Lab #3: Electrocardiogram (ECG / EKG)

An introduction to the recording and analysis of cardiac activity

Introduction

The beating of the heart is triggered by an electrical signal from the **pacemaker**. The pattern of electrical activity produced by each heart beat cycle is called the **electrocardiogram** or **ECG** (or EKG). One complete heart beat cycle is called a **cardiac cycle** (i.e., the systole, diastole, and the rest until the start of the next systole). The ECG contains several components that precede specific events in the cardiac cycle. Some of the events, such as valve closure, also have corresponding sounds. The aim of this session is to analyze ECGs to study the cardiac cycle, to relate the components of the ECG to **characteristic sounds of the heart**, to study how the heart delivers more blood during **exercise**, and to study the relationship between ECG and **peripheral circulation**.

Background

The 4-chambered heart has two atria and two ventricles, which contract to drive blood throughout the body (Figure 1). Blood enters the atrial chambers of the heart at a low pressure, the atria contract to drive blood into the ventricles, and the thick muscle of the ventricles produce forceful contractions that drive blood out of the ventricles at high pressure. It is this **high arterial pressure** that provides the energy to force blood through the circulatory system.

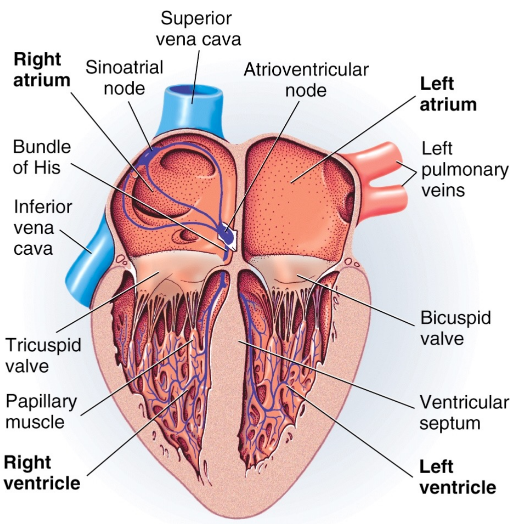

Figure 1. The 4 chambered heart

The 4-chambered heart is a **dual pump**: one circuit pushes blood around the body, and the second circuit through the lungs (Figure 2). Blood returning from the body arrives at the right side of the heart and is pumped through the lungs to pick up oxygen and release carbon dioxide. This oxygenated blood arrives at the left side of the heart, from where it is pumped back to the body.

The **cardiac cycle** involves a sequential contraction of the atria and the ventricles. Unlike other excitable tissues, cardiac contractions are not initiated by a nerve supply from the central nervous system. Instead, the heart generates its own electrical stimuli from a group of weak muscle cells called a **pacemaker** (**sinoatrial** or sinuatrial **node**, **SA node**; Figure 2). These cells rhythmically produce **action potentials** that

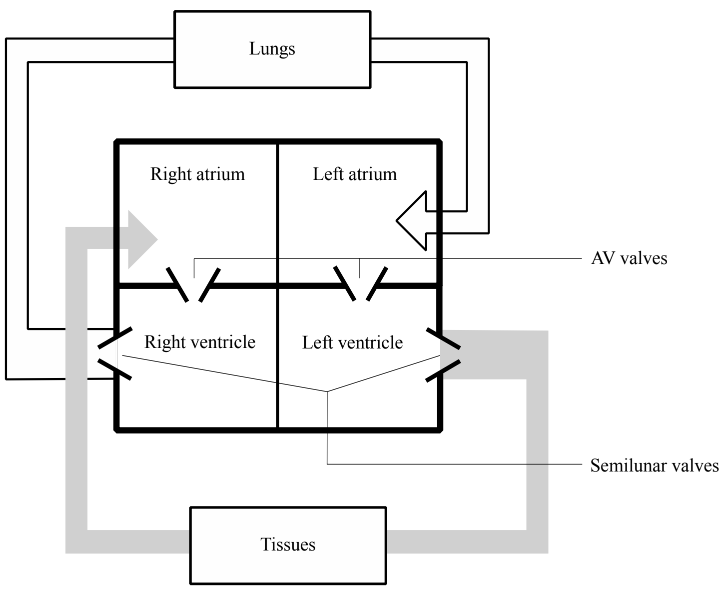

Figure 2. A schematic diagram of the human heart and circulatory system.

spread through the muscle fibers of the atria. The resulting contraction pushes blood into the ventricles. The action potential spreads (relatively) slowly across the atria (allowing a time delay for ventricular filling), until it reaches the **atrioventricular (AV) node** which provides an electrical connection to the ventricles. The AV node is connected to the **AV bundle** and **Purkinje fibers**, which are large muscle fibers specialized to rapidly conduct the electrical impulse and coordinate a simultaneous, powerful ventricular contraction.

