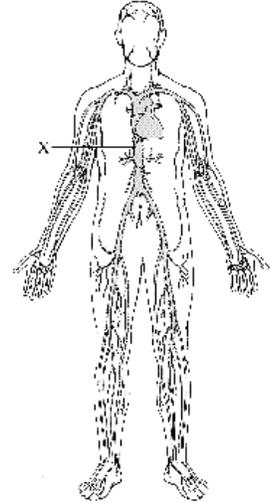


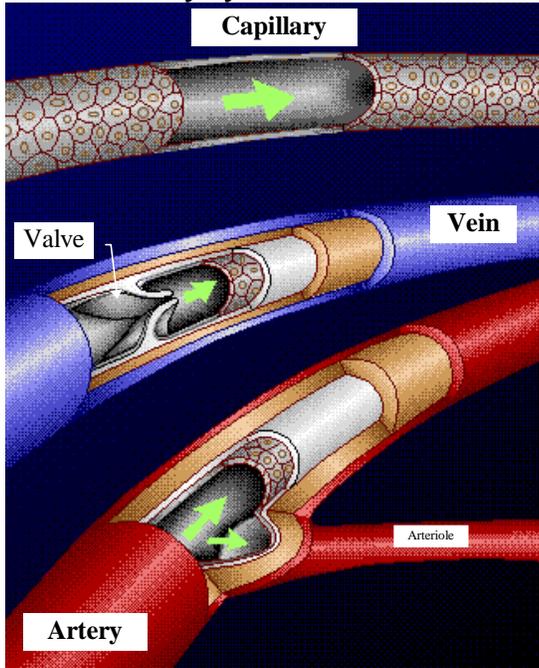
Biology 12 - Circulation - Chapter Notes

Multicellular organisms (above the level of roundworms) rely on a **circulatory system** to bring **nutrients** to, and take **wastes** away from, cells.

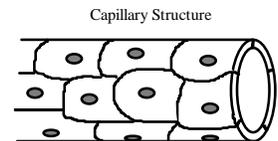
- In higher organisms such as ourselves, circulation is so important that if the heart stops beating for a few minutes, death results.
- In this chapter, we will learn about the **heart** and how it works, plus the major **vessels** of the circulatory system.



The **Circulatory System** consists of:

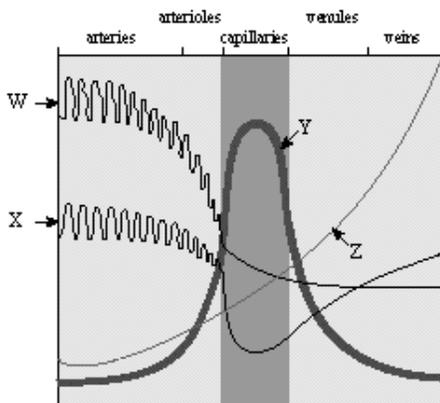


- **Blood Vessels** - carry blood from heart to tissues (**arteries & arterioles** do this) and then back to heart (**veins & venules** do this). **Capillaries** connect the arterioles to venules, and exchange material with the tissues.
- **Arteries and Arterioles** - Arteries carry **blood away from the heart**. They have **thick walls** composed of elastic and muscular fibers (plus supporting tissue). Arteries branch into **Arterioles**, which are small branches of arteries that are about 0.2 mm in diameter or smaller.
- **Capillaries** - arterioles branch into **small vessels** called **capillaries**. Capillaries are very **narrow, microscopic** tubes. The walls of these tubes are **one cell layer thick**. **Gases** and **small molecules like glucose exchange**



