Yale National Initiative
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Curriculum Units by Fellows of the National Initiative
2011 Volume VII: Organs and Artificial Organs

The Cardiovascular System: Mechanics and Dynamics

Curriculum Unit 11.07.03, published September 2011
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Overview

The cardiovascular (or circulatory) system is one of the most vital systems in the human body. This system provides a transport mechanism for oxygen through the body as a fuel source for cellular respiration, and then the return transport of carbon dioxide, a byproduct of cellular respiration, that the body expels as waste through breathing. It also provides for the transport of amino acids, nutrients, hormones, and the other components that make up blood. Cardiovascular diseases of varying sorts are among the leading causes of death in industrialized nations around the world. Understanding the importance of this system in providing the nutrients the body needs for survival is an important step in helping to reduce cardiovascular disease. Proper diet and exercise can help alleviate many of the problems associated with cardiovascular diseases. For areas that cannot be helped (due to normal aging or genetic defects), biomedical engineers have developed sustainable heart valve replacements, artificial hearts, and materials for use in creating artificial blood vessels, and artificial hemoglobin.

Rationale

Seventh grade life science in Georgia is a general study of biology including an introduction to the kingdoms of life, the interdependence of life, and the structure of life. The state standards require students to understand the structure of cells and their functions as well as how cells form tissues, organs, and organ systems. Unfortunately a fascination for the human body is never developed through these lessons; rather, students are taught in depth about the cell and in limited breadth of tissue and organs.

This unit takes an alternate approach, to provide an interesting backdrop about one body system and its functions. Through the instruction of this unit students will be able to redefine their understanding of cell structure and apply it to an understanding of oxygen transport in the body through the circulatory system. This will also allow for further study into the structure of the cardiovascular system. This will be accomplished by developing an understanding of the physical structure of the circulatory system, and the relation of this structure to function. This unit is designed to be conceptual in nature and not delve into the technical nature of the math associated with it. The reason for concentrating on the conceptual route is that it will provide a greater understanding of the properties associated with the system, at a level which students and teachers at this age range can feel comfortable with. The culmination of the unit will be a developed understanding of the advancements taking place in research facilities around the world in order to better maintain the human body.

The Circulatory System

The circulatory system is made up of the heart and the blood vessels, which are the arteries, veins and capillaries, and the fluid or the blood itself. Failure of any of these components can result in a catastrophic failure of the entire system. The heart provides the driving force behind the circulatory system as it acts as the hydraulic pump for the body constantly moving the blood in a continuous flow though the various vessels. The action of the heart is dynamic and measurable: for example, blood pressure can be measured as the result of the heart contracting and relaxing. The blood vessels act as the carrying agent. Capillaries (the smallest of the blood vessels) provide the mechanism for oxygen to transport via diffusion through the vessel walls to all of the cells in the body. Blood is a combination of red blood cells, white blood cells, platelets, and blood plasma. It is the red blood cells that facilitate the transport of oxygen from the lungs into the circulatory system; this is accomplished by the iron-based protein hemoglobin which allows for the transport and binding of oxygen as hemoglobin enhances oxygen solubility.

Heart

The heart represents the basic organ that is understood at least in part by, most individuals. Young children understand at least basic functions of the heart. They understand it beats rhythmically over and over again. They draw pictures of a heart (granted, not anatomically correct), most understand that blood flows because of the heart, and most seem to understand that without the heart functioning you die. These are easy concepts to understand, unfortunately, we usually do not go much beyond that in the middle school classroom. The following represents a bit more information, which should be provided in order to have students understand concepts at their age level.

The heart is a hydraulic pump in an organic system that works without rest through the course of a lifetime. During a lifetime the heart will beat approximately 3 billion times, pushing 5 liters of blood around the body every minute. This represents a tremendous amount of work; there are few manmade devices being used in the world today that could stand up to these same rigors for 80 years.

The structure of the heart is related to its function. The heart is asymmetrical in appearance with the right side being slightly smaller in muscle size than the left. Upon dissection, the heart has four chambers, each isolated by a set of four valves. In the upper hemisphere of the heart are the atria, and the lower hemisphere are the ventricles (figure 1).