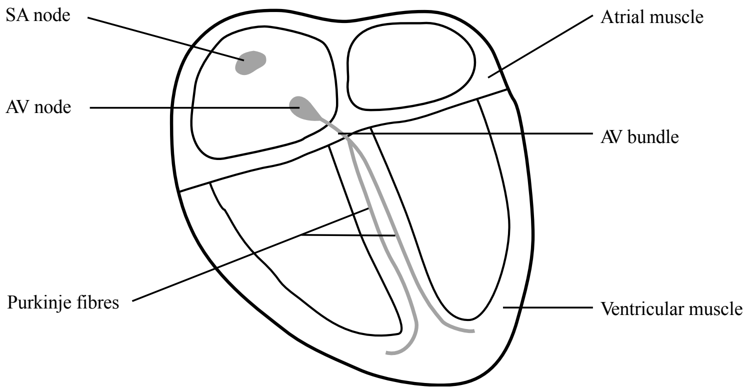

Figure 3. Components of the human heart involved in conduction.

The ECG records the combined electrical activity of the different myocardial cells. The heart produces electrical currents that spread through the body fluids and are large enough to be detected by recording electrodes placed on the skin. The regular pattern of peaks produced by each heart beat cycle is called the electrocardiogram or ECG (Figure 4).

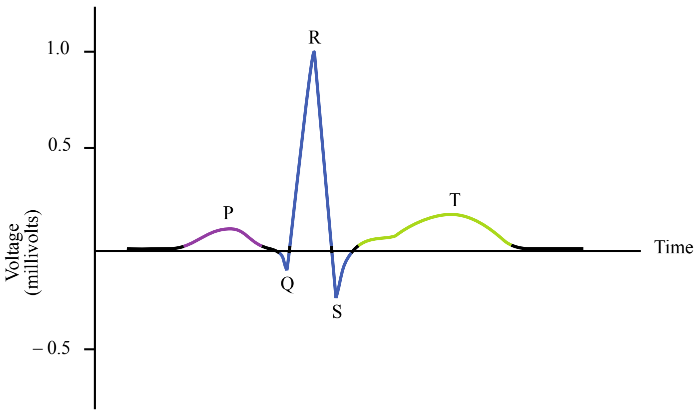

Figure 4. A typical ECG showing the fundamental parts that make up the signal.

The action potentials recorded from atrial and ventricular fibers have a different wave pattern than those recorded from nerves and skeletal muscle. The cardiac action potential is composed of three phases:

- Atrial depolarization (contributes to the **P-wave)**
- Ventricular depolarization/ atrial repolarization at same time (**QRS complex)**
- Ventricular repolarization (**T-wave**).

The characteristic sound produced by the heart is usually referred to as a '**lub-dup**' sound. The lower-pitched '**lub**' sound occurs during the early phase of **ventricular contraction** and is produced by closing of the **atrioventricular valves** (the mitral valve and tricuspid valve), which prevent blood from flowing back into the atria. When the ventricles relax, the blood pressure drops below that in the artery and the **semilunar valves** (aortic and pulmonary) **close**, producing the higher-pitched '**dup**' sound.

Variation occurs in blood pressure during the cardiac cycle. *The arterial system can even be thought of as a pressure reservoir, dampening the high pressure coming out of the heart*. When the ventricles suddenly contract ('systole') increasing the blood pressure, the blood flow forces the semilunar valves open, expanding the arteries. Then the ventricles relax ('diastole'), filling with blood from the veins to get ready for the next systole. At the same time, during diastole, blood flows out of the arterial system through the capillaries and the arterial pressure decreases. Although the variation in arterial blood pressure during the cardiac cycle is smoothed out by the inherent elasticity of the major arteries, blood still exhibits pulsatile flow through the arteries and arterioles. We can see this in variations in the volume of blood during each pulse, the "**volume pulse**."

Cardiac output is the volume of blood delivered by the heart per minute. When oxygen demand increases, for example during exercise, the heart must produce more cardiac output. **Cardiac output = heart rate** (in beats per minute) x **stroke volume** (the volume of blood pumped in one heartbeat).