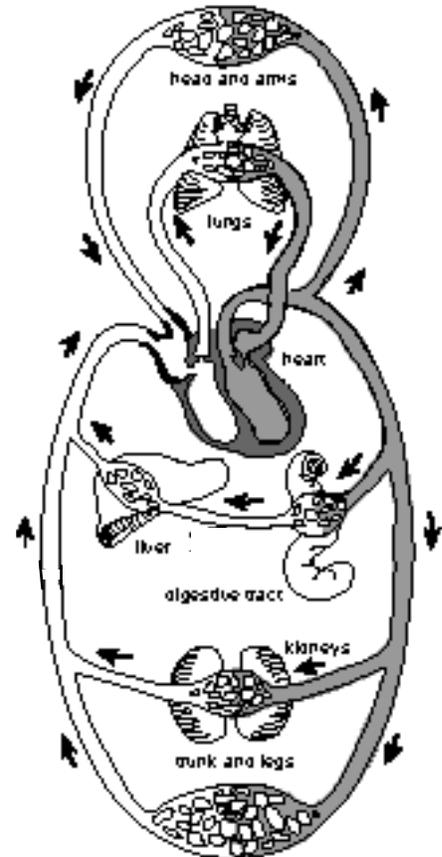
across the walls of the capillaries. **Sphincter muscles** encircle the entrance to each capillary.

- In a **capillary bed** (networks of many capillaries), some, many, or most of these sphincter muscles may be closed off so that less or more blood flows to that area, as needed (e.g. more blood to muscles when they are working).
- **Veins and Venules** - take blood from the capillaries to the heart. Venules drain the blood from capillaries and then **join** to form a vein. Walls are thinner than arterial walls. Veins have **valves**. **Valves** allow blood to flow only toward the heart when they are open and prevent the



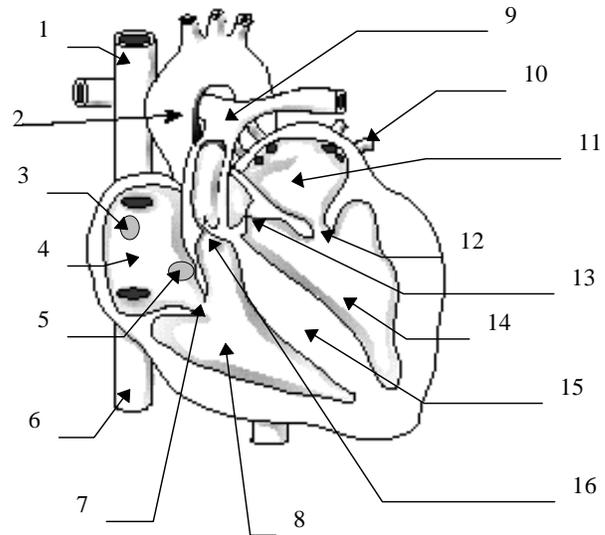
Which letter represents a graph indicating the total cross-sectional area of the body's blood vessels?

- At any one time the veins contain about 75% of the body's blood. About 20% of the body's blood is in the arteries and only about 5% is in the capillaries. You have close to 100,000 km of blood vessels!



THE HEART : 3,000,000,000 beats in an 80 year lifetime!

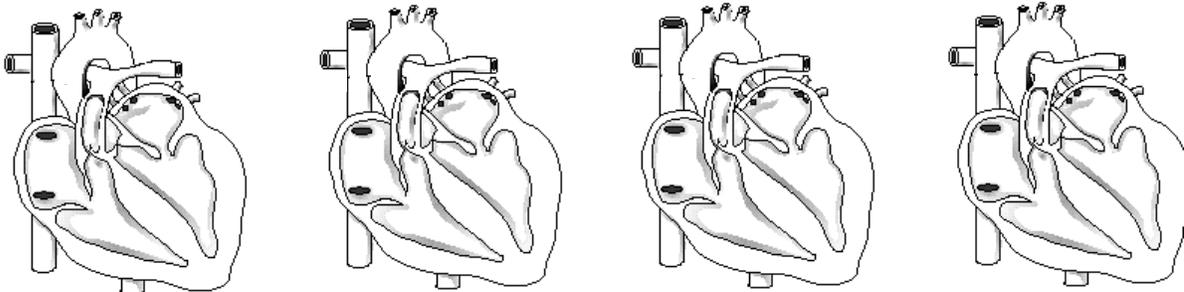
- The heart is a very **muscular** organ about the size of a **fist**.
- The major portion of the heart is called the **MYOCARDIUM**, and is mostly composed of **CARDIAC MUSCLE**.
- Epithelial and fibrous tissue called **pericardium** covers the heart. This tissue forms **PERICARDIAL SAC**, in which the heart is located. The sac contains **LUBRICATING LIQUID**.
- Think of the heart as **TWO SEPARATE PUMPS**: one (on the right side of the heart) pumps blood to the **lungs**, and the other (on the left side of the heart) pumps blood to the **rest of the body**.
- The left and right side of the heart is divided by the **SEPTUM**.
- On **each side** are **two chambers**. The smaller one, located on the top, is called the **ATRIUM** (plural = "atria"). The larger one, on the bottom, is called the **VENTRICLE**. The **left ventricle** is considerably **larger** than the **right ventricle** because while the right ventricle only pumps blood to the **lungs**, the left ventricle must pump to the **rest of the body**.