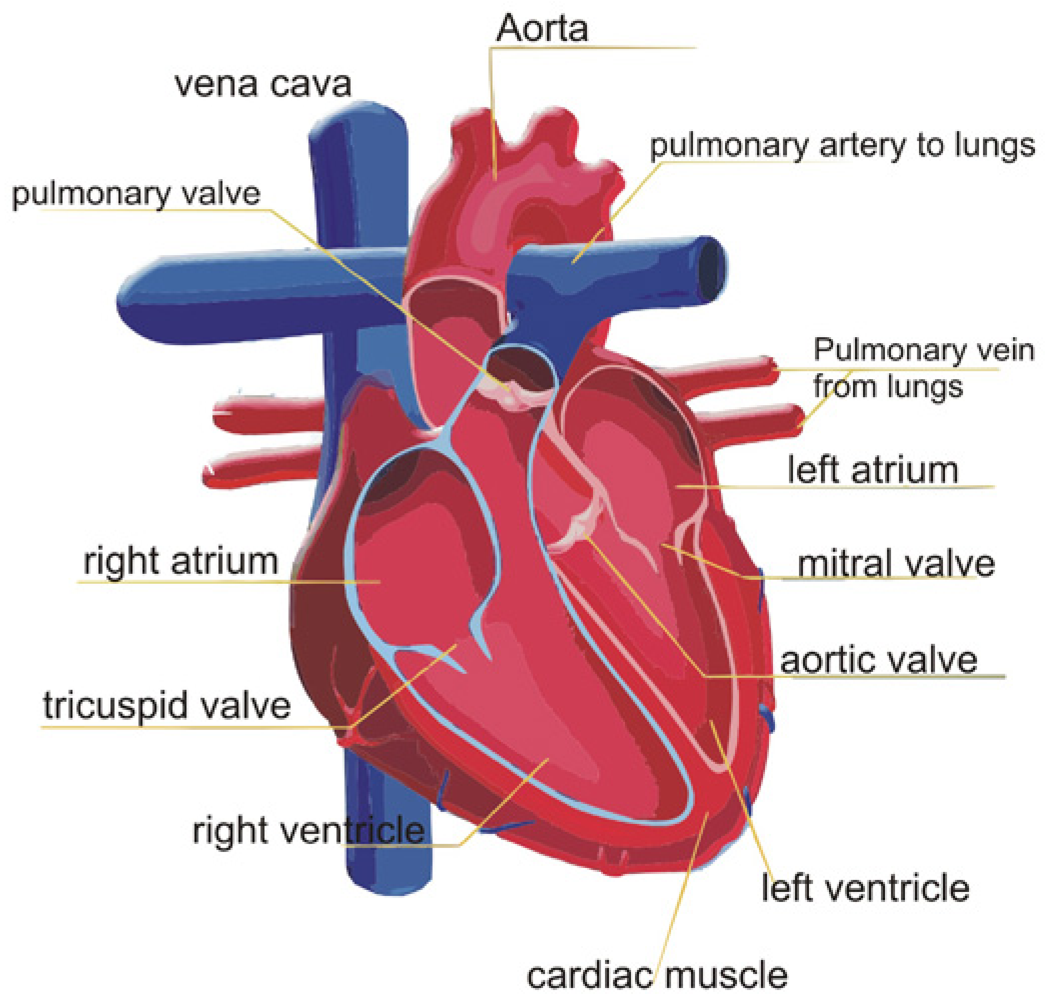

figure 1 (drawn by Stephen Griffith)

Oxygen-poor and carbon dioxide-rich blood flows into the right atrium from the body and is contained there momentarily until the opening of the tricuspid valve, which allows it to travel into the right ventricle (this process happens during diastole, one part of a complete cardiac cycle). During systole, the second part of the cardiac cycle, the heart muscles contract. The atrium contracts first, producing an additional blood flow from the right atrium to the right ventricle. Once the right ventricle fills completely the ventricle contracts allowing for a rush of blood up through the pulmonary valve and into the pulmonary artery where the blood will be transported to the lungs in order to allow the carbon dioxide to exit the blood and allow for an intake of oxygen. The structure of the heart with its valves allows for the heart to work while preventing backflow into the chambers due to low pressure drops when certain chambers are empty or filled.

This process is repeated as oxygen rich blood returns to the left atrium from the lungs via the pulmonary veins. When the mitral valve opens, blood flows into the left ventricle. During the same beat which previously allowed the right ventricle to contract (systole) the left ventricle contracts pushing the blood through the aortic valve and into the aorta. The aorta carries oxygen rich blood to the systemic circulation, which provides the entire body oxygen.

