Part 1: The Electrocardiogram

Background

The cardiac cycle involves a sequential contraction of the atria and the ventricles. The combined electrical activity of the different myocardial cells produces electrical currents that spread through the body fluids.

These currents are large and can be detected by recording electrodes placed on the skin. In this lab you will attach three electrodes to a student volunteer. These electrodes will be connected to the iWorx unit and the signal will be displayed on the computer screen in a strip chart format. The regular pattern of "peaks" produced by each heart beat cycle is called the electrocardiogram or ECG (Figure 1).
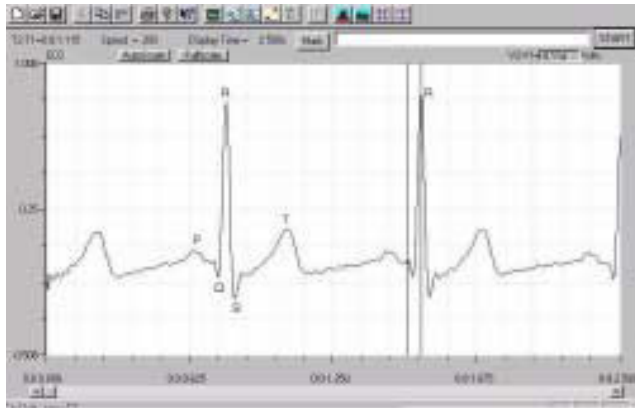

Figure 1: ECG trace in the Main window with labels showing the P, QRS and T waves.

The action potentials recorded from atrial and ventricular fibers are different from those of nerves and skeletal muscle. The cardiac action potential is composed of three phases: a rapid depolarization, a plateau (which is pronounced in ventricular fibers), and a repolarization back to resting membrane potential. The components of the ECG (Figure 1) can be correlated with the electrical activity of the atrial and ventricular fibers such that:
• Atrial depolarization produces the P wave.
• Atrial repolarization and ventricular depolarization produce the QRS complex.
• Ventricular repolarization produces the T wave.
In this lab you will record the ECG from a volunteer and listen to the characteristic "lub-dub" heart sounds.

Contraction/relaxation (mechanical event) follows the action potential (electrical event), and this causes changes in pressure in the heart chambers. Changes in pressure cause changes in the valve positions (open/closed)

The "lub" sound occurs during the early phase of ventricular contraction and is produced by closing of the atrioventricular valves, which prevents blood flow into the atria. When the ventricles relax, the pressure drops below that in the artery and the semilunar valves close, producing the "dub" sound.

Equipment Required
PC Computer
iWorx unit, and USB or serial cable
AAMI cable and three ECG leads
Alcohol swabs
Stethoscope

Equipment Setup
1 Connect the iWorx unit to the computer

2 The volunteer should remove all jewelry from their wrists and ankles.

3 Use an alcohol swab to clean and scrub a region of each wrist that has little or no hair. Let the area dry.

4 Remove the plastic disk from a disposable electrode and apply the electrode to the scrubbed area on one wrist. Repeat for the other wrist and the right ankle.
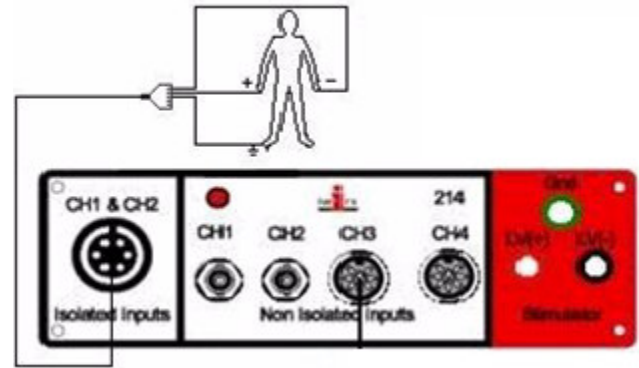

Figure 2: The equipment used to measure the ECG from a volunteer.

5 Attach the AAMI connector on the end of the gray patient cable to the isolated Channel 1 & 2 inputs of the iWorx unit (Figure 2).

6 Attach three color-coded electrode cables to the ground and Channel 1 inputs on the lead pedestal and snap the other ends onto the disposable electrodes, so that:
• the red "-1" lead is attached to the right wrist,
• the black "+1" lead is connected to the left wrist,
• the green "C" lead (the ground) is connected to the right leg.

