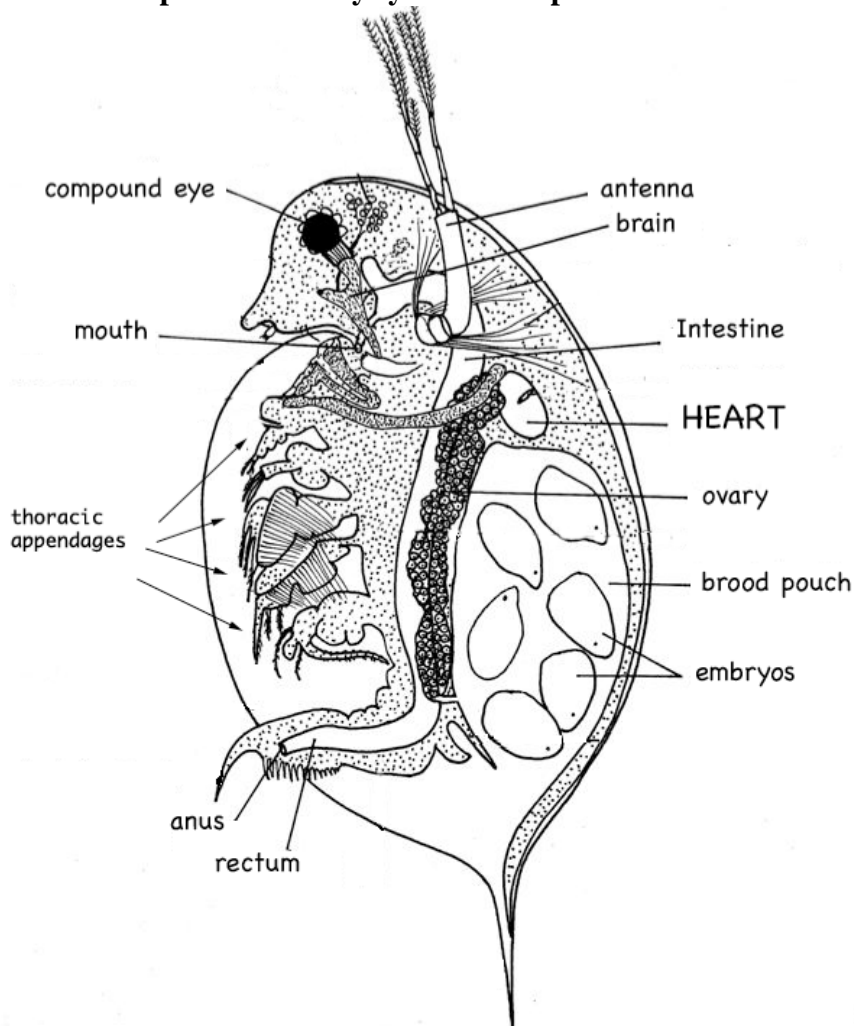


Circulation and Gas Exchange

Introduction

All animals need to obtain oxygen (O₂) and nutrients from the environment and get rid of carbon dioxide (CO₂) and wastes. For single-celled organisms, Sponges and Cnidarians, this can be accomplished by diffusion directly between the cells of the organism and the environment or through the gastrovascular cavity. However, for larger animals, the exchange of gases and nutrients is accomplished through specialized systems for circulation and gas exchange. Humans and other vertebrates have a closed circulatory system where blood is confined to the heart and blood vessels. Gas exchange with the environment occurs through the lungs. Today we will observe a small crustacean that uses a different strategy. We will also examine aspects of the human circulatory and respiratory system.

Exercise 1 – Open circulatory system of Daphnia



Daphnia magna, sometimes called the water flea, is a crustacean in the phylum Arthropoda. Like other arthropods, daphnia has an **open circulatory system**. Blood-like fluid, called **hemolymph**, is pumped throughout the body cavity. This type of cavity, called a **hemocoel**, is well developed in arthropods and mollusks where the coelom is small. An open circulatory system is not as efficient as a closed one, but for many **ectotherms**, it is perfectly adequate.

