# **Lab 8: Blood Pressure and Blood Characteristics**

## **Pre-Lab Reading**

**Blood Flow and Regulation of Blood Pressure**

Blood supplies the necessary nutrients and oxygen to the body’s cells and transports products produced by cells, such as hormones and metabolic waste, away from those cells. To ensure a continuous supply of blood to the cells, the cardiovascular system must regulate blood flow (measured in L/min) to the entire body and to each part of the body under a variety of conditions. The flow of blood through any part of the circulatory system is affected by two interrelated factors as demonstrated by the flow rule equation:

**Flow (L/min) = ∆P (mm Hg) / Resistance (peripheral resistance units)**

The pressure difference between two points (∆P) is simply the blood pressure at the beginning minus the blood pressure at the end of the region of interest. These pressures are recorded in units of mm Hg because if a mercury-filled tube, known as a manometer, is placed through the wall of a vessel, the pressure from the fluid in that vessel will cause the column of mercury to rise a certain number of millimeters. Blood pressure thus represents the force being placed upon the walls of the vessel by the blood within that vessel.

Resistance is the drag experienced by the molecules as they flow past the wall of the blood vessel. There is no easy way to measure resistance in a living system; however, it can be calculated (using the above equation) if one knows the flow rate and the pressure difference between the beginning and end of the system. Resistance to blood flow is affected primarily by (1) the diameter of the vessels, (2) the length of the vessels, and (3) the viscosity of the blood.

The blood flow pathway from the left ventricle to the right atrium supplies blood to all of the organs of the body and is called the systemic circuit. The pathway of blood flow from the right ventricle to the left atrium passes through the lungs and is known as the pulmonary circuit. The length of the systemic circuit is much greater than that of the pulmonary circuit; therefore, the resistance in the systemic circuit is much greater than that of the pulmonary circuit.

The volume of blood pumped by each ventricle of the heart per minute is called the cardiac output (CO), which is a measure of blood flow. The pressure difference between the left ventricle and the right atrium, the beginning and end of the systemic circuit, can be calculated as the mean arterial pressure (MAP) minus the central venous pressure (CVP). You will learn about how MAP is calculated later in this lab. For practical purposes, CVP is usually 0 mm Hg. Thus, the ∆P for the systemic circuit is MAP – 0 mm Hg, or MAP. The combined resistance of all blood vessels within the systemic circuit is referred to as total peripheral resistance (TPR). Thus, the original flow rule equation from above can be rewritten as:

**CO = MAP / TPR**

As mentioned above, adequate cardiac output must be maintained to supply all parts of the body properly. The heart is the main organ responsible for maintaining the cardiac output. The cardiac output can be changed by changing the heart rate (HR) and/or the stroke volume (SV). Stroke volume is the volume of blood pumped by a ventricle per contraction or beat and is measured in L/beat. The relationships among these variables is demonstrated by the following equation:

**CO (L/min) = HR (beats/min) x SV (L/beat)**

Besides the pumping action of the heart, blood flow is also affected by: 1) the force of gravity, 2)the recoil of arterial elastic tissue following the pressure wave of cardiac muscle contraction, 3)the total blood volume, 4)the milking action of skeletal muscles surrounding veins contracting and relaxing (called the skeletal muscle pump), and 5)the expansion of the chest cavity during respiration (called the respiratory pump).

All the factors that modify heart rate, stroke volume, blood pressure, and resistance interact to determine the cardiac output and delivery of blood to the tissues under a variety of conditions. For a complete discussion of the cardiac cycle and the regulation of blood flow during exercise, see your text.

The two equations above, **CO = HR x SV** and **CO = MAP / TPR**, can be combined so that all the variables of interest are addressed in one equation:

**HR x SV = MAP / TPR**

which can also be written as:

**MAP = HR x SV x TPR**

Due to the relationships in the equation above, MAP is closely regulated by the nervous and endocrine systems to maintain correct blood flow (CO) to the organs. There are sensory receptors to monitor blood pressure in the carotid bodies, aortic arch, and vena cava. When the cardiovascular control center in the medulla oblongata in the brainstem receives information from these sensory receptors, it will adjust the activity of the sympathetic and parasympathetic nervous systems as needed to maintain the required blood pressure for adequate blood flow.