I strongly suggest you label this diagram!

- There are **VALVES** between the atria and ventricles, collectively referred to as **ATRIOVENTRICULAR VALVES**. These valves control the flow of blood between the chambers, and prevent "**backflow**."
- The atrioventricular valve separating the Right Atrium from the Right Ventricle is called the **TRICUSPID VALVE** (has 3 flaps or "**cusps**"), while the atrioventricular valve between the left atrium and left ventricle is called the **BICUSPID VALVE** or **MITRAL VALVE** (has 2 cusps).
- Very strong, fibrous strings called the **CHORDAE TENDINAE** support the valves and prevent them from inverting. The chordae tendinae are firmly attached to muscular projections of the ventricular wall.
- Each ventricle also has a **SEMILUNAR VALVE** (called that because they look like half-moons) between it and its attached blood vessels. The blood flows through the semilunar valves on its way out of the heart. The right ventricle then, has a **pulmonary semilunar valve** (since it pumps blood out through the pulmonary artery), while the left side has an **aortic semilunar valve** (since it pumps out through the aorta).
- The semilunar valves have no chordae tendinae. *Why do you think this is so?*

THE PATH OF BLOOD THROUGH THE HEART



1. Blood **LOW IN OXYGEN** ("**deoxygenated**") enters the **RIGHT ATRIUM** through the **SUPERIOR (top)** and **INFERIOR (bottom) VENAE CAVAE**, the body's largest veins.
2. The **RIGHT ATRIUM** contracts, forcing blood through the **TRICUSPID VALVE** and into the **RIGHT VENTRICLE**.
3. The right ventricle contracts, sending blood through the **PULMONARY SEMILUNAR VALVE** and into the **PULMONARY TRUNK**.
4. The pulmonary trunk divides into **PULMONARY ARTERIES**, which take the deoxygenated blood to the capillaries of the **LUNGS**.
5. At the lungs, carbon dioxide diffuses out of the blood, and, oxygen diffuses into it. The blood is now **OXYGENATED**.

6. The oxygenated blood feeds into the **PULMONARY VEINS**, which take it from the lungs to the **LEFT ATRIUM**.
 7. The left atrium **CONTRACTS**, forcing blood through the bicuspid valve into the **LEFT VENTRICLE**.
 8. The left ventricle **CONTRACTS**, forcing blood through the **AORTIC SEMILUNAR VALVE** into the **AORTA**, the body's largest artery.
 9. The aorta divides into smaller arteries, which carry oxygenated blood to all **BODY TISSUES**.
- Note that **deoxygenated** blood **NEVER MIXES** with **oxygenated** blood.
 - **IN REALITY**, the events described above don't happen in a linear sequence. Instead, the **two atria contract SIMULTANEOUSLY**, and the **two ventricles** also **contract simultaneously**.

THE HEARTBEAT

- The heartbeat that you can hear (the "**lub-DUPP**" sound) can be divided into **TWO PHASES**.
- First the **ATRIA CONTRACT** (the "**lub**" part) while the **ventricles** are **relaxed**.
- Then the **VENTRICLES CONTRACT** (the "**-DUPP**" part) while the **atria relax**.
- The actual **sound** you hear is caused by the vibrations of the heart when the **VALVES CLOSE**. "**lub**" = closing of **atrioventricular valves**, "**DUPP**" = closing of the **semi-lunar valves**.
- If there is a problem with a valve closing, this can cause **HEART MURMURS**.
- **RHEUMATIC FEVER** (caused by a bacterial infection) can cause a faulty valve (usually the bicuspid valve). Surgery or replacement with an artificial valve can often cure this.
- *There are two terms that describe contraction and relaxation of heart muscle:*

SYSTOLE = **CONTRACTION** of heart muscle.