We will conduct a 3-lead ECG. In medicine, 12-lead ECGs are generally performed. If you go on to medical training, you will learn much more about interpretation of variation in ECG traces. See http://www.ecglibrary.com & http://medlib.med.utah.edu/kw/ecg if interested.

Exercise 1: ECG and volume pulse at rest

Objectives

Measure the ECG of a resting volunteer, and analyze the resultant signal. Observe the effects of slight movement on the signals (why are you doing this? - note what happens in your notebook). For each volunteer, perform exercises 1 through 3 leaving the ECG electrodes in place on the skin (unplug the leads and take the with you).

Procedure

1. Make some noisy data: Ask the volunteer to open and close his or her hands, and then move both arms across the chest. Note that the trace moves all over the place, and the ECG becomes distorted.
2. Record and save at least 4 good heart beats with comment "Resting ECG - name".

Analysis

1. Choose some regularly occurring ECG cycles to analyze.
2. Measure the amplitudes of four P waves, QRS complexes and T waves from the ECG trace (as in Fig. 5) using the cursor and the amplitude values from the display directly above the 'ECG' channel title. Record these values in your notebook.
3. Using the Marker and cursor, measure the durations of four P waves, QRS complexes and T waves from the ECG trace.
4. Calculate the heart rate.

5. Measure the lag time between QRS and finger pulse peaks during at least four heartbeats.

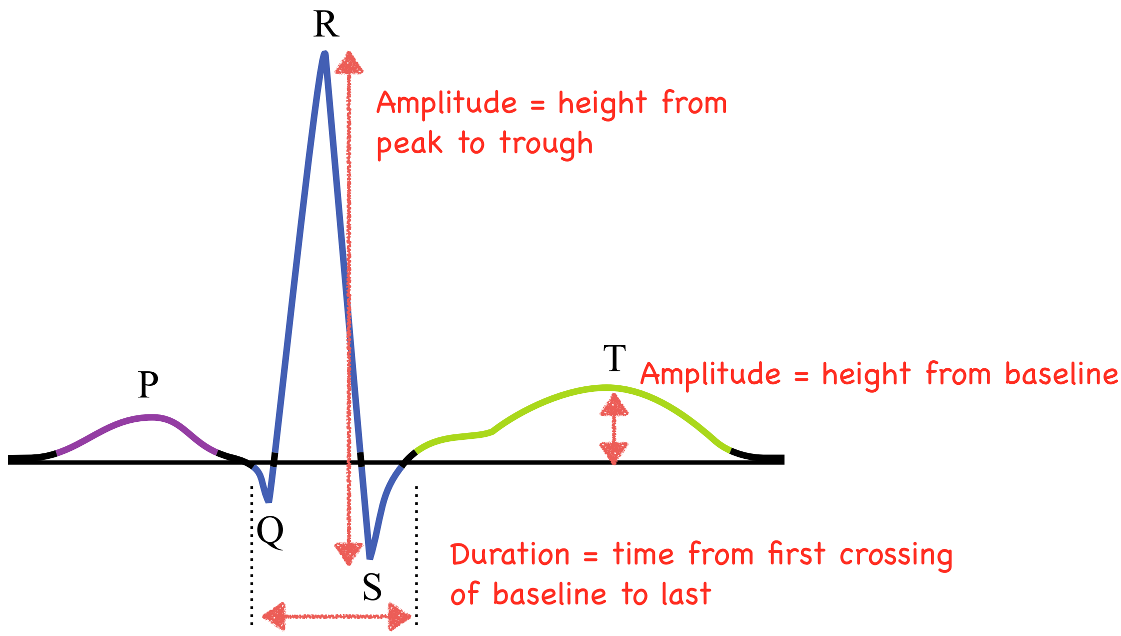

Figure 5. Measuring amplitude and duration of peaks

Questions for thought…

1. Why is it important to know what a this signal looks like? How can you minimize noise?
2. The P wave and the QRS complex represent depolarization of the atrial and ventricular muscle respectively. Why does the QRS complex have the largest amplitude?
3. What does the peak in the blood flow trace represent? Why is there a lag between the QRS complex and the blood flow peak?
4. What does the peak in the Volume Pulse represent? Is there evidence for a small transient plateau or upward deflection? (Figure 6) This is called a dicrotic notch.
5. Would you expect a transient increase in blood pressure as the elastic arteries recoil after being stretched by blood entering from the ventricles? Why?
6. The range for a normal resting heart rate is 60 to 90 bpm. A trained athlete could have a resting heart rate of 45 to 60 bpm. Why might a very fit person have a slower heart rate than someone of average fitness?

