Laboratory 10 - Measurements of Pulmonary Function

Overview

Ventilation is the process of exchanging air between the atmosphere and the lungs. It can be divided into two parts, inspiration (inhalation) is the movement of air into the lungs and expiration (exhalation) is the movement of air out of the lungs. Like fluids, air moves from areas of high pressure to areas of low pressure. In the circulatory system the heart acts as a pump that provides the high pressure necessary to move the blood through the blood vessels. Ventilation relies on pressure changes created by changes in volume to move the air. Boyle's Law tells us that if the temperature of a gas remains constant then the pressure of that gas is inversely proportional to its volume. Therefore, if the volume in the lungs is increased the pressure will decrease and air will move from the atmosphere into the lungs and conversely if the volume of the lungs decreases the pressure in the lungs will increase and air will move out of the lungs. Volume changes in the thoracic cavity are accomplished through contraction of the muscles of respiration. The primary inspiratory muscles are the diaphragm, the sternocleidomasotoids, the scalenes and the external intercostals. Under normal conditions expiration is passive but when we begin to breath more deeply, as during exercise, the internal intercostals and abdominal muscles become involved.

The human body can inhale and exhale varied air volumes, depending on its needs. Certainly you know that the volume of air you are exhaling with each breath now is much less than the volume you would eliminate just after running a mile? When you are sleeping, the volume of air that you move with each breath is different again. **Spirometry** is a technique used to measure lung volumes and capacities and to measure ventilation as a function of time. A measured vital capacity (see below) that is below the normal range is diagnostic of **restrictive lung disorders**, such as pulmonary fibrosis. A person who has asthma or bronchitis may have a normal vital capacity but not be able to exhale this volume at a normal rate. Such **obstructive disorders** are detected by an abnormally slow forced expiratory volume ($FEV_{1.0}$). Emphysema is lung disease that is usually both restrictive and obstructive.

Measurement of respiratory movements reveals how the respiratory central pattern generating neurons direct the rate and depth of breathing. The volumes and capacities of respiratory input and output have traditionally been measured with a spirometer (*spiro* = breath, *meter* = to measure) and various closed systems to measure respiratory function. Pulmonary volumes and capacities are generally measured when assessing health of the respiratory system because the volume and capacity values change with pulmonary disease. We will the iWorx system to measure various lung volumes and capacities.

The amount of air that moves in or out of the lungs during any one breathing cycle is called the tidal volume. After normal inspiration, it is possible to breathe in additional air—this is called the inspiratory reserve volume. Similarly, after a normal expiration, it is possible to exhale additional air from the lungs—this is the expiratory reserve volume. Even if the expiratory reserve volume is fully expelled from the lungs, there is still a volume of air in the lungs, called the residual volume that cannot be exhaled. The residual volume has low oxygen and high carbon dioxide concentrations. Upon inhalation, fresh air mixes with stale air from the residual volume to create air in the alveoli that still has oxygen (O2) and carbon dioxide (CO2) concentrations that facilitate the diffusion of O2 into and CO2 out of the capillaries.

The respiration center in the medulla insures that gaseous exchange at the lung matches the requirements of the body. During times of increased demand, the tidal volume can be increased, using some of the reserve lung volumes to bring more fresh air into the body. In addition, the rate of breathing and the rate of air movement in and out of the lungs can be changed. In this lab you will measure these parameters in a subject at rest and immediately after exercise, when the body's demands for oxygen have been elevated.

Listed below is a list of the various lung volumes and measurements of lung function.