DIASTOLE = **RELAXATION** of heart muscle.

- The **CARDIAC CYCLE** (= "**heartbeat**") occurs about **70 times per minute**, and **100,000 times per day** in the average adult. Each heartbeat can be divided up as follows:

TIME (DURATION)	ATRIA are in...	VENTRICLES are in...
0.15 SEC.	SYSTOLE	DIASTOLE
0.30 SEC.	DIASTOLE	SYSTOLE
0.40 SEC.	DIASTOLE	DIASTOLE

WHAT CONTROLS THE HEARTBEAT?

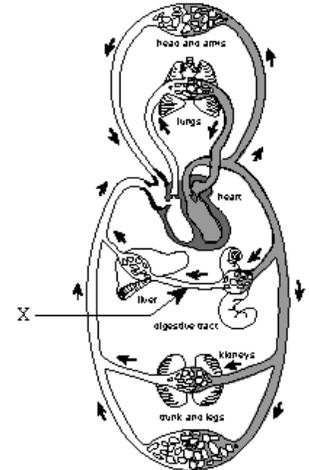
- The heart can beat without the brain telling it what to do! That is, the heartbeat is **INTRINSIC**. How is this possible?
- The answer is that the heart has its own **SPECIAL TISSUE**, called **NODAL TISSUE**, which has **characteristics of both nerve and muscle tissue**, which controls the heartbeat.
- There are **TWO** nodal regions in the heart:
 1. **SA (sinoatrial) NODE** (also called the **PACEMAKER**): located in the **upper back wall** of the **right atrium**. The SA node **INITIATES THE HEARTBEAT** by sending out a signal automatically about every 0.85 seconds to make the **ATRIA CONTRACT**. The SA node is called the "**PACEMAKER**" because it keeps the beat **regular**. If it doesn't work, the heart will beat irregularly. This can be corrected by implanting an **ARTIFICIAL PACEMAKER**, which will send out an electric signal every 0.85 seconds to stabilize the heart rate.
 2. **AV (atrioventricular) NODE**: found in the **base of the right atrium** near the septum. The SA node sends its signal along fibers to the atria and also to the AV node. When the pulse sent out by the SA node reaches the AV node, the AV node itself sends out a signal along special conducting fibers called **PURKINJE FIBERS**. These fibers take the message to the **VENTRICLES**, and cause them to **contract**. The contraction of the ventricles begins at the base of the heart and moves up like a wave. This is because the Purkinje fibers first stimulate cardiac muscle at the base of the heart.
- While the heart can keep a steady beat on its own, the **how fast it goes (heart rate)** is under **NERVOUS CONTROL**. Specifically, there is a **HEART-RATE CENTER** in the brain (to be precise, in the **MEDULLA OBLANGATA**, which is an **evolutionary ancient** part of the brain right on top of the spinal cord).
- This center can **speed up** or **slow down** the heart rate according to the prevailing stimuli received by the **AUTONOMIC NERVOUS SYSTEM**. Various factors, such as **stress**, **oxygen levels**, and **blood pressure** determine how the autonomic system will affect heart rate.

VASCULAR PATHWAYS

- As previously mentioned, the heart can be viewed as two separate pumps. Similarly, the cardiovascular system can be looked at as **TWO CIRCUITS**: the **PULMONARY** and the **SYSTEMIC CIRCUITS**.
- The **PULMONARY CIRCUIT** circulates blood through the **LUNGS**, and the **SYSTEMIC CIRCUIT** circulates blood through body tissues.