The heart also has its own circulatory system allowing for transport of oxygen to the muscle tissue of the heart. The heart is made from cardiac muscle, which is unlike the skeletal muscle that allows the body to accomplish voluntary motion. Cardiac muscle contractions are involuntary: the heart will continue beating whether we are thinking about it or not. This occurs due to the electrical impulses that originate in the sinoatrial node located near the top of the right atrium. When humans exercise the increase in the heart rate is a direct result of the cells needing oxygen at a faster rate and therefore the blood must deliver it at a higher flow rate through the body.

Blood Pressure

Blood pressure is so much more then the test that we take when we go to the doctor. It is important to get these tests as they do help to indicate stresses on the body and possible cardiac problems. A routine blood pressure measurement is concerned with arterial blood pressure, that is, the pressure as blood is leaving the heart, where the pressure is highest. But blood pressure varies throughout the body.

Blood pressure measured when you go to the doctor is recorded in millimeters (mm) of mercury (Hg). Average air pressure is 760 mm of Hg. Average blood pressure is 120 mmHg over 80 mmHg, with the first number representing systole, and the second measuring diastole. The numbers represent the relative pressure in the blood, which is above atmospheric pressure. This means that the actual pressure in the body is 760mm of Hg plus the systole or the diastole number.

Blood pressure is generated by the rhythmic pumping of the heart. Here, I focus on the action of the left side of the heart. Figure 2 shows the cardiac cycle. The length of time for the cardiac cycle is .8s for a person with an average heartbeat of 72-74 beats per minutes. As blood flows into the heart from the lungs it enters the left atrium and is prevented from entering the left ventricle by the closed mitral valve. The mitral valve opens as the upper hemisphere of the heart contracts forcing the blood into the ventricle. Contraction of the muscle in the ventricle forces blood up through the aortic valve and into the aorta at high pressure. The pressure produces blood flow through the body. As the ventricle relaxes, the aortic valve closes, preventing backflow into the ventricle. [1]

In figure two, the top picture follows the cardiac cycle starting in late diastole. The graph below the diagram emphasizes changes in pressure in different regions of the heart. The aortic pressure goes through a periodic increase and decrease in pressure, between diastole and systole, with its lowest (diastole) being about 40 mm of Hg less than the greatest (systole). Blood pressure measured by your doctor reflects the pressure changes in the aorta. [2]

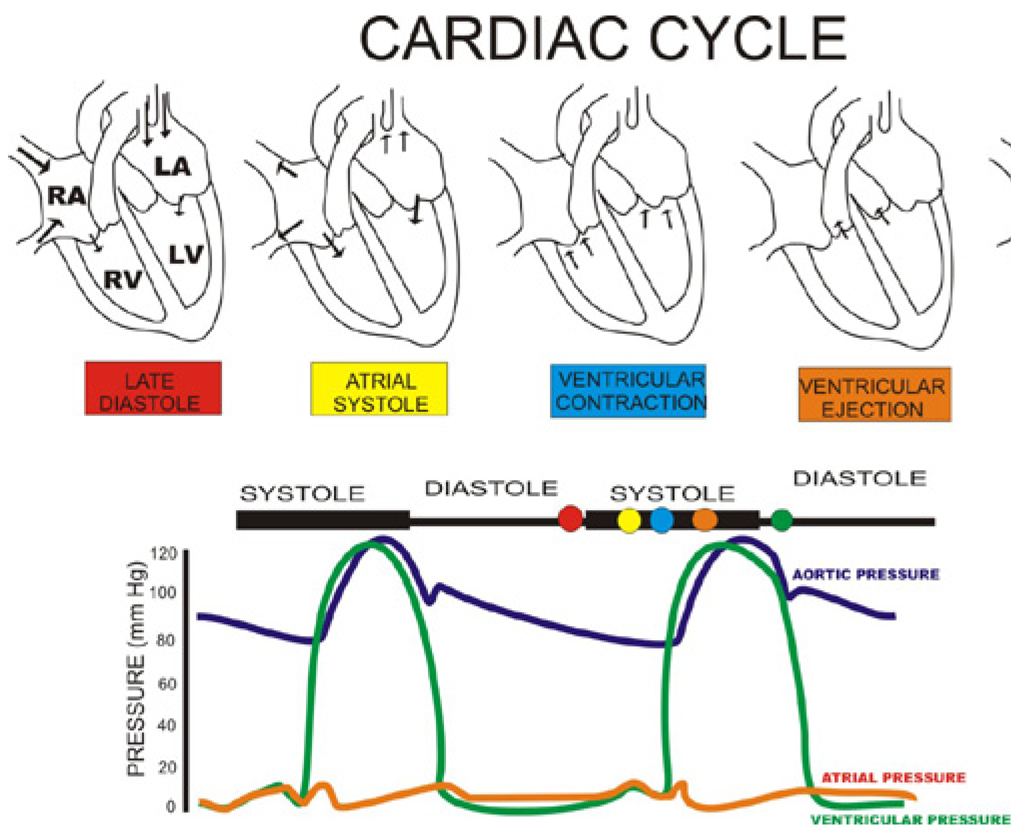

figure 2 (drawn by Stephen Griffith)

