 0.6-Liter (AFT6 or AFT6A+AFT11A) or 2-Liter (AFT26)
- Optional—BIOPAC Autoclavable Mouthpiece (AFT8)
- Biopac Student Lab System: BSL 4 software, MP36, MP35 or MP45 hardware
- Computer System (Windows 8, 7, Vista, XP, Mac OS X 10.5 – 10.8)

IV. EXPERIMENTAL METHODS

A. SETUP

FAST TRACK Setup

1. Turn your computer ON.
2. Turn OFF MP36/35 unit.
   • If using an MP45, make sure USB cable is connected and “Ready” light is ON.
3. Plug the Airflow Transducer (SS11LA) into Channel 1.
4. Turn ON the MP36/35 unit.

Fig. 12.8 MP3X (top) and MP45 (bottom) equipment connections

Setup continues...
CALIBRATION

Calibration establishes the hardware’s internal parameters (such as gain, offset, and scaling) and is critical for optimal performance. Calibration will vary based on the Preference set by your lab instructor.

**FAST TRACK Calibration**

1. Hold the Airflow Transducer upright and still, making sure no air is flowing through it (Fig. 12.12).

2. Click Calibrate.
   - Wait for Calibration to stop

3. Check Calibration data:
   - Verify data is flat and centered. If necessary, click Redo Calibration.
   - To proceed, click Continue.

4. **IF CALIBRATION STAGE 2 IS REQUIRED**—Attach Calibration Syringe and filter to Airflow Transducer (Fig. 12.14).

   **IMPORTANT!**
   - Always insert on the side labeled “Inlet.”
   - Pull Calibration Syringe plunger all the way out.
   - Hold syringe horizontally. Airflow Transducer must be vertical and unsupported.
   - Review Calibration procedure.

**Detailed Explanation of Calibration Steps**

Calibration Stage 1 precisely zeroes the baseline. Any baseline shift during this calibration can cause errors in the subsequent recordings. Baseline shift can occur from:

- Airflow through the transducer from movement, an HVAC duct or even from breathing close to the unit.
- Changes in transducer orientation. The transducer should be held still and in the same orientation that will be used during the recording.

Calibration lasts from 4 to 8 seconds.

Based on Lesson Preference settings, the calibration syringe may not be required. If not required, proceed to Step 9.

**Notes:**

- A bacteriological filter must be used between the transducer and syringe in order for calibration to be accurate.
- Different syringe sizes are supported via File > Lesson Preferences > Calibration Syringe Size. Check the pictures in SET UP > Calibration tab to make sure they match your setup. If incorrect, the lesson must be re-run and the preference changed prior to calibration Stage 1. If you are using a non-BIO PAC syringe, always check the Preference setting prior to beginning calibration Stage 1.

Never hold onto the Airflow Transducer handle when using the Calibration Syringe or the syringe tip may break.

Always insert syringe assembly on the transducer side labeled “Inlet” so that the transducer cable exits on the left.

Fig. 12.11 Example AFT6A/6 connections.
9. **Optional** Validate Calibration.
   a) Click **Record**.
   b) Cycle the syringe plunger in and out completely 3 times (6 strokes) waiting about two seconds between strokes.
   c) Click **Stop**.
   d) Measure P-P on CH2 Volume (Fig. 12.16) to confirm the result matches the syringe volume:
      - AFT6 = 0.61 L acceptable range: 0.57 to 0.64 liters
      - AFT26 = 2 L acceptable range: 1.9 to 2.1 liters
   e) If measurements are correct, click **Redo** and proceed with **Subject** recording.
   f) If measurements are not correct:
      - Click **Redo** then choose File > **Quit**.

10. Re-launch the application and re-run the lesson.

**END OF CALIBRATION**

**C. DATA RECORDING**

**FAST TRACK Recording**

1. **Prepare** for the recording.
   - Remove calibration syringe/filter assembly (if used).
   **IMPORTANT!**
   Subject must be relaxed to obtain accurate measures.

2. Insert the filter into the “Inlet” side of the transducer, and then attach the mouthpiece (Fig. 12.16).
   - If your lab does not use disposable filters, attach a sterilized mouthpiece (AFT3) directly to the “Inlet” side of the transducer (Fig. 12.17).

