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The Human Circulatory and Respiratory Systems

Objective

Students will understand the components and functions of the human circulatory and respiratory systems, and how they are related.

National Science Education Standards

Content Standard A: Science as Inquiry (9-12)
  Understandings about Scientific Inquiry
Content Standard C: Life Science (9-12)
  Matter, Energy, and Organization in Living Systems

Warm-Up

1. Ask students to guess which structures of the body, if laid end to end, would have a total length of more than 60,000 miles, or two and a half times the diameter of Earth. (Answer: blood vessels which include arteries, veins, and capillaries)

2. Ask students to guess how many gallons of blood the heart pumps in a day, and guide them by telling them to guess "higher" or "lower" until they guess the answer (about 1000 gallons per day).

3. Ask students to think back to when they were little, and to raise their hands if they ever remember telling their parents they were going to hold their breath if they didn't get their way about something. Next ask them why they think that didn't work out so well, and remind them that should be thinking of *physiological* reasons.

The Circulatory (or Cardiovascular) System

The human circulatory system is composed of the heart, blood, and blood vessels. Its function is to distribute oxygen and nutrients to tissues and organs, and to carry away waste products. It also regulates body temperature, carries immune system cells to sites of infection or injury, and is responsible for blood clotting. *(For animations and interactive graphics of the circulatory system, please see the links listed under Additional Resources.)*

Heart

The **heart** consists of four chambers: two **ventricles** which pump blood out of the heart, and two **atria** which receive blood from the body. It is a muscular organ about the size of your fist, and has the tireless job of pumping about 1000 gallons of blood through your body every day.

Each heartbeat has two stages: **systole**, when the heart contracts to pump the blood, and **diastole**, when the heart is at rest. The "thump" that we associate with a heartbeat is actually the sound of heart valves closing. **Blood pressure** is the pressure generated when the heart pushes blood to the arteries. A certain level of pressure is needed to ensure that blood keeps flowing through the body. This pressure is what prevents blood from gathering in the lower body when we stand up quickly. Blood pressure is measured during systole and diastole using a sphygmomanometer, and is expressed as a ratio. For example, the normal reading for blood pressure is about 120/80, though it can vary throughout the day in response to emotions, sleep, or physical changes.

Blood

Blood has many critical functions in the body. It carries nutrients, water and oxygen to the body's cells, carries carbon dioxide and other wastes away for removal, helps regulate body temperature, and contains infection-fighting cells and chemicals that maintain appropriate pH levels, clots when there is an injury and closes off injured blood vessels. Blood consists of **red blood cells**, which are formed in the bone marrow and contain a substance called **hemoglobin** which binds to oxygen. Hemoglobin allows a red blood cell to carry about fifty times more oxygen than it normally would. **White blood cells** are the infection-fighting components of the blood, and are produced by the spleen, lymph glands, and in the marrow of long bones. Platelets function in blood clotting when there is a wound and, like the other cells, are formed in the bone marrow. **Plasma** is the liquid part of blood, which is about 90% water and has a yellowish color. In addition to containing the other cells mentioned above, plasma contains fats, proteins, salts, vitamins, minerals, dissolved gases, and hormones.

Blood Vessels

Arteries, veins, and capillaries are the three types of blood vessels that transport blood throughout the body. **Arteries** carry blood away from the heart and are thick-walled, muscular and elastic. These vessels can have diameters that range from a fraction of an inch to about one inch, and branch out into even smaller **arterioles**. **Veins** carry blood to the heart for purification, and have thin walls and valves to prevent the backflow of blood away from the heart. Like the arteries, veins branch out into smaller vessels called **venules**. Blood travels through the veins at a lower pressure than in the arteries, which have to withstand the pressure of blood pumping out of the heart. **Capillaries** connect the smaller arteries with the veins, and blood cells flow through them in single file. These tiny vessels can only be seen with a microscope, and if ten were place side by side, they would be only about the thickness of a single human hair. In summary, the direction of blood flow is as follows:

Heart → Arteries → Arterioles → Capillaries → Venules → Veins → Heart

During exercise, blood vessels expand as demand for blood increases, and is used to cool the body. Muscles used during physical activity generate heat, which is absorbed by the blood as it carries the heat to other parts of the body. Blood vessels near the skin surface enlarge in order to let the heat out, and the opposite happens in cold environments.

Historically Speaking

The discovery that blood moves in a cycle throughout the body is fairly new (about 400 years). Scientists in the sixteenth century thought that new blood was constantly created in the liver, gained warmth when it passed through the heart, and was then absorbed by the body tissues. An English physician was the first to theorize that veins have one-way valves that lead blood back to the heart, and that the heart worked as a very efficient pump, moving about four tons of blood per day. He argued that earlier theories were foolish in the presumption that the liver could produce this much blood on a daily basis. His theory was later proven correct, and now forms the basis of medical science today.

There are two systems of blood circulation in the body. **Systemic circulation** transports oxygenated blood from the heart to the rest of the body except the lungs, and returns to the heart carrying blood that is deoxygenated and contains waste products. In **pulmonary circulation**, blood is carried from the heart to the lungs where it absorbs oxygen and leaves carbon dioxide, which is eliminated when we exhale. On average, it takes about thirty seconds for a blood cell to make one loop through either the pulmonary or systemic circuit.