7 The volunteer should sit quietly with their hands in their lap.

Start the Software
1 Click on the LabScribe icon on the Desktop

2 Click on the **Settings** menu again and select the **ECGHeart Sounds** settings file.

3 After a short time, LabScribe will appear on the computer screen as configured by the **ECG-Heart Sounds** settings. A pdf file will automatically open as well. Close this file.

Exercise 1: The ECG in a Resting Volunteer
Aim: To measure the ECG in resting individuals.

Procedure
1 Click **Start**, and then click **AutoScale** in the Channel 1 title area; see the rhythmic ECG signal (Figure 1). If the trace is upside down (R wave goes down), click **Stop** and switch the positive and negative electrodes. If a larger signal is needed, the electrodes should be moved from the wrists to the skin immediately below each clavicle.

2 When you have a suitable trace, type "XYZ's lead I" (where XYZ is the volunteer's name) in the comment line to the right of the **Mark** button. Press the **Enter** key on the keyboard to attach the comment to the data.

3 Click **Stop** to halt recording. Your data may look like Fig 1.

4 Switch the electrodes so that the right arm is connected to the "black" and the left leg is to the "red".

5 Click **Start** to begin recording.

6 When you have a suitable trace, type "XYZ's Lead II" in the comment line to the right of the Mark button. Press the Enter key on the keyboard to attach the comment to the data.

7 Click **Stop** to halt the recording.

8 Finally, switch the electrodes so that the left arm is connected to the "black" and the left leg to the "red".

9 When you have a suitable trace, type "XYZ's Lead III" in the comment line to the right of the **Mark** button. Press the **Enter** key on the keyboard to attach the comment to the data. Select **Save As** in the **File** menu, type a name for the file.

Data Analysis
1 Click the **2-Cursor** icon (Figure 3) so that two blue vertical lines appear over the recording window of lead I.

Figure 3: The LabScribe toolbar.

2 Drag the lines left and right so that four complete heart beat cycles are located between the two blue lines.

3 Click the **Analysis** icon (Figure 3) to open the **Analysis** window.

4 Display only the ECG trace by clicking and deselecting Channels 2 and 3 in **Display Channel** list, on the left side of the **Analysis** window.

5 Use the mouse to click and drag the cursors around the **Analysis** window to measure:
• the amplitude (V2-V1 from Q to R) of a QRS complexe (Figure 1).
• the amplitude (V2-V1 from base to peak) of a P waves.
• the amplitude (V2-V1 from base to peak) of a T waves.
• the time interval (T2-T1) between four adjacent R waves (Figure 4); you should have three values.

6 For the calculation of electrical axis of the heart (Part 5 below), use the mouse to click and drag the cursors around the **Analysis** window to measure (see Fig 11) and then average:
• the amplitude (V2-V1 from base to *peak*) of a QRS wave.
• the amplitude (V2-V1 from base to *trough*) of a QRS wave.
• repeat this for each lead, I, II, and III, and record values.

Remember the **Display Time** can be halved (as in the **Main** window) to expand the horizontal axis and obtain a very accurate time measurement. The trace can be scrolled horizontally using the arrows in the lower margin of the **Analysis** window.
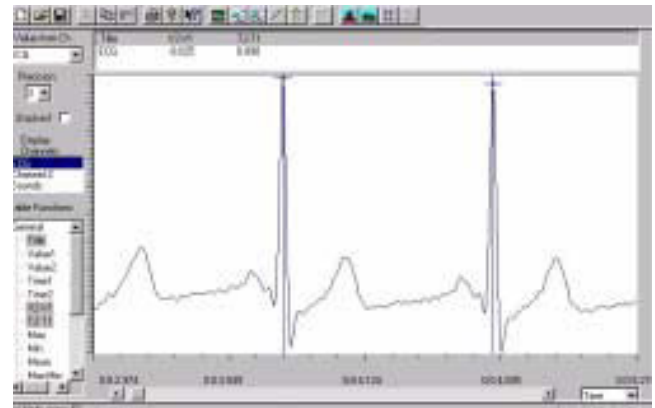

Figure 4: ECG in the Analysis window. The two cursors are positioned to measure the time interval between adjacent QRS complexes – in this example the value (T2-T1) is 0.890s.