Blood Vessels

The blood vessels make up the vascular system. The three main parts are: arteries, which consist of vessels taking blood away from the heart; veins, which are vessels that take blood to the heart; and capillaries, which are the vessels that connect the arteries and veins together to form the complete circuit.

The vascular tree allows the vascular system to create multiple pathways for the blood to flow, so that it can ultimately reach all areas of the body and deliver oxygen to the cells. These pathways appear as branches from aorta. At each branch or bifurcation, the original is split into two new pathways. At each bifurcation, the diameter of the vessel also gets smaller.

Arteries

Arteries are the vessels that carry the flow of blood from the heart. The arteries can be broken down into smaller constituent components beginning with the aorta, followed by the large arteries, which branch into progressively smaller arteries, and finally the arterioles.

All arteries have similar layered structures, with the primary difference being their diminishing size. The layers are: the innermost, or tunica intima, the center section, or tunica media, and the outermost, or tunica adventitia. These vessels are made up primarily of elastin (which acts as a connective tissue that resumes its primary shape after stretching), collagen (the connective tissue between the layers), and smooth muscle (which provides active constriction and relaxation of the vessels). [3] There is also a network of very fine blood vessels traveling through the arterial walls allowing for the diffusion of oxygen to take place for the cells and tissue that make up this region.

A cross section of an artery reveals that the innermost section consists of a layer of endothelial cells, connective tissue, and basement membrane. The inner section of the blood vessels (tunica intima) has a thin layer of the endothelial cells in order to prevent blood clotting and lower turbulence created by the flow of blood. The middle layer of the arteries (tunica media) are made up primarily of a "prominent layer of elastic tissue" which helps to provide the flexibility needed for vessels to constrict and relax in order to help regulate blood flow in the system. The outermost layer (tunica adventitia) is made up "mostly of stiff collagenous fibers". [4]

The elastic tissue in the arteries are concentrically distributed and attached by smooth muscle cells and connective tissue. As bifurcations occur, from the aorta down through large and small arteries, the number of elastic laminae decreases with distance from the aorta, but the amount of smooth muscles increases as well as the relative wall thickness of the vessels. This is a needed byproduct of the function of the arteries: their ability to constrict and relax helps to control the flow of blood and thus blood pressure. [5]

Coronary Arteries

The coronary arteries are a network of small arteries found on the surface of the heart. These vessels are extremely important to the health of an individual, as they provide the pathways for blood flow, and therefore oxygen delivery, to the tissue of the heart. Due to the small diameter of these vessels, they are susceptible to blockage.

Arterioles

The arterioles are small diameter blood vessels at the end of the arterial system. This is the area where the greatest amount of pressure drop takes place in the circulatory system, as this is where regional variations in blood flow are regulated. Although similar in structure to the rest of the artery system, there are some key differences that should be noted. Similar to the other parts of the arterial system these areas have the ability to contract restricting blood flow, and also relax allowing for greater flow.

Capillaries

Capillaries are largely ignored in middle school textbooks, simply being referred to as the region where the arteries and the veins are connected. There is little discussion about why they are so small or what there purpose is. The reality is that the capillaries are an integral part of the circulatory system for without them there would not be any transport of oxygen to the cells of the body and those cells would perish.

Capillary structure is simpler than arterial structure. The capillaries are made of endothelial cells in a single layer joined together with molecular cement. The diameter of the capillaries varies throughout the circulation, but is often the width of a red cell, meaning the cells need to line up in order to pass through these vessels. This confluent monolayer of endothelial cells does not allow blood cells to seep through the capillary wall, but it does allow for a leakage of oxygen, glucose, carbon dioxide, and even some proteins. This leakage, which is often driven by molecular diffusion, gives the capillary bed an essential role in the circulatory system. [6]

