

MODULE 1: LAB 2

THE CARDIOVASCULAR SYSTEM

Week of January 31-February 4, 2005

Learning objectives

- To identify the different chambers of a cow's heart.
- To identify the major arteries and veins of a cow's heart.
- To learn the function of all of the above structures.

- To understand the differences among the systemic circuit and pulmonary circuit.
- To distinguish between cross-sections of arteries and veins.

- To record your electrocardiogram (ECG).
- To identify the P, QRS, and T waves within an ECG, and to be able to relate each wave to the electrical events that occur during the cardiac cycle.
- To estimate heart rate using ECG recordings.
- To assess the effect of exercise on heart rate.

Discussion questions

- Is it true that the arteries always carry oxygenated blood, and the veins always carry deoxygenated blood? Explain.
- Do gases and nutrients pass directly between arteries and tissue beds? If not, what is the function of the arteries?
- Define a cardiac cycle. Explain the functional significance of the delay between the P wave and the QRS wave in the ECG.
- What occurs in the heart between the T wave of one cardiac cycle and the P wave of the next cardiac cycle?
- Why does exercise cause an increase in heart rate?

Readings: *Asking about Life*, 3rd edition, Chapter 38: pp. 736-753.
Anatomy & Physiology for Dummies pp. 182-190.

EXERCISE 1

Cardiovascular system of the cow heart

This lab exercise will examine the cardiovascular system of mammals. You will use the cow (bovine) heart as a model system for understanding the structure and function of the mammalian heart. Use the key provided below to determine the structure and function of the cow heart and to label the diagrams on worksheet 1. Remember that you will also need to learn the functional significance of each structure.

The primary function of the cardiovascular system is the transport of materials to and from all parts of the body. To do this, the cardiovascular system is composed of the heart, blood vessels, and the cells and plasma of the blood that flow inside the heart and the vessels.

The heart is divided by a central wall, or **septum**, into left and right halves. Each half consists of a **ventricle**, which pumps blood out into the blood vessels and an **atrium**, which receives blood returning to the heart from the blood vessels. The right side of the heart receives blood from the body's tissues and sends it to the lungs for oxygenation. The left side of the heart receives the newly oxygenated blood from the lungs and pumps it to tissues throughout the body. Inside the heart, the blood flows from atrium to ventricle. Valves between the atrium and ventricle prevent the blood from flowing backward.

In vertebrates, the blood vessels that carry blood away from the heart are called **arteries**, and those that carry blood back to the heart are called **veins**. In between the smallest branches of arteries and veins (arterioles and venules), there are **capillary beds** where the materials and gas of the blood can be exchanged with those of the tissues.

The arteries, veins, and capillaries are all lined with a thin layer of **endothelial** cells. Veins and arteries are also surrounded by **smooth muscle** and **connective tissue**. When the smooth muscles contract, they make the diameter of the vessels smaller. The arteries have more smooth muscle fibers than veins, which makes the artery walls thick and strong. The arteries can therefore withstand the blood pressure generated by the heart. Because the blood pressure of veins is lower than that of arteries, large veins have **valves** to prevent backward blood flow.

You are strongly encouraged to work with your labmates to complete Worksheet 1. However, remember that you must write your answers in YOUR OWN WORDS.

Heart structures/functions you need to know:

right atrium	vena cava (superior and inferior)
right ventricle	pulmonary artery and veins
left atrium	aorta
left ventricle	septum

Interesting Heart Rate Information

The average resting heart rate for adult humans is approximately 70 bpm. Slower heart rates are typically found in individuals who regularly exercise. Athletes are able to pump enough blood to meet the demands of the body with resting heart rates as low as 50 bpm. Athletes tend to develop larger hearts, especially the muscle in the left ventricle—a condition known as “left ventricular hypertrophy.” Because of their larger and more efficient hearts, athletes also exhibit other differences in their ECG’s. For instance, low heart rate and hypertrophy exhibited in sedentary individuals can be an indication of failing hearts, but these changes are “normal” for well-trained athletes.

Lance Armstrong, a cyclist who has won the Tour de France several times, has a resting heart rate averaging 36 bpm and a heart rate of 194 bpm when cycling uphill. *(Please take these numbers with a grain of salt; obviously there will be variation depending on many variables.)*

Table 1. Selected Animal Heart Rates (bpm)

blue-throated hummingbird	1260	monkey	192
hamster	450	dog	115
chick (immature)	400	cat	120
chicken (adult)	275	pig (adult)	70
rabbit	205	cow	65
		boa constrictor	26

Figure 1. Labeled diagram of human heart.

