Effects of Position, Dead Air Space and Exercise on Breathing

Background information

Spirometry is a diagnostic technique used to measure respiratory volumes. The instrument used to measure these volumes is called spirometer.

The four pulmonary volumes include tidal volume, inspiratory reserve volume, expiratory reserve volume, and residual volume. The lung volumes for a patient are usually compared with predicted lung volumes based on age, sex, and body size. There are also four standard lung capacities, which consist of two or more standard lung volume in combination. The four lung capacities are inspiratory capacity, vital capacity, functional residual capacity, and total lung capacity.

The volume of air that enters or leaves the lungs during one breathing cycle is called the tidal volume (TV). Normally, the amount of air that is expired during a breathing cycle is equal to the amount of air that is inspired during the cycle. Resting tidal volume is the amount exchanged during normal, resting breathing (eupnea). According to Levitzky (2007), "during normal, quiet breathing (eupnea) the tidal volume of a 70-kg adult is about 500 mL per breath, but this volume can increase dramatically, for example, during exercise". During times of increased demand, for example, during exercise, the tidal volume can be increased using some of the inspiratory or expiratory reserve lung volume to bring more fresh air into the body.

The volume of gas that is inhaled into the lungs during a maximal forced inspiration starting at the end of a normal tidal inspiration is called the inspiratory reserve volume (IRV). It is determined by the strength of contraction of the inspiratory muscles, inward elastic recoil of the lung and the chest wall.

After a normal expiration it is possible to forcibly exhale additional air from the lungs. This is called the expiratory reserve volume (ERV).

The air that cannot be exhaled from the lungs is called the residual volume (RV) and averages 1200 mL. Residual volume is important because it prevents the lungs from collapsing at very low lung volumes. It increases in diseases such as emphysema.

The inspiratory capacity is the amount of air that can be moved into the lungs during a maximal inspiratory effort starting after a normal expiration. The inspiratory capacity is the sum of the inspiratory reserve volume and resting tidal volume.
**Functional residual capacity** is the amount of air that remains in the lungs after a normal, resting exhalation. It is a combination of expiratory reserve volume and residual volume.

The maximum amount of air that can be exhaled after a maximal inspiration is called **vital capacity (VC)**. It includes the tidal volume, inspiratory reserve volume and expiratory reserve volume varies with gender, height and age. Vital capacity can be predicted based on these factors as follows (Sarikas 2007):

For males: \( VC = 0.052H - 0.022A - 3.60 \)
For females: \( VC = 0.041H - 0.018A - 2.69 \)
Where: \( VC \) = vital capacity
\( H \) = height in centimeters
\( A \) = age in years

Short term exercise will not change vital capacity. However, long term exercise where the body becomes accustomed to increased airflow and rate of breathing over time can increase the vital capacity.

Vital capacity is a reliable diagnostic indicator of pulmonary function. A person's vital capacity should be at least 80% of the predicted value based on sex and height. Healthy individuals who exercise regularly will usually have vital capacities that are greater than predicted values. Restrictive lung diseases cause measured \( VC \) to be consistently lower than predicted values.

The **forced vital capacity (FVC)** measures the vital capacity as the subject exhales forcefully and rapidly. **Forced expiratory volume at 1 second (FEV\(_1\))** is the portion of the vital capacity that is exhaled during the first second. The \( FEV_1/FVC \) ratio is an important indicator of lung and airway health. Healthy individuals can expire 75-85% of their FVC in the first second. This pulmonary function test can help the clinician distinguish between obstructive and restrictive pulmonary diseases.

In obstructive disorders like asthma, bronchitis, emphysema, where airway resistance is increased, \( FEV_1 \) is reduced to a greater extent than is FVC, and \( FEV_1/FVC \) is usually less than 0.70. In restrictive lung diseases, like fibrosis, polio, tuberculosis, both \( FEV_1 \) and FVC are reduced, but because of the low compliance and high recoil of the lungs, the \( FEV_1/FVC \) ratio may be normal (~0.80) or greater than normal (>0.85).

