Chapter 6

# Human Cardiopulmonary Laboratory


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## Contents



## Introduction

This exercise was designed for use in an autotutorial course in introductory biology, but can be easily adapted for more traditional courses. The course has about 185 students and the lab runs over a 3-week period. The first week students attend a 3-hour laboratory session to learn about various aspects of cardiopulmonary function and techniques useful for assessing such functions. Once they are familiar with the techniques and equipment, the students, working in pairs, devise an experimental procedure which will allow them to determine the effect of some experimental variable(s) on pulse rate, blood pressure, respiratory volumes, or other related cardiopulmonary functions such as rate of breathing. Their experimental design is submitted to the instructor for approval. Once the design has been evaluated and approved, perhaps with additions or corrections, the students carry out their experiments, on their own, and write a lab report on their results.

## Materials

Recommended material for each lab (six to seven pairs of students):

Meter sticks, 3
ECG with leads, electrodes, paper, ink, etc.

Blood pressure kits (sphygmomanometer and stethoscope), 6–7

Heart model

Posters showing circulatory and gas exchange systems

Audiotape players, 3

Audio tapes with heart sounds

Head sets, 3

Wet spirometer (1) with mouthpiece for each student

## Notes for the Instructor

Our students have thoroughly enjoyed this lab sequence and have come up with some very creative proposals. The formal lab which begins the sequence is a very straightforward techniques lab. The students learn how to take a pulse and blood pressure, have an ECG done, do a venous pressure, and do their own spirogram. Students do have trouble learning to take blood pressure, they find it is not as easy as it looks. Most cannot hear the sounds at first. Venous pressure and the spirogram are easily done without supervision. Generally, the instructor starts the lab with a brief introduction, helps the students with learning how to take blood pressure, gets them started with the venous pressure and spirogram, and takes the students in small groups to demonstrate the ECG machine. Sometimes, the lab goes fast enough that each student gets their own ECG done; other times, we do ECGs on only a few students and cut up the tracings, giving each student a section. We have two machines, one for each lab. The machines are different, and there are many on the market, so a description of how to use it is not possible. We simply follow the instructions that came with each machine and have had no unsolvable problems.

The instructors are given training in the use of all the equipment before lab. The ECG is really the only part of the lab that has the potential to cause problems. Things like blockages in the ink pen and lack of good contact of the electrodes with the skin are the major problems. The disposable electrodes work the best. The lab can be run without the ECG if you do not have a machine; it is not essential.

At the end of the introductory lab, we spend some time talking with the students about their experimental design. Most will already have an idea, and we critique their ideas in class. The instructors (mostly TAs) go over the proposals very carefully and try to help the students arrive at a reasonable and feasible design. The usual problem is that the students want to do too much. We tell them, as a guideline, that their data collection should not take more than 3 hours. Most of them get very involved in their project and willingly spend more time than is required. Also, they overestimate their ability to take blood pressure in an efficient manner. (By the time they get ready and take the blood pressure, it may well be back to normal). Pulse rate and breathing rate are much faster and easier to obtain, and probably more accurate.

As the students go through the planning procedure for their proposal, they begin to realize that they have to control for sex, size, fitness, etc., and that it is not as easy to design an experiment as they thought. You have to make sure that your students understand about multiple measurements, controls, and the use of more than one subject. They need to anticipate which kinds of statistical analysis (if any) they will be using. It is usually best to keep the experiment simple.

Work put into the design pays off handsomely later when the students actually write up the report. The experimental design write-up, when done properly, should be good enough to be used, with some modification, as the introduction of their lab report. We found that the quality of the proposals, and of the final lab report itself, improved markedly when we started grading the experimental design proposals. We now allot 12 of the 100 points for the lab report to the proposal. We expect the student to do library research before turning in their experimental design, and to cite at least two references in their experimental design. We do put some books on reserve in the library, a list of which is provided in Appendix A.

Requiring library research ensures that students will be able to find references to cite in their report. It also helps them refine their proposals if they know in advance what biological explanations they will offer to account for the results. A copy of the experimental design form is found in Appendix B. Appendix C shows the form used by the instructors in evaluating the design. Both forms are returned to the students.