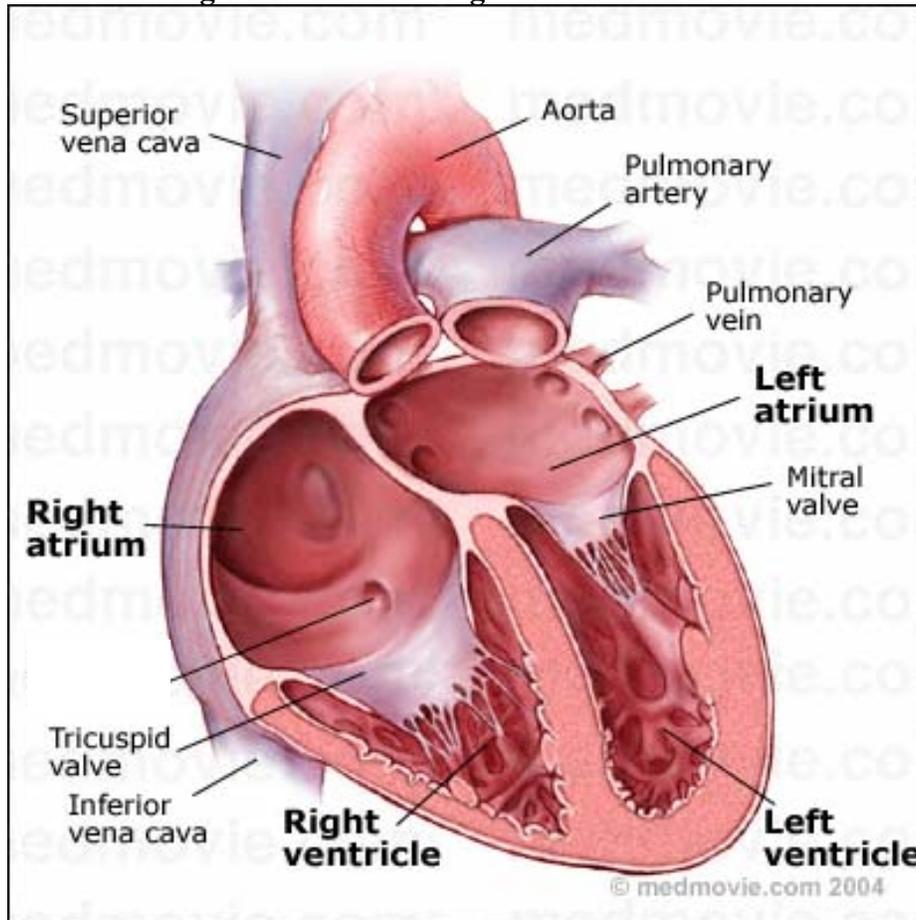
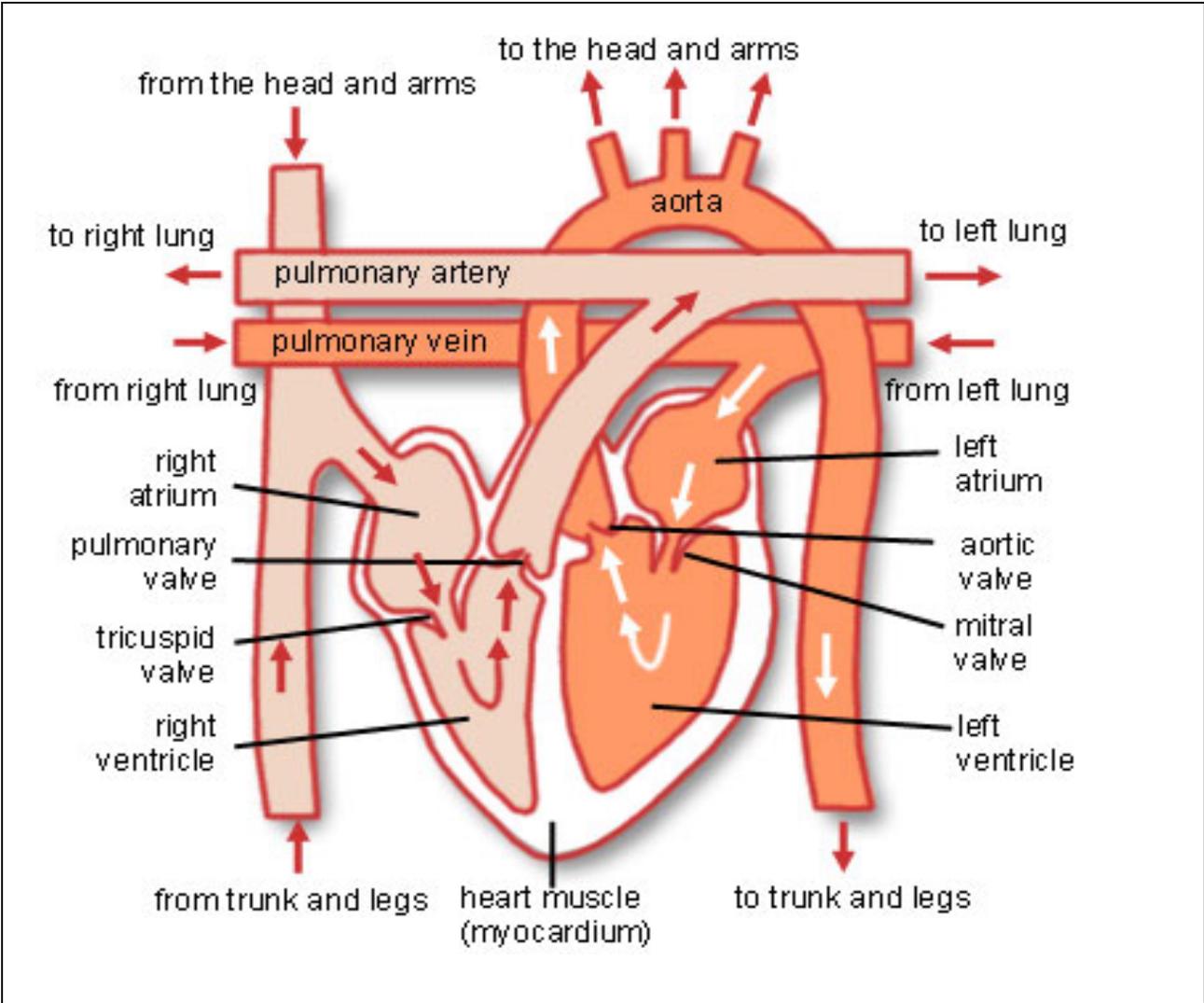


Figure 2. Diagram of blood flow through the human body.