Various lung volumes and capacities will change when changing from standing to sitting to supine (lying down) position. Inspiratory and expiratory volumes will be greater when sitting than lying. This is explained by gravity pulling the abdominal contents away from the diaphragm when standing, therefore increasing the volume of the thoracic cavity.
In a supine position the patient’s TV, IRV and ERV will decrease as the abdominal organs rest against the diaphragm limiting its movements. Thus, the vital capacity will decrease.

The volume of air passing into and out of the lungs in one minute is called minute volume. This volume depends on both the depth of breathing (tidal volume) and the ventilation rate (breaths per minute). Minute volume increases during exercise and continues to be elevated for a short period after exercise. This is due to a combination of the increase in both rate and depth of breathing.

The minute volume influences but is not equal to the volume of air available for gas exchange in the alveoli, called the alveolar ventilation. Alveolar ventilation is less than the minute volume because the last part of each inspiration (and expiration) remains in the conducting passageways of the respiratory system. The part of the respiratory system where gas exchange between air and blood does not take place is called the dead space. Anatomic dead space, which generally averages 150 mL, is formed by the nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles, and terminal bronchioles. Physiological dead space consists of anatomical dead space plus the volume of any alveoli in which gas exchange is less than normal. The physiological dead space will decrease during exercise due to greater ventilation and perfusion of the lungs. However, it will increase in a case of obstructive diseases, and decrease in restrictive diseases.

Methods

These exercises are based on using iWorx HK204 equipment but could be adapted to the newer HK214 equipment. The number of students listed on the summary data sheet is based on a class size of 24 with six groups of four students each.

Equipment needed

PC computer
Flash drive
iWorx/204 and serial cable
Spirometer flow head and plastic tubes
SP 304, spirometer unit with cable

Equipment setup

If the following have not already been done by your lab instructor, you will need to:

1. Connect the iWorx/204 unit to the computer (figure 1).
2. Push the two air flow tubes into the flow head outlets. The tubes on the flow head should always be in the upright position to avoid problems with condensation.

3. Attach the other ends of the two air flow tubes to the two outlets on the SP 304 spirometer unit.

4. Connect the output cable on the spirometer unit to the DIN input channel 3 of the iWorx/204 so that the spirometer will display flow on channel 3. The software is set to integrate the data you are recording on channel 3 and display it as a volume on channel 4. The LabScribe software will report volume in liters on channel 4 using a conversion factor of 150 mVsec/liter. If the calibration number written on the spirometer serial number tag is larger or smaller (by more than 10%) than 150mVsec/liter you may have to recalibrate channel four. Check to be sure that the software is set to integrate the flow data by moving the mouse to place the cursor over channel 4, right click the mouse and check that the Integrate option is checked. If it is not checked, select it now.

**Starting the Software**

1. Click LabScribe icon on the desktop if it has not been opened for you. You can also access the program by moving the mouse to Programs (from the Start menu) and then to the iWorx folder and selecting LabScribe.

2. When the program opens, select Lung #1 under Settings. If Lung #1 is not an option, select Load (under Settings); choose HK204 from the menu and click OK; return to Settings and select Lung #1.

**Note:**

To avoid turbulent air flow through the flow head that will produce a noisy signal be sure that the flow opening is inside the mouth.

Air that enters or leaves through the nose is not counted in the volume calculation and will cause errors in the reading so the nose should be closed off. A nose clip works better than simply pinching the nose and should be used for all activities.

The student volunteer should not look at the screen as he or she is breathing through the spirometer because that could affect his/her breathing pattern.
Experiment #1: Affect of Position on ventilation

Purpose: To measure respiratory volumes in individuals and to examine the effect of body position (seated, supine and standing) on lung volumes of resting individuals.

Activity 1: Breathing in a Seated Volunteer

Procedure

1. Because age, height, sex, smoking and regular exercise affect breathing, record this information about your student volunteer on the raw data sheet before beginning.

2. Click Start before the student picks up the spirometer flow head. The LabScribe software does a zero calibration during the first 5 seconds of recording so no air should be flowing through during that time.

