Exercise 4: Cardiovascular Physiology

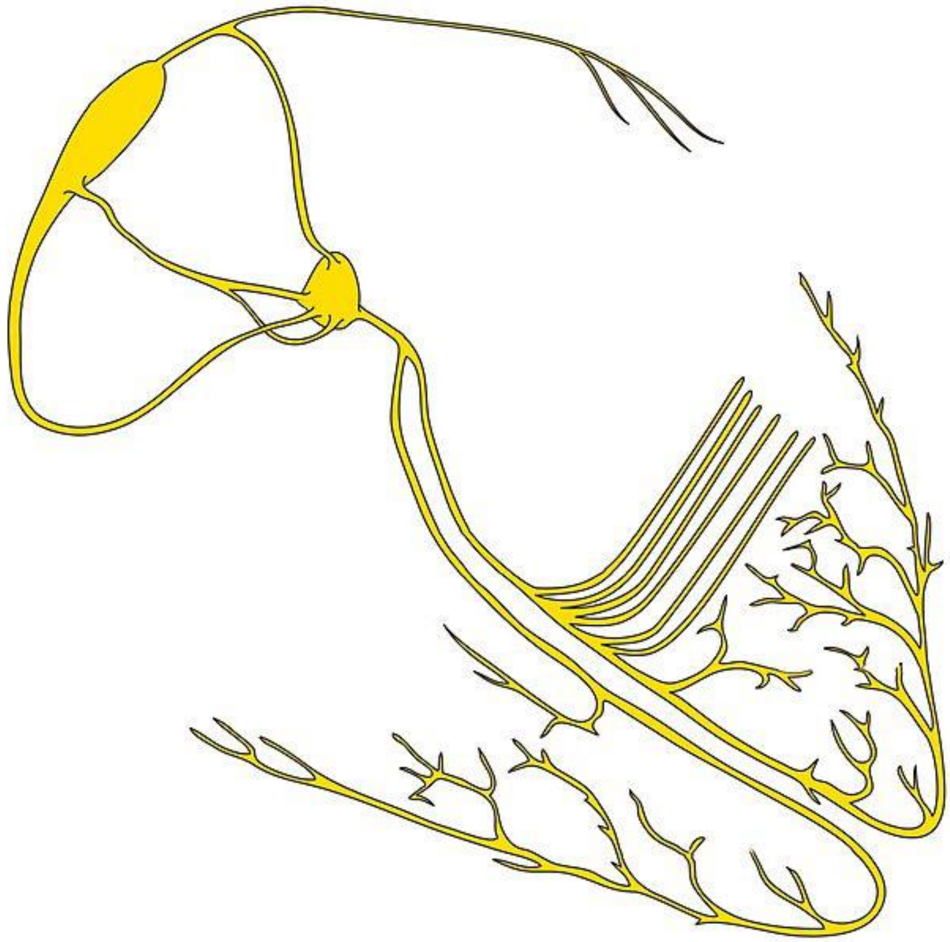

Figure 4.1: Electrical Conduction Pathway of the Heart Credit: [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)]

Exercise 4 Learning Goals

After completing this lab, you should be able to:

- Explain the relationship between electrical and mechanical events in the heart.
- Identify a normal EKG tracing and define its individual components.
- Understand arterial blood pressure and how it is measured.
- Describe how the auscultations of the heart relate to the functioning of valves.
- Be able to take a manual pulse rate and calculate beats per minute.
- Practice operating a manual sphygmomanometer; be able to place and accurately measure blood pressure using a semi-manual cuff.

Pre-Lab Exercise 4

Background

The heart serves as a pump to drive the flow of blood through the body. It does so by undergoing a cycle of contraction and relaxation called the cardiac cycle. During the initial portion of the cardiac cycle, an electrical signal is generated in so-called "pacemaker cells" that is distributed through the heart through an electrical conduction system. In response to electrical stimulation, the myocardium of first the atria and then the ventricles undergoes contraction (systole), followed by sequential relaxation (diastole) of the two sets of chambers a fraction of a second later. This cycle of compressing on the blood in the ventricles during systole followed by the filling of the ventricles during diastole induces pressure changes in the ventricles that cause one-way valves in the heart to close audibly at different intervals of the cardiac cycle. The result of the injection of blood into the arteries by the ventricles undergoing systole is the generation of blood pressure, the primary driving force for the flow of blood through the body. In this exercise we will examine both electrical and mechanical events that take place during the cardiac cycle as well as measure the resultant blood pressure generated through this contractile activity.