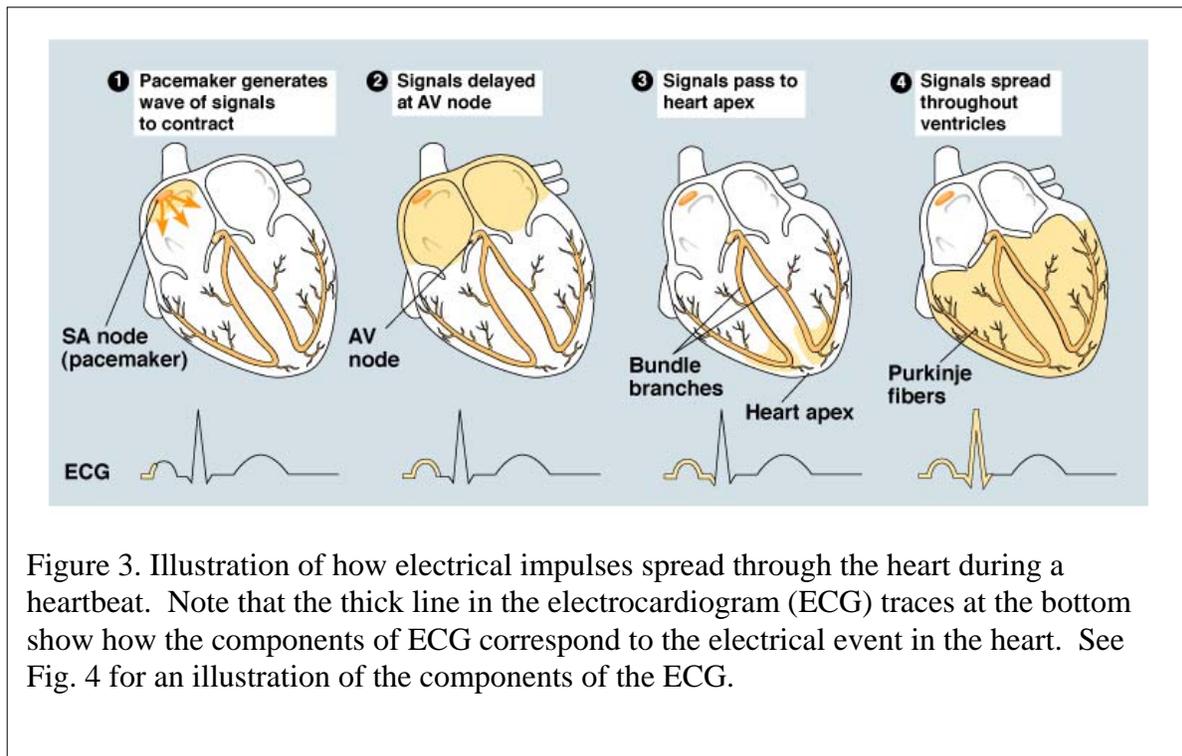


The function of the heart is to pump blood throughout the body. The right side of the heart (i.e., the right atrium and right ventricle) delivers blood to the lungs, and the left side of the heart (i.e., the left atrium and left ventricle) delivers blood to the rest of the body. This pumping activity is controlled and powered by three types of cells:

Pacemaker cells provide the rhythmic pattern of electrical impulses that initiates each contraction of the heart; they are in the **sinoatrial (SA)** and the **atrioventricular (AV)** nodes of the heart (see Fig. 3). Because the pacemaker cells in the SA node have the highest intrinsic rate of beating, they determine the beating rate of all other cardiac cells within the heart.

Conducting cells form a pathway that conducts electrical impulses from the SA node throughout the heart along a precise and predictable course (see Fig. 3).

Myocardial cells constitute 99% of the heart's mass, and are responsible for generating the force required to pump blood to the lungs and throughout the body



EXERCISE 2: CARDIAC PHYSIOLOGY

One of the distinguishing features of all of these heart cells is that they display a property called **autorhythmicity**—that is, they beat spontaneously in the absence of input from the central nervous system (CNS). It is important to remember, however, that even though cardiac cells beat without nervous input, the central nervous system nevertheless directly modulates the pacemaker cells within the SA and AV nodes, causing them to beat more quickly or more slowly.

Before we launch into more details, let's take a step backwards and think about the big picture (see Fig 3). The electrical impulses that initiate a heartbeat begin in the SA node. From there, they spread through the myocardial cells in the atrial muscle, causing them to contract. Once the electrical impulses reach the AV node, their ability to move into the ventricles is impeded by cells with a relatively high resistance to electrical impulses. This “delay” gives the atria time to contract fully and move almost all of the blood into the ventricles. After leaving the AV node, the electrical impulses spread throughout the ventricles, causing them to contract forcefully and drive blood both into the lungs and throughout the body; this phase is called ventricular **systole**. Immediately after ventricular systole, the ventricles start to relax; this final phase is called ventricular **diastole**.

The electrocardiogram (ECG)

You can record the electrical activity of the heart as it completes each beat. This recording procedure involves placing a pair of sensitive receivers (called **electrodes**) on the skin of each ankle and a third electrode on the skin of the right wrist. Then, after connecting the electrodes to a specialized computer system, you can observe the echoes of the heart's electrical activity—i.e., electrocardiograms (ECGs; see Fig. 4). Each ECG represents the summed electrical activity of all heart cells during a single heartbeat. Physicians use ECG recordings to study the timing and nature of the heart's pumping activity.

Parenthetically, you might wonder why we record electrical activity of the heart from the ankles and wrist. The simple answer is that they are convenient (and accessible) sites for recording the cardiac cycle. The reason that these remote locations work is that the total electrical signal generated by the heart is relatively large and thus radiates throughout all tissues of the body.

The ECG is divided into 4 sections:

- The **baseline** (isoelectric line) is a straight line on the ECG that is the point of departure for the electrical activity during the cardiac cycles.
- The **P wave** reflects the electrical impulses as they move through the atria, from the SA node to the AV node, which leads to atrial contraction (**systole**)
- The **QRS complex** reflects the movement of electrical impulses through the ventricles, which leads to ventricular contraction (**systole**).
- The **T wave** reflects the beginning of ventricular relaxation (**diastole**).

The atria also relax, but the electrical signal from atrial repolarization is hidden by the larger electrical signal of the QRS complex.

Note: it is likely that the shape of each subject's ECG will differ markedly from the ideal one presented on the next page. Thus, subjects should not become concerned if the shape of their ECG differs from the one depicted in Fig. 4—ECG shape depends on the configuration of the surface electrodes and the type of recording equipment.