6 Data can be entered into the **Journal** by either typing the titles and values directly or by using the **right-click** menu. Place the cursors to take measurements; then, select **Add Title to Journal** or **Add Data to Journal** from the **rightclick** menu to add the measurements to the **Journal.**

7 Calculate the following values and type your results into the **Journal** (use lead I for all measurements unless noted):
• The average amplitude of the P wave, the QRS complex (in lead II), and the T wave.
• The average time interval between adjacent R waves, or beat period, in seconds/beat.
• The heart rate, in beats per minute, is calculated from the equation:

$$\text{Heart Rate (BPM)} = \frac{60 \text{ secs/minute}}{(x \text{ seconds/beat})}$$

Exercise 2: ECG Recordings from Other Students

Aim: To measure heart rate from all students.

Procedure

1 Disconnect the leads from the first volunteer's wrists and ankle and place them on the electrodes of a second student. Record the ECG from the second subject, as described in the procedures section.

2 Repeat until all students have recorded their ECG.

3 MAKE SURE TO KEEP STICKERS ON FOR OTHER EXERCISES!

Data Analysis

Make measurements as outlined in Exercise 1.

Phase of Complex	Duration (sec) (V, mV)
P wave	0.1 (0.2)
QRS complex (lead II)	0.08-0.12 (1)
T wave	0.16-0.27 (0.2-0.3)
PR interval	0.13-0.16
QT interval	0.3-0.34
PR segment	0.03-0.06
ST segment	0.08

Table 1: Normal values for Duration (and V) of different phases of an ECG complex.

Exercise 3: ECG and Exercise

Aim: To determine the effects of exercise on an ECG.

Procedure

1 This test is to be performed by one subject only. Have the subject perform some type of exercise. Immediately afterwards, hook them up to perform an ECG as before on **lead II**.

2 Record an ECG as before.

3 Click Stop to halt the recording

4 Save this file.

Data Analysis

1 Determine the heart rate of the individual after exercise as was done in exercise 1.

Thought Questions

1 How is heart rate affected by exercise?

Exercise 4: ECG and the Diving Reflex

Aim: To determine illustrate the effects of a diving reflex on an ECG.

Procedure

1 This test is to be performed by one subject only. Hook up the student to perform an ECG as before on **lead II**.

2 Have the student lay down on a table.

3 Click **Start** to begin recording.

4 Type "Diving" in the comment line to the right of the Mark button.

5 After 10 seconds of regular recording, place a wet towel over the students face and continue to record for 10 seconds, marking the diving response, and then remove the towel and continue to record for 10 more seconds. Then click **Stop** to halt recording.

Data Analysis

1 Determine the heart rate of the individual after the towel was placed over their head as was done in exercise 1.

Thought Questions

1 How does the divining reflex affect heart rate?

Part 2: Pulse Waves

Background

The walls of large arteries are composed of smooth muscle cells, collagen fibers, and elastin fibers, all embedded in a non-fibrous matrix. The elastin fibers, which are arranged in lamellae or sheets, and the collagen fibers give large arteries the ability to distend and recoil. Because of these elastic properties, the arterial system dampens the dramatic pressure changes created when the ventricle ejects blood into the aorta. As the arteries close to the heart distend with each ventricular contraction, they cushion the rest of the arterial system from the large pressure waves generated by the ventricle (Figure 5). The elastin fibers stretch easily and distribute pressure uniformly across the artery wall, and as the pressure and the diameter of the artery increase, the force is gradually transferred to the more rigid collagen fibers.
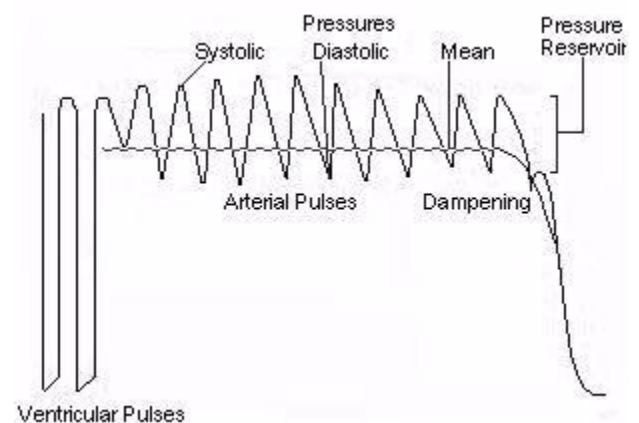

Figure 5: Dampening effect of aorta and large arteries on ventricular pressures due to the elasticity of these vessels.