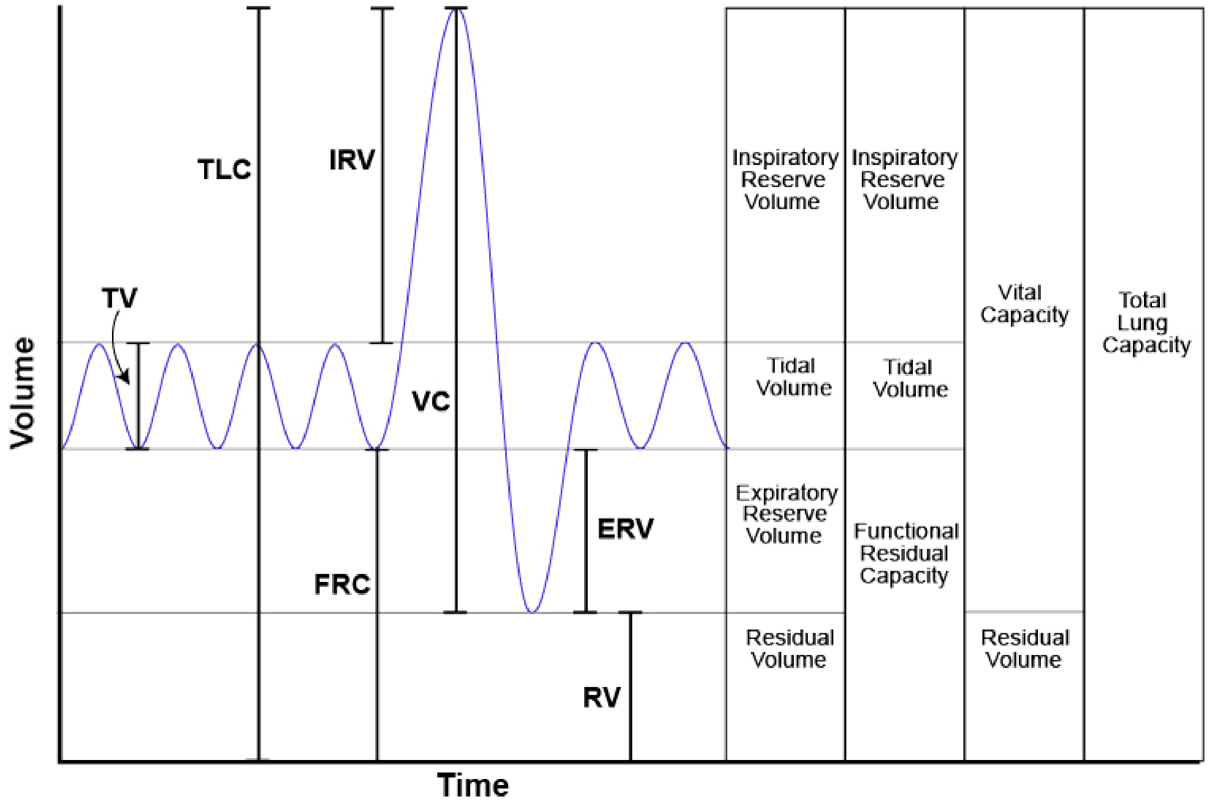
Residual volume (RV) – Volume of air remaining in the lungs after a maximal exhalation.
Tidal volume (TV) - Volume of air moved into or out of the lungs during quiet breathing.
Inspiratory Reserve volume (IRV) – Maximal volume that can be inspired from end-inspiratory level.
Expiratory reserve volume (ERV) – Maximal volume of that can be exhaled from the end-expiratory position.
Minute volume – Volume of air expired in one minute during tidal respiration.
Maximal voluntary ventilation (MVV) – Volume of air expired in a specified period during repetitive maximal effort.

Pulmonary capacities are the sums of two or more primary lung volumes. There are five pulmonary capacities, which can be calculated as shown:

Inspiratory capacity (IC)	IC = TV + IRV
Expiratory capacity (EC)	EC = TV + ERV
Functional residual capacity (FRC)	FRC = ERV + RV
Vital capacity (VC)	VC = IRV + TV + ERV
Total lung capacity (TLC)	TLC = IRV + TV + ERV + RV

Other important data can be collected when the patients is trying to force the air out of their lungs as rapidly as possible.