Most of the successful projects involve the effect of exercise on pulse rate, breathing rate, and/or blood pressure. Some varsity athletes, for instance, have studied the effect of different parts of practice or different drills on cardiopulmonary function. Many of the students do experiments that compare the heart rate and blood pressure before and after exercise of athletes vs. non-athletes, males vs. females, or of smokers vs. nonsmokers, etc. Others have looked at different types of exercise and their effects on heart rate and blood pressure (e.g., swimming vs. jogging, or biking, or rowing, etc.), the effect of anaerobic vs. aerobic exercise, the differences between water aerobics and land aerobics, or even the effect of wearing a heavy backpack when walking up the hill to class. One student did a nice study correlating the vital capacities of members of the varsity marching band with their instruments. One interesting study is to look at the effect of walking blindfolded vs. not blindfolded on pulse rate and blood pressure. The possibilities are limitless. And of course, because each pair of students is doing something different, problems with plagiarism are minimized.

We have found that, in general, experiments involving exercise work out the best. Every year we have proposals submitted concerning the effect of classical music vs. rock music on heart rate and blood pressure, or the effect of horror movies, or X-rated movies, or pornography, etc. Over the years students have done these things, and the results have never been satisfactory. We now discourage (but allow) such studies, but point out that it is much easier to write a lab report when you have interpretable data.

Because the students are doing their experiment on their own time, we make equipment available for them all hours of the day or night. Some of the students will be using the ECG machine, spirometer, variable resistance bicycle, and variable resistance rowing machine available in the labs, so we set up times when the labs will be open for their use and (minimally) supervised. Many of the students do their projects using the exercise equipment available in the gyms and dorms on campus.

We have the following monitoring devices and equipment available for use which can be removed from the building: sphygmomanometers and stethoscopes (24), and jump ropes (12). Also available for use on special projects (which instructor must approve) are: wristwatch-style pulse monitors (3), chest heart rate monitors (2), digital blood pressure and pulse monitor (finger monitor, rather inaccurate) (1), and portable dry spirometer (1). Students reserve these items in advance for a specific time on a first-come, first-served basis. Sign-up sheets are posted on the course bulletin board.

Once they have gathered their data, the students are expected to write a formal lab report detailing their findings. We ask that those techniques not used directly in the experiment (usually venous pressure, ECG, and respiratory volumes) be presented in appendices rather than in body of the lab report. A separate appendix is used for each technique and the student must briefly explain what he or she did and describe the results in each case. The actual lab report contains only the results of their experiment. Though the students work in pairs, each must write his or her own report. (When we grade the reports, we always grade the partner's reports at the same time, to guard against copying.)

## Student Outline

### Introduction

In this lab sequence, you will attend a laboratory session to learn about various aspects of cardiopulmonary function and to learn techniques useful for assessing such functions. You will then devise and carry out at a later time an experimental procedure which will allow you to determine the effect of some experimental factor(s) on chosen aspects of human cardiopulmonary functioning. Your experiment should be carefully chosen to ask a single, clear question about the relationship between the experimental conditions you have chosen and the performance of your subjects. You must provide a biological explanation for the results that you obtain.

**To do in this lab:**

1. Sign up for a lab time *with a partner*.
2. Read the Lab Guide before coming to lab.
3. Attend the lab session to learn the techniques.
4. Read the Reserve Readings which have been placed in folders available at both Mann Library and the BioCenter, and locate two references for your particular experiment.
5. Hand in your experimental design by 3:45 p.m. on November 6. Experimental designs will be returned on November 9.
6. Sign up for the equipment needed and carry out your experiment.
7. Hand in a formal, typed report on your experimental results and conclusions. All lab reports are due at 12:45 p.m. on Saturday, November 21 (no extensions available). Though you and your partner should evaluate your results together, you must each *write your own report*! The lab reports are discussed more fully at the end of this exercise.

## Background

The varying energy needs of the body are provided for by controlled changes in blood flow through the lungs and the tissues. Elevated $CO_2$ levels in the blood lead to increased ventilation, so that more effective gas exchange can take place in the lungs. Both stroke volume and beating rate of the heart are increased during exercise, leading to an increase in blood pressure, and therefore an increase in blood flow rate through the peripheral tissues and the lungs. A great deal can be learned about heart and lung function by measurement of pulse rates, blood pressure, and respiratory volumes. The electrocardiogram gives more detailed information about heart function. Because the heart's contraction is initiated in a special area, the atrioventricular node, and spreads through defined tracts to other areas, small voltage changes in one area of the body relative to others are induced. Skilled interpretation of ECG tracings enables physicians to distinguish among different kinds of heart disorders.