Large arteries also function as pressure reservoirs; when they are expanded, they store pressure in their walls. Then, the large arteries elastically recoil and release pressure which propels the blood forward into smaller arteries (Figure 6). Even though the large pressure waves generated by the ventricles are truncated by the distension of the aorta and other large arteries, the pulsatile flow of blood still occurs

through smaller arteries and arterioles because of the pulsatile recoil of the larger arteries. Only when the blood reaches the capillaries does the pulsing smooth to a continuous laminar flow. The stiffness of arterial walls is determined by thickness, smooth muscle tone, and age. As humans age, their arteries stiffen, which results in changes in hemodynamics. The lower distensibility or compliance of arterial walls produces a higher systolic pressure, a lower diastolic pressure, a widening of the pulse pressure, stronger pulsatile flow in smaller arteries, and more cardiac work. Compliance is defined as the change is volume in the vessel divided by the change in pressure in the vessel. Aortas in young healthy subjects are more distensible and contain a greater volume of blood at a given systolic pressure than aortas of older or less healthy subjects (Figure 7). With aging, structural changes occur in the arterial wall: elastins fragment and degenerate, collagen increases, walls thicken, and lumens progressively dilate. The rate of stiffening is different for each individual, and it can be used as measures of the aging of the vascular system, the prognosis of systolic hypertension, and the risk of vascular disease (atherosclerosis). Therefore, studying vascular stiffness has become an important part of studying cardiovascular disease.
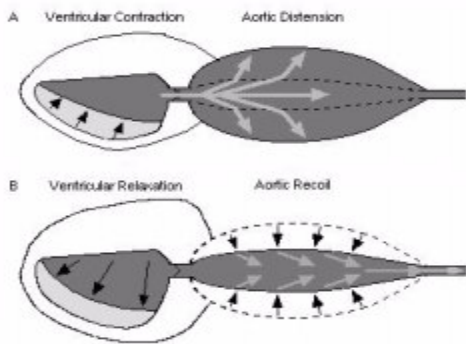

Figure 6: The aorta and arteries expand and store pressure in their elastic walls (A). The elastic recoil of the arteries propels the blood forward through the smaller arteries (B).

Researchers have developed three basic approaches to studying arterial stiffness:
- Using ultrasound to determine the increase in the diameter of the arterial lumen (carotid) during systole.
- Using pattern recognition technology to analyze the pulse pressure signal and identify characteristic changes in that signal which indicate changes in aortic compliance.
- Using pulse wave velocity (PWV) between two points in the arterial system (usually the carotid and femoral arteries) to measure the relative stiffness of the aorta.
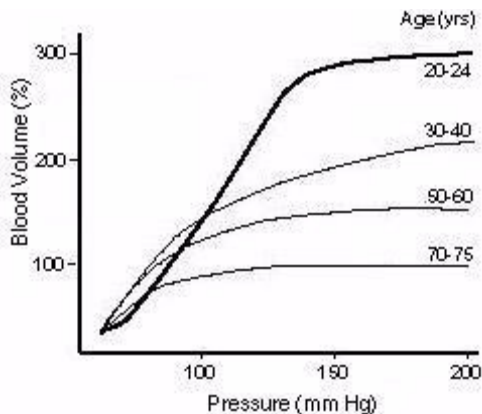

Figure 7: This graph shows how the distended volume of the aorta is a function of filling pressure and age. The slope of each line (age group) is the compliance (C), C = dV/dP.

In this experiment, we will determine the variations on pulse pressure when taken on the wrist as it is at table level, raise and lowered and during the valsalva maneuver, and also at the upper arm.

Equipment Required
PC Computer
iWorx unit, and USB or serial cable
Blood pressure cuff
Plug in extender

Equipment Setup
1 Connect the iWorx unit to the computer.

