Laboratory 8: Hemodynamics

Introduction:

The purpose of this laboratory is to give you practice with the measurement of arterial blood pressure in humans and to explore some of the environmental changes which can effect hemodynamics. If the circulatory system is modeled as a simple pump and tube system then,

\[ \text{Pressure} = \text{Flow} \times \text{Resistance} \]

and

\[
\text{Blood Pressure} = \text{Cardiac Output} \times \text{Peripheral Vascular Resistance}
\]

Because the heart is a pulsatile pump, blood pressure is not a constant value but varies throughout the cardiac cycle. The highest pressure that the heart produces when it contracts is the \textit{systolic pressure}. The lowest value to which the pressure in the arteries falls while the heart is relaxing is the \textit{diastolic pressure}. The blood pressure is normally reported as a fraction: systolic/diastolic. The mean blood pressure can be estimated as follows:

\[
\text{BP} = \frac{[\text{systolic} + 2(\text{diastolic})]}{3}
\]

Cardiac Output, in turn, is equal to the product of the volume of blood pumped by the heart with each beat times the heart rate in beats per minute.

\[
\text{Cardiac Output} = \text{Stroke Volume} \times \text{Heart Rate}
\]

Of these parameters, blood pressure and heart rate are measurable with simple noninvasive means. Heart rate is determined by counting the pulse at the wrist (thumb side = radial artery) or carotid artery (on the neck) for one minute. If you are the experimenter, be sure to use fingers other than your thumb with which to count. Your thumb has a pulse so if you use it you may be counting your own heart rate not the subject’s! Stroke volume and cardiac output can be estimated noninvasively by ultrasound but are usually measured with a catheter which enters the right side of the heart from the venous circulation and traverses into the pulmonary circulation. Once blood pressure and cardiac output are measured, peripheral vascular resistance is calculated.

In this experiment we will ask the following questions:

1. What are our subject’s normal resting blood pressure and heart rate?
2. How are these values affected by mental activity?
3. How are these values affected by exercise?
4. How are these values affected by posture?
5. How does the blood pressure in a limb vary as a function of relationship to the height of the heart?
**Materials:**

- Watch or timer
- Blood pressure cuff (sphygmomanometer)
- Tennis balls
- Lists of numbers
- Stethoscope

**Methods:**

**Figure 1**

![Figure 1](image_url)

**A. Determining Blood Pressure:**

1. Wrap the cuff around the upper arm just above the elbow so that the bag covers the arm above the artery which is to be compressed (brachial artery).
2. Turn the subject’s hand so it is palm up and find the pulse just medial of the midline on the inside of the elbow’s bend (anticubital space).
3. Place the stethoscope over the pulse (see Figure 1). You should not hear any sounds because the blood is running smoothly through this vessel and thus is not making much noise.
4. Pump the cuff up until the pressure reads over 150 mm Hg. At this pressure you will have constricted the artery so that no blood will flow. Again, you will hear no noise.
5. Let the cuff down slowly. When the cuff pressure falls just below the systolic blood pressure, blood will begin to squeeze through the artery. You will hear a noise because the blood flow will be turbulent through the narrowed artery.
6. When the cuff pressure falls below diastolic blood pressure the artery is no longer constricted at any part of the cardiac cycle. The noise will stop. Thus, as you let the cuff down, the pressure at which sounds begin is the systolic blood pressure and the point at which they end or become very muffled is the diastolic blood pressure. (See Figure 2.)
B. Determining the subject’s blood pressure and heart rate under varying conditions:

1. Measure your partner’s blood pressure as instructed above while s/he is sitting at rest.
2. Calculate your subject’s heart rate at this time as well.
3. Measure both blood pressure and heart rate for the following conditions:
   a. Lying down with their arm at their side.
   b. Held vertically above them.
   c. Lying down with their arm dangling down below their body level.
   d. While adding a list of numbers in their head.
   e. While squeezing a tennis ball as hard as possible with the opposite hand.
   f. Immediately after running up and down the stairs 3 times and walking quickly back to the lab.

N.B. Be sure to wait several minutes after steps 3a-3d and at least 5 minutes after step 3e to allow the subject’s values to return to baseline!
Figure 3. The effects of gravity on blood pressure
Results:

Record blood pressure and heart rate in the table below. State, in words, the effect of mental activity, exercise, posture and limb position on blood pressure below in this chart.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Measured blood pressure</th>
<th>Mean blood pressure</th>
<th>Heart Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>At rest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Arm at side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Arm above</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Arm dangling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Adding list</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Tennis ball</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. Stairs</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discussion:

1. A number of physiological inputs can affect blood pressure. For instance, stress can lead to stimulation of the sympathetic branch of the autonomic nervous system and increase blood pressure. Compare the blood pressure at rest to that during mental activity in light of this fact. How might sympathetic activity have affected hemodynamic function?