3. After 5 seconds, the student should pick up and hold the spirometer head with the air flow tubes up and breathe normally into the flow head (although it’s difficult to do so when one thinks about it). The student should sit quietly and become accustomed to breathing through the flow head. He or she may want to hold their nose to make sure the air is only passing through the spirometer.

4. Type “seated” and click Mark; the student should continue breathing normally.

5. After seven (7) normal breathing cycles, type “vital capacity” and have the student inhale as deeply as possible followed by as great an exhalation as possible. The student should continue blowing until the tracing line no longer changes.

6. Have the student return to normal breathing for 5 seconds then click Stop to end the recording. Have the student remove the spirometer from his/her mouth.

7. Save your file by clicking Save As under File and choosing your flash drive. Choose an appropriate name for the file so that it won’t be confused with the files for the other exercises or other students’ files.

Data Analysis

1. Use the slider bar at the bottom of the display to return to the start of normal breathing during seated rest.

2. Click the 2 cursor icon (see figure 2), so that two blue vertical lines appear over the recording window.

3. Use the mouse to position the two lines to the right and left of five normal breathing cycles.

4. Click the Analysis button on the toolbar to open the Analysis window.
5. Click on all display channels other than Volume to deselect them.

6. Use the mouse to reposition one line at the bottom of the trough before the first crest and the second line to the top of the next crest (figure 3). The tidal volume (TV) will be the voltage difference between the trough and peak. Record this on the data sheet.

7. Repeat to measure the tidal volume of three of the normal breaths, recording each on the data sheet. Calculate the average tidal volume and record that on the raw data sheet and in the summary data table.

8. Measure the duration (time interval) for each breath by positioning the two vertical lines in adjacent troughs; the duration is T2-T1. Record the time interval on the raw data sheet. Measure two more intervals and record the time intervals on the raw data sheet. Determine the average duration and use it to calculate the breathing rate as:

\[
\text{Breathing rate} = \frac{60 \text{ breaths/minute}}{\text{mean duration}}
\]

9. Multiply the tidal volume times the breathing rate to determine the minute volume (MRV).

10. The maximum rate of air movement during exhalation (peak expiratory airflow) can be measured by placing the two vertical lines at two close points together on the steepest part of the exhalation curve (upward part of the curve) of one of the tidal breaths (figure 4). Determine the rate by dividing the measured change in volume (v2-v1) by the time difference (T2-T1). Measure the maximum expiratory flow rate for three breaths and calculate the average.

11. Measure the maximum rate of air movement during inspiration as above, but position the two vertical lines on the inhalation curve (downward part of the curve).

12. Measure the vital capacity by moving the slide bar at the bottom of the Analysis window so that the vital capacity air movements are seen (figure 5). Position one cursor at the level of the top of the peak for expiration, the other at the bottom of the peak for inspiration. The voltage difference (v2-v1) between them is the vital capacity.
13. Measure inspiratory reserve volume (IR) by placing one cursor at the bottom of the vital capacity trough (maximum inspiration) and the other at the bottom of the previous trough for tidal volume. The voltage difference (v2-v1) between them is the inspiratory reserve. Record on your raw data sheet.

14. Measure expiratory reserve volume (ERV) by placing one cursor at the top of the vital capacity peak (maximum expiration) and the other at the top of the previous tidal breath (figure 5). The voltage difference (v2-v1) between them is the expiratory reserve. Record on your raw data sheet.

Activity 2: Breathing in a Standing Volunteer

Procedure

1. Have the student volunteer stand.

2. Click Start before the student picks up the spirometer flow head to allow the software to perform a zero calibration.

3. After 5 seconds, the student should pick up and hold the spirometer head with the air flow tubes up and breathe normally into the flow head (although it’s difficult to do so when one thinks about it). The student should stand quietly and become accustomed to breathing through the flow head. He or she may want to hold their nose to make sure the air is only passing through the spirometer.