Of course, many factors besides the intensity and duration of exercise determine the effects of exercise on cardiopulmonary function. These include the age, sex, general physical condition (muscle tone, etc.), and immediate physical state (health, mental state) of the subjects. In addition, these factors as well as a variety of experiences have effects apart from exercise. The effects of factors which influence cardiopulmonary condition via their modification of one's mental state can be very difficult to understand or anticipate.

# Cardiopulmonary Techniques

## Exercise 1: Heart Sounds

Listen to 30 seconds or so of the taped heart sounds. With a stethoscope, listen to the sounds of your heart. The stethoscope is a sound-amplifying device that converts a small displacement of a large volume of air into a large displacement of a small volume of air. Two sounds can be heard during the cardiac cycle. The first sound is of relatively long duration and low-pitch, described as "lub." This sound is associated with the closing of the valves between the atria and ventricles (the tricuspid and bicuspid valves, or AV valves). The second sound is a shorter, high-pitched "dup." It arises from vibrations set up in the blood column and the arterial walls as the valves of the aorta and pulmonary trunk close. Be sure you know where the two sounds fit into the cardiac cycle.

Since each sound is associated with a particular structure in the heart, maximum intensity of the sound should occur when the stethoscope is placed over the appropriate structure. Try to locate the site of maximum intensity of the sounds. What can you deduce about the position of the heart based only on sounds?

## Exercise 2: Arterial Pulse

Contraction of heart chambers is called systole; relaxation is called diastole. In the aorta, the pulmonary artery, and other arteries of large diameter, most of the vessel wall is occupied by circular smooth muscle interspersed with elastic fibers. These circular muscles and elastic fibers allow radial expansion of the artery. During systole, the left ventricle forces blood into the aorta. This causes a pressure wave that travels along the arteries. The travelling expansion of the arteries' walls is the arterial pulse.

The pulse that you feel in your wrist is the pulse of the radial artery. The radial artery runs along the radius bone of the forearm and comes close to the surface across a body ridge near the base of the thumb.

Sit and relax for 5 minutes so that disturbance due to activity or emotion may pass. With the tips of your fingers, feel the radial artery at the wrist. Do not squeeze hard. Once you have located the pulse, try to detect some of the subtleties of the pulse.

*Rate*: Count and record the number of beats per minute.

*Rhythm*: Do the pulsations follow at regular intervals? The heart rate may increase slightly during inspiration of air into the lungs. This is called *sinus arrhythmia* and is a normal phenomenon. Can you detect this? Make at least three determinations of resting arterial pressure.

The arterial pulse travels 5–8 m/s. Although the velocity fluctuates, blood in the aorta can reach a velocity of 1.2 m/s. Compare the velocity of blood with the velocity of the arterial pulse. Can you explain the difference?

## Exercise 3: Venous Pressure

The blood pressure in the veins is much less than that in the arteries. Veins have much thinner walls than arteries and the pressure within them is readily affected by conditions outside the vessels themselves, such as the contraction of surrounding skeletal muscles and changes in the pressure within the thoracic cavity during inhalation and exhalation.

The blood pressure in the venules is 12–18 mm Hg, and the pressure falls steadily in the larger veins to about 5.5 mm Hg in the venae cavae outside the thorax. Peripheral venous pressure, like arterial pressure, is affected by gravity. It increases by 0.77 mm Hg for each cm below the right atrium and decreases a like amount for each cm above the right atrium. Thus, in the upright position, the venous pressure in the parts of the body above the heart is decreased by the force of gravity, and the neck veins actually collapse above the point where the venous pressure is close to zero.

The methods used to measure arterial pressure do not suffice for venous pressure, but a fairly accurate estimate of venous pressure can be made without any elaborate equipment. Do this exercise against a chalkboard or wall. Use chalk to mark the levels noted during the procedure.

With your back against the marking surface, let your arm hang vertically downward. The veins of the arm should slowly become distended. (Why?)

Raise your arm until the veins above the wrist begin to empty. Have your partner make a chalk mark at this wrist height. Then, your partner should mark (below or above the first mark) the level of your nipple as a reference mark. This level corresponds to the level of entry of the superior vena cava into the right atrium. Measure the vertical distance (in mm) between the two chalk marks by subtracting the height of the reference mark from the height of the first mark (you may get a negative number). This height difference is a measure of the pressure in the right atrium in mm $H_2O$. Make at least three determinations of resting venous blood pressure.