2. The blood pressure is sensed by pressure receptors (baroreceptors) in the neck and modulated so that the brain is presented with a constant blood pressure. If the arm is held at chest level then arm BP should be equal to heart BP. How did the measured blood pressure for sitting and lying subjects compare? How do you explain this in terms of keeping the brain blood pressure constant?

3. How does the position of a limb relative to the heart affect the blood pressure measured in that limb? Explain this result in terms of gravitational effect on blood pressure (see Figure 3). What result would you expect if you measured the leg blood pressure in a standing subject? Consider the special problems of the giraffe. What adaptations exist in the circulatory system of the giraffe?

4. During exercise, stroke volume changes little in humans, so heart rate can be taken as an indicator of cardiac output. Given this assumption, compare the effect of squeezing a tennis ball and running on peripheral vascular resistance. Use mean blood pressure in these calculations.

5. Exercise where large muscle groups are involved (running) can selectively increase the blood flow to skeletal muscle. How might this increase be achieved and how might this help explain the vascular resistance changes calculated in #2 above?
Laboratory 9:
Electrocardiogram

Introduction:

The purpose of this laboratory exercise is to give you a chance to explore the properties of the normal and abnormal electrocardiogram. The EKG is a very useful diagnostic tool which provides information about the flow of electrical current through the heart based on changes in electrical potential sensed on the body surface. Each part of the EKG wave form corresponds to the electrical activity in a specific part of the heart, as noted below. An abnormality in the flow of electrical current through any part of the heart will cause a change in the corresponding part of the EKG trace.
A contraction starts with electrical activity in the pacemaker, the S-A node. Depolarization of the atria gives rise to the P-wave of the EKG. The wave of depolarization then spreads down to the ventricles via the A-V node. Depolarization of the ventricles results in the QRS-wave. Depolarization precedes the contraction of each chamber: the P-wave is followed by atrial contraction, the QRS-wave is followed by ventricular systole. The T-wave is followed by ventricular diastole.

It is possible to examine the electrical activity of the heart from multiple perspectives by moving the positive and negative electrodes. Different electrode positions are referred to as different “leads”. A full diagnostic EKG contains recordings made from 12 different leads but for the purpose of this exercise we will restrict ourselves to 3 leads – aVR, aVL, and aVF.

Different leads are useful because the height and direction of the EKG deflection in any lead is determined by the relationship between the electrode positions and the direction in which the electrical activity of the heart is moving. The largest positive deflections are recorded when the electrical activity of the heart is moving from the negative and toward the positive electrode. The positions of the three electrodes are given below. It is also important to know that the larger the muscle mass through which the electrical activity is moving, the larger the EKG deflection will be.
Part A. The EKG

Materials:

- EKG recorder
- Watch or timer
- Disposable electrodes

Methods:

1. Have the experimental subject lie comfortably and attach the 3 limb leads to the appropriate arms and legs. Attach leads over soft tissue and not over bone. Attach the leads to the PowerLab. The subject should be seated comfortably and should not move.

2. Count your subject’s heart rate (pulse) and record the number.

3. Beginning recording and obtain several normal EKGs.

4. While recording, have your subject breathe in deeply, hold their breath for a few seconds and then breathe out. After a short rest, repeat this procedure. Repeat several times. You can label these different steps on the PowerLab recording by using the comments window.

5. Have your subject move their legs and arms while recording their EKG.

6. Detach the subject from the PowerLab but keep the electrodes attached to the subject's arms and legs. Have the subject run up and down the staircase until he/she is tired and breathing fast. When the subject has finished exercising, quickly re-attach the electrodes and record the EKG.

Results:

1. Select short segments of your subject’s EKG at rest, while holding their breath, while moving their extremities, and after exercising. We will make PDF files of these traces available on the Web by the next day. These should be handed in with your lab report.

Discussion:

1. Describe how holding your breath, muscular activity, and exercise affect the EKG.

2. Determine the time elapsed between the onset of an atrial depolarization and the onset of the next atrial depolarization. Use the principle that frequency is the inverse of time to compute your subject’s heart rate and compare your computed value to the heart rate you counted from the pulse. Can you suggest an easy formula to compute the heart rate from an EKG strip?