4. Type “standing” and click Mark; the student should continue breathing normally.

5. After seven (7) normal breathing cycles, type “vital capacity“ and have the student inhale as deeply as possible followed by as great an exhalation as possible.

6. Have the student return to normal breathing for 5 seconds then click Stop to end the recording. Have the student remove the spirometer from his/her mouth.

7. Save your file by clicking Save As under File and choosing your flash drive. Choose an appropriate name for the file so that it won't be confused with the files for the other exercises.
Data Analysis

Perform the data analysis as you did for Activity 1. Transfer data to the data summary sheet and share with other groups in the class. Answer the questions on the summary data sheet.

Activity 3: Breathing in a Supine Volunteer (optional)

Procedure

1. Place a mat or thick towel on the floor and have the student volunteer should get into a supine position flat on his/her back.

2. Click Start before the student picks up the spirometer flow head to allow the software to perform a zero calibration.

3. After 5 seconds, the student should pick up and hold the spirometer head with the air flow tubes up and breathe normally into the flow head (although it's difficult to do so when one thinks about it). The student should lie quietly and become accustomed to breathing through the flow head. He or she may want to hold their nose to make sure the air is only passing through the spirometer.

4. Type “supine” and click Mark; the student should continue breathing normally.

5. After seven (7) normal breathing cycles, type “vital capacity” and have the student inhale as deeply as possible followed by as great an exhalation as possible.

6. Have the student return to normal breathing for 5 seconds then click Stop to end the recording. Have the student remove the spirometer from his/her mouth. Save your file by clicking Save As under File and choosing your flash drive. Choose an appropriate name for the file so that it won't be confused with the files for the other exercises.

Data Analysis

Perform the data analysis as you did for Activity 1. Transfer data to the data summary sheet and share with other groups in the class. Answer the questions on the summary data sheet.
Exercise 2: FEV₁/FVC in a Standing Volunteer

Purpose: To measure forced vital capacity and forced expiratory volume in 1 second in a standing volunteer.

1. Have the student volunteer stand.
2. Click *Start* before the student picks up the spirometer flow head to allow the software to perform a zero calibration.
3. Type “FVC” into the space next to *Mark*.
4. After 5 seconds, the student should pick up and hold the spirometer head with the air flow tubes up and inhale as much as possible.
5. Click *Mark* just before the student forcibly exhales as much air as possible into the spirometer flow head as rapidly as possible. The student should continue exhaling until he or she can no longer exhale. The student may bend over to increase the exhalation.
6. Click *Stop* to stop the recording and allow the student to sit down, relax and return to normal breathing.

Data Analysis

1. Use the slider bar at the bottom of the display to return to the start of the inhalation.
2. Click the *2 cursor icon* (see figure 2), so that two blue vertical lines appear over the recording window.
3. Use the mouse to position one of two lines slightly to the left of the start of the exhalation and the other to the left of the end of the expiration. This will surround the entire period of the forced expiration.
4. Click the *Analysis* icon to go to the *Analysis* window.
5. Click all of the channels except *Volume* to deselect them.
6. Position one cursor at the top of beginning of the exhalation and the other at a point 1 second later (i.e., move the second cursor until T₂-T₁ equals 1 second). The voltage difference will be the volume of air moved in 1 second, or the forced expiratory volume in 1 second (FEV₁). Record the FEV₁ on the raw data sheet.
7. Move the second cursor to the right until voltage no longer changes (i.e., there’s no change in V₂-V₁). This will occur at the point of maximum expiration that corresponds to the forced vital capacity (FVC). Record the voltage difference on the raw data sheet.
8. Calculate the FEV₁/FVC ratio and compare them to expected values as calculated based on the equations in the background information.
Experiment #3: Effect of Extending Dead Air Space

Purpose: To determine the effect of extending dead air space on ventilation volumes in resting individuals.

Procedure

1. Extend the dead air space by connecting a length of tubing to the spirometer flow head. A tube can be made of thin plastic rolled to the appropriate diameter and attached with tape will work.

2. Click Start before the student picks up the spirometer flow head. The LabScribe software does a zero calibration during the first 5 seconds of recording so no air should be flowing through during that time.