THE PULMONARY CIRCUIT

- is the path of blood from the heart through the **LUNGS**.
- deoxygenated** blood from **all tissues** collects in the **RIGHT ATRIUM**, is pumped to the **right ventricle**, then is sent to the **pulmonary trunk**, which divides into **pulmonary arteries**, which divide up into the **arterioles** of the lungs.
- These arterioles take blood to the **pulmonary capillaries**, where **CO₂** and **O₂** are **exchanged**.
- The oxygenated blood then enters **pulmonary venules**, then the **pulmonary veins**, and finally back to the **LEFT ATRIUM**.



THE SYSTEMIC CIRCUIT

- The systemic circuit includes all blood vessels except those in the Pulmonary Circuit. It takes blood from the **LEFT VENTRICLE**, through the **tissues & organs of the body**, and back to the **RIGHT ATRIUM**.
- in the systemic system, **veins carry deoxygenated blood**, and **arteries carry oxygenated blood**.
- The systemic circuit contains some blood vessels you should know:
 - AORTA**: the largest artery. Branches of the aorta lead to all major body regions and organs.
 - SUPERIOR VENAE CAVA**: large vein that collects blood from head, chest, and arms.
 - INFERIOR VENAE CAVA**: large vein that collects blood from the lower body regions and organs.
 - HEPATIC PORTAL SYSTEM**: connects the blood vessels of villi to the liver, carries nutrient rich blood to liver for processing. A **portal system** begins and ends in **capillaries** (in small intestine, and other end in liver).
 - HEPATIC VEIN** carries blood from liver to inferior venae cava.

Summary of the Major Blood Vessels you Should know:

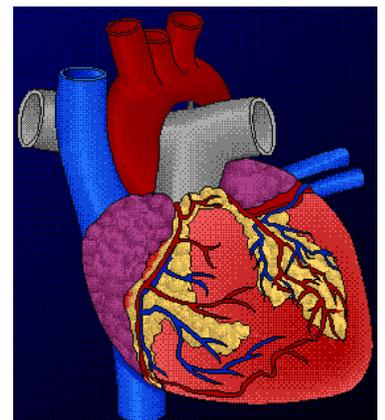
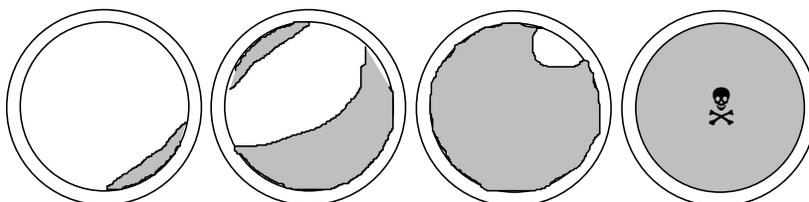
• SUBCLAVIAN ARTERY AND VEIN - around clavicle	• JUGULAR VEIN - blood from head
• CAROTID ARTERY - neck	• MESENTERIC ARTERIES - connect to intestines
• ANTERIOR AND POSTERIOR VENAE CAVA - superior above, inferior below heart	• PULMONARY VEIN - carry oxygenated blood to left atrium
• HEPATIC VEIN - connects to inf. venae cava	• HEPATIC PORTAL VEIN - connects intestine with liver
• RENAL ARTERY AND VEIN - connect kidneys and veins	• ILIAC ARTERY AND VEIN - leads from aorta into legs
• CORONARY ARTERY AND VEIN	• AORTA - largest artery, supplies all tissues

You should also be able to describe the flow of blood around the body through any major organ. For example:

- e.g. path of blood to **kidneys**: Left ventricle ⇒ aorta ⇒ renal artery ⇒ renal arterioles ⇒ capillaries ⇒ venules ⇒ renal vein ⇒ venae cava ⇒ right atrium

CORONARY ARTERIES and VEINS

- these are vitally important blood vessels that supply blood to the **heart muscle itself** (the heart **does not** use the blood in its inner chambers).
 - arteries** branch off the aorta just above the aortic semilunar valve, and lie on the outside of the heart.
 - coronary **veins** empty into the right atrium.
- if a coronary artery becomes **plugged** (e.g. with **cholesterol**), and blood is not supplied to part of the heart, a **heart attack** occurs.