Forced Vital Capacity (FVC) – Determination of the vital capacity from a maximally forced expiratory effort.
Forced Expiratory volume (timed) (FEV_t) – A the volume of air exhaled under forced conditions in the first *t* seconds. "t" is usually 1 second in FEVt. When t is 1 second, we call it FEV_1 and this would be the maximal volume of air that is possible to exhale in one second after a maximal inhalation.



Of these lung capacities, **vital capacity** and the **forced expiratory volume** are of great interest to us. Among adults, the average pulmonary capacities decrease with age. Women tend to have smaller volumes than men of the same age and height. As height increases (with the exception of increasing beyond a normal, healthy range), volumes tend to increase. We can take these size and age related variables into account and estimate **predicted vital capacity**:

Male: VC = 0.052H - 0.022A - 3.60
Female: VC = 0.041H - 0.018A - 2.69

VC = vital capacity in liters
H = height in centimeters
A = age in years

A measured VC consistently below the normal range is diagnostic of restrictive lung disorders, such as pulmonary fibrosis. Vital capacity is considered normal if it is within 80% of the predicted VC. A person who has asthma or bronchitis may have a normal vital capacity but not be able to exhale this volume at a normal rate. Such obstructive disorders are detected by an abnormally slow forced expiratory volume ($FEV_{1.0}$). A healthy young adult should be able to expel at least 80% of their VC in the first second ($FEV_{1.0}$/FVC X 100). Individuals with mild obstructive lung disturbances would have an $FEV_{1.0}$/FVC ratio of 60-79%. An $FEV_{1.0}$/FVC ratio of 40-59% would indicate moderate obstructive lung disturbances and someone with a severe obstructive lung disturbance would have an $FEV_{1.0}$/FVC ratio of less than 40%.

Exercise 1: Breathing While Resting

Aim: To measure breathing parameters in a healthy, resting subject.

Procedure

1. The instructor will explain how to set up the Iworx machine. After the Iworx equipment is set up and ready to go, click the record button.
2. The LabScribe software will zero the Volume channel during the first 10 seconds of recording. **Do NOT breath into the machine for the first 10 second (No air should be moving through the flow head during this time).**

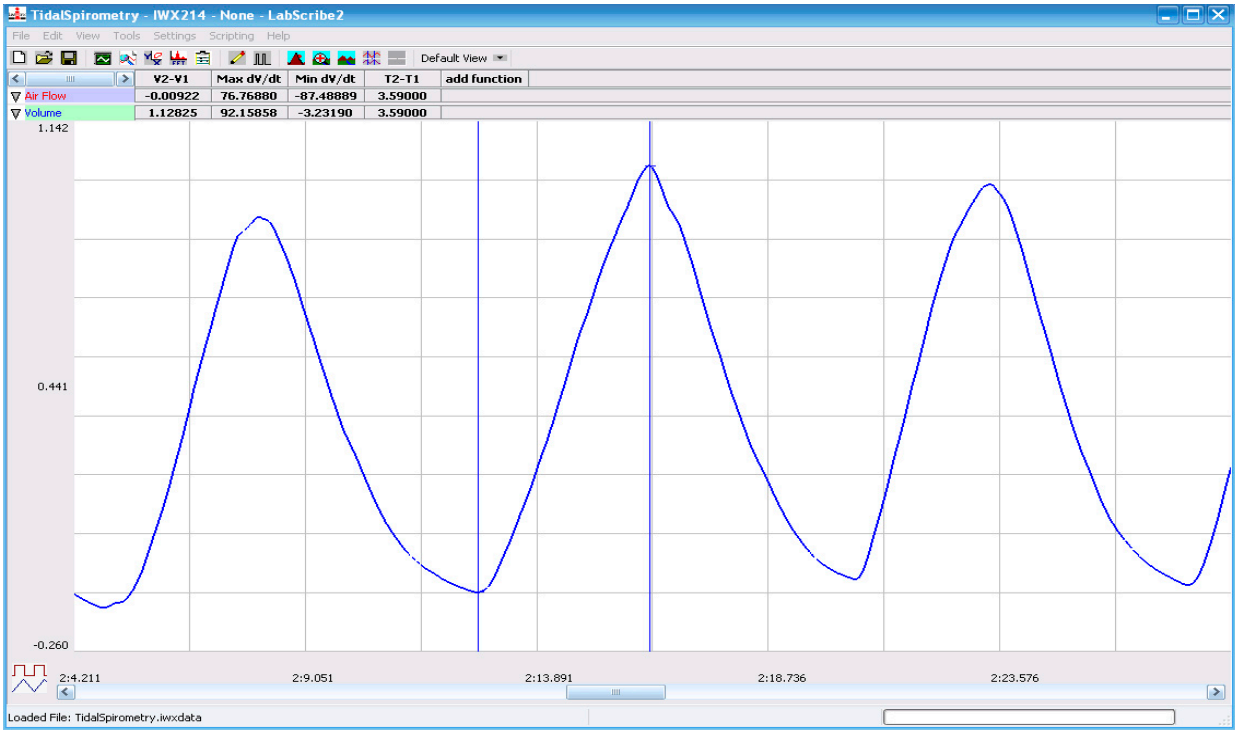
   After waiting 10 seconds for the Volume channel to zero, have the subject place the flow head in his or her mouth and begin breathing. Type " <Subject's Name> Resting" in the Mark box that is to the right of the Mark button (top middle screen). Press the Enter key on the keyboard to mark the recording.