3. After 5 seconds, the student should pick up and hold the spirometer head with the air flow tubes up and breathe normally into the flow head (although it's difficult to do so when one thinks about it). The student should sit quietly and become accustomed to breathing through the plastic tubing (or straws) attached to the flow head. He or she may want to hold their nose to make sure the air is only passing through the spirometer.

4. Type "extended" and click Mark; the student should continue breathing normally.

5. After ten (10) normal breathing cycles click Stop to end the recording. Have the student remove the spirometer from his/her mouth.

6. Save your file by clicking Save As under File and choosing your flash drive. Choose an appropriate name for the file so that it won't be confused with the files for the other exercises.

Data Analysis

Perform the same data analysis as you did for Experiment #1, Activity 1. Transfer data to the data summary sheet and share with other groups in the class. Answer the questions on the summary data sheet.

Experiment #4: Affect of Exercise on Ventilation

Purpose: To measure ventilation volumes in individuals and to examine the effect of exercise on rate and depth of breathing.

Procedure

1. Have the student exercise vigorously enough to noticeably elevate breathing rate and depth. Jogging in place, running up and down flights of stairs, or doing jumping jacks are good ways to increase ventilation rate and depth.
2. Just before the student stops exercising, click Start to allow the LabScribe software to perform its zero calibration. The student should continue exercising until ready to breathe into the spirometer. After 5 seconds, type “immediately after” and click Mark.

3. Have the student sit down, pick up and hold the spirometer head with the air flow tubes up and breathe into the flow head without thinking about rate or depth of breathing. The student may want to hold his or her nose to make sure the air is only passing through the spirometer.

4. After seven (7) breathing cycles, type “vital capacity” and have the student inhale as deeply as possible followed by as great an exhalation as possible.

5. Have the student return to normal breathing until a total of 2 minutes has passed since he or she stopped exercising. Type “2 minutes” after and click Mark. Record seven normal breathing cycles at this point then type “vital capacity” and have the student inhale as deeply as possible followed by as great an exhalation as possible.

6. Have the student return to normal breathing for 5 seconds then click Stop to end the recording. Have the student remove the spirometer from his/her mouth.

Data Analysis

1. Return to the first breathing cycle after exercise and measure the TV, VC, breathing rate, and peak flow rates during inspiration and expiration as before. Record your data on the raw data and summary data sheets.

2. Calculate the MRV as before and record on the raw and summary data sheets.

3. Use the slider bar to locate the period two minutes after exercise ceased and measure the TV, MRV, VC, IRV, ERV, peak flow rates during inspiration and expiration as before. Record your data on the raw data and summary data sheets. Answer the questions on the summary data sheet.

___________________________________________________________________

Instructions and questions have been modified from the iWorx HK204 manual:


Background information was gathered from:


Spirometry Raw Data Sheet

Student #____:
Age _____ Height _____ Sex _____ Smoker _____ Exercise _____

**Seated Breathing at Rest**
- Measured TV (v2-v1) _____ _____ _____ Average TV............ ______
- Measured interval/breath (T2-T1) _____ _____ _____ Average interval .. ______
- Breathing rate (calculated as (60 breaths/minute) / (interval/breath)) .................. ______
- Measured maximum expiratory flow rate (record as (v2-v1)/(T2-T1))
  _____ _____ _____ Average rate .......... ______
- Measured maximum inspiratory flow rate (record as (v2-v1)/(T2-T1))
  _____ _____ _____ Average rate .......... ______
- Measured vital capacity ................................................................. ______
- Measured inspiratory reserve volume (IRV) .................................................. ______
- Measured expiratory reserve volume (ERV) .................................................. ______