Electrical stimulation of the heart and electrocardiograms.

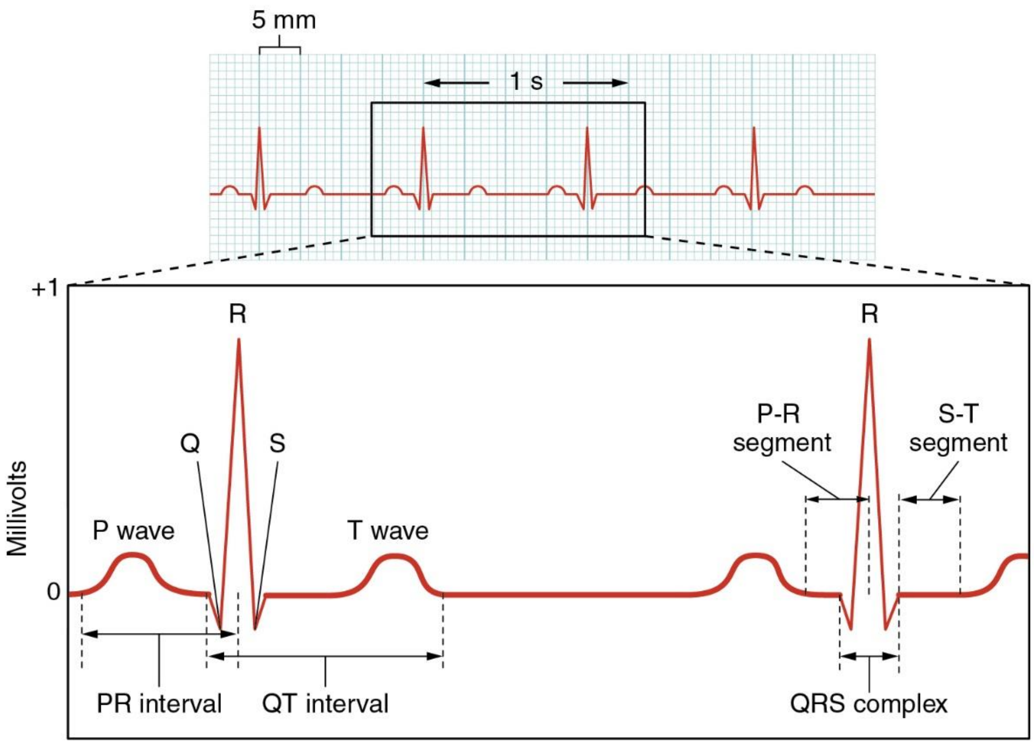

Figure 4.2 **Electrocardiogram** A normal tracing shows the P wave, QRS complex, and T wave. Also indicated are the PR, QT, QRS, and ST intervals, plus the P-R and S-T segments. Credit:Open Stax Anatomy & Physiology

The heart is auto-excitatory. Action potentials are formed spontaneously at regular intervals in specialized cells called pacemaker cells. These cells are arranged in a network that enables signals to be conducted throughout the myocardium from the point of origin. Four major structures are found within the conduction network (Fig 1). The sinoatrial node (SA node), which is located in the right atrial wall near the junction for the superior vena cava, contains pacemaker cells that undergo spontaneous depolarizations at a higher rate than any of the other pacemaker cells in the heart. As a result, the SA node sets the basic tempo for heart contraction (the sinus rhythm), and thus is often referred to as the pacemaker of the heart. Action potentials originating in the SA node are conducted rapidly through both atria through tracts of pacemaker cells. Located in the medial wall of the right atrium, near its junction with the right ventricle, is the atrioventricular node (AV node). The AV node contains the only pacemaker cells that lead out of the ventricles, thus normally electrical signals originating in the SA node and passing through the atria can only be conducted to the ventricles through this structure. The pacemaker cells in the AV node have very low conduction velocities, thus electrical signals pass through this region very slowly. Once the signal passes through the AV node, it is transferred to a structure called the atrioventricular bundle (AV bundle) or Bundle of His, which conducts the signal through the interventricular septum towards the apex of the heart. Soon after entering the interventricular septum the AV bundle bifurcates into two separate branches. The conduction of the electrical signal through the interventricular septum, coupled with the slow conduction velocity of the AV node, causes a delay from when action potentials form in atrial myocardium and when they form in the ventricular myocardium (and subsequently in when the two sets of chambers contract) called the atrioventricular delay. This delay ensures that atrial systole is complete at the onset of ventricular systole. Once the signal reaches the apex of the heart it is conducted up the lateral walls of the ventricle through branched tracts of pacemaker cells called Purkinje fibers, which distribute the electrical signal to the ventricular myocardium.