3 Place the blood pressure cuff on the **lower arm**, toward the wrist.

4 Use the extension cord to extend the transducer connector to the iWorks box and plug into channel 3 (Figure 8).
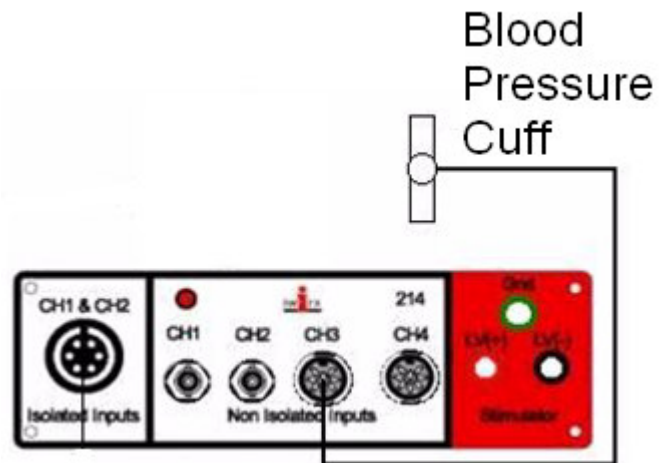

Figure 8: The equipment used to measure an ECG and blood flow from a volunteer.

Start the Software
1 Click on the LabScribe icon on the Desktop.

2 Click on the **Settings** menu again and select the **BloodPressure – Body Position** settings file.

3 After a short time, LabScribe will appear on the computer screen as configured by the **BloodPressure – Body Position** settings. A pdf file will also open and can be closed.

Exercise 1: The Pulse Waves
Aim: To measure the pulse wave velocity in a resting individual with their arm on a table, lowered, raised, on the upper arm, and while performing the valsalva maneuver.

Procedure
1 Have the volunteer to sit quietly with their arm on a table. Pump up the cuff to 100mmHg and click on the start button.

2 Click the **AutoScale** buttons for Channel 3 (**Pulse**), and see the rhythmic signals get bigger. If the pulse wave on Channel 3 (**Pulse**) goes down, use the **Invert** function in the **right-click** menu for Channel 3 to orient the image in the correct direction.

3 When you have a suitable trace, type "Normal" in the comment line to the right of the **Mark** button. Press the **Enter** key on the keyboard to attach the comment to the data. Then click **Stop** to halt recording.

4 Now, have the volunteer lower their arm by their side and make a recording as before.

5 When you have a suitable trace, type "Lowered" in the comment line to the right of the **Mark** button. Press the **Enter** key on the keyboard to attach the comment to the data. Then click **Stop** to halt recording.

6 Now, have the volunteer raise their arm above their head and record as before.

7 When you have a suitable trace, type "Raised" in the comment line to the right of the Mark button. Press the **Enter** key on the keyboard to attach the comment to the data. Then click **Stop** to halt recording.

8 Now, after you hit **Start** on the keyboard, have the student inhale as deeply as possible, hold his/her breath and exert as much internal abdominal pressure as possible (this is called the *valsalva maneuver*).

9 When you have a suitable trace, type "Valsalva" in the comment line to the right of the Mark button. Press the Enter key on the keyboard to attach the comment to the data. Then click **Stop** to halt recording.

10 Select **Save As** in the **File** menu, type a name for the file. Choose a destination on the computer in which to save the file (e.g. the **iWorx** or class folder). Click the **Save** button to save the file (as an ***.iwd** file).

11 Lastly, place the blood pressure cuff on the upper arm of the volunteer.

12 When you have a suitable trace, type "Upper Arm" in the comment line to the right of the Mark button. Press the **Enter** key on the keyboard to attach the comment to the data. Click **Stop** to halt recording.

Data Analysis

1 Go to the section of the recording marked "**Normal**".

2 Click the **2-Cursor** icon (Figure 9) so that two blue vertical lines appear over the recording window.

Figure 9: The LabScribe toolbar.

3 Drag the cursors left and right so that three complete pulse wave cycles are located between the two blue lines.

4 Click the **Analysis** icon (Figure 9) to open the **Analysis** window.

5 Display the **Pulse** (CH 3) by clicking and deselecting Channels 1 & 2 in **Display Channel** list, on the left side of the **Analysis** window.

6 Use the mouse to click and drag one cursor to the peak of one pulse wave and the second cursor to the peak (Figure 10) the next pulse wave on the **Pulse** channel (CH 3). Measure the time difference (**T2-T1**) between these two cursors.

7 Use the mouse to then click and drag one cursor to the start of the pulse wave and the second cursor to the peak of the pulse wave and measure the height different **(V2-V1)** between these two cursors (Figure 10).