**Standing Breathing at Rest**
- Measured TV (v2-v1) _____ _____ _____ Average TV............ ______
- Measured interval/breath (T2-T1) _____ _____ _____ Average interval .. ______
- Breathing rate (calculated as (60 breaths/minute) / (interval/breath)) .................. ______
- Measured maximum expiratory flow rate (record as (v2-v1)/(T2-T1))
  _____ _____ _____ Average rate .......... ______
- Measured maximum inspiratory flow rate (record as (v2-v1)/(T2-T1))
  _____ _____ _____ Average rate .......... ______
- Measured vital capacity .............................................................................. ______
- Measured inspiratory reserve volume (IRV) .................................................. ______
- Measured expiratory reserve volume (ERV) .................................................. ______
### Supine Breathing at Rest (optional)

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<thead>
<tr>
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<th>Average TV .......... _____</th>
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<td>Average interval .. _____</td>
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<td>Measured maximum expiratory flow rate (record as (v2-v1)/(T2-T1))</td>
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<td>Average rate .......... _____</td>
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<td>Measured maximum inspiratory flow rate (record as (v2-v1)/(T2-T1))</td>
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<td>Average rate .......... _____</td>
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<td>Measured vital capacity</td>
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<td>Measured inspiratory reserve volume (IRV)</td>
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<td>Measured expiratory reserve volume (ERV)</td>
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### Extended Dead Air Space at Rest (optional)

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<th>Measured TV (v2-v1)</th>
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<td>Measured interval/breath (T2-T1)</td>
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<td>Average rate .......... _____</td>
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<td>Measured vital capacity</td>
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### FEV₁/FVC While Standing

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<tr>
<th>Measured FEV₁</th>
<th>_____</th>
<th>Measured FVC</th>
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<td>Value 2</td>
<td>Value 3</td>
<td>Average 1</td>
<td>Value 4</td>
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<td><strong>Breathing Immediately After Exercise</strong></td>
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<td>Average TV..........</td>
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<td>Measured TV (v2-v1)</td>
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<td>Measured vital capacity</td>
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<td><strong>Breathing 2 Minutes after Exercise</strong></td>
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<td>Average TV..........</td>
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## Spirometry Summary Data Sheet - Sitting and Standing Rest

<table>
<thead>
<tr>
<th>Student #1: Age _____</th>
<th>Height ____</th>
<th>Sex ____</th>
<th>Smoke ____</th>
<th>Exercise _____</th>
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<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC ratio</td>
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# Spirometry Summary Data Sheet -
## Supine Rest and Extended Dead Air Space

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**Spirometry Questions - Exercises 1-3**

**Questions:**
1. Would you expect there to be differences in the lung volumes among the students? Why or why not? What factors might have contributed to differences among the students?

2. What differences did you see in lung volumes when students were in different positions (i.e., standing, sitting, supine rest)
   a. What might have caused the differences seen in the lung volumes when the students were in different positions?
   b. What differences, if any, might you predict in the levels of $O_2$ and $CO_2$ in the exhaled air of people standing and lying down?

3. Calculate predicted VC based on the student’s age, height and gender.
   a. How do your FEV$_1$/FVC data compare to expectations for each student?
   b. How would the measured FEV$_1$, FVC and FEV$_1$/FVC ratio change in obstructive airway diseases, like asthma, bronchitis, or emphysema?
c. How would the measured FEV$_1$, FVC and FEV$_1$/FVC ratio change in restrictive lung diseases like fibrosis?

4. What effect, if any, did the larger dead air volume have on ventilation rates and tidal volume? Was this expected? Why or why not? Relate your observations to alveolar ventilation.

a. What implications might this have on the aquatic activity called snorkeling?

b. Would there be a length of tubing at which the alveoli could not be ventilated? What lung capacity would be close to that point?
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<th>Respiratory Volume or Capacity / Range</th>
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1. Compare the measurements made immediately after exercise with those made 2 minutes after exercise. How might you account for differences between the two conditions?
2. Compare the measurements made immediately after and at 2 minutes after exercise with those made when the student was sitting at rest before exercise.

a. Was the tidal volume different after exercise? If the tidal volume changed, can this be accounted for by changes in the IRV or the ERV or some combination of both?

b. Was the rate of breathing different after exercise? If so, how? How might this be beneficial during exercise?