Electrical changes occurring during the cardiac cycle can be monitored from the surface of the body in a recording called an electrocardiogram (ECG, or EKG). A normal ECG recording associated with a single cardiac cycle contains three distinctive waveforms (Fig 2). The P wave is generated when the atria depolarize as the action potential wave spreads out from the sinoatrial node. The QRS complex (which consists of the Q, R, and S waves) is triggered by the depolarization of the ventricles just before ventricular systole. During the QRS wave the atria are repolarizing, but the small electrical disturbance caused by this is masked by the massive change in extracellular charge caused by the ventricles depolarizing. The last waveform, the T wave, is triggered by the repolarization of the ventricles at the end of ventricular systole.

A number of important intervals can be measured from an ECG recording. A simple measure of the duration of the cardiac cycle can be measured simply as the time that elapses between a particular point in one cardiac to that same point in the next cardiac cycle (e.g., from R wave to R wave). The P-R interval, (which here we will measure as from the start of the P wave to the peak of the R wave), indicates the duration of time that the atria are depolarized, which is roughly equal to the duration of atrial systole. In addition, the P-R interval indicates how long it takes electrical signals to travel from the atria to the ventricles (i.e., the AV delay). During the R-T interval (here measured as the duration from the peak of the R wave to the start of the T wave), the ventricles remain in a depolarized state. The duration of this interval is roughly the duration of ventricular systole, thus the amount of time that blood is being forced out of the heart and into the arteries. Conversely, the T-R interval (here measured as the duration between the start of the T wave of one cardiac cycle to the peak of the R wave of the next cycle) indicates how long the ventricles remain in a polarized state between depolarizations, corresponding to the duration of ventricular diastole and thus how long the ventricles refill with blood following contraction. Finally, the S-T interval (the segment of baseline between the end of the S wave and the start of the T wave) is an important diagnostic interval, in that this section may become elevated as a result of a recent myocardial infarction (“heart attack”) or depressed in individuals with coronary ischemia.

ECGs are important diagnostic tools for evaluating cardiac abnormalities.

Activity P4.1.1: Components of an EKG tracing

Draw a normal EKG tracing below. Identify and label the various deflections, segments, and intervals.

Include:

- P wave
- QRS complex
- T wave
- PR interval
- QT interval
- QRS interval
- ST interval
- P-R segment
- S-T segment

Activity P4.1.2 Explain what is occurring in terms of both electrical and mechanical events of the heart for each named item above.