The time interval from the beginning of one heartbeat and the beginning of the next heartbeat is called the **cardiac cycle** (e.g., from one P wave complex to the next P wave). You can use this time interval to estimate the subject's heart rate—simply divide the duration of the cardiac cycle (in seconds) into 60 sec. You can also measure heart rate by listening to the chest with a stethoscope.

Because the ECG reflects changes in electrical activity within the heart, it provides a useful “picture” of heart activity. Any deviations in the normal ECG pattern can help physicians diagnose cardiac problems.

In this exercise, you will record ECGs from one of your classmates as she is sitting, resting lying down, and after she has completed a brief period of exercise. Your experimental objectives are:

- (a) to identify the P, QRS, T waves of the sitting subject's ECG;
- (b) to develop and test hypotheses concerning how the shape, magnitude, and frequency of the cardiac cycle will change while resting and after exercise;
- (c) to determine heart rate under two conditions: after lying down for 5 min and after exercise.

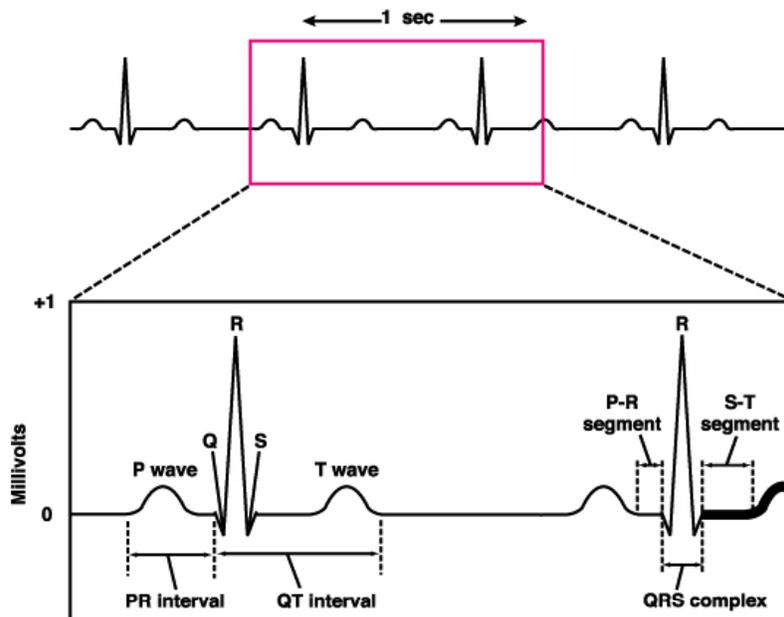


Fig. 4. The electrocardiogram (ECG). The ECG is divided into waves (P, Q, R, S, and T), segments between waves, and intervals that include waves. The cardiac cycle can be determined by measuring the amount of time that elapsed between two waves (e.g., two R waves). The label on the Y-axis of the lower graph (millivolts) is a measure of the amount of the electrical activity in the heart at any given point during the cardiac cycle. The X-axis will be time in seconds.

Procedure (perform this part of the lab in groups of 4)

Electrode placement

- Your first task is to attach 3 surface electrodes, and their associated leads, to the subject. **NOTE THAT ELECTRICITY WILL BE GOING FROM THE BODY TO THE COMPUTER, NOT THE OTHER WAY AROUND. THIS PROCEDURE IS VERY SAFE AND CARRIES NO RISK OF INJURY FROM ELECTRICITY.**
- Ask the subject to sit down on a chair near the recording equipment.
- Clean the subject's right wrist and both ankles with an alcohol pad where the electrodes will be attached. This will ensure good contact between the electrode and the skin.
- Attach one electrode to the medial surface of each leg, just above the ankle, and the third electrode to the inside of the right wrist (see Fig. 5 for details).
- Clip the 3 leads (via the pinch connectors) onto each of the surface electrodes as shown in Fig. 5. The pinch connectors on the leads work like a small clothespin, but will only latch onto the nipple of the electrode from one side of the connector.

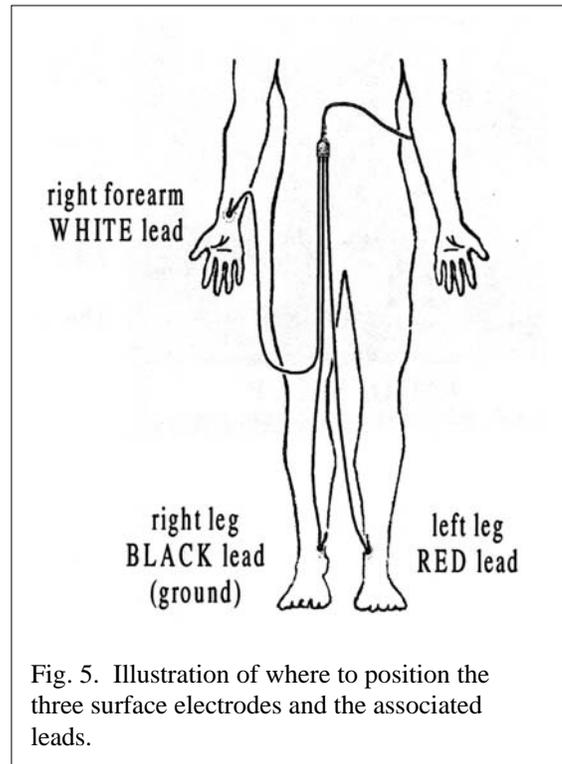


Fig. 5. Illustration of where to position the three surface electrodes and the associated leads.

Turning on and calibrating the EMG analysis program

Now direct your attention to the computer. Click on the desktop icon labeled “ECG Activity I and EMG Activity I.” A menu will appear asking you to select among several lessons. Select the lesson titled “LO5-ECG-1” and click “ok.” If you wish, type in the name of the subject in the box that appears (this is not necessary for the program to work). Next, a screen will appear with an empty window filling the top 2/3 of the screen.