Recording continues...

It is advisable to validate calibration once per lab session. Syringe must be pushed in and pulled out all the way.

![Fig. 12.15 Calibration Validation shows P-P result 0.6 liters](image)

If recording does not resemble the Example Data:

- If the data is noisy or flatline, check all connections to the MP unit.

Clicking **Redo** will erase the validation data and allow the **Subject** recording to continue.

It is necessary to re-launch the application in order to allow a new Stage 2 (Syringe) calibration. Prior to the next recalibration, make sure the lesson preference setting “Calibration Syringe Values” is assigned “Set each time lesson is launched” (see Setup Step 8).

**Detailed Explanation of Recording Steps**

The filter used during calibration should not be re-used by the **Subject** as it will not be sterile.

**Hints for obtaining optimal data:**

- **Subject** should wear loose clothing so clothing does not inhibit chest expansion.
- **Subject** must try to expand the thoracic cavity to its largest volume during maximal inspiratory efforts.
- Air leaks will result in inaccurate data. Make sure all connections are tight, noseclip is attached and that Subject’s mouth is sealed around the mouthpiece.
- Keep the Airflow Transducer vertical and in a constant position (Fig. 12.18).
- If recording is started on an inhale, try to stop recording on an exhale, or vice versa. (A breath is considered a complete inhale-exhale cycle.)

**IMPORTANT:** Each **Subject** must use a personal filter, mouthpiece and noseclip. The first time they are used, the **Subject** should personally remove them from the plastic packaging. It is advisable to write **Subject**’s name on the mouthpiece and filter with a permanent marker so they can be reused later (i.e. Lesson 13).

If your lab sterilizes the airflow heads after each use, make sure a clean head is installed prior to **Subject** use.
7. Click **Done**.

8. Choose an option and click **OK**.

---

**END OF RECORDING**
2. Review the measurements described in the Introduction to identify the appropriate selected area for each.

3. Calculate the Predicted Vital Capacity, then measure VC and then compare the two.

4. Take two measures on the third TV cycle:
   a) Use the I-beam cursor to select the inhalation of cycle 3 and note the P-P result (Fig. 12.24). The selected area should be from the valley to the peak of the third cycle.
   b) Use the I-beam cursor to select the exhalation of cycle 3 and note the P-P result (Fig. 12.25). The selected area should be from the peak to the valley of the third cycle.

Data Analysis continues...
PULMONARY FUNCTION I

* Volumes and Capacities

DATA REPORT

Student’s Name: _____________________________________________
Lab Section: _________________________________________________
Date: _______________________________________________________

Subject Profile

Name: ___________________________________________ Height: ______ Gender: Male / Female
Age: ___________________________________________ Weight: ______

I. Data and Calculations

A. Vital Capacity

i) Predicted: Use the equation below to calculate your Predicted Vital Capacity:

Table 12.1

<table>
<thead>
<tr>
<th>Equations for Predicted Vital Capacity</th>
<th>Where</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Kory, Hamilton, Callahan, 1960)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>V.C.</td>
</tr>
<tr>
<td>V.C. = 0.052H - 0.022A - 3.60</td>
<td>H</td>
</tr>
<tr>
<td>Female</td>
<td>V.C.</td>
</tr>
<tr>
<td>V.C. = 0.041H - 0.018A - 2.69</td>
<td>A</td>
</tr>
</tbody>
</table>

ii) Observed: Use the P-P result to note Observed Vital Capacity:

\[ \text{Observed Vital Capacity} = 2 \text{ P-P} \]

iii) Observed vs. Predicted

What is Subject’s observed Vital Capacity to predicted Vital Capacity as a percentage?

\[ \text{Observed/Predicted VC} = \frac{\text{Observed VC}}{\text{Predicted VC}} \times 100 = \text{_____%} \]

Note: Vital capacities are dependent on other factors besides age and height. Therefore, 80% of predicted values are still considered “normal.”
II. Questions

D. Why does predicted vital capacity vary with height?

E. Explain how factors other than height might affect lung capacity.

F. How would the volume measurements change if data were collected after vigorous exercise?

G. What is the difference between volume measurements and capacities?

H. Define Tidal Volume.

I. Define Inspiratory Reserve Volume.

J. Define Expiratory Reserve Volume.

K. Define Residual Volume.

L. Define Pulmonary Capacity.

M. Name the Pulmonary Capacities.
B. Volume & Capacity Measurements

Complete Table 12.2 with the requested measurement results and calculate results per the formulas provided.