3. Measure the time interval from the atrial to the ventricular depolarization for resting, holding breath, and exercise. Does this time change? Explain these results.

4. Which deflection was greater, the P wave or the QRS complex? Using what you know about the function of the atria and the ventricles, explain this result.

5. Use what you know about the factors which modulate the activity of the SA node to explain the effect of taking a deep breath on the EKG.
6. Heart muscle is not the only type of muscle that has electrical activity. Use this idea to explain the effect of moving a limb on the EKG.

7. How do you explain results the results of exercise on the EKG?

8. What was the time difference between the QRS interval and the pulse wave at rest and after exercise. Explain why there is a lag between these two peaks - what is happening during this time? Did exercise affect this time difference? Use the equation Flow = pressure/resistance to describe two mechanisms that the body uses to change the rate of blood flow.

**Part B. Cardiac dysfunction**

1. **Tachycardia and Bradycardia**

   Altered SA Node Rhythm: In the EKG traces below the SA node is functioning as the heart’s pacemaker, but the frequency of its activity is abnormal in B and C. Compute the heart rates for each trace. Note that “tachy” means fast and “brady” means slow.

   ![A. Normal rhythm](image)

   ![B. Tachycardia](image)
2. First, second, and third degree block

The function of the AV node is to slow conduction between the atria and ventricles so that ventricular contraction occurs after atrial. In abnormal situations the AV node may slow this conduction too much, giving rise to heart block. Three degrees of heart block of increasing severity are shown below. In first degree block, conduction through the AV node is delayed but each impulse eventually reaches the ventricle. The time from the onset of atrial depolarization to the onset of ventricular depolarization (P-R interval) is an estimate of how long the impulse is delayed in the AV node. Compute the P-R interval of your subject and compare this value to that for first degree heart block. What do you find?

Second degree heart block occurs when some of the impulses initiated by the SA node fail to cross the AV node into the ventricles at all. Describe the B trace in terms of the relationship between P waves and QRS complexes.

Third degree heart block occurs when the AV node blocks all impulses from the SA node, preventing them from depolarizing the ventricles. Ventricular contraction may still occur but the electrical activity for this will be initiated by a site in the ventricle itself and will be very slow. Describe the C trace in terms of the relationship between the P waves and QRS complexes.

C. Bradycardia
3. Atrial and ventricular fibrillation

The normal function of the cardiac conduction system is to coordinate the depolarization and contraction of the cardiac chambers. However, chaotic electrical activity can occur in either the atria or the ventricles. This will disrupt the pumping activity of the chamber causing it to quiver or fibrillate rather than contracting. The consequences of atrial vs. ventricular fibrillation are very different. Atrial fibrillation does not disrupt ventricular function and blood supply to the lungs and body continues to be adequate even though ventricular filling is somewhat compromised. However, ventricular fibrillation prevents the heart from pumping blood to the lungs or body effectively. Death will result if ventricular fibrillation is not terminated by externally applied electrical depolarization (defibrillation). Note the irregular occurrence of QRS complexes in atrial fibrillation. Why does this pattern occur? Compare the QRS complexes in atrial vs. ventricular fibrillation.
Atrial fibrillation

Ventricular fibrillation
Part C. Flow calculations

Introduction:

The purpose of this problem set is to give you practice with several quantitative aspects of cardiovascular and respiratory physiology. These problems illustrate ideas important to comparative physiology and clinical medicine.

Flow Through A Tube

The flow of gas or liquid through a tube, driven by a pressure gradient describes the delivery of blood to the body and lungs of all animals with a closed circulation. It also describes oxygen delivery to the lungs of mammals, amphibians and birds, and water flow to the gills of fish. The rate of flow of a gas or liquid through a tube is determined by the ratio of the driving pressure to the resistance.

\[ F = \frac{P}{R} \]

where:
- \( F \) = flow
- \( P \) = driving pressure
- \( R \) = resistance

Resistance is determined by the length and radius of the tube and the viscosity of the gas or liquid.

\[ R = \frac{8n\ell}{\pi r^4} \]

where:
- \( n \) = gas or liquid viscosity
- \( \ell \) = tube length
- \( r \) = tube radius
Questions:

Graph questions 1-3 on graph paper.

1. Let P = 10. Plot Flow (on the y axis) as a function of Resistance (on the x axis) for resistance values starting at 10 and falling to 1. All units are arbitrary.

2. Either an increase in tube length or a decrease in tube radius will increase the resistance to flow, but these two effects are quite different. Start with the following values: n = 1; l = 100; r = 2 (arbitrary units). Increase length by 50 up to 500, and plot the effect of increasing tube length (on the x axis) on resistance (on the y axis).