The parasympathetic nervous system innervates the sinoatrial (SA) and atrioventricular (AV) nodes in the heart. If MAP is too high, the cardiovascular control center in the medulla oblongata increases stimulation of the parasympathetic nervous system to decrease the HR, which then decreases MAP. At the same time, sympathetic stimulation is decreased, which also decreases MAP due to its effects discussed below.

The sympathetic nervous system innervates the SA and AV nodes of the heart, the ventricular walls, and the smooth muscle around blood vessels. Epinephrine and norepinephrine are also released by the adrenal medulla into the blood and will bind to the same targets. If MAP is too low, the cardiovascular control center in the medulla oblongata increases stimulation of the sympathetic nervous system to increase the HR, increase the strength of ventricular contraction (increase SV), and increase TPR by causing mainly vasoconstriction. All of these effects increase MAP. In addition, parasympathetic stimulation is decreased, which increases the HR and thus MAP as well.

The endocrine system also regulates MAP. Epinephrine, norepinephrine, antidiuretic hormone (ADH), and angiotensin II all act to increase MAP. Atrial natriuretic peptide (ANP) released from the atria decreases MAP. These hormones have different targets, but in general, they affect blood vessel diameter (which affects TPR) and blood volume via effects on the kidneys.

**Local Control of Blood Flow**

Cardiac output is not divided evenly among the organs and is based on need. Local blood flow to an organ or tissue is regulated mainly by altering the resistance of the arterioles (vasoconstriction or vasodilation). Arteriole resistance can be controlled extrinsically (via hormones or the autonomic nervous system) or intrinsically (via myogenic control, metabolic factors, or locally secreted chemical messengers).

The goal of myogenic control is to keep blood flow to an organ constant even though MAP can vary depending on activity (ex- MAP is higher when you are exercising). The smooth muscles around an arteriole will either contract or relax depending on the pressure of the blood that reaches that arteriole. If MAP is high, blood flow to the organ increases. The arteriole smooth muscle is stretched and responds by vasoconstricting, thus decreasing blood flow to the organ. If MAP is low, blood flow to the organ decreases. The arterioles are not stretched and respond by vasodilating to increase blood flow to the organ. Myogenic control is very important in maintaining a constant blood flow to the brain and kidneys.

Local control of blood flow to an organ can also be affected by metabolic factors produced in the area. Arteriole smooth muscle is sensitive to chemicals produced during metabolism and will either contract or relax depending on the concentration of the chemicals. For example, in the systemic circuit, an increase in CO2 and H+ and decrease in O2, will cause arteriole vasodilation, which increases the blood flow to the area.

Vasoconstriction and decreased blood flow will occur in the opposite conditions. An increase in blood flow to a local area due to arteriole dilation is called hyperemia. Hyperemia can be either active or reactive.

Active hyperemia refers to increased blood flow to an area in part due to local (increased metabolic activity) or general (autonomic nervous system) factors which cause dilation of the arterioles. For example, active hyperemia to skeletal and cardiac muscle occurs during exercise. Also, during exercise, sympathetic stimulation causes arteriole dilation in the skin to get rid of excess body heat. The increased blood flow causes the skin to turn red.

Reactive hyperemia is increased blood flow to a tissue or body part following temporary ischemia (reduced or restricted blood flow to an area), which was caused by functional vasoconstriction or physical obstruction of blood vessels. The high levels of CO2 and low levels of O2 cause the arterioles to dilate. This increases blood flow to the area once the obstruction is removed.

**Measuring Blood Pressure**

The contraction of the ventricles and ejection of blood into the aorta (systemic circuit) or pulmonary artery (pulmonary circuit) generates a pressure wave that is transmitted through the blood vessels. Since it is more easily accessible, aortic pressure in the systemic circuit is measured much more commonly than pulmonary pressure and will be the focus of this discussion.