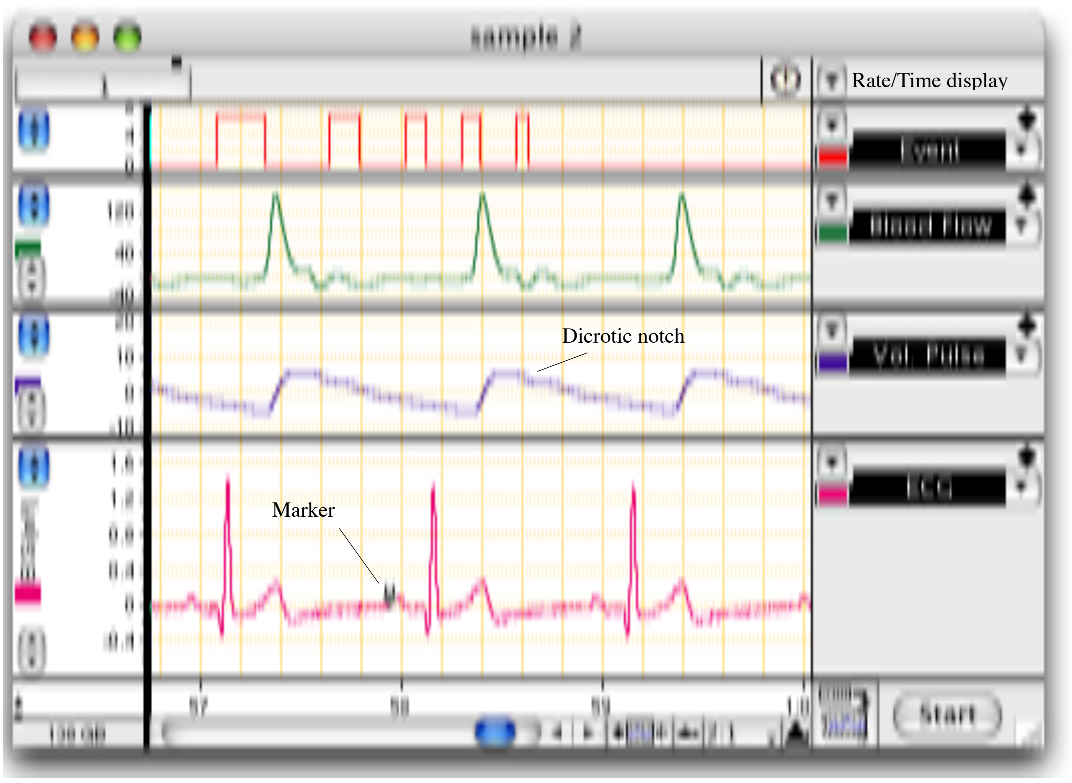

Figure 5. An example of the type of recording you should see for Exercise 1: the Marker and Waveform Cursor are set to measure the duration of the P wave.

Exercise 2: ECG and heart sounds

Objectives

To measure and correlate the ECG and heart sounds in a resting volunteer.

Procedure

Everything should be set up as described in the general notes above.

1. The volunteer should hold the bell of the stethoscope over his or her heart directly on the skin, while a second student listens.
2. When the listener can clearly hear the heartbeat, start recording. Press the push-button switch upon hearing ‘lub’, and release it on ‘dup’.
3. Record a few heartbeat cycles.

Analysis

1. Select a region of data with two or three cardiac cycles (selecting both of the displayed channels).
2. Select Zoom Window from the Window menu. The Zoom window appears with the Event and ECG signals overlaid.
3. Note the correlation between Event and ECG signals.

Hint: If you followed the instructions given earlier, the Event signal should go high (signaling the ‘lub’ sound) very soon after the QRS complex, and the Event signal should go low (signaling the ‘dup’ sound) at or shortly after the T wave.

4. Note any differences from the expected timing of the Event signal.

Questions for thought…

1. Explain why ventricular contraction (systole) and the 'lub' sound occur immediately after the QRS complex.
2. Explain why ventricular relaxation (diastole) and the 'dup' sound occur after the T wave.
3. Your recordings probably show some differences from the correct timing of the heart sounds. How do you think such wrong results occur? What additional apparatus might improve the experiment and prevent errors in the recorded timing?