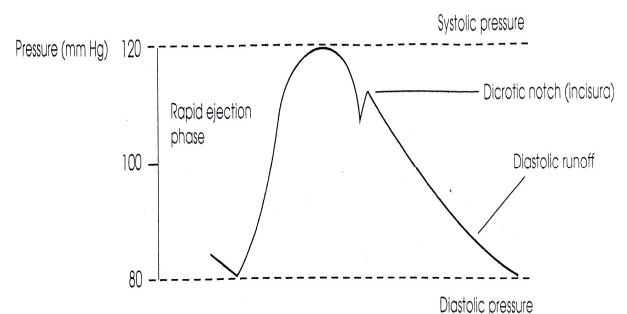**8** Repeat these measurements for the **lowered, raised, valsalva,** and **upper arm** recordings.

Figure 10: A typical arterial pulse wave.

Part 3: Blood Pressure

Background

The ventricles contract to push blood into the arterial system and then relax to fill with blood before pumping once more. This intermittent ejection of blood into the arteries is balanced by a constant loss of blood from the arterial system through the capillaries. When the heart pushes blood into the arteries there is a sudden increase in pressure, which slowly declines until the heart contracts again. Thus, the pressure in the arteries varies during the cardiac cycle, being at its highest level immediately after the ventricle contracts (systolic pressure) and at its lowest level immediately prior to the pumping of blood into the arteries (diastolic pressure). These two values for blood pressure are traditionally measured by a trained nurse using a stethoscope and a sphygmomanometer (blood pressure cuff). The cuff is placed on the upper left arm and inflated to stop arterial blood flow to the arm—the cuff creates a high pressure, which causes the arteries to collapse. The

pressure in the cuff is released and, when the systolic pressure in the arteries is greater than in the cuff, blood flows momentarily to the arm through the partially collapsed artery—this is heard through the stethoscope and the systolic pressure is noted from the pressure gauge on the cuff. When cuff pressure declines to the diastolic pressure the sound heard through the stethoscope changes and this pressure value is noted. Measuring blood pressure using a blood pressure cuff and a stethoscope takes a great deal of practice. In addition to measuring the blood pressure from all willing participants, the effects of cooling the arm, and body position will be examined. *Warning: As explained above, this procedure involves stopping blood flow to the arm, which is potentially dangerous. Please take the following precautions:*

1 Know what you are doing ahead of time.

2 Do not leave the cuff inflated for any prolonged period of time (>30 seconds).

3 The volunteer should flex and extend their fingers between experiments to maintain blood flow.

4 This experiment should be performed by healthy individuals who do not have a personal or family history of cardiovascular or respiratory problems. If possible, use more than one volunteer during the course of the lab session.

Exercise 1: Taking Blood Pressure
Aim: To learn how to take blood pressure, what the blood is doing in the arteries during this time and hear Korotkoff sounds.

Procedure
1 Place a blood pressure cuff on the upper arm between the shoulder and the elbow.

2 Place a stethoscope bulb over the brachial artery (noted on cuff). Use your fingers (rather than your thumb) to hold the stethoscope in place.

3 Inflate the cuff to around 160 mmHg- you should hear nothing.

4 Slowly deflate the cuff until you hear the spurting of blood in the artery.   At the onset of this sound, this is your **Systolic Pressure**. The sounds that you hear are calls **Korotkoff Sounds.**

5 Continue to deflate the cuff until the point at which the sound disappears. This is your **Diastolic Pressure**.

6 Repeat this procedure for all members of the lab group.

Exercise 2: Cooling the Forearm
Aim: To measure the effects of cold on blood pressure.

Procedure
1 Take the subject's blood pressure as in exercise 1, 3 times at 2 minute intervals until their blood pressure stabilizes.

2 Then, have the subject place their arm in a bucket of cold water (the arm without the cuff on).

3 Take the blood pressure of the subject as often as possible for the next 60 seconds.

Data Analysis
1 Analyze the recording as was done in experiment 1 to obtain systolic and diastolic blood pressure readings.

Thought Questions
1 What is the effect of cooling on peripheral circulation and blood pressure?

2 Would you expect blood pressure to change during this process? Why or why not?

Exercise 3: Postural effects on Blood pressure
Aim: To measure the effects of posture on blood pressure.

Procedure
1 Measure the blood pressure of one subject when he/she is **lying down** (supine), and **standing.** Make sure to have the subject get into position about 5 minutes before taking his/her blood pressure in order for the body to make appropriate accommodations.