**Table 12.2 Measurements**

<table>
<thead>
<tr>
<th>Title</th>
<th>Measurement Result</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume TV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a = 2 P-P</td>
<td>Cycle 3 inhale:</td>
<td>(a + b + c + d) / 4 =</td>
</tr>
<tr>
<td>b = 2 P-P</td>
<td>Cycle 3 exhale:</td>
<td></td>
</tr>
<tr>
<td>c = 2 P-P</td>
<td>Cycle 4 inhale:</td>
<td></td>
</tr>
<tr>
<td>d = 2 P-P</td>
<td>Cycle 4 exhale:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspiratory Reserve Volume IRV</td>
<td>2 Delta</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expiratory Reserve Volume ERV</td>
<td>2 Delta</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Volume RV</td>
<td>2 Min</td>
<td>Default = 1 (Preference setting)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspiratory Capacity IC</td>
<td>2 Delta</td>
<td>TV + IRV =</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expiratory Capacity EC</td>
<td>2 Delta</td>
<td>TV + ERV =</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional Residual Capacity FRC</td>
<td></td>
<td>ERV + RV =</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Lung Capacity TLC</td>
<td>2 Max</td>
<td>IRV + TV + ERV + RV =</td>
</tr>
</tbody>
</table>

C. Observed vs. Predicted Volumes

Using data obtained for Table 12.2, compare Subject’s lung volumes with the average volumes presented in the Introduction.

**Table 12.3 Average Volumes vs. Measured Volumes**

<table>
<thead>
<tr>
<th>Volume Title</th>
<th>Average Volume</th>
<th>Measured Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Volume TV</td>
<td>Resting subject, normal breathing: TV is approximately 500 ml. During exercise: TV can be more than 3 liters</td>
<td>greater than equal to less than</td>
</tr>
<tr>
<td>Inspiratory Reserve Volume IRV</td>
<td>Resting IRV for young adults is males = approximately 3,300 ml females = approximately 1,900 ml</td>
<td>greater than equal to less than</td>
</tr>
<tr>
<td>Expiratory Reserve Volume ERV</td>
<td>Resting ERV for young adults is males = approximately 1,000 ml females = approximately 700 ml</td>
<td>greater than equal to less than</td>
</tr>
</tbody>
</table>
5. Repeat TV measurements, as in Step 4, but on cycle 4 data. Calculate average value of all four TV measurements.

6. Use the I-beam cursor and measurement tools to record the volumes and capacities required by the data report (defined in Fig. 12.22).

7. Answer the questions at the end of the Data Report.

8. Save or Print the data file.

9. Quit the program.

Note that the Delta measurement requires precise placement of the selected area.

Fig. 12.26 Example selection for measurements of TLC (Max) and IRV (Delta)

An electronically editable Data Report is located in the journal (following the lesson summary, or immediately following this Data Analysis section. Your instructor will recommend the preferred format for your lab.

END OF LESSON 12
Complete the Lesson 12 Data Report that follows.
V. DATA ANALYSIS

FAST TRACK Data Analysis

1. Enter the Review Saved Data mode.
   - Note channel number (CH) designations:
     - Channel: CH 1; Displays: Airflow (hidden)
     - Channel: CH 2; Displays: Volume
   - Note the measurement box settings:
     - Channel: CH 2; Measurement: P-P
     - Channel: CH 2; Measurement: Max
     - Channel: CH 2; Measurement: Min
     - Channel: CH 2; Measurement: Delta

Detailed Explanation of Data Analysis Steps

If entering Review Saved Data mode from the Startup dialog or Lessons menu, make sure to choose the correct file.

![Example data](image)

All measurements will be performed on the Volume (CH 2) data. The Airflow (CH 1) data, used to calculate volume, is hidden to avoid confusion. It can be shown by “Alt + click” (Windows) or “Option + click” (Mac) the channel number box.

The measurement boxes are above the marker region in the data window. Each measurement has three sections: channel number, measurement type, and result. The first two sections are pull-down menus that are activated when you click them.