Exercise 3: ECG and volume pulse after exercise

Objectives

Measure the ECG and volume pulse at intervals after exercise, analyze the resultant signals, and compare them with resting ECG and volume pulse.

Procedure

1. Disconnect the Bio Amp cable from the PowerLab. Check that the ECG leads are not tangled; the volunteer should gather them up and hold them.
2. The volunteer should run up and down the four flights of the Edmondson stairs two times (do not overexert).

Remember that the ECG leads are still attached, **so take care as to not to break the leads or move the electrodes.**

3. Immediately after exercise, reconnect the Bio Amp cable and mount the finger pulse transducer while the volunteer sits down and relaxes.
4. Start recording as quickly as possible, and record until the heart and breathing rate have returned to normal (2 minutes or more). Save.

Examine your data

You should now have recordings in a single file from a volunteer both resting and recovering from exercise. For each of the two recordings:

1. Select a short part of the resting ECG trace containing two or three cardiac cycles.

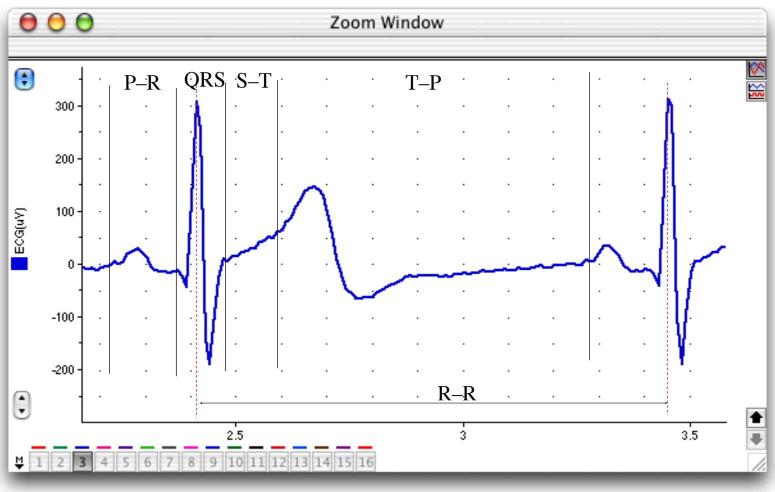

Figure 7. The Zoom window view of a portion of a resting ECG: the various intervals are shown.

2. Select the Zoom Window command from the Window menu. Your trace should resemble Figure 7. (**Note: the P–R interval is the time from the start of the P wave to the start of the QRS complex. A more logical name would be 'P–Q' interval, but P–R is traditional.**)
3. Make the following time measurements from the ECG:

P–R time interval, QRS duration, S–T time interval, T–P time interval, R–R time interval, and heart rate.

4. Repeat the above measurements using the first 'good' ECG traces immediately after exercise, and then again at 30, 60, and 120 s after exercise. (You can also recall your data from Part 1 and make these measurements as a second estimate of resting-state.)

Exercise 4: ECG for a range of volunteers

Procedure and analysis

1. Repeat Exercises 1-3 for each of the remaining members of your group to examine inter-individual variation in cardiac physiology.
2. Everything should be set up as described in the general notes above. Record and analyze the ECG signals of the other members of your group as described in Exercises 1-3.

Enter the following data into the group spreadsheet:

- Heart rate
- Amplitude and duration of the P wave
- Amplitude and duration of the QRS complex
- Amplitude and duration of the T wave
- Sex

Questions for thought…

1. What happened to the R–R interval and the heart rate after exercise?
2. Note that the R–R interval consists of the sum of QRS, S–T, T–P and P–R. Which of these become shorter when the heart rate is raised? Another way to think about this is which phase of the heart beat cycle is shortened in order to increase heart rate? Do you think there are constraints so that some phases are much harder to shorten than others?
3. Immediately after exercise, was the amplitude of the pulse smaller or larger than in the resting treatment?
4. What happened to the pulse amplitude during recovery?
5. How does the volume pulse vary immediately after exercise? (Compress the view to about 100:1 or 200:1 so that you can see the whole course of recovery over time)
6. With exercise, how does the heart deliver more oxygen to the tissues? What is changing between the treatments that you can identify in the ECG waves, heart rate, and pulse volume that change with exercise?