To compare your measurements of venous pressure to normal values (and to values you have obtained for arterial blood pressure), it is necessary to first convert your data from mm $H_2O$ to mm mercury (Hg). To do this, divide the mm $H_2O$ by the density of mercury: 13.6. Normal values for venous pressure are around 7.1 mm Hg. However, in advanced congestive heart failure or obstruction of the superior vena cava, venous pressure may reach values of 20 mm Hg or more.

Next, repeat the procedure to demonstrate the effect of increased thoracic pressure on venous pressure. This can be shown using Valsalva's maneuver. This requires that the subject go through all the motions of forcefully exhaling without actually blowing any air from the lungs. (Keep the nostrils and mouth closed.) While the subject is performing this maneuver, measure the subject's venous pressure again by checking the height to which his hand can be raised before the veins collapse.

### Use of the Sphygmomanometer

The sphygmomanometer is a device for measuring blood pressure. “Sphygmos” is Greek for pulse; a manometer is a pressure gauge. An inflatable cuff is connected to a rubber bulb and a pressure gauge. The rubber bulb is squeezed to inflate a bladder in the cuff. *Do not overinflate the cuff or squeeze it hard.* The pressure in the cuff is measured by the aneroid pressure gauge. The pressure indicated on the aneroid gauge is in units of mm Hg.

The pressurized cuff can be used to determine arterial blood pressure. The cuff is placed around the upper arm over the brachial artery. The cuff is inflated until the cuff pressure exceeds the systolic pressure in the artery and constricts the artery. Then, as the cuff pressure is lowered, it approaches the maximum pressure of a spurt of arterial blood. This maximum pressure is the arterial systolic pressure; when the cuff pressure equals the systolic pressure, the number on the gauge represents the systolic pressure in the artery. When the decreasing cuff pressure no longer interferes with arterial blood flow, the reading on the gauge represents the diastolic pressure. Traditionally, blood pressure is expressed in mm Hg in this arrangement: systolic pressure/diastolic pressure.

### Exercise 4: Auscultation Method for Measuring Arterial Blood Pressure

Your arm should be bared to the shoulder. Locate your brachial artery in the bend of your elbow. Feel the brachial artery pulse with your fingers so that you can locate it easily. (Note that this artery usually does not lie along the midline of your arm, but more toward the body side of the bend of the elbow. Hyperextending the forearm or pulling it against resistance may make the brachial artery pulse easier to feel.)

Place the center of the completely deflated sphygmomanometer cuff over the brachial artery approximately 3 cm above the bend of the elbow. Wrap the cuff around the arm and let the velcro hold the cuff in place.

*Safety reminder:* Do not over-inflate the sphygmomanometer cuff, nor keep it at pressure for more than the shortest time needed to be sure that arterial blood flow is stopped. Wait at least 2 minutes between determinations of blood pressure. Blood flow should never be obstructed for more than 1 minute. Be respectful of your own and other's physical limitations.

Before you inflate the cuff, examine the pressure relief valve, a knob located between the squeeze bulb and the tubing. Two kinds of pressure relief valves are common. If the knob pushes in, you have an automatic pressure relief valve. The pressure in the cuff will decline automatically at the correct rate for measuring blood pressure. (If the rate is too fast or too slow for you, turning the slotted screw while holding the rest of the knob tight will change the rate of pressure release.) With the automatic pressure relief valve, pressure can be released very quickly by pushing in this knob; you will want to do this as soon as you have determined the diastolic value or if your subject indicates discomfort. The other kind of pressure relief valve is a manual pressure relief valve. It releases pressure only if you unscrew the knob a little bit. The farther you unscrew the knob, the faster the pressure will decline. Note that with the manual pressure relief valve, you must screw the knob all the way clockwise for the cuff to hold pressure as you pump the squeeze bulb. We have both kinds of pressure relief valves available, so know which kind you have before you inflate the cuff.

By squeezing the bulb, inflate the cuff to about 150 mm Hg, then release the pressure gradually. Notice the spurting feeling that occurs at about 110–130 mm Hg. Release the rest of the pressure. What was that spurting? Remember that blood pressure varies in the artery from a systolic high to a diastolic low. When the cuff pressure exceeds systolic pressure, the artery collapses and blood flow stops. Then, as pressure in the cuff declines, cuff pressure eventually equals systolic pressure; and soon pressure in the cuff is slightly less than the artery's systolic pressure. You will be listening for this spurting when you measure your partner's blood pressure.