**Brief definition of measurements:**
- **P-P (Peak-to-Peak):** Subtracts the minimum value from the maximum value found in the selected area.
- **Max:** Displays the maximum value in the selected area.
- **Min:** Displays the minimum value in the selected area.
- **Delta:** Computes the difference in amplitude between the last point and the first point of the selected area.

The “selected area” is the area selected by the I-Beam tool (including endpoints).

**Useful tools for changing view:**
- Display menu: Autoscale Horizontal, Autoscale Waveforms, Zoom Back, Zoom Forward
- Scroll Bars: Time (Horizontal); Amplitude (Vertical)
- Cursor Tools: Zoom Tool
- Buttons: Overlap, Split, Show Grid, Hide Grid, - +
- Hide/Show Channel: “Alt + click” (Windows) or “Option + click” (Mac) the channel number box to toggle channel display.
3. Prepare the **Subject**:
   - **Subject** must be seated, relaxed and still, facing away from the monitor.
   - Place noseclip on **Subject's** nose.
   - **Subject** holds airflow transducer vertically, breathing through mouthpiece.
   - Before recording, **Subject** acclimates by breathing normally for 20 seconds.
   - Review recording steps.

4. Click **Record**.
   - Breathe normally for five cycles.
   - Inhale as deeply as possible then exhale completely.
   - Breathe normally for five more cycles.

5. Click **Stop**.

6. Verify that Volume channel reading resembles the example data.
   - If **similar**, proceed to Step 7.

   **Recording continues...**

Verify there are no air leaks; mouthpiece and filter are firmly attached, the noseclip is snug and the **Subject's** mouth is tightly sealed around mouthpiece.

![Fig. 12.16 SS11LA with unsterilized head](image)

![Fig. 12.17 SS11LA with sterilized head](image)

![Fig. 12.18 Keep Airflow Transducer vertical at all times](image)

1 cycle = inspiration + expiration
If a recording is started on an inhale, try to stop recording on an exhale, or vice versa. (A breath is considered a complete inhale/exhale cycle.)

After clicking **Stop**, the Biopac Student Lab software will automatically calculate volume data based on the recorded airflow data. At the end of the calculation, both waveforms will be displayed on the screen (Fig. 12.19).

The deep inhale/exhale should be clearly seen in the **Volume** data and there should be five normal breathing cycles both before and after deep breathing. It is common to have some “tilt” in the volume data as shown in Fig. 12.19. If the volume data exhibits excessive tilt (Fig. 12.20), redo the recording.
5. Click **Calibrate**.

6. Cycle plunger in and out five times (10 strokes total).
   - Wait two seconds between each stroke.

7. Click **End Calibration**.

8. Verify recording resembles the example data.
   - If similar, click **Continue** to proceed.
   - If necessary, click **Redo Calibration**.

---

**Important:**
- Complete exactly five cycles. Less or more cycles will result in inaccurate volume data.
- Syringe must be pushed in and pulled out all the way.
- Hold the assembly as still as possible.
- Use a rhythm of about one second per stroke with two seconds rest between strokes.

There must be five downward deflections and five upward deflections. The first deflection must be downward. If the first stroke (push) resulted in an upward data deflection, the syringe/filter assembly must be reversed by inserting the assembly into the other port of the airflow transducer and rerunning the Calibration.

---

**Fig. 12.12 AFT6A calibration stage 2 starting position**

**Fig. 12.13 AFT26 calibration stage 2 starting position**

**Fig. 12.14 Example Calibration (stage 2) Data**
5. **Start** the Biopac Student Lab program.
6. Choose “L12 – Pulmonary Function I” and click **OK**.
7. Type in a unique **filename** and click **OK**.

8. **Optional**: Set Preferences.
   - Choose File > **Lesson Preferences**.
   - Select an option.
   - Select the desired setting and click **OK**.

If your lab is using multiple MP hardware types, choose the appropriate BSL program (shortcut icon contains MP number).

No two people can have the same filename, so use a unique identifier, such as **Subject’s** nickname or student ID#.

A folder will be created using the filename. This same filename can be used in other lessons to place the **Subject’s** data in a common folder.