c. Was the peak inspiratory flow rate immediately after exercise and at 2 minutes after exercise different from the peak inspiratory flow rate measured when the student was sitting at rest before exercise? If so, how was it different?

d. Was the peak expiratory flow rate immediately after exercise and at 2 minutes after exercise different from the peak expiratory flow rate measured when the student was sitting at rest before exercise? If so, how was it different?

e. Was the minute volume (MRV) immediately after exercise and at 2 minutes after exercise different from the minute volume measured when the student was sitting at rest before exercise? If so, how was it different?

f. How might the change in TV and MRV be beneficial during and after exercise?
g. Was there a change in vital capacity after exercise? Would you have expected a change in vital capacity during this short-term exercise? Explain.

3. Review your data from the blood pressure exercises. Did you observe a similar increase in heart rate after exercise? Discuss the importance of matching ventilation to blood supply.

4. Review your data from the blood pressure exercises. Did you observe a similar pattern in blood pressure after exercise? What effect would you expect blood pressure to have on alveolar perfusion?
Answers to Spirometry Questions
Spirometry Questions – Exercises 1-3

Questions:
1. Would you expect there to be differences in the lung volumes among the students? Why or why not? What factors might have contributed to differences among the students?
   Lung volumes vary with height, age, sex, physical condition (including regular exercise and weight).
   Vital capacity, FEV\textsubscript{1}, IRV and ERV would be expected to be greater in:
   - Younger people
   - Taller people
   - Males
   - People who exercise regularly
   Vital capacity, FEV\textsubscript{1}, IRV and ERV would be expected to be lower in:
   - Smokers
   - Obese people

2. What differences did you see in lung volumes when students were in different positions (i.e., standing, sitting, supine rest)?
   Lung volume increases during standing, will decrease while sitting, and are the lowest in supine position (lying down) due in part to changes in how the abdominal organs affect the diaphragm.
   a. What might have caused the differences seen in the lung volumes when the students were in different positions?
      Gravity pulls abdominal digestive organs downward, thus increasing ERV when standing. Because ERV increases but TLC doesn't, IRV decreases. When lying down, the abdominal organs restrict the movement of the diaphragm, thus decreasing IRV.
   b. What differences, if any, might you predict in the levels of O\textsubscript{2} and CO\textsubscript{2} in the exhaled air of people standing and lying down?
      There may be less CO\textsubscript{2} exhaled in a person lying down. The level of O\textsubscript{2} should be normal.

3. Calculate predicted VC based on the student’s age, height and gender.
   a. How do your FEV\textsubscript{1}/FVC data compare to expectations for each student?
      Answers will vary depending on data. Smokers and people with asthma would be expected to have lower than normal FEV\textsubscript{1}/FVC ratios.
b. How would the measured FEV₁, FVC and FEV₁/FVC ratio change in obstructive airway diseases, like asthma, bronchitis, or emphysema?

*FEV₁ is reduced to a greater extent than is FVC and FEV₁/FVC is usually less than 0.70. FVC may be nearly normal or less than normal.*

c. How would the measured FEV₁, FVC and FEV₁/FVC ratio change in restrictive lung diseases like fibrosis?

*Both FEV₁ and FVC would be reduced, but because of the low compliance and high recoil of the lungs, the FEV₁/FVC ratio may be normal (~0.80) or greater than normal (>85)*

4. What effect, if any, did the larger dead air volume have on ventilation rates and tidal volume? Was this expected? Why or why not? Relate your observations to alveolar ventilation.

*TV and MRV will increase, as expected, because there of the increased anatomic dead space through which the air travels to the lungs. Rate may increase as well, although an increase in tidal volume alone can sufficiently return the alveolar ventilation to normal. Alveolar ventilation is affected by both rate and depth of breathing, but depth is more important. Increased depth allows the person to overcome the added dead space while keeping the rate steady. If there were no compensation, alveolar ventilation would decrease due to the increased dead air volume. Increased tidal volume compensates for increased dead air volume.*

a. What implications might this have on the aquatic activity called snorkeling?