The Cardiac Cycle and Heart Sounds

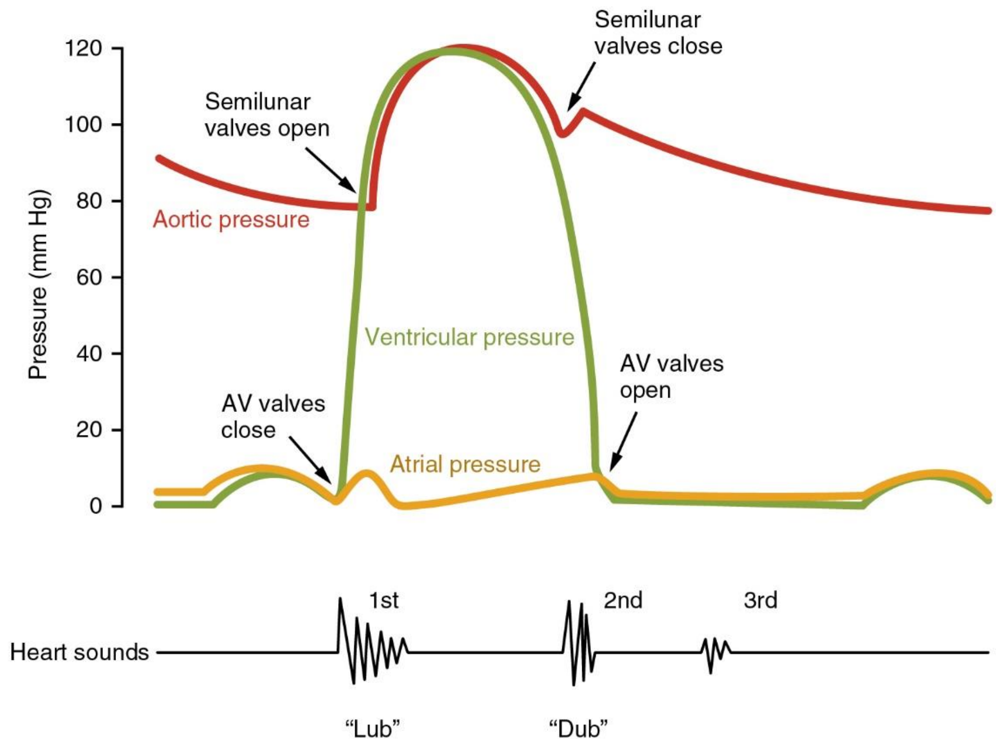

Figure 4.3 Heart Sounds and the Cardiac Cycle In this illustration, the x-axis reflects time with a recording of the heart sounds. The y-axis represents pressure. Credit:Open Stax Anatomy & Physiology

The electrical signals recorded on an ECG are caused by intermittent periods where the myocardium of the heart undergoes action potentials. These action potentials trigger the myocardium of the ventricles to contract for a period of time and then relax. The resultant cycle of contraction and relaxation of the heart is called the cardiac cycle. During the contraction phase of the cardiac cycle (systole), the walls of the ventricles contract on the blood within these chambers. This elevates the pressure of this blood above that of the blood in the arteries, thus forcing blood out of the ventricles and into the

arteries (Fig 4). During the relaxation phase (diastole), the blood pressure in the ventricles falls below venous pressure. Thus blood drawn from the veins fills the ventricles, and the volume of the ventricles expands.

A series of one-way valves prevents backflow of blood from the ventricles into the atria during systole and from the arteries into the ventricles during diastole (Fig 5). The closure of these valves can be heard during the cardiac cycle (Fig 4). The first sound produced, the "lub" sound, is caused by the closure of the atrioventricular valves at the beginning of ventricular systole when pressure in the ventricles exceeds atrial pressure. The second sound, the "dub" sound, is generated at the beginning of ventricular diastole when ventricular pressure falls below arterial blood pressure.

The Cardiac Cycle and Arterial Blood Pressure

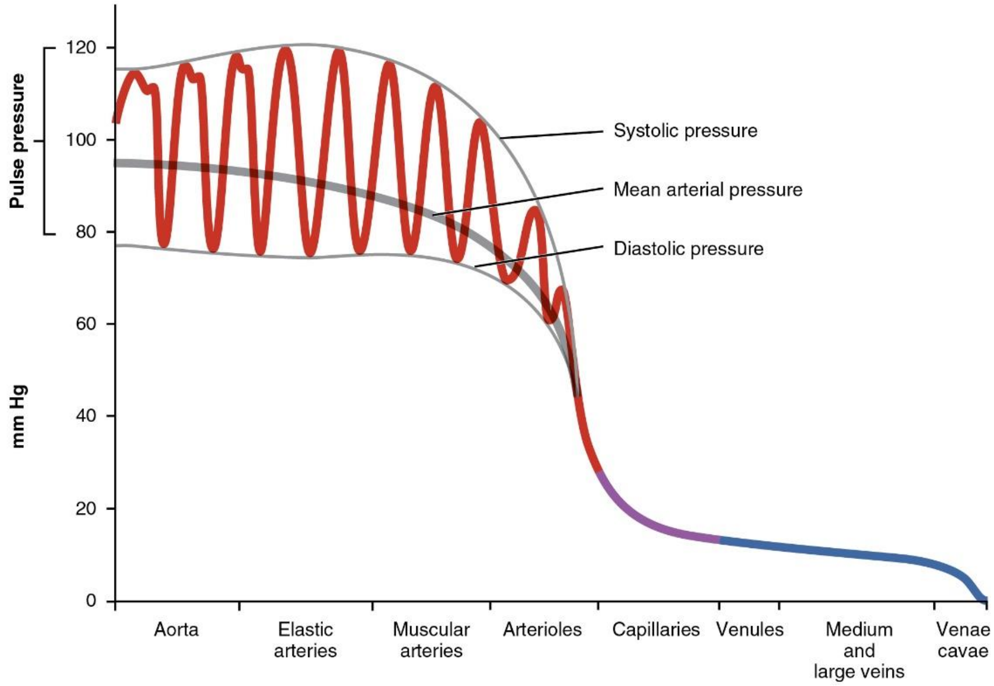

Figure 4.4 Systemic Blood Pressure The graph shows the components of blood pressure throughout the blood vessels, including systolic, diastolic, mean arterial, and pulse pressures. Credit:Open Stax Anatomy & Physiology