Next, in quiet surroundings, put the cuff on your partner's arm. Arrange the pressure gauge so that only you can see it. (Why?) Twist the coupler on the stethoscope so that the flat disk is in place for picking up sounds. Place the center of this disk's diaphragm over your partner's brachial artery at the elbow, just over the site of maximum pulsation. Listen for the pulse. (If you cannot hear it, refer to “Stethoscope Hints” below.)

Inflate the cuff until the pressure gauge reads about 150 mm Hg; then allow the pressure to decline slowly. When the systolic pressure is just equal to the cuff pressure, sharp tapping sounds should be heard; these are the *sounds of Korotkow*. These are due to interruption of streamlined blood flow; blood flows through only at the peak of systole, and this turbulence makes the tapping sound. Note the gauge reading at which the sounds of Korotkow are first heard; this is the systolic pressure. As the pressure is further reduced, the sounds should increase in intensity and then decrease, gradually at first. Then the sounds will change abruptly from loud tapping sounds to dull, muffled sounds. The point at which the loud tapping abruptly becomes muffled is the diastolic pressure. At this pressure, the blood flow is turbulent, but not interrupted; the sound is continuous, giving it a muffled quality. Rapidly release the pressure in the cuff. Allow a few minutes for the circulation to return to normal.

Practice until you are confident of your technique. The normal blood pressure for an adult at rest is about 120/80. The actual readings you obtain may differ depending on emotional state and technique.

*Stethoscope Hints for Taking Blood Pressure*

1. Do not let the black rubber tube bend; the sound will dissipate too fast and never reach your ears.
2. The diaphragm of the flat disk is moved by the brachial artery and this movement alters the air column in the black tube; this air movement moves your eardrum. If you hold the disk too hard against the arm, the artery will not move the disk and you will hear nothing. If you hold the disk too lightly against the arm, you will also hear nothing.
3. Also, try just above and just below the crook of the elbow if you have trouble hearing the sounds. The best place is where you can feel the pulse most distinctly with your fingertips.
4. Notice that the metal tubes attached to the earpieces are not entirely planar; they bend either forwards or backwards. Put the earpiece in your ears so that the curve is toward your front; you will hear more easily and they will fit better.
5. Try inflating the sphygmomanometer cuff up to about 90 mm Hg and then releasing the pressure as you listen to the artery with the stethoscope. Tapping sounds indicate that you have positioned the stethoscope properly and are ready to measure your partner's blood pressure.

## The Electrocardiograph (ECG) Machine

The electrocardiogram, first recorded by Eindhoven in 1912, is a tracing of the electrical potential (i.e., voltage) produced by the heart during its contraction and relaxation. The voltage detected varies in frequency with the extent of electrical stimulation of the heart, and in amplitude and shape with placement of electrodes, type of electrodes, and preparation of skin.

The body fluids that lie between the heart and the body surface are good conductors; consequently, it is possible to record the heart's electrical activity on the body surface. This is accomplished by using electrodes, small flat pieces of metal that are connected by wires to the electrocardiograph machine. A conducting solution of gel is used between the electrode and skin to ensure good electrical contact. The electrocardiograph machine measures the changes in electrical potential and records the changes on a moving strip of chart paper. A typical tracing is shown in Figure 6.1.

Conventions about the location of electrodes have been developed to allow recording of traces which can be compared easily with others:

Standard I: Potential difference between left arm (+) and right arm.
Standard II: Potential difference between right arm and left leg (+).
Standard III: Potential difference between left arm and left leg (+).

So, for Lead I, when the left arm becomes positive with respect to the right arm, you should see an upward deflection on the chart.

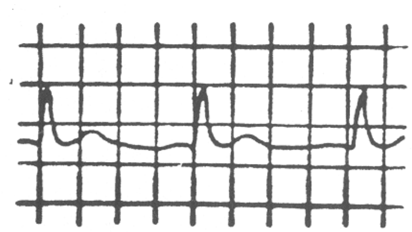

**Figure 6.1.** A typical ECG tracing.

A typical Lead II trace for one cardiac cycle is shown in Figure 6.2, with the standard identifying letter for each feature. The *P wave* is produced by the spread of excitation over the atria (atrial depolarization). The *QRS complex* comes from the ventricular depolarization. Ventricular relaxation (repolarization) creates the *T wave*. Some of the letter designations for intervals and segments of the trace are not entirely obvious, such as *PR*. Labelled intervals and segments are shown in Figure 6.3. (The electrocardiogram is discussed in some detail in the Reserve Readings; you will want to refer to this material.)