Procedure – work in pairs

1. Carefully pick up a single daphnia with a plastic pipette and place it on a depression slide. Use the pipette to remove all but a thin film of water covering the daphnia. This will immobilize the daphnia while still allowing it to breathe. **Observe under a dissecting microscope. Don't let your specimen dry out. Add small amounts of water as necessary.**
2. Observe the various structures noted on the diagram. The thoracic appendages will be actively moving. These are used to generate feeding currents and for swimming. Find the oval shaped heart – it is almost transparent. The circulatory fluid, hemolymph, is clear also. **You may see reddish tissue running the length of the animal. What do you think this is?**

Can you count the rate of the heartbeat? Do you think this is the “normal” resting heart rate of daphnia? Why or why not?

How does the heart rate in daphnia compare to your own?

What would account for the difference?

How do you think daphnia acquires O₂ and expels CO₂?

Introduction to the Heart

The heart is a muscular organ that pumps circulatory fluid – blood or hemolymph – throughout the body. In Arthropods and Annelids, the simplified “heart” is just a thicker, more muscular part of the circulatory system, with no compartments or valves. We observed this in the two previous labs. Vertebrates have hearts with compartments and valves for more efficient circulation.

Can you think of characteristics of animals that would require more efficient circulation?

Different groups of vertebrates have different numbers of circuits in their circulatory systems and different numbers of chambers of the heart (see Fig. 42.5 in Campbell). Regardless of the number, there are two types of chambers: the **atrium** (plural atria), and the **ventricle**, the more muscular pump. Valves that separate the chambers insure that the blood flows in only one direction through the system.

The simplest of the chambered hearts is that of fish with a 2-chambered heart comprised of one atrium and one ventricle. The blood flows in a single circuit from the body to the heart, then to the gill, and on to the body again. The atrium is separated from the ventricle by a valve. When the ventricle pumps, it forces the valve closed so that the blood can only flow toward the gill capillaries where the blood is oxygenated. When the heart muscle relaxes, there is negative pressure so the valve opens and allows passive flow down the pressure gradient of blood from the atrium. Flow of blood in fish is also facilitated by muscular contractions of the body. We observed the 2-chambered heart in the fish we dissected last week.