The flow of blood through the cardiovascular system is driven by pressure differences between one segment of a blood vessel circuit and the next. Blood pressure drops sequentially throughout the circuit (Fig 6), and thus the blood at one point will flow to the next where the pressure is lower. The contractions of the heart elevate blood pressure high enough so that it can be propelled through the entire circuit.

Arteries have particularly important roles in ensuring adequate blood flow through the cardiovascular system. Arteries serve as pressure reservoirs—their elastic walls expand during ventricular systole to accommodate the influx of fresh blood, and then compress back on the blood during ventricular diastole, maintaining relatively high blood pressure even when ventricular blood pressure has dropped to near 0 (Fig 6). This ensures that blood flows constantly through the cardiovascular system throughout the cardiac cycle.

Blood pressure in the arteries oscillates during the cardiac cycle. Systolic blood pressure (i.e., the pressure in the arteries during ventricular systole) is ~120 mmHg, similar to that of blood in the ventricles during this period. Diastolic blood pressure (pressure in the arteries during ventricular diastole) is somewhat lower at ~80 mmHg, although not nearly as low as the pressure in the ventricles at this time. The difference in pressure between systole and diastole is called the pulse pressure, which is a useful diagnostic measure for cardiovascular health. Another derived measurement is the mean arterial pressure, which is the average blood pressure in the arteries throughout the cardiac cycle. Mean arterial pressure is calculated as follows:

Mean Arterial Pressure (mmHg) = Diastolic pressure + 1/3 (Pulse pressure)

Mean arterial pressure is an important diagnostic measurement in identifying chronic hypertension.

Blood pressure can change based on activity levels and on body position. For example, when a person is standing, blood will tend to be drawn into the extremities (particularly the legs) with the force of gravity. Thus the heart will need to pump harder in order to recover blood and to deliver blood to the brain against the force of gravity, thus blood pressure will become elevated. In contrast, if a person is reclining, blood tends to pool in the abdomen and thorax, and the effects of gravity become less, thus the heart does not need to pump blood as rigorously to ensure adequate circulation, thus blood pressure will tend to become lower.

Cardiovascular Fitness

Blood flow through the cardiovascular system is adjusted in order to meet the demands of the tissues. During high levels of activity, cardiac output (the rate that blood is pumped into circulation by the heart) becomes elevated. This is typically due to an increase in both components of cardiac output: heart rate (how frequently the heart beats) and stroke volume (how much blood is ejected from the ventricles with each beat). Although both normally elevate during exercise, the relative contributions of each can differ substantially based on cardiovascular fitness. If an individual exercises regularly, they tend to increase the number of myofibrils in their cardiac muscle cells, and thus the ventricles can contract more forcefully during systole and increasing the stroke volume. As a result, heart rate does not need to increase as much during exercise to generate the same degree of cardiac output. This enables individuals who exercise regularly to sustain the same level of exercise for longer periods, to recover more quickly from exercise, and to be able to compensate for changes in circulation (e.g., positional changes) more effectively.