- ATHEROSCLEROSIS** is a form

of **arteriosclerosis**. Atherosclerosis is the **hardening of the arteries** caused by **cholesterol plaque deposits**. It can occur in the coronary arteries, the carotid arteries, the aorta, and the leg arteries.

- Healthy arteries are flexible, strong, and elastic. The inner layer, the *tunica interna*, is smooth, enabling blood to flow freely. As a person ages, the arteries normally become thicker and less elastic, and their calcium content increases. This **natural** "hardening" process occurs throughout the artery system. Atherosclerosis, by contrast, affects only the **larger** arteries.
- As the plaque builds up, the inner layers of the artery walls become thick and irregular. **Fat, cholesterol**, and other materials accumulate in certain areas. This gradual build-up over a long period of time reduced the circulation of blood and increases the risk of **heart attack, stroke**, and other **serious arterial diseases**.
- A person having atherosclerosis will often experience symptoms of **angina, stroke**, and **claudication** (limb pain or tiredness). All of the symptoms are caused by **insufficient blood flow** due to atherosclerosis.
- **Stroke**: when portion of brain dies due to lack of oxygen -- usually when arteriole bursts or is blocked by an embolism. Strokes usually cause death or paralysis.
- **Heart Attack**: when portion of heart dies due to lack of oxygen. At first, the victim may suffer **angina pectoris** (radiating pain in the left arm). Death may result if immediate treatment not given.
- **CORONARY BYPASS SURGERY**: segments of leg veins are grafted between the aorta and coronary vessels, in order to **bypass a blockage**. Two to four such bypasses may be performed in a single operation. e.g. three such grafts would be known as a "triple-bypass" operation.
- **Coronary bypass, donor heart transplants**, and **artificial heart implantation** (which don't work yet!) are surgical methods that have been used for the treatment of heart attacks.
- More than **50% of all deaths** in Canada & U.S. are due to hypertension (high blood pressure), stroke, and heart attack.

Some more nasty circulatory events:

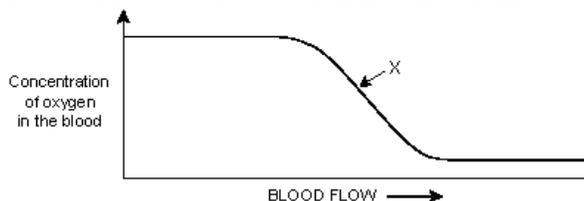
- **THROMBUS**: a stationary clot attached to an arterial wall. Slows the flow of blood.
- **EMBOLUS**: a thrombus that has become **dislodged** and **moves** along with the blood. When the vessel narrows, the embolus gets stuck and **entirely blocks** the flow of blood in a small vessel. This is called an **EMBOLISM**.
- **VARICOSE VEINS**: abnormal and irregular dilations in superficial (near surface) veins, especially in lower legs.
- Varicose veins in rectum are called **HEMORRHOIDS**.
- Varicose veins develop when the **valves of the veins become weakened** due to a **backward pressure** of the blood (often made worse by crossing legs, poor sitting posture).
- **PHLEBITIS**: inflammation of a vein. Blood in the inflamed vessel may clot, in which case a **thromboembolism** occurs. If embolism here winds up in a pulmonary arteriole, blocking circulation through lungs, this is called a **PULMONARY EMBOLISM** (can kill).

Pulse, Blood Pressure

- **PULSE**: the alternate **expanding and recoiling of an arterial wall** that can be felt in any **artery** that runs near the **surface** of the body. **Radial** artery in wrist, **carotid** artery in neck are common places to check. Pulse rate indicates the rate of heartbeat.
- **BLOOD PRESSURE**: the pressure of the blood against the wall of a vessel, created by the pumping action of the heart.
- **HYPOTENSION**: **lower** blood pressure than usual.
- **HYPERTENSION**: **higher** blood pressure than normal. Over **20%** of Canadians/Americans suffer from it. Usually **associated with cardiovascular disease**. Many **unaware** they have it.
- Can be caused by **diet**, (e.g. high salt diet causes water to be retained) **stress** (causes blood vessels to constrict), and **kidney** involvement (renin = hormone that kidney releases to increase blood pressure by retaining salt and water).
- Atherosclerosis due to **plaque buildup** also causes hypertension --> due to saturated fats and cholesterol. Cholesterol is carried in body by **Lipoproteins**. High levels of **Low Density Lipoproteins** (LDL's) is thought to lead to atherosclerosis.
- **DIET** is the most important factor. Animal products are the only source of dietary cholesterol.
- **Treatments** for high blood pressure include **Beta-blockers**, which prevent stimulation of autonomic nervous system. **Vasodilators** prevent arteries from constricting. **Diuretics** cause kidneys to excrete excess salts and fluids.