3. After the subject seems comfortable breathing into the apparatus, have them inhale as **deeply** as possible and then exhale **as quickly and as completely as possible**. This will record the subject's vital capacity and forced expiratory volume.
4. After the forced exhalation is complete, the subject should continue to breathe normally through the spirometer for five or six more breath cycles.
5. Click Stop to halt recording.

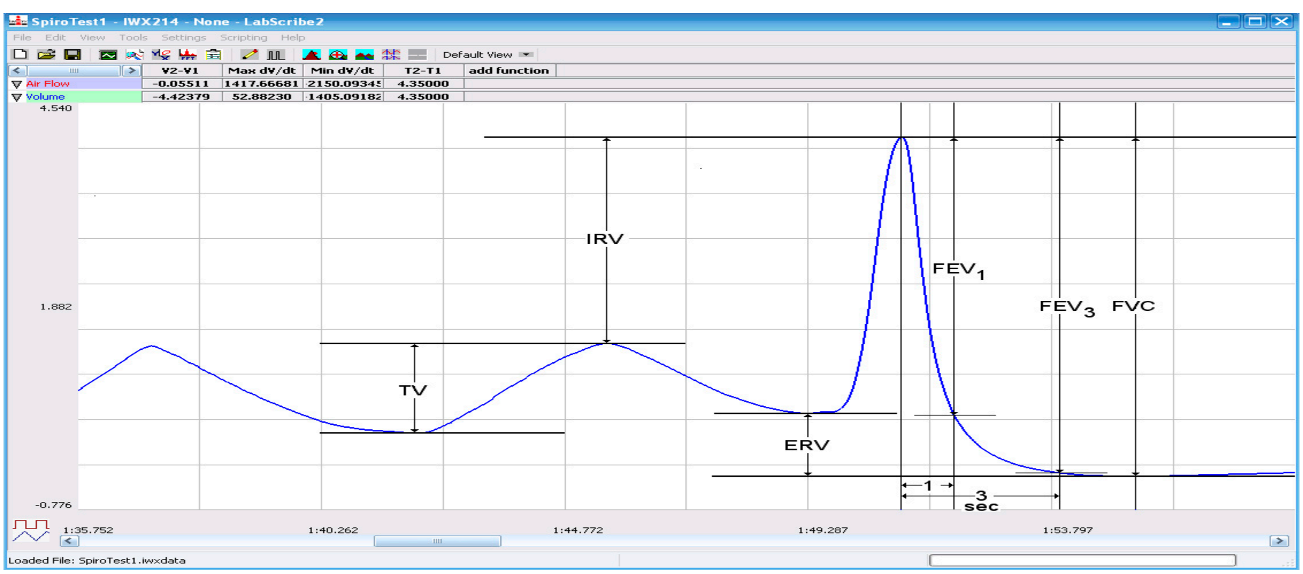
   Always remember to hold the flow head so that its outlets are pointed **up.
   **Always remember to hold the flow head level.