Systolic pressure (SP) is the maximal pressure that occurs during ventricular contraction. At rest, a typical systolic pressure is 120 mm Hg. After contraction, the ventricular muscles relax and the pressure within the larger arteries drops to its lowest point, which is called the diastolic pressure (DP). The diastolic pressure is about 80 mm Hg at rest. Blood pressure is expressed as the systolic pressure over the diastolic pressure, which at rest is 120/80 mm Hg. Systemic hypertension occurs when the blood pressure is 130/80 or higher at rest, and it increases the risk of cardiovascular disease (ex- heart attack, stroke, aneurysm, heart failure), kidney failure, dementia, and vision problems.

Because the blood pressure fluctuates between the systolic and diastolic pressure, the average pressure in the aorta during the cardiac cycle (MAP) is measured. Since more time is spent in diastole than in systole during the cardiac cycle, MAP is calculated as a weighted average. The formula below shows how MAP is calculated.

**MAP = 1/3 SP + 2/3 DP**

Blood pressure can be measured directly or indirectly. Direct blood pressure measurement measures the blood pressure directly in the artery. It involves inserting a catheter into an artery and monitoring the systolic and diastolic pressures capable of supporting the weight of a column of mercury (Hg) in a manometer. Direct blood pressure measurement is invasive and impractical to use in most clinical settings.

Blood pressure can be measured indirectly by the auscultatory technique. This method involves placement of a pressure cuff around the upper arm at the junction of the elbow. The cuff is then inflated to approximately 160 mm Hg to produce complete occlusion of the brachial artery. While listening with the stethoscope diaphragm over the brachial artery distal to the cuff, the pressure in the cuff is slowly released (approximately 3 mm Hg/second) until the pressure of the blood during ventricular contraction is sufficient to surge past the occlusion of the artery. The first sound heard indicates the systolic pressure. As the pressure in the cuff continues to fall, the sounds first grow louder and then decline in intensity. The sound disappears when there is no longer deformation of the artery from the pressure cuff, and blood flows smoothly. The point at which the sound disappears marks the diastolic pressure. Both of those pressures are read from the sphygmomanometer (pressure gauge) attached to the pressure cuff. The pressure units measured with the sphygmomanometer are calibrated with a mercury manometer and are read in mm Hg. The blood pressure should always be monitored with the stethoscope diaphragm at the same horizontal level as the heart to most nearly represent the pressure of blood exiting the heart.

**Measuring Heart Rate or Pulse**

The normal resting heart rate (HR) is under the control of a group of specialized cardiac muscle cells that make up the sinoatrial (SA) node. The SA node is the pacemaker of the heart because the cells are autorhythmic and are capable of initiating action potentials in the heart independent of nerve or hormone stimuli. Modification of this intrinsic heart rate is under the control of the autonomic nervous system. Due to normal parasympathetic control via the vagus nerve, the resting heart rate of 70 contractions per minute is slightly slower than the heart rate initiated by the pacemaker cells (90-120 beats per minute). One can monitor the heart rate with a stethoscope placed over the chest, with an ECG (electrocardiogram), or by simply palpating the pulse in an artery. The sounds of the heart heard when a stethoscope is placed over the chest are due to the turbulent blood flow created by the closing heart valves.

When the heart contracts and ejects blood into the arteries, the arteries expand and then recoil, creating a noticeable change in pressure called the pulse. The arterial pulse reflects the heart rate and can be monitored by lightly touching the radial or carotid artery or by placing a pulse oximeter on a fingertip.

When the body is in a given position - for example, reclining or standing- for a period of time, the pulse may be monitored for fifteen seconds and that value multiplied by four to give the pulse. When the pulse is changing (ex- during exercise, when exercise is stopped, or upon standing from a reclining position), the pulse should be monitored for only 10 seconds. That value will then be multiplied by six to give the pulse.

**The Buffering Capacity of Blood**

The buffering capacity of blood, serum, and a saline solution will be demonstrated using a pH meter, an instrument that measures the relative concentrations of hydrogen and hydroxide ions in a solution.