Exercise P4.2.1 Define the following terms

• EKG/ECG

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____

• Auscultation

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____

•Pulse rate

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• Sphygmomanometer

____

____

• mmHg

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Exercise 4 Lab Activities

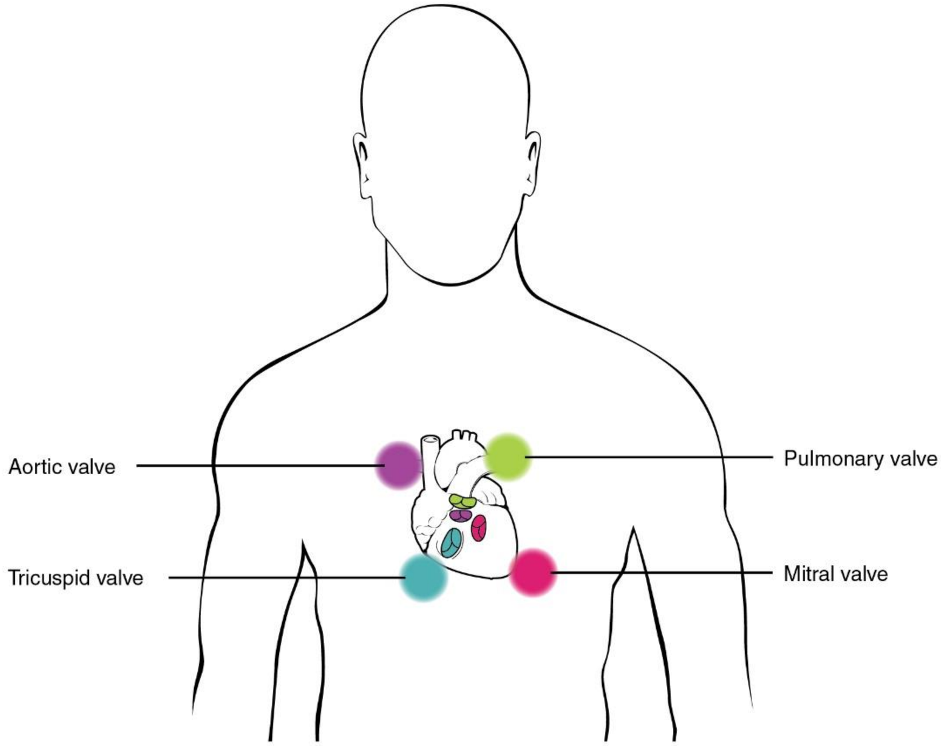

Figure 4.5 Stethoscope Placement for Auscultation Proper placement of the bell of the stethoscope facilitates auscultation. At each of the four locations on the chest, a different valve can be heard. Credit:Open Stax Anatomy & Physiology

Activity 4.1 Heart Auscultation

Supplies needed: Lab partner, stethoscope, & alcohol wipes to clean ear-tips & diaphragm of stethoscope

Place the earpieces of the stethoscope into both ears and position the bell of the stethoscope at the various positions indicated in Fig 4.5 to hear the closures of the different valves.

Activity 4.1.1 Describe the differences in the valves

	Describe sounds heard	Location of valve in heart	Type of valve
Tricuspid valve			
Pulmonary valve			
Mitral valve			
Aortic valve			

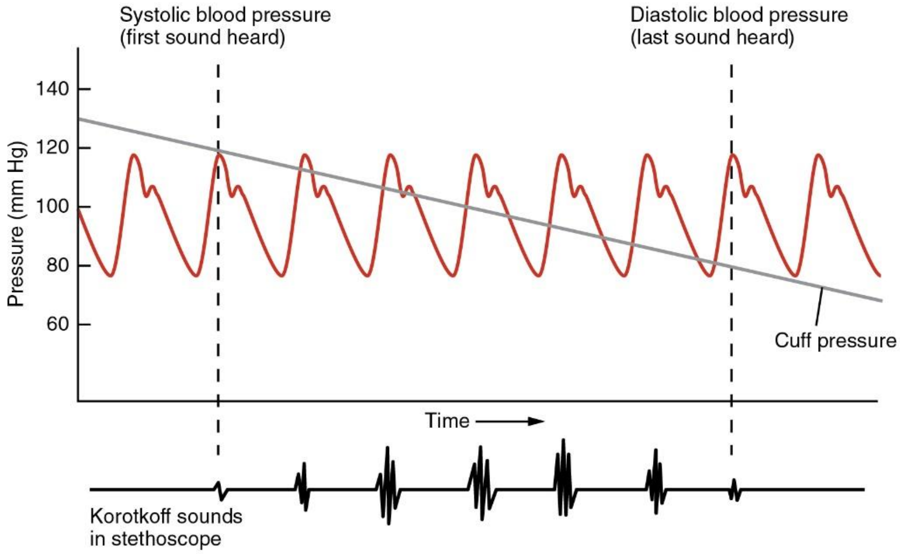

Figure 4.7 Blood Pressure Measurement When pressure in a sphygmomanometer cuff is released, a clinician can hear the Korotkoff sounds. In this graph, a blood pressure tracing is aligned to a measurement of systolic and diastolic pressures. Credit:Open Stax Anatomy & Physiology

Activity 4.2 Arterial Blood Pressure

Supplies needed: Lab partner, manual sphygmomanometer, stethoscope

1. With the subject seated, feet supported flat on the floor, apply the cuff of the sphygmomanometer around the upper arm of the subject so that the hosing for the cuff is positioned over the cubital fossa.