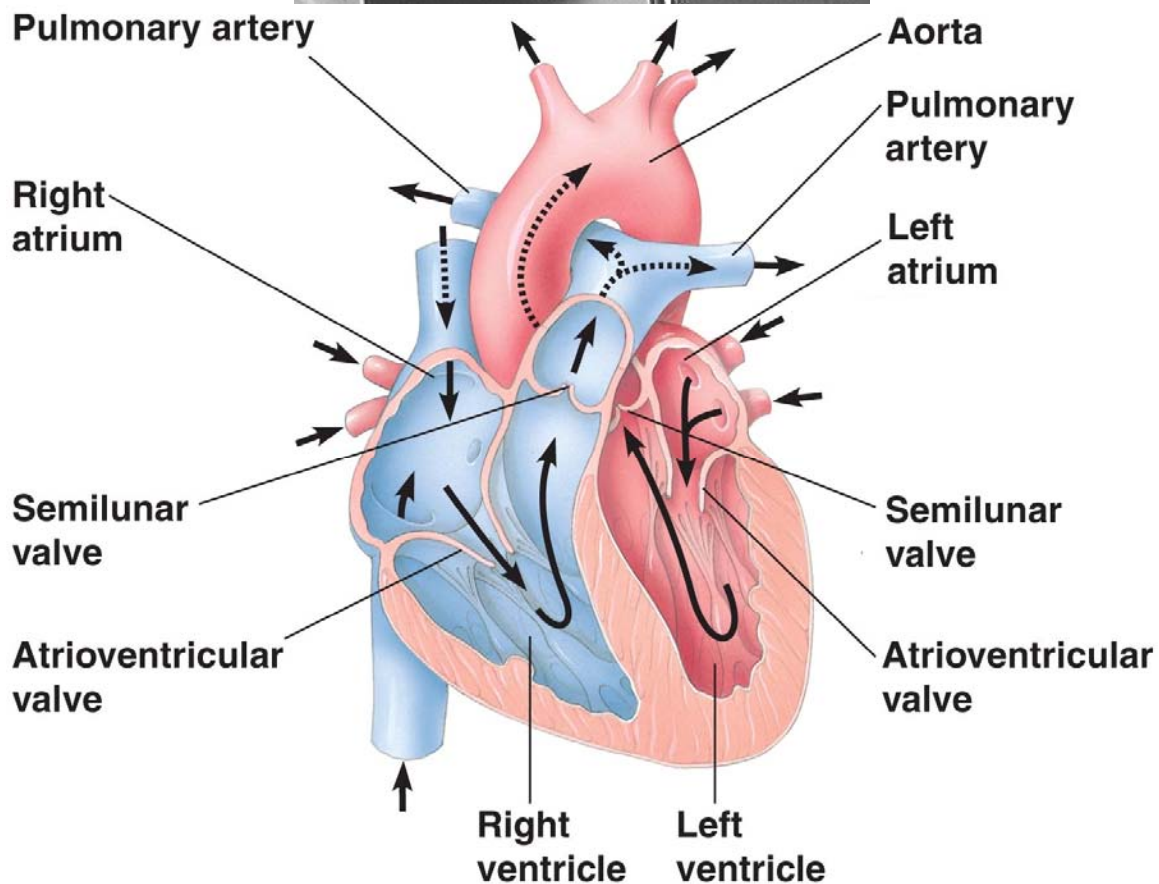
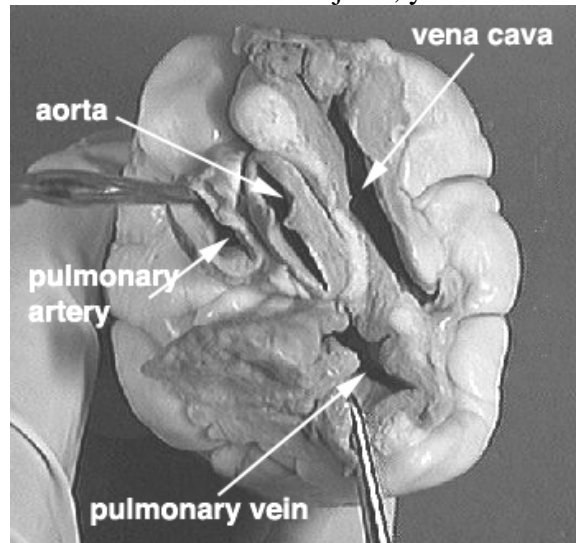
Amphibians have a 3-chambered heart that pumps blood through two circuits. The first is the pulmocutaneous circuit (pulmo=*lung*, cutaneous=*skin*) where the blood is oxygenated. The second is a systemic circuit throughout the body to deliver O₂ and remove CO₂. The single ventricle pumps a mixture of oxygenated and deoxygenated blood to both circuits. Deoxygenated blood from the body goes into the right atrium whereas the oxygenated blood from the pulmocutaneous circuit enters into the left atrium. Reptiles (except crocodiles) also have a 3-chambered heart, but they have a partial division in the single ventricle that helps to separate the oxygenated and deoxygenated blood.

Mammals and birds (and crocodiles) have a 4-chambered heart with two atria and two ventricles. This allows the two blood circuits of oxygenated blood and deoxygenated blood to be completely separated, thus making for a very efficient circulatory system. In addition to the sheep heart dissection below, we dissected a quail in a last week. Look at Figure 42.5 in Campbell for comparison of vertebrate circulatory systems.

Exercise 2 – Sheep Heart Dissection

The sheep heart, like that of humans is a 4-chambered heart with 4 valves. First, observe the heart from the outside. The white areas are fat and the dark red areas, the muscle. The muscular ventricles comprise a great majority of the heart. Depending upon where the arteries and veins were cut, there may be four or more openings. The aorta comes out from the left ventricle where the oxygenated blood goes to the body. The pulmonary artery sends deoxygenated blood from the right ventricle to the lungs. The pulmonary vein then brings the oxygenated blood back to the left atrium. Finally, there are vena

cava, that bring deoxygenated blood back to the heart from the body. The vena cava in the photo below looks large because it was cut below where the anterior and posterior vena cava join. If your heart was cut above this joint, you will see 2 openings.