Electrical conduction in the AV node is slower than in the atria. Thus there is a delay, the AV node delay, before the ventricles begin to depolarize. Where would the AV node delay occur in the ECG?

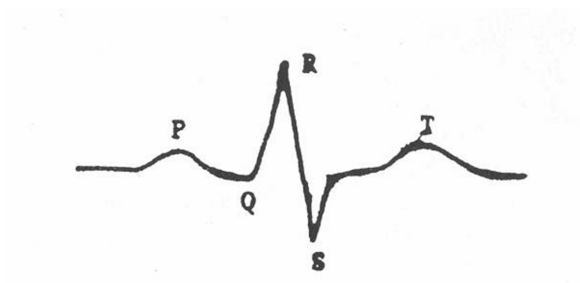


**Figure 6.2.** An ECG tracing, Lead II.

## Exercise 5: Obtain an Electrocardiogram

The instructor will set up the ECG connections to a volunteer and run the machine. To avoid shock hazard, the subject must not touch the ECG machine. You should be sure to obtain a tracing of the record for your report, and note which leads and instrument settings are in use. Observe the effect of exercise on the ECG.

## Use of the Spirometer

The amount of air drawn into and out of the lungs during quiet breathing is only a fraction of that which can be inhaled and exhaled during deep breathing. An instrument called a spirometer can be used to measure different volumes of breathed air. In this instrument, water is displaced by the breathed air, and the volume can be recorded.

## Exercise 6: Determining Respiratory Volume

1. **Tidal Volume** (TV) is the volume of air inhaled or exhaled during normal breathing. Sitting quietly, breathe easily for about 1 minute. Inhale a normal breath, then exhale normally into the spirometer mouthpiece. Repeat the measurement twice.
2. **Expiratory Reserve Volume** (ERV) is the amount of air that can be forced out of the lungs after normal exhalation. Stand and breathe normally for about 1 minute. Exhale normally (not into the spirometer); then forcibly exhale all additional air possible into the spirometer mouthpiece. Repeat this measurement twice.

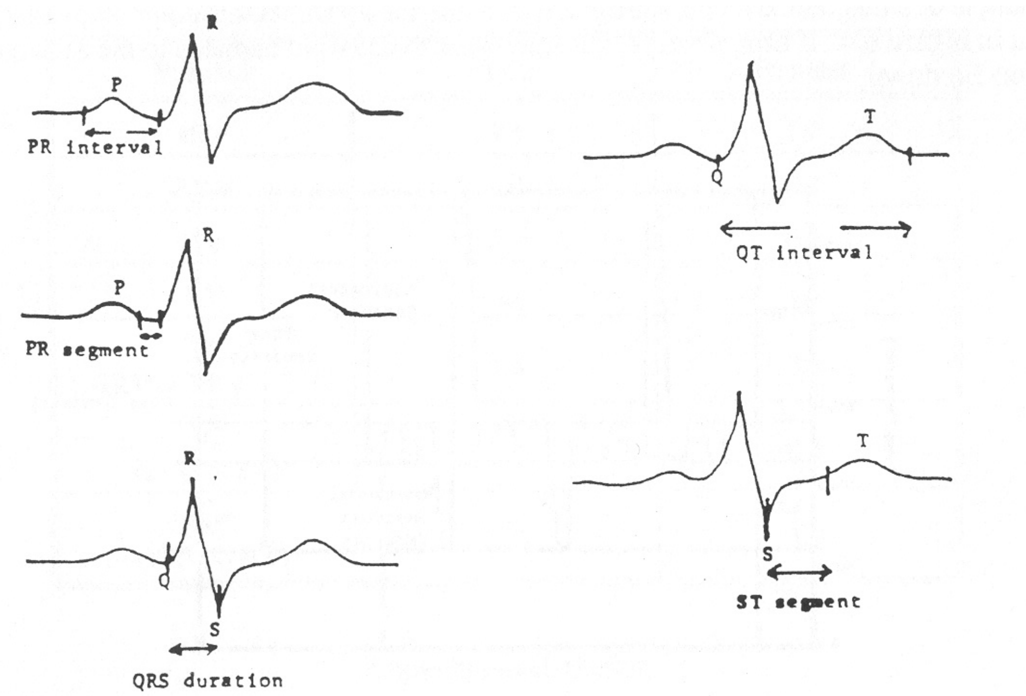


**Figure 6.3.** Labelled ECG tracings, Lead II

3. **Inspiratory Reserve Volume** (IRV) is the volume of air that can be inhaled after normal inhalation. Stand and breathe normally for about 1 minute. Inhale as deeply as possible; then exhale normally into the spirometer mouthpiece (do not forcibly exhale). From this value, subtract the tidal volume to obtain the IRV. Repeat twice.