2. Apply the bell of the stethoscope to the skin over the brachial artery in the cubital fossa.

3. Close the screw valve on the hand pump and pump the cuff to a pressure of ~160 mmHg. Do not exceed 180 mmHg.

4. Open the screw valve on the pump to slowly release the pressure, listening to the brachial artery through the stethoscope and noting at what pressure the sounds of Korotkoff (the sounds generated by blood turbulence in a partially occluded artery) begin (systolic pressure) and end (diastolic pressure).

   Record the values for:

   Systolic pressure (SP):_______________mmHg

   Diastolic pressure (DP):_______________mmHg

Calculate the pulse pressure (PP) for the subject as follows: Pulse Pressure = Systolic BP – Diastolic BP

_____________ = _____________ - ______________

PP SP DP

Calculate the mean arterial pressure (MAP) for the subject as follows: MAP = Diastolic BP + 1/3 (Pulse Pressure)

_______________ = ______________ + 1/3(________________)

MAP DP PP

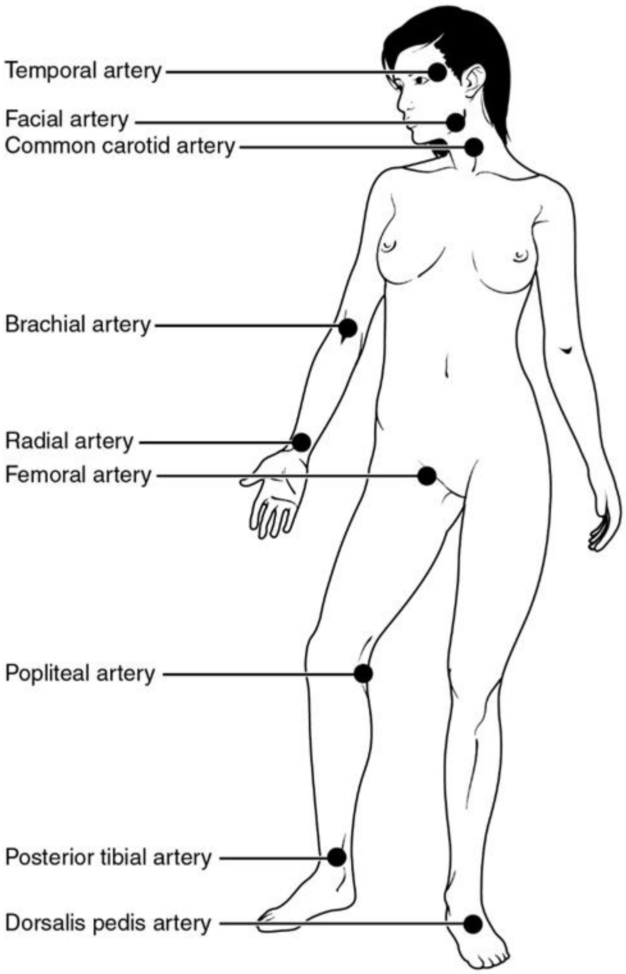

Figure 4.6 Pulse Sites The pulse is most readily measured at the radial artery, but can be measured at any of the pulse points shown. Credit:Open Stax Anatomy & Physiology

Activity 4.3 Heart Rate Measurement

Activity 4.3.1 Reclining HR

Supplies needed: Lab partner

1. Have the subject recline on the lab table or prop their feet up for a period of 5 minutes.

2. Record reclining heart rate by measuring either radial or carotid pulse (See Fig 4.6) for 30 seconds and multiplying that value by two. Record this value

Reclining HR: _____________ bpm

Activity 4.3.2 Standing HR

1. The subject should stand up and their pulse should be immediately measured for 30 seconds then multiplied by 2.

Standing HR: _____________ bpm

Activity 4.4 EKG

Supplies needed: Lab partner, device with EKG set-up, & electrode pads

Follow your device's instructions for EKG electrode placement and system operation.