At the top left of the window, you should see a button labeled CALIBRATE. Before clicking this button, you need to make sure that the subject is relaxed and sitting as still as possible, with her palms turned upward and resting on her knees. Because the ECG device is extremely sensitive to small changes in voltage caused by contraction of the skeletal muscles, it will be corrupted by any movement of the arms or legs and by laughing or talking.

Now you are ready to run the calibration procedure, which establishes the recording device's internal parameters (e.g., gain, offset and scaling) and is critical for optimum performance. All you need to do is click the CALIBRATE button and wait 8 seconds. You should see a horizontal line move across the computer screen with small blips every half second or so. If the horizontal line shows any large spikes, jitter, or baseline drifts, then you should redo the calibration by clicking on the REDO CALIBRATION button and repeating the entire calibration sequence. It is quite likely that you will need to redo the calibration at least once.

Once the calibration is completed, you will be ready to run the experiment. Your goal is to estimate the subject's heart rate under 3 conditions:

- while sitting in a chair
- after lying down for 5 minutes in a supine (flat) position
- after 2 minutes of jumping jacks

Data collection and hypothesis generation

1. Sitting condition: Ask the subject to sit down in a chair and attach three leads attached to the correct electrodes (see Fig. 5). Then, click on the **RECORD** button. Halt the recording process **10** seconds later by clicking on the **SUSPEND** button.

Note: For this and all subsequent tests, you will need to redo the recording if

- (i) the SUSPEND button was pressed prematurely;*
- (ii) an electrode became detached from the subject, causing a large baseline drift, spikes, or loss of signal; or*
- (iii) the subject has too much muscle artifact.*

If any of these problems occur, then you should redo the recording by clicking on REDO and repeating the recording. Note that once you press REDO, the data you have recorded will be erased.

Hypothesis generation: You have now generated a record of the cardiac cycle of a seated subject. What do you hypothesize will happen to your subject's cardiac cycle after resting or after exercise? As a group, develop a hypothesis about how the shape, magnitude, and frequency of the ECG will change after exercise.

Record your thoughts in Worksheet 2. Explain the reasoning behind your prediction. Then move on to the next section of the lab "Exercise condition" in which you will gather data in order to determine if your hypothesis is correct. When you are finished, return to the "Cardiac Cycle Hypothesis Worksheet" and explain whether your hypothesis was supported by your data or not. PLEASE note that you can NEVER "PROVE" a hypothesis. NEVER, EVER. Your data can support a hypothesis or not, but NEVER use the word "prove."

2. Rested condition: Ask the subject to lie on her back for 5 min with the three leads attached to the correct electrodes. Then after the five minutes and while the subject is still lying down, click on the RESUME button. Halt the recording process 10 sec later by clicking on the SUSPEND button.

3. Exercised condition: Remove the leads from the subject, and ask her to do jumping jacks for 2 min, or until she feels a bit out-of-breath. Then, have the subject sit back down in the chair, replace the electrodes as *quickly as possible*, and click on the RESUME button. Halt the recording 10 sec later by clicking on the SUSPEND button. Then, click on the DONE button and let the computer know that Yes, you are sure you are finished.

Finally, remove the leads from your subject, peel off the electrodes (and dispose of them), and then wash the electrode residue off the subject's skin with soap and water.

Method for analyzing ECG records

Select "Analyze current data file" to analyze your findings.

To select the parameters you will measure, click on the little box that says "none" next to the first number in the top left hand side of the screen. Select "p-p" from the drop-down menu. *What does "p-p" represent on the graph?* The box to the right of "p-p" will display these values. From the second "none" box, select "delta T" from the drop-down menu? *What does "delta T" represent on the graph?* The box to the right of "delta T" will display these values.

Click on the small icon that looks like an "I" (with curved tops and bottoms) on the lower right end of the graph. Using your cursor, trace each cycle of on your graph, beginning at the far left side with cycle 1. Using Worksheet 3, record "p-p" and "delta T" for each of the 10 cycles for a) sitting; b) resting; and c) after exercising. This is the data you will use to test your hypotheses.

To trace each cycle, hold the left mouse button down while you move the cursor over the desired part of the cycle. Release the button when you are finished. It is not crucial where you begin and end your tracings, but you **MUST BE CONSISTENT**. If you start your trace at the top of the P wave, you should stop your trace just before the top of the next P wave. Begin the second tracing at the same point in the second cycle as you did for the first.

To print an ECG sample, click on any numbered value on the x-axis (seconds). For the sitting ECG, change the scale range to upper: 2.00 seconds and lower: 7.00 seconds. Next, go to "print" in the drop-down menu under "File." Next, click on the "setup" button, change the page setup from portrait to landscape, and click ok. Then, print 4 copies (one for each member of your group).

For the rested ECG, change the scale range to maybe 12.00-17.00 seconds (or some other time period during the rested measurements), and print as before.

For the exercised ECG, change the scale range to maybe 22.00-27.00 seconds (or some other time period during the post-exercise measurements), and print as before.

Printing summary:

Print five cycles each of : 1) sitting (~seconds 2.00-7.00)
 2) rested (~seconds 12.00-17.00)
 3) exercised (~seconds 22.00-37.00)

Change scale range to sitting.

Select Print from File menu.

 Select graph.

 Select set-up.

 Select landscape.

 Select OK.

 Select 4 copies to print.

 Select OK.

Change scale range from sitting to rested and print.

Change scale range from rested to exercised and print.

When your group is finished:

Select Quit from the File menu. You will be prompted to save changes, but

**DO NOT SAVE CHANGES TO THE
PROGRAM!!!!**

EXERCISE 3: BLOOD VESSEL HISTOLOGY

You should complete Worksheet 4 individually, and by the end of today's lab you should be able to recognize several gross features of **arteries** and **veins** that allow you to distinguish between the two. It is helpful to understand how both structures are organized.