The Respiratory System

When we take a breath, air enters the **nose**, moves through the nasal passages, down the throat into the **larynx** (where the vocal cords are located), and then into the **trachea**, which is also known as the windpipe. The trachea then divides into right and left **bronchial tubes** that enter the **lungs**. These bronchi further divide into **bronchioles**, which are less than 1 millimeter in diameter. These tiny tubes narrow into still smaller tubes, known as **alveolar ducts**. At the end of each duct is a cluster of air sacs, called **alveoli**, which resemble a bunch of grapes. There are more than 300 million alveoli in each lung, with a combined surface area of about 70 square meters, or about 35 times the surface area of the skin. Alveoli are located very close (no more than one cell away) to the capillaries, which receive blood from the arteries. Gas exchange occurs at the alveoli/capillary interface through the process of **diffusion** (the movement of materials from a higher to lower concentration.) As air diffuses into the blood in the capillaries, these blood vessels take up oxygen that is carried to the heart. At the same time, the blood releases carbon dioxide, which is eliminated through the lungs when we exhale.

How We Breathe

Breathing is the process we use to move air into and out of our lungs, but the word "breathing" is often used incorrectly in place of "respiration." Respiration is actually the various processes that we use to get oxygen to our body tissues, and includes breathing, transport of oxygen and carbon dioxide in the blood, and the process of gas exchange by diffusion.

Breathing has two phases: **inspiration** (inhaling) and **expiration** (exhaling). When we inhale, muscles in the chest wall contract, lift the **ribs**, and pull them outward. The **diaphragm** (the muscle between the chest and abdominal cavity) moves downward, expanding the chest cavity along with the lungs. Air is pulled into the lungs because the air pressure inside the lungs is lower than the pressure outside the lungs. During expiration, the muscles that lifted the ribs and moved the diaphragm relax, the lungs contract, and air is released. About 500 ml of air is moved with each breath.

Don't Hold Your Breath

You can vary your rate of breathing, and can even stop breathing for a short time, but have you ever wondered why you can't hold your breath indefinitely? The reason is because breathing, like our heartbeats, is controlled by nerve centers in the lower part of the brain, and involves both involuntary and voluntary responses. The breathing nerve centers are connected to the rib muscles and diaphragm, and react when they sense that carbon dioxide levels are rising: they increase the rate and depth of breathing. This is why when you exercise, your heart rate increases in order to supply more oxygen-rich blood to the muscles, and you breathe more rapidly and deeply. The nerve centers sense a buildup of carbon dioxide, and they react accordingly by moving the muscles involved in respiration.

If you were to go hiking in mountains that were at an altitude above 10,000 feet, you might notice a loss of appetite or nausea. This is termed "mountain sickness" and results from a decrease in atmospheric pressure, which causes the amount of oxygen in the blood's hemoglobin to decrease. This results in less oxygen in the blood, and the sickness symptoms actually stem from a loss of carbon dioxide due to increased breathing as the body tries to take in more oxygen. People who are born at high altitudes actually have more alveoli and lung capillaries as adults than do people born at lower altitudes. Animals that live high up in the mountains have also adapted to the altitude by forming hemoglobin that has a higher affinity for oxygen.

Student Activities

1. Calculate the number of heartbeats and number of breaths you've taken so far at:
http://cgi.intellihealth.com/IH/ihtIH/WSDSC000/9273/24321.html
Based on your answers, calculate the number per year, month, and day. Compare and discuss your results with the rest of the class.

2. One of the goals of the Global Heartbeat program is to help students realize that all living things are interconnected. Compare your circulatory and respiratory systems with those of a crab (see related lesson on crabs). Give specific examples of how crabs and humans could both be affected by the same polluted estuary.

3. Visit the website below, which contains an experiment for measuring lung capacity using a balloon and a ruler.
http://www.geocities.com/CapeCanaveral/Hall/1410/lab-B-23.html
Try the experiment and fill in the data table. Discuss and compare your results with fellow students.

4. Some marine mammals are able to dive deep in search of food and have certain respiratory adaptations that allow them to do so. For example, the Weddell seal can dive to depths of 1200 feet and stay there for over an hour. By using the Internet or other sources, describe this animal's

respiratory adaptations by comparing its oxygen storage capabilities to that of a human, and explain how it can withstand pressure at extreme depths.

Assessment

Have students work in small groups. Tell them they are a public relations team who have been assigned the task of creating a travel brochure which advertises tours of the human circulatory and respiratory systems. The brochure should contain information about the components and functions of each system, how the systems are related, and should contain the words in this lesson that are in bold type. Students may also need to do additional research to find interesting facts to use in promoting their tour. Ask students to present their brochures to the class.

Additional Resources

Pulmonary and Systemic Circulation
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/Circulation.html

Science Museum of Minnesota - 11 Lessons on the Heart and Lungs
http://www.smm.org/heart/lessons/top.html

Interactive Exploration of the Heart
http://www.smm.org/studio3d/julie/hearthome.htm

Photos and Videos of Heart Surgery
http://www.smm.org/heart/videos/top.html

Animation of Blood Pumping Through the Heart
http://www.smm.org/heart/heart/pumping-f.htm

Animation of the Respiratory System
http://www.smm.org/heart/lungs/breathing-f.htm

An Online Exploration of the Heart
http://sln.fi.edu/biosci/heart.html

Nova Online - photos of diseased hearts
(includes a Map of the Human Heart, and Pioneers of Heart Surgery)
http://www.pbs.org/wgbh/nova/heart/troubled.html

American Lung Association - Images of Lungs
http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=22577

The Human Respiratory System
http://www.stemnet.nf.ca/~dpower/resp/main.htm

Respiratory Adaptations of Weddell Seals
http://www.stemnet.nf.ca/~dpower/resp/adapt~1.htm
http://scilib.ucsd.edu/sio/nsf/gallery/gallery13.html