This lesson has optional Preferences for data and display while recording. Per your Lab Instructor’s guidelines, you may set:

- **Residual Volume**: RV cannot be determined using a normal spirometer or airflow transducer, so the BSL software sets a value between 0 and 5 liters (default is 1 L)
- **Grids**: Show or hide gridlines
- **Calibration Syringe Values**:
  - *Set each time lesson is launched*: Syringe (Stage 2) calibration is required the first time the lesson is run. After the lesson is re-run without closing the application, Syringe calibration is not required.
  - *Set once and use stored values*: After Syringe calibration is performed once, it will not be performed again. This is only recommended when specific SS11L Airflow transducers are matched to specific MP units.
- **Calibration Syringe Size**:
  - 0.61 L (AFT6A/6), 1 L, 2 L (AFT26), 3 L, 4 L, or 5 L
There are four non-overlapping primary compartments of total lung capacity (Fig. 12.7):

1. Tidal volume
2. Inspiratory reserve volume
3. Expiratory reserve volume
4. Residual volume

Fig. 12.7 Example of respiratory volumes and capacities

- **Tidal Volume** (TV) is the volume of air inspired or expired during a single breath. When a resting person breathes normally, tidal volume is approximately 500 ml. During exercise, tidal volume can be more than 3 liters.
- **Inspiratory Reserve Volume** (IRV) is the volume of air that can be maximally inhaled at the end of a tidal inspiration. Resting IRV is approximately 3,300 ml in young adult males and 1,900 ml in young adult females.
- **Expiratory Reserve Volume** (ERV) is the volume of air that can be maximally exhaled at the end of a tidal expiration. Resting ERV is approximately 1,000 ml in young adult males and 700 ml in young adult females.
- **Residual Volume** (RV) is the volume of gas remaining in the lungs at the end of a maximal expiration. In contrast to IRV, TV, and ERV, residual volume does not change with exercise. Average adult values for RV are 1,200 ml for males and 1,100 ml for females. Residual volume reflects the fact that after the first breath at birth inflates the lungs, they are never completely emptied during any subsequent respiratory cycle.

**Pulmonary Capacity** is the sum of two or more primary lung volumes. There are five pulmonary capacities, which can be calculated as shown below:

1. **Inspiratory Capacity** (IC)
   \[ IC = TV + IRV \]
2. **Expiratory Capacity** (EC)
   \[ EC = TV + ERV \]
3. **Functional Residual Capacity** (FRC)
   \[ FRC = ERV + RV \]
4. **Vital Capacity** (VC)
   \[ VC = IRV + TV + ERV \]
5. **Total Lung Capacity** (TLC)
   \[ TLC = IRV + TV + ERV + RV \]

Each of these capacities is represented graphically in Fig. 12.7 above.

Pulmonary volumes and capacities are generally measured when assessing health of the respiratory system because the volume and capacity values change with pulmonary disease. For example, inspiratory capacity is normally 60-70% of the vital capacity.

In this lesson, you will measure tidal volume, inspiratory reserve volume, and expiratory reserve volume. Residual volume cannot be measured using a spirometer or airflow transducer. You will then calculate inspiratory capacity, vital capacity, and the % observed vital capacity to the average values for comparison. Next, you will compare your observed vital capacity with the predicted vital capacity.

The following equations can be used to obtain the predicted vital capacities for men or women of your height and age. Vital capacities are dependent on other factors besides age and height. Therefore, 80% of the calculated values are still considered normal.

### Table 12.1

| Equations for Predicted Vital Capacity (Kory, Hamilton, Callahan: 1960) |
|-----------------------------|-----------------------------|
| **Male**                   | V.C. = 0.052H - 0.022A - 3.60 |
| **Female**                 | V.C. = 0.041H - 0.018A - 2.69  |

**Where**
- V.C. Vital Capacity in liters
- H Height in centimeters
- A Age in years

Using the equation in Table 12.1, you can estimate the vital capacity of a 19 year old female who is 167 centimeters tall (about 5'6") as 3.815 liters:

\[ 0.041 \times (167) - 0.018 \times (19) - 2.69 = 3.815 \text{ liters} \]
Gas exchange between the air in the lung and the blood is a process of simple diffusion (Fig. 12.3). A gas diffuses from a region of higher concentration to a region of lower concentration, or, from an area of higher partial pressure to an area of lower partial pressure. Partial pressure is simply a way of expressing the concentration of gas molecules. It is the pressure exerted by a gas when it is in a mixture with other gases, and is equal to the pressure the same volume of the gas would exert if no other gases were present. The partial pressure of a gas is easily computed if its percentage of the gas mixture and the total pressure of the mixture is known. For example, the atmosphere at sea level exerts a pressure of 760 mm of Hg. If oxygen were to make up 20% of the atmosphere, its partial pressure would be 20% of 760 mm of Hg, or 152 mm of Hg.