Data Analysis-Normal Breathing at Rest

1. Scroll through the recording and find the section of data recorded when the subject was breathing just before the maximal inspiration.
2. Using the cursors in the analysis window determine the following values: V_t, IRV, ERV, VC, $FEV_{1.0}$, maximum inspiratory flow rate, maximum expiratory flow rate and breathing rate.



3. Use the analysis window to measure Maximum Inspiratory Flow Rate, which is the maximum rate of air movement during inhalation, place the first cursor on the trough of a normal tidal breath and the second cursor on the peak to the right of the trough (see example above). The value for the Max_dv/dt function on the Volume channel is the maximum inspiratory flow rate of that breath cycle.
4. To measure Maximum Expiratory Flow Rate, which is the maximum rate of air movement during exhalation, place the first cursor on the peak of the breath cycle, and the second cursor in the trough to the right of that peak. The value for the Min_dv/dt function on the Volume channel is the maximum expiratory flow rate of that breath cycle. This function is used since the exhalation portion of the breath cycle has a negative slope.
5. To compute the breathing rate measure the time between 4-5 consecutive tidal breaths and compute the average breath time. Divide this number into 60 seconds to compute breaths per minute.).



Exercise 2: Breathing Immediately After Exercise

Aim: To measure the breathing parameters of the same healthy subject after exercise.

Procedure

1. In this exercise, use the same healthy subject whose breathing parameters at rest were measured in Exercise 1.

2. The subject should exercise to sufficiently elevate breathing rate by riding the stationary bicycles or running up and down the stairs several times.
3. Repeat procedures as in exercise 1 and perform the same analysis of the data
4. How did VT, IRV and ERV change after the subject exercised? What physiological modifications occurred to create these changes? Which respiratory muscles were involved at rest and after exercise?
5. Did the rate of air flow during the inhalation phase increase or decrease with exercise? How can you account for the change?
6. Did the rate of air flow during the exhalation phase increase or decrease with exercise? If so, how can you account for the change?
7. How did the volume of air passing in and out of the resting subject's lungs each minute change after exercise? Which parameters changed the most, rate or VT?
8. With the changes in tidal volume observed during exercise, which of the pulmonary reserves played the greatest role in the changes.