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Because the heart is a vital and continually working muscle, it needs its own blood supply, the coronary arteries. You may be able to see these arteries that originate from the

aorta and run down both sides of the surface of the heart. These vessels serve the tissues of the heart itself. It is when these arteries get clogged that you have a heart attack!

Now cut the heart open parallel to the line connecting the aorta and pulmonary vein. Remember that the thickness of the muscle determines its strength.

Which is thicker, the region surrounding the atrium or the ventricle?

What about the difference in thickness of the right versus left ventricle?

Note also the valves between atrium and ventricle and also the valves exiting from the ventricle. Notice the fibrous connective tissue that connects the flaps to muscles. These help the valves flaps to be positioned so that they can close properly.

Use the diagram above to trace the flow of blood in the sheep heart.

Introduction to Human Circulatory System

The human circulatory system is comprised of the heart, blood, and vessels. Blood is carried in three types of vessels: arteries, veins, and capillaries. Arteries are defined as vessels that carry blood away from the heart whereas veins carry the blood back to the heart. (This definition does NOT include whether the blood is oxygenated or not. Refer to the previous section on sheep heart for arteries that carry deoxygenated blood and veins that carry oxygenated blood.) Connecting arteries and veins are the tiny capillaries. Capillaries form a vast system of branched vessels. If you could remove all the vessels from an adult human and lay them end-to-end, they would measure almost 100,000 miles!


The function of veins, arteries and capillaries are reflected in their structure. The walls of the capillaries are relatively thin and made of flat endothelial cells to facilitate exchange of gases, nutrients, and waste between the blood and the fluid surrounding the cells. Arteries, by contrast, have thick, strong walls to withstand the high speed and pressure of blood pumped from the heart. Blood in the veins returns to the heart from the capillary bed at much lower pressures, and thus veins have thinner walls than arteries and are equipped with one-way valves to prevent the blood from flowing backwards.

Exercise 3 –EKG or ECG - Electrocardiogram

Heart muscle autonomically contracts and relaxes, that is, it does not require any conscious thought for our hearts to beat. A pacemaker (**sinoatrial node**), composed of a set of specialized muscle cells, (located near the superior vena cava's entrance to the right atrium) sets the heart rate by sending out electrical signals. This signal is relayed to the rest of the heart by another group of specialized cells located between the right atrium and right ventricle, called the **atrioventricular node**. These electrical signals can be

detected on our skin and are the basis of the electrocardiogram, EKG or ECG. Because an EKG is a recording of the heart's electrical events, it is valuable in diagnosing diseases or ailments that damage the heart. An EKG can show cardiac arrhythmia, where the heart skips a beat or where the heart beats too fast, sometimes called heart palpitations. The duration for an electrical signal to travel through the heart is indicates the condition of the tissue through which the signal passes. For actual medical diagnosis, 12 electrodes are used.

Procedure

1. Prepare the computer for data collection by double-clicking on the EKG icon.
2. Attach three electrode tabs to your arms, as shown in Figure 2. The key to obtaining a good EKG recording is to have good electrical conductivity of the electrodes. This means cleaning the area well with an alcohol swab (oils and lotion reduce conductivity), and then letting it dry before attaching the electrodes. A single patch should be placed on the inside of the right wrist, on the inside of the right upper forearm (below elbow), and on the inside of the left forearm (below elbow).
3. Connect the EKG clips to the electrode tabs as shown in Figure 2. Sit in a reclined position in a chair. The arms should be hanging at the side unsupported. When everything is positioned properly, click COLLECT to begin data collection. If your graph has a stable baseline as shown below, continue to Step 4. If your graph has an unstable baseline, collect a new set of data by clicking . Repeat data collection until your graph has a stable baseline.