Blood transports gases to and from the body's cells. The respiratory system supplies oxygen to the blood, and removes carbon dioxide from the blood. Most of the gas exchange occurs at the level of the alveoli and the process is completely dependent on the maintenance of gas partial pressures favorable for adequate diffusion of oxygen and carbon dioxide. During inspiration (inhalation) the alveoli enlarge and take in fresh air. During expiration (exhalation) the alveoli get smaller, forcing some of the air back out into the atmosphere. The process of continually and cyclically moving air into and back out of the respiratory tree is called pulmonary ventilation. This process serves to maintain favorable partial pressures of oxygen and carbon dioxide in the alveoli, thereby facilitating oxygen uptake by the blood and carbon dioxide removal from the blood.

The mechanics of pulmonary ventilation are best understood by applying Boyle's law, which states the volume of a given quantity of gas at a constant temperature varies inversely with the pressure of the gas. In other words, as the volume of a gas at constant temperature increases, the pressure of the gas decreases. If the volume instead decreases, then the pressure increases. Mathematically, the product of the pressure and volume of a gas at constant temperature is itself a constant (PV = K). Ignoring units, if P = 6 and V = 3, then K = 18. If P decreases to 2, then V must increase to 9 because the value of K is 18 and constant as long as the temperature is constant.

The lungs are enclosed by the thoracic cage, which is comprised of the sternum, ribs, vertebral column, and the diaphragm (Fig. 12.1). The tissues of the thoracic cage form the thoracic cavity that is partitioned into smaller cavities by membranes. Each lung is covered with a thin membrane called the visceral pleura. At the root of each lung, where the bronchi enter, the visceral pleura is reflected back around the lung to form the parietal pleura, a lubricating membrane which lines the thorax and covers part of the diaphragm (Fig. 12.4). Normally, each lung completely fills its pleural cavity formed by the reflection of the visceral pleura. The pleural membranes allow the lung to slide freely within the pleural cavity during the respiratory cycle. The space between visceral and parietal pleura, called the pleural space, is only a potential space. Normally, only a thin layer of lubricating fluid separates the two layers of pleura. The pleural cavities are airtight and form part of the thoracic cavity; however, the interior of the lungs is open to the atmosphere via the airways. Therefore, whenever the thoracic cavity enlarges, the pleural cavities along with the lungs also enlarge.

Changes in the volume of the thorax are produced by contraction of skeletal muscles collectively called respiratory muscles. They are arbitrarily divided into two groups. Inspiratory muscles contract and increase thoracic volume. The diaphragm and the external intercostals muscles are examples. Expiratory muscles contract and decrease thoracic volume. Examples include the internal intercostals muscles and the abdominal muscles.

At the beginning of inspiration, the thoracic cavity is enlarged by contraction of the diaphragm and the external intercostals (Fig. 12.5). The diaphragm, normally dome-shaped at rest, becomes flatter when its muscle fibers contract, thereby increasing thoracic volume. The external intercostals elevate the ribs, a kind of bucket-handle lift that increases the diameter, and hence the volume of the thorax. An increase in thoracic volume is accompanied by an increase in intrapulmonic volume, and, according to Boyle's law, a decrease in intrapulmonic pressure. As soon as intrapulmonic pressure falls below atmospheric pressure, air flows down the pressure gradient from the atmosphere through the airways and into the expanded air spaces in the lungs, continuing to flow until intrapulmonic pressure is again equal to atmospheric pressure (Fig. 12.5). At the end of inspiration, intrapulmonic pressure equals atmospheric pressure and airflow ceases even though intrapulmonic volume is larger than at the beginning of inspiration.