*When snorkeling, one breathes through a tube, thus increasing dead air volume. Therefore, one would expect TV and MRV to increase to compensate to maintain alveolar ventilation. In addition, TV and MRV would have already increased somewhat to support the additional work being done while swimming.*

b. Would there be a length of tubing at which the alveoli could not be ventilated? What lung capacity would be close to that point?

*The person can’t exchange more than vital capacity. Though normally the IRV is the larger of the two reserved lung volumes and would be the main determinant of increased ventilation at any given rate.*
Spirometry Questions – Effect of Exercise

1. Compare the measurements made immediately after exercise with those made 2 minutes after exercise. How might you account for differences between the two conditions?
   
   Breathing rate and tidal volume increases during exercise and remains elevated for a few minutes afterwards. Therefore, MRV also increases. As carbon dioxide and oxygen levels return to normal breathing rate and depth slowly decrease toward normal as well.

2. Compare the measurements made immediately after and at 2 minutes after exercise with those made when the student was sitting at rest before exercise.

   a. Was the tidal volume different after exercise? If the tidal volume changed, can this be accounted for by changes in the IRV or the ERV or some combination of both? How might this be beneficial during exercise?
      
      Tidal volume normally increases during exercise and remains elevated for a few minutes afterward. Most of the increase usually comes from the IRV, but ERV may increase, too. This would increase alveolar ventilation and bring in more oxygen and increase removal of CO₂.

   b. Was the rate of breathing different after exercise? If so, how was it different? How might this be beneficial during exercise?
      
      Breathing rate normally increases during exercise and remains elevated for a few minutes afterward. The benefit is increased ventilation with less effort to increase tidal volume.

   c. Was the peak inspiratory flow rate immediately after exercise and at 2 minutes after exercise different from the peak inspiratory flow rate measured when the student was sitting at rest before exercise? If so, how was it different?
      
      Peak inspiratory flow rate is expected to increase. This would allow faster exchange of air thereby allowing MRV and alveolar ventilation to increase. The rate should slowly return to pre-exercise levels.

   d. Was the peak expiratory flow rate immediately after exercise and at 2 minutes after exercise different from the peak expiratory flow rate measured when the student was sitting at rest before exercise? If so, how was it different?
      
      Peak inspiratory flow rate is expected to increase. This would allow faster exchange of air thereby allowing MRV and alveolar ventilation to increase. The rate should slowly return to pre-exercise levels.

   e. Was the minute volume (MRV) immediately after exercise and at 2 minutes after exercise different from the minute volume measured when the student was sitting at rest before exercise? If so, how was it different?
MRV is expected to increase. This would allow faster exchange of air thereby allowing MRV and alveolar ventilation to increase. The rate should slowly return to pre-exercise levels.

f. How might the change in TV and MRV be beneficial during and after exercise?
   Increased TV and MRV would increase alveolar ventilation, thus increasing removal of CO₂ and increase O₂ intake to support aerobic metabolism.

g. Was there a change in vital capacity after exercise? Would you have expected a change in vital capacity during this short-term exercise? Explain.
   Since vital capacity is already the maximum amount of air that can be exchanged (maximal inspiration followed by maximal expiration), it does not change during or after short-term exercise. Aerobic exercise performed over time, however, may increase vital capacity by increasing the strength of the muscles used during inspiration and expiration.

3. Review your data from the blood pressure exercises. Did you observe a similar increase in heart rate after exercise? Discuss the importance of matching ventilation to blood supply.
   When you begin to exercise, your heart rate increases rapidly based on the intensity with which you are exercising. This brings more blood to the muscles and lungs more quickly.

4. Review your data from the blood pressure exercises. Did you observe a similar pattern in blood pressure after exercise? What effect would you expect blood pressure to have on alveolar perfusion?
   Blood pressure is also expected to increase during exercise (although it may not have been measured during exercise due to logistical constraints). Increased pulmonary blood pressure would increase perfusion of the alveoli, thereby increasing gas exchange and allowing the person to increase O₂ intake and CO₂ removal.