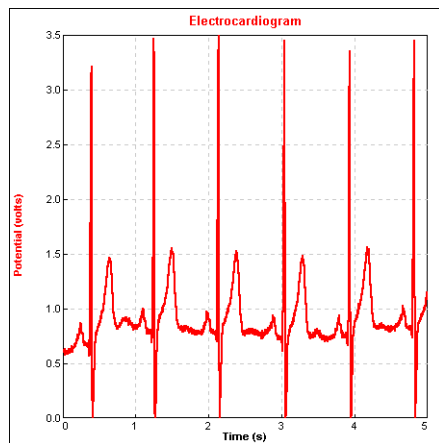


Figure 3: Stable baseline

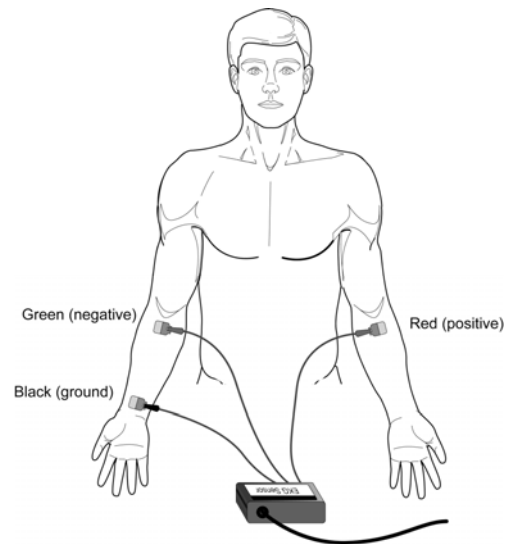
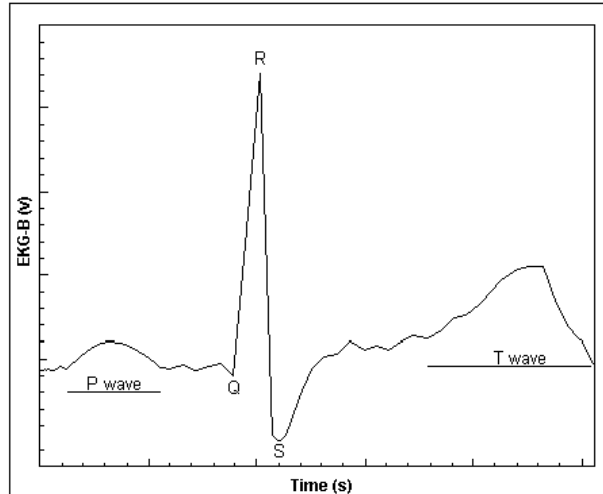


Figure 2

3. Click the examine button, to analyze the data. As you move the mouse pointer across the screen, the x and y values are displayed in the Examine window that appears. For three heart beats, identify parts of an EKG waveform referring to the following figure.



The atria make the first wave, “P wave”, whereas the ventricles make the next wave called the “QRS complex” and the last group called the “T wave” is the recovery to the resting state. This time interval is compared to the standard. Of course, we do not have the equipment to accurately measure for medical diagnostic purposes, but you may wish to compare your time intervals to the following standard time intervals.

Time from the beginning of P wave to the start of the QRS complex: 0.12 to 0.2 sec. The time from Q deflection to S deflection: < 0.1s. The time from Q deflection to the end of the T wave: 0.3 to 0.4 s.

You will find that not all EKGs look alike. Do not be alarmed by this. Each heart will differ from one individual to another. What you can see is that EKGs contain the same waveforms even though they differ in size and shape.

Two common problems that can be diagnosed from an EKG are atrial fibrillation and ventricular fibrillation. During atrial fibrillation, the atria quiver instead of beating effectively. Blood isn't pumped out completely, so it may pool and clot. If a blood clot in the atria leaves the heart and becomes lodged in an artery in the brain, a stroke results. About 15 percent of strokes occur in people with atrial fibrillation. During ventricular fibrillation, abnormal impulse conduction in the ventricles results in rapid disorganized contractions (the ventricles "flutter" rather than beat) in which the heart pumps little or no blood. Below are examples of atrial fibrillation and ventricular fibrillation.