Three layers, or tunica, form the structure of the vein and artery. They are

- (1) the **tunica interna**, which is the innermost lining adjacent to the lumen;
- (2) the **tunica intermedia** composed of connective tissue and some amount of smooth muscle; and
- (3) the **tunica externa**, a thick layer of connective tissue.

Figure 6. Photomicrograph of artery and vein.



In both arteries and veins, blood flows through the hollow core (**lumen**) of the vessels. In both, the **tunica interna** is comprised of a lining of **simple squamous epithelial cells**. The epithelial cells lining the interior of the vessels are extremely thin and flat. *Why is this functionally important?*

The **tunica intermedia** of an artery consists of a layer of elastic connective tissue, which allows the artery to expand when necessary, surrounded by a layer of the smooth muscle, which allows the artery to constrict. The **tunica intermedia** of a vein also has a layer of elastic tissue and a layer of smooth muscle tissue, but the layer of smooth muscle tissue is generally much thinner than in an artery.

The difference in the thickness of the smooth muscle tissue layer is because arteries receive blood pumped directly by the heart, so that there is usually enough pressure in the arteries to move blood through the arteries and arterioles. Sometimes however, the arteries need a boost to increase the blood pressure and force the blood through, so that a larger layer of smooth muscle is needed. The blood pressure in capillaries is low, and from there, the blood moves into the venous system, where there is essentially no blood pressure.

Blood moves through veins not because of direct pressure from the pumping heart, but as a result of the contraction of skeletal muscles.

As you move, the skeletal muscle movements provide a kneading action to squeeze blood through the veins a little bit at a time. The **valves** present in the veins prevent the blood from moving backwards. The valves open in the direction that the blood is moving, and then close when the blood passes through to keep blood moving toward the heart. All veins in the body lead to the **superior vena cava** or to the **inferior vena cava**.

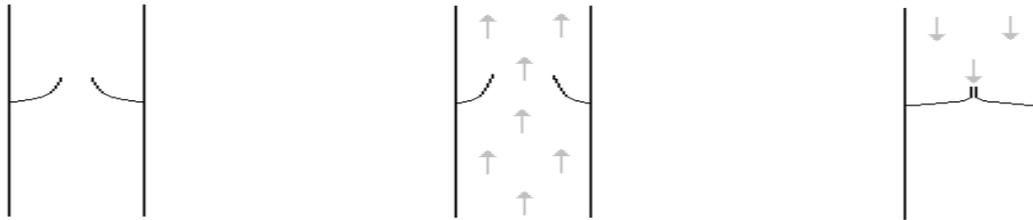


Figure 7. Valves keep blood moving in the correct direction in veins (towards the heart).

The problem of getting blood back to the heart is most difficult in your legs when you are standing up. The blood in the veins is working against gravity to get back up to the heart. There is plenty of skeletal muscle help when you are walking, but when you are standing still for a long period of time, the blood does have trouble getting back up. If the valves (particularly in the leg where they work the hardest) begin to fail, then blood moves backwards in the veins and begins to pool—this can cause pressure to build up on the walls of the vessels, which can lead the veins to stretch out, lose their elasticity, and bulge (this is what causes varicose veins—those big, blue, bulging veins that 70% of you are likely to develop when you are over 60).

In summary, there are two major structural differences between veins and arteries.

- Only veins have **valves** (*why do veins need valves whereas arteries do not?*), and you or one of your classmates may be able to see valves when viewing a microscopic cross-section of a vein (although this is quite unlikely because the valves are widely spaced and the cross-sections are very thin). If you follow the instructions given during recitation, you can probably pinpoint the location of a valve in a vein on the back of your hand.
- The tunica intermedia of an artery includes a thicker layer of **smooth muscle**, compared to the tunica intermedia of a vein. As a result, arteries appear to be more open and circular while the veins look collapsed.

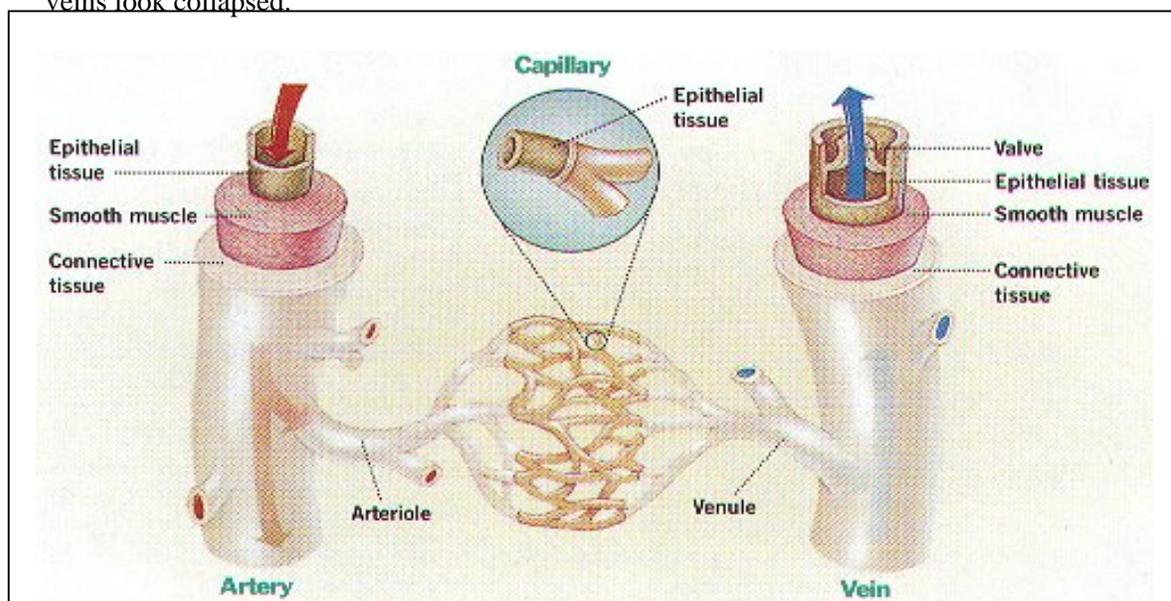


Figure 8. Comparison of the structure of arteries, veins, and capillaries.