4. **Residual Volume** (RV) is the air remaining in the lungs after maximum exhalation. Since this is not breathed air, you cannot measure this with a spirometer. Estimates of adult RV vary between 1000 and 1500 ml. You should use one of these values for residual volume: 1100 ml for females, 1200 ml for males. In addition to these volumes, which do not overlap, there are three capacities that are combinations of two or more volumes:

   (a) **Vital Capacity** (VC) is the largest volume of air that can be exhaled forcibly after a maximum inhalation. Standing, breathe slowly and deeply for 1 minute (do not hyperventilate — if you feel dizzy, sit down). Breathe in as deeply as possible; then exhale forcibly into the spirometer mouth-piece as much air as possible. Repeat several times. The result should approximate the added totals of IRV + ERV + TV.

   (b) **Inspiratory Capacity** (IC) is the amount of air that can be inhaled after normal exhalation. This is calculated by the formula: IC = IRV + TV.

   (c) **Functional Residual Capacity** (FRC) is the amount of air remaining in the lungs after a normal expiration. This is calculated by the formula: FRC = RV + ERV.

   A sample of a diagram, called a spirogram, showing the above relationships measured and calculated is shown in Figure 6.4. If time permits, you may want to see what happens to the above measurements when you lie down.

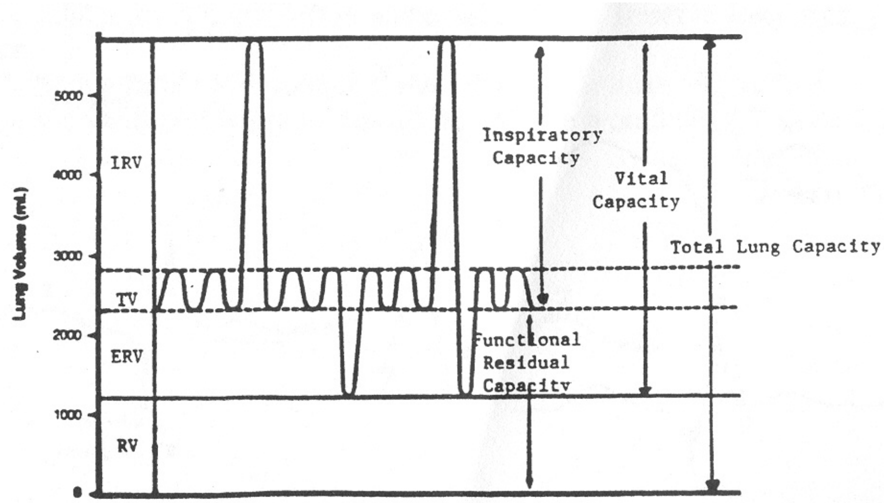


**Figure 6.4.** A spirogram showing the divisions of the respiratory air. (IRV = Inspiratory volume; TV = Tidal volume; ERV = Expiratory reserve volume; RV = Residual volume)

## Interpreting Respiratory Volumes

Several investigators have shown a relationship between certain body measurements and vital capacity. For the normal, healthy individual, there is a relationship between body weight (in grams) and vital capacity:

$$VC=\frac{W^n}{K}$$

where $W$ = body weight in grams; $n$ = 0.72; and $K$ = 0.690 g/ml. Calculate your predicted vital capacity using the above relationship and compare it to the measured vital capacity in your report.

A fairly close relationship also exists between total height and vital capacity: *Vital Capacity* = $N \times$ *height* (in cm); where $N$ is a factor that depends on sex and physical activity ($N$ converts height in centimeters to vital capacity in cubic centimeters, or milliliters). Thus, using this formula, your predicted vital capacity based on height will be in cc or ml. In females, $N$ = 20 cc/cm; in males, $N$ = 25 cc/cm; and in male athletes in good shape, $N$ = 29 cc/cm. Calculate your predicted vital capacity based on height and again compare it to the measured vital capacity. Place your calculations in the appendix of your report along with the spirogram.

The normal values for males and females are given in Table 6.1. As you might guess, the vital capacity is reduced in many diseased conditions, especially those involving the cardiopulmonary system, such as pneumonia, tuberculosis, emphysema, tumors, and heart disease.