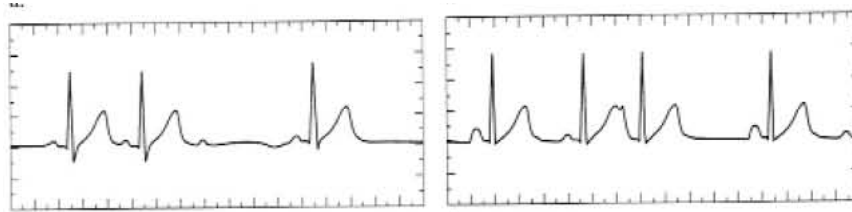


Atrial fibrillation



ventricular fibrillation

Additional examples of abnormal EKG's are shown below. **Can you find all 3 parts of the wave? What abnormalities can you detect?**



Some diseases affect the heart without altering its electrical properties. A physical defect such as a faulty pulmonary or aortic valve will disturb the mechanical action of the heart, but not the electrical activity that shows up on an EKG.

Introduction: Gas exchange

Organisms require a continuous supply of O_2 for cellular respiration and they need to expel the CO_2 created. Most organisms must expose a large moist area to the environment where the diffusion of these gases can occur (remember diffusion?). In single-celled organisms, gases simply diffuse through the cell membrane. Some small animals, such as earthworms, use their entire outer skin for gas exchange. Insects have an extensive system of internal tubes, called *tracheae*, that delivers air directly to body cells. Many other aquatic animals, such as fish and some salamanders, exchange gases through specialized organs called *gills*. Most terrestrial vertebrates exchange gases to and from the blood across the lining of the *lungs*.

Exercise 4: Control of Breathing (Ventilation)

When you inhale, O_2 from the air diffuses into the blood that flows in the tiny capillaries in your lungs. Carbon dioxide diffuses out of the blood and into the lung cavities to be exhaled. This exercise demonstrates not only our need for O_2 , but also the necessity of ridding the body of CO_2 . The concentration of CO_2 in the blood is the main factor regulating the rate and depth of breathing. **Working with a lab partner, determine the length of time you can hold your breath.**

Procedure - Work in pairs

First one partner should do Part A while the other partner times. Then the second person does Part A while the first student times. Then in a similar manner, do Parts B, C, D, E, and F.

Be sure to recover completely between tests! If you feel light-headed during any of these activities, stop immediately!

Record your results.

- A. Seconds breath is held after a normal exhalation
- B. Seconds breath is held after a normal inhalation
- C. Seconds breath is held after a maximal exhalation
- D. Seconds breath is held after a maximal inhalation
- E. Seconds breath is held after several maximal inhalations and exhalations taken in rapid succession. Start holding your breath with an inhalation.
- F. Repeat Part E but inhale and exhale into a paper bag instead of in the open air.

Breath-hold divers, who dive for long periods without air tanks, take several deep breaths before each dive. This practice does not increase the levels of oxygen in their blood.

What does it do?

Exercise 5: Vital Capacity

The volume of air an animal inhales and exhales with each breath is called the *tidal volume*. The average tidal volume in humans is about 500 ml. The maximum volume of air that can be inhaled and exhaled during forced breathing is called *vital capacity*, which averages about 3400 ml and 4800 ml for college-age females and males respectively. Among other factors, vital capacity depends on the resilience of the lungs. Vital capacity diminishes as a result of aging or disease.

Procedure

Determine your vital capacity by blowing into the spirometer after taking a deep breath *in the open air*. **Measure the volume of water displaced: _____ml.** If you wish, you may retest using the same mouthpiece. When you are finished, dispose of your mouthpiece in the trash (one mouthpiece per student please). **Reset the spirometer to zero between tests.**

Compare your results with others to see if there was any relationship between vital capacity and results from Exercise 4. Also, what other factors might vital capacity be related to?