Assignments (due at the beginning of next week's lab)

As a group (you only need to turn in one per group):

- 1. A completed Cardiac Cycle Hypothesis and Data Analysis Worksheet (Worksheet 2).**
 - 2. A completed ECG Data Collection Worksheet (Worksheet 3). Attach the three types of ECG printouts recorded; you only need to print out about 3-4 different cardiac cycles for each. There is no need to print out all ten. Be sure to note the conditions under which you captured each ECG.**
 - 3. On one of these printouts, label: (a) the P, QRS, and T waves; (b) the period of ventricular diastole; and (c) concisely state what happens to the heart at each stage of the cardiac cycle.**
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As an individual (make sure to answer questions in your own words):

- 4. A completed Worksheet 1: anatomy and physiology of the heart**
- 5. A completed Worksheet 4: vein and artery histology**

Name _____ Lab day/time/instructor _____
BC1002 _____ Spring semester 2005

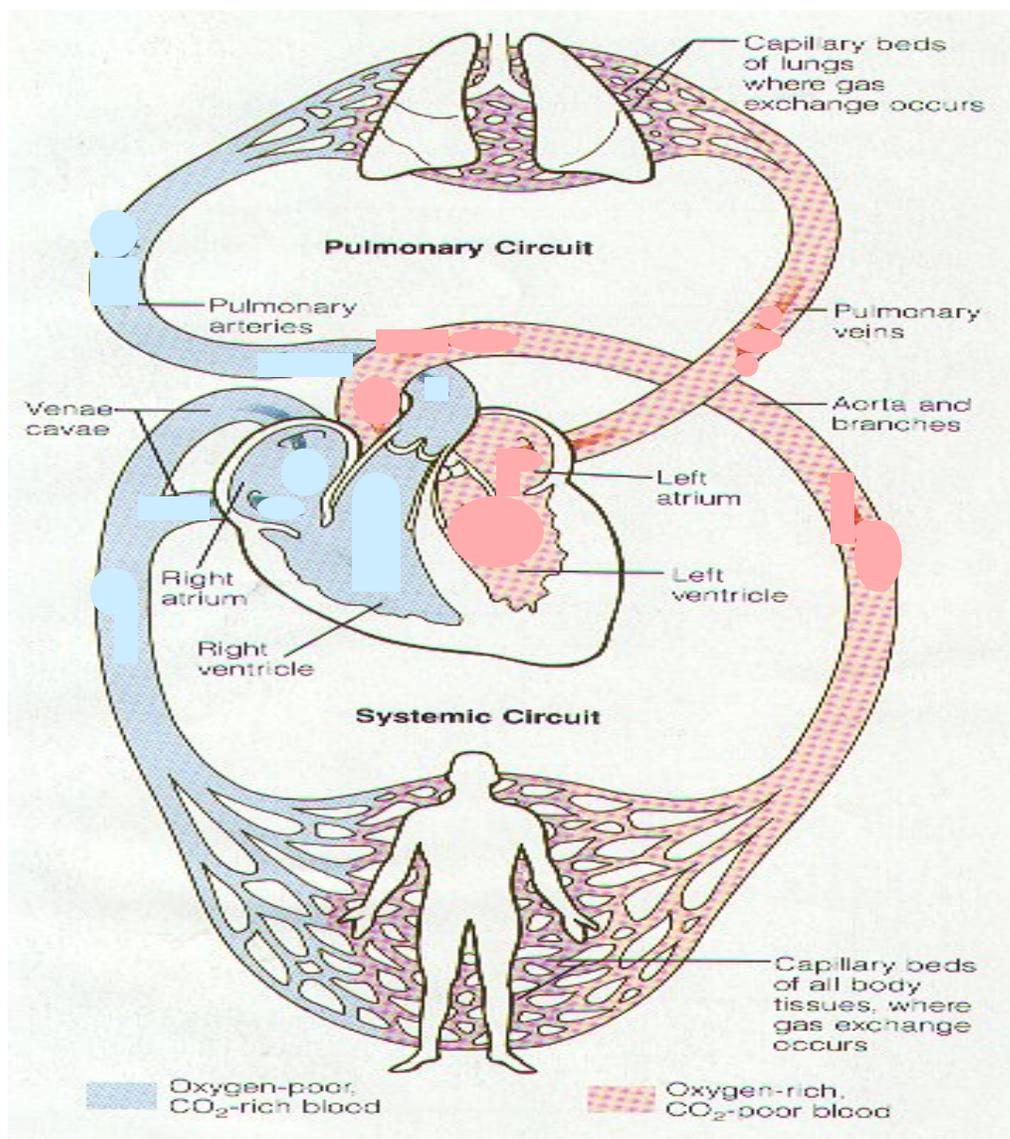
Module 1, Lab 2 Worksheet 1: Heart anatomy and physiology

Structure:	Function:
Right Ventricle	
Left Ventricle	
Right Atrium	
Left Atrium	
Aorta	
Pulmonary Artery	
Pulmonary Veins	

Module 1, Lab 2 Worksheet 1 continued: Heart anatomy and physiology

Draw numbered arrows on the diagram to indicate the flow of blood for each of the following. Also, color the oxygenated blood red and the deoxygenated blue (using the colored pencils).

- 1) from superior and inferior vena cava to right atrium
- 2) from right atrium to right ventricle
- 3) from right ventricle to pulmonary artery
- 4) from pulmonary artery to pulmonary circuit (lungs)
- 5) from pulmonary circuit to pulmonary veins
- 6) from pulmonary veins to left atrium
- 7) from left atrium to _____
- 8) from _____ to systemic circuit



Group members _____

Lab day/time/instructor _____

BC1002

Spring semester 2005

Module 1, Lab 2, Worksheet 2: Cardiac cycle hypothesis and data analysis worksheet

A. Hypothesis: How will the frequency, height, and shape of the ECG change after resting?
Explain the reasoning behind your hypothesis.