Veins

The veins carry the flow of blood back to the heart. In the systemic circulation, venous blood is low in oxygen content but high in carbon dioxide. In the pulmonary veins, which are bringing blood back to the heart from the lungs, the veins contain oxygenated blood. The smallest veins, called venules, are directly connected to the capillaries. Smaller veins join together to form larger veins, with the largest vessels returning blood to the heart. The blood flowing through the veins is passive in nature as the veins do not have the smooth muscle that the arteries have and therefore do not contract and relax in order to promote higher or lower resistance to flow. Flow through veins, which occurs at low pressure, is unidirectional by the presence of valves within many veins, allowing the blood to only flow towards the heart. The walls of veins are collagenous, similar to the arterial wall, and veins have the same trilayer structure as arteries, but the layers are less distinct. There are smooth muscles associated with the tunica media of some veins, but they are not as organized or abundant as in arteries. Veins, like all vessels in the circulatory system, are covered with endothelial cells on their lumenal surface (the side containing the blood). [7]

Vascular Tree

The blood vessels that lead away from the heart go through a series of bifurcations. These bifurcations are associated with a diminishing size of the blood vessels. Although bifurcation is the most common form of branching in the system there is also trifurcation and multiple (more than three) branching throughout the circulatory system in order to meet the demands of supplying oxygen to all cells and tissue of the body. This bifurcation continues to occur at regular intervals as the vessels get further from the heart and nearer regions that the oxygen is needed. In order for oxygen diffusion to occur properly there must be both a sufficient drop in size of the blood vessel and a sufficient number of vessels to reach cells within all regions of the body.

As in any system that is produced by sequential bifurcations, the overall surface area of the blood vessels increases with each generation of bifurcation. By analogy, imagine the bifurcating branches of an oak tree: the majority of the trees total surface area is contained on the smallest branches, which outnumber the trunk and large branches. Because the total cross-sectional area of all smallest branches also increases, the velocity of blood is slowest in the capillaries. The total flow rate from the heart is 5 l/min and remains constant throughout the cycle; the flow rate at any point in the bifurcating network (that is, at any distance from the heart) is equal to the velocity of flow times the total cross-sectional area at that point.

The variation of velocity throughout the circulatory system has important consequences. Because the same volume of blood must flow through each segment of the circulation each minute, the velocity of blood flow is inversely proportional to vascular cross-sectional area. The cross sectional area for an adult human aorta is approximately 2.5cm^2 compared to the cross sectional area of the capillary bed which is approximately 2500 cm^2. But the overall flow rate of blood is 5 l/min in both of these sections. Due to this difference in area though the velocity of the blood at the aorta is ~2,000 cm/min (5,000 cm^3/min divided by 2.5 cm^2) whereas the velocity in the capillaries is ~2 cm/min (or 0.3 cm/sec). This tremendous slowing of the blood velocity in the capillary section provides the time needed for oxygen (and other molecules) to diffuse across the thin vascular walls of the capillaries. [8]

To understand this in more general terms, consider a garden hose that is split into two hoses at a Y junction, and then each of these two hoses is further split by Y junctions thus creating a tree-like structure, in which one tube flows into four. Also consider a reduction in overall diameter of the hose at each Y junction from a 1" hose, down to a ¾" hose continuing down to hose with a diameter of ¼". The flowrate of water going through each segment of the hose must be identical, replicating total flow through the cardiovascular system. Although the flowrate is identical, the velocity of through each section is different, due to the different cross sectional area in the different regions that are produced by bifurcation.

Figure 3 shows the blood pressure variations throughout the systemic circulation. As the blood leaves the heart, the blood pressure fluctuates between the systolic and diastolic pressure. As you progress to the right on the diagram, multiple branchings have taken place and then you see the biggest drop in pressure at the arteriole region. Finally there is a drop at the capillary region down to almost zero (note that zero on the graph is not zero pressure, it is equal to one atmospheric pressure of 760mm of Hg). Pressure differences are the driving force for flow through the circulatory system: the higher pressure in the aorta drives flow into the lower pressure regions: to arteriole and then to capillary. [9]

As blood flows through the capillary bed, and diffusion is taking place, oxygen is lost from the blood and carbon dioxide is collected. This oxygen-poor, carbon dioxide-rich blood flows into the veins. Instead of a decrease in size associated with each branching from the aorta to the capillaries, the numerous capillaries join together to create larger venules, and the venules join together to create larger veins. There is an increase in overall diameter of the veins until the branching ceases at the vena cava and heart. The veins are a passive conduit for carrying the blood (controlled by the initial compression and contraction of the heart, arteries and arterioles) emphasizing the need for unidirectional valves inside of the veins in order to prevent backflow of blood.