Exercise 3: Alveolar Ventilation

9. The following measurements were made on a normal subject:

    Minute ventilation = 9 liters

    Alveolar ventilation = 6 liters

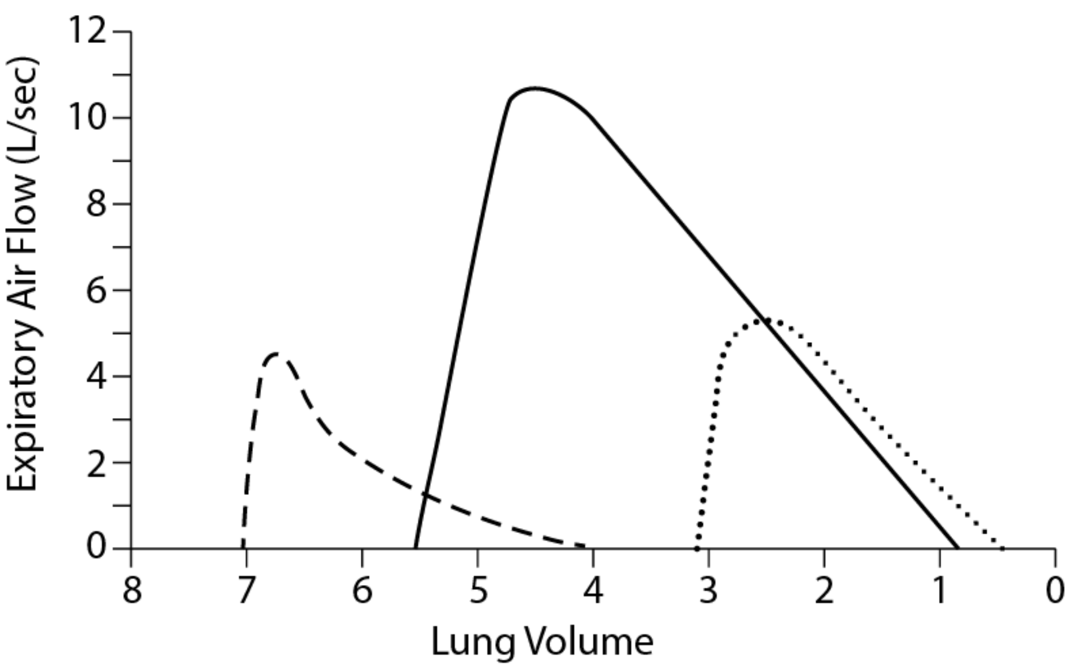
    Breathing rate (f) = 15 breaths/minute

    Arterial P_{O2} (P_aO_2) = 100 mm Hg

Which of the following breathing patterns would not change the subject's P_aO_2? There may be more than one correct answer. Explain your answer.

a. VT = 400, f = 30
b. VT = 500, f = 30
c. VT = 800, f = 7.5
d. VT = 800, f = 10
e. VT = 900, f = 10

10. For the patient above, which of the breathing patterns would reduce the subjects P_aO_2 to less than 100 mmhg? Explain your answer.
11. The figure below shows the expiratory pattern of three patients. The solid line is a patient with normal pulmonary function. What pathological conditions are demonstrated by the dashed and the dotted lines. Explain your answer.



Exercise 4: Case Study

A 50-year-old woman is in intensive care for treatment of pulmonary edema caused by heart failure. Edema fluid is in both the interstitial and alveolar spaces of her lungs. For the moment she is breathing on her own. Her respiratory rate is 30 breaths per minute. Previously, she had normal lung capacities.

1. Based on this limited information, how would you characterize the following parameters as high, low, or normal? State your reasons and explain:

    Total lung capacity
    Surface tension
    Lung compliance
    Work of breathing

The patient eventually recovers completely. Two months later she returns to the pulmonary function laboratory. She is asked to inhale fully, then exhale as forcefully and fully as possible, and then resume normal breathing. During the test, the volume of air exhaled and rate of air flow are measured.

2. What is the term for the volume of air that is; a) in her lungs at the point of maximal inhalation; b) exhaled from full inhalation to full exhalation; and c) in her lungs at the point of full exhalation?

3. At what point in this maneuver is her air flow the fastest? If she did not inhale maximally before commencing this maneuver, would her maximal air flow be the same, higher, or lower than maximal inhalation?

4. What is the term for the volume of air in her lungs at the end of quiet, normal exhalation? What is her intrapleural pressure at this point relative to atmospheric pressure (negative or positive)? Explain the elastic recoil forces acting at this point. If one side of her chest wall is punctured, what will happen to the lung on that side and why?

5. Patients with recurrent episodes of pulmonary edema sometimes don't recover fully, but may develop pulmonary fibrosis, or chronic lung scarring. Fibrotic lungs differ from emphysemic lungs. How do each of the following parameters compare to normal (increased, decreased, or no change)?

	Emphysema	**Fibrosis**
Elastic recoil		
Compliance		
Total lung capacity		
Forced vital capacity		
Residual volume		