B. Observation: What happened to the frequency, height, and shape of the ECG after resting?
(You'll need to complete Worksheet 3 before you can answer this question.) Attach a copy of
the ECG printouts (your data) to this worksheet.

C. Explanation: Did your data support your hypothesis? Explain.

D. Hypothesis: How will the frequency, height, and shape of the ECG change after exercise?
Explain the reasoning behind your hypothesis.

E. Observation: What happened to the frequency, height, and shape of the ECG after exercise?
(You'll need to complete Worksheet 3 before you can answer this question.) Attach a copy of the ECG printouts (your data) to this worksheet.

F. Explanation: Did your data support your hypothesis? Explain.

Group members _____
 Lab day/time/instructor _____
 BC1002 Spring semester 2005

M1: LAB 2, WORKSHEET 3: ECG DATA COLLECTION WORKSHEET

A. Record ECGs under three experimental conditions (sitting, rested, and exercised). Record the duration of the cardiac cycle (ΔT) and the maximum peak in the QRS wave (P-P). Record each variable for 10 cardiac cycles. For cycle duration and maximum peak, calculate the average for each variable.

SITTING (UNRESTED)	ΔT	P-P
Cycle 1		
Cycle 2		
Cycle 3		
Cycle 4		
Cycle 5		
Cycle 6		
Cycle 7		
Cycle 8		
Cycle 9		
Cycle 10		
Mean		
SUPINE (RESTING)	ΔT	P-P
Cycle 1		
Cycle 2		
Cycle 3		
Cycle 4		
Cycle 5		
Cycle 6		
Cycle 7		
Cycle 8		
Cycle 9		
Cycle 10		
Mean		
EXERCISE	ΔT	P-P
Cycle 1		
Cycle 2		
Cycle 3		
Cycle 4		
Cycle 5		
Cycle 6		
Cycle 7		
Cycle 8		
Cycle 9		
Cycle 10		
Mean		

When you have completed this table, use your data to finish answering the questions on Worksheet 2.

Name _____ Day/Time/Instructor _____

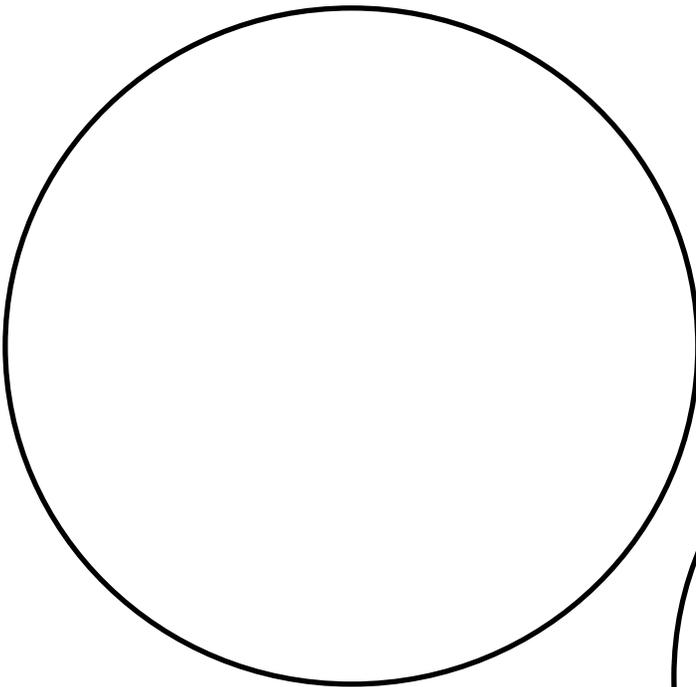
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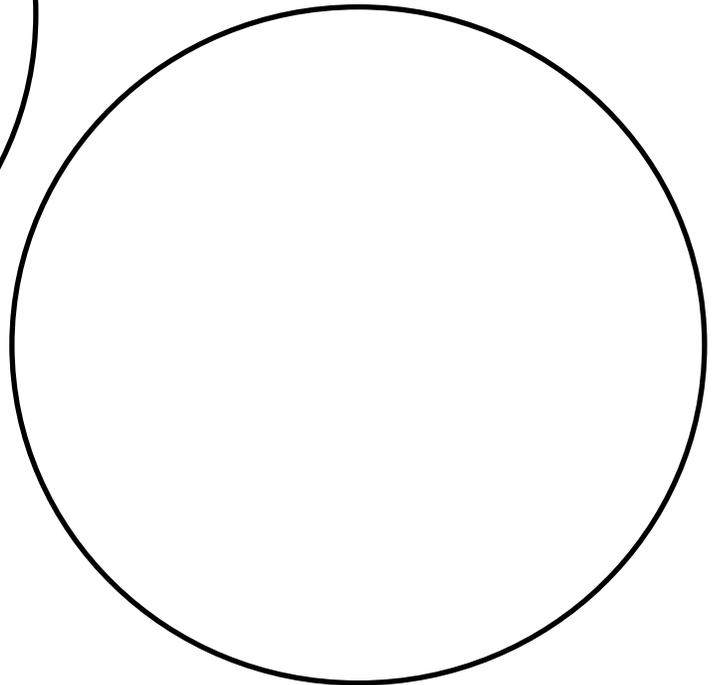
MODULE 1: LAB 2, WORKSHEET 4: VEIN AND ARTERY HISTOLOGY

Examine cross section slides of vein and artery tissue. Be sure you are able to differentiate a vein from an artery in cross section. What gross features allow you to do this?

Make sketches of each specimen and, as appropriate, label the following structures: lumen, tunica interna, tunica media, tunica externa, and valve (if present). Label the following tissues: squamous epithelium, smooth muscle, and connective tissue (made of elastin and collagen).



Vein
Total Magnification_____



Artery
Total Magnification_____