3. Starting with the same values as in #2, plot the effect of decreasing tube radius on resistance (decrease radius in increments of .25 from 2 to 0.25).

4. Compare (in words) the effect of doubling tube length to the effect of reducing tube radius by half.

5. When a person gets a respiratory tract infection (even a cold) they may secrete mucus which can narrow their breathing tubes. Explain why the secretion of enough mucus to narrow the breathing tubes by a fixed amount might cause severe respiratory distress in a small baby but go virtually unnoticed in an adult.

6. The blood which supplies the oxygen needs of the heart muscle is delivered to that muscle by the coronary arteries. These arteries leave the aorta immediately after the aortic semilunar valve and reach all parts of the heart muscle. Narrowing of the coronary arteries can impede blood flow until the oxygen supplied to the heart falls below the oxygen needs of that organ. When this occurs, chest pain (angina pectoris) and even the death of some heart tissue (myocardial infarction) can occur. Some lifestyle choices can cause progressive narrowing of the coronary arteries (high fat diet, smoking, lack of exercise). How would you predict that progressive narrowing of the coronary arteries will affect blood flow through the coronary arteries and oxygen delivery to the heart muscle? Graph radius to flow using the values in question 3 and a fixed value for P.
Laboratory 10: Respiration

Introduction:

The purpose of this laboratory exercise is to acquaint you with several important aspects of respiratory physiology which lend themselves to quantitative analysis (understanding by equations). Please read the descriptions in each section and answer the questions or plot the graphs requested. When plotting graphs be sure to clearly label both axes, including units of measurement!

I. Measurement of Tidal Volume and Vital Capacity:

Figure 1. Diagram of the output from a spirometer

A spirometer is a bellows-like instrument filled with gas that opens only to a mouthpiece. Changes in the gas volume in the spirometer fluctuate the transducer and are recorded on a computer (using PowerLab) while the subject breathes in and out from the mouthpiece. We can make two important measurements with this simple instrument: the tidal volume and vital capacity. To measure the tidal volume, have the experimental subject sit quietly and breathe normally through the mouthpiece. The volume of air moved in and out with each breath is the tidal volume. The vital capacity is the maximum volume a subject can exhale after starting at the greatest volume the lungs can hold (total lung capacity). To measure vital capacity have the subject breathe in as deeply as possible and then blow out as much air as they can. From these measurements, minute ventilation can be calculated. Minute ventilation is the volume of air moved by the subject per minute or tidal volume x respirations per minute.
Materials & Methods:

- Spirometer
- PowerLab

1. Set the units conversion on the PowerLab as instructed by your TA.

2. Record the tidal volume and vital capacity of your subject. Compute the minute ventilation by multiplying tidal volume x respiratory rate (breaths per minute). Include proper units with all measurements. Record in Results section.

3. Measure tidal volume and minute ventilation on several subjects of varying size.

4. Have the subject increase their minute ventilation by breathing faster and more deeply for one minute. Measure tidal volume and minute ventilation again directly after this hyperventilation period.

5. After resting for a few minutes, have the subject exercise by running up and down the stairs. Measure tidal volume and minute ventilation again directly after this exercise period.

Results:

1. Tidal Volume __________
2. Vital Capacity __________
3. Chart

<table>
<thead>
<tr>
<th>Subject</th>
<th>Height</th>
<th>TV</th>
<th>Resp. rate</th>
<th>Min. vent.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. After hyperventilation:

   TV __________
   Respiratory rate __________

5. After exercise

   TV __________
   Respiratory rate __________
Discussion:

a. Use what you know about control of ventilation in warm blooded vertebrates to explain the results of hyperventilation.

b. Does the tidal volume and minute volume increase after exercise? How do you account for this?

c. Do the measured volumes vary as a function of body size? If so, how do you explain this? Use the figure below and class data in formulating your answer:

II. Calculation Of Functional Residual Capacity - Spirometer Method

Questions:

1. What is the amount of helium (in ml) present in the spirometer before the test begins?

2. What is the total amount of helium present in the spirometer plus the lung at the end of the test?

3. What is the concentration of helium in the lung at the end of the test?

4. What is the subject's FRC?

III. Calculation of FRC - Plethysmograph Method

Questions:

1. What is the increase in box volume during the attempted expiration? (Use Boyle's law).

2. What is the decrease in lung volume during the attempted expiration?
3. What is the FRC? (Use Boyle's law again).

REFERENCES