The right side of the heart pumps blood to the lung region, which is geographically centered around the cardiac region. Figure 3 shows that the pressure in the pulmonary circulation is much lower than the systemic pressure. As the blood leaves the heart through the pulmonary artery it must again go through a vast array of branching to allow for a significant amount of capillaries in the lung region. The reverse is then happening once again as it ravels back to the left atrium of the heart. All of this is possible due to the complexity of the vascular branching, which results in the vascular tree. [10]

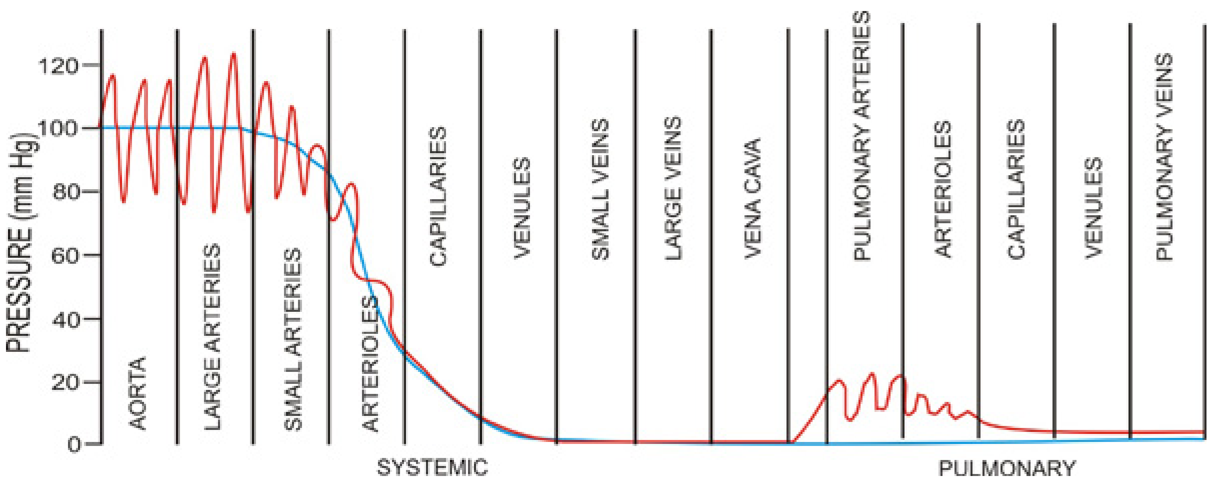

figure 3 (drawn by Stephen Griffith)

Teaching Strategies

This section presents one approach to teaching middle grade learners the information on cardiovascular physiology that has just been presented. The information should be presented in a two week unit for a class that meets daily or a three week unit for classes that meet on a block schedule every other day. Depending on the level of learners in the class the information can be expanded to by using the information in the resources found in the bibliography section of this paper.

Getting Started

This unit is designed to enhance and enrich the education already taking place in a general life science class. The information contained is for furthering background information to an instructor in the classroom that has limited resources based on the limits of textbooks for the middle school age children.

The instruction is to be focused on tying everything together about cells, tissue, organs, and organ systems in order to create a better framework of concepts for students. Instruction of the cell should be as complete as possible prior to teaching this unit: including the structures of different cells, the organelles and their functions, and the mechanisms for transport materials into and out of the cell. Students should also have a foundation of specialized cell structures for use in different tissues in order to make up different organs. Once students have achieved mastery on this they are ready to delve deeper into one organ system, this being the cardiovascular system.

The framework for explaining and enriching students should follow same flow as the background information of this paper. Students should then be introduced to the parts of the cardiovascular system focusing on the structure and function of the heart, what blood pressure is, and the vast vascular network the blood flows through. This concludes with a section on cellular respiration as it ties all the information learned back to the functions of the cell and develops in students the relationship between cells, tissue, organs, and organ systems.

Cellular Respiration and Tying it Together

Cellular respiration is briefly taught in seventh grade life science in Georgia. In brief, I mean to suggest that students are shown the equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

After the equation has been shared, there is little else on the subject in the curriculum, even though students in Georgia receive a 12 week session of chemistry in 8 th grade. This provides an additional opportunity within the framework of this unit to further explain this concept and further prepare students for the next level in science they will encounter.