Measuring Blood Pressure

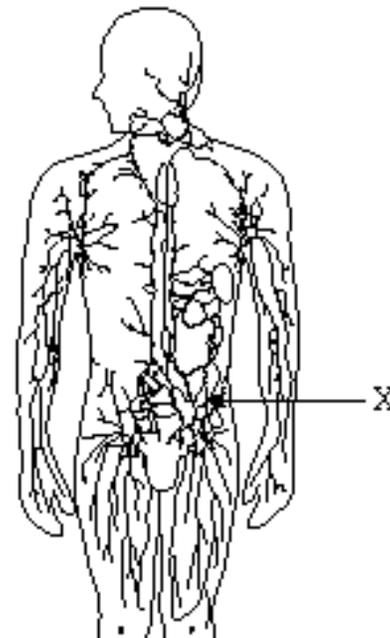
- Measure blood pressure with an instrument called a **SPHYGMOMANOMETER**.
- **SYSTOLIC BLOOD PRESSURE**: the **highest arterial pressure** reached during ejection of blood from the heart.
- **DIASTOLIC BLOOD PRESSURE**: **lowest** arterial pressure. Occurs while the **ventricles** are **relaxing**.
- Normal resting blood pressure is **120 mm Hg** over **80 mm Hg** in **brachial artery** of arm (120/80). Of course, blood pressure **decreases** with **distance** from left ventricle. It is higher in the arteries than in the arterioles, for example.
- Blood pressure accounts for the flow of blood in the arteries and arterioles, while **SKELETAL MUSCLE CONTRACTIONS** accounts of the flow of blood in the **venules and veins**.



The above graph represents the levels of oxygen in the blood as it flows through the body. At point X the blood is flowing in a/an a) artery b) venule c) arteriole d) capillary

The Lymphatic System

- The lymphatic system is **another vascular system** in your body. It is **separate from your cardiovascular system** (i.e. it has its own veins and capillaries) but it is ultimately connected back with the cardiovascular system (i.e. the fluid from the lymphatic system eventually gets sent back into the bloodstream). Basically, the lymphatic system takes up **excess tissue fluid** (fluid that surrounds cells and tissues) from the **tissues** and **returns** it to the **cardiovascular system**.
- It is a **one-way system** that starts in the tissues and empties into the cardiovascular system.
- Lymph vessels consist of **LYMPH CAPILLARIES** and **LYMPH VEINS** (which have **valves**). Note: there are **no lymph "arteries"** since there is no "pump" in this system. Once fluid enters the lymph vessels it is called **LYMPH**.
- Lymph is collected in vessels that join to form two main **trunks**:
 1. the **RIGHT LYMPHATIC DUCT**, which drains the **upper right portion of the body** and empties into the **right subclavian vein**
 2. **THORACIC DUCT**, which **drains the rest of the body** and drains into the **left subclavian vein**.
- Lymph contains **LYMPHOCYTES** which are a type of white blood cell. Some lymphocytes produce **antibodies**.