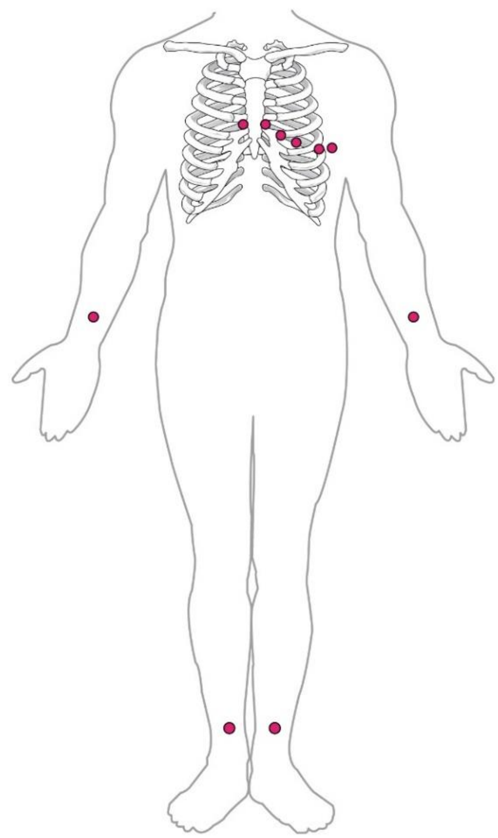

Figure 4.8 Standard Placement of ECG Leads In a 12-lead ECG, six electrodes are placed on the chest, and four electrodes are placed on the limbs. Credit:Open Stax Anatomy & Physiology

Activity 4.5 Changes in Heart Rate with Exercise

Supplies needed: Healthy lab partner, semiautomatic sphygmomanometer

In this activity, you and your lab partner will assist one another to evaluate your individual cardiovascular fitness using an old but very reliable index called the Schneider index (developed by E.C. Schneider and published in the Journal of the American Medical Association in 1920).

The activities in this exercise evaluate the ability of the cardiovascular system to compensate for changes in body position (which alter the effects of gravity on circulation) and changes in activity (a brief amount of exercise).

This is a **low intensity exercise**. However, if you have any potentially serious cardiovascular conditions (e.g., chronic severe hypertension, heart disease, etc.) or respiratory issues that could be aggravated by these activities, please only assist in the collection of data.

1. Have the subject exercise for 15-20 seconds continuously (jumping jacks, jogging, burpees). The goal is to get just a little hot and sweaty.

2. After 15-20 seconds, when the subject feels a change in their heart rate and breathing, they should immediately stop exercising. At this point, their partner will measure the subject's blood pressure, as well as their heart rate for 15 second and multiply the number of pulses by 4.
   Record these values.
   0s Post-Ex HR:______________ **0s Post-Ex BP:______________**

3. Repeat the exercise and 15-second pulse measurements at 30, 60, 90, and 120 seconds **post-**exercise. Take a post-exercise BP reading at the 60s and 120s post- time points.

4. While HR and BP measurements are being taken by their partner. The subject can assist by determining the time it takes their pulse to return back to normal rate after stopping exercise.

   Record the data as follows:

   Exercise 15-20 s; **wait 30 s**; take 15 s pulse x4: ___________; Time (s) for HR to return to baseline: _____________

   Exercise 15-20 s; **wait 60 s**; take 15 s pulse x4: ____________; Blood pressure (mmHg):________________________

   Time (s) for HR to return to baseline: __________

   Exercise 15-20 s; **wait 90 s**; take 15 s pulse x4: ___________; Time (s) for HR to return to baseline: ______________

   Exercise 15-20 s; **wait 120 s**; take 15 s pulse x4: ____________; Blood pressure (mmHg):_______________________

   Time (s) for HR to return to baseline: __________

Cardiovascular Physiology Lab Report

Data Graphs:

Bar graph: **1. Your PP vs. Class Avg. with your MAP vs. Class Avg.**

Line graphs: **2. Your reclining/standing HRs vs Class Avgs.**

3. Your reclining/standing BPs (Sys/Dia) vs. Class Avgs.

Systolic & Diastolic are graphed on 2 separate lines

4. Your Post-Ex HRs vs. Class Avgs

Timepoints: Standing pre-ex.; 0s post-ex (PE); 30s PE; 60s PE; 90s PE; 120s PE

5. Your Post-Ex BPs vs. Class Avgs

Timepoints: Standing pre-ex.; 0s post-ex (PE); 60s PE; 120s PE

Critical Thinking

Answer the following questions for *each graph* **after** you have created it and analyzed the results. Give physiological evidence to support your reasoning. Use appropriate, reputable academic sources for any claims you make.

- How were your heart rate/blood pressure similar or different from the class averages?
- Why do you think the differences or similarities occurred?
- What general conclusions can you make about the effects of exercise on HR/P?
- What individual factors can change HR /BP during exercise

  How would those factors change HR/BP?