By presenting concepts of the heart as the pump and the blood as the carrier of oxygen through the network of blood vessels, students will gain a clearer understanding of what is actually happening in the cardiovascular system of the body. Utilizing this unit as a counterpart to a unit on cells provides a natural outgrowth of knowledge by introducing students to different cells needed for the different tissue layers of the cardiovascular system. Once students understand that cells allow certain molecules to cross their membrane (and enter or exit the cell), they will be able to grasp the concepts of cellular respiration more readily. Students can be taught how oxygen diffusion occurs in the alveoli of the lungs to the red blood cells in the capillary system found in the lungs.

Understanding of the heart and its dynamics will help to illustrate the intricate workings of this system as a transportation network to the other organs of the body allowing teachers the flexibility to continue this process by discussing the pancreas and glucose exchange, which also utilize the circulatory system. Students can then through demonstrations in the classroom of diffusion which is also a concept students must learn.

The following are some basic activities that could be used in the classroom for enriching and further explaining these concepts.

Teaching Activities

Although limited by space in this document, there are a plethora of teaching ideas and strategies that can be used for creating mastery of the concepts being taught that can be found on the Internet with a simple search. In order to provide a start and some examples of what to do the following are explored further at the end of this document.

The first is a blood pressure / pulse rate lab that is easy to complete in a classroom, but allows students to understand the reasons for intense pressure, and also why the pulse needs to be sped up at times of work compared to times at rest.

Another important aspect is understanding the velocity of the blood, and how it varies in different size blood vessels, which can be accomplished by following some simple instructions that are provided below in demonstrating how blood velocity increases and decreases based on the diameter of the vessel.

To tie everything together it is important for students to understand the concept of different size blood vessels and the diffusion of gasses across the membrane of different vessels. In order to do this there are instructions of using Jell-o to demonstrate how students can determine this in order to enhance knowledge of cellular respiration by showing the diffusion of a liquid through the Jell-O membrane.

CLASSROOM ACTIVITIES

Resting Heart Rate

Purpose: To learn how to measure your pulse or heart rate.

Materials: A stopwatch, a lab sheet, and a pencil.

Procedure:

1. Divide students into pairs. As one student takes their pulse one student will

time.

2. Students must then choose a pulse point on their body, which they will use to

detect their heart rate.

Finding Pulse Points and Your Heart Rate:

1. Feel with the fingertips of your index and middle finger for your pulse point until

you detect pulsations.

2. Keep yourself as still as possible while you are taking your heart rate.

3. Count the number of heartbeats you feel in one minute. Record the results.

4. Now repeat steps 1-3 measuring your heart rate at a different pulse point.

5. Repeat the procedure for your partner.

6. Graph and compare results.

Pressure

Purpose: To learn how to measure your blood pressure.

Materials: A sphygmomanometer (blood pressure cuff), a stethoscope, a lab sheet, and a pen or pencil.

Procedure:

1. Divide students into pairs.

2. One student will be the patient having his/her blood pressure measured. The other student will be the student doctor who measures the blood pressure.

3. Switch jobs.

How to measure blood pressure:

1. Student patient should extend arm on table with palm up.

2. Place blood pressure cuff above the bend in the arm. The cuff should be snug yet have enough room to insert two fingers.

3. Check to see if valve is open or closed.

4. Place stethoscope ear tips into ear.

5. Position stethoscope on arm to hear pulse.

6. Pump pressure up to 180 mm.

7. Release valve slowly.

8. The first pulse sound you hear as you release the valve is the systolic pressure. Have the student patient place their finger on the number of the first sound to mark the spot.

9. Continue to release the valve. Approximately 40 mm down from the first sound you will hear is called the diastolic pressure.

10. Record the systolic and the diastolic pressure on the chart.

11. Jog in place for two minutes.

12. Repeat steps 1-10.

13. Record results.

14. Make a bar graph of results.

15. Present, analyze, and compare results in class.

Factors Affecting Blood Pressure and Heart Rate

Purpose: To analyze the factors that may affect heart rate.

Materials (per group): A sphygmomanometer, a stethoscope, a clock or stopwatch, a student handout, a graph paper, and a pen or pencil.

Procedure:

1. Assign students to lab groups of four.

2. In your group choose two students to measure the heart rate and two students to

measure the blood pressure.

3. Heart rate pair: Take resting heart rate and record. Blood pressure pair: Take

resting blood pressure and record.

4. The group will then choose two factors that they believe will cause a change in

heart rate and blood pressure.