Because of its wide distribution and exchange of material with cells, blood has a major role in pH homeostasis. pH measures the H+ concentration of a solution, and it is calculated with the formula, pH = -log[H+]. Recall that the pH scale ranges from 0 to 14, and that lower pH numbers indicate a higher H+ concentration. Also keep in mind that the terms “acidic pH” and “basic pH” are used in a somewhat confusing way. The term “acidic pH” really refers to pH values lower than 7, which actually is not a reference to the concentration of acid in the solution, but to the relatively higher concentration of H+ ions in the solution. A pH value lower than 7 is called an “acidic pH” because acids are a common source of H+ ions. Similarly, the term “basic pH” refers to the relatively lower concentrations of H+ ions, not to the concentrations of bases in the solution. A pH value higher than 7 is called a “basic pH” because bases can accept H+ ions and remove them from solution. (H+ ions only contribute to the pH value when they are free in solution).

The blood and intercellular fluids of the body are maintained in a narrow pH range at pH 7.35-7.45. This is necessary because chemical reactions are affected by pH, and because most proteins cannot function properly at a pH outside of this range. pH homeostasis is maintained by buffers and related mechanisms. Many metabolic reactions result in the production of hydrogen ions (H+ = protons) and hydroxide ions (OH-) that are found in more acidic or more basic solutions, respectively. An example is the production of H+ by fatty acids in fat metabolism. Buffers have the ability to bind with considerable numbers of hydrogen and hydroxide ions and thus minimize changes in pH. Specifically, a buffer system consists of a weak acid that can donate H+ ions when there are too few, and a corresponding weak base that can accept H+ ions when there are too many. Because of the abundance of blood in the body, the buffer systems in the blood are particularly important.

The most important buffer mechanism in the blood is described in the chemical reaction below. In this buffer system, bicarbonate ions (HCO3-) act as a weak base, and carbonic acid (H2CO3) acts as a weak acid. Both the weak acid and the weak base are found in the plasma portion of the blood.

carbonic anhydrase

H+ + HCO3- <------------- > H2CO3 <-------------------------------> H2O + CO2

Bicarbonate ion carbonic acid

Hydrogen ions readily combine non-enzymatically with bicarbonate ions that are available in the blood, to form carbonic acid, a weak acid. In the presence of the enzyme carbonic anhydrase, which is located inside red blood cells, carbonic acid is converted to water and carbon dioxide. The CO2 is eliminated from the lungs by exhalation. Note that these reactions are reversible. During hydrogen ion excess, more carbon dioxide is formed, and during hydrogen ion deficiency, more free hydrogen ions are released. In addition to red blood cells, carbonic anhydrase is also produced in the kidney by renal tubule cells, and this allows those cells to secrete free hydrogen in the urine as an additional buffer mechanism.

This is the reason urine is acidic.

A hemoglobin molecule, the oxygen carrying pigment in red blood cells, is composed of protein plus a heme group. All proteins are charged molecules and are capable of absorbing hydrogen ions. Thus, the hemoglobin found in red blood cells also acts as a buffer.

**Determination of Blood Hematocrit and RBC Count**

The hematocrit (Hct) is the percentage of red blood cells in whole blood (Figure 6). A normal Hct value of 45% leaves the plasma as 55% of the blood volume. The Hct may fluctuate normally within limits. A hematocrit less than normal indicates that the person has a lower than normal concentration of RBCs in the blood and is anemic. A high hematocrit means that there is a higher than normal concentration of RBCs in the blood. This could be caused by various factors, including dehydration and living at high altitudes where the oxygen content of the air is lower.

The red blood cell count is the number of RBC/mm3 of blood. It can be calculated using a hemocytometer or by machine in hospital labs.

Anemia (reduced oxygen carrying capacity of the blood) is the term used for conditions of reduced numbers of RBCs and/or reduced hemoglobin in the red blood cells. There are a number of causes of anemia including blood loss, kidney failure, iron deficiency anemia, and immune-mediated anemia. Symptoms of anemia include fatigue, becoming out of breath easily, rapid heart rate, and pale gums.

Anemia can occur due to a variety of conditions, each of which would require a different treatment; thus, a series of clinical tests have been developed to determine what type of anemia a person is suffering from. These tests include the Hct, the hemoglobin concentration, and the red blood cell count. The MCV is a measure of the average volume of each red blood cell, and it is calculated using the following equation:

**MCV = [Hct (%) x 10 RBC] / RBC count (10-6/mm3)**