Other Parts of the Lymphatic system you should know:

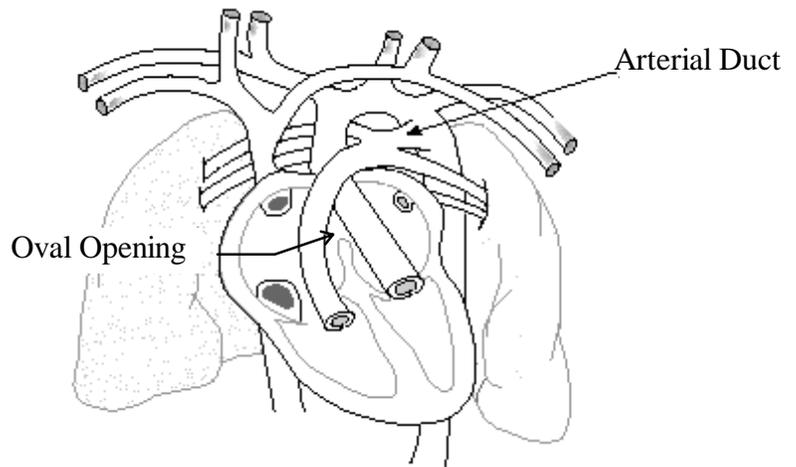
- **Lacteal**: blind ends of lymph vessels in villi of the small intestine. **Products of fat digestion** enter here.
- **LYMPH NODES**: small **oval or round structures** that occur along strategic places on lymph vessels. They **produce and store lymphocytes**, and **filter lymph** of **damaged cells and debris**.
- **SPLEEN**: located **behind the stomach**. **Contains white blood cells and stores blood**.
- **THYMUS GLAND**: located in the upper thoracic cavity, **functions in production and maturation of some lymphocytes**. Decreases in size with age (may be a factor in aging).

Summary of Main Functions of Lymphatic System

1. **transport** of excess tissue fluid back to cardiovascular system
2. **absorption** of **fat** from the intestine and transport to blood
3. **fighting infection** by cleansing lymph and production of **lymphocytes** (a type of white blood cell). Some lymphocytes produce **antibodies**.

Differences between Fetal and Adult Systems

- Heart develops in **3rd and 4th weeks** in uterus. At end of **8 weeks**, the embryo's **organ systems**, including heart, are functioning. During **fourth month**, fetal heartbeat is loud enough to be heard with stethoscope.
- However, the fetal circulatory system can't be the same as the adult, if you stop to think about it. The fetus, first of all, can't breathe air inside the womb, so sending blood to the lungs won't do much good. Likewise, the fetus must get all its nutrients from Mom, as well as let her take care of its wastes. Obviously, some serious plumbing problems must be solved.
- To solve these problems, the fetus has **FOUR FEATURES not present in adults**:



1. **OVAL OPENING** (*foramen ovale*): **opening** between the **two atria**, covered by a **flap** that acts like a **valve**. Some of the blood from the right atrium is therefore pumped through this flap and into the **left atrium**, **bypassing the pulmonary circuit**.
- If the oval opening doesn't close after birth, it can cause **mixing of blood** and "blue babies". Correct with open heart surgery.
2. **ARTERIAL DUCT**: (*ductus arteriosus*) connects **pulmonary artery** and **aorta**. Much of the blood being pumped out of the heart to the lungs will be directed away from the lungs and into the aorta. Like the oval opening, the arterial duct's function is to bypass the pulmonary circuit.
3. **UMBILICAL ARTERIES AND VEINS**: vessels that travel to and from **PLACENTA** (a membrane shared by the mother and baby across which gases, nutrients, and wastes are exchanged). The umbilical arteries are grafted to the iliac arteries.
4. **VENOUS DUCT** (*ductus venosus*): **connects umbilical vein to the venae cava** to bring the blood back to the baby's heart. It attaches right at the baby's liver, but **bypasses most of the liver**. This is why chemicals ingested by the mother can seriously affect the baby!

PATH OF BLOOD THROUGH FETUS

1. Begin with blood collecting in Right Atrium
2. From there, blood can go into **Left Atrium** through Oval opening **plus** into **Right Ventricle** through **atrioventricle valve**.
3. **Right Ventricle** to **Pulmonary Artery**. Most of blood will go through **arterial duct** into **aorta**.
4. **Aorta** to **tissue**. **Umbilical arteries** lead to **placenta**, where **exchange of gases** and **nutrients** take place.
5. Umbilical vein carries O₂-rich blood. It enters the **venous duct**, passes through **liver**.
6. **Venous duct** joins with **inferior venae cava** (it mixes here with **deoxygenated blood**) and this mixed blood goes back to the back to heart.