Part 4: Valves in the Veins

Background
A simple, yet classic, experiment by William Harvey performed on the venous valves can be duplicated in class. What will be demonstrated helped Harvey formulate his theory that blood moved in one direction pathway throughout the body.

Procedure
1 Tie a tourniquet around the arm above the elbow.

2 Watch as the veins fill up with blood and notice the location of the valves.

3 Press one finger down firmly on a distal part of a vein. With another finger, massage the blood out of the vein toward the heart by pushing up the vein past the next valve.

4 Remove the fingers and notice the filling of the veins and from which direction.

Part 5: Electrical Axis of the Heart

Background
Ever curious about the position of you heart in your thoracic cavity? By using Einthoven's triangle and law, we can calculate the overall direction and magnitude of the electrical impulses conducted over the heart.

Procedure

1 Find your measurements of the QRS deflections determined in Part 1 (Figure 11).

2 The resultant deflections are plotted on Eithoven's triangle (Figure 12) as vectors, appropriate units being used to represent the V height of each deflection. Each vector is drawn along the side of the triangle corresponding to the lead it represents. The vector is drawn from the center of each side and toward the (+) pole or electrode. If Eithoven's law is valid, perpendicular lines dropped from the point of each vector should meet a single point inside the triangle (there may be a slight deviation – see discussion notes from the end of your lab period). A line drawn from this intersection to the center of the triangle represents the electrical axis of the heart. The position of the axis is measured in degrees from the horizontal line drawn through the center of the triangle (75° in figure 12). The length of the axis vector is a measure of the overall electrical potential of the heart in the axis direction.

3 Calculate your electrical axis as shown Figure 12, add it to the class data sheet, and compare it to the normal.

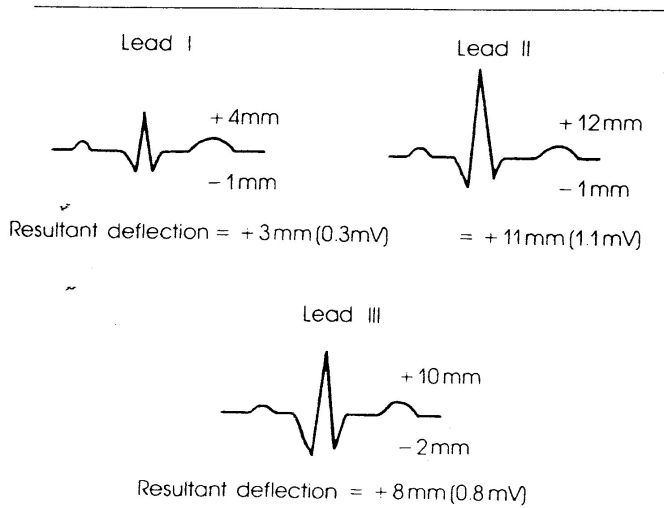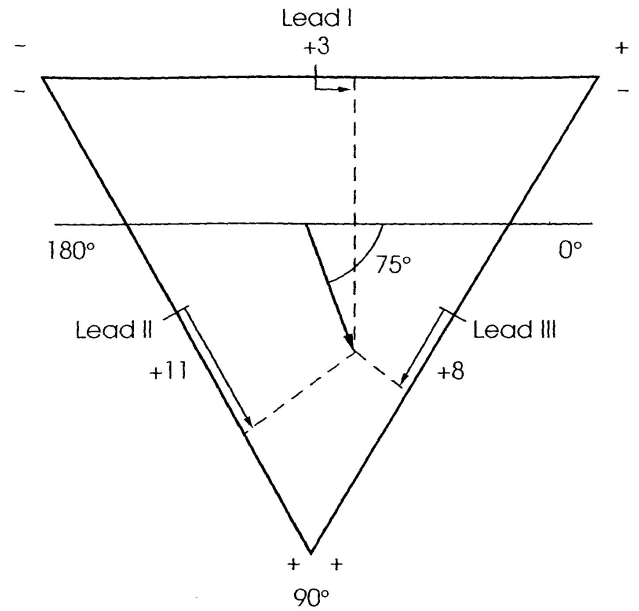Figure 12. Electrical Axis of the heart.

Figure 11. QRS deflections.

Normally, the heart has an electrical axis of 45-90°, with a mean of 59°. What are some things that could cause this number to deviate?