5. Test these factors and collect the data using time as an independent variable.

6. Graph and analyze results.

7. Present and compare results with class.

Flow Rate of Blood

Purpose: A lab activity for students to gain an understanding of the flow rate of blood

Procedure: When teaching the vascular system one can easily demonstrate the constriction of blood vessels by using different sizes (diameter) of PVC pipes and skittles or another candy the students may wish to eat. Using three different sizes of pipe 1", ½", and ¼" students will be given a bag of skittles and will have to determine how fast they can get all of the skittles through each size pipe as well as determining how many they could then get through in a full minute of time.

Students will discover that the larger diameter pipe allows fast movement of the particles (skittles) through the pipe while the smaller diameter pipe takes more time in order for the same amount of material to flow. Using this information, students can create a table that shows how many more of the smaller diameter pipes they would need in order to get the same amount of flow of particles in a 1 minute time period. This will help demonstrate and create the ideas behind the need for bifurcation of the vascular system.

Jell-O blood vessels

Purpose: An activity where students can study the flow rate of diffusion across different diameter semi-permeable membranes.

Materials: A tincture of iodine, cornstarch/water solution, plastic sandwich bags (cheap is good), and beakers or plastic cups.

Procedure (can be done by teacher or student): Fill beaker about halfway and put about ten drops of iodine. Put about a teaspoon of starch and about 50 ml of water in baggie and tie. (Actual measurements can vary) Put the baggie in the beaker and wait. In about 15 minutes the solution in the baggie will turn purple as a result of the iodine diffusing through the bag. You may want to discuss with students beforehand that iodine is an indicator for starch.

Possible discussion questions: The plastic bag is permeable to which substance? Why did the iodine enter the bag? Why didn't the starch enter the beaker? How is the plastic bag like the cell membrane?

Going Further

Using PVC pipes from blood velocity experiment use clear wrap inside of each pipe and fill completely with Jell-O. Before placing in refrigerator to gel fill a straw for each pipe with water and red food coloring capping both ends with clay and carefully place in center of each pipe (meaning pipes must stand up in refrigerator in order to gel).

For experimentation students remove Jell-O cast of pip and place in a tray. Student removes straw and caps hole where straw came out with clay leaving behind the dyed water. Students can then observe diffusion through the different thickness materials seeing that it will not completely diffuse through the largest diameter pipe, but will completely go through the smallest diameter pipe. This helps demonstrate the diffusion of oxygen through the blood vessels and shows that the arteries do need diffusion of oxygen in them in order for survival of smooth muscle cells, and also shows that the small capillaries will allow complete diffusion of oxygen across the capillary walls.

Appendix

The Georgia Standards that are used in the framework of this unit are:

S7L2: Students will describe the structure and functions of cells, tissues, organs, and organ systems.

a. Explain that cells take in nutrients in order to grow and divide and to make needed materials.

b. Relate cell structures (cell membrane, nucleus, cytoplasm, chloroplasts, mitochondria) to basic cell functions.

c. Explain that cells are organized into tissues, tissues into organs, organs into systems, and systems into organisms.

d. Explain that tissues, organs, and organ systems serve the needs cells have for oxygen, food, and waste removal.

e. Explain the purpose of major organ systems in the human body**.**

Acknowledgement

I would like to thank the teamwork achieved during the 2011 Yale National Initiative between myself and Eric Laurenson of the Pittsburgh Teachers Institute. Together we combined efforts in designing and creating a working model of a pumping heart which was invaluable to the overall understanding of the function of the heart and as a result gives me the ability to make a working heart to use as a demonstration for the students in the classroom. This project was also designed to produce a working vascular tree with bifurcations going from a large diameter hose of 5/8" representing the Aorta to a ¼" tube representing capillaries with the other sizes being ½", and 5/16" thus replicating the arterial and venous system of the vascular system as a demonstration of the pressure drop that occurs from the aorta to the capillary bed.

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Up to date and fresh. A look at how the venous system works and how to model it in chapters 12 - 14.

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Dated in some respects as microbiology has made huge advances, but for the macrosystem of the vascular very helpful.

End Notes

1. 1 Rushmer, Robert F.. *Organ physiology: structure and function of the cardiovascular*
2. 2 ibid p 40-67
3. 3 Li, John K. *Dynamics of the vascular system* p384 ibid p42
4. 5 ibid p48
5. 6 Batzel, Jerry J.. *Cardiovascular and respiratory systems: modeling, analysis, and control*
6. 7 Berne, Robert M., and Matthew N. Levy. *Cardiovascular physiology*
7. 8 ibid p58
8. 9 ibid p62-70
9. 10 Peterson, Donald R., and Joseph D. Bronzino. *Biomechanics: principles and applications*