**Table 6.1.** Normal values for respiratory volumes.

| Variable | Males | Females |
|---|---|---|
| IRV | 3.3 | 1.9 |
| ERV | 1.0 | 0.7 |
| TV | 0.5 | 0.5 |
| RV | 1.2 | 1.1 |
| VC (IRV + ERV + TV) | 4.5 | 3.1 |
| IC (IRV + TV) | 3.8 | 2.4 |
| FRC (ERV + RV) | 2.2 | 1.8 |

## Experimental Design

With your partner, plan a simple experiment to study the effect of some variable on pulse rate, blood pressure, respiratory volumes, or other related cardiopulmonary functions such as rate of breathing. Many successful experiments have related exercise to pulse rate and blood pressure. For example, you could compare the heart rate and blood pressure before and after exercise of an athlete vs. a non-athlete. Some varsity athletes have studied the effect of different parts of practice on cardiopulmonary function. Or you could look at different types of exercise and their effects on heart rate and blood pressure. Other experiments have looked at the effect of walking blindfolded vs. not blindfolded, the effect of anaerobic vs. aerobic exercise, or even the effect of wearing a heavy backpack and walking up the hill to class. Be creative! Remember that measurements should be made at least three times to be sure that representative values are obtained.

You and your partner are to submit one copy of the experiment that you have designed, using the form provided. The experimental design is worth 12 of the 100 points of your lab report, so it is important to do it well. Place the form in the lab report mailbox no later than 3:45 p.m. on Friday, November 6. Your lab TA will review and grade your experimental design and may suggest some changes. It is important that you pick up your designs at the front desk on Monday, November 9, in case changes are required.

In the experimental design, you should include the following: a statement of the hypothesis, the general methods to be used, and the possible/expected results. A detailed materials and methods should follow, stating exactly the procedures to be used. Lastly, cite at least two references you will be using. The work you put into your design will pay off handsomely for you later when you actually write up your report. The experimental designs will count 12 of the 100 points for this laboratory.

Rules:

1. No ingestion of substances.
2. No experiments involving sexuality.
3. No experiments involving physical danger.

## The Lab Report

The main body of your lab report should present your experiment using the format you have used for the first two labs of this course. Note that your lab report must include data on each of the following: venous pressure, ECG tracings, respiratory volumes (as a spirogram), arterial blood pressure, and pulse rate. Those techniques not used in your experiment (usually venous pressure, ECG, and respiratory volumes) should be presented in your appendices. Use a separate appendix for each additional technique and briefly explain what you did and describe your results in each case. Reference to these additional exercises should appear only in your abstract and introduction where the reader can be alerted to the existence of the appendices and apprised of their contents.

Your spirogram and ECG tracings, whenever they appear in your report, should have their various wave components properly identified and labelled. A copy of your raw data and an explanation of any statistical methods used should also be included in your appendices.

## APPENDIX A
*List of Reserve Readings*

Below are listed the books we place on reserve for student use. There is nothing special about these books; they are all human physiology books written at a level that is appropriate for freshman. All provide general information about the techniques they will be using in lab and in doing their experiment. We expect the student to find references specific to their particular experiment on their own.

Chapman, C.B., and J. H. Mitchell. 1965. The physiology of exercise. Scientific American, 212(5):88–96.

Fox, S. 1987. Respiratory physiology. Pages 441–442, *in* Human physiology (Second edition). Wm. C Brown, Dubuque, Iowa, 762 pages.

Ganoung, W. F. 1991. Chapters 29 and 30. Pages 521–549, *in* Review of medical physiology. Appleton and Lange, Norwalk, Connecticut, 754 pages.

## APPENDIX B
*Cardiopulmonary Laboratory: Experimental Design Sheet*

[The following is an a condensed version of the Experimental Design sheet:]

Partner's names:
Phone numbers:
Lab session (date and time):
Lab TA:

1. Statement of hypothesis, general methods, and possible or expected results:

2. Materials and methods:

3. References:

APPENDIX C

*Experimental Design Evaluation Sheet*

| | | |
|---|---|---|
| What are they going to do? (Proposal) | ______ | (2) |
| Why is this of interest? | ______ | (2) |
| How are they going to do it?<br>(Precise description of methods) | ______ | (2) |
| Expectations? (Include references) | ______ | (2) |
| Biological justification<br>(Must include references) | ______ | (3) |
| Creativity | ______ | (1) |
| **Total